DISTRIBUTION OF HIGHLY MIGRATORY MARINE MAMMALS AND SEABIRDS IN THE EASTERN NORTH PACIFIC: ARE EXISITNG MARINE PROTECTED AREAS IN THE RIGHT PLACE?

by
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ABSTRACT

To date, only five marine protected areas (MPAs) have been established along the West Coast of the United States, none of which extend more than 30 nautical miles from shore. These areas do not afford habitat protection for a number of highly migratory and often endangered pelagic seabird and cetacean species found in the Northeastern Pacific Ocean. Using sightings data for fourteen species from a Minerals Management Service Computer Database Analysis System, I analyzed species distribution based on oceanographic season (countercurrent, upwelling, oceanic), year (El Nino, La Nina, neutral), patchiness, bathymetry (shelf, shelf-break, slope, pelagic), and index of dispersion (Gx). The species density data were also compared to areas of existing MPAs to determine how well current MPAs protect these species. The results indicate that current MPAs do not protect the habitats of highly migratory species. I therefore compared existing MPA coverage to suggested MPA locations and found much stronger protection in the suggested areas. Recommendations include not only general areas for improved protection, such as the North Bend, Oregon region, but also specific season and bathymetric features to protect as hotspots within the larger regions.

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OBJECTIVES:

a. My first objective is to describe the distribution of fourteen highly migratory marine mammals and seabirds based on spatial and temporal parameters.
b. In doing so, I aim to eliminate any confounding factors such as the effect of effort on the frequency of observation.
c. By relating animal distribution to spatial and temporal components, I will make suggestions for the development of future marine protected areas.
d. My fourth objective is to assess whether the borders of existing marine protected areas protect a significant portion of the densities of each species.
e. The final goal is to assess the spatial patchiness or amount of aggregation of each species.

HYPOTHESES:

1. Species occupy predictable habitats which can be determined by longitudinal studies and environmental correlations such as season and bathymetry.
2. Observational effort partially determines the frequency of sighting for each species.
3. The seasonal movement patterns of marine mammals and seabirds will describe the areas where a marine protected area should be created
4. Marine protected areas adequately incorporate the highest observational densities of each species.
5. Odontocete distribution can be described as patchy while seabird and mysticete whale distributions are uniform.

INTRODUCTION – SELECTED SPECIES AND STUDY AREA

SPECIES SELECTION PROCESS

The goal of this project is to describe the habitat of fourteen highly migratory marine mammal and seabird species in the Eastern North Pacific and based on this habitat, to suggest locations for future marine protected areas. Although the Marine Mammal Protection Act (1972) demands protection for marine mammals and the Endangered Species Act (1973) offers protection for threatened species, neither of these two acts adequately protects the habitats of these species. Both Acts contain provisions for the protection of habitat, but to date no habitat has been protected. In light of this reality, this study aims to describe the critical habitat in need of protection for a wide range of cetaceans and seabirds.

For this study, eight seabird and six marine mammal species serve as indicators for assessing a wide range of preferred foraging habitat. The cetaceans include two mysticete whales (the fin and blue whale) one beaked whale, (Baird's beaked whale), and three odontocetes: Risso's dolphin, Pacific white-sided dolphin, and Dall's porpoise. The birds include two albatross (Laysan's and black-footed), two auklets (Cassin's and rhinoceros), two shearwaters (pink-footed and sooty) one murrelet (Xantus) and one storm petrel (Leach's). This assemblage provides a broad range of characteristics, including, foraging technique, population status, bathymetric range, seasonal distribution and year-type (El Nino, La Nina, neutral) response.

The status of the individual species affected the selection process. I selected some endangered or rare species in order to provide protection for those most in need of a marine protected area. While it was important to include endangered species like blue whales, fin whales, and Xantus murrelet, plus rare species like Baird's beaked whale, data from those species alone provides an incomplete understanding of highly migratory species distribution in the Eastern North Pacific. Because they are endangered or rare, there are significantly fewer sightings of those species and less statistical confidence in the results. It was therefore also important to obtain data from abundant species like sooty shearwater and Pacific white-sided dolphins. Although sooty shearwaters may be abundant in the area, they too are susceptible to anthropogenic and environmental changes to their habitat. In fact, the populations of sooty shearwater, the most prevalent species in the study area, declined by 75% in the 1990's; this change was attributed mostly to ENSO events in 1992-1993 and in 1998 (Wahl, 2000).

Bathymetric preference also factored into the decision of which species to select. Some of these species tend to forage close to shore (pink-footed shearwater), while others are pelagic birds ranging far offshore (Cassin's auklet). An understanding of these preferences is extremely important in predicting the distribution of these species and assigning boundaries for a marine protected area.

Seasonal and yearly preferences are two more factors which help elucidate distribution and can be of aid in the MPA design process (see Background – Marine Protected Area Design). Black-footed albatross breed in the winter and spring in the Hawaiian Islands and then migrate northeast, first to California in June and then up to the Aleutian Islands in the fall. Knowledge of where to find the birds based on season can significantly affect marine protected areas decisions, particularly for seasonal closures. El Niño years may cause a bird species to leave an area and move north in search of cooler, upwelling waters, and this information significantly factors into predictions of distribution. In sum, all species included in the study are highly migratory, spending some portion of each year off the West Coast of the United States. They were not selected based on their common characteristics, but rather for the diversity of their foraging and protection needs. This makes the ultimate MPA choice more difficult, but also more realistic, and therefore effective. By using highly migratory species as indicators of diverse, productive habitats, the ultimate MPA aims to protect not just a few charismatic species, but the upper trophic level biodiversity of an entire ecosystem.

SELECTED SPECIES NATURAL HISTORY TABLE

Selected natural history characteristics of each of the focal highly migratory species within the range of the US West Coast are provided in table 1.

Table 1

Species	Breeding location/Summer migration	Migratory	Over-wintering grounds	Prey	Ideal temperature	Status	Bathymetry preference
Leach's storm petrel (*Oceanodrama leucorhoa*)	Aleutians to Baja, CA	Yes	Southern, tropical waters	Crustaceans, fish	Unknown	Uncertain	Unknown
Sooty shearwater (*Puffinus griseus)*	South pacific	Yes	Aleutians – summer; move South (WA, OR, CA) in fall	Anchovies	Colder waters	Common	Non-specific
Pink-footed shearwater *(Puffinus creatopus)*	Southern Chile	Yes	CA, OR, WA and up to Southern Bering Sea	Fish	Unknown	Uncertain	Unknown
Laysan Albatross (*Phoebastria immutabilis)*	Northwestern Hawaii – migrate North in summer	Yes	Open ocean (HI, Japan, Aleutians)	Euphausiids	4.4 deg – 18.3 deg C – limited by need for high salinity waters		Slope – pelagic zone
Black-footed Albatross (*Phoebastria nigripes)*	Hawaiian Islands	Yes	Central Pacific; migrate north, first CA (june-july) OR, WA, BC, Alaska (August-November)	Food generalists – fish, squid, jellyfish, shrimp, amphipods, polychaetes	prefer 3.4 - 30 deg C waters	Common	Slope

Pacific White-sided Dolphin (*Lagenorhynchus australis)*	Gulf of CA north to Gulf of Alaska – May off OR/WA	Yes	November – April: off-Southern CA	Fishes and cephalopods	Cold-temperate waters; 38°-47°C	Common	Shelf and slope
Risso's Dolphin (*Grampus griseus)*	Gulf of Alaska to Chile	uncertain	Gulf of Alaska to Chile	Cephalopods	Water over 10°C	Common	Offshore (off slope)
Dall's Porpoise (*Phocoenoids dalli)*	North of 32 °C in summer	uncertain	BC, WA, OR, and CA (southern CA only in winter)	Small fish and squid	Between 9-15°C	Common	Pelagic (Off slope)
Baird's Beaked Whale (*Berardius bairdii)*	May-October slope waters North of 34°C N	Yes	Offshore California	Squid, fish	Unknown	Uncertain	Offshore (winter); slope in summer
Xantus Murrelet (*Synthliboramphus hypoleuca)*	Majority breed in Southern California	Sometimes	WA, OR, CA	Anchovies and rockfish	Uknown	Vulnerable	Offshore
Fin Whale (*Balaenoptera physalus*)	Aleutians (Alaska), BC, Hawaii	Yes	WA,OR, CA – Baja, CA	Krill	Polar and temperate waters	Endangered	NA
Blue Whale (*Balaenoptera musculus*)	Aleutians, BC,CA	Yes	WA, OR,CA, Costa Rican Dome	Krill	Polar, Temperate and tropical	Endangered	Slope
Cassin's Auklet (*Ptychoramphus aleuticus)*	Baja, CA to Aleutians	Yes	Pelagic waters off WA,OR, CA	Copepods, euphasiids, fish	Temperate	Uncertain	NA
Rhinocerous Auklet (*Cerorhinca monocerata)*	Alaska, Triangle Island, BC	Yes	WA, OR, CA	Fish	Polar and temperate	Uncertain	NA

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THE STUDY AREA

The Eastern North Pacific, from 30°N to 50°N out to 130°W, was selected as the study area because of the availability of data through the Minerals Management Service. The California Current System moves throughout the region and attracts a large diversity of marine species. The currents of the California Current System upwell cold, nutrient-rich waters, which in turn routinely aggregated fish, squid and their predators (NSF, 1999). The region can be divided into three sections based on hydrography, the physical environment and biology. These three sections, as outlined by the US GLOBEC program (1999) are:

1. Region I. Vancouver Island, Canada to Cape Blanco (Washington, Oregon 50°N-43°N)
2. Region II. Cape Blanco to Point Conception (California, 43°N –35°N)
3. Region III. Point Conception to Punta Baja in northern Baja California (the Southern California Bight and offshore waters, 35°N-30°N)

These three regions serve as boundaries for the different surveys included in the Minerals Management Service Computer Database Analysis System.

BACKGROUND

FACTORS DRIVING SPECIES DISTRIBUTION

When discussing the selection process for the fourteen species in this study, I addressed the factors which drive the distribution of highly migratory species; these factors are an essential component of this research, and I will therefore discuss what drives the distribution of species before I consider marine protected areas.

How do species choose their habitat? The primary factor driving the distribution of both cetaceans and sea birds is the distribution of their prey (Cockcroft and Peddemors, 1990, Acevedo and Würsig, 1991, Smith and Whitehead, 1993 all from Gowans and Whitehead, 1995). Although I would ideally predict the movement of cetaceans and seabirds based on their prey, research cruises observing cetaceans and seabirds have rarely sampled prey concurrently and it would be significantly more difficult than using static features. In addition, predictions based on the ephemeral movements of prey are highly variable and it is nearly impossible to make long-term predictions. Therefore, I will make indirect correlations of cetaceans and seabirds with easily predictable oceanographic parameters such as such as fronts, thermoclines, upwelling plumes, Langmuir cells, and larger-scale temperature and productivity patterns (Whitehead and Glass, 1985; Payne et al, 1986, 1990; Boyd and Arnbom, 1991; Piatt and Methaven, 1992; Kenney et al, 1995; Winn et al.; 1995 all from Croll et al, 1998). I can make these correlations because prey, such as fish, squid, and crustaceans are often found associated with their prey – zooplankton, and phytoplankton – whose movements are controlled by the above mentioned hydrographic parameters. For example, the movements of Risso's dolphins' prey, mesopelagic cephalopods, may drive the dolphins' steep bottom distribution. Circulation patterns causing local increases in primary productivity and food availability are induced by the topography of the ocean bottom. This current-enhanced productivity could determine the patchy distribution and abundance of Risso's dolphins world-wide (Au *et. al*., 1979; Breaker and Broenkow, 1989, both taken from Kruse, 1999).

Although correlations between cetacean and seabird distribution and environmental variables such as depth and sea surface temperature are indirect causal relationships, they are useful predictors of species distribution, and often the only indicators available for describing distribution (Gaskin, 1986; Selzer and Payne, 1988; and Reilly, 1990 all from Gowans and Whitehead, 1995). In addition, environmental variables such as season, bathymetry, or sea-surface temperature are more practical for designating marine reserve boundaries than prey distribution.

Marine protected areas, like the Gully reserve in Canada (Hooker et al., 1999), have been designated based on bathymetry as the primary indicator of habitat. Other factors, such as chlorophyll (an indicator of productivity and hence, prey location) and sea-surface temperature (another indicator for prey species) may be more useful, but they are ephemeral features often tied to bathymetry. Therefore, because of the type of data available and the relative ease of developing a marine protected area based on bathymetry, my research will focus on bathymetry, season, and year as indicators of species distribution. As this is a preliminary analysis of the data, future work should incorporate more parameters for a more comprehensive assessment.

STATUS OF EXISITNG US WEST COAST MARINE PROTECTED AREAS

Biodiversity is severely threatened throughout the world in both terrestrial and marine environments. Efforts to diminish habitat destruction and exploitation of species in terrestrial systems via protected areas have been more numerous and successful than attempts in marine systems. The historic emphasis imbalance between terrestrial and marine systems may be due to uncertainties in the marine environment and logistical difficulties in researching these areas. Nevertheless, extensive networks of protected areas and reserves have been established to help maintain biodiversity on land, whereas only a handful of rather unsuccessful attempts at developing reserves have occurred in the world's oceans.

Along the entire 1300 miles of the West Coast of the United States, only five marine sanctuaries exist, covering in total less than 500 miles of the coast. I am using the term sanctuary here as a more specific term than Marine Protected Area (MPA). The term Marine Protected Area is a broad term which includes a variety of different zones of protection. For example, a marine protected area could be a national marine sanctuary, a fishery management zone, a national seashore, a national park, a national monument, a critical habitat, a national wildlife refuge, a national estuarine research reserve, a state conservation area, etc. (National MPA Center, 2002). Although there are a few small national estuarine reserves and national parks within the study area, only five national sanctuaries extend off-shore into regions occupied by these highly migratory species. Although the sanctuaries overlap with highly migratory species' habitat, they were not designed to protect these highly migratory species and therefore may not offer significant protection.

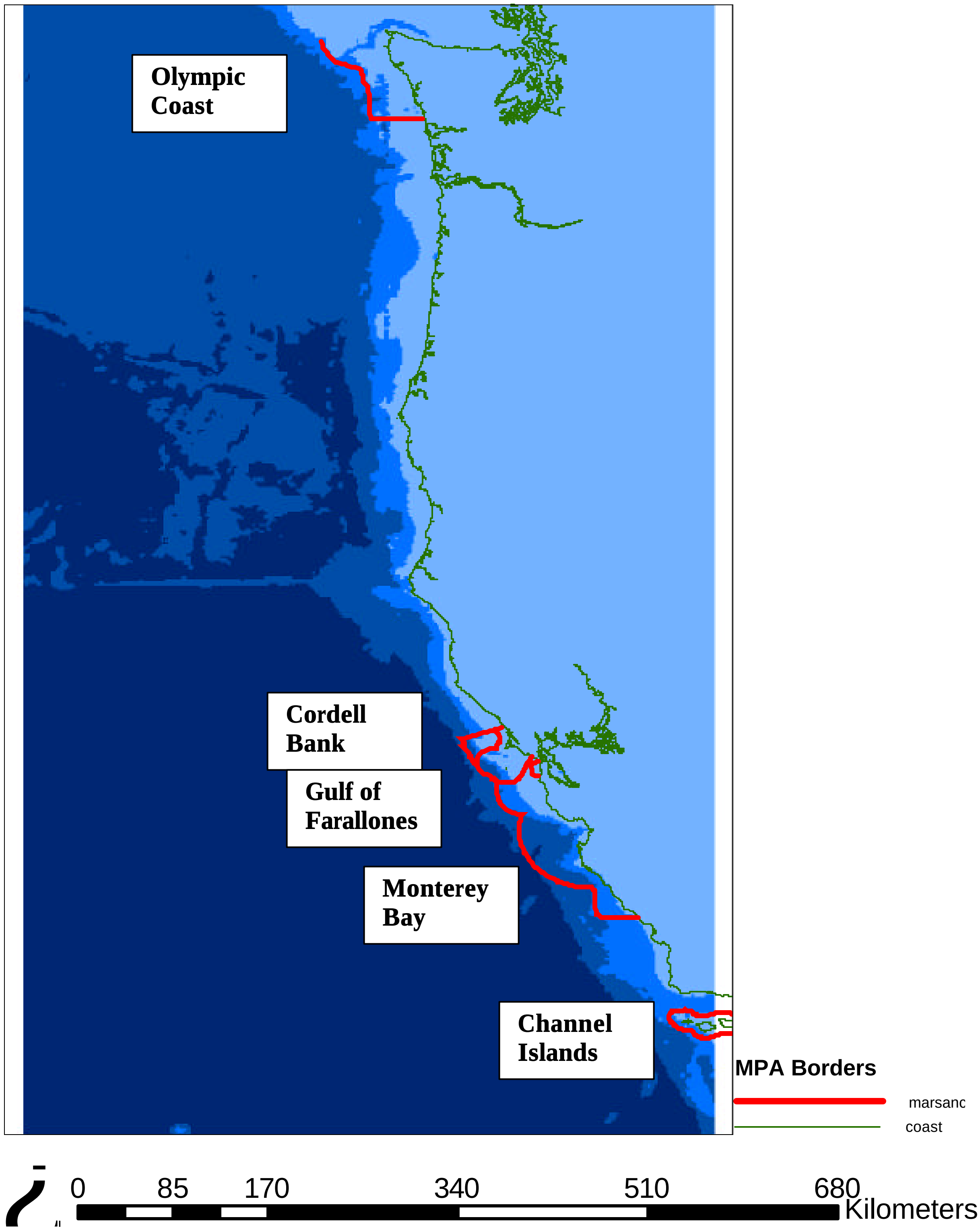
The northernmost marine sanctuary, the Olympic Coast National Marine Sanctuary was established in 1994 with the goal to protect the natural resources within its borders. This sanctuary covers a total of 2,500 nm^2 off Washington state and extends beyond the Olympic Peninsula; north to south, and the borders of the sanctuary cover 135 miles of the coastline.

The next three sanctuaries, Cordell Bank, Gulf of Farallones, and Monterey Bay are situated continuously off the coast of northern and central California, covering a total of 4,302 nm^2 of ocean. The northernmost sanctuary of the three, Cordell Bank, is the smallest (397 nm^2) and was established the most recently, in 1989. The Gulf of Farrallones Sanctuary is sandwiched in the middle, covers 948 nm^2 of water, and was the first to be established in 1981. The largest sanctuary of the three, Monterey Bay, covers 276 miles of coastline and a total area of 2957 nm^2. Monterey Bay was established in 1982 and, like the other two sanctuaries in its vicinity, exists to protect the high biodiversity in the area.

The last sanctuary, the Channel Island National Marine Sanctuary (NMS) was established in 1980, and forms a 25-mile perimeter around all five islands, covering a total of 1,252 nm^2 of ocean. Of all five sanctuaries, Channel Islands NMS offers the strongest protection for the species within its borders. Each of these sanctuaries is a multi-use sanctuary that prohibits oil and gas exploration within its borders, but Channel Islands restricts specific types of harvesting as well.

Marine Protected Areas off the West Coast of the United States

Figure 1



MARINE PROTECTED AREA DESIGN

Introduction

Under the assumption that highly migratory species and their habitat need to be protected by preserving their pelagic ecosystems, the first step is to define the purpose of reserve. Although reserves can be designed to answer solve many problems such as conflict resolution among user groups, habitat restoration, or preservation of "natural" areas, a clearly laid out goal from the beginning is imperative. In this case, the goal is to protect habitats or ecosystems used by highly migratory species and their prey. A significant problem in protecting pelagic marine habitat is identifying the appropriate ecological boundaries and including these in the design of the protected areas (Hooker et al., 1999). Ecological boundaries range from static to dynamic features, which can span the borders of countries. This brings up two difficult problems to consider when selecting a reserve location: 1) basing reserves on ephemeral, dynamic features such as currents and sea surface temperature and 2) cross-border issues.

The links between marine ecosystems are widespread both temporally and spatially and vary as currents wander or alter direction under the influence of physical processes. This said, basing reserve boundaries on ephemeral currents is a huge obstacle to address. The pelagos (water column) carries nutrients and pollutants, which have traveled to the sea via runoff, erosion, rain and river outflows. These currents can transport plankton and nutrients and rates of almost 500 kilometers a week. (Kenchington and Agardy, 1990). Given the complexity and dynamic nature of marine ecosystems, it is simple to understand they rarely fall within local, federal or even international political boundaries. Thus, political cooperation, both domestic as well as international, is essential in the formulation of a pelagic MPA.

In this case, I have selected static features (bathymetry, season, and year) which describe species distribution and can be used for selecting a marine reserve location. This largely eliminates the dynamic feature concern. The second problem, that of political borders, is also not a n issue in this case as the area of concern is lies completely within United States jurisdictional waters.

Selection of the Site

Once the objective of the marine protected area is clear, there are a series of steps to be completed to develop a marine protected area, as proposed by Agardy (1997). The goal of providing the below outline of the MPA design process is to provide a framework to use for this and future work. The results from this study only complete Step A, the identification of critical habitat, in the site selection process. My hope is that future work can finish selecting priority areas and, with the involvement of stakeholders, complete the design process.

A. First, identify the critical habitats used by certain endangered species of special economic, ecological or cultural value. If possible, map this information using GIS or cartography.
B. Next, determine the level of resource use and the causes of habitat damage. Basically, determine and map threats, including resource use conflicts, to the critical habitat selected above. [SEE THREATS BELOW FOR EXAMPLES OF DAMAGING ACTIVITIES AND IMPORTANT USER GROUPS.]
C. Find areas where local populations may be amenable to conservation and/or areas from where there is sound science. Speak to decision-makers and select these areas as potential protected site sections.
D. Overlay the GIS layers from part A) with the threatened areas from part B) and then topped off with the areas determined in part C). This will show where the priority areas are located.
E. Relying largely on the stakeholders – local users, decision makers and the public as a whole – determine the feasibility of creating one or more marine protected areas from the priority areas.

THREATS TO MARINE SYSTEMS; *USER GROUPS*

1. Fishing
   a. Commercial and sport
      - ex: trawling/gillnetting/box trapping/live shelling/seining/crabbing/ghost fishing of lost gear
2. Commercial activities
   a. Oil and mining spills
   b. Shipping
   c. Tourism (mostly of whales and turtles)
   d. Recreation (mostly of whales and turtles)
      - motor boating/wave runners/jet skis
      - diving
      - snorkeling

3. Municipal Activities
   a drainage/sewerage

Basic Design Steps

Once the site has been selected, the next question to answer in designing the MPA is what type of protected area (i.e. park, sanctuary with no-take zone, multiple-use sanctuary, etc . . .) will be created. This is largely a theoretical consideration and the solution is driven by the ecology of the region. For example, if the animals to protect are cetaceans, particularly the Northern bottlenose whale off Nova Scotia, and their range is largely a static area such as the center of the Gully canyon, then a single reserve with a core (no-take) canyon area surrounded by a buffer zone may be appropriate (Hooker et al. 1999). Rarely is pelagic conservation this simple, but again it depends entirely on the ecology and to some extent the user groups.

The types of MPAs that can be considered range from single, static reserves such as the one mentioned above to networks of reserves with dynamic buffer zones surrounding multiple use areas. Depending on the types of use regularly occurring in the region, the zones could be as extensive as: a core area (which is a no-take zone and may not even allow any boat traffic), a principal area (which is less restrictive but still a sensitive region), a restoration zone (for habitat restoration), a sustainable use area, a transition area, a priority research area and then a buffer region.

Now that the site is selected and the type of MPA matched to the ideal site, the design process begins. An example of the step-wise process involved in the design of the MPA is as follows: (National Academy of Sciences, 2000)

1. Locate and include all user groups (stakeholders)
2. Set objectives for the protected area – practical goals determined by and agreed upon by all the user groups
3. Determine borders of MPA
4. Work out an initial plan for specific regions and uses for those regions within the borders
5. Devise a management plan for regulation of the area
6. Closely monitor the design of the MPA at all steps to ensure that goals from all parties (sociological and scientific) are met

After the above steps are completed, implementation and enforcement of the MPA follow based on the user groups and politics of the area.

MATERIALS AND METHODS

The data for this project was acquired from a Minerals Management Service (MMS) Computer Database Analysis System (citation). This database compiles observations from fourteen different studies completed over a 22 year period off California, Oregon, and Washington. These studies employed different observation platforms (e.g., high / low aerial surveys, vessel-based surveys), and surveyed different areas (e.g. Southern California, Central-Northern Californa, and Oregon-Washington), and time periods (e.g., seasons, years). Nevertheless, all surveys used standardized survey line and strip transect protocols designed to provide indices of relative abundance expressed as encounter rates (individuals sighted per km surveyed) and density (individuals sighted per km^2 surveyed) (Tasker et al. 1984, Buckland et al. 1993).

Southern California:

From May 1975 to March 1978, three aerial surveys (two low ~200 ft, one high ~750-1000ft) and one ship survey searched the Southern California Bight region (from Point Conception south to the U.S.-Mexico border) out to the 2,000m isobath for both marine mammals and birds. The goal of this effort was aimed at characterizing the marine mammal and seabird abundances in the Southern California Bight region. Both high and low altitude surveys were repeatedly conducted along pre-established transects. The 24 low aerial surveys recorded observations of pinnipeds and seabirds along eight parallel latitude lines separated by 25 nm (46.5 km). Seabirds within a 50m corridor on the side of best visibility (e.g., shaded side of the aircraft) were recorded. Marine mammals were also observed only on one side of the aircraft, but within an unbounded corridor. (MMSCDAS) The 35 high altitude surveys sampled only cetaceans along 15 Loran lines separated by 12-15 nm (22 – 28 km) and oriented northeast-southwest. The 29 ship surveys were conducted in waters inshore of the shelf break on predetermined and replicated transects. The resulting total effort was: 75,489 km of high altitude cetacean observations, 37,843 km of low altitude mammal observations, 35,445 km of low altitude bird observations, and 17,903 km of ship observations for seabirds and marine mammals.

Central - Northern California:

Thirty-six high-altitude and thirty-six low-altitude aerial surveys were completed from February 1980 through June 1983 on the continental shelf, slope, and off-shore regions of Central and Northern California (from Point Conception to the CA - OR border). This study aimed to assess the seasonal variability of seabird and marine mammal populations off central and northern California. Forty east-west transects extending about 60 (112 km) were selected randomly from 92 predetermined lines spaced at 5' latitude intervals. Seabirds were only recorded within a 50m corridor of the shaded side of the low altitude (200ft) aerial surveys. Marine mammal sightings were recorded in unbounded corridors on both high altitude (750-1000ft) and low altitude (200 ft) surveys.

In the spring and summer of 1985, one ship and four aerial surveys were conducted in waters from Monterey Bay to the Gulf of the Farallones. These surveys were part of a project entitled the Seabird Ecology Study and the four aerial surveys followed the same protocol used by the low-altitude Central and Northern California surveys. The three ship surveys were similar to those conducted in the Southern California Bight, except that the survey strip extended 300m at a right angle to the ship's heading.

Oregon –Washington

Oregon and Washington waters were sampled via low-altitude aerial and ship surveys from April 1989 to October 1990. This study aimed to determine marine mammal and seabird diversity, distribution and abundance in Oregon and Washington waters. Thirty-two pre-determined transects were surveyed on twelve aerial surveys; seabirds were counted only within a 50m corridor on the shaded side of the plane and marine mammals were censused using an unbounded corridor. One ship survey was conducted in August of1989.

OSPR-MMS Surveys

From June 1994 through 1997, 31,271 km of transects were flown in coastal and inland marine waters of California. This survey was conducted with the objective of developing a capability for aerial surveys flown in response to oil-spills. Seventy-four low aerial (200ft) surveys were conducted in this region to count marine mammals and seabirds. Two 50m corridors determined using an inclinometer were surveyed on both sides of the aircraft.

Table 2 summarizes the area, year and season for each of the surveys.

DATA SET	TYPE OF EFFORT	HABITAT COVERED	YEARS	OCEANOGRAPHIC SEASONS
Southern California Bight Surveys	High aerial – Cetaceans, Low aerial – Mammals and Birds, Ship Surveys – Birds and Mammals	Shelf, slope	1975-1978	Year round
Central and Northern California	High aerial – cetaceans, Low aerial – birds and mammals	Shelf, slope, pelagic	1980-1983	Year round
Seabird Ecology	Low Aerial – birds and mammals	Shelf, slope	1985	Mainly upwelling
Oregon and Washington	High Aerial – cetaceans Low Aerial – birds and mammals, Ship – birds and mammals	Shelf, slope, pelagic	1989-1990	Year-round
OSPR/MMS Surveys	Low Aerial Surveys – birds and mammals	Shelf, slope	1994-1997	Year round

The Minerals Management Service compiled the data from all these surveys into a publicly-available computer database analysis system, which enables the user to subset and display observations of specific species, studies, months and years. These observations appear visually on a map of the US West Coast and can be exported into a comma-delimited file containing latitude, longitude, effort, animals, record # and density (animals per km ^{2}). When a query for a given month and year yields survey effort but no observations of the species of interest, these observations cannot be visualized, though the raw data can still be exported. Queries that generate no survey effort generate an error message.

As discussed above, I selected fourteen focal species for analysis: six cetaceans and eight seabirds. These taxa have one common characteristic – they are all highly migratory animals spending a significant portion of their lives in the open ocean, in habitats which have no protection from human use and damage. Some of the species selected are endangered and some are not in any immediate threat of extinction, but all visit the area from the continental shelf to the pelagic zone (greater than 4000 m. deep)off the West coast of North America, a region heavily used by anthropogenic activities, including fisheries, oil / gas exploitation and vessel traffic. Thus, these species commonly interact with humans and are often negatively by human activities.

For each focal species, I analyzed only the studies which had documented observations of that animal. For example, the rhinoceros auklet is easily observed during vessel-based or low-altitude aerial surveys, but is hard to see from high altitude aerial surveys. Thus, the inclusion of the latter surveys would provide underestimate the presence / density of this species. This conservative approach was designed to restrict the analyses by including only "effective" effort from surveys that observed the focal species. Because different taxa are more easily detected by certain types of surveys, the total amount of survey effort and the make-up of that effort (e.g., ship-based, high-altitude and low-altitude aerial surveys) varies among species.

Output files were generated for each month for all fourteen species. Months with no effort were documented for each species. Upon completion of data gathering for all species, date columns were added and the files were batched. In a GIS, data points for each species were joined with a bathymetry grid with a spatial resolution of two minutes (MCBI, 2003), obtained from the publicly-available Marine Conservation Biology Institute (MCBI) Bering to Baja CD-ROM (Etnoyer, 2003). Bathymetry cells were divided into four classes: 0-199 m (shelf), 200-999 m (shelf-break), 1000-2999 (slope), and > 3000 (pelagic). The dates were divided into season and year columns, and classified on the basis of the three primary oceanographic periods recognized for the California Current System (CCS): the Counter Current Period (December – March), the Upwelling Period (April – August) and the Oceanic Period (September – November) (Bolin & Abbott, 1963; Ford et.al., 2003). For each year, months were ranked on the basis of NOAA's Multivariate ENSO Index (MEI). MEI is ideal to classify months into the three year types: El El Niño / La Niña / Neutral. This index, compiled by NOAA, is a monthly monitor of El Niño Southern Oscillation by using six variables. These variables include sea-level pressure (P), zonal (U) and meridional (V) components of the surface wind, sea surface temperature (S), surface air temperature (A), and total cloudiness fraction of the sky (C). (NOAA-CIRES, 2003).

Statistics on were run using SYSTAT and with the help of David Hyrenbach. With the completed files, we were able to use statistics to determine which variable had the most impact on the distribution of each species. Because we were initially looking at discrete data with two options, 1 = presence and 0 = absence, we decided to run a logistic regression model. This model allows us to test our dependent variable (presence) against our seven independent variables (latitude, longitude, effort, season 1, season 2, year, bathymetry). Using the SYSTAT 7.0 statistical software (Wilkinson, 1997) we first ran a backwards, step-wise logistic regression, which progressively discards the ill-fitting variables (those with high p-values) and arrives at a stronger model where all of the independent variables significantly ($p < 0.05$) explained the distribution of presence / absence (the dependent variable). This approach was used to define the range of conditions inhabited by each focal species.

After the logistic regression model was complete, we ran a generalized linear model to determine the effect of the independent variables on the species density (dependent variable). This analysis was limited to presence data only, and was designed to identify "hotspots" of aggregation identified by high density concentrations of the focal species Because initial analysis revealed that the density data were not normally distributed we used a generalized linear model approach to analyze the relationships between log-transformed density data and the predictor variables.

Following the statistical analysis, I assessed the ability of existing sanctuaries to protect the fourteen highly migratory species densities. This analysis was completed in a GIS and a percentage was generated for the amount of density covered by the sanctuary compared with the total density for each species. After analyzing existing sanctuaries, I proposed three new sanctuary locations based on the hot spot locations where there were high densities for each species. I then analyzed these three new areas for coverage of each species density in a GIS in a similar manner to the existing sanctuary analysis.

The last analysis completed on the data was a spatial analysis of patchiness. Using Green's Index of Dispersion, a method which calculates the degree of species' aggregation using the following equation: $G_x = [(S^2 / X) - 1] / [\Sigma x - 1]$. In this equation, S^2, X is the sample mean and Σx is the sum of all the values in the sample. The Gx values range from a maximum aggregation of animals (value of 1) to a uniform distribution of animals (number equal to $- [1 / (\Sigma x - 1)]$) (Andrew and Mapstone 1987).

RESULTS

The three survey types, high and low aerial and vessel-based, generate varying amounts of effort for each of the fourteen species, a result displayed in Table 4. Due to the high variability of effort depending on survey type, density values are included, and those density values are considered the most valuable for the analyses. Density is a measure of the number of animals sighted per unit of search effort and the use of this value for each species standardizes the results.

Figures 2-4 highlight the oceanographic season with the highest density for each species; shown in blue are the occasions when the highest density was in a different season than the highest amount of effort. Density values were highest for black-footed albatross, Xantus murrelet, pink-footed shearwater, sooty-shearwater, and Leach's storm petrel during the upwelling season, the season with the highest effort for all fourteen species. The two auklets, rhinoceros and Cassin's, were found predominantly during the counter-current season despite higher search effort in the upwelling period. The laysan albatross was the only seabird with the highest density during the oceanic period.

Four of the cetaceans; Dall's porpoise, Baird's beaked whale, blue whale and fin whale, were found where the highest effort was concentrated, during the upwelling season. The highest densities of pacific white-sided dolphin and Risso's dolphin occurred not in the season with the highest effort, but instead in the oceanic season. Although the densities for Dall's porpoise were highest during the upwelling period (43.6%), they maintained a strong presence during the oceanic period as well (41.2%).

Similar results as displayed in Figures 2-4 are found in Table 5 where the upwelling season is statistically compared to the other two seasons (OC = oceanic, CC = counter-current) and differences from the upwelling season are recorded. The statistics were calculated using a backwards, stepwise logistic regression in SYSTAT. In this table, a positive value indicates a higher density in that season compared to upwelling whereas a negative value means more animals were seen in the upwelling period. The values that are statistically significant are highlighted in red.

For eight of the fourteen species, the bathymetry class with the highest effort differed from the bathymetry class with the highest sighting density (Figures 5-8). In each of these eight situations, the shelf-break region was the area where there was the highest effort. In fact, in twelve of the fourteen cases, shelf-break was the area with the highest amount of effort. The slope region was the area where the rest of the effort was directed for most of the species. Nevertheless, only four species -- black-footed albatross, xantus murrelet, blue whale and fin whale -- preferred this habitat over the other three bathymetry regions. Seven of the species -- laysan albatross, rhinoceros auklet, Leach's storm petrel, pacific white-sided dolphin, Risso's dolphin, Dall's porpoise and Baird's beaked whale -- preferred to be distributed over the slope region. The two shearwaters were most common in the shelf area and Cassin's auklet was the lone species preferring the pelagic zone. This same information is presented statistically in Table 5 with the shelf class being the reference class.

I have mentioned comparisons with effort and incidences where the highest amount of effort does not correlate with the highest species density. In order to really understand how effort affects observations of animals, species per unit effort is graphed for the seabirds (Figure 9) and the cetaceans (Figure 10). Both of these figures indicate that effort does influence observations in a near-linear manner. Although the R-squared values for these correlations are significant, there are clearly some species, like Cassin's auklet and Dall's porpoise which fall below the average of species per unit effort for the seabirds or cetaceans.

The influence of effort on species distribution is quantified statistically in Table 5 with only four species not having a statistically significant correlation with effort. Nevertheless, in all fourteen situations effort positively influences species observations. In addition to this value and the correlations with season and bathymetry, Table 5 provides two more pieces of information. It includes an analysis of year type's (El Niño, neutral, or La Niña) affect on species density and a value for the percent of correct predictions based on a best fit model. Although not all values were statistically significant, the regression found seven of the fourteen species to be less dense in an El Niño year whereas the other seven had higher densities in an El Niño year. In all but two cases (Cassin's auklet and sooty shearwater), the model was over 92% accurate in its predictions for each species.

Patchiness in space was measured with Green's Index of Dispersion (Table 6). As evident from the results, none of these species were found to have a patchy distribution over the entire range for each species. This table also includes information of how well the existing MPAs cover the highest densities of each species. One species, sooty shearwater, was adequately covered more than 50% of the time; seven species – black-footed albatross, pink-footed shearwater, pacific white-sided dolphin, Risso's dolphin, Dall's porpoise, blue whale and fin whale – were covered between 10% and 31% of the time and the other six species had less than 10% of their species density covered by existing MPAs.

The last analysis included an assessment of species density within the three proposed new sanctuaries and a comparison of this result to the percent coverage by the existing sanctuaries. (Table 7). Results indicate that two of the proposed sanctuaries – the North Bend, Oregon region and Humbolt Bay, CA region – protect over 55% of the density hot spots for each species, a percentage that is greatly improved from all the existing sanctuaries except for Monterey Bay. The existing sanctuaries range from covering 8.3% (Gulf of Farallones) of the species densities to 53.8% (Monterey Bay) with the latter the only existing sanctuary to cover more than 30% of the species.

Total number of observations for each of the fourteen species is provided below (table 3).

Table 3

Scientific Name	**Common Name**	**Total Animals Observed**
Phoebastria nigripes	Black-footed Albatross	1,426
Phoebastria immutabilis	Laysan Albatross	29
Ptychoramphus aleuticus	Cassin's Auklet	19,869
Cerorhinca monocerata	Rhinoceros Auklet	727
Synthliboramphus hypoleuca	Xantus Murrelet	239
Puffinus creatopus	Pink-footed Shearwater	3,698
Puffinus griseus	Sooty Shearwater	83,514
Oceanodrama leucorhoa	Leach's Storm Petrel	2,069
Berardius bairdii	Baird's Beaked Whale	81
Lagenorhynchus obliquidens	Pacific White-sided Dolphin	53,628
Grampus griseus	Risso's Dolphin	7,172
Phocoenoids dalli	Dall's Porpoise	1,902
Balaenoptera musculus	Blue Whale	96
Balaenoptera physalus	Fin Whale	103

The number of animals sighted, density, and effort are divided into color-coded survey types for each species (Table 4). The final column provides the total amount of effort covered for each species.

Table 4

Species	Survey type	# of Animals	Density	Effort (km)	Total effort (km)
Black-footed Albatross	Ship	359	89	689	5148
	Low aerial	1067	3009.532	4459	
Laysan Albatross	Low aerial	29	106.538	205	205
Cassin's Auklet	Ship	302	122.266	690	24874
	Low aerial	19558	54037.72	24184	
Rhinoceros Auklet	Ship	387	173.479	918	1703
	Low aerial	340	714.431	785	
Xantus Murrelet	Ship	171	81.797	477	735
	Low aerial	68	144.310	258	
Pink-footed Shearwater	Ship	1817	496.786	2216	7929
	Low aerial	1881	4873.837	5713	
Sooty-shearwater	Ship	8669	2013.628	3061	33868
	Low aerial	74845	152783.200	30807	
Leach's storm petrel	Ship	164	459.584	687	8093
	Low aerial	0	0	7406	
Baird's Beaked Whale	Ship	4	1.076	11	215
	Low aerial	21	36.699	70	
	High aerial	56	4.539	134	
Pacific White-sided Dolphin	Ship	3825	1337.432	375	5411
	Low aerial	18562	20200.38	3066	
	High aerial	31241	3515.176	1970	
Risso's Dolphin	Ship	276	84.797	149	1589
	Low aerial	2188	2130.764	501	
	High aerial	4708	783.270	939	
Dall's Porpoise	Ship	212	116.273	182	4044
	Low aerial	110	90.349	2714	
	High aerial	0	0.000	1148	
Blue Whale	Ship	12	4.169	94	574
	Low aerial	30	50.444	177	
	High aerial	54	4.967	303	
Fin Whale	Ship	7	2.727	42	537
	Low aerial	40	59.56	139	
	High aerial	56	5.182	356	

Figure 2: Seasonal distribution of albatross and auklets.

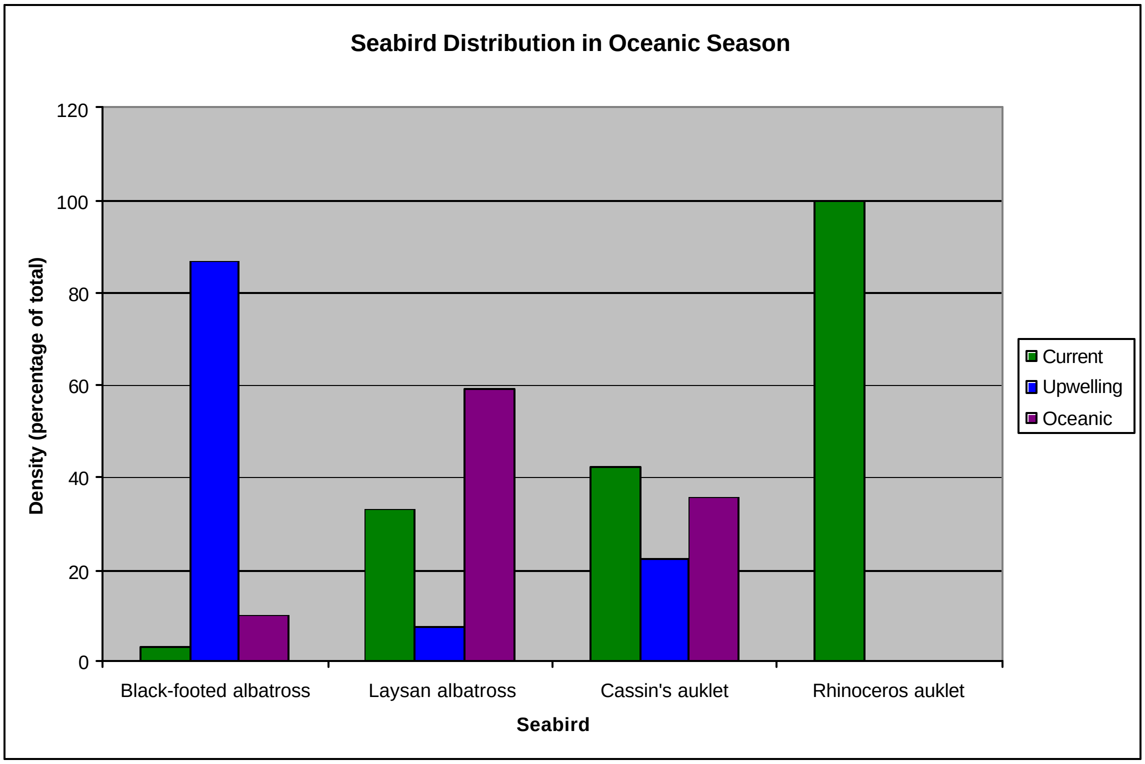


Figure 3: Seasonal distribution of Xantus murrelet, pink-footed shearwater, sooty shearwater, and Leach's storm-petrel.

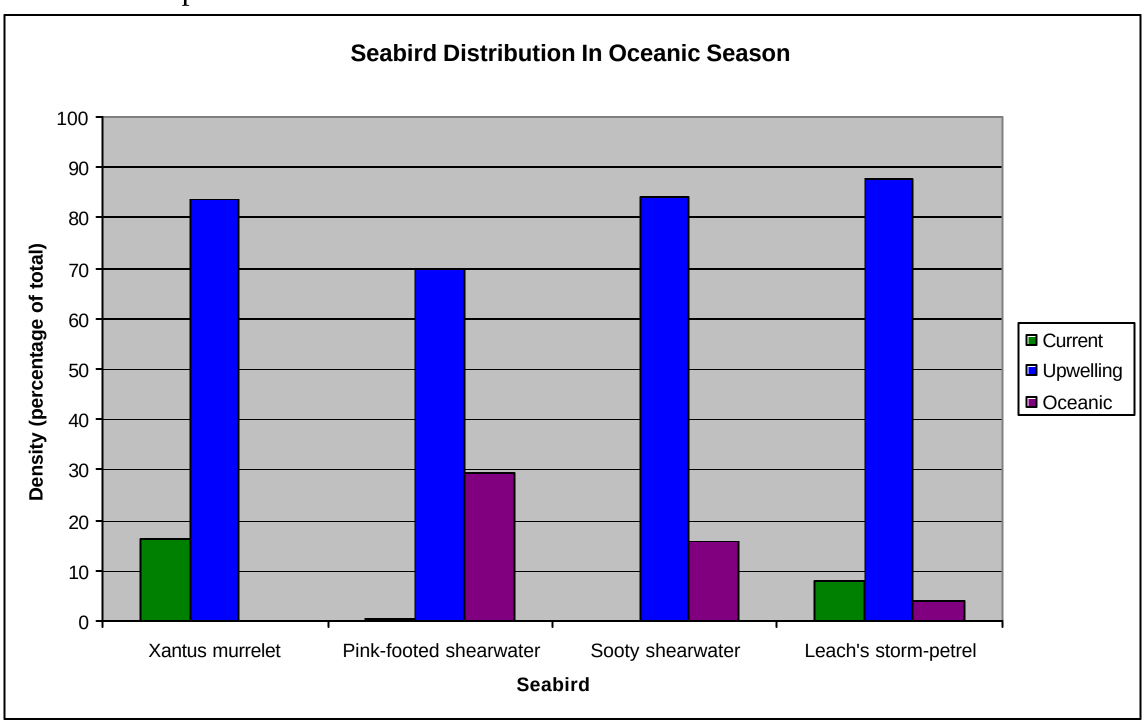


Figure 4: Cetacean seasonal distribution.

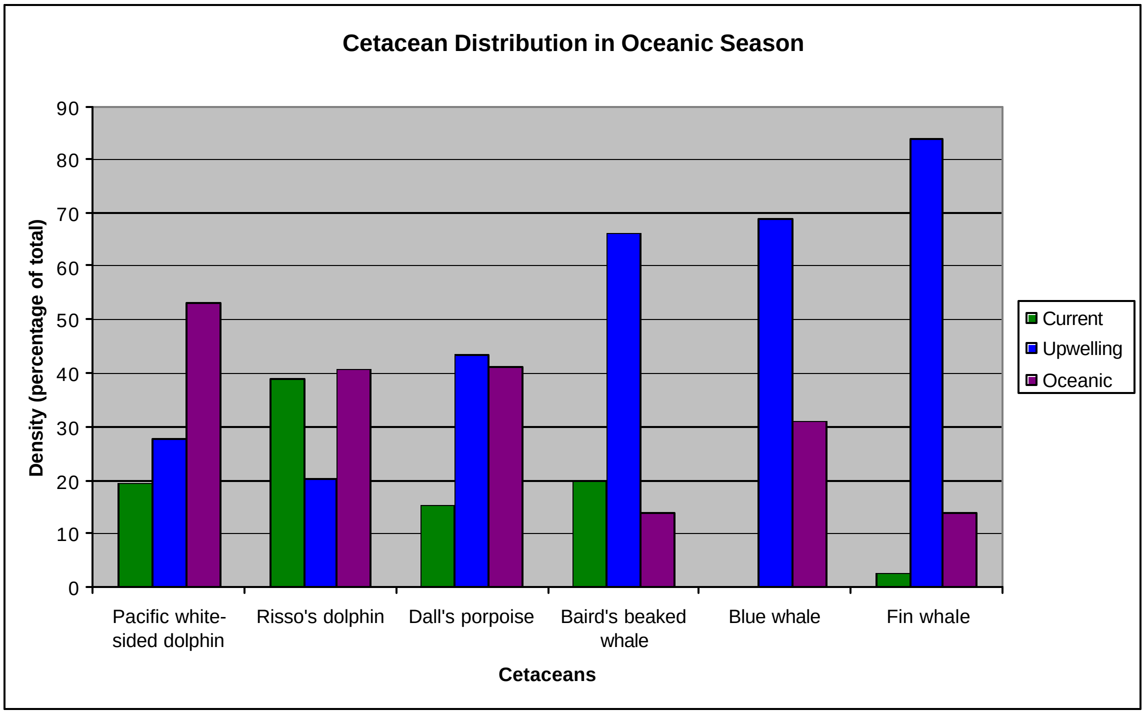


Figure 5: Distribution of albatross and auklets based on bathymetry class.

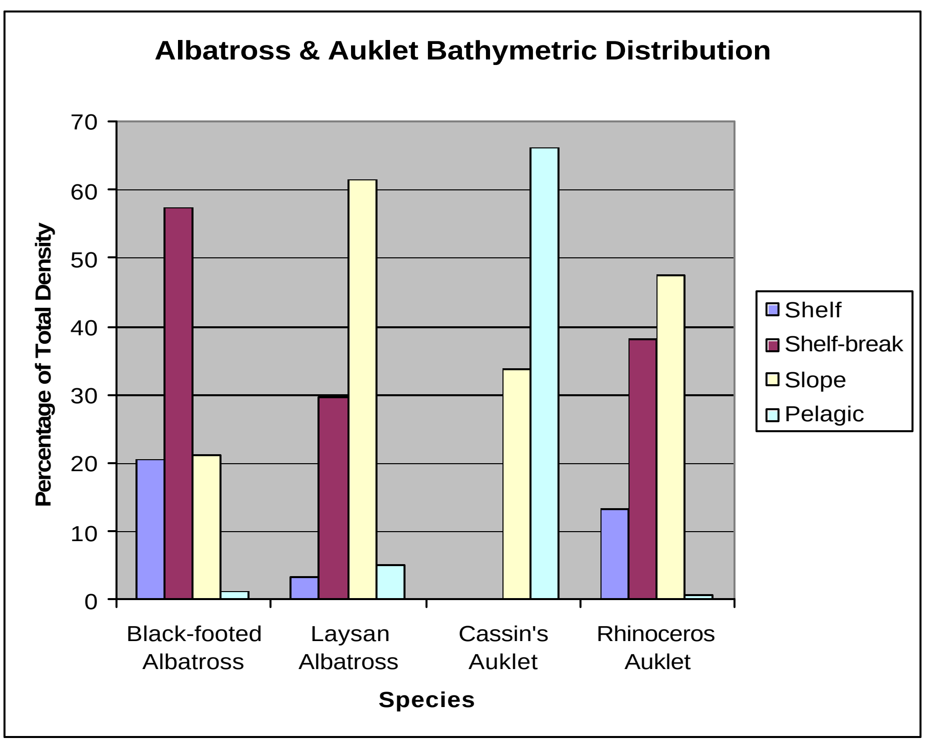


Figure 6: Distribution of Xantus murrelet, pink-footed shearwater, sooty shearwater and Leach's storm petrel based on bathymetry class.

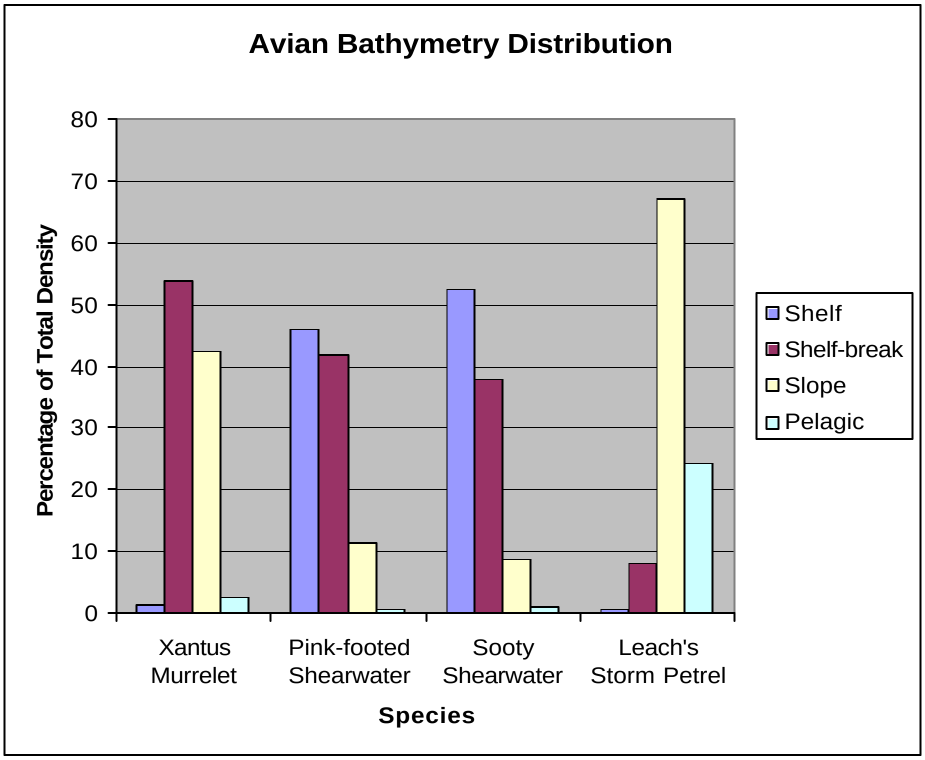


Figure 7: Dolphin and porpoise distribution based on bathymetry class.

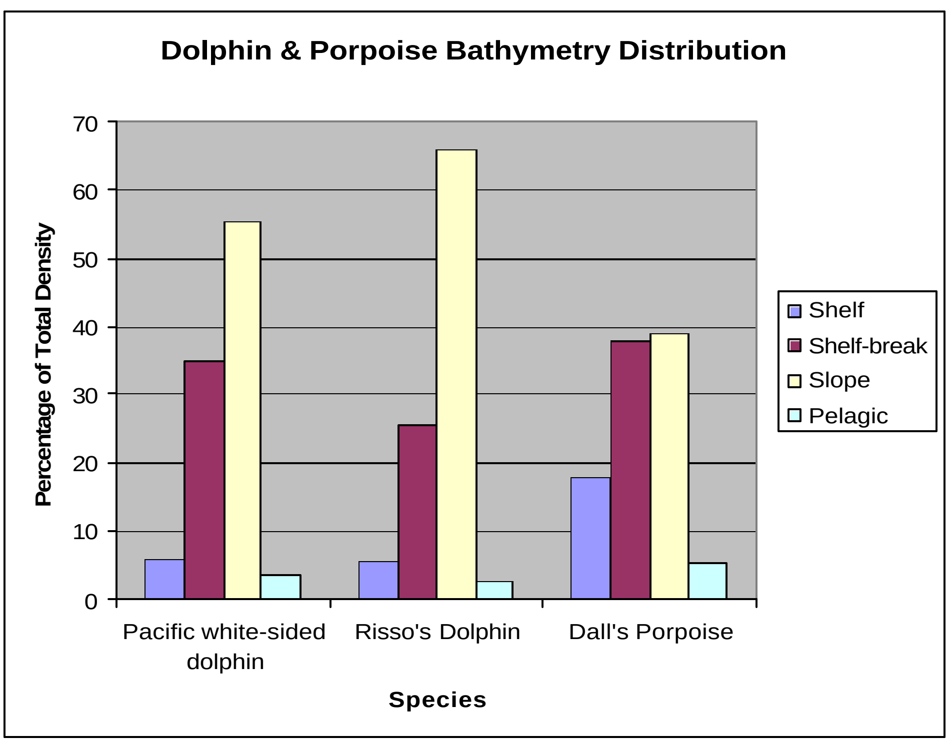
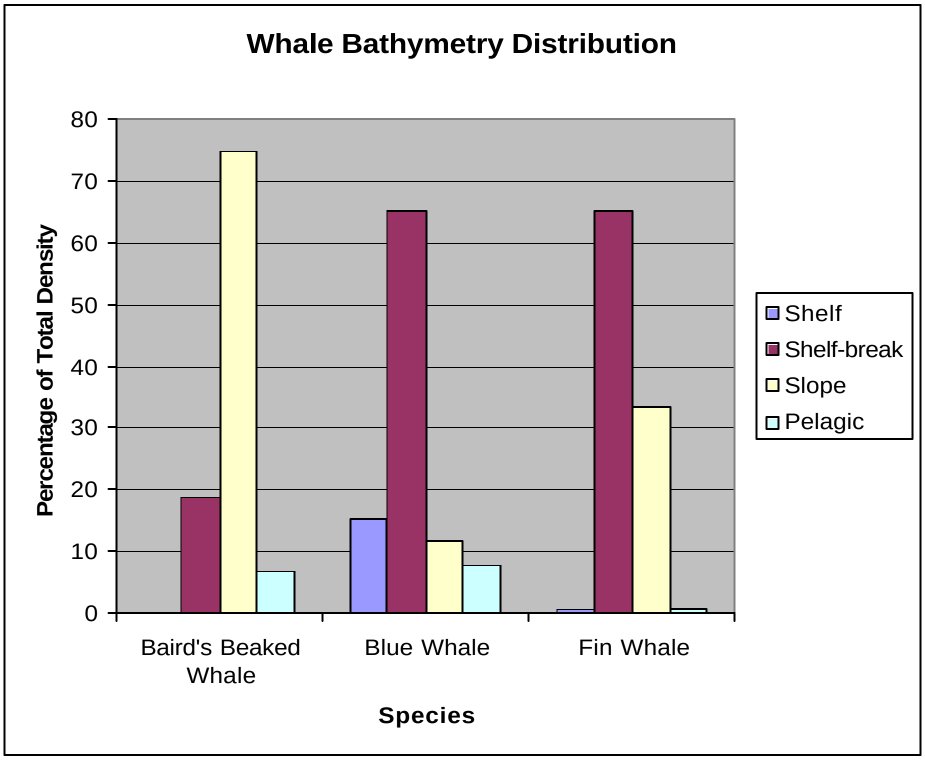


Figure 8: Whale distribution based on bathymetry class.



Effort's affect on seabird observations (Figure 9) and cetacean observations (Figure 10) can be accounted for by graphing total effort for each species versus total number of animals. A linear relationship with R^2 values over 0.5 is observed for both cetaceans and seabirds indicating that effort does have an impact on species distribution.

Figure 9: Sightings per unit effort for all seabirds.

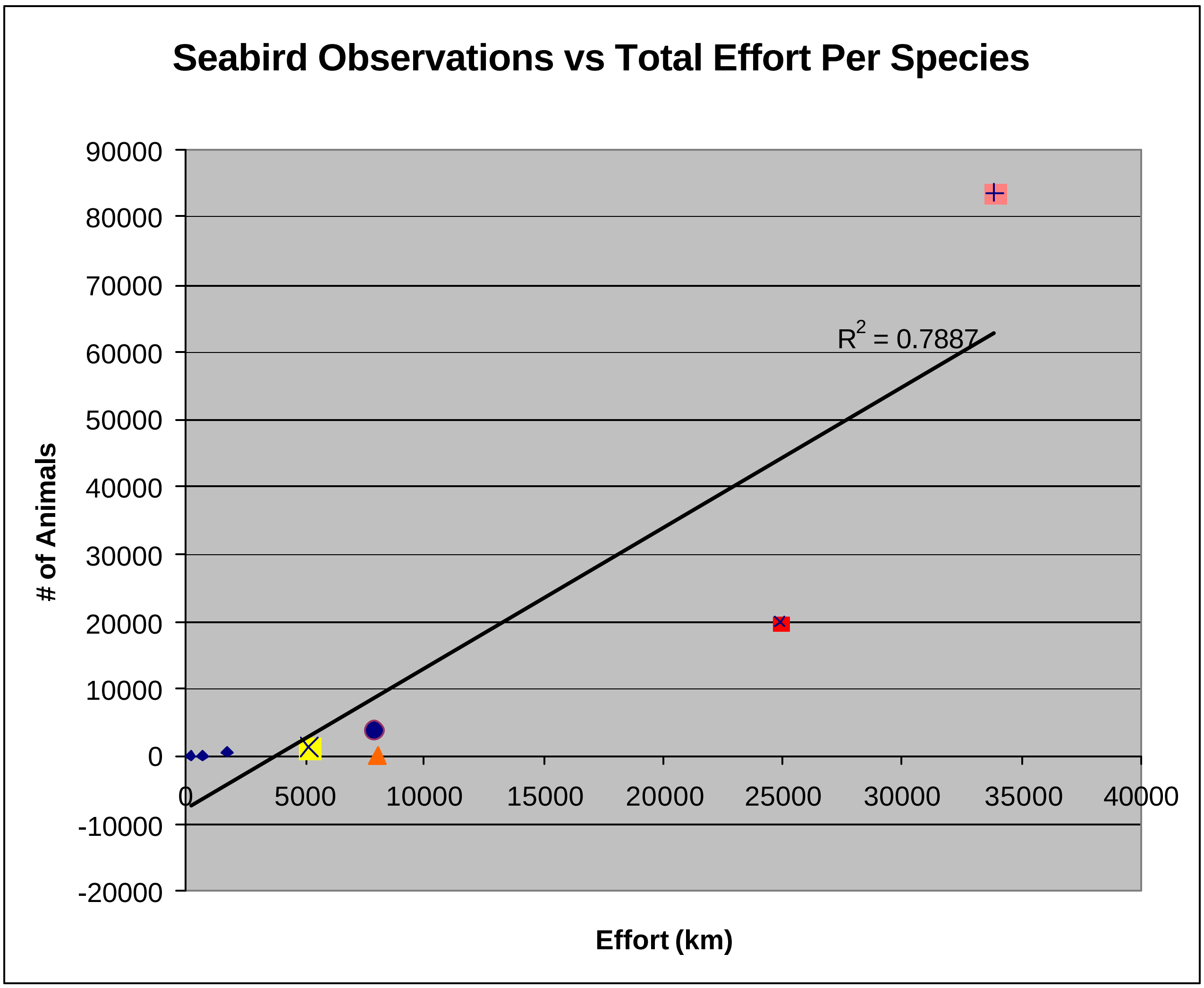
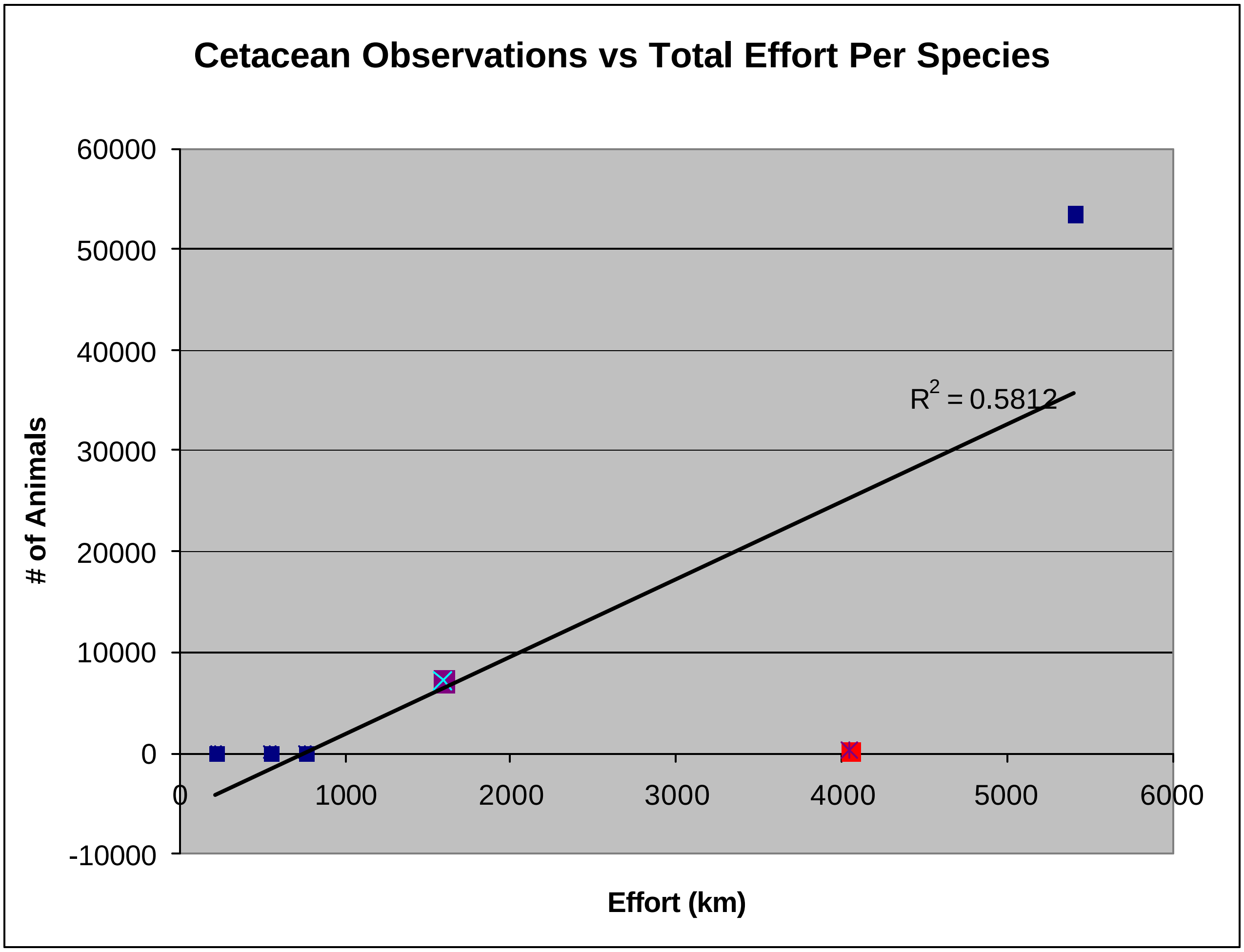


Figure 10: Sightings per unit effort for all six cetaceans.



Statistical analysis of presence versus absence of species density was completed with a stepwise backwards logistic regression. This shows that effort has a positive affect on species observations (Table 5). Bathymetry class, season and year preference per species are included as well as an analysis of the success of the model (columns 3-10, Table 5).

NOTE: Seasonal comparisons against the UPWELLING PERIOD
NOTE: Habitat comparisons against the SHELF AREA

Table 5

Species Code	Effort coeff.	Pelagic coeff.	Slope coeff.	Shelf-break coeff.	CC season coeff.	OC season coeff.	Year coeff.	Best-fit Model ? ^{2} (df)	% Correct Predictions
BFAL	0.023 (<0.001)	- 1.724 (<0.001)	- 0.407 (0.002)	1.057 (<0.001)	- 2.393 (<0.001)	- 2.050 (<0.001)	- 0.011 (0.005)	1194.482 (9) (< 0.001)	95.5
CAAU	0.054 (<0.001)	2.423 (<0.001)	2.124 (<0.001)	- 0.505 (0.497)	1.414 (<0.001)	0.936 (<0.001)	0.007 (<0.001)	3238.639 (9) (<0.001)	78.2
LESP	0.090 (<0.001)	4.831 (<0.001)	4.556 (<0.001)	3.055 (<0.001)	- 1.709 (<0.001)	- 1.523 (<0.001)	0.005 (0.126)	1525.148 (8) (<0.001)	92.6
LYAL	0.033 (0.454)	1.041 (0.341)	1.371 (0.095)	1.451 (0.066)	2.449 (<0.001)	2.224 (<0.001)	0.039 (0.031)	35.675 (4) (<0.001)	99.8
PFSH	0.023 (<0.001)	- 2.362 (<0.001)	- 0.788 (<0.001)	0.173 (0.031)	- 3.451 (<0.001)	- 0.694 (<0.001)	- 0.029 (< 0.001)	1004.117 (8) (<0.001)	94.7
RHAU	0.021 (0.024)	- 2.741 (<0.001)	- 0.628 (<0.001)	- 0.043 (<0.001)	13.419 (0.656)	- 0.632 (0.992)	- 0.044 (<0.001)	238.546 (7) (<0.001)	94.7
SOSH	0.036 (<0.001)	- 1.854 (<0.001)	- 0.950 (<0.001)	- 0.033 (<0.001)	- 4.370 (<0.001)	- 1.142 (<0.001)	- 0.001 (0.689)	4163.907 (8) (<0.001)	79.5
XAMU	0.025 (0.279)	- 1.613 (0.175)	0.173 (0.775)	1.045 (0.053)	- 1.157 (<0.001)	- 26.034 (0.999)	- 0.019 (0.010)	243.553 (4) (<0.001)	99.3
BABW	0.042 (0.072)	9.138 (0.024)	10.318 (0.008)	10.108 (0.006)	- 0.831 (0.204)	0.141 (0.778)	- 0.007 (0.700)	17.939 (3) (<0.036)	99.9
BLWH	0.033 (0.077)	- 1.054 (0.109)	- 0.501 (0.289)	0.227 (0.591)	- 24.125 (0.999)	0.745 (0.009)	0.006 (0.561)	54.218 (4) (<0.001)	99.8
DAPO	0.018 (<0.001)	- 1.181 (<0.001)	- 0.039 (0.779)	0.449 (<0.001)	- 0.223 (0.112)	0.383 (<0.001)	0.003 (0.551)	177.082 (8) (<0.001)	96.7
FIWH	0.056 (0.021)	0.353 (0.669)	1.188 (0.056)	1.164 (0.059)	- 0.772 (0.105)	0.865 (0.005)	0.021 (0.069)	47.633 (4) (<0.001)	99.8
PWSD	0.030 (<0.001)	- 0.330 (0.238)	0.976 (<0.001)	1.443 (<0.001)	- 0.278 (0.021)	0.191 (0.077)	- 0.004 (0.329)	272.029 (8) (<0.001)	98.2
RIDO	0.017 (0.005)	0.020 (0.964)	0.991 (0.003)	0.645 (0.054)	0.139 (0.496)	0.090 (0.663)	0.034 (<0.001)	76.668 (7) (<0.001)	98.4

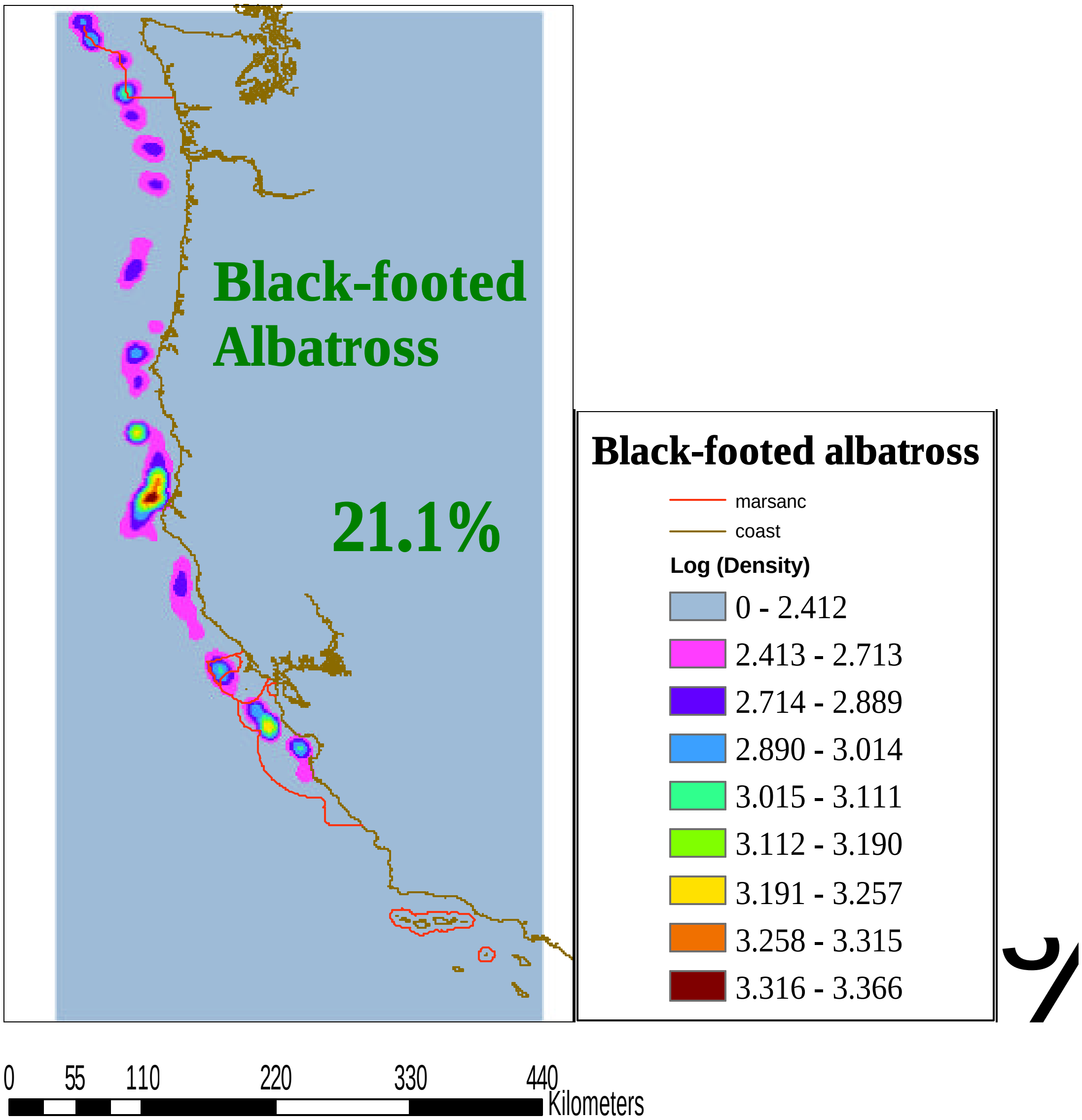


Figure 11: Density map of black-footed albatross. The percentage is how much of the albatross density is covered by existing sanctuaries (outlined in red).

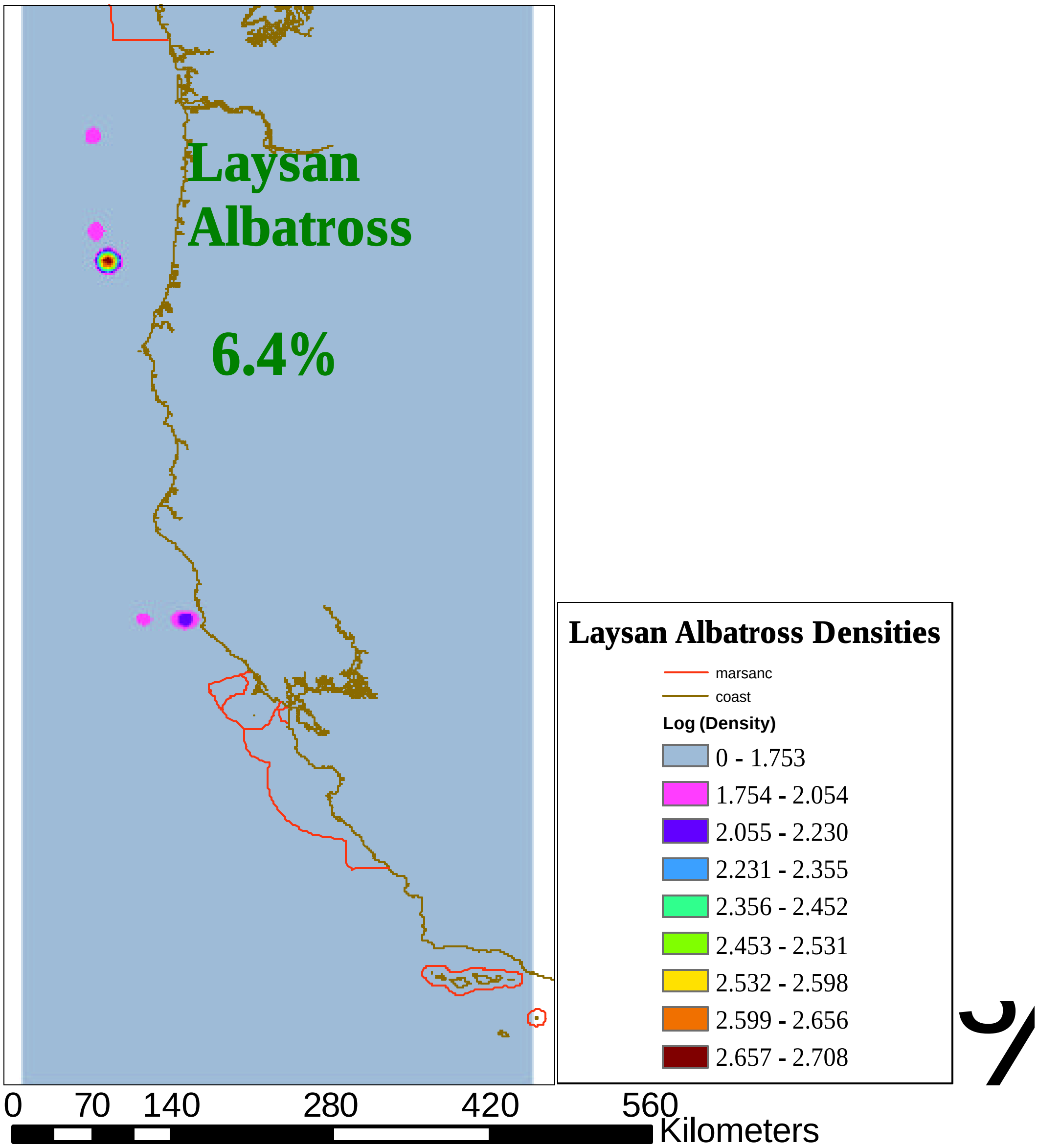


Figure 12: Density map of laysan albatross. The percentage is how much of the albatross density is covered by existing sanctuaries (outlined in red).

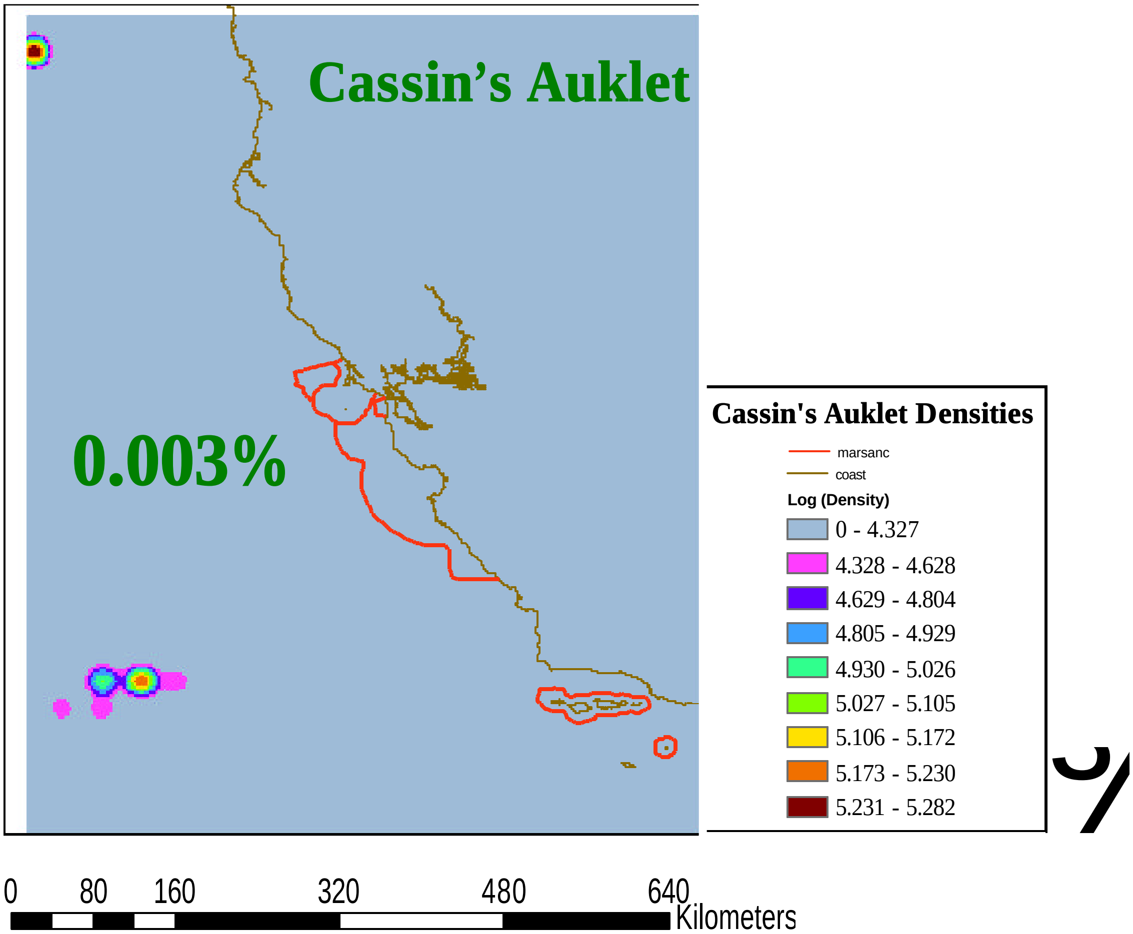


Figure 13: Density map of Cassin's auklet. The percentage is how much of the auklet density is covered by existing sanctuaries (outlined in red).

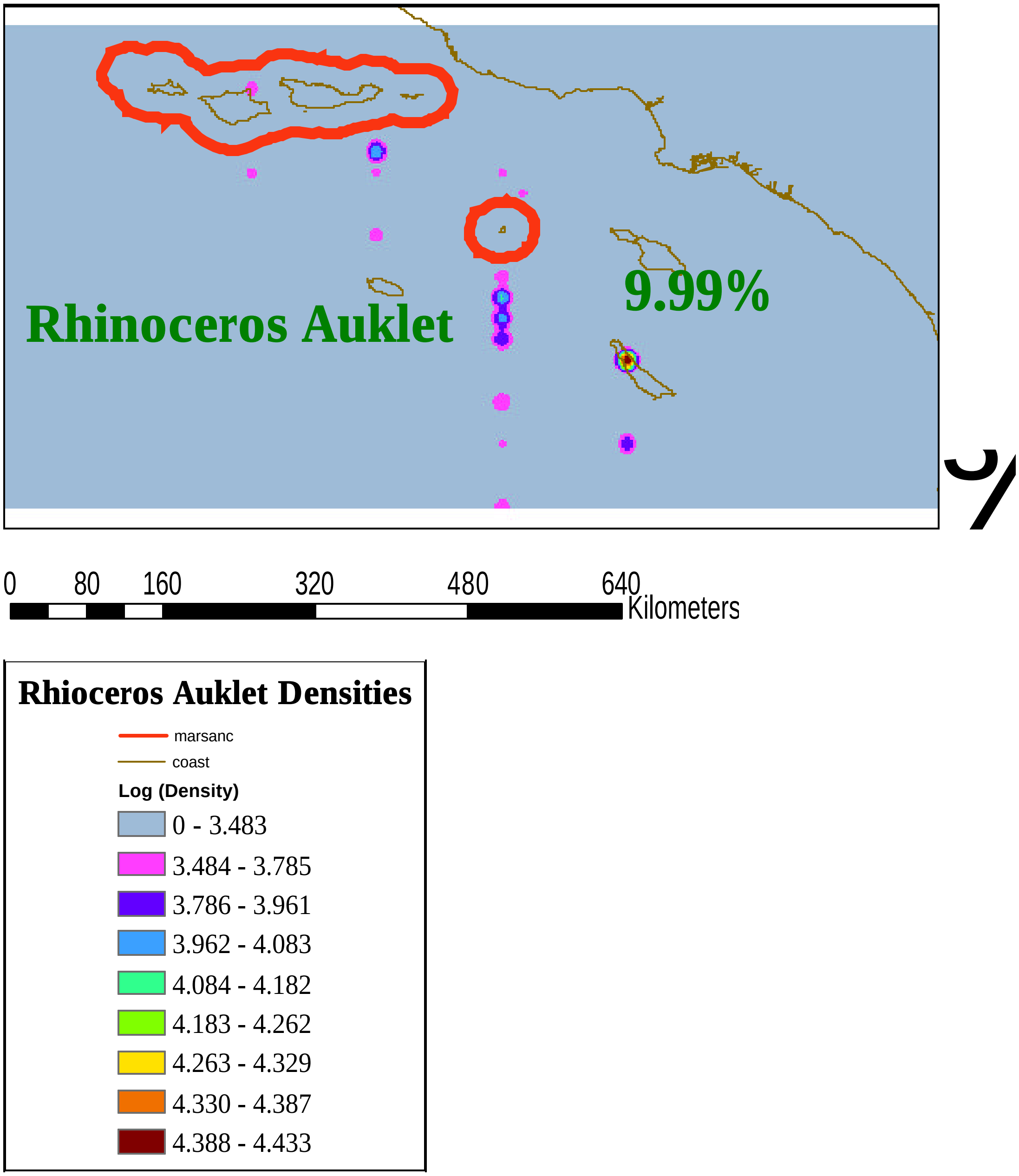
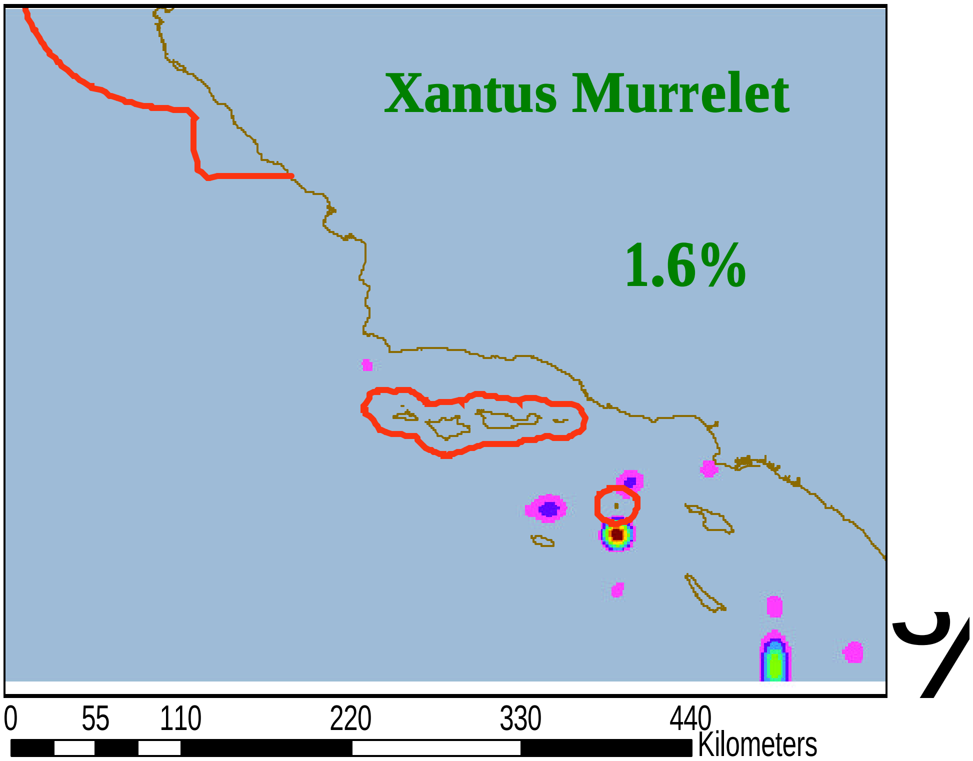


Figure 14: Density map of rhinoceros auklet. The percentage is how much of the auklet density is covered by existing sanctuaries (outlined in red).



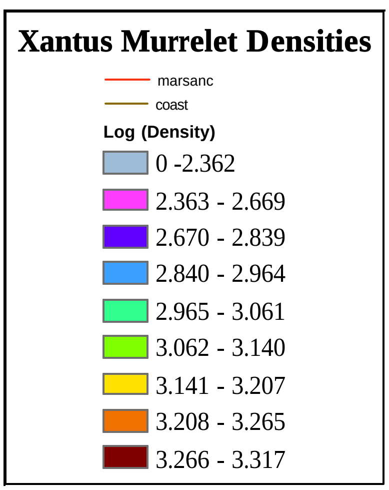


Figure 15: Density map of xantus murrelet. The percentage is how much of the murrelet density is covered by existing sanctuaries (outlined in red).

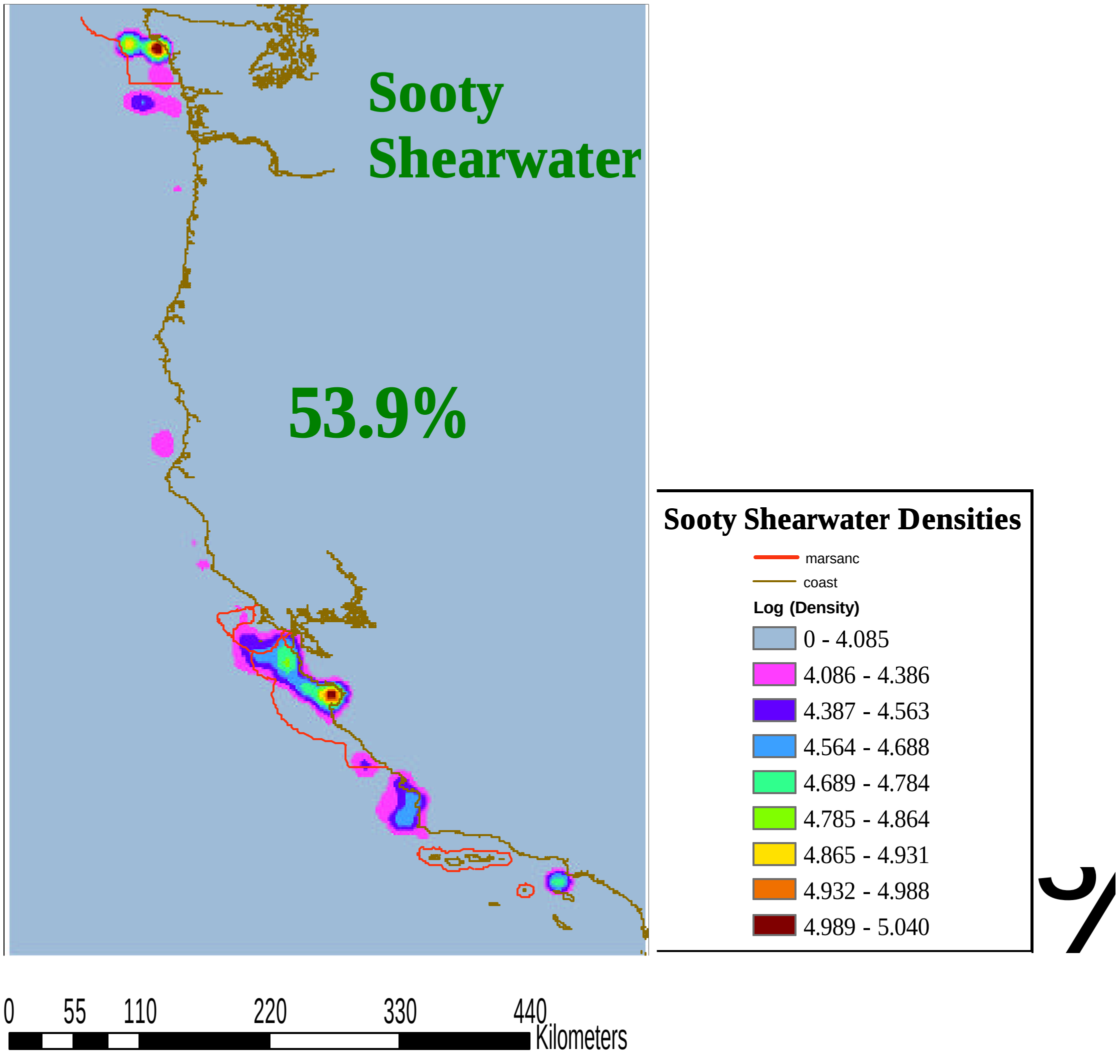


Figure 16: Density map of sooty shearwater. The percentage is how much of the shearwater density is covered by existing sanctuaries (outlined in red).

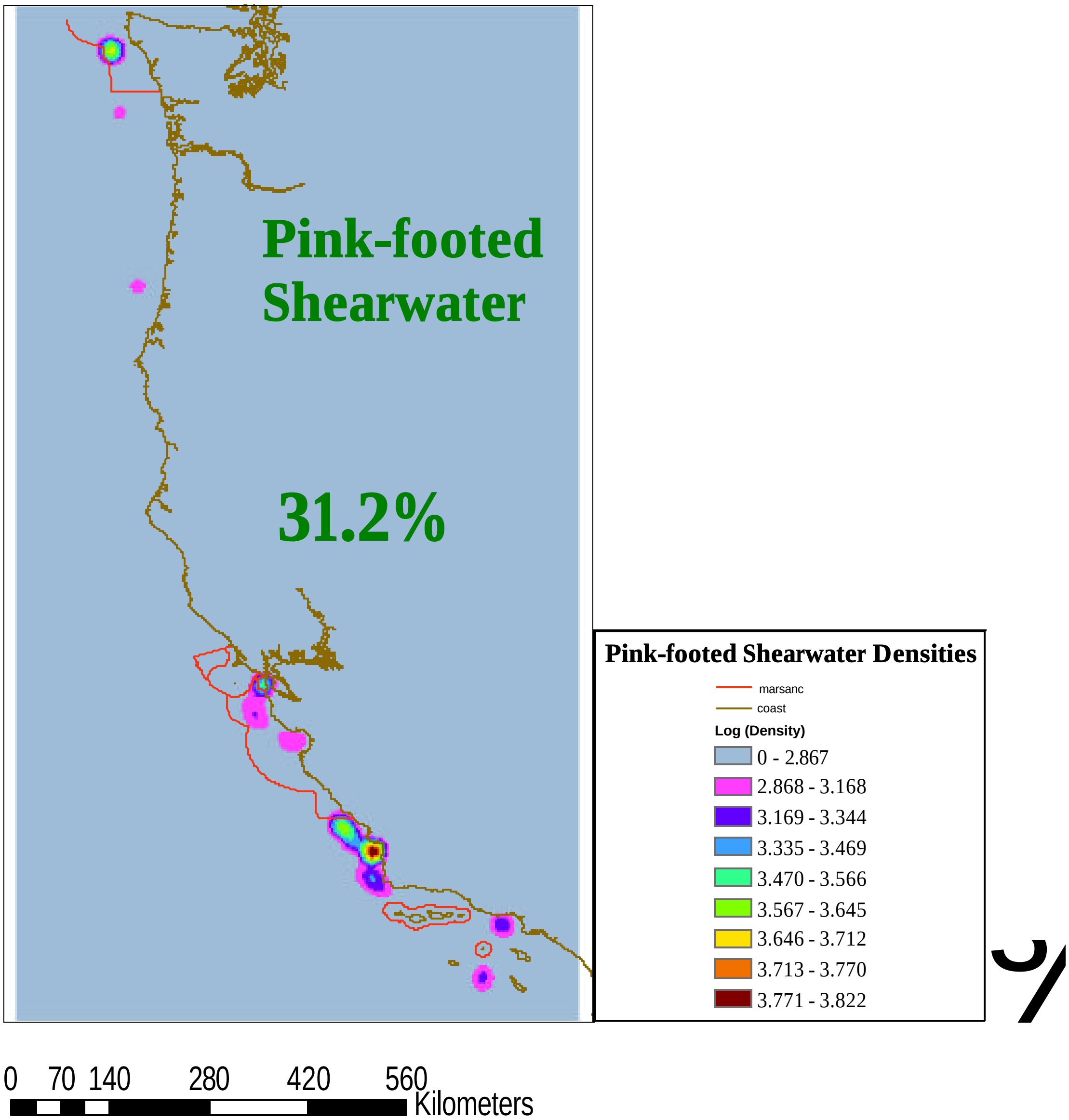


Figure 17: Density map of pink-footed shearwater. The percentage is how much of the shearwater density is covered by existing sanctuaries (outlined in red).

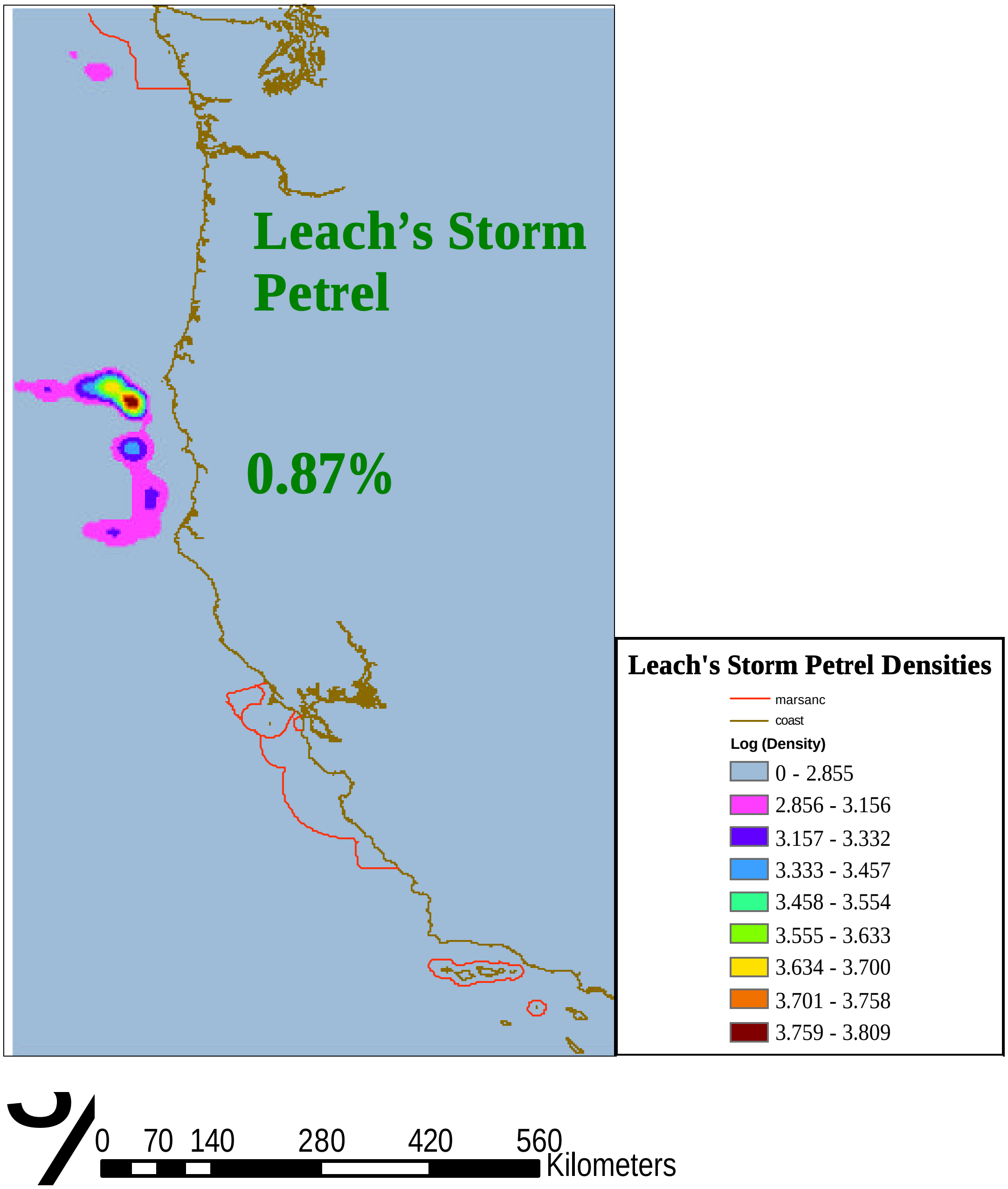


Figure 18: Density map of Leach's storm petrel. The percentage is how much of the storm petrel density is covered by existing sanctuaries (outlined in red).

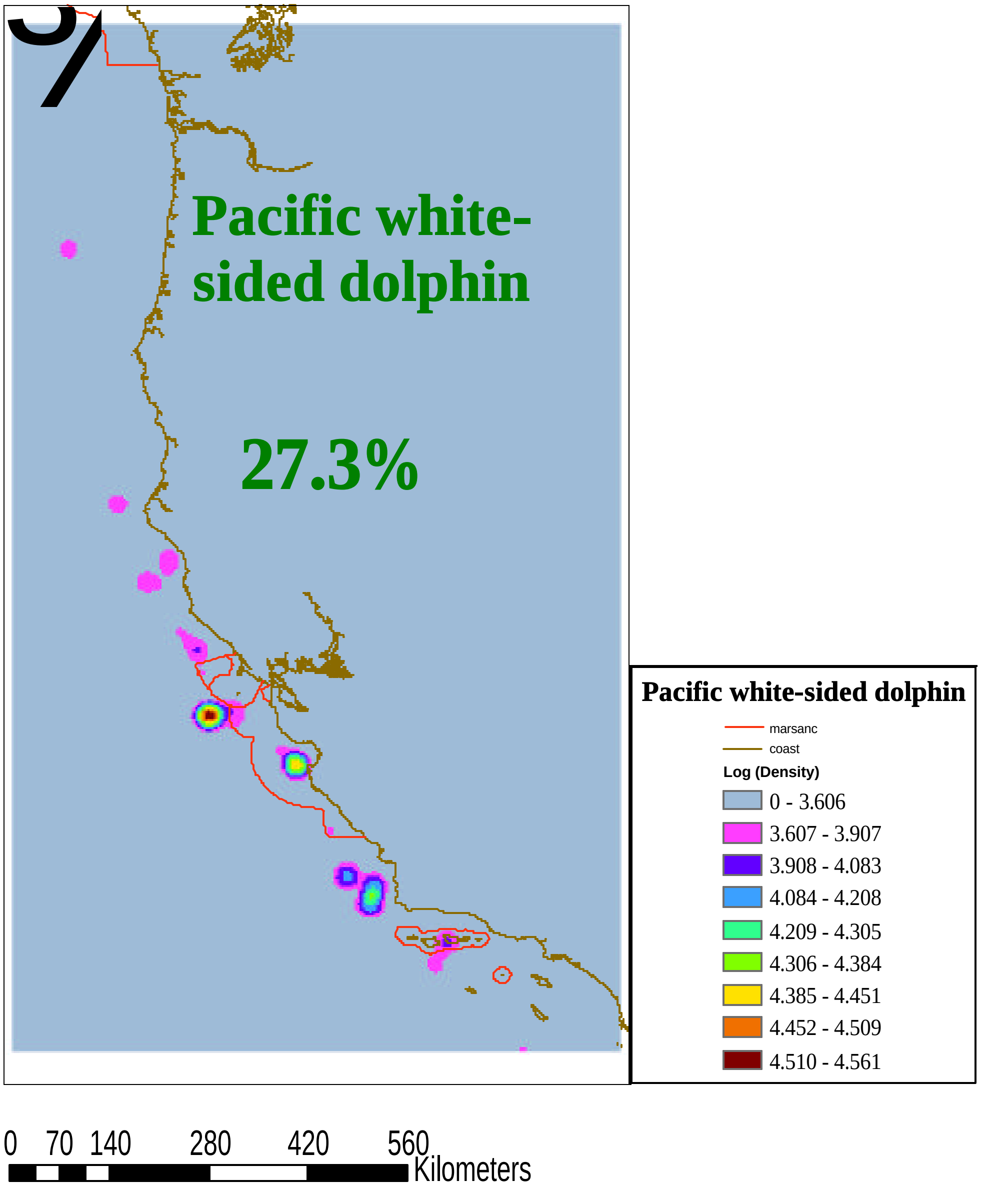


Figure 19: Density map of Pacific white-sided dolphin. The percentage is how much of the dolphin density is covered by existing sanctuaries (outlined in red).

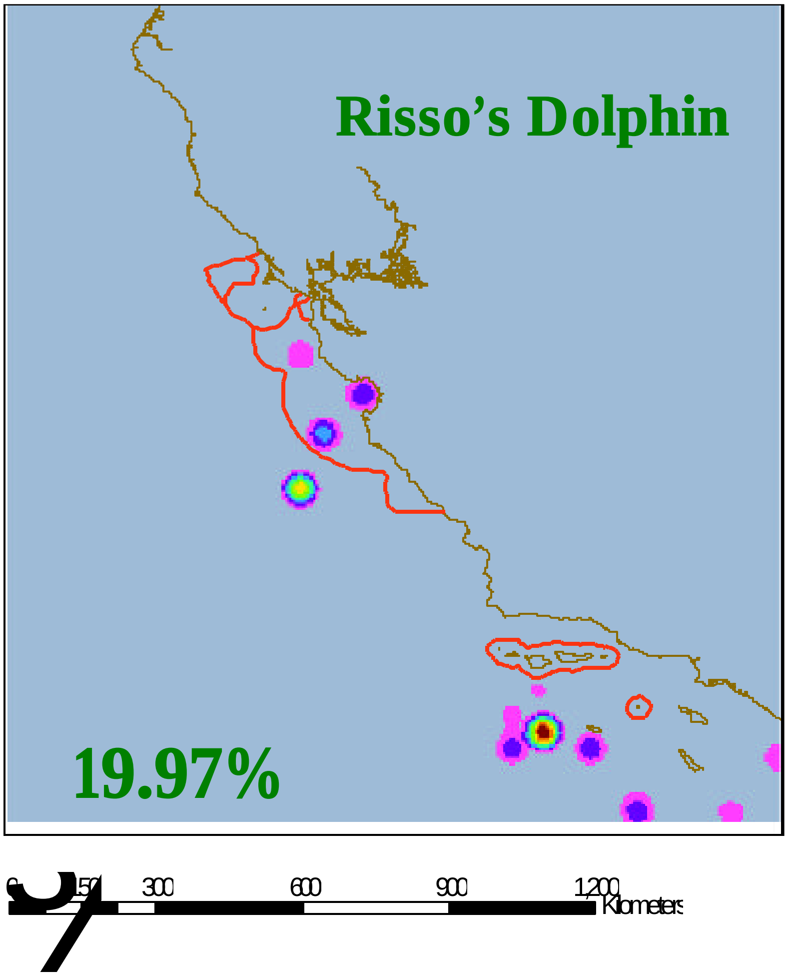


Figure 20: Density map of Risso's dolphin. The percentage is how much of the dolphin density is covered by existing sanctuaries (outlined in red).

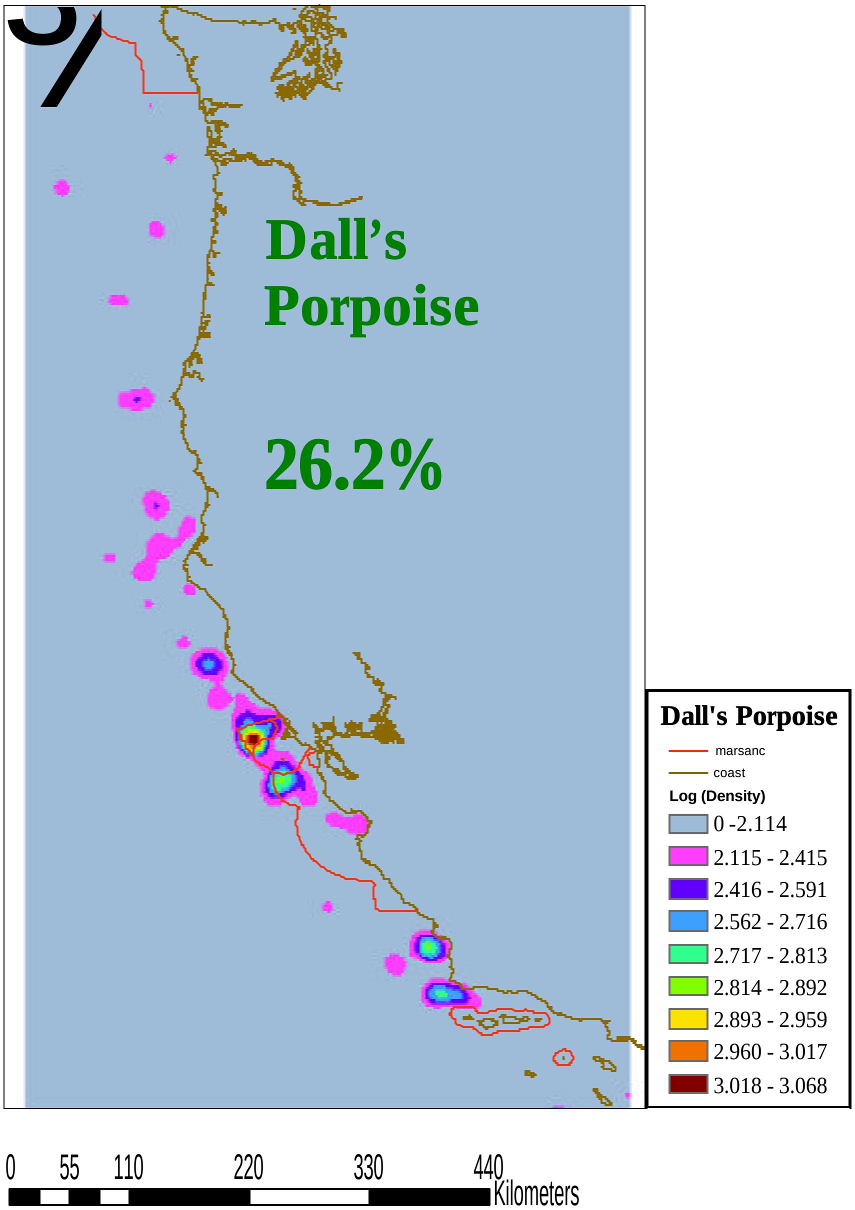


Figure 21: Density map of Dall's porpoise. The percentage is how much of the porpoise density is covered by the sanctuaries (outlined in red).

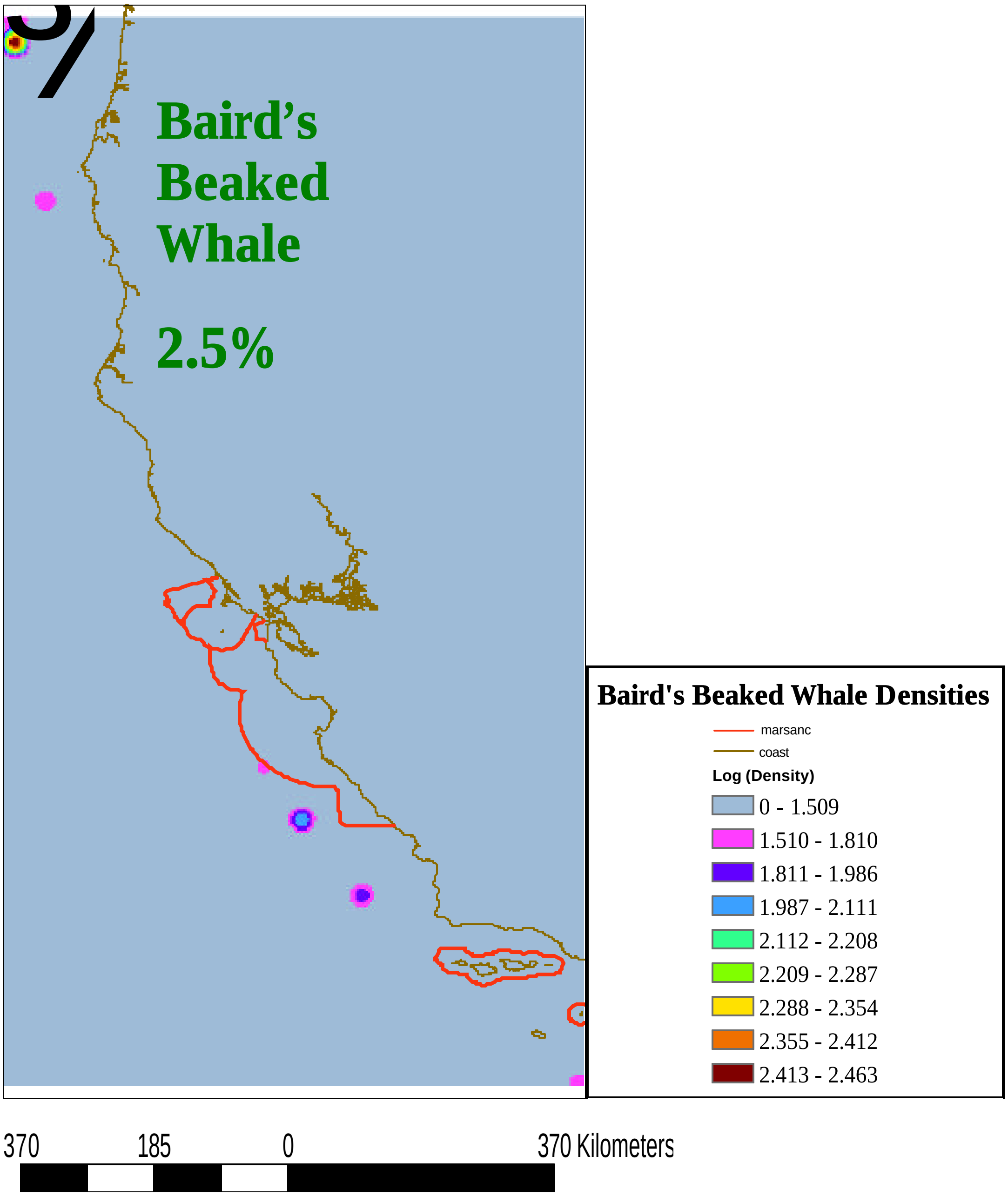


Figure 22: Density map of Baird's beaked whale. The percentage is how much of the beaked whale density is covered by the sanctuaries (outlined in red).

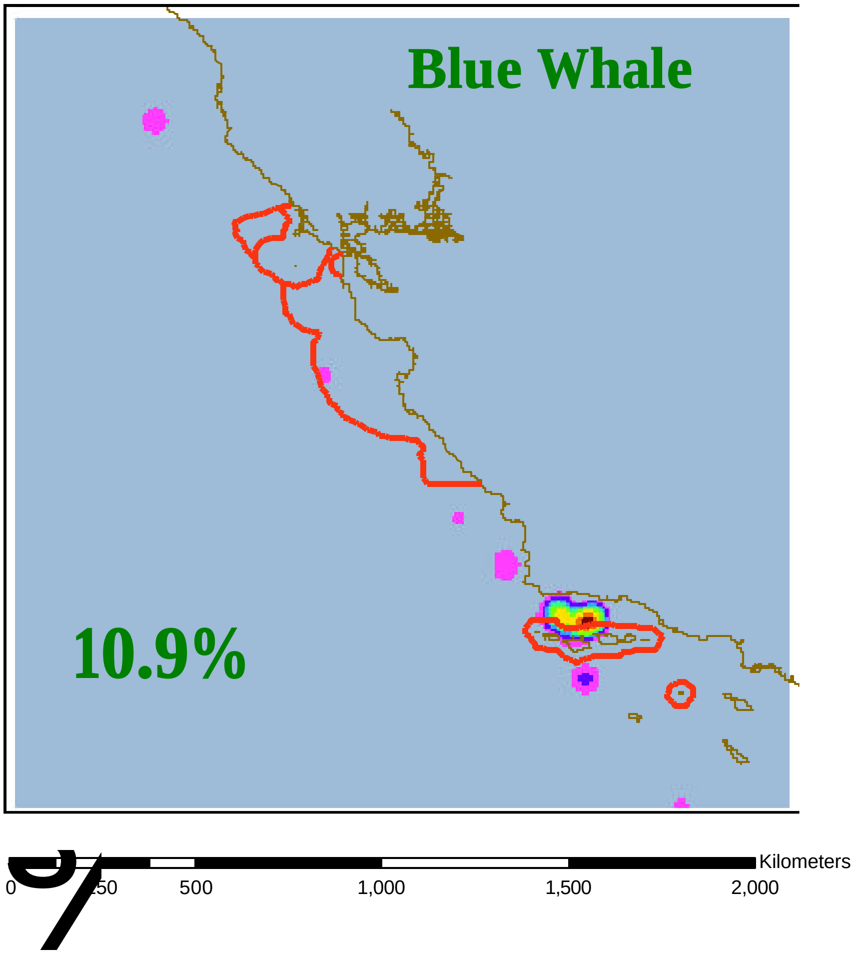


Figure 23: Density map of blue whale. The percentage is how much of the whale density is covered by the sanctuaries (outlined in red).

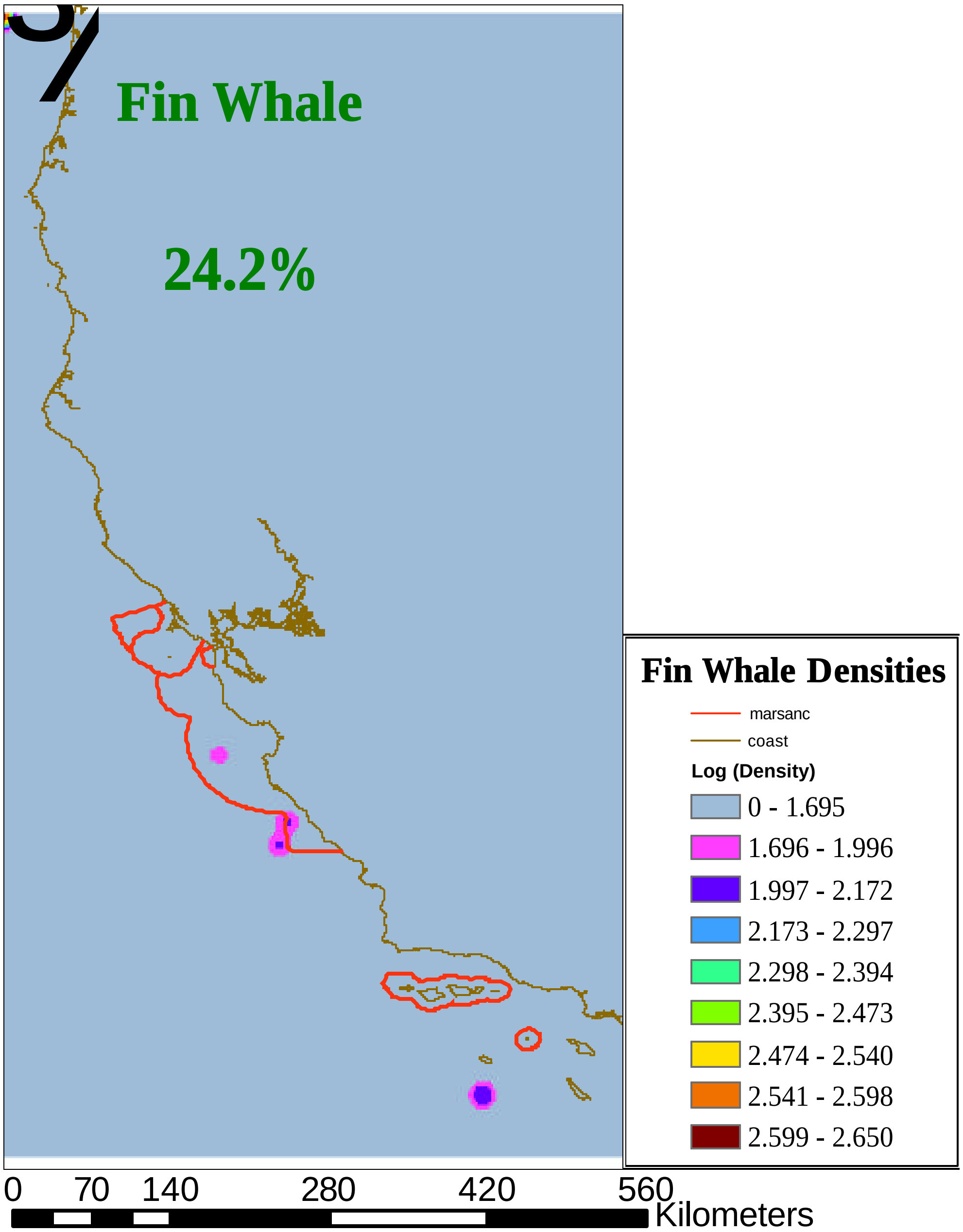


Figure 24: Density map of fin whale. The percentage is how much of the whale density is covered by the sanctuaries (outlined in red).

Green's coefficient of dispersion measures patchiness or aggregation versus dispersion or uniformity. A value of 1 reflects high patchiness, i.e. the animals of that species aggregate. A small negative value implies a uniform, dispersed distribution. All of the species are more dispersed than aggregated; the species highlighted in red are the closest to displaying aggregation of all fourteen species (Table 6).

Table 6

Species	**In Sanctuary Gx**	**Out of Sanctuary Gx**
Black-footed Albatross	0.025	0.005
Laysan Albatross	-0.07	0.063
Cassin's Auklet	0.1	0.002
Rhiocerous Auklet	0.05	0.03
Xantus Murrelet	-0.352	0.027
Pink-footed Shearwater	0.07	0.024
Sooty Shearwater	0.029	0.013
Leach's Storm Petrel	0.0277	0.012
Pacific white-sided Dolphin	0.151	0.0497
Risso's Dolphin	0.188	0.075
Dall's Porpoise	0.04	0.003
Baird's Beaked Whale	NA	0.124
Blue Whale	-0.005	0.086
Fin Whale	0.153	0.299

Analysis of high density coverage by each existing and three proposed marine protected areas includes only the species whose range is encompassed by the sanctuary (Table 7). The first three sanctuaries were suggested based on areas of high density for many of the selected species. The sanctuaries with greater than 50% density coverage for the species included in their areas are highlighted in blue.

Table 7

MPA Site	Total # w/High Density in Site	Total ranges in covering site	Percentage covered
North Bend, Oregon	6	9	66.7%
Humbolt Bay, California	5	9	55.6%
Point Conception, California	5	13	38.5%
Olympic Coast	2	7	28.6%
Cordell Bank	2	12	16.7%
Gulf of Farallones	1	12	8.3%
Monterey Bay	7	13	53.8%
Channel Islands	2	14	14.3%

DISCUSSION

The first objective of this project was to describe the spatial and temporal distribution of fourteen highly migratory species off the west coast of the United States. Results from temporal correlations indicate that there is a common preferred season for most of the fourteen species (Figures 2-4). Upwelling is the season with the highest density for nine of the fourteen species. The upwelling season is the most important for productivity in the region and occurs from April to September, often decreasing with latitude (Wahl, 1993). Because upwelling is known to increase production and concentrate prey, seabirds, and cetaceans in predictable locations, finding the highest density of species during this time period is not unexpected (Spindler, 1976, Hunt 1993; from Gould and Piatt, 1993, Croll et al, 1998). The other five species are divided in their preference between oceanic (three) and counter-current (two). Laysan albatross, who breed in the Hawaiian Islands in the winter, were likely observed in the California region in the fall (oceanic period) before their migration. Because laysan albatross breed on the Hawaiian Islands during the summer; they only spend the oceanic period in the off the US west coast, generally on or seaward of the continental slope (McDermond, 1993).

Both pacific white-sided dolphins and Risso's dolphins are common off the West coast of the US, particularly in California waters. Previous research on Risso's has focused on their distribution in the Mediterranean, Atlantic, and off the coast of California. (Dohl et al., 1981; Fritts et al., 1983; Mullin et al., 1994; Baumgartner, 1997 from Davis et al., 1998). All of this work has connected Risso's distribution with bathymetry classes, not temporal parameters. Therefore, discovery of the highest density of Risso's during the oceanic period despite higher effort during the upwelling season (Figure 4), is novel and can help resolve uncertainties found by Kruse et al. (1999) about the temporal component of Risso's distribution.

Previous studies of Pacific white-sided dolphins are contradictory to my results. Off Southern California, the peak abundance of Pacific white-sided is during the oceanic and counter-current periods (Leatherwood et al., 1982 from Brownell et al., 1999). This is not dissimilar from my finding that the oceanic period has the highest numbers of Pacific white-sided dolphins. However, the most recent abundance estimates off the entire California coast find numbers during the counter-current period an order of magnitude higher than during the oceanic period (Forney et al., 1995 from Brownell et al., 1999). My results do not support this finding (Figure 4 and Table 5) and therefore are significant until another more conclusive study can be performed. Differing results are possibly due to the time scale of my study in comparison to the others. This work combines data from a 22 year period and hence a follow-up analysis dividing the data by decades (1970's, 80's, 90's) may find a change in Pacific white-sided dolphin abundance based on oceanographic period over time.

Both Cassin's auklet and rhinoceros auklet, the two species preferring the counter-current period, have been observed to have the highest densities during the winter months due to immigration from northern colonies (Tyler et al., 1993). Therefore the winter estimates, commonly off the California coast, combine the locally breeding birds with new immigrants from the North.

Bathymetry was used as the spatial component of species distribution. Six of the fourteen species preferred the shelf-break region (Figures 6-8), an area known to aggregate many prey species (Croll et al., 1998). The slope region was the most frequented by the fourteen species with half of all species densities the highest in this area of the ocean (Figures 6-8). These results were expected and should drive the establishment of a marine protected area on the upper slope and shelf-break regions.

Both of the shearwaters preferred the shallowest two regions of the study area,: the shelf and shelf-break. This is consistent with research on sooty shearwaters (Wahl et al., 1993, Ford et al., in press), but differs slightly for pink-footed shearwaters. Recently, Ford et al. (in press) found Pink-footed to be more numerous in slope areas. The most pelagic of all the species, Cassin's auklet, preferred the off-shore, deeper areas – waters greater than 4000 meters deep. This is a new finding for this species as most other work has observed Cassin's further inshore (Hunt et al, 1993; Ford et al., in press). Some indication of this offshore preference has been mentioned (Ford et al., in press) because Cassin's tend to prefer deeper waters than their diving abilities would indicate. Although the results for Cassin's are conclusive, data from this species had the worst fit with the model (only 78.2%, Table 5) due largely to the high variability in the Cassin's observations.

The second objective was to account for effort's impact on species distribution. Do species only exist where we look for them? If so, there should be a direct correlation between increased effort and increasing density of sightings for each species. Evidence of this effect of effort on observations is provided in both Figures 9-10 and Table 5. Although many of the species fit the liner relationship between effort and observations, some species such as Cassin's auklet and Dall's porpoise, fall way below average for other seabirds and cetaceans respectively. This is likely because the surveys completed did not adequately cover Cassin's or Dall's habitat. This result can be useful to other researchers conducting survey cruises for these species.

The third hypothesis assumes that existing sanctuaries adequately protect highly migratory species habitat. Only one of the fourteen species had >50% coverage by existing sanctuaries (Figure 16). Sooty shearwater had a 53.9% coverage by existing sanctuaries; a percentage nearly doubling that of all the other species. Six species had less than 10% of their density covered by existing marine protected areas (Figures 11-24). The low coverage of marine mammal and seabird habitat by existing marine protected areas is not that surprising. Most of the existing MPAs were established to protect endemic species, not the highly productive upwelling shelf-break and slope regions necessary for cetacean and seabird foraging. Therefore, a new sanctuary design must be based on information gathered from sightings analysis in order to adequately protect the habitat of these species.

Determining species patchiness in space is a way of describing species distribution. Many species are shown to aggregate spatially in groups. Aggregation can be a predator defense behavior or a foraging behavior. Patchiness is measured using Green's Index of Dispersion (Gx) and, in situations where the data are very sparse and cannot be analyzed statistically, finding a Gx value can be one way of analyzing the data (Wolanski, 1997). A Gx value of 1 indicates a highly aggregated species whereas a very small negative Gx value identifies a highly dispersed species. On the large thousand kilometer scales of each species' range, no species was found to have a highly aggregated distribution. This could be due to the large scales over which each species was observed or to the inclusion of a variety of year types and seasons included in the analysis. For each species, all years and all seasons were included in the Gx calculation; this could confound any finding of patchiness as some species are known to respond to El Nino years by dispersing (Ford et al, in press). Therefore, a future analysis could group by year type and season before performing the Gx analysis to account for behavioral changes associated with environmental variables.

The final hypothesis, that density maps for each species will help elucidate areas of critical marine mammal and seabird habitat which can be protected with the establishment of marine protected areas was addressed using a GIS. Three areas of off the US West Coast where five or more species had some of their highest densities were selected as potential sites for the development of marine protected areas (Table 9). The first of these sites is off the coast of North Bend, Oregon from 43°0’N to 44°36’N. Further south, off the Humbolt Bay, CA region, the ideal area ranges from 40°13’N to 42°0’N. Both of these areas should extend to 125°22’W off the coast. The final area, off Point Conception, CA (34°14’N to 35°0’N out to121°15’W) is an area where the California Current System and local currents combine to create upwelling and high species diversity. Within these geographic regions, use of the information gathered from the spatial and temporal results can provide specific areas and times for MPA location. This will be further discussed in the recommendations section to come.

MANAGEMENT IMPLICATIONS

The results from this study pose significant implications for management. These implications include recommendations for future research and management in the form of increased monitoring for pelagic/offshore species (see recommendations). In addition, three regions for the development of a new marine protected area have been proposed (Table 10). The fourteen selected species for this study indicate the need to protect the shelf-break and slope habitats of both North Bend, Oregon area and Humbolt Bay, CA area during the upwelling season (April – August). Therefore, selection of either or both of these sites for sanctuary development with closure from human activities such as oil and gas drilling, trawling, dredging, and all other fishing activities (gillnetting) within the core sanctuary area specifically during the upwelling season would increase the protection of highly migratory species habitat.

RECOMMENDATIONS

One driving force for this study was the goal of providing recommendations to scientists and sanctuary designers about the protection of highly migratory species. The first suggestion is to increase survey effort in pelagic areas. The habitats of some species like Cassin's auklet and Dall's porpoise are not adequately covered by past surveys. In addition, the inclusion of more ship surveys which have the ability to sample for prey, a measurement that will greatly improve the quality of data and habitat predictive ability of that data. Given that all background information points to the importance of understanding prey distribution in order to accurately describe cetacean and seabird distribution, surveys that can provide that data would be highly valuable in efforts to describe and protect the habitat of highly migratory species.

Much of this data can also be generated from remotes sensing. Therefore correlations with chlorophyll A, sea surface temperature, and salinity should be made with the current sightings information. Like the bathymetry correlations, this can be done using a GIS to generate numbers that can be imported into a statistical package.

A realization that existing US West Coast MPAs do not protect the habitat of highly migratory species and concomitant suggestion for future MPA development may be the most significant information to take from this research. Large-scale regions have been suggested for MPA development; within those regions, the bathymetry and seasonal parameters which most often predict species distribution should be the focus of the MPA core areas. These regions include the waters off and around North Bend, Oregon, Humbolt Bay, California and Point Conception, California which should be protected from human activities like dredging, trawling, and fishing by a multi-zone sanctuary.

In sum the recommendations from this study are:

- Increased survey/monitoring effort year-round in pelagic (>3000m) zone
- Surveys measuring prey, chlorophyll, SST, salinity and depth along with cetacean and seabird distribution
- Correlating remote sensing of environmental parameters with species densities
- Design a sanctuary to protect the critical habitat of highly migratory species, specifically a number of endangered species
- The new MPA should could be around the North Bend, OR or Humbolt Bay, CA area and encompass shelf-break and slope waters. A seasonal closure of human activities during the upwelling season (April-August) could be established.

CONCLUSION

Using data from fourteen highly migratory species, I was able to develop statistical models predicted distribution over 92% of the time (Table 8) for 12 of the 14 highly migratory species used in this study. Although species preferring a wide range of bathymetry and season classes were chosen for analysis, I was able to isolate three factors, two of which predict distribution in 93?% of the cases. These factors are quite valuable for the development of a new marine sanctuary, particularly in light of the discovery that existing West Coast marine sanctuaries protect only one of the fourteen species. In addition to these factors (shelf-break, slope, and upwelling) which aid in MPA development, three locations were selected for the borders of a new sanctuary. The two highest priority locations protect over 55% of the species' habitat. Therefore, I recommend that managers and policy makers further investigate the possibility of developing a new sanctuary in either the North Bend, OR or Humbolt Bay, CA regions to protect the habitat of these highly migratory species.

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