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U.S. DEPARTMENT OF COMMERCE
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Southwest Fisheries Science Center
3333 Torrey Pines Court
La Jolla, California, USA 92037

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U.S. DEPARTMENT OF COMMERCE
Gary F. Locke, Secretary
National Oceanic and Atmospheric Administration
Jane Lubchenco, Undersecretary for Oceans and Atmosphere
National Marine Fisheries Service
James W. Balsiger, Acting Assistant Administrator for Fisheries

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(SI-1391)

Jay Barlow

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Lisa T. Ballance

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Jay Barlow, Megan C. Ferguson, Elizabeth A. Becker, Jessica V. Redfern, Karin A. Forney, Ignacio L. Vilchis, Paul C. Fiedler, Tim Gerrodette, and Lisa T. Ballance

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14. ABSTRACT

To meet the information needs of the Navy and other users of the marine environment, cetacean density is modeled as a continuous function of oceanographic variables for 12 species in the California Current Ecosystem (CCE) and 15 species in the Eastern Tropical Pacific (ETP) based on line-transect surveys conducted from 1986 to 2003. Models are validated with new survey data from 2005 & 2006. To evaluate effects on models, different modeling approaches, different sampling scales, different interpolation methods, and different sources of habitat information were explored. The effect of seasonal changes in cetacean density was also investigated. Final models for all years were incorporated into a software system that will allow users to estimate density for all cetaceans in any user-defined area within the CCE and ETP study areas. Stratified density estimates are also included in the software system for those species for which density modeling was not possible. Our models and associated software will greatly improve the ability to estimate the density of cetaceans within these study areas.

15. SUBJECT TERMS
Cetacean, whale, dolphin, porpoise, population density, habitat models, spatial models, eastern Pacific Ocean

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Acronyms and Abbreviations

AIC	Akaike Information Criterion
ASPE	Average Squared Prediction Error
CART	Classification and Regression Trees
CCA	Canonical Correspondance Analysis
CCE	California Current Ecosystem
CHL	Surface Chlorophyll
CTD	Conductivity, Temperature, and Depth measurment instrument
CV	Coefficient of Variation
CZCS	Coastal Zone Color Scanner
EEZ	Exclusive Economic Zone
ER	Encounter Rate
ESW	Effective Strip Width
ETP	Eastern Tropical Pacific
GAM	Generalized Additive Model
GCV	Generalized Cross Validation
GIS	Geographic Information System
GLM	Generalized Linear Model
MLD	Mixed Layer Depth
NASC	Nautical Area Scattering Coefficient
NOAA	National Oceanic and Atmospheric Administration
SCORE	Southern California Offshore Range
SDSS	Spatial Decision Support System software
SE	Standard Error
SeaWIFS	Sea-viewing Wide Field-of-view Sensor
SERDP	Strategic Environmental Research and Development Program
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SWFSC	Southwest Fisheries Science Center
TD	Thermocline Depth
TS	Themocline Strength
US	United States
XBT	eXpendable BathyThermograph

Acknowledgements

This project was funded by the Strategic Environmental Research and Development Program (SERDP) and by the National Oceanic and Atmospheric Administration (NOAA). Initial funding for cetacean habitat modeling was provided by the U.S. Navy’s Office of Naval Operations (N45), and we particularly thank Frank Stone and Ernie Young for their early support of this project. The marine mammal survey data and oceanographic data used to model cetacean density were collected by a large dedicated team at the Protected Resources Division of NOAA’s Southwest Fisheries Science Center. We particularly thank the cruise leaders, marine mammal observers, oceanographers, survey coordinators, ship’s crew, and officers who have worked hard over the past 20 years collecting the data that we use here. Physical oceanographic and mid-tropic data were collected and processed by Candice Hall, Melinda Kelley, Liz Zele, Bill Watson, Thomas J. Moore, Robert Holland, Valerie Andreassi, David Demer, Kerry Koptisky, George Watters, and Lindsey Peavey. We also thank Lucy Dunn, Barbara MacCall and Ioana Ionescu who collectively spent hundreds of hours sorting Bongo and Manta samples. Aerial survey efforts were lead by Jim Carretta. Steve Reilly and Robert Brownell were leaders of the Protected Resources Division during most of the surveys and were instrumental in providing the foundations upon which this project were based. We thank Dave Foley at SWFSC's Environmental Research Division for sharing his extensive knowledge of physical oceanography and providing code to automate the acquisition of remotely sensed data and Ray Smith at the University of California, Santa Barbara, for his thoughtful comments and insights on the results of our analyses. Our project benefitted greatly from our close collaboration with the SERDP Team at Duke University (SI-1390), particularly Ben Best, Andy Read, and Pat Halpin. We thank John Hall and an anonymous reviewer for their helpful suggestions on the draft final report.

Executive Summary

The Navy and other users of the marine environment conduct many activities that can potentially harm marine mammals. Consequently, these entities are required to complete Environmental Assessments and Environmental Impact Statements to determine the likely impact of their activities. Specifically, those documents require an estimate of the number of animals that might be harmed or disturbed. A key element of this estimation is knowledge of cetacean (whale, dolphin, and porpoise) densities in specific areas where those activities will occur.

Cetacean densities are typically estimated by line-transect surveys. Within United States Exclusive Economic Zone (US EEZ) waters and in the Eastern Tropical Pacific (ETP), most cetacean surveys have been conducted by the US National Marine Fisheries Service as part of their stock assessment research and typically result in estimates of cetacean densities in very large geographic strata (e.g., the entire US West Coast). Although estimates are sometimes available for smaller strata (e.g., the waters off southern California), these areas are still much larger than the operational areas where impacts may occur (e.g., the Navy's Southern California Offshore Range (SCORE) off San Clemente Island). Stratification methods cannot provide accurate density estimates for small areas because sample size (i.e., the number of cetacean sightings) becomes limiting as areas become smaller. Recently, habitat modeling has been developed as a method to estimate cetacean densities. These models allow predictions of cetacean densities on a finer spatial scale than traditional line-transect analyses because cetacean densities are estimated as a continuous function of habitat variables (i.e., sea surface temperature, seafloor depth, distance from shore, prey density, etc.). Cetacean densities can then be predicted wherever these habitat variables can be measured or estimated, within the area that was modeled.

We use data from 16 ship-based cetacean and ecosystem assessment surveys to develop habitat models to predict density for 15 cetacean species in the ETP and for 12 cetacean species in the California Current Ecosystem (CCE). All data were collected by NOAA's Southwest Fisheries Science Center (SWFSC) from 1986-2006 using accepted, peer-reviewed survey methods. Data include over 17,000 sightings of cetacean groups on transects covering over 400,000 km. The expected number of groups seen per transect segment and the expected size of groups were modeled separately as functions of habitat variables. Model predictions were then used in standard line-transect formulae to estimate density for each transect segment for each survey year. Predicted densities for each year were smoothed with geospatial methods to obtain a continuous grid of density estimates for the surveyed area. These annual grids were then averaged to obtain a composite grid that represents our best estimates of cetacean density over the past 20 years in the ETP and the past 15 years in the CCE. Many methodological choices were required for every aspect of this modeling. In completing this project, we explored as many of these choices as possible and used the choices that resulted in the best predictive models. To evaluate predictive power, we used cross-validation (leaving out one survey year and predicting densities for that year with models built using only the other years). Data from the two most recent surveys (2005 in the CCE and 2006 in the ETP) were used for this model validation step.

We explored three modeling approaches to predict cetacean densities from habitat variables: Generalized Linear Models (GLMs) with polynomials, Generalized Additive Models (GAMs) with nonparametric smoothing functions, and Regression Trees. Within the category of GAMs, we tested and compared several software implementations. In summary, we found that Regression Trees could not deal effectively with the large number of transect segments containing zero sightings. GLMs and GAMs both performed well and differences between the models built using these methods were typically small. Different GAM implementations also gave similar, but not identical results. We chose the GAM framework to build our best-and-final models. In some cases, only the linear terms were selected, making them equivalent to GLMs.

We explored the effects of two aspects of sampling scale (resolution and extent) on our cetacean density models. To explore the effect of resolution, we sampled transect segments on scales ranging from 2 to 120 km. We found that differences in segment lengths within this range had virtually no effect on our models in the ETP, but that scale affected the models for some species in the CCE where habitats are more geographically variable. For our best-and-final models, we accommodated this regional scale difference by using a longer segment length in the ETP (10 km) than in the CCE (5 km). To explore the effect of extent, we constructed models using data from the ETP and CCE separately and for the two ecosystems combined. We found that the best predictive models were based on data from only one ecosystem; therefore, all our best-and-final models are specific to either the CCE or the ETP.

We explored five methods of interpolating oceanographic measurements to obtain continuous grids of our *in situ* oceanographic habitat variables. Cross-validation of the interpolations gave similar results for all methods. Ordinary kriging was chosen as our preferred method because it is widely used and because, qualitatively, it did not produce unrealistic "bull's eyes" in the continuous grids.

We explored the use of CCE oceanographic habitat data from two available sources: *in situ* measurements collected during cetacean surveys and remotely sensed measurements from satellites. Only sea surface temperature (SST) and measures of its variance were available from remotely sensed sources, whereas the *in situ* measurements also included sea surface salinity, surface chlorophyll and vertical properties of the water-column. We conducted a comparison of the predictive ability of models built using *in situ*, remotely sensed, or combined data and found that the combined models typically resulted in the best density predictions for a novel year of data. In our best-and-final CCE models we therefore used the combination of *in situ* and remotely sensed data that gave the best predictive power.

In some years, *in situ* data also included net tows and acoustic backscatter. We explored whether indices of "mid-trophic" species abundance derived from these sources improved the predictive power of our models. The plankton and small nekton (mid-trophic level species) sampled by these methods are likely to include cetacean prey and were therefore expected to be closely correlated with cetacean abundance. We tested the predictive power of models built with 1) only physical oceanographic and chlorophyll data, 2) only net-tow indices, 3) only acoustic backscatter indices, or 4) the optimal combination of all three *in situ* data sources. We found that models for some species were improved by using mid-trophic measures of their habitat, but the improvement was marginal in most cases. Although the results look promising, our best-and-final models do not include indices of mid-trophic species abundance because acoustic backscatter was measured on too few surveys.

We explored the effect of seasonality on our models using aerial survey data collected in February and March of 1991 and 1992. Due to logistic constraints, our ship survey data are limited to summer and fall seasons, corresponding to the "warm-season" for cetaceans in the CCE. Although some data in winter and spring (the "cold-season") are available from aerial surveys in California, these data are too sparse to develop habitat models. We therefore tested whether models built from data collected during multiple warm seasons could be use to predict density patterns in the cold season. We used the 1991-92 aerial surveys to test these predictions. Although the warm-season models were able to predict cold-season density patterns for some species, they could not do so reliably, because some of the cold-season habitat variables were outside the range of values used to build the models. Furthermore, the two available years of cold-season data did not include a full range of inter-annual variation in winter oceanographic conditions. An additional complication is that some cetaceans found in the CCE during the warm season are migratory and nearly absent in the cold season. For these reasons, our best-and-final models based on warm-season data in the CCE should not be used to predict cetacean densities for the cold season.

Our best-and-final models for the CCE and the ETP have been incorporated into a web-based GIS software system developed by Duke University's SERDP Team in close collaboration with our SWFSC SERDP Team. The web site (http://serdp.env.duke.edu/) is currently hosted at Duke University but needs to be transitioned to a permanent home. The software, called the Spatial Decision Support System (SDSS), allows the user to view our model outputs as color-coded maps of cetacean density as well as maps that depict the precision of the models (expressed as point-wise standard errors and log-normal 90% confidence intervals). The user can pan and zoom to their area of interest. To obtain quantitative information about cetacean densities, including the coefficients of variation, the user can define a specific operational area either by 1) choosing one from a pull-down menu, 2) uploading a shape file defining that area, or 3) interactively choosing perimeter points. Density estimates for a user-selected area are produced along with estimates of their uncertainty.

Although our models include most of the species found in the CCE and the ETP, sample sizes were too small to model density for rarely seen species. Additionally, we could not develop models for the cold season in the CCE or for areas around the Hawaiian Islands due to data limitations. To provide the best available density estimates for these data-limited cases, we have included stratified estimates of density from traditional line-transect analyses in the SDSS where available: cold-season estimates from aerial surveys off California, estimates from ship surveys in the US EEZ around Hawaii, and estimates for rarely seen species found in the CCE and the ETP.

The transition of our research to operational use by the Navy was facilitated throughout our project through a series of workshops conducted with potential Navy users. These workshops ensured that the SDSS would meet Navy user needs. The on-line SDSS web site will ensure continued availability of the density estimates from our models and will be available for use by Navy planners within a month of the completion of this report. The SDSS will, however, be just the first step in the transition to general usage. Although Duke University is willing to host the web site in the short term, a permanent site is needed with base-funded, long-term support. Because the models and software have utility to a much greater user community than just the Navy or other branches of the military, the software might be best maintained by NOAA. In addition to maintenance of the web site, the models themselves need to be maintained to incorporate new survey data. Furthermore, there is a need to expand the models to include more areas (e.g., Hawaii), different seasons (e.g., the cold-season in the CCE), migration patterns (e.g., baleen whales), and additional species (e.g., pinnipeds). Recent advances in processing and integrating remotely sensed data, ocean circulation models, buoy data, ship reports, and animal tagging data may offer new approaches to improving models in the future. There is also a need to obtain buy-in from the regulatory agencies (primarily NOAA) for the use of these models as the “best available” estimates of cetacean density in environmental compliance documents. This buy-in can best be achieved by educating the staff in NOAA Headquarters and Regional Offices on the use of, and scientific justification for, model-based estimates. The maintenance and improvement of our SDSS for cetaceans might be best achieved by a long-term partnership between Navy and NOAA.

1.0 Objective

Our project was initiated to address two of the objectives given in the SERDP Statement of Need CSSON-04-02, specifically:

1) to determine the relationships of unique features or properties of the physical, biological and chemical ocean environment and their contribution to the presence, distribution and abundance of marine mammals stocks, and

2) to forecast the presence and abundance of marine mammals stocks based on ecological factors, habitat and other aspects of their natural behavior.

To meet these objectives, we investigated the statistical relationships between measures of density for cetacean species (whales, dolphins, and porpoises) and characteristics of their habitat, we developed habitat models that estimate the density of cetacean species within large sections of the eastern Pacific Ocean, and we developed software tools that will allow the Navy to use these models to forecast cetacean densities for any defined area. Model development was based on the extensive ship survey data collected in summer/fall of 1986-2003 by the Southwest Fisheries Science Center (SWFSC) in the eastern tropical Pacific (ETP) and along the US West Coast within the California Current Ecosystem (CCE). Models were validated based on new SWFSC surveys conducted in summer/fall of 2005 (CCE) and 2006 (ETP).

Because available survey data are almost entirely limited to the summer/fall season, the models we develop are representative of those seasons. However, the Navy also needs to be able to estimate cetacean densities in other seasons. Therefore, a secondary objective of our project was to evaluate whether habitat models developed based on summer/fall data are able to accurately estimate cetacean densities in winter/spring. Evaluation of this seasonal predictive ability is based on aerial survey data collected off California in winter/spring of 1991-1992.

In conducting our study, we found that habitat could not be modelled for several species because the number of observations was inadequate. For completeness, however, we wanted our software tools to allow users to estimate the densities for all cetacean species within the CCE and the ETP, without having to access other sources of information. We therefore added a new objective to summarize all the published density information for species within our study area for which we could not develop a model-based estimate. These density estimates take the format of uniform densities within a defined stratum. We further expanded this objective to include stratified estimates of cetacean density from outside of our study area (specifically the Hawaii EEZ area) and from the winter/spring time period within our CCE study area.

2.0 Background

The Navy and other military users of the marine environment are required to assess the impact of their activities on marine mammals to comply with the Marine Mammal Protection Act, the Endangered Species Act, and the National Environmental Policy Act. The number of marine mammals that might be impacted by Navy activities must be estimated in any such Environmental Assessment or Environmental Impact Statement. However, existing marine mammal density data are typically estimated for areas that are much larger than the area of interest for a naval exercise. For example, the Navy might be interested in knowing the number of whales and dolphins in a portion of their Southern California Offshore Range (SCORE), and density estimates are only available collectively for all of California's offshore waters. Stratification to estimate density in smaller areas is not effective because the number of sightings is typically not sufficient to make an estimate. Clearly, a method is needed to estimate cetacean density on a finer geographic scale. Also, marine mammal densities are known to change as a function of the oceanographic variables that define their habitat, and historical densities might not be the best estimates of current or projected density. There is therefore a need to predict marine mammal density based on measured or projected oceanographic conditions. In addition to their need for absolute estimates of marine mammal density (the expected number of animals per square km), the Navy also could use relative measures of marine mammal density in selecting among alternative sites for their training activities.

The development of tools for the statistical analysis of geographic distribution and abundance has accelerated recently, as evidenced by special issues of two journals dedicated to this subject (Ecological Modelling 2002, Vol. 157, Issues 2-3 and Ecography 2002, Vol. 25, Issue 5). Although Generalized Linear Models (GLMs) are still commonly used (Martínez et al. 2003), there is a growing recognition that species abundances should not be expected to vary linearly with habitat gradients (Austin 2002, Oksanen and Minchin 2002). There is growing acceptance of non-linear habitat relationships including Huisman-Olff-Fresco and Gausian models (Oksanen and Minchin 2002) as well as non-parametric Generalized Additive Models (Guisan et al. 2002, Wood and Augustin 2002). Active areas of current research in this field include methods of model selection such as ridge regression (Guisan et al. 2002), dealing with spatial autocorrelations (Keitt et al. 2002, Wood and Augustin 2002), and investigations of the appropriate scale for modeling (Dungan et al. 2002).

The development of spatially explicit methods of analyzing cetacean line-transect data has increased rapidly in recent years (see review by Redfern et al. 2006). Reilly (1990) used multivariate analysis of variance to examine the relationship of dolphin distributions to environmental variables in the ETP. Reilly and Fiedler (1994) and Fiedler and Reilly (1994) used canonical correspondence analysis (CCA) to quantitatively determine the relationship between cetacean presence and oceanographic variables for dolphins in the ETP. CCA allowed the geographic mapping of dolphin habitats for the first time. Forney (2000) used GAMs to determine the relationship of cetacean encounter rates with oceanographic and geographic variables. However, none of these approaches allow the geographically explicit estimation of cetacean density. Ferguson and Barlow (2001) used a stratification approach to finer scale density estimation, but found that sample sizes still required that they use relatively large areas. Hedley et al. (1999), Hedley (2000), and Marques (2001) developed the first spatially explicit methods for modeling density from cetacean line-transect data. The GAM-based framework is now clearly established as a method for modeling cetacean density as a function of fixed geographic and stochastic habitat variables.

Although analytical methods are clearly necessary for geographically explicit modeling of cetacean density, another requirement for the development of accurate models is a large amount of survey data collected using rigorous line-transect methods. Ever since line-transect methods were first established (Burnham et al. 1980), the SWFSC has been a leader in the application and improvement of line-transect methods to estimate cetacean abundance (Holt and Powers 1982, Holt 1987, Barlow 1988, Barlow et al. 1988, Holt and Sexton 1989, Gerrodette and Perrin 1991, Wade and Gerrodette 1993, Forney and Barlow 1993, Barlow 1994, Barlow 1995, Forney et al. 1995, Barlow et al. 1997, Forney and Barlow 1998, Carretta et al. 1998, Barlow 1999, Ferguson and Barlow 2001, Barlow et al. 2001). Here we base our models of cetacean densities on SWFSC ship line-transect data collected from 1986 to 2006. These surveys include over 17,000 sightings of cetacean groups on over 400,000 km of transect line.

In addition to cetacean line-transect data, our model development is dependent on having measures of the oceanographic conditions that define cetacean habitat. Since 1986, the SWFSC has consistently gathered basic oceanographic data on virtually all of their cetacean line-transect surveys (Reilly and Fiedler 1994) and has been increasingly gathering additional data on mid-trophic levels, including plankton and neuston net tows and acoustic backscatter measurements (Fiedler et al. 1998). Although we also build models of cetacean density with remotely-sensed oceanographic data, the concurrent collection of line-transect data and cetacean habitat data ensures a closer correspondence between the real-time distribution of cetaceans and their measured habitat variables and has allowed us to sample more aspects of their habitat than is possible with remotely-sensed data.

Most of our shipboard line-transect data were collected during summer and fall, and these data cannot be used directly to build models for other seasons. However, SWFSC has conducted aerial surveys at other times of the year in portions of the California Current. This region is known to have pronounced seasonal variation in the distribution and abundance of marine mammals (Forney and Barlow 1998). The aerial survey data contain too few sightings to build predictive environmental models, but we use these data to evaluate whether models constructed for summer/fall using the extensive shipboard sighting data are applicable to other seasons. This comparison is based on a separate set of models developed from remotely-sensed environmental variables instead of *in situ* shipboard data. Predictive ability across seasons is estimated by applying these models to aerial survey data collected during different seasons. This approach provides the advantages of a large, robust data set for construction of models (the shipboard data) and a more comprehensive seasonal data set (the aerial survey data) for examination of seasonal predictions.

Although the foundations for habitat and spatial modeling had been laid at the time we started our project, many questions were still unanswered. Our project focused on improving the science of cetacean habitat modeling in several key areas. We studied and compared the effectiveness of three different modeling approaches, GLMs, GAMs, and tree-based models. We studied the importance of scale (both resolution and extent) in habitat modeling and used this information to chose the most appropriate scales for our final models. We evaluated alternative methods for interpolating habitat variables and cetacean density estimates. We evaluated alternative statistical models (Poisson, quasi-likelihood, and negative binomial) for describing the variance seen in cetacean encounter rates. We developed new methods to estimate the uncertainty in cetacean density estimates based on habitat models. We evaluated the improvements in the precision of habitat models that would result from adding additional information about mid-tropic components of cetacean habitat. Finally, we applied what we learned from these basic research topics to obtain habitat-based density models for 12 species/guilds in the California Current Ecosystem and 15 species/guilds in the Eastern Tropical Pacific Ecosystem.

3.0 Materials and Methods

3.1 Data Sources

3.1.1 Marine Mammal Surveys

Shipboard surveys

We base our habitat models primarily on 16 cetacean surveys conducted by the Southwest Fisheries Science Center in the eastern Pacific from 1986 to 2006. Rigorous line-transect methods were consistently used on all of these surveys (see Kinzey and Gerrodette 2000 for detailed methods). Most of these surveys are limited to the summer-fall season, but they cover a wider geographic scale than any other line-transect data collection. Each survey consisted of 90 to 240 days of survey effort on one or two NOAA research ships (the *David Starr Jordan*, the *McAthur* and/or the *McArthur* II) and one survey also included 120 days on the R/V *Endeavor* from the University of Rhode Island. The surveys can be generally classified as 1) surveys designed to evaluate the status of ETP dolphin stocks that are caught in tuna nets (in 1986, 1987, 1988, 1989, 1990, 1998, 1999, 2000, 2003 and 2006), 2) surveys of CCE cetaceans (in 1991, 1996, 2001, and 2005), and 3) surveys of common dolphin stocks (*Delphinus* spp) in both ecosystems (in 1992 and 1993). Sightings of all cetacean species were recorded on every survey. Search effort was recorded including Beaufort sea state and other aspects of search condition that affect the likelihood of seeing cetaceans. Transect lines covered on these surveys are illustrated in Figures 1 and 2. Additional data were collected on oceanographic conditions and other cetacean habitat features during these shipboard surveys (see *in situ* data collection, below).

Aerial Surveys

In addition to the summer/fall shipboard surveys described above, the SWFSC conducted aerial surveys during the winter/spring periods of 1991 and 1992 (March-April 1991, February-April 1992; Carretta and Forney 1993). The transects followed an overlapping grid (Fig. 3) designed to survey systematically along the entire California coast out to 100 nmi off central and northern California and out to 150 nmi off southern California. The transect lines were spaced approximately 22-25 nmi apart. The survey platform was a twin-engine, turbo-prop Twin Otter aircraft outfitted with two bubble windows for lateral viewing and a belly port for downward viewing.

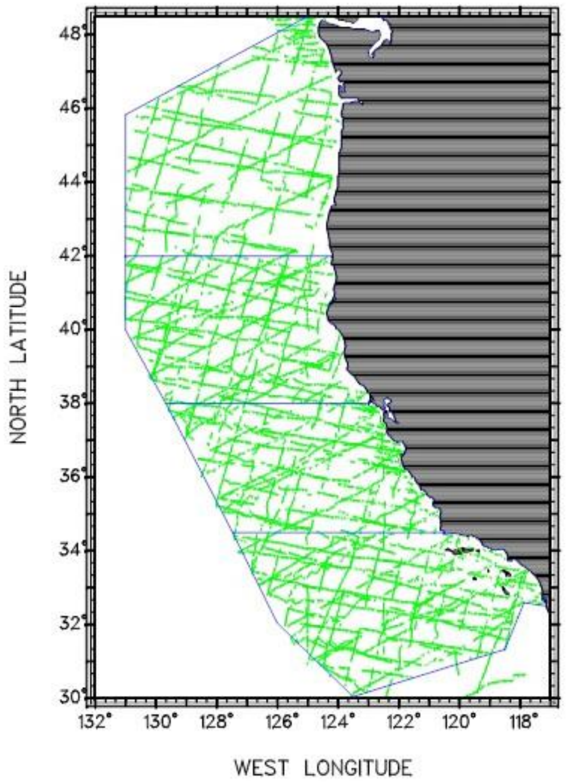


Figure 1. Transects (green lines) surveyed for cetaceans in the California Current Ecosystem by the SWFSC, 1991-2005.

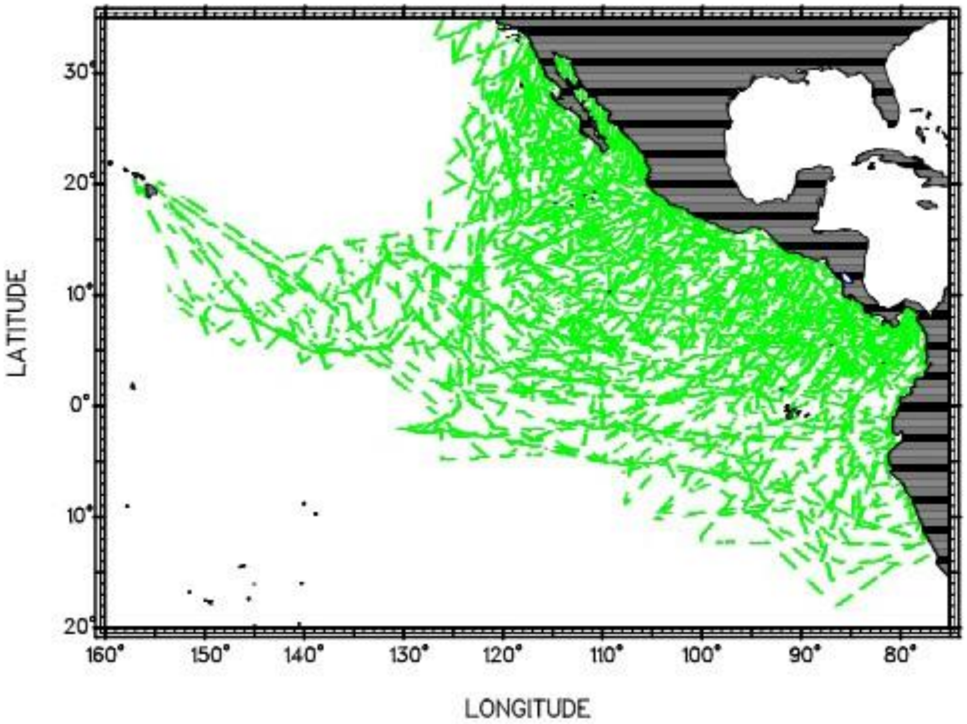


Figure 2. Transects (green lines) surveyed for cetaceans in the ETP by the SWFSC, 1986-2006.

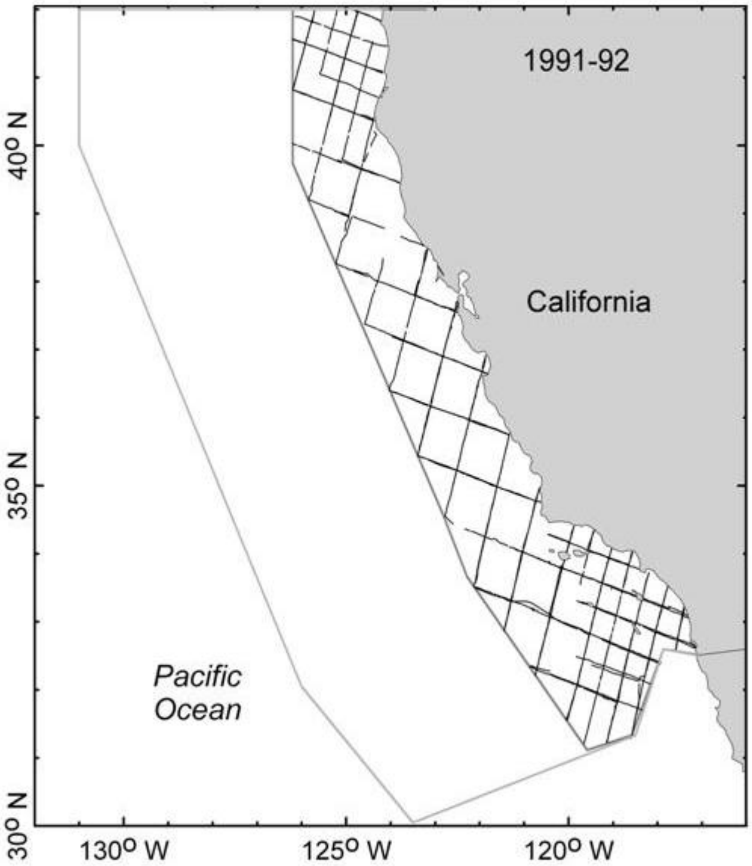


Figure 3. Completed transects for the winter/spring aerial line-transect surveys conducted off California in March-April 1991 and February-April 1992. The light gray line west and offshore of the aerial survey study area marks the boundary of the shipboard survey area within California.

The survey team consisted of four researchers: two "primary" observers who searched through the left and right bubble windows, a "secondary" observer who used the belly window to search the transect line and report sightings missed by the primary team, and a data recorder who entered sighting information and updated environmental conditions throughout the survey using a laptop computer connected to the aircraft's LORAN or GPS navigation system. Following line-transect methods, perpendicular distances were calculated based on the declination angle to each sighting and the aircraft's altitude. Surveys were flown at approximately 185 km/hr (100 knots) airspeed and 700 ft ASL altitude. When cetaceans were sighted, the aircraft circled over the animals to identify species and make group size estimates; any time the aircraft diverted from the transect was considered "off effort" and additional cetacean sightings made during this time were not included in the abundance estimates.

These surveys were designed to estimate the abundance of cetaceans off California during the winter/spring period (Forney et al. 1995, Forney and Barlow 1998). Although there were insufficient sightings to develop cetacean-habitat models, these aerial survey data were used to evaluate the ability of summer/fall models to predict winter/spring cetacean density patterns (Section 3.8).

3.1.2 In situ Oceanographic Measurements

Oceanographic variables were measured on NMFS cetacean and ecosystem assessment surveys in the ETP during 1986-2006 and in the CCE during 1991-2005. Sea surface temperature (SST) and salinity (SSS) from a thermosalinograph were recorded continuously at 0.5 to 2 minute intervals and averaged over 5-10 km intervals to reduce both the number of observations and the discrepancy in sample spacing along and between transects. Thermocline depth (TD, depth of maximum temperature gradient in a 10 m interval), thermocline strength (TS, ºC m^{-1}), and mixed layer depth (MLD, the depth at which temperature is 0.5ºC less than surface temperature) were estimated from expendable bathythermograph (XBT) and conductivity-temperature-depth (CTD) casts collected three to five times per day. Surface chlorophyll (CHL, mg m^{-3}) was estimated at the same stations from the surface bottle on the CTD or from bucket samples analyzed by standard techniques (Holm-Hansen et al. 1965). CHL was log-transformed (using natural logarithms) to normalize the data for interpolation. Details of the field methods can be found in Philbrick et al. (2001, 2003).

3.1.3 Remotely Sensed Oceanographic Measurements

Remotely sensed sea surface temperature (SST) data were considered for models within the California Current Ecosystem. Models included SST and measures of its variance as potential predictors. SST data (National Oceanic and Atmospheric Administration/National Environmental Satellite, Data, and Information Service/Pathfinder v5) were obtained via an OPeNDAP server using Matlab code that enabled remote, automated downloading of data for user-specified positions and resolutions. As part of this analysis (Becker 2007), we examined the predictive power of six different spatial resolutions of satellite SST data ranging from one pixel (approximately 31 km^2) to 36 pixels (approximately 1,109 km^2). Three temporal resolutions were also compared: 1) 1-day, 2) 8-day, and 3) 30-day composites. We used the coefficient of variation of SST, CV(SST), for resolutions greater than one pixel as a proxy for frontal regions in the California Current study area. Results are summarized below and details can be found in Becker (2007).

Our SST temporal resolution analysis for the satellite-derived data indicated that, while 30-day SST composites had good within-dataset explanatory ability, predictive ability across datasets was poor at this coarser temporal resolution. A correlation analysis showed high correlation between the 1-day and 8-day SST values ($R^2 = 0.96$), indicating that the 8-day composites provided adequate representation of average conditions on the day of the survey. Based on this evaluation and the greater availability of 8-day composite data compared to 1-day composites, we selected 8-day running average SST composites, centered on the date of each survey segment.

The SST spatial resolution comparison indicated that, for the majority of species, the greatest predictive ability was observed for the coarsest SST spatial resolution (Table 1). The predictive ability of different spatial resolutions of satellite-derived CV(SST) was more variable than that of SST. For many species, the best CV(SST) spatial resolution was among the finer resolutions considered in this study, perhaps reflecting the importance of localized upwelling events or small-scale frontal features.

Table 1. Summary of satellite-derived sea surface temperature (SST) and CV(SST) spatial resolutions selected for ten California Current Ecosystem species. Numbers refer to the number of pixels included in the resolution. The spatial resolutions tested included 1, 4, 9, 16, 25, and 36 pixels, corresponding to 5.55-33.3 km boxes (i.e., 30.8 – 1,108.9 km^2). Models are described in more detail in Section 3.3.

	Encounter Rate Models		**Group Size Models**	
Species	**SST**	**CV(SST)**	**SST**	**CV(SST)**
Striped dolphin	36	25	36	9
Short-beaked common dolphin	36	36	36	25
Risso’s dolphin	9	16	36	16
Pacific white-sided dolphin	36	9	36	9
Northern right whale dolphin	36	9	36	36
Dall’s porpoise	25	36	36	36
Sperm whale	36	36	36	36
Fin whale	36	9	36	9
Blue whale	36	36	36	36
Humpback whale	36	4	36	16

Past studies have shown relationships between cetacean sightings and other remotely sensed measures such as chlorophyll (Smith et al. 1986, Jaquet et al. 1996, Moore et al. 2002). However, satellite-derived measures of chlorophyll concentration were not available for 3 of the 4 survey years used to develop our CCE habitat models. The Coastal Zone Color Scanner (CZCS), one of the first satellite sensors to collect ocean color data, ceased operation in 1986 and the Sea Wide-Field-of-View Sensor (SeaWiFS) began operating shortly after our 1996 cetacean survey was over. Since chlorophyll data were not available for most of our time series, we did not include this variable as a potential predictor in our habitat models.

3.1.4 Water Depth and Bottom Slope

Water depth was derived from the ETOPO2 2-minute global relief data (U.S. Department of Commerce 2006), re-gridded to match the pixel resolutions used for modeling. Slope was calculated as the magnitude of the bathymetry gradient using the gradient operator tool in Generic Mapping Tools (Wessel and Smith 1998). Depth and slope values for each geographic location were obtained using the “sample” tool in ArcGIS (version 9.2, ESRI, Inc.).

3.1.5 Mid-trophic Sampling with Net Tows and Acoustic Backscatter

Most of the readily available measures of oceanic habitats are from physical oceanographic measurements (such as temperature and salinity) and from lower trophic levels (such as chlorophyll concentration and primary production). Cetacean distributions are likely to be determined more by the distribution of their prey, which are typically mid-trophic level species. To determine whether data about mid-trophic species distributions can improve cetacean-habitat models, we sorted and analyzed net-tow data and analyzed acoustic backscatter data that were collected on SWFSC cetacean and ecosystem assessment surveys.

Manta net tows were conducted on 10 SWFSC surveys of the ETP since 1987, and bongo net tows were conducted on eight surveys of the ETP and CCE since 1998 (Fig. 4). Manta tows are conducted at the surface, and bongo tows are conducted between the surface and 200 m depth. Sorting samples collected with manta and bongo tows is labor-intensive and requires approximately one year of processing after each cruise. Both types of tows provide ichthyoplankton abundance and diversity data, but zooplankton volume and cephalopod abundance and diversity are recorded only from bongo tow samples.

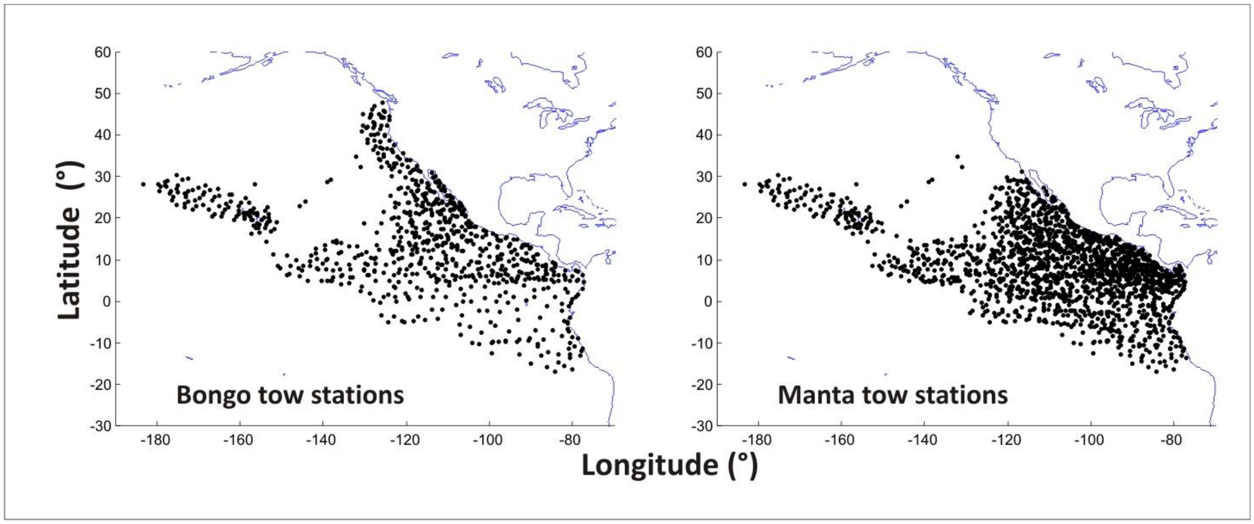


Figure 4. Geographical distribution of manta and bongo tow stations.

Acoustic backscatter is a method of remotely measuring the biomass of fish and zooplankton in the water column using sonar. Acoustic backscatter data were collected on SWFSC surveys of the ETP in 1998, 1999, and 2000 using a Simrad EQ-50 scientific echosounder operating at a frequency of 38 kHz. The individual acoustic signals (i.e., pings) were averaged in horizontal bins during data collection on these cruises. This averaging was done before noise was removed from the data and the individual signals were not retained. Concern about the potential bias created by including noise in the acoustic backscatter variables led to a change in data collection protocols, which was implemented for the 2001 and all subsequent assessment surveys. This change in protocol invalidated comparison between data collected before and after 2001. Consequently, only net-tow and acoustic backscatter data collected after 2001 were used to build cetacean-habitat models (see Section 3.7).

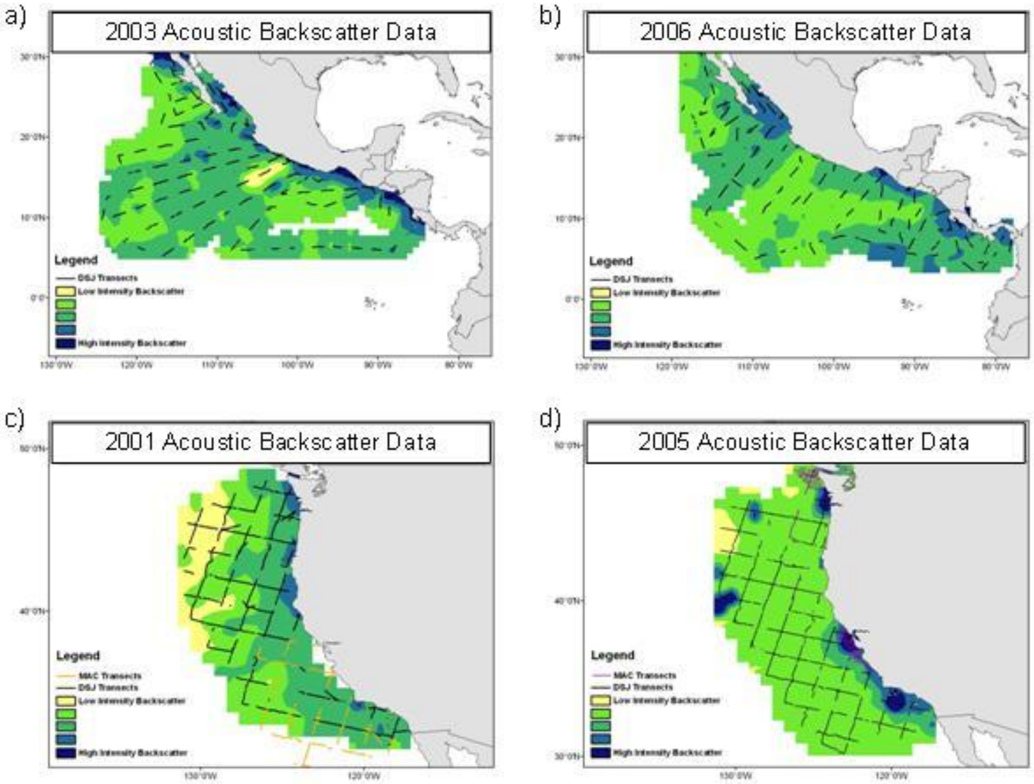


Figure 5. Mean volume backscattering strength, $S_v$mean, in six hour segments along the a) 2003 and b) 2006 transects surveyed by the NOAA ship *David Starr Jordan* in the eastern tropical Pacific, and c) 2001 and d) 2005 transects surveyed by the NOAA ships *David Starr Jordan* and *McArthur* in the California Current ecosystem.

A more powerful Simrad EK-500 with three frequencies (38 kHz, 120 kHz, and 200 kHz) was used on SWFSC surveys of the CCE in 2001 and 2005 and the ETP in 2003 and 2006. We developed a new two-step noise removal method to process these data, which resulted in higher quality acoustic backscatter variables. The first step of the method identifies and eliminates high intensity irregular noise; the second step of the method targets low intensity "drop-outs" or returns within a ping that are significantly lower than expected. We evaluated the effect of the two-step noise removal method on the $S_v$mean (dB) and nautical area scattering coefficient (NASC) (m^2/nmi^2) in 0-500 m, 0-100 m, 100-200 m, 200-300 m, 300-400 m, and 400-500 m depth bins. The $S_v$mean is the average of the volume backscattering strength data logged by an echosounder; the NASC is a measure of area, rather than volume, scattering. Areas with higher intensity returns (i.e., areas with more scatterers) are indicated by larger $S_v$mean and NASC values. The results indicate that the method is effective at removing both high-intensity irregular noise and low-intensity drop outs. Its efficacy is greatest when the entire water column is examined (e.g., our 0-500 m depth bin) and when the NASC is used as the summary output variable. Interpolated maps of the $S_v$mean, calculated from 0-500 m at a six hour resolution are shown for the ETP and CCE in Figure 5.

3.2 Oceanographic Data Interpolation

For cetacean-habitat modeling, and predictions based on such models, we examined the use of interpolated estimates of oceanographic parameters to predict cetacean densities at unsampled locations. The interpolated estimates are a matrix or grid calculated from sample values. Inevitably, there are errors due both to interpolation across the spatial gaps between sample points and to measurement inaccuracy and imprecision We investigated whether the interpolation method affects the interpolated values and, if so, identified the optimal method for interpolating observed oceanographic data for use in predictive models. The best estimate of an independent variable at an unsampled point in space (and time) is derived from an interpolation of sampled data that minimizes both the influence of measurement or sampling error in the observations and error introduced by the statistical technique, either between observations or at edges. Below we report on 1) a comparison of interpolation methods for oceanographic observations used in cetacean-habitat modeling and 2) the production of yearly interpolated fields of these variables.

Five smoothing interpolation methods were compared to evaluate their relative performance. We did not consider exact interpolators because their emphasis on “honoring the data” does not work as well in cases with sampling error. The smoothing interpolators considered were (Golden Software, 2002):

> *Inverse Distance Squared* - data are weighted during interpolation such that the influence of an observation declines with the square of the distance from the grid point.
>
> *Kriging* (ordinary kriging) – a popular method that produces visually appealing maps from irregularly spaced data by incorporating anisotropy and underlying trends in the observations so that, for example, high points might be connected along a ridge rather than isolated by bull's eye type contours.
>
> *Local Polynomial* - assigns values to grid points by using a weighted least squares fit to data within the grid point’s search ellipse.
>
> *Radial Basis Function* - a multiquadric method, considered by many to be the best among this diverse group of methods, that uses basis kernel functions, analogous to variograms in kriging, to define the optimal set of weights to apply to the data when interpolating a grid point.

Minimum Curvature - the interpolated surface is analogous to a thin, linearly elastic plate passing through each of the data values with a minimum amount of bending, although it is not an exact interpolator.

For the comparison of interpolation methods, Surfer scripts (Golden Software) were used for data manipulation and interpolation. Three variables (SST, TD, CHL) from one ETP survey (2006) and one CCE survey (2005) were investigated. For each dataset, subsets of observations were selected and removed from the dataset, the remaining observations were interpolated, and the residuals of the omitted observations were calculated, where the residual is the difference between an omitted data value and the interpolated value (i.e., the predicted value) at that point. Two jackknife procedures were used to calculate the mean and standard deviation of residuals at each data point: 1) single: omit each observation one at a time and 2) daily: omit each ship-day of observations (typically five observations) one ship-day at a time. In general, the only resultant difference between these two procedures was that daily jackknife residuals were slightly greater than single jackknife residuals.

For each variable, a variogram analysis estimated length scale (i.e., how rapidly variance changes with increased distance between sampling points), error variance or the nugget effect (this source of error can be due to measurement error or small scale heterogeneity in the system), and anisotropy (Table 2). Then, jackknifing and interpolation were performed with similar search parameters for each of the five interpolation methods (search radii in Table 3). No additional smoothing was performed for methods that allowed this in Surfer (radial basis function, minimum curvature). Grid resolution was one degree of latitude and longitude.

Yearly fields (interpolated surfaces) were created from data collected annually on NMFS cetacean and ecosystem assessment surveys in both the ETP and CCE study areas. These estimates were for the development of cetacean-habitat models and (potentially) the prediction of cetacean density in any user-selected polygon. Yearly fields were calculated for five CCE surveys (1991, 1993, 1996, 2001, and 2005) and for ten ETP surveys (1986, 1987, 1988, 1989, 1990, 1998, 1999, 2000, 2003, and 2006).

Table 2. Variogram model results. Anisotropy constrained as described in the text; for the CCE, the angle = 30º to account for the orientation of the California coast.

CCE	**Model (r^2)**	**Nugget**	**Scale**	**Length**
SST	Spherical (0.43)	0.72	5.37	7.85
SSS	Gaussian (0.73)	0.05	0.74	8.03
MLD	Quadratic (0.59)	80.1	156.9	5.54
TS	R. quadratic (0.84)	0.0031	0.0025	1.94
CHL	Spherical (0.24)	0.026	0.042	5.69

ETP	**Model (r^2)**	**Nugget**	**Scale**	**Length**
SST	R. quadratic (0.20)	3.27	7.46	27.4
SSS	Gaussian (0.64)	0.96	2.16	38.0
TD	R. quadratic (0.96)	494	2.15e6	1561
TS	R. quadratic (0.75)	0.0075	0.0125	25.1
CHL	Gaussian (0.43)	0.012	0.0057	13.6

Table 3. Range of annual sample sizes (N) and search parameters for kriging of grid points. Search radii are in degrees latitude/longitude; the two values are for the x and y directions, rotated 30º for the CCE. The two values differ due to anisotropy and thus define a search ellipse around each grid point. Anisotropy was constrained as described in the text. N_{max} is the maximum number of samples allowed to interpolate a grid point value.

CCE	**N within study area**	**Search radii**	**N within search ellipses**	**N_{max}**
SST	1681 - 3736	1.5, 2	282 - 492	200
SSS	1631 - 3718	1.5, 2	280 - 490	200
MLD	166 - 427	2, 2.67	40 - 81	40
TS	166 - 427	2, 2.67	28 - 60	40
CHL	390 - 695	2, 2.67	68 - 146	40

ETP	**N within study area**	**Search radii**	**N within search ellipses**	**N_{max}**
SST	1686 - 7551	15, 10	638 - 2417	400
SSS	1681 - 7551	15, 10	638 - 2417	400
TD	719 - 1368	15, 10.7	218 - 375	80
TS	719 - 1368	15, 7.5	179 - 310	80
CHL	489 - 1676	15, 7.5	117 - 442	80

3.3 Modeling Framework

3.3.1 GLM and GAM Models

Cetacean population density predictions were derived from encounter rate and group size models developed within a generalized additive modeling framework developed by Hedley et al. (1999) and Ferguson et al. (2006a and b). We also examined alternative methods of computing density, including: 1) predicting density directly by creating a single cetacean-habitat model with "number of individuals" as the response variable and 2) deriving density from a two-step process in which the probability of a species being present in a given habitat is multiplied by the expected number of individuals given favorable habitat. The primary reason we decided to use separate models to predict encounter rate and group size is that this approach breaks the process down into ecologically meaningful quanta: differences in distribution may arise from variability in group size or number of groups in a given region, with potentially different environmental factors affecting the variability in each model. The two-step process of computing the probability of presence and then multiplying by the expected number of individuals does not have this flexibility because environmental effects on encounter rate and group size are confounded in a single model.

GAMs are commonly used to relate characteristics of a species, such as distribution or abundance, to environmental characteristics. A GAM may be represented as

$$g(\mu) = \alpha + \sum_{j=1}^{p} f_j\left(X_j\right)$$

(Hastie and Tibshirani 1990). The function $g(\mu)$ is known as the link function, and it relates the mean of the response variable given the predictor variables $\mu=E(Y|X_1,\ldots,X_p)$ to the additive predictor $\alpha+\Sigma_j f_j(X_j)$. GAMs are nonparametric extensions of generalized linear models (GLMs). The components $f_j(X_j)$ in the additive predictor of a GAM may include nonparametric smooth functions of the predictor variables, whereas a GLM is composed of a linear predictor, $\alpha+\Sigma_j\beta_jX_j$, in which the terms β_j are constants. This difference between the additive and linear predictor allows GAMs to be more flexible than GLMs.

Model Comparison Analysis

When working with ecological data, it is often difficult to distinguish meaningful signals from noise arising from the unexplainable variability and complex interactions inherent in ecological systems. Even in the absence of noise, relationships among ecological variables rarely can be explained by simple mathematical equations. Working within the framework of generalized additive models may be useful for analyzing ecological data because the nonparametric model structure of GAMs provides flexibility in model building and fitting, often allowing GAMs to exhibit more fidelity to the data than alternative model structures. Nevertheless, there are disadvantages to GAMs. For example, if appropriate model building and selection methods are not used, the resulting GAM may overfit the data, reliably reproducing the data upon which the model was built at the cost of sacrificing accuracy when predicting on novel data. In addition, GAMs may be difficult to interpret because they cannot always be defined by a simple formula comprised of a constant coefficient tied to each explanatory variable that indicates the strength, magnitude, and direction of the covariate's effect on the response variable.

Finally, because the smoothing splines in the additive predictor are functions of the data used to build the model, predicting on novel data is not straightforward. We tested three different algorithms for constructing GAMs using a common set of environmental and cetacean line-transect survey data to evaluate how each approach addressed these problems. We also compared output from the GAMs to that produced by comparable GLMs to address whether the additional complexity of GAMs is warranted.

In the model comparison analysis, three GAM algorithms and one GLM algorithm were tested:

1. S-PLUS *gam* (version 6 for Windows) with cubic smoothing splines of up to three degrees of freedom. Variable selection was implemented by *step.gam* using forward/backward stepwise selection with AIC.

2. R (version 2.6.2) *gam* from package **gam** with cubic smoothing splines of up to three degrees of freedom. Variables were selected by *step.gam* from package *gam* using forward/backward stepwise selection with AIC.

3. R (version 2.6.2) *gam* from package **mgcv** (version 1.3-29) using cubic regression splines (specified as *bs = "cs"*) and thin plate regression splines (*bs = "ts"*) with shrinkage. Variable selection in **mgcv** does not take a stepwise approach; rather, a smoothing parameter, which determines the effective degrees of freedom, is estimated for each predictor variable by minimizing the Generalized Cross Validation (GCV) score (Wood 2006). The *gam.method* argument to **mgcv**'s *gam* function specifies which numerical method is used to optimize the smoothing parameters. We tested six different *gam.method* options, namely outer, perf.outer, perf.magic, and perf.mgcv to construct the encounter rate models, and magic and mgcv to construct the group size models. Because GCV is known to select models that are overfit on occasion (Kim and Gu 2004), we tested two values of the parameter *gamma* that **mgcv** uses to compute GCV. Larger values for *gamma* penalize model complexity more than smaller values, so we tested the default, *gamma* = 1.0, and an alternative, *gamma* = 1.4.

4. R (version 2.6.2) *glm* from package *stats* with polynomial terms of up to three degrees of freedom. Variable selection was implemented by a forward/backward stepwise selection algorithm with AIC using the *step.gam* function from package **gam**. The use of polynomials allowed a degree of non-linearity between predictor and response variables in these linear models.

Encounter Rate and Group Size Models

For each species or species group, we built separate models of cetacean encounter rate (number of sightings per unit of effort on the transect) and group size (number of individuals per sighting). In preparation for building the models, the cetacean sighting data and environmental data were summarized into segments of on-effort transect. Encounter rate models were built using all transect segments, regardless of whether they contained sightings. Group size models were built on only the subset of segments that contained sightings.

Cetacean sighting data are essentially count data with relatively more zeroes than expected from a standard Poisson distribution. Therefore, we modeled encounter rate as a quasipoisson distribution with variance proportional to the mean and a logarithmic link function. The natural logarithm of segment length was included as an offset term to standardize each sample for effort.

Cetacean group sizes can be highly variable, spanning up to three orders of magnitude. Estimating the mean group size associated with each line segment involved three steps. First, we computed an estimate of group size for each observer for each sighting based on the observer's best, high, and low estimates of group size. Second, we computed the arithmetic mean of all observer's group size estimates for each sighting. Finally, we computed the arithmetic mean group size of all sightings in each line segment. This three-step process resulted in non-integer group size estimates. Given the wide range of cetacean group sizes and the fact that the group size estimates are continuous data, we constructed lognormal GAMs for group size, using the natural logarithm of group size as the response variable and an identity link function. It was necessary to apply a bias-correction factor to the group size predictions from the GAMs because the models were built in log space and then the results were transformed back to arithmetic space, converting the group size estimate to a geometric mean in the process (Finney 1941, Smith 1993). The ratio estimator was used to correct for this back-transformation bias (Smith 1993).

Density Computations

To estimate cetacean density, the encounter rate and group size model results were incorporated into the standard line-transect equation:

$$D = \left(\frac{n}{L}\right) \cdot S \cdot \frac{1}{2 \cdot ESW \cdot g(0)}$$

where,

n/L = encounter rate (number of sightings per unit length of transect),
S = expected (or mean) group size,

ESW = effective strip width (one-sided), or 1/*f(0)*, where *f(0)* is the sighting probability density at zero perpendicular distance
g(0) = probability of detecting an animal on the transect line.

Estimates of *f(0)* and *g(0)* were derived from previously published studies, as described in Section 3.5.

3.3.2 CART Tree-based Models

We also applied Classification and Regression Trees (the *CART* algorithm in S-PLUS) to build a regression tree using the encounter rate data, but we found that the method was not appropriate for two reasons. First, it was not able to handle the zero-rich dataset. Second, the predictions were categorical not continuous, constrained to fall into one of the categories of observed encounter rate. Other methods of machine learning may perform better or provide additional insights for cetacean-habitat modeling, and further investigation is warranted.

3.4 Model Scale: Resolution and Extent

The results of spatial modeling often depend on the scale used. A pattern or relationship seen at one scale may be entirely different if viewed at a different scale (Wiens 1989). The choice of scales within a model must be appropriate to the questions being asked and the variation of the object being modeled.

One aspect of scale is spatial resolution, which refers to the physical dimension of the smallest unit being studied. In the case of cetacean line-transect surveys, resolution refers to the length of the transect segments for which densities are estimated. The number of sightings of a species or the group size within each segment is the response variable (or dependent variable) which is predicted by the model. The predictor variables (or independent variables) used in the model to predict cetacean density would ideally be measured on the same scale, but may be measured on a smaller scale (in which case values can be averaged) or on a larger scale (in which case values can be interpolated). We examined the effect of resolution on models of cetacean encounter rates and group sizes by building models using a range of segment sizes. Specifically, we examined spatial resolutions from 2 to 120 km in both the ETP and the CCE. Habitat is expected to be more spatially heterogeneous in the CCE. A detailed description of the modeling technique used in both ecosystems can be found in Redfern et al. (2008).

Another aspect of scale is extent, which refers to the maximum area being studied. Our study areas encompass what are considered to be two distinct ecosystems: the eastern tropical Pacific and the California Current. We explored the effect of extent by comparing models that were built separately for each of these ecosystems with a model that was built using pooled data from both ecosystems. Modeling methodology followed Redfern et al. (2008), but only the 60km resolution was used.

3.5 Model Selection

Model validation using an independent data set is an integral part of building robust cetacean-habitat models (Forney 1997 and 2000, Becker 2007). In this analysis, final models for the CCE and the ETP were selected using a two-part process in which models were initially built using stepwise variable selection based on the available SWFSC survey data through 2003. Candidate models were then evaluated in terms of their predictive capabilities when applied to data from the novel 2005 (CCE) and 2006 (ETP) SWFSC cetacean surveys (see 3.1.1 Marine Mammal Surveys). Predictions and overall model performance were compared to identify the best models.

A collection of quantitative and qualitative methods were used to compare models. Average squared prediction error (ASPE) was used to assess each model's prediction accuracy across all segments (n) within the entire study area, where

$$ASPE = \sum \frac{(observed - predicted)^2}{n}.$$

Prediction accuracy was addressed in a spatial context using ratios of observed to predicted number of sightings (for the encounter rate models) or group size within each geographic stratum. These geographic strata were defined to be large enough to encompass a sufficient number of observations for a meaningful comparison of model predictions, yet environmentally distinct in terms of the biological and physical processes that determine habitat. In addition to examining the observed-to-predicted ratios themselves, we computed the sum of absolute deviations of the observed-to-predicted ratios, defined as

$$\sum \left| 1 - \frac{observed}{predicted} \right|,$$

where the sum is taken over all geographic strata used in model evaluation. For both the ASPE and observed-to-predicted ratio computations, the Beaufort sea state variable was set to the observed value to generate encounter rate and group size predictions. Explained deviance, the likelihood analogue of explained variance, was used to assess each model's fit to the assumed distribution for the data. Model complexity was evaluated by examining the number of predictor variables selected and their associated degrees of freedom, in conjunction with visual inspection of the smooth functions relating the effects of each predictor variable to the response variable. Finally, density predictions derived from the encounter rate and group size models were plotted on a map of the study area and the spatial distribution was evaluated by eye. Following model selection and validation, the best models were then re-fit to the additional year of data to parameterize the final predictive models. Details on the methods used to select and validate our final models within each geographic region are provided below.

3.5.1 California Current Ecosystem Models

In preparation for model selection and validation using the 2005 west coast survey data, *in situ* models built at scales of 2 and 10 km for the scale analyses (see Section 3.4 Model Scale: Resolution and Extent) were compared to 5 km models built with remotely sensed data (Becker 2007). For each species, we compared key predictor variables and associated functional shapes, study area density ratios (density calculated using standard line-transect methods divided by density predicted by the habitat model), standard errors (SE) of density ratios, and average squared prediction errors (ASPE). We found that the models built with remotely sensed data performed as well or better than the models built with *in situ* data. However, for some species the *in situ* oceanographic variables had a large effect on one or both response variables (encounter rate and group size) relative to the other predictors. Based on these analyses, we developed two sets of CCE models at the 5 km scale: 1) a set that included only remotely sensed habitat variables, and 2) a set that included a combination of *in situ* and remotely sensed predictor variables. These two types of models were subsequently compared to develop and finalize models on a species-specific basis.

Initial Model Selection and Evaluation Process

Initial models for both the *in situ* and remotely sensed data sets were selected using a "pseudo-jackknife" cross-validation approach (Becker 2007). Specifically, three data sets were constructed by excluding one of the four survey years available for model building (1991, 1993, 1996, and 2001). [Note: Data collected during 1993 were included in all model combinations because 1993 was the year with the warmest mean sea surface temperatures and was considered essential to capture the observed inter-annual variability in oceanographic conditions.] Each model was then used to predict the excluded year, and ASPE was calculated. This process of cross validation on all model combinations produced four ASPE values for each of the six initial models (three encounter rate models and three group size models). The paired models with the lowest sum of ASPE values (i.e. with lowest prediction errors across all survey years) were selected as the best overall models. Group size and encounter rate models were constrained to be paired because preliminary analyses indicated that variable selection was not independent; an increase in animal densities (e.g., with higher sea surface temperature) could be reflected in either a higher encounter rate or larger groups, and this effect varied among years. If models were built from different yearly subsets, this could result in the loss or overrepresentation of one or more variables, causing bias.

Expanding models to the entire U.S. West Coast

All of our initial west coast analyses (e.g., scale evaluation, seasonal predictions, etc.) were based on models developed using survey data collected only in California waters in 1991, 1993, 1996, and 2001, because Oregon and Washington waters were not surveyed in 1991 and 1993 and it was important to capture the greatest degree of inter-annual variability possible. Using four years of California-only data provided the most robust data set for construction of models, model validation, and other associated analyses. However, the inclusion of waters off Oregon and Washington in the final West Coast Spatial Decision Support System (SDSS) required a new approach to model selection, because the pseudo-jackknife cannot be used when regional coverage is unequal, and the varying survey extent could result in biased models. Therefore, we explored alternate 'best model' selection criteria for models encompassing the entire West Coast study area.

First, we compared key predictor variables and associated functional shapes of independent models built with California only vs. Oregon and Washington data. Based on the similarities of the variables and their functional forms, we concluded that we could combine the datasets for model building without introducing bias. This approach has the advantage of maximizing sample sizes and building models based on a broader range of environmental conditions. We then selected the five models that minimized AIC, and chose the best model based on non-AIC criteria applied to each individual survey year and the collective data set. These criteria included density ratios (line-transect derived density divided by predicted density) and a visual evaluation of spatial patterns in the model compared to the sighting data. For evaluation purposes, we built nested models for six species using only the California survey data. The species selected represented a broad range of habitat preferences: short-beaked common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), northern right whale dolphin (*Lissodelphis borealis*), Dall's porpoise (*Phocoenoides dalli*), fin whale (*Balaenoptera physalus*), and humpback whale (*Megaptera novaeangliae*). Models constructed for California waters using these methods were similar or identical to those selected using the pseudo-jackknife procedure; therefore, this alternate selection process was used for the final West Coast model development. Two candidate 'pre-final' models were developed for each species: one built only with remotely sensed habitat variables and another built with a combined set of *in situ* and remotely sensed predictor variables ("combined" models).

Habitat predictor variables

Predictor variables for the remotely-sensed models included sea surface temperature (SST), the coefficient of variation (CV) of SST within a 6x6 pixel (1,109 km^2) box (to serve as a proxy for frontal regions; Becker 2007), water depth, bathymetric slope, distance to the 2,000 m isobath, and Beaufort sea state. Distance to the 2,000 m isobath was added to the list of predictors because sighting plots suggested that this variable could potentially improve model performance for some species (e.g., sperm whale, *Physeter macrocephalus*, and Baird's beaked whale, *Berardius bairdii*) that are generally found only in slope or deep waters. This variable was coded to indicate whether the location was deeper (-) or shallower (+) than the 2,000 m isobath. Beaufort sea state affects the probability of detecting animals (Barlow et al. 2001), and the average observed sea state value on each segment was included as a continuous predictor variable in our models in order to account for sighting conditions.

In addition to the variables used for the remotely-sensed models, the combined models included three potential predictors derived from data collected *in situ*: sea surface salinity, the natural logarithm of surface chlorophyll concentration, and mixed layer depth, measured as the depth at which the water temperature was 0.5°C less than at the surface. Remotely sensed measures of SST and CV(SST) were used in the combined models because the remotely-sensed CV(SST) was found to be more effective at characterizing frontal regions than our *in situ* CV(SST) measures (Becker 2007), and SST measures performed similarly. The *in situ* data were derived in one of two ways. Salinity was sampled continuously along the transect and segment-specific estimates were obtained by averaging values within 5 km of the mid-point of each transect segment included in the analysis. Chlorophyll and mixed layer depth were measured much less frequently, and a linear interpolation between nearby stations did not accurately capture values at the edges of the study area or when samples were sparse, causing 'bull's eye' effects in estimated cetacean density. Therefore, the data were first contoured (see Section 3.2) to provide a 2-D surface of estimated chlorophyll and mixed-layer depth values, and segment mid-point values were extracted from the contour grid using the Surfer 8.0 (Golden Software, Inc) *Residuals* feature.

Density Estimation

Segment-specific density estimates were derived by incorporating the predicted values for encounter rate and group size into the standard line-transect equation (Buckland et al. 2001) as described by Becker (2007) and in Section 3.3.1. We relied on published values of detection probability (f(0) and g(0)) for each species as estimated from the same survey data used for model development (Barlow 2003). Published values for many species were stratified by group size and, for purposes of estimating densities, we incorporated weighted f(0) and g(0) values based on the number of small and large groups observed during the surveys (Becker 2007, Table 4). All final model predictions were made using the average observed Beaufort sea state for conditions 0-5 during the SWFSC cruises. This is appropriate because it corresponds to the conditions for which the line-transect parameters f(0) and g(0) were estimated (Barlow 2003). For Dall's porpoise and small beaked whales, published f(0) and g(0) values were available only for Beaufort conditions of 0-2. Model predictions for this species and guild were made using the average observed Beaufort sea state for conditions 0-2.

Table 4. Summary of the weighted effective strip width (ESW = 1/ f(0)) and g(0) estimates used to calculate predicted densities for the CCE. The original values are those estimated from the 1991-2001 survey data (Barlow 2003), which included both perception and availability bias to the extent possible. These values are weighted by the number of small and large groups observed during the 1991, 1993, 1996, 2001, and 2005 surveys.

Species	**Group size**	**ESW**		**g(0)**	
		original	**weighted**	**original**	**weighted**
Striped dolphin	1-20	0.50		0.77	
	21-100	1.24	0.97	1.00	0.89
	100+	1.88		1.00	
Short-beaked common dolphin	1-20	0.50		0.77	
	21-100	1.24	1.32	1.00	0.95
	100+	1.88		1.00	
Risso's dolphin	1-20	1.37		0.74	
	20+	2.18	1.63	1.00	0.82
Pacific white-sided dolphin	1-20	0.50		0.77	
	21-100	1.24	0.92	1.00	0.86
	100+	1.88		1.00	
Northern right whale dolphin	1-20	0.50		0.77	
	21-100	1.24	0.78	1.00	0.84
	100+	1.88		1.00	
Dall's porpoise	all	0.82	0.82	0.79	0.79
Sperm whale	all	4.61	4.61	0.87	0.87
Fin whale	all	1.72	1.72	0.90	0.90
Blue whale	all	1.72	1.72	0.90	0.90
Humpback whale	all	2.89	2.89	0.90	0.90
Baird's beaked whale	all	2.83	2.83	0.96	0.96
Small beaked whales	all	1.76	1.76	0.34*	0.34

*Based on average g(0) for Mesoplodon (*Mesoplodon* spp.) and Cuvier's beaked whales (*Ziphius cavirostris*).

Final CCE Model Selection

As described above, we developed two candidate "pre-final" CCE models for each species: one built with remotely sensed habitat variables, and one 'combined' model built with both remotely sensed data and interpolated *in situ* data (see Section 4.1). Initially, models were built for the ten species with the greatest number of sightings in order to provide the most robust environmental models: striped dolphin (*Stenella coeruleoalba*), short-beaked common dolphin, Risso's dolphin, Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), northern right whale dolphin, Dall's porpoise, sperm whale, fin whale, blue whale (*Balaenoptera musculus*), and humpback whale.

As part of the final model selection process, we convened an expert workshop to solicit feedback on the pre-final spatial models for both the CCE and ETP study areas. The scientists who participated in the workshop all have significant field and research experience within these oceanic regions and are recognized for their extensive knowledge of cetacean distributions in the study areas. The experts were shown maps with smoothed density predictions for 10 species in the CCE and 15 species in the ETP. At least two maps were presented for each species; competing maps varied either by the predictor variables included in the models (CCE) or by the analytical methods used to develop the models (ETP). The experts provided comments and participated in open discussions regarding the ability of the models to capture known distributions for each species. For those cases where the maps failed to capture overall distribution patterns, the experts provided input on predictor variables that might be included in future models to increase their predictive ability. For species like Risso's dolphins whose modeled density plots did not appear to capture major distribution patterns, the experts suggested that it would be worth investigating the performance of a model that included one or two static variables, such as categorical stratum variables. Based on workshop discussions, we built CCE habitat models for two additional species/guilds: Baird's beaked whale, and small beaked whales (*Ziphius* and *Mesoplodon*).

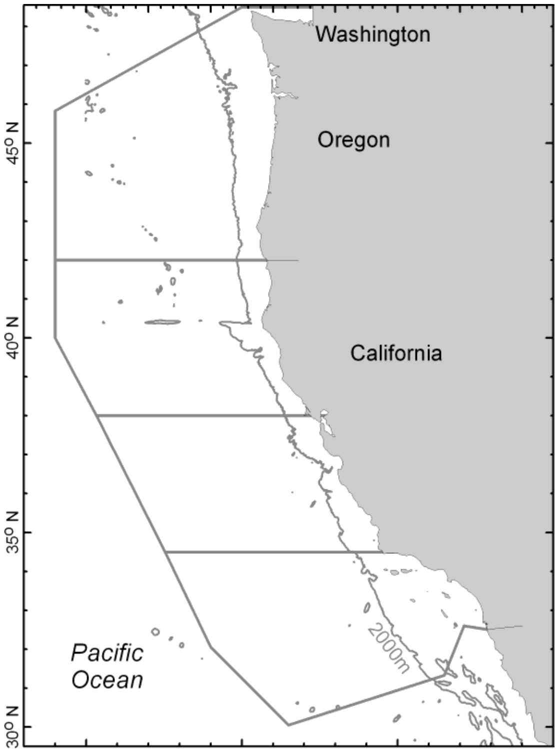


Figure 6. Geographic strata used for the CCE spatial predictions. The eight strata include waters inshore and offshore of the 2000 m isobath in Oregon/Washington, Northern California, Central California, and Southern California.

In addition to input received at the expert workshop, final model selection was based on a comparison of the models' ability to predict on a novel dataset. We compared total study area density ratios and standard errors (SEs) of density ratios for the competing models' 2005 predictions. In addition, these measures were compared to those of predictions made on the individual years that went into the model building. We also included a spatial measure of model performance in our evaluation by looking at the density ratios on a geographically stratified basis. To facilitate the spatial analysis, we stratified the study area into eight regions (Fig. 6).

Consistent with Barlow and Forney (2007), we created four northern/southern strata: waters off Oregon and Washington (north of 42°N), northern California (south of 42°N and north of Point Reyes at 38°N), central California (south of Point Reyes and north of Point Conception at 34.5°N), and southern California (south of Point Conception). These regions were further stratified into western and eastern regions at the 2,000 m isobath. Therefore, we were able to evaluate spatial predictions on a yearly basis as well as for all years combined. In addition, inspection of predicted species density maps overlaid with survey sighting locations provided a means for qualitatively comparing the models' predictions.

Density Interpolation

The segment-specific predictions from the model were interpolated to the entire study area using Surfer 8.0 (Golden Software, Inc). For the California Current models, interpolation grids were created at a resolution of 25 km, using inverse distance weighting to the power of 2. This weighting method gives points closer to each grid node greater influence than those farther away. All data within a search radius of 2 degrees latitude (222 km) were used for interpolation, because transect spacing ranged from 150 to 230 km during the five different survey years, and contouring results were more robust when data from more than one transect line were included.

Grids were created for each of the individual survey years (1991, 1993, 1996, 2001, and 2005) for the California Current Ecosystem. Subsequently, the individual grid cells were averaged across all years to calculate mean species density and its variance. To eliminate occasional over-specification ('bull's eye' effects) in the final average prediction grid, a 5x5 pixel moving average filter with equal weights was applied to the entire grid. The complete gridding process provided smoothed multi-year average cetacean densities, taking into account both the varying oceanographic conditions and different levels of sampling coverage achieved during the SWFSC cetacean surveys. Standard errors and upper and lower lognormal 90% confidence limits were calculated from the grid cell averages and variances using standard formulae.

Following selection of the final models, we performed an abundance cross-check to further validate model predictions. We compared the final model overall study area density predictions to the Barlow (2003) estimates derived using line-transect analyses to examine potential bias. Although the estimates provided by Barlow (2003) also have uncertainty associated with them, they provide a benchmark against which our model predictions can be evaluated. If the model-based estimate was substantially different from the line-transect estimate, we re-examined the model and performed additional analyses as necessary. In sum, evaluation factors used to select and validate our final models included expert opinion, temporal and spatial density ratios (including novel dataset predictions), density plots reflecting both yearly and averaged predictions, and abundance cross checks.

3.5.2 Eastern Tropical Pacific Models

Data Extraction

Data used for constructing and validating ETP cetacean-habitat models were collected during SWFSC cruises to the eastern tropical Pacific between 1986 and 2006. Sufficient sample sizes were available to build GAMs for 15 species or guilds: offshore spotted dolphin (*Stenella attenuata*), eastern spinner dolphin (*Stenella longirostris orientalis*), whitebelly spinner dolphin (*Stenella longirostris longirostris*), striped dolphin, rough-toothed dolphin (*Steno bredanensis*), short-beaked common dolphin, bottlenose dolphin (*Tursiops truncatus*), Risso's dolphin, Cuvier's beaked whale, blue whale, Bryde's whale (*Balaenoptera edeni*), short-finned pilot whale (*Globicephala macrorhynchus*), dwarf sperm whale (*Kogia sima*), *Mesoplodon* beaked whales (including *Mesoplodon* spp., *Mesoplodon densirostris*, and *Mesoplodon peruvianus*), and small beaked whales (*Mesoplodon* beaked whales plus "unidentified beaked whale"). Only data from surveys conducted after 1990 were used to construct the offshore spotted dolphin models because *Stenella attenuata* was not distinguished from the coastal spotted dolphin, *Stenella attenuata graffmani*, in the earlier survey years. Table 5 lists summary statistics for each species.

To build the ETP encounter rate and group size GAMs, line-transect survey data were divided into segments of approximately 10 km of on-effort transect. The potential predictor variables included closest distance to shore (continents or islands), depth, and *in situ* oceanographic data collected during the line-transect surveys, specifically, sea surface temperature (SST), sea surface salinity (SAL), mixed layer depth (MLD), and the natural logarithm of the surface chlorophyll concentration (CHL). In addition, the average Beaufort sea state on each segment was considered as a potential predictor variable in all models to account for potential biases due to visibility. Although it is possible to account for the sea state visibility bias elsewhere in the density analysis, including Beaufort as a predictor variable in the generalized additive model automatically accounts for correlations among other predictor variables. Furthermore, the Beaufort covariate in the encounter rate models provides information about the segments in which zero sightings were made that can be used to distinguish poor habitat from data collected during poor visibility conditions. Only survey effort conducted in Beaufort sea state condition of 5 or less was used to build the models. Latitude and longitude were initially omitted from all models because they are static predictors that do not reflect the dynamic environment in which these cetaceans live, bringing into question the ability of these covariates to accurately predict densities from novel data. The only species for which latitude and longitude were included in the final model was the eastern spinner dolphin because its distribution is contiguous with the whitebelly subspecies of spinner dolphin. The habitat occupied by the eastern spinner dolphin might be affected by the distribution of whitebelly spinners in addition to other physical and biological characteristics of the environment;

incorporation of geographic coordinates into the model is a simple way to account for this relationship.

Table 5. Total number of sightings used to build, validate, and parameterize the final models for the ETP. The sightings used to build the initial models are from the SWFSC's 1986, 1987, 1988, 1989, 1990, 1998, 1999, 2000, and 2003 surveys of the ETP. Sightings from the SWFSC survey in 2006 were used to validate the best models. The best models were re-fit to the additional year of data to parameterize the final predictive models. Numbers reflect sightings made in Beaufort sea states of 0-5 and for which *in situ* data were available.

Guild	Total number of sightings		
	build	**validate**	**re-fit**
Offshore spotted dolphin	886	116	1002
Eastern spinner dolphin	395	62	457
Whitebelly spinner dolphin	168	16	184
Striped dolphin	1081	124	1205
Rough-toothed dolphin	212	34	246
Short-beaked common dolphin	423	66	489
Bottlenose dolphin	626	87	713
Risso's dolphin	250	25	275
Cuvier's beaked whale	116	9	125
Blue whale	74	35	109
Bryde's whale	267	29	296
Short-finned pilot whale	296	58	354
Dwarf sperm whale	99	13	112
Mesoplodon spp.	116	14	130
Small beaked whales	257	26	283

Oceanography values for each segment were calculated as weighted averages of the oceanography data collected on the same day as, and within a radius of 50 km of, each segment midpoint. Inverse distance weighting (distance^{-1}) was used in the weighted average computations.

GAM Model Construction

Encounter rate and group size models for the ETP were constructed using survey data from 1986, 1987, 1988, 1989, 1990, 1998, 1999, 2000, and 2003. All models were created using the R (version 2.6.2) **mgcv** package (version 1.3-29), as described under *Model Comparison Analysis* in Section 3.3. Models containing univariate smooths were constructed first. Interactions were introduced on a case-by-case basis to improve model fit and predictive ability.

The eastern spinner dolphin was the only species for which interactions were included in the GAMs.

Model Evaluation

For each guild and response variable, a "simple" and a "complex" model were compared using ASPE and ratio criteria for the geographic strata shown in shown in Figure 7. The "simple models" had relatively few effective degrees of freedom and the smallest sum of absolute deviations of the observed-to-predicted ratios. Similarly, the "complex models" represented those having a relatively large number of effective degrees of freedom in addition to good agreement between observed and predicted values of the response variable. For cases in which a single model clearly outperformed all of the others, only one model was selected.

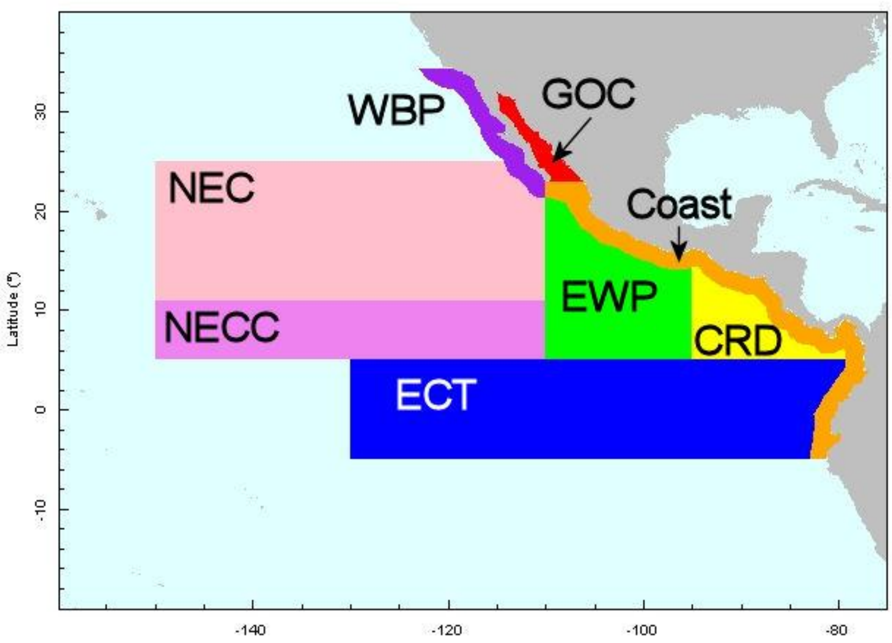


Figure 7. Geographic strata used for ETP model selection and validation. WBP: West Baja Peninsula. GOC: Gulf of California. NEC: North Equatorial Current. NECC: North Equatorial Countercurrent. EWP: Equatorial Warm Pool. CRD: Costa Rica Dome. ECT: Equatorial Cold Tongue. Coast: Coastal stratum (separated from other geographic strata only for the offshore spotted dolphin analysis).

As discussed above under *Final CCE Model Selection* for the California Current ecosystem, we convened a workshop for cetacean experts to solicit feedback on preliminary model results. We incorporated all of the experts' comments into the final models, as summarized below:

- Build a model for "small beaked whales" that includes all sightings for the genus *Mesoplodon*, in addition to "unidentified small beaked whale" sightings.
- Include sightings of "Bryde's or sei (*Balaenoptera borealis*) whales" in the Bryde's whale model. Bryde's and sei whales can be difficult to distinguish from a distance, but the

overwhelming majority of "Bryde's or sei whale" sightings in the ETP region are Bryde's whales.

- Include sightings of "*Kogia* spp." in the *Kogia sima* model because the majority of *Kogia* sightings unidentified to species in the ETP are believed to be *K. sima*.
- Do not include Beaufort sea state as a predictor variable in the spotted dolphin models because the primary visual cue for *Stenella attenuata* sightings is flocks of birds flying overhead.
- Incorporate latitude and longitude, or a latitude/longitude/SST interaction term in the eastern spinner model to differentiate eastern spinner from whitebelly spinner habitat.
- Include islands in the distance-to-shore computation to improve the prediction accuracy of the bottlenose dolphin encounter rate models in particular.
- Select simple models for the final models, unless strong support exists for the alternative complex model.
- Use geographically stratified estimates of density rather than predictions derived from cetacean-habitat models for sperm whales, killer whales (*Orcinus orca*), and coastal spotted dolphins.

Image Quality Analysis (IQA; Wang et al. 2004), a quantitative, spatially-explicit method for comparing two images, was implemented as an additional model evaluation technique, but it was not used in final model selection because we found that people had difficulty interpreting the resulting statistics. Nevertheless, the IQA approach seems promising and future work into making the results accessible to a non-expert audience would be valuable.

Density Estimation

The values for the line-transect sighting parameters f(0) and g(0) used to compute population density in the ETP analysis came from published reports, as summarized by Ferguson and Barlow (2001). For species in which the f(0) values were stratified by group size, selection of the appropriate group size stratum for determining which value of f(0) to use was determined by the group size predictions from the preferred group size model for the species.

Similar to the California Current analysis, the value of Beaufort sea state used to compute the final encounter rate and group size predictions for the SDSS was set to the average Beaufort, weighted by survey effort, of all segments used to build the models. The f(0) values for all beaked whales and *Kogia* were computed from data collected during Beaufort sea states from 0 to 2. Therefore, computation of weighted average Beaufort for beaked whales and *Kogia* predictions included only segments with average Beaufort conditions of 2 or less.

Encounter rate and group size were predicted to segment midpoints located directly on the survey transects, and the resulting densities were interpolated (as described under *Density Interpolation* in the California Current section above) to provide gridded density predictions throughout the study area. Grids were created for each of the individual survey years (1986-1990, 1998-2000, 2003, and 2006) and interpolated at a resolution of 100 km. All data within a search radius of 10 degrees latitude (1,111 km) were included in the inverse distance weighting calculations.

Model Validation

Data from the 2006 line-transect surveys in the ETP were used to validate the encounter rate and group size models constructed using data from 1986-2003. Data processing for this model validation task followed that described under *Data Extraction* for the ETP above. To assess the models' fit to the validation data set and to examine the inter-annual variability in model predictions, density was predicted separately for each survey year from 1986 to 2006. Methods used to evaluate model fit included visual inspection of geographic contour plots of the annual density predictions and computation of geographically stratified ratios of observed to predicted density.

3.5.3 Line-transect densities for unmodeled species

The predictive habitat models described above were developed for all ETP and CCE species with sufficient sightings and survey data during the summer/fall season. Several additional species were observed during the surveys, but too few observations were made to develop models. Similarly, a SWFSC survey of waters surrounding Hawaii yielded too few sightings for modeling of cetacean densities in that region. Therefore, constant densities were derived for these species and regions, based on published line-transect estimates applied to the most appropriate species-specific strata. Coefficients of variation and lognormal 90% confidence limits were estimated from the published CVs, or re-calculated for specific strata using the same methods as the original studies.

Within the California Current Ecosystem, line-transect estimates derived from the 1991-2005 U.S. West Coast surveys (Barlow and Forney 2007; Table 6) were used for the following species during summer: long-beaked common dolphin (*Delphinus capensis*), short-finned pilot whale, bottlenose dolphin, killer whale, minke whale (*Balaenoptera acutorostrata*), Bryde's whale, sei whale, and a combined category for pygmy and dwarf sperm whales (*Kogia* spp.). Similarly, average winter densities estimated for cetaceans off California (Forney et al. 1995) based on aerial line-transect surveys were applied to appropriate geographic strata on a species-specific basis. These species included: common dolphins (*Delphinus* spp.), Pacific white-sided dolphin, northern right whale dolphin, Dall's porpoise, Risso's dolphin, bottlenose dolphin, killer whale, blue whale, fin whale, humpback whale, sperm whale, minke whale, North Pacific right whale (*Eubalaena japonica*) and a category of 'small beaked whales' which includes species of the genera *Ziphius* and *Mesoplodon*. Constant line-transect densities for two additional coastal species that are present year-round were derived from published values: harbor porpoise (*Phocoena phocoena*; Carretta et al., in press), and coastal bottlenose dolphins (Dudzik et al. 2006, Carretta et al. 2007).

Geographically stratified density estimates for the three unmodeled ETP cetacean species (killer whale, sperm whale, and coastal spotted dolphin) were taken from Ferguson and Barlow (2003) without further combining or splitting of strata (Fig. 8, Table 7).

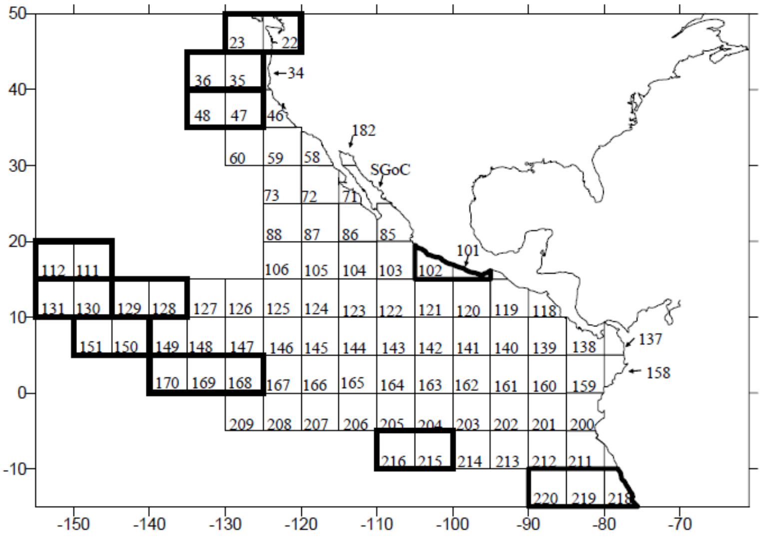


Figure 8. Stratum numbers for ETP line-transect density estimates for coastal spotted dolphin, killer whale, and sperm whale (from Ferguson and Barlow 2003).

Estimates of abundance and density for Hawaiian cetaceans (Table 8) were largely derived from a 2002 shipboard line-transect survey (Barlow 2006). Although Barlow defined two geographic strata for the analysis (Main Hawaiian Islands and Outer EEZ), variance estimates were only provided for the combined Hawaiian EEZ area. For most species, density estimates were similar in the two geographic strata (with wide, overlapping confidence intervals), so a single EEZ-wide density and associated variance were considered appropriate. Three species, however, exhibited markedly higher densities within the Main Hawaiian Islands stratum. In these cases, stratum-specific density estimates were retained (to increase accuracy), and variance was approximated by assuming the coefficient of variation (CV) was equal to that estimated for the overall study area (likely underestimating the true variance). Lastly, Barlow and Rankin (2007) provided updated estimates of false killer whale abundance in Hawaiian waters, based on additional sighting data obtained during a 2005 Pacific Islands Survey.

Table 6. Geographically stratified estimates of abundance (N), density (D), coefficient of variation (CV), and lognormal 90% confidence intervals of density for unmodeled cetacean species in the California Current Ecosystem.

			CALIFORNIA CURRENT ECOSYSTEM			
Species	**Area**	**N**	**CV**	**D**	**L90%**	**U90%**
SUMMER ESTIMATES (Barlow and Forney 2007)						
Long-beaked common dolphin	*Southern CA*	17530	1.03	0.05504	0.01365	0.22200
	Central CA	4375	1.03	0.01800	0.00446	0.07262
	Northern CA	0	-	0.00000	-	-
	Oregon and Washington	0	-	0.00000	-	-
Bottlenose dolphin (offshore stock)	*Southern CA*	1831	0.47	0.00575	0.00276	0.01196
	Central CA	61	0.77	0.00025	0.00008	0.00077
	Northern CA	133	0.68	0.00052	0.00019	0.00142
	Oregon and Washington	0	n/a	0.00000	-	-
Short-finned pilot whale	*California, Oregon, Washington*	350	0.48	0.00031	0.00015	0.00065
Killer whale	*California, Oregon, Washington*	809	0.27	0.00071	0.00046	0.00109
Minke whale	*California, Oregon, Washington*	823	0.56	0.00072	0.00031	0.00170
Bryde's whale	*California, Oregon, Washington*	7	1.01	0.00001	0.00000	0.00002
Sei whale	*California, Oregon, Washington*	98	0.57	0.00009	0.00004	0.00020
Pygmy/dwarf sperm whales	*California, Oregon, Washington*	1237	0.45	0.00108	0.00054	0.00219
WINTER ESTIMATES (Forney et al. 1995, variances re-calculated using same methods)						
Common dolphins	Southern California Bight	272,101	0.373	5.87691	3.25151	10.62215
	Outer Southern CA waters	26,535	0.731	0.41609	0.14229	1.21678
	Central California	7,058	0.977	0.05876	0.01535	0.22499
	Northern California	0	-	0.00000	-	-
Pacific white-sided dolphin	Southern California Bight	2,654	0.659	0.05732	0.02141	0.15348
	Outer Southern CA waters	18,779	0.670	0.29447	0.10848	0.79938
	Central California	74,678	0.620	0.62176	0.24401	1.58427
	Northern California	25,583	0.956	0.75045	0.20020	2.81308
Northern right whale dolphin	Southern California Bight	6,381	0.369	0.13782	0.07671	0.24762
	Outer Southern CA waters	8,895	0.871	0.13948	0.04068	0.47826
	Central California	4,091	0.510	0.03406	0.01548	0.07494
	Northern California	1,966	0.893	0.05767	0.01643	0.20247
Dall's porpoise	Southern California Bight	1,582	0.393	0.03417	0.01835	0.06361
	Outer Southern CA waters	716	0.827	0.01123	0.00344	0.03668
	Central California	4,744	0.314	0.03950	0.02389	0.06531
	Northern California	1,418	0.427	0.04160	0.02126	0.08138
Risso's dolphin	Southern California Bight	9,396	0.405	0.20294	0.10710	0.38454
	Outer Southern California waters	636	0.990	0.00997	0.00257	0.03868
	Central California	22,343	0.637	0.18602	0.07143	0.48443
	Northern California	0	-	0.00000	-	-
Bottlenose dolphin (offshore stock)	Southern California Bight (SCB)	3,165	0.501	0.06836	0.03146	0.14854
	California excluding SCB	95	1.032	0.00062	0.00015	0.00249
Killer whale	California	65	0.689	0.00025	0.00009	0.00068
Blue whale	California	30	0.990	0.00011	0.00003	0.00044
Fin whale	California	49	1.012	0.00019	0.00005	0.00073
Humpback whale	California	319	0.407	0.00121	0.00064	0.00229
Sperm whale	California	892	0.990	0.00338	0.00087	0.01309
Small beaked whales	California	392	0.408	0.00148	0.00078	0.00282
Minke whale	California	73	0.616	0.00028	0.00011	0.00070
North Pacific right whale	California	16	1.110	0.00006	0.00001	0.00026
YEAR-ROUND ESTIMATES (Carretta et al., in prep, Dudzik 2006, Carretta et al. 2007)						
Harbor porpoise	*Morro Bay Stock (inshore)*	2066	0.4	0.9591	0.50991	1.80417
	Morro Bay Stock (offshore)	280	0.65	0.0617	0.02329	0.16324
	Monterey Bay Stock (inshore)	1354	0.4	0.9993	0.53123	1.87963
	Monterey Bay Stock (offshore)	324	0.8	0.1504	0.04746	0.47671
	SF/Russian River Stock (inshore)	8830	0.38	1.8195	0.99626	3.32299
	SF/Russian River Stock (offshore)	520	1.39	0.1033	0.01885	0.56587
	No. CA & So. OR Stock (inshore)	13291	0.44	3.6424	1.82707	7.26126
	No. CA & So. OR Stock (inshore)	837	0.69	0.1146	0.04119	0.31892
Bottlenose dolphin (coastal stock)	*Within 1km of shore*	358	0.13	0.3612	0.29209	0.44660

Table 7. Geographically stratified estimates of abundance (N), density (D), coefficient of variation (CV), and lognormal 90% confidence intervals of density for three ETP cetacean species. Stratum numbers are from Ferguson and Barlow (2003), shown in Figure 8.

Coastal spotted dolphin					
Stratum	**N**	**CV**	**D**	**L90%**	**U90%**
85	11,327	0.64	0.0536	0.0205	0.1401
103	394	1	0.0013	0.0003	0.0051
118	11,297	0.55	0.0800	0.0344	0.1859
119	239	1	0.0009	0.0002	0.0035
137	10,148	0.48	0.0971	0.0460	0.2049
138	771	0.71	0.0037	0.0013	0.0106
158	4,473	0.71	0.0432	0.0152	0.1232
179-181	3,070	0.58	0.0291	0.0120	0.0704

Killer whale					
Stratum	**N**	**CV**	**D**	**L90%**	**U90%**
35-36	1,370	0.9	0.0030	0.0008	0.0106
46	37	1	0.0003	0.0001	0.0012
47-48	188	1	0.0004	0.0001	0.0016
59	111	0.71	0.0004	0.0001	0.0011
72	63	1	0.0002	0.0001	0.0008
85	28	1	0.0001	0.0000	0.0004
86	84	0.71	0.0003	0.0001	0.0009
87	61	1	0.0002	0.0001	0.0008
101-102	15	1	0.0001	0.0000	0.0004
103	20	1	0.0001	0.0000	0.0004
104	59	1	0.0002	0.0001	0.0008
105	39	1	0.0001	0.0000	0.0004
119	62	0.71	0.0002	0.0001	0.0006
121	82	1	0.0003	0.0001	0.0012
122	40	1	0.0001	0.0000	0.0004
124	232	0.71	0.0008	0.0003	0.0023
126	59	1	0.0002	0.0001	0.0008
127	449	0.71	0.0015	0.0005	0.0043
128-129	835	0.58	0.0014	0.0006	0.0034
138	14	1	0.0001	0.0000	0.0004
139	54	1	0.0002	0.0001	0.0008
140	45	1	0.0001	0.0000	0.0004
141	292	0.58	0.0010	0.0004	0.0024
142	217	1	0.0007	0.0002	0.0027
143	219	0.58	0.0007	0.0003	0.0017
147	110	1	0.0004	0.0001	0.0016
150-151	477	1	0.0008	0.0002	0.0031
159	108	0.71	0.0004	0.0001	0.0011
160	220	0.63	0.0007	0.0003	0.0018
164	55	1	0.0002	0.0001	0.0008
166	231	0.58	0.0007	0.0003	0.0017
182	50	1	0.0018	0.0005	0.0071
200	58	1	0.0002	0.0001	0.0008
201	349	0.64	0.0011	0.0004	0.0029
202	372	1	0.0012	0.0003	0.0047
203	139	0.71	0.0004	0.0001	0.0011
205	156	1	0.0005	0.0001	0.0020
207	902	1	0.0029	0.0007	0.0114
212	170	1	0.0006	0.0002	0.0024
213	772	0.71	0.0025	0.0009	0.0071
215-216	296	1	0.0005	0.0001	0.0020
218-220	3,116	0.58	0.0040	0.0017	0.0097

Sperm whale					
Stratum	**N**	**CV**	**D**	**L90%**	**U90%**
22-23	419	0.71	0.0017	0.0006	0.0048
35-36	75	0.71	0.0002	0.0001	0.0006
46	440	0.59	0.0035	0.0014	0.0086
47-48	507	0.47	0.0010	0.0005	0.0021
58	35	0.71	0.0003	0.0001	0.0009
59	282	0.42	0.0011	0.0006	0.0021
60	64	1	0.0002	0.0001	0.0008
71	53	0.71	0.0008	0.0003	0.0023
72	128	0.43	0.0005	0.0003	0.0010
73	63	1	0.0002	0.0001	0.0008
85	206	0.71	0.0010	0.0004	0.0029
86	348	0.53	0.0013	0.0006	0.0029
87	110	1	0.0004	0.0001	0.0016
103	886	0.72	0.0030	0.0010	0.0087
104	31	0.71	0.0001	0.0000	0.0003
105	78	1	0.0003	0.0001	0.0012
106	195	0.71	0.0007	0.0002	0.0020
111-112	56	1	0.0001	0.0000	0.0004
119	487	0.47	0.0018	0.0009	0.0037
121	113	0.71	0.0004	0.0001	0.0011
124	261	0.77	0.0009	0.0003	0.0028
137	450	0.43	0.0043	0.0022	0.0084
138	534	0.62	0.0026	0.0010	0.0066
139	1,253	0.52	0.0041	0.0018	0.0091
140	297	0.75	0.0010	0.0003	0.0030
141	336	0.71	0.0011	0.0004	0.0031
142	378	1	0.0012	0.0003	0.0047
143	272	0.64	0.0009	0.0003	0.0024
144	311	0.58	0.0010	0.0004	0.0024
145	702	1	0.0023	0.0006	0.0090
147	194	1	0.0006	0.0002	0.0024
148	306	0.71	0.0010	0.0004	0.0029
149	204	1	0.0007	0.0002	0.0027
150-151	50	1	0.0001	0.0000	0.0004
158	1,010	0.86	0.0098	0.0029	0.0332
159	1,583	0.41	0.0051	0.0027	0.0097
160	1,072	0.5	0.0035	0.0016	0.0076
161	158	0.58	0.0005	0.0002	0.0012
162	271	0.58	0.0009	0.0004	0.0022
164	169	1	0.0005	0.0001	0.0020
165	164	0.71	0.0005	0.0002	0.0014
166	140	1	0.0005	0.0001	0.0020
179-181	240	0.55	0.0023	0.0010	0.0053
200	2,829	0.69	0.0105	0.0038	0.0292
201	318	0.64	0.0010	0.0004	0.0026
202	295	0.6	0.0010	0.0004	0.0025
203	162	1	0.0005	0.0001	0.0020
204	312	1	0.0010	0.0003	0.0039
205	253	0.58	0.0008	0.0003	0.0019
206	1,004	0.66	0.0033	0.0012	0.0088
207	36	1	0.0001	0.0000	0.0004
211	2,057	0.67	0.0071	0.0026	0.0193
212	63	1	0.0002	0.0001	0.0008
213	66	1	0.0002	0.0001	0.0008
214	77	1	0.0003	0.0001	0.0012
215-216	409	0.58	0.0007	0.0003	0.0017
218-220	11,969	0.71	0.0152	0.0053	0.0433

Table 8. Geographically stratified estimates of abundance (N), density (D), coefficient of variation (CV), and lognormal 90% confidence intervals of density for unmodeled cetacean species within EEZ waters of the Hawaiian Islands.

HAWAIIAN ISLANDS (Barlow 2006, Barlow and Rankin 2007)						
Species	**Area**	**N**	**CV**	**D**	**L90%**	**U90%**
Offshore spotted dolphin	Outer EEZ stratum	4,695	0.485	0.00210	0.00099	0.00445
	Main HI Islands stratum	4,283	0.485	0.02012	0.00947	0.04274
Striped dolphin	Hawaiian EEZ	13,143	0.464	0.00536	0.00260	0.01105
Spinner dolphin	Outer EEZ stratum	1,863	0.737	0.00083	0.00028	0.00245
	Main HI Islands stratum	1,488	0.737	0.00699	0.00237	0.02059
Rough-toothed dolphin	Hawaiian EEZ	8,709	0.450	0.00355	0.00176	0.00718
Bottlenose dolphin	Hawaiian EEZ	3,215	0.586	0.00131	0.00054	0.00320
Risso's dolphin	Hawaiian EEZ	2,372	0.647	0.00097	0.00037	0.00255
Fraser's dolphin	Hawaiian EEZ	10,226	1.156	0.00417	0.00092	0.01888
Melon-headed whale	Hawaiian EEZ	2,950	1.172	0.00120	0.00026	0.00553
Pygmy killer whale	Hawaiian EEZ	956	0.826	0.00039	0.00012	0.00127
False killer whale	Hawaiian EEZ	484	0.930	0.00020	0.00005	0.00072
Short-finned pilot whale	Outer EEZ stratum	5,680	0.380	0.00254	0.00139	0.00463
	Main HI Islands stratum	3,190	0.380	0.01498	0.00821	0.02735
Killer whale	Hawaiian EEZ	349	0.982	0.00014	0.00004	0.00055
Sperm whale	Hawaiian EEZ	6,919	0.806	0.00282	0.00088	0.00900
Pygmy sperm whale	Hawaiian EEZ	7,138	1.124	0.00291	0.00066	0.01282
Dwarf sperm whale	Hawaiian EEZ	17,519	0.742	0.00714	0.00241	0.02115
Small beaked whale	Hawaiian EEZ	371	1.172	0.00015	0.00003	0.00069
Blainville's beaked whale	Hawaiian EEZ	2,872	1.250	0.00117	0.00024	0.00575
Cuvier's beaked whale	Hawaiian EEZ	15,242	1.434	0.00621	0.00110	0.03516
Longman's beaked whale	Hawaiian EEZ	1,007	1.256	0.00041	0.00008	0.00202
Sei whale	Hawaiian EEZ	469	0.452	0.00019	0.00009	0.00039

3.6 Variance Estimation

The output from an ecological model is an approximation to truth (Burnham and Anderson 1998); as such, it has two components: a point estimate (such as the predicted number of whales resulting from a GAM) and an estimate of uncertainty associated with the point estimate. There are numerous sources of uncertainty in the cetacean-habitat population density models described in Section 3.3. The survey design is a source of uncertainty because altering the spatial or temporal distribution of the survey transects would have produced a different set of cetacean and oceanographic data. The process of sighting the animals is stochastic, with some unknown probability that animals within sighting distance will be detected. The environmental data used as predictor variables in the GAMs have measurement error. Sampling error arises from the stochasticity inherent in the process generating the encounter rates and group sizes. Error is introduced when parameters are estimated in fitting the detection functions to estimate f(0) and in building the encounter rate and group size GAMs. Model selection errors are associated with designing the model structure and choosing the appropriate predictor variables and their corresponding degrees of freedom. Finally, there is a component of uncertainty due to a disassociation between the animals' distribution and the predictor variables used to try to understand the ecology of the system. To complicate matters, the sources of uncertainty outlined above, and the data themselves, are not independent, making the development of analytical methods for estimating variance an intractable, if not impossible, process.

It is not realistic to account for all sources of uncertainty when estimating the variance in population density estimates. Furthermore, due to the large range in the magnitude of uncertainty introduced by each of the sources described above, it is not necessary to quantify the uncertainty associated with every source in order to derive a relatively accurate estimate of overall uncertainty. Rather, estimation of the uncertainty contributed by the dominant sources is often sufficient. In our analyses, the greatest source of uncertainty is inter-annual variability in actual population density due to movement of animals within or outside of the study areas. We focus on this source of uncertainty to produce estimates of variance or standard error for the population density estimates in the California Current and ETP ecosystems.

In the SDSS, we provide variance estimates at two spatial scales, the grid cell and the user-defined polygon. Estimating uncertainty at the scale of a grid cell was briefly mentioned in Section 3.5. It involves the following two steps:

1. Computation of gridded population density estimates throughout the study area for each survey year using the methods outlined in Sections 3.3 and 3.5.
2. Computation of the variance in population density estimates among survey years for each grid cell.

To estimate the variance in the density estimates for any given polygon, the same annual grids of density predictions are used, average density is computed for the polygon in each year, and the variance in the resulting density estimates is computed across years using standard statistical formulae. Lower and upper 90% lognormal confidence limits for species density are calculated from the estimated polygon variance.

3.7 Inclusion of Prey Indices from Net-Tow and Acoustic Backscatter Data in Models

For many SWFSC cetacean and ecosystem assessment surveys, only physical and biological oceanographic data are available for use in cetacean-habitat models. Currently, it is unknown whether these oceanographic data are adequate proxies for the abundance of cetacean prey or whether prey indices should be directly included in habitat models. To explore whether oceanographic data are adequate proxies of cetacean prey, we tested how well our direct measurements of cetacean prey abundance (38 kHz acoustic backscatter data collected by a Simrad EQ-50 echosounder during cetacean and ecosystem assessment surveys conducted in the ETP from 1998 to 2000) could be predicted from basic oceanographic data.

We developed GAMs to relate oceanographic variables, such as surface temperature and salinity, thermocline depth and strength, and surface chlorophyll, to the following acoustic backscatter variables: mean backscatter throughout the water column, mean backscatter near the surface, and vertical variability of backscatter. These backscatter variables are related to the density and vertical distribution of small fish and krill-sized organisms. Explained deviance in the GAMs was generally about 25%, although results for individual years were higher. These results suggest that oceanographic variables are not perfect proxies for prey abundance and, therefore, the backscatter variables should be used directly in the models.

We built cetacean-habitat models using mid-trophic prey indices to determine whether predictor variables comprised of oceanographic measurements, mid-trophic prey indices, or a combination of both improves model fit and predictive power. Mid-trophic prey indices were derived from manta and bongo net-tow samples and from acoustic backscatter data. Oceanographic, net-tow, and acoustic backscatter data from which noise was removed were only available for four years of surveys: 2003 and 2006 in the ETP and 2001 and 2005 in the CCE. Species modeled in each ecosystem varied and were selected based on sample size (Table 9). We developed GAMs to model the expected number of sightings of each species; group size models could not be developed because sample sizes were too small.

Table 9. Number of segments containing a sighting and the total number of sightings used to build mid-trophic models in the ETP and CCE.

	ETP			**CCE**	
Species	Number of segments containing a sighting	Total sightings	Species	Number of segments containing a sighting	Total sightings
Striped dolphin	46	109	Striped dolphin	19	24
Short-beaked common dolphin	25	64	Short-beaked common dolphin	38	103
Eastern spinner dolphin	40	83	Dall's porpoise	24	94
Bryde's Whale	16	26	Blue whale	17	22
Number of unique segments	111		Number of unique segments	95	

3.8 Seasonality

Ideally, comprehensive shipboard surveys would be conducted year-round in the CCE to better assess seasonal patterns in the distribution and abundance of cetaceans. However, weather constraints often prohibit shipboard surveys during the winter and spring (hereafter "winter"), and therefore most of our shipboard line-transect data were collected during summer and fall (hereafter "summer"). SWFSC has conducted aerial surveys during the winter in portions of the CCE, but the aerial survey data contain too few sightings to build predictive environmental models. However, they can be used as test data to evaluate whether models constructed for summer using the extensive shipboard sighting data are able to predict distribution patterns in other seasons. This comparison required the development and evaluation of a separate set of models that rely on remotely-sensed environmental variables instead of *in situ* shipboard data. Predictive ability across seasons was estimated by applying the summer models to remotely sensed environmental data for winter and assessing performance based on winter aerial survey data (Becker 2007). This approach provided the advantages of a robust data set for construction of models (the shipboard data) and a more comprehensive seasonal data set (the aerial survey data) for examination of seasonal predictions.

Initially, we developed cetacean-habitat models for the CCE study area using multi-year (1991-2001) summer ship survey data and remotely sensed oceanographic data. GLMs and GAMs for both cetacean encounter rates and group sizes were developed for the ten species with the greatest number of sightings to provide the most robust environmental models: striped dolphin, short-beaked common dolphin, Risso's dolphin, Pacific white-sided dolphin, northern right whale dolphin, Dall's porpoise, sperm whale, fin whale, blue whale, and humpback whale.

Prior to evaluating the across-season predictive ability of the final shipboard models, we examined the performance of models built with remotely sensed SST data vs. analogous *in situ* measurements. Predictor variables included a combination of temporally dynamic, remotely sensed environmental variables (SST and measures of its variance, the latter serving as a proxy for frontal regions) and geographically fixed variables (water depth, bathymetric slope, and a categorical variable representing oceanic zone). For this comparison, we constructed a separate set of GAMs and GLMs by replacing the satellite data with analogous *in situ* data collected during the shipboard surveys.

The *in situ* GAMs and GLMs with the highest predictive ability were selected based on the pseudo-jackknife cross validation procedure described above (Becker 2007, see Section 3.5). To compare model performance by type (GAM or GLM) and data source (satellite or *in situ*), we re-fit each of the final models to a commonly shared dataset using all segments available for the species-specific SST resolution (i.e., segments for which both remotely sensed and *in situ* data were available) and calculated ASPE for each encounter rate and group size model. We also used paired encounter rate and group size predictions from each model type (GAM/GLM) and data source (satellite/*in situ*) to estimate density by species for the total study area and compared these to density estimates derived by standard line-transect analyses of the sighting data.

Aerial survey data collected off California during winter 1991-1992 (see Section 3.1) were used to assess the across-season predictive ability of the final summer shipboard models. We selected five species that are known to be present year-round and had sufficient sightings during the winter aerial surveys to evaluate the models: short-beaked common dolphin, Risso's dolphin, Pacific white-sided dolphin, northern right whale dolphin, and Dall's porpoise. Differences in platform-specific biases for ship vs. aerial surveys (e.g., the proportion of diving animals missed) prevented a direct quantitative comparison of estimated densities from aerial and shipboard surveys. For this reason the winter predictions can only be considered relative densities. To evaluate the between-season predictive ability of our final shipboard models, we used a nonparametric Spearman rank correlation test, as well as visual inspection of predicted and observed distributions by species. To enable a rank analysis, the study area was geographically stratified into six biogeographic regions. Predictive ability was based on a comparison of the models' ranked predicted values across biogeographic strata to those derived from the actual survey data for each species' encounter rate, group size, and density. Results from the Spearman rank correlation tests were also compared to results obtained when the models were used to predict data from the shipboard surveys that were used for model building, as well as to a "null" model, defined as the density derived from summer shipboard surveys without consideration of environmental data. To qualitatively evaluate the models' predictive ability, density estimates for each segment were smoothed on a grid resolution of approximately 12 km, and the resultant predictions of distribution and density were compared with actual sightings made during the winter aerial surveys.

3.9 Model Output and Visualization Software

Although the models of cetacean density we develop can be viewed as hard copy (see Appendices A and B) or as digital graphics, the real value of models can only be realized if they are interactively accessible via a geographically based software system. Two SERDP projects, ours (SI-1391) and a sister project at Duke University (SI-1390) are both developing geospatial habitat models for cetaceans. Their project covers the Atlantic Coast and the Gulf of Mexico and our project covers the Pacific Coast (CCE) and the ETP. The Navy has expressed their desire for models of all areas to be accessible with a single software system. Consequently, we have been coordinating closely with the Duke team in developing what we call a Spatial Decision Support System (SDSS) for viewing cetacean habitat models and obtaining desired output from those models.

Our SERDP team has met four times with the Duke SERDP team and with potential Navy users of the SDSS system to design it: 7-9 June 2004 at Duke University, 20-21 June 2005 at the SWFSC in La Jolla, California, 22-23 March 2007 in La Jolla, California, and 17-18 June 2008 in Durham, North Carolina. Initially, ArcGIS was chosen as the software package to form the foundation of our SDSS system. In meeting with Navy users, however, we discovered that there are problems with standardization of versions and access to upgrades within the Navy. To avoid these problems, we decided to use ArcGIS only as an optional method for viewing model outputs and extracting information from geospatial images. The primary software would be hosted on a website and would not require any specialized software on the user's computer. Because of their long experience in developing web-based data servers for marine mammal research, the Duke Team agreed to take the lead in developing this web-based SDSS software. Furthermore, Duke University volunteered to initially host the SDSS software on their website. Subsequent to the March 2007 user's workshop, the Duke Team developing the SDSS decided to use Google Earth as the primary visualization tool within the SDSS software.

Most of the specifications for the SDSS were developed at the 2007 Users Workshop in La Jolla. The primary recommendations of the users were:

- Nobody likes to read manuals. Therefore, we should try to minimize the need for a user manual by testing the SDSS software on naïve users to develop a user-friendly interface.
- Absolute population density estimates are the highest priority model products. Relative population density and probability of occurrence are the second- and third-best options, respectively.
- We should obtain peer-review of the bootstrap approach for estimating the CVs of density estimates within the scientific community.
- We should allow survey effort and sightings from input datasets to be displayed on all maps of model output.
- We should allow the user to set the categories and extents for figure legends.
- We should provide spatial plots of user-specified upper and lower confidence limits for density or probability of occurrence estimates as an output option.
- We should provide a session history tool to record user choices.
- Software documentation should provide a stepwise explanation of everything from model development to the extraction of model results from the SDSS.
- We should provide a complete list of model assumptions, caveats, and limitations.
- The users prefer a single, peer-reviewed model per species/species group per region and time period rather than a collection of alternative models.
- Contingent upon future funding, the SDSS development team should send the user community regular updates of relevant changes to the software.

4.0 Results and Accomplishments

4.1 Oceanographic Data Interpolation

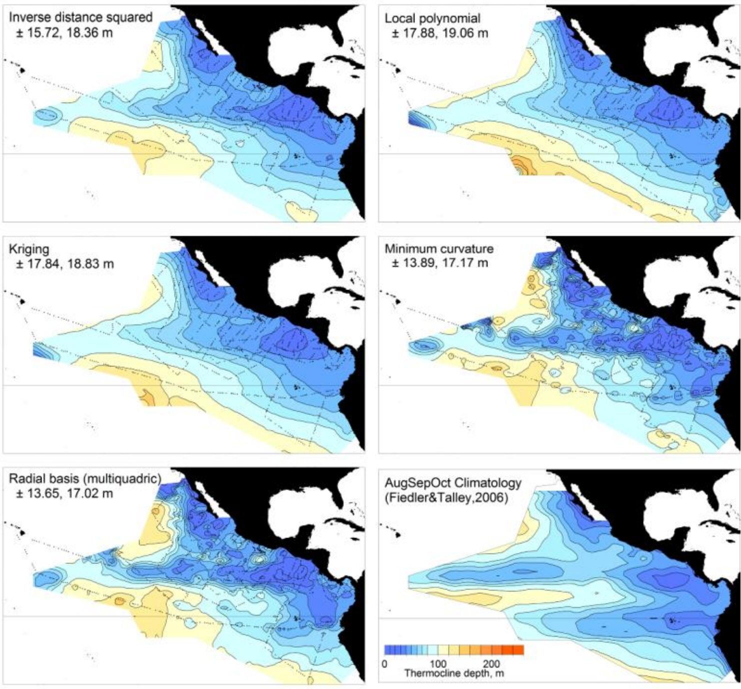
4.1.1 Comparison of Interpolation Methods

An example of thermocline depth interpolations in the ETP, calculated from 933 CTD and XBT profiles collected in 2006, shows basic differences between the interpolation methods (Fig. 9). Minimum curvature, radial basis function and, to a lesser extent, inverse distance squared tend to produce isolated areas of high or low values (i.e., bull's eyes). These interpolation methods have slightly lower residuals than other methods because local changes in the observed values are captured. Local polynomial interpolation tends to produce extreme highs or lows beyond the edge of the sampled area; this problem was minimized by using a first-order polynomial. Kriging results in the fewest number of bull's eyes, but has higher residuals. In spite of these obvious visual differences, residuals at individual sample points are very similar for all interpolation methods (Fig. 10 shows inverse distance squared and kriging, for example; r^2=0.94 between single jackknife residuals of the two interpolation methods and r^2=0.93 and 0.99 between single and daily jackknife residuals for the two methods). This result suggests that the residuals comprise measurement error more than error introduced by the interpolation method. In addition, the magnitude and spatial pattern of residuals does not change substantially with the jackknife procedure (Fig. 10).

Results using other variables in both the ETP and CCE are similar (California Current surface chlorophyll from 2005 is shown in Fig. 11). Kriging was selected as the best method for interpolating the oceanographic data collected on cetacean and ecosystem assessment surveys. This decision was based on the prevalence of its use in geostatistical spatial mapping and the fact that patterns of variability in the data are used directly in the kriging process through the fitted variogram model. It is likely that manipulation of parameters for the inverse distance squared or local polynomial methods could have produced interpolated fields very similar to the kriged fields.

4.1.2 Yearly interpolated fields of habitat variables

Initally, yearly fields were created at a very high resolution: 0.05 degree (5 km) for the CCE and 0.10 degree (10 km) for the ETP. In both cases, these resolutions are much smaller than the spacing of sample points. We found that kriging at this resolution results in fine-scale artifacts of two types:



F

Figure 9. Thermocline depth (m) observed in 2006 interpolated using five methods; the ±sd of residuals are shown for both jackknife procedures (single, daily). The map on the lower right is an August-October climatology from Fiedler and Talley (2006).

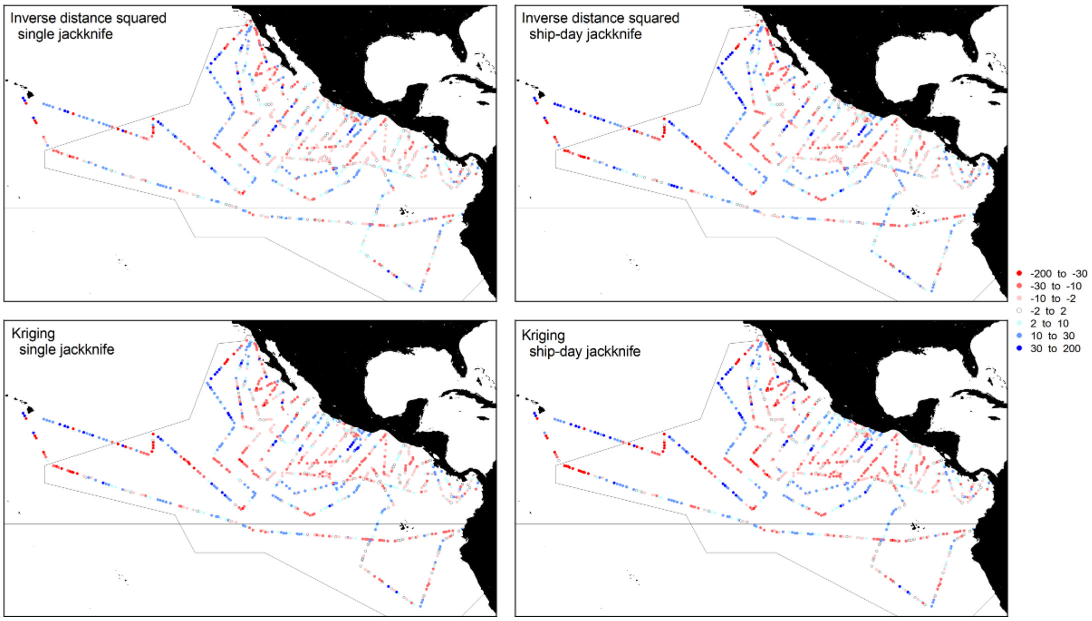
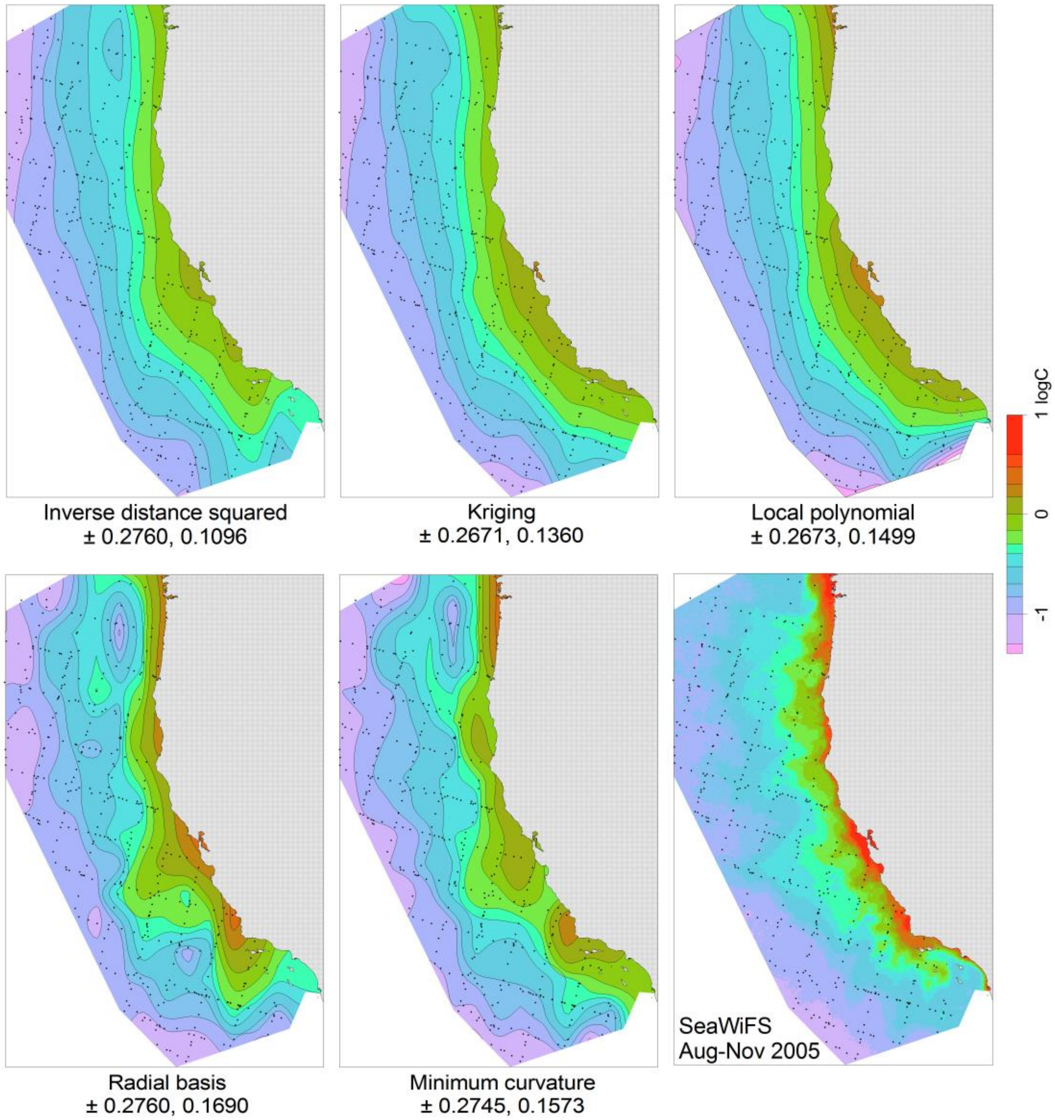


Figure 10. 2006 thermocline depth residuals (observed value – interpolated value, m) for interpolation by inverse distance squared and kriging, from jackknifing of observations singly and daily (by ship-day).



Inverse distance squared
± 0.2760, 0.1096

Kriging
± 0.2671, 0.1360

Local polynomial
± 0.2673, 0.1499

Radial basis
± 0.2760, 0.1690

Minimum curvature
± 0.2745, 0.1573

Figure 11. Surface chlorophyll (mg m^{-3}) observed in 2005 interpolated using five methods; the ±sd of residuals are shown for both jackknife procedures (single, daily). The map on the lower right is mean of monthly SeaWiFS composites (http://oceancolor.gsfc.nasa.gov).

1) Kriging weights do not go to zero at the edge of the search ellipse; consequently, in sparse data areas the interpolated field will suddenly change due to the loss of the influence of a sample near the search limits. Interpolated fields show oval-shaped step changes in these areas.

2) Interpolated fields also show fine-scale variations, such as jagged wiggles in the contours. Presumably these are a result of the kriging process, rather than true patterns in the observed data, but we have not investigated the cause.

Attempts to adjust search parameters to avoid these artifacts resulted in overly smoothing the grids and loss of mesoscale variability (100-200 km) that might be important for habitat modeling. Therefore, the data were kriged at 10x the desired resolution (i.e., 0.5 degrees in the CCE and 1.0 degrees in the ETP, which is approximately the average separation of samples). Spline interpolations of the low-resolution kriged fields were then used to produce final interpolated fields at the desired resolution. The final fields are nearly identical to the original high-resolution fields, but do not contain the previously described artifacts. This method preserved the mesoscale variability present in the observed data.

An additional constraint for CCE interpolation was needed because the variogram analyses typically gave cross-shore to alongshore anisotropy of 0.5 or less (i.e., variability was much greater when sampling from the coast to offshore compared to alongshore). The recommended anisotropy range is 0.5 to 2.0, if the x and y axes have the same units. Use of such an extreme anisotropy estimated from the variogram resulted in overly smoothing the grids. Therefore, CCE anisotropy was constrained to ≥0.75. ETP anisotropy was similarly constrained (≤1.50 or ≤2.00). The constraints on anisotropy resulted in a lower goodness of fit for the variogram model, but the interpolated surfaces seemed to be better representations of spatial patterns in the data.

Yearly fields of ETP thermocline depth, CCE surface chlorophyll, and CCE sea surface temperature are shown in Figures 12-14 to illustrate typical results. Differences in fitted variogram models between variables and regions probably reflect differences in sampling frequency and error, regional oceanography, and the processes controlling each variable. The search parameters that determine which observations are used for each interpolated point were chosen to be appropriate for each region and variable. Note that the number of observations within the search ellipse was almost always greater than the maximum number of data to use (N_{max}), so that only the N_{max} closest observations were used. In general, the interpolation is not very sensitive to tweaks in the variogram model or search parameters.

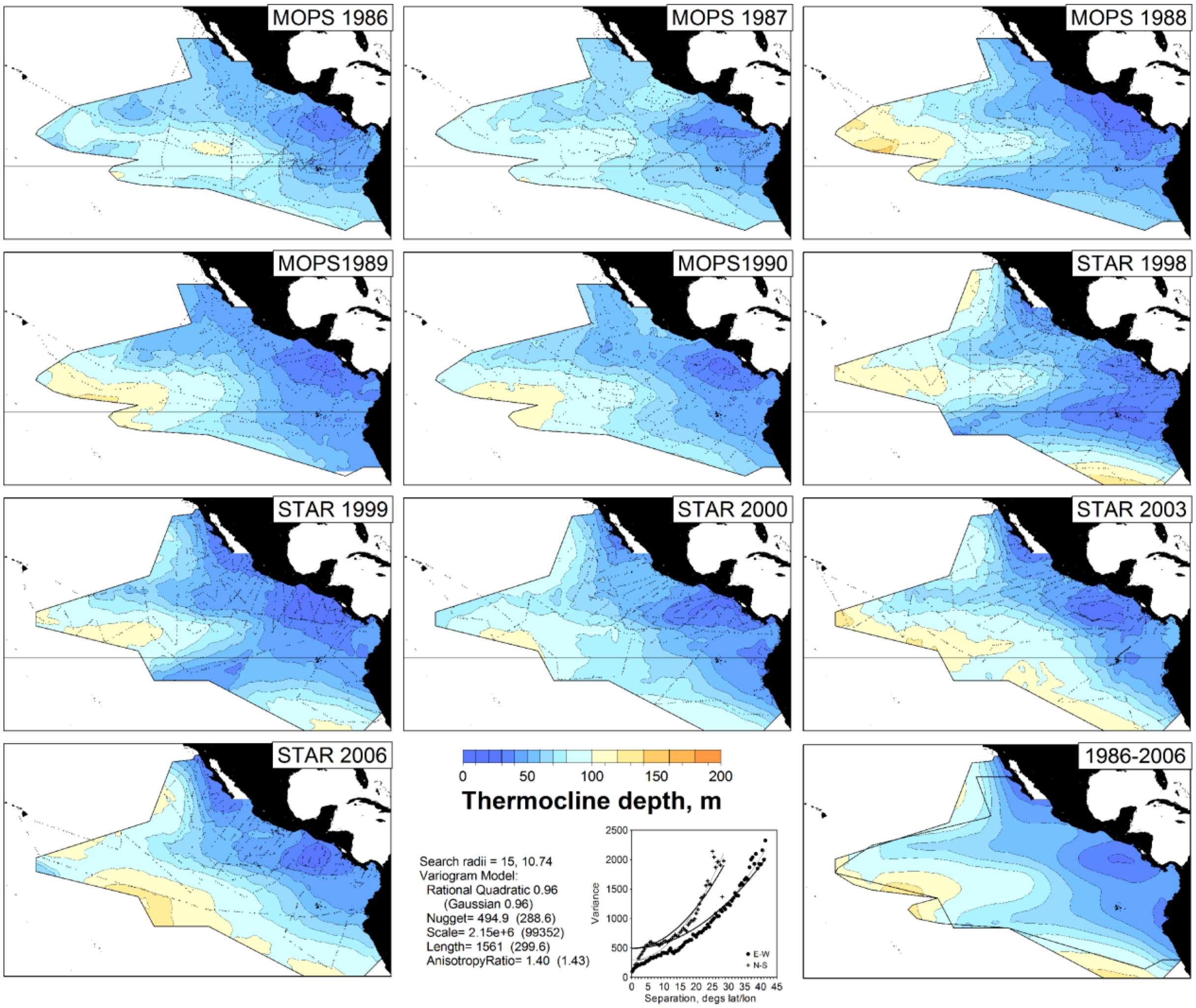


Figure 12. Yearly grids of ETP thermocline depth. Bottom right plot is a climatology from all samples pooled. Bottom center panel gives variogram model and search parameter information.

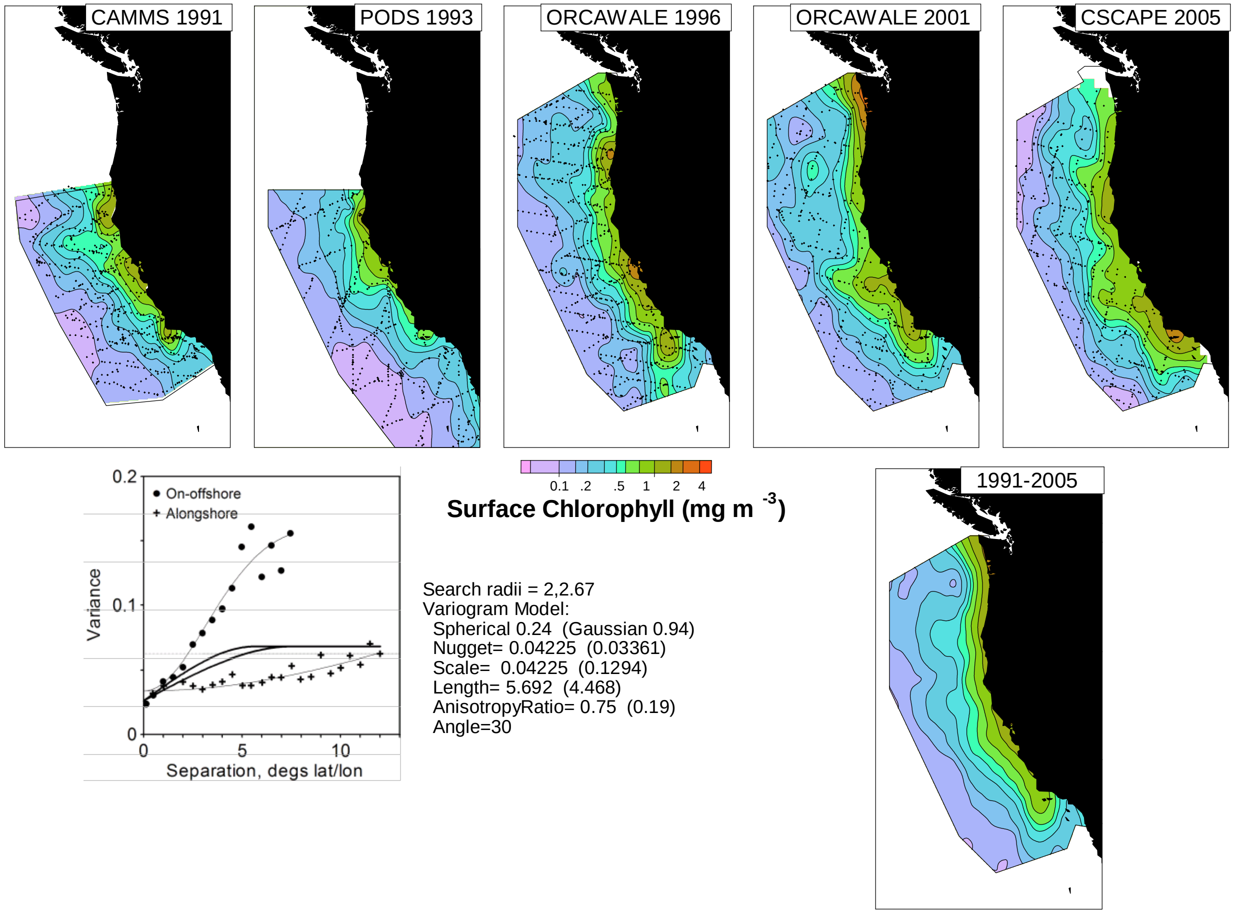


Figure 13. Yearly grids of CCE surface chlorophyll. Bottom right plot is a climatology from all samples pooled. Bottom center panel gives the variogram model and search parameter information.

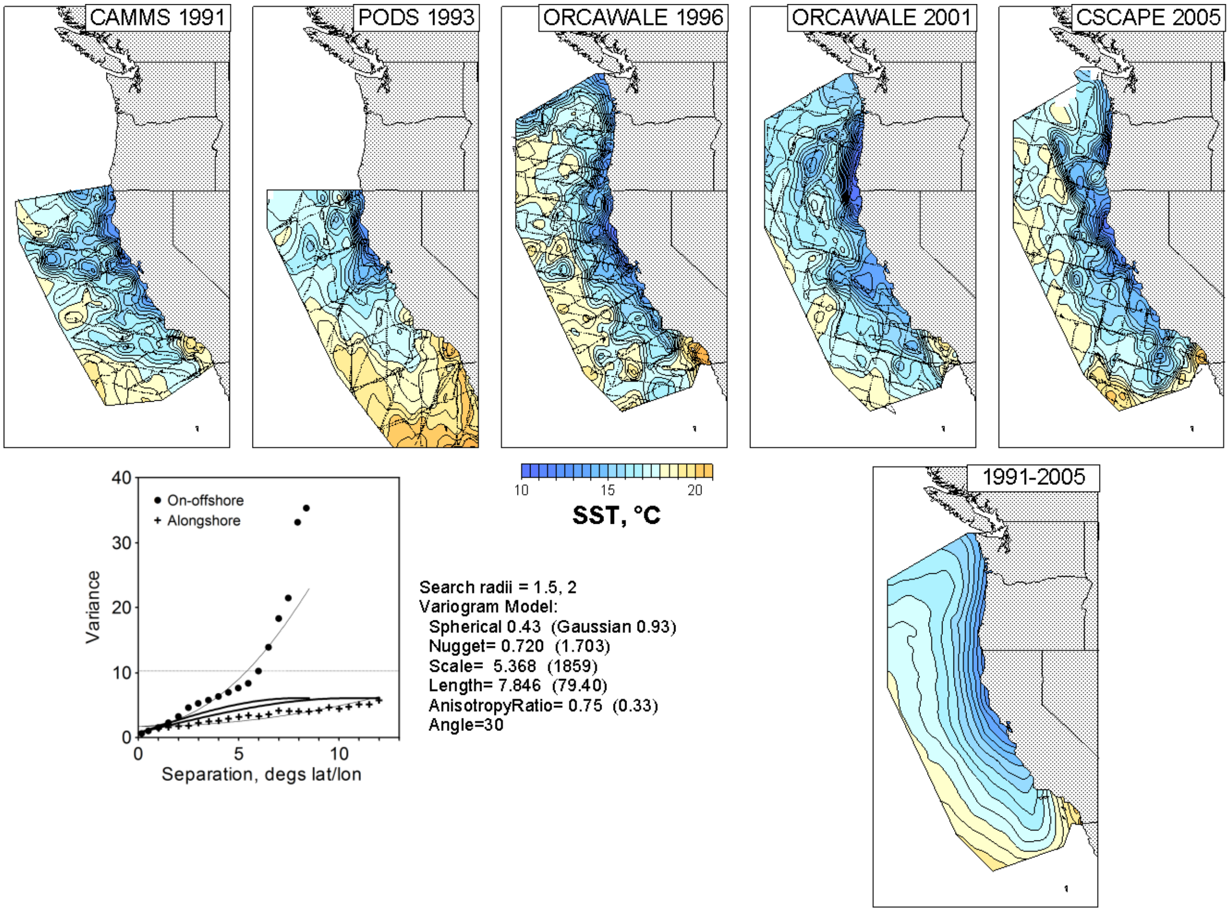


Figure 14. Yearly grids of CCE sea surface temperature. Bottom right plot is a climatology from all samples pooled. Bottom center panel gives variogram model and search parameter information.

The comparison of interpolation methods showed that there is not a single "best" method for interpolating our oceanographic observations to produce what we judge to be reasonably realistic fields of predictor variables. We chose ordinary kriging because this method was least susceptible to bull's eyes, edge effects, or other artifacts where data are sparse. The kriged yearly fields produced for cetacean-habitat modeling capture both mesoscale and larger scale habitat variability that might influence the distribution of cetaceans. However, it is important to remember that the yearly field is neither a snapshot nor a mean of oceanographic conditions during the three- to four-month survey. It is appropriate to use such a field in developing habitat models using cetacean data collected concurrently with the oceanographic data. When using these models for prediction, however, it might be better to use fields of oceanographic parameters derived from ocean-atmosphere models that assimilate ship, buoy, or even remotely-sensed data (e.g., Carton et al. 2000).

4.2 Modeling Framework : GLM and GAM

4.2.1 Comparisons of GAM Algorithms

During the comparison of GAM algorithms, we found a bug in the step.gam function from the R package gam code that previously had not been reported to the R mailing lists, and that was unknown to the package developer (pers comm. with Hastie). The bug prevented step.gam from including the offset term for survey effort in any encounter rate model that was examined during the stepwise search. As a result, we only modeled group size (and not encounter rates) using the step.gam algorithm from R package gam.

The group size GAMs built using the S-PLUS and R package gam algorithms were essentially identical: the best models contained the exact same predictor variables and associated degrees of freedom, and the parameterization of the smoothing splines were identical, except for small differences that were likely due to the precision of the software platforms.

GAMs built using R package mgcv were more variable. The mgcv gam algorithm allows users to adjust more parameters and settings to build the models compared to the S-PLUS analogue. To the knowledgeable user, this flexibility enables fine-tuning of the GAMs. On the other hand, having numerous adjustable arguments makes the algorithm less user-friendly because a greater investment of time must be spent to learn how to build appropriate models.

Tables 10 and 11 show the range of encounter rate and group size models, respectively, selected as the final model by mgcv gam given the specified combination of settings for the gam.method, smoothing spline, and gamma arguments. The paired models for each species/response variable that are provided in these tables were chosen based on the sum of the absolute value of the deviation of the observed-to-predicted ratios of the response variable in the geographic strata shown in Figure 7. The “simple models” in Tables 10 and 11 represent the models having relatively few effective degrees of freedom and the smallest sum of absolute deviations of the observed-to-predicted ratios. Similarly, the “complex models” represent those having a relatively large number of effective degrees of freedom in addition to good agreement between observed and predicted values of the response variable. For cases in which a single model clearly outperformed all of the others, only one model is presented in the table.

The variability in model complexity can be illustrated using the rough-toothed dolphin encounter rate models, where the preferred simple model had 8.9 degrees of freedom and the preferred complex model had over fifty degrees of freedom. The sum of absolute deviations of the observed-to-predicted ratios is smaller for the complex model. This is to be expected because the data used for predictions were also used to build the models; in this scenario, a complex model is more likely to exhibit fidelity to the data.

When cetacean experts were shown geographic contour plots of the predictions from the competing simple and complex mgcv gam models for each species during the SWFSC Cetacean Experts' Workshop, the simple models were overwhelmingly preferred to the complex models. The dominant criticisms of the complex models from the expert panel were twofold: the predictions from the complex models either 1) exhibited relatively small-scale details in population density that are unexplainable given existing knowledge of the dynamics of the ecosystem, or 2) were nearly identical to those from the simple model and, therefore, the extra model complexity was not necessary for capturing the spatial patterns.

Overall conclusions to be made from this investigation into the behavior of mgcv gam (summarized in Tables 10 and 11) are as follows:

4.2.2 Encounter Rate Models

- The gam.method perf.magic produced the simple models with the greatest predictive performance. The best complex models were developed using outer (6 models), perf.outer (4 models), and perf.magic (2 models).

- Cubic regression splines were preferred for building simple encounter rate models, whereas the complex models were constructed using either cubic or thin plate regression splines.

- To our surprise, the preferred simple models were split almost equally between those built using gamma = 1.0 (8 models) and 1.4 (6 models). The best complex models were generally constructed using gamma = 1.0.

- The sum of absolute deviations of the observed-to-predicted ratios was smaller for the complex models in most instances, although this is to be expected because the predictions were based on the same data used to build the models for this exercise.

4.2.3 Group Size Models

- The gam.method magic produced the simple models with the greatest predictive performance. The best complex models were divided among gam.methods mgcv and magic.

- The preferred simple models were constructed by thin plate regression splines, in general, whereas cubic regression splines were found in more of the preferred complex models.

- The gamma parameter performed close to our expectations in the group size models, with the majority of simple models constructed using gamma = 1.4 and the majority of complex models using the default value of 1.0.

- The trend in the sum of absolute deviations of the observed-to-predicted ratios was similar to that found for the encounter rate models, with simple models tending to have slightly larger values.

4.2.4 Conclusions Regardings Modeling Approaches

Three additional features of the mgcv gam algorithm distinguish it from the S-PLUS counterpart and make it the preferred algorithm for future work. First, the predict.gam function in mgcv does not require the original dataset in order to make predictions from a parameterized GAM. This is in contrast to the S-PLUS predict.gam algorithm, which will produce a run-time error and stop working if the original dataset is not in the working directory. The practical consequence of this restriction is that a model developer working in the S-PLUS environment must provide both the original data and the GAM model object to anyone interested in making predictions from the model. The second desirable feature of mgcv gam is its ability to construct a variety of multidimensional smooth terms. Incorporating tensor product smooths improved the predictive performance of the ETP eastern spinner dolphin and Cuvier's beaked whale encounter rate models, as discussed further in Section 4.8. Finally, the developer of the mgcv package is very active in the field of statistics and is constantly updating and improving the package.

The differences between GLMs and S-PLUS GAMs for a given dataset were surprisingly little based on a comparison of ASPE, explained deviance, the predictor variables and associated degrees of freedom in the final models, the shape of the smoothing splines for each predictor variable, and visual examination of geographic contour plots of predicted density. Greater differences in statistical details (but not in geographic contour plots of predicted densities) were observed between GLMs and GAMs constructed using mgcv because the GLMs and S-PLUS GAMs were constrained to a maximum of three degrees of freedom per term, whereas the mgcv gam function allowed higher degrees of freedom. As evident from the comparison between simple and complex mgcv gam models in Tables 10 and 11, however, and the outcome of the SWFSC Cetacean Experts' Workshop, greater complexity frequently does not result in better models.

Two lessons emerged from this model comparison exercise:

1. It is worthwhile to compare models built using a variety of tools. Choice of the "preferred" tool is likely to be case-specific, but it is best to be fully aware of the advantages and disadvantages of alternative modeling methods and algorithms.

2. Model evaluation should encompass a suite of model evaluation techniques. It was rare that all model evaluation techniques pointed to the same model to be the best model. Quantitative statistics such as the observed-to-predicted ratios provide nice summaries, but they lose spatial accuracy. Visual examination of geographic contour plots maintain spatial details, but it is difficult to quantify concordance between observations and predictions or between plots derived from different models.

Table 10. Comparison of the simple and complex encounter rate GAMs for the ETP. All models were built using the *gam* algorithm in the R package **mgcv**. The term *gam.method* refers to the numerical method used to optimize the smoothing parameter estimation criterion for the gam. Splines were either cubic regression splines with shrinkage (cs) or thin plate regression splines with shrinkage (ts). The *gamma* parameter determines the penalty for model complexity, with larger values of gamma resulting in greater penalty. Also shown are the total effective degrees of freedom (EDF), the sum of the absolute value of the deviance in the ratio of observed to predicted number of sightings, the explained deviance, and the average squared prediction error (ASPE) for the best model re-fit using all data from 1986-2006 (or 1998-2006 for offshore spotted dolphins). If a single model outperformed all others, the corresponding elements of the table show "NA" for the type of model that was not considered any further.

Guild	**Model Type**	***gam.method***	**Spline**	***gamma***	**Total EDF**	**sum(abs(1-R))**	**Explained Deviance**	**ASPE**
Offshore spotted dolphin	Simple	perf.magic	cs	1.400	6.914	1.443	0.104	0.044
	Complex	outer	ts	1.000	42.143	1.303	0.116	0.044
Eastern spinner dolphin	Simple	perf.magic	cs	1.000	32.200	1.947	0.252	0.018
	Complex	NA	NA	NA	NA	NA	NA	NA
Whitebelly spinner dolphin	Simple	perf.magic	cs	1.000	22.627	2.070	0.165	0.007
	Complex	NA	NA	NA	NA	NA	NA	NA
Striped dolphin	Simple	perf.magic	cs	1.000	22.533	1.149	0.086	0.048
	Complex	outer	ts	1.400	53.388	1.048	0.094	0.048
Rough-toothed dolphin	Simple	perf.magic	cs	1.000	8.914	1.355	0.155	0.010
	Complex	outer	cs	1.000	60.560	0.745	0.180	0.010
Short-beaked common dolphin	Simple	perf.magic	cs	1.400	16.733	1.599	0.162	0.020
	Complex	perf.outer	cs	1.000	59.646	1.494	0.183	0.020
Bottlenose dolphin	Simple	perf.magic	ts	1.400	14.240	1.806	0.163	0.029
	Complex	perf.outer	ts	1.000	51.457	1.475	0.178	0.029
Risso's dolphin	Simple	perf.magic	cs	1.000	14.238	2.196	0.088	0.011
	Complex	outer	cs	1.000	59.795	1.797	0.111	0.011

Table 10 cont. Comparison of the simple and complex encounter rate GAMs for the ETP.

Guild	**Model Type**	***gam.method***	**Spline**	***gamma***	**Total EDF**	**sum(abs(1-R))**	**Explained Deviance**	**ASPE**
Cuvier's Beaked Whale	Simple	perf.magic	cs	1.000	7.027	2.023	0.056	0.005
	Complex	perf.magic	ts	1.000	8.973	1.742	0.057	0.005
Blue Whale	Simple	perf.magic	cs	1.400	24.174	4.092	0.215	0.005
	Complex	NA	NA	NA	NA	NA	NA	NA
Bryde's Whale	Simple	perf.magic	ts	1.000	10.284	1.697	0.058	0.012
	Complex	NA	NA	NA	NA	NA	NA	NA
Short-finned Pilot Whale	Simple	perf.magic	cs	1.000	16.160	1.715	0.061	0.014
	Complex	outer	ts	1.400	57.162	1.625	0.086	0.014
Dwarf Sperm Whale	Simple	perf.outer	cs	1.400	26.920	1.273	0.342	0.005
	Complex	outer	cs	1.000	61.997	0.646	0.388	0.005
Mesoplodon spp.	Simple	perf.outer	cs	1.000	52.296	1.736	0.140	0.005
	Complex	NA	NA	NA	NA	NA	NA	NA
Small Beaked Whale	Simple	perf.magic	cs	1.000	12.934	1.276	0.091	0.012
	Complex	perf.outer	cs	1.000	44.111	1.152	0.109	0.012

Table 11. Comparison of the simple and complex group size GAMs for the ETP. All models were built using the *gam* algorithm in the R package **mgcv**. The term *gam.method* refers to the numerical method used to optimize the smoothing parameter estimation criterion for the gam. Splines were either cubic regression splines with shrinkage (cs) or thin plate regression splines with shrinkage (ts). The *gamma* parameter determines the penalty for model complexity, with larger values of gamma resulting in greater penalty. Also shown are the total effective degrees of freedom (EDF), the sum of the absolute value of the deviance in the ratio of observed to predicted number of sightings, the explained deviance, and the average squared prediction error (ASPE) for the best model re-fit using all data from 1986-2006 (or 1998-2006 for offshore spotted dolphins). If a single model outperformed all others, the corresponding elements of the table show "NA" for the type of model that was not considered any further.

Guild	**Model Type**	***gam.method***	**Spline**	***gamma***	**Total EDF**	**sum(abs(1-R))**	**Explained Deviance**	**ASPE**
Offshore spotted dolphin	Simple	magic	cs	1.400	3.830	1.663	0.038	6734.449
	Complex	NA	NA	NA	NA	NA	NA	NA
Eastern spinner dolphin	Simple	magic	ts	1.400	13.222	2.161	0.105	12863.707
	Complex	mgcv	cs	1.000	21.621	1.992	0.150	12517.964
Whitebelly spinner dolphin	Simple	magic	ts	1.000	1.783	0.776	0.083	41435.168
	Complex	NA	NA	NA	NA	NA	NA	NA
Striped dolphin	Simple	magic	ts	1.400	12.641	0.543	0.089	2898.201
	Complex	mgcv	ts	1.000	17.934	0.473	0.098	2890.072
Rough-toothed dolphin	Simple	magic	ts	1.400	6.789	1.672	0.148	114.062
	Complex	NA	NA	NA	NA	NA	NA	NA
Short-beaked common dolphin	Simple	magic	cs	1.400	10.974	1.627	0.138	83237.681
	Complex	magic	ts	1.000	21.745	1.094	0.215	77358.863
Bottlenose dolphin	Simple	magic	ts	1.400	10.162	1.183	0.060	12433.442
	Complex	mgcv	cs	1.000	27.789	1.292	0.118	12461.770
Risso's dolphin	Simple	magic	ts	1.400	5.031	0.570	0.096	353.787
	Complex	magic	cs	1.000	20.570	0.294	0.208	304.655

Table 11 cont. Comparison of the simple and complex group size GAMs for the ETP.

Guild	Model Type	*gam.method*	Spline	*gamma*	Total EDF	sum(abs(1-R))	Explained Deviance	ASPE
Cuvier's Beaked Whale	Simple	magic	ts	1.000	10.324	0.543	0.217	1.138
	Complex	mgcv	cs	1.000	16.626	0.621	0.202	1.185
Blue Whale	Simple	magic	ts	1.400	7.571	0.737	0.300	2.469
	Complex	magic	cs	1.000	33.089	0.324	0.586	1.519
Bryde's Whale	Simple	magic	ts	1.000	6.194	0.705	0.073	1.108
	Complex	NA	NA	NA	NA	NA	NA	NA
Short-finned Pilot Whale	Simple	magic	ts	1.000	5.428	1.080	0.059	261.772
	Complex	magic	cs	1.000	11.473	1.391	0.117	248.580
Dwarf Sperm Whale	Simple	magic	ts	1.400	1.847	1.368	0.051	1.343
	Complex	mgcv	cs	1.000	18.484	1.118	0.330	0.977
Mesoplodon spp.	Simple	magic	ts	1.000	9.422	0.763	0.238	0.678
	Complex	mgcv	ts	1.000	14.329	0.768	0.274	0.653
Small Beaked Whale	Simple	magic	ts	1.000	5.117	0.876	0.067	0.850
	Complex	magic	cs	1.000	21.796	0.689	0.175	0.758

4.3 Model Scale: Resolution and Extent

4.3.1 Resolution

Selecting an Appropriate Resolution for ETP Cetacean-Habitat Models

We found that resolution did not affect the functional form of habitat relationships or maps of predicted densities and that inter-annual habitat variability had a greater impact on the predictive power of the habitat models than resolution. The absence of scale dependence in these models suggests that the resolutions evaluated (2 to 120 km) occur within a single domain of scale, which is defined as a range of resolutions over which ecological patterns do not vary (Wiens 1989). Results of our analyses have already been published (Redfern et al. 2008) and are therefore not repeated in detail here. A transect segment length of approximately 10 km was used for the ETP models.

Selecting an Appropriate Resolution for CCE Cetacean-Habitat Models

We summarized dolphin and oceanographic data in 2, 10, 20, 40, 60, and 120 km segments along the transect lines. We selected four species which represented a broad range of habitat preferences: striped dolphin, short-beaked common dolphin, Risso's dolphin, and northern right whale dolphin. Over 15,000 km of sampling data (Fig. 15) collected by the Southwest Fisheries Science Center (NOAA Fisheries) were used in the analyses. The data were collected from two comparable research vessels from late July until early December in 1991, 1993, 1996, and 2001. Data collection procedures are reported elsewhere (Kinzey et al. 2000, Barlow et al. 2001, Fiedler and Philbrick 2002). Encounter rate and group size models were built at each resolution for the four species considered in our analyses; methods followed those published in Redfern et al. (2008). The total number of segments and number of dolphin sightings are presented in Table 12. Habitat variables used in our analyses include surface temperature and salinity, the natural logarithm of surface chlorophyll concentration, thermocline depth and strength, seafloor depth, an estimate of temperature fronts defined as the difference between the minimum and maximum temperatures on a segment, and Beaufort sea state, which was used to account for the difficulty of detecting dolphins at higher Beaufort sea states (Barlow et al. 2001).

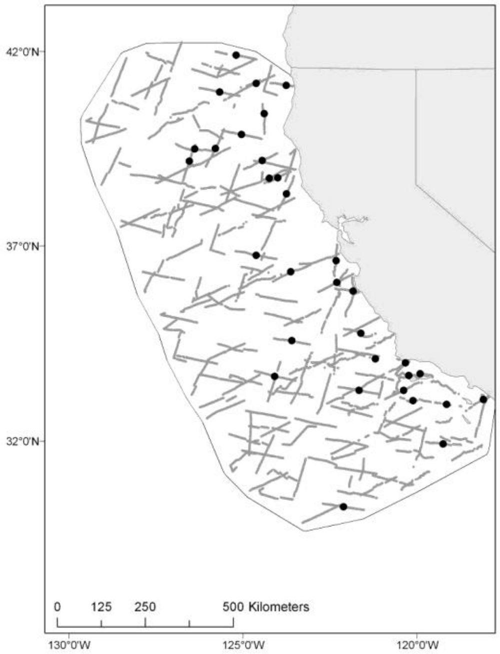


Figure 15. The transect lines used to collect dolphin and oceanographic data in the California Current ecosystem are shown for 1991, 1993, 1996, and 2001. The locations of the largest 20% of temperature fronts at the 120 km resolution are shown as black dots for all years of data. Fronts were defined as the difference between the minimum and maximum temperatures recorded on a segment.

Table 12. Number of encounters for the four species and six spatial resolutions considered in our California Current ecosystem analyses. The 120 km resolution has the highest number of encounters for several species because segments with Beaufort sea state values greater than 5.5 were excluded from our analyses. In particular, 2 km segments containing an encounter and occurring in Beaufort sea states greater than 5.5 may not contribute to the analyses at the smaller resolutions but may contribute at the larger resolutions if the average Beaufort sea state on the longer segment was less than or equal to 5.5.

Spatial Resolution (km)	Striped dolphin	Short-beaked common dolphin	Risso's dolphin	Northern right whale dolphin	Total number of segments
2	28	177	37	30	8216
10	29	184	38	30	1888
20	29	188	38	30	966
40	29	193	39	30	490
60	29	191	39	30	329
120	29	193	39	30	168

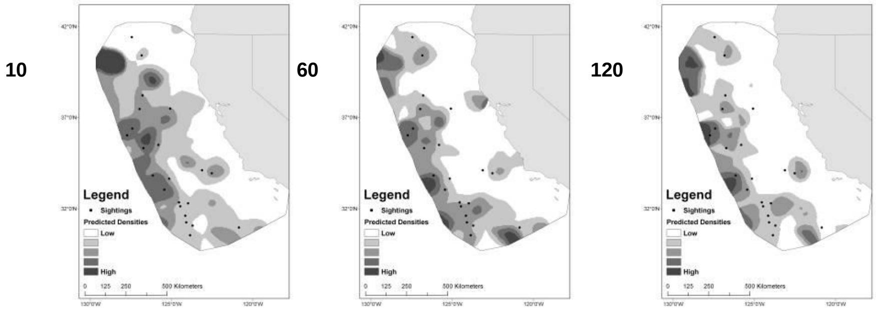
Although the results of these analyses suggest that dolphin-habitat relationships in the CCE are resolution dependent (Fig. 16), instability in the models necessitates further analyses. The variables included in the models, their functional form, and the degree of difference among models built at the various resolutions changed when we looked at different subsets of data. We discovered this result while exploring criteria for the minimum number of temperature and salinity measurements to include in the average for each segment. The variability in the models suggests that the sample size may not be large enough to address the effect of resolution in such a heterogeneous ecosystem. Only short-beaked common dolphin had more than 40 sightings in the total data set. A minimum of 40 sightings has been suggested as a conservative estimate of the sample size needed to build a cetacean-habitat model for species in heterogeneous ecosystems (Becker 2007).

We lost a large number of sightings due to the constraints imposed by our analytical design. In particular, we had to restrict our analyses to days on which the ship traveled 120 km and days on which complete oceanographic data were collected; we also had to exclude effort that occurred outside the 120 km segment. The best means for increasing the sample size in these analyses is to use the data collected in the CCE during August-December 2005. We did not complete this extension of the analyses as part of the SERDP project because we are using the 2005 data to validate our final models; it would be circular to use the 2005 data to both determine the appropriate resolution for the models and validate the models. Instead, we compared the results of the models built at the 2-km and 10-km resolutions, which used *in situ* oceanographic data, to the models built at a 5-km resolution using only remotely sensed data. We found that the models built using only the remotely sensed data performed as well as or better than the *in situ* models. These results increased our confidence in building models at a 5-km resolution and using remotely sensed oceanographic data for the final CCE models. However, we did find that some species showed a strong response to oceanographic variables for which there are no remotely sensed counterpart, such as measures of water column temperature gradients. Consequently, our final models were derived from a comparison of models built at a 5-km resolution using only remotely sensed habitat variables to those built using both remotely sensed and *in situ* oceanographic variables.

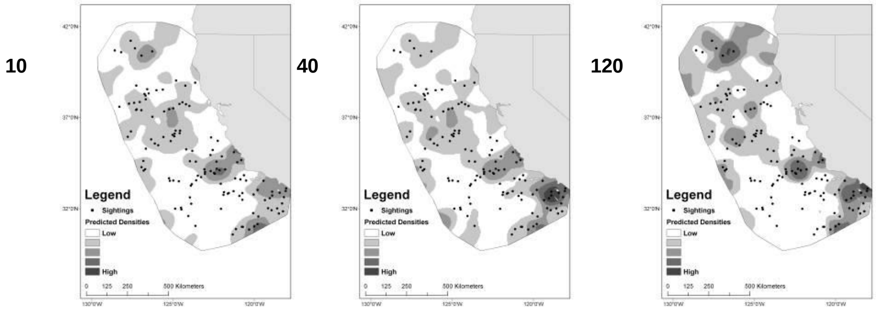
4.3.2 Extent

We explored the effect of extent by building models using data from the ETP and CCE separately, and from both ecosystems combined. The combined models incorporate a larger range for many habitat variables (e.g., temperatures are colder in the CCE than the ETP) and a larger sample size for each species. We were interested in determining whether the combined models had increased predictive power. We used the methods derived for the resolution analyses (see Redfern et al. 2008) to explore the effect of extent. Encounter rate models were built at a 60km resolution for two species that occur in both habitats: striped dolphin and short-beaked common dolphin.

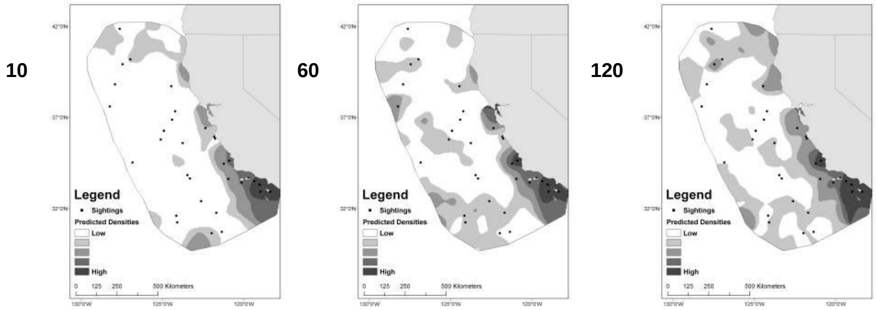
A) Striped dolphin



B) Short-beaked common dolphin



C) Risso's dolphin



D) Northern right whale dolphin

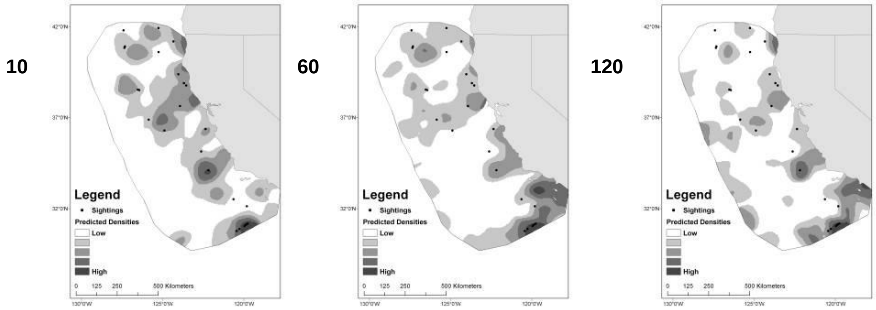


Figure 16. Densities were predicted at small, intermediate, and large resolutions and interpolated in a 5 km x 5 km grid using negative exponential distance weighting to produce the maps shown. The midpoints of segments containing at least one sighting are shown as black dots. The differences in predicted densities shown in these maps suggest that dolphin-habitat relationships in the CCE may be resolution dependent.

The number of striped dolphin sightings was 553 in the ETP and 43 in the CCE. The large number of striped dolphin sightings in the ETP exerted a tremendous influence on the combined model. In particular, the variables selected in the combined model and their function forms were identical to the ETP model, with the exception that the combined model showed an increase in the number of sightings in temperatures greater than 16 degrees (Fig. 17). Habitat variables selected for the CCE model were different, showing a strong avoidance of areas with temperature fronts (Fig. 17). Ratios of observed to predicted encounter rates were biased (i.e., had a value of 0.907, rather than the expected value of 1.0) when the combined model was used to predict striped dolphin distributions in the CCE.

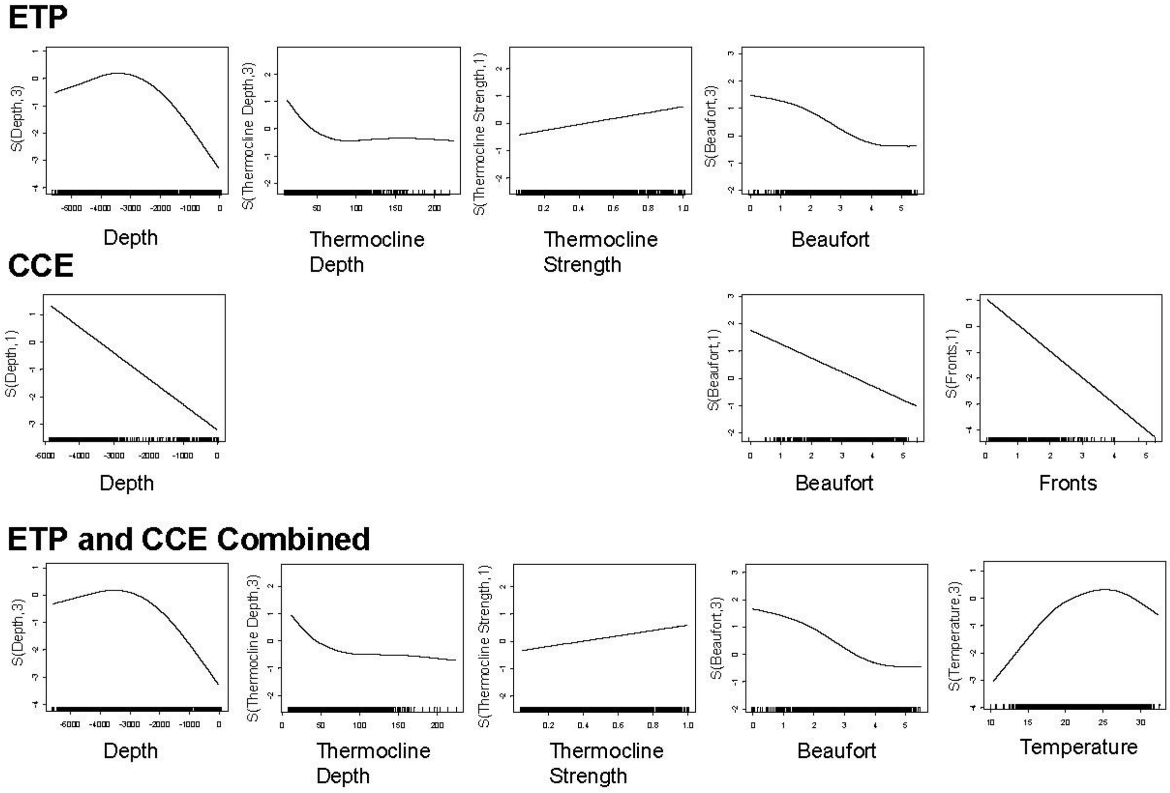


Figure 17. Encounter rate models built at a 60-km resolution for striped dolphin to explore the effect of extent. Using the combined model to predict encounter rates in the California Current ecosystem resulted in a bias, suggesting that the best predictive power was achieved by the ecosystem-specific models.

The number of short-beaked common dolphin sightings was 334 in the ETP and 301 in the CCE. The variables selected in all models were the same, with the exception of the inclusion of a salinity variable with a weak effect on the number of sightings in the CCE model (Fig. 18). However, the functional form of some variables was ecosystem dependent. For example, the number of sightings peaked at an intermediate temperature of approximately 17 degrees in the combined model (Fig. 18). Different functional forms of the temperature variable were observed in each ecosystem because their temperature range covered approximately half of the combined temperate range (Fig. 18). Ratios of observed to predicted encounter rates were close to the expected value of 1.0 (range 1.012 to 0.987) for the individual and combined models in both ecosystems.

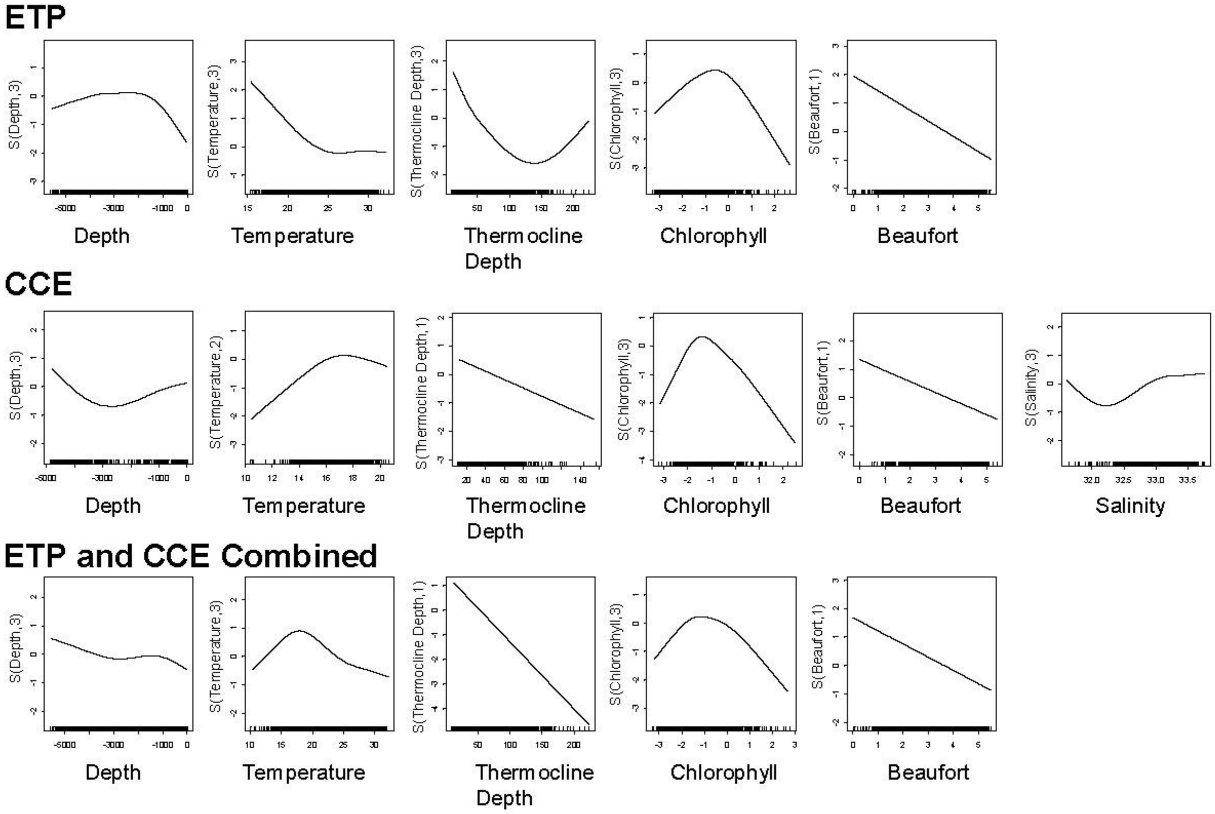


Figure 18. Encounter rate models built at a 60-km resolution for short-beaked common dolphin to explore the effect of extent. The similarity of all models resulted in similar predictive power in both ecosystems.

Our assessment of extent suggests that the best predictive models are built using ecosystem-specific data. For example, no predictive power was gained by using the combined model for short-beaked common dolphins, but biased encounter rates were obtained when the combined model for striped dolphins was used to predict distributions in the CCE. Consequently, we used ecosystem-specific models in the spatial decision support system. We will continue to pursue these analyses, however, because of their potential to increase our understanding of species ecology. For example, the combined model for striped dolphins showed a temperature threshold at 16 degrees, above which encounters were relatively high and stable. This pattern was not observed in the models for the individual ecosystems. These analyses also suggest that habitat preference is similar for short-beaked common dolphins, which are characterized as a habitat specialist in the ETP (Reilly and Fiedler 1994), in both cool-temperate and tropical ecosystems. In contrast, striped dolphins, which are characterized as a habitat generalist in the ETP (Reilly and Fiedler 1994), appear to have different habitat preferences. These results suggest a general hypothesis that species habitat selectivity, which is related to the breadth of a species niche, in low productivity ecosystems may determine whether their habitat preferences are the same across multiple ecosystems.

4.4 Variance Estimation

One advantage of predictive density models, compared to simple stratified line-transect analyses, is the ability to estimate variance at a finer spatial resolution. This provides useful information on areas where abundance estimates are likely to vary the most (or least). Geographic contour plots showing annual model predictions, multi-year average densities, standard errors, and lognormal 90% confidence intervals are shown in Appendix A for cetaceans in the CCE and in Appendix B for cetaceans in the ETP.

The greatest source of variability was attributable to the strong inter-annual variability in oceanographic conditions (See Section 4.1). In contrast, the specific methods used to build the models were a small source of variability among model predictions. For example, plots of predicted average ETP striped dolphin density and the associated estimates of standard error and lognormal 90% confidence intervals derived from the complex vs. simple encounter rate (53.4 vs. 22.5 effective degrees of freedom) and group size (17.9 vs. 12.6 effective degrees of freedom) models are nearly indistinguishable (Fig. 19 and 20, respectively).

In the CCE region, uncertainty was generally greater off Oregon and Washington, where fewer surveys were conducted (1991 and 1993 surveys were only conducted off California). Variance was also greater for species with a large range in group size, e.g. short-beaked common dolphins, and smaller for large whale species and Dall's porpoises, which occur in smaller groups (Fig. 21). Similar patterns of variance were evident for the ETP, where estimates of uncertainty were greatest in areas where survey effort was least (for example, around the margins of the study areas), and for species having the greatest range in encounter rate and group size (for example, spotted, striped, eastern spinner, and whitebelly spinner dolphins).

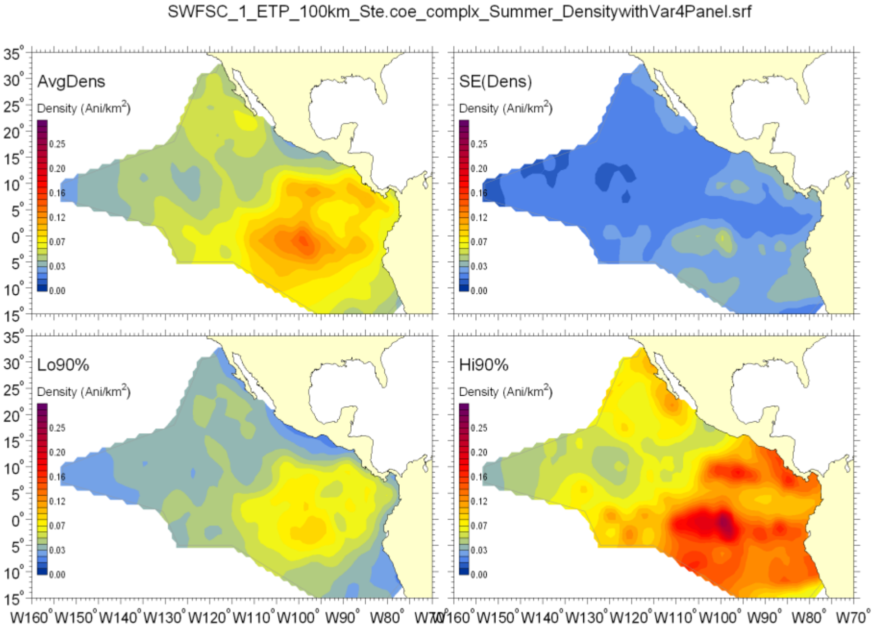


Figure 19. Predicted average density (AveDens), standard error (SE(Dens)), and upper and lower lognormal 90% confidence limits(Lo90% and Hi90%) based on the final complex ETP encounter rate (53.4 effective degrees of freedom) and group size (17.9 effective degrees of freedom) models for striped dolphins.

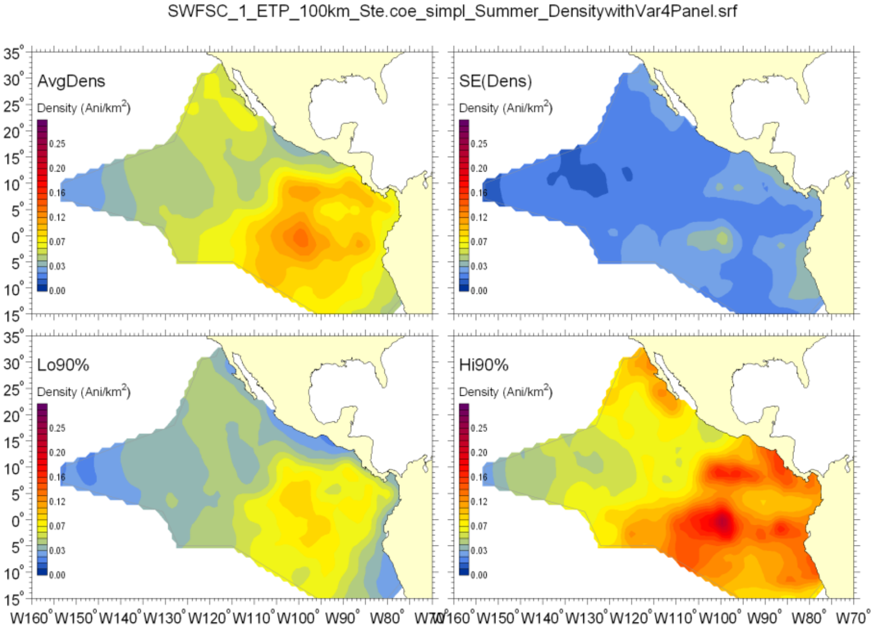


Figure 20. Predicted average density (AveDens), standard error (SE(Dens)), and upper and lower lognormal 90% confidence limits(Lo90% and Hi90%) based on a simple ETP encounter rate (22.5 effective degrees of freedom) and group size (12.6 effective degrees of freedom) models for striped dolphins.

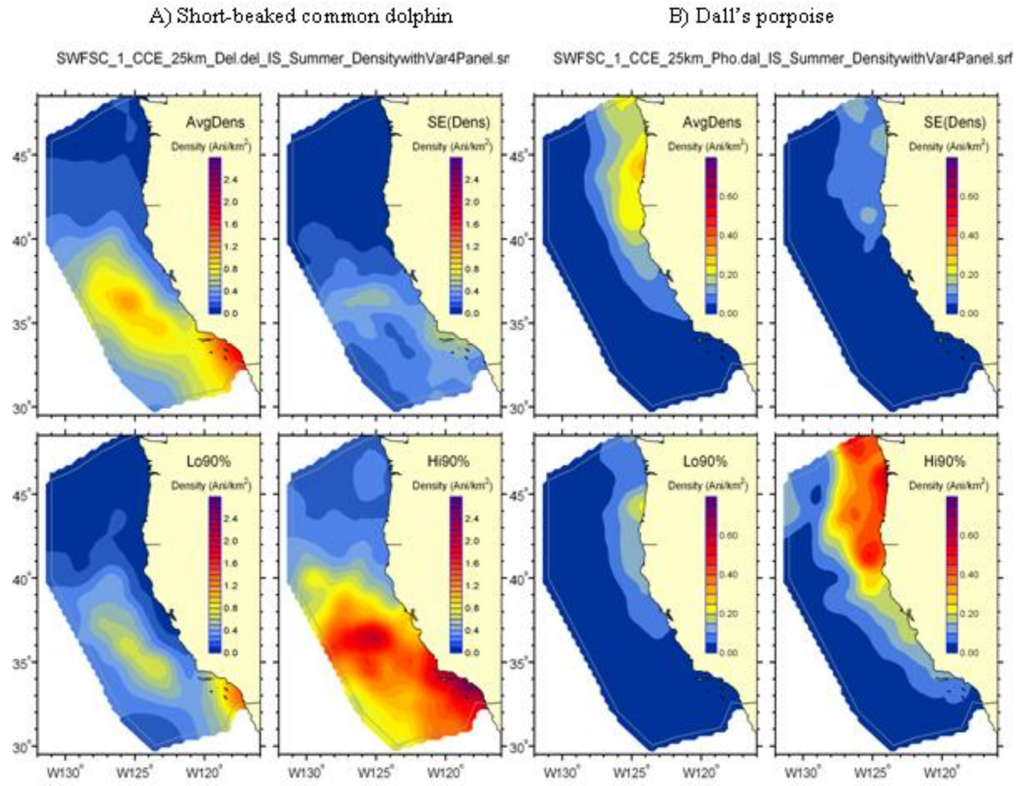


Figure 21. Predicted average density (AveDens), standard error (SE(Dens)), and upper and lower lognormal 90% confidence limits (Lo90% and Hi90%) based on models for: (A) short-beaked common dolphin and (B) Dall's porpoise.

4.5 Inclusion of Prey Indices in Habitat Models

We used daily transects as our unit of analysis to explore whether the inclusion of mid-trophic species data improves the fit and predictive power of cetacean-habitat models. The use of daily transects increased the number of segments containing a sighting, but results in segments of different lengths. Our analysis of the effect of scale on cetacean-habitat models in the ETP suggests that segment lengths from 2 to 120 km occur within a single domain of scale. Consequently, segments of varying lengths should not impact model results for the ETP. Analyses for the CCE, however, were not conclusive. Therefore, to help standardize the length of the segments, we used only days on which a minimum distance of 60 km was travelled on effort.

Sample sizes were large enough to model striped dolphins and short-beaked common dolphins in both the ETP and CCE. We also modeled a species unique to each ecosystem, eastern spinner dolphins in the ETP and Dall's porpoises in the CCE, and two large baleen whale species, Bryde's whales in the ETP and blue whales in the CCE. The data were collected on the *David Starr Jordan*, a NOAA research vessel, from July to early December in 2003 and 2006 in the ETP and in 2001 and 2005 in the CCE.

Four models were built for the number of sightings of each species using all data available in each ecosystem. Models differed in the candidate predictor variables. The only candidate variable common to all models was Beaufort sea state, which was used to account for the increased difficulty of detecting cetaceans at higher sea states (Barlow et al. 2001). Oceanographic models were built using depth of the seafloor (depth), sea surface temperature (SST), sea surface salinity (SSS), mixed layer depth (MLD), and the natural logarithm of surface chlorophyll concentrations (CHL).

During the years for which unbiased acoustic backscatter data were available, only manta tows were available to develop net-tow indices in the ETP and only bongo tows were available in the CCE. Indices from each tow type were developed using the same technique. Details of the technique can be found in Vilchis and Ballance (2005); hence, we only provide a brief synopsis here. The SWFSC net-tow database contains 1,869 manta and 835 bongo tow records, which are comprised of abundance and distribution data for hundreds of taxonomic categories. A majority of the taxa occur only once; hence, data matrices have a high dimensionality and many zeroes. To mitigate these analytical challenges, species were consolidated into families. In addition, data were standardized to represent percent dominance on a per station basis, and rare taxa were removed (those contributing less than 0.5% of mean dominance at all stations). The combined reduction in dimensionality resulted in matrices with 15 and 28 families for manta and bongo samples, respectively.

Hierarchical clustering and multidimensional scaling methods were used to group fish families into categories based on similarity using Bray-Curtis measures. In our models, we used only indices that had pair-wise correlations less than 0.5 and that were greater than zero for at least 17 daily transects. Candidate predictor variables in net-tow models for the ETP were the combined abundance of Polynemidae, Mugilidae, Gerridae, Carangidae, Clupeidae and Engraulidae (manta_1), the combined abundance of Gonostomatidae and Myctophidae (manta_2), and the combined abundance of Phosichthydae, Nomeidae, Scombridae, Coryphaenidae, Exocoetidae and Hemiramphidae (manta_3). Candidate variables in the CCE were the combined abundance of Myctophidae, Stomiidae, Phosichthydae and Bathylagidae (bongo_1), the combined abundance of Sebastidae and Paralichthyidae (bongo_2), the combined abundance of Paralepidae, Gonostomatidae and Sternoptychidae (bongo_3), the abundance of Cephalopods (bongo_4), and total zooplankton volume caught (bongo_5).

Candidate predictor variables derived from acoustic backscatter data, the $S_v$mean and NASC, are highly correlated; consequently, we only used $S_v$mean in our acoustic backscatter models. Because our acoustic backscatter data were collected during daytime surveys (when vertically migrating prey are deep), we only used the 0-500 m integrated values, which included the deepest recorded depths. Finally we built a combined model in which candidate predictor variables were derived from the variables selected in the other three models. Variables were selected using an automated forward/backward stepwise approach based on Akaike's Information Criterion (AIC). Comparison of the four models was also based on AIC values, as well as explained deviance and temporal ratios of the number of observed to predicted sightings. Maps of the predicted number of sightings were interpolated using exponential distance weighting (decay = 250 km and neighborhood = 500 km for the ETP, decay = 100 km and neighborhood = 200 km for the CCE).

Short-beaked common dolphins were unique in each ecosystem in that none of the mid-trophic variables were selected in combined models. Also, only Beaufort sea state was selected in the net-tow and acoustic backscatter models for the ETP (Table 13). Although $S_v$mean was selected in the acoustic backscatter model for the CCE, it was not selected in the combined model (Table 13). Short-beaked common dolphins specialize in cool, upwelling habitat in the ETP (Reilly and Fiedler 1994). Our analyses of the effect of extent on dolphin-habitat models (see Section 4.3) suggest that the same variables define short-beaked common dolphin habitat in the CCE. Hence, it is possible that this habitat is so well defined by oceanographic measurements that the data about mid-trophic species we used are not needed to improve habitat models for short-beaked common dolphin. It is possible that other mid-trophic species data, such as fine resolution acoustic backscatter indices, would improve the models.

Oceanographic and combined models produced very similar results for Bryde's whales in the ETP (Fig. 22 and Tables 14, 15, and 16). The only variable added to the combined model was the abundance of Phosichthydae and Myctophidae. Expected prey for Bryde's whales include species in the families Clupeidae, Engraulidae, and Scombridae as well as euphausiids and pelagic crabs (Vilchis and Ballance 2005). The lack of congruence between the manta tow index selected in the model and the expected prey species for Bryde's whales may explain why the manta tow index does not have a strong influence on the predictions from the combined model.

Table 13. Variables selected for models built using oceanographic, net-tow, acoustic backscatter, and a combination of all data to determine whether indices of mid-trophic species improve cetacean-habitat models. The variables selected in the final models for each data type are shown using the following abbreviations: seafloor (depth), sea surface temperature (SST), sea surface salinity (SSS), mixed layer depth (MLD), and the natural logarithm of surface chlorophyll concentrations (CHL). Definitions of the net-tow indices are provided in the text.

Area	Species	Oceanographic	Net tow	Acoustic Backscatter	Combined
ETP	Striped dolphin	Depth MLD Beaufort	Manta$_1$ Beaufort	S$_v$mean Beaufort	Depth MLD Manta$_1$ S$_v$mean Beaufort
	Short-beaked common dolphin	Depth SSS MLD Beaufort	Beaufort	Beaufort	Depth SSS MLD Beaufort
	Eastern spinner dolphin	Depth SST	Beaufort	Beaufort	Depth SST Manta$_2$ S$_v$mean
	Bryde's Whale	SSS MLD CHL Beaufort	Beaufort	Beaufort	SSS MLD CHL Manta$_1$ Beaufort
CCE	Striped dolphin	Depth Beaufort	Bongo$_1$ Bongo$_3$ Bongo$_5$ Beaufort	S$_v$mean Beaufort	Depth Bongo$_1$ Bongo$_5$ Beaufort
	Short-beaked common dolphin	Depth SSS CHL Beaufort		S$_v$mean Beaufort	Depth SSS CHL Beaufort
	Dall's porpoise	Depth SST MLD CHL Beaufort	Bongo$_3$ Bongo$_4$ Bongo$_5$ Beaufort	S$_v$mean Beaufort	Depth SST MLD Bongo$_3$ Bongo$_5$ S$_v$mean Beaufort
	Blue whale	SSS MLD	Bongo$_1$ Bongo$_3$ Beaufort	S$_v$mean	SSS MLD Bongo$_1$ Bongo$_3$

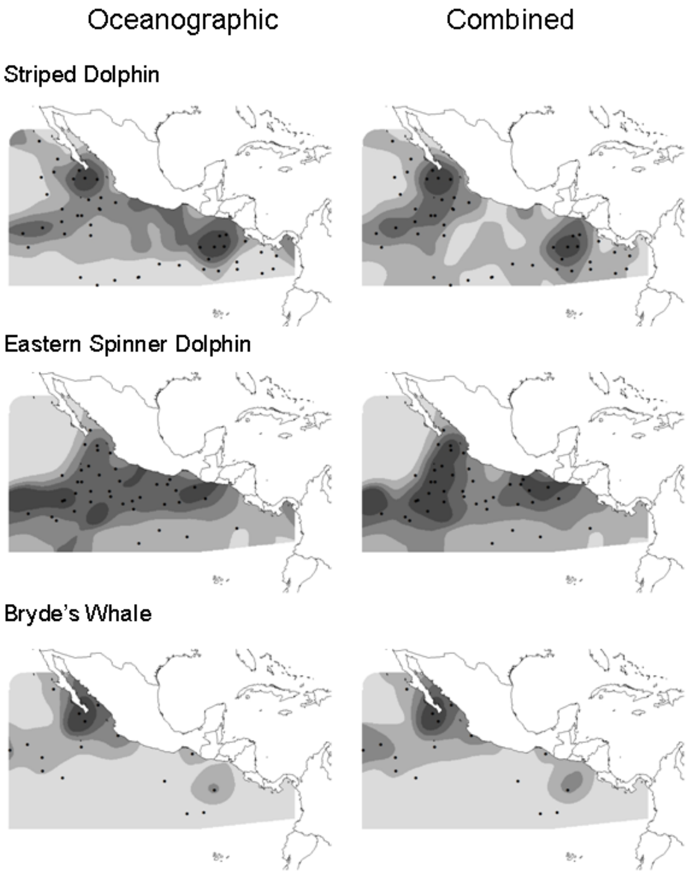


Figure 22. Maps of the predicted number of sightings in the ETP for models that include only oceanographic data or a combination of oceanographic, net-tow, and acoustic backscatter data. Darker colors indicate higher predicted densities.

The combined model gave the best fit blue whales in the CCE (Tables 14 and 15). However, predictive power was higher for the oceanographic models (Table 17), and maps of the predicted number of sightings showed several instances in which the combined model predicted higher numbers of sightings in regions where no sightings occurred (Fig. 23). Consequently, the best model for blue whales in the CCE may depend on the question that the model is built to address.

Table 14. Starting and final AIC values for models of the number of sightings of each species built using oceanographic, net-tow, acoustic backscatter, or a combination of all data.

		Starting AIC value	Oceanographic data	Net-tow data	Acoustic backscatter data	Combined data
ETP	Striped dolphin	306.93	230.94	253.62	245.67	216.45
	Short-beaked common dolphin	245.77	155.52	197.42	197.42	155.52
	Eastern spinner dolphin	207.36	152.79	207.21	207.21	144.15
	Bryde's Whale	132.13	74.23	107.81	107.81	73.23
CCE	Striped dolphin	90.09	64.21	63.50	75.68	45.15
	Short-beaked common dolphin	245.88	188.33	245.88	221.78	188.33
	Dall's porpoise	370.30	146.14	173.55	187.26	99.79
	Blue whale	92.31	74.95	78.79	87.66	66.35

Table 15. The explained deviance for the models of the number of sightings of each species built using oceanographic, net-tow, acoustic backscatter, or a combination of all data.

		Oceanographic data	Net-tow data	Acoustic backscatter data	Combined data
ETP	Striped dolphin	0.35	0.24	0.29	0.48
	Short-beaked common dolphin	0.46	0.21	0.21	0.46
	Eastern spinner dolphin	0.33	0.02	0.02	0.40
	Bryde's Whale	0.56	0.24	0.24	0.59
CCE	Striped dolphin	0.37	0.44	0.25	0.60
	Short-beaked common dolphin	0.37	0.00	0.21	0.37
	Dall's porpoise	0.76	0.67	0.53	0.83
	Blue whale	0.25	0.27	0.08	0.39

Table 16. Ratios of observed to predicted number of sightings in the ETP (SE = Standard Error). Predictions were made using models in which habitat was defined using oceanographic, net-tow, acoustic backscatter, or a combination of all data.

	Oceanographic data	Net-tow data	Acoustic backscatter data	Combined data
Striped dolphin				
2003	0.656	0.603	0.655	0.682
2006	1.518	1.746	1.521	1.435
All	1.000	0.999	1.000	1.000
SE	0.431	0.571	0.433	0.376
Short-beaked common dolphin				
2003	0.796	0.664	0.664	0.796
2006	1.249	1.646	1.646	1.249
All	1.000	0.999	0.999	1.000
SE	0.227	0.491	0.491	0.227
Eastern spinner dolphin				
2003	0.941	0.871	0.871	1.025
2006	1.085	1.225	1.225	0.971
All	1.000	1.000	1.000	1.000
SE	0.072	0.177	0.177	0.027
Bryde's Whale				
2003	1.126	1.507	1.507	1.126
2006	0.263	0.106	0.106	0.263
All	1.000	0.999	0.999	1.000
SE	0.432	0.700	0.700	0.431

The combined model gave the best fit for striped dolphins in both ecosystems, for eastern spinner dolphins in the ETP and for Dall’s porpoises in the CCE (Tables 14 and 15). For these species, predictive power was also highest for the combined model (Tables 16 and 17). Maps of the predicted number of sightings (Fig. 22 and 23) suggest that the combined model did a better job at capturing gaps in species distributions. For striped dolphin in both ecosystems and for eastern spinner dolphin, all oceanographic variables were retained in the combined model. Dall’s porpoise retained all oceanographic variables except chlorophyll, which had a relatively weak effect in the oceanographic model. These results suggest that the net-tow and acoustic backscatter data provide information about the distribution of these species that is not captured by the oceanographic variables.

Table 17. Ratios of observed to predicted number of sightings in the CCE. Predictions were made using models in which habitat was defined using oceanographic, net-tow, acoustic backscatter, or a combination of all data.

	Oceanographic data	Net-tow data	Acoustic backscatter data	Combined data
Striped dolphin				
2001	0.253	0.344	0.261	0.408
2005	1.366	1.209	1.345	1.152
All	1.000	1.000	1.000	1.000
SE	0.556	0.432	0.542	0.372
Short-beaked common dolphin				
2001	1.035	0.830	0.850	1.035
2005	0.982	1.124	1.105	0.982
All	1.000	1.000	1.000	1.000
SE	0.027	0.147	0.127	0.027
Dall's porpoise				
2001	1.164	1.012	0.916	1.005
2005	0.759	0.972	1.255	0.988
All	1.000	1.000	1.000	1.000
SE	0.203	0.020	0.169	0.009
Blue Whale				
2001	0.927	0.785	0.696	0.876
2005	1.057	1.233	1.433	1.107
All	1.000	1.000	1.000	1.000
SE	0.065	0.224	0.368	0.116

It is difficult to determine whether the net-tow indices correspond to preferred prey families because little is known about cetacean diets. The tow indices selected in the combined models for striped dolphin in the CCE and eastern spinner dolphin and Bryde's whales in the ETP do include families found in their diets (Vilchis and Ballance 2005). However, diets for striped dolphin in the ETP and Dall's porpoise in the CCE do not correspond to the net-tow indices selected in the combined models. An additional difficulty in relating net-tow indices to prey preferences occurs because larval fish are caught in the tows and cetaceans are expected to feed primarily on adult fish. The age of the larval fish caught in the tows conducted by the SWFSC has not been estimated. Without this estimate, it is difficult to determine how well the distribution of larval fish corresponds to the distribution of adults (e.g., the younger the larvae, the closer their distribution should correspond to that of spawning adults). Consequently, the net-tow indices may be representative of water masses or features, such as fronts or upwelling, rather than the distribution of families of adult prey fish.

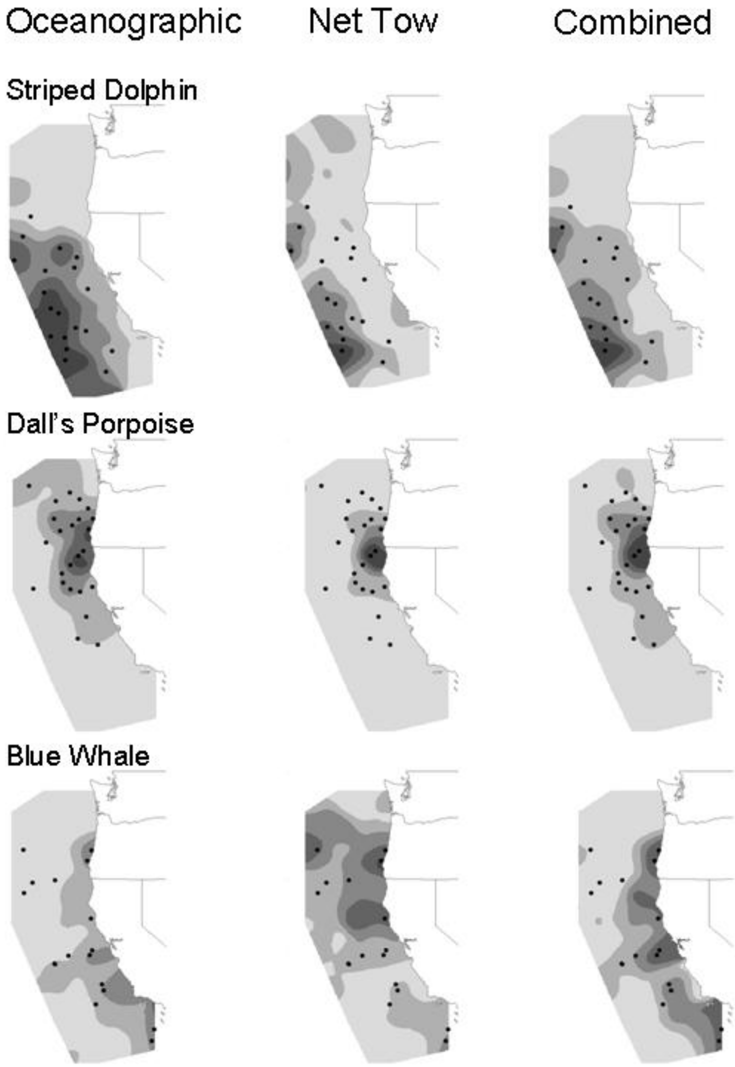


Figure 23. Maps of the predicted number of sightings in the CCE for models that include only oceanographic data, only net-tow data, or a combination of oceanographic, net-tow, and acoustic backscatter data. Darker colors indicate higher predicted densities.

We calculated the $S_v$mean over a 24 hour period for these analyses. Many cetacean species feed at night; however, on SWFSC surveys, cetacean distribution data are collected only during the day. Hence, an estimate of $S_v$mean calculated over a 24 hour period was selected as an appropriate potential indicator of prey availability. However, acoustic backscatter data are collected continuously and it is possible to use the data to develop fine-scale indices of prey availability. It is possible that fine-scale indices may have a stronger relationship with cetacean distributions. Additionally, data about the species represented in the acoustic backscatter data are not currently available. Hence, the $S_v$mean is simply an estimate of the total fish and zooplankton from 0 to 500 m. Improvements in acoustic backscatter indices may be obtained from analyses that relate acoustic signatures to specific prey species.

The effect of including data about mid-trophic species distributions in cetacean-habitat models was species specific. Substantial improvements were not noticed for short-beaked common dolphins in either ecosystem, for Bryde's whales in the ETP, or for blue whales in the CCE. However, mid-trophic indices did appear to provide additional information about species distributions for striped dolphin in both ecosystems, eastern spinner dolphin in the ETP, and Dall's porpoise in the CCE. In addition to the improvements to the mid-trophic indices suggested above, a more conclusive understanding about the effect of mid-trophic species data may be obtained with the addition of more data. When interpreting our results, it is important to bear in mind the small sample size available for our analyses. We have found that models using small samples sizes can be unstable, particularly in dynamic ecosystems such as the CCE (see the CCE resolution analyses in Section 4.3). Hence, our results must be further explored using a longer time series of data, which will increase sample sizes and expand the range of habitat conditions included in the models.

4.6 Seasonal Predictive Ability of Models

4.6.1 Model performance

Although results varied by species, we found that both model type (GAM/GLM) and data source (remotely sensed/*in situ*) exhibited similar performance (Becker 2007). This conclusion is based on 1) the type and form of predictor variables included in the models, 2) ASPE values, 3) ratios of line-transect derived densities divided by predicted densities for the total study area, and 4) plots of predicted species densities and sightings from the survey data. Given sufficient sample size (ideally greater than 100 sightings), GAMs and GLMs built with remotely sensed measures of SST and CV(SST) performed as well, and in some cases better, than models built with analogous *in situ* measures. It is likely that models built with remotely sensed data are more appropriate for some species than others, particularly those species that exhibit a strong association to SST. We found satellite-derived estimates of sea surface temperature variance to be more effective at characterizing frontal activity due to their ability to measure heterogeneity in two dimensions. The predictive ability of cetacean-habitat models was affected by the level of complexity of the oceanographic environment, because more data were required to parameterize models for species that inhabit diverse environments.

4.6.2 Seasonal Predictive Ability

Results indicated that inter-annual variability in environmental parameters can explain part of the variation in the seasonal distribution patterns of some cetacean species, particularly for species with large numbers of sightings during the summer survey periods (Becker 2007). Seasonal geographic patterns in ranked species density were captured for three of the five species considered. Density plots for Dall's porpoise (Fig. 24) illustrate a species for which summer models were effective at predicting the southward shift of animals during winter. However, the predictions for northern right whale dolphins demonstrate that extreme over-predictions can result in the areas off northern California where waters were cooler during winter than observed during the summer surveys (dark blue shading in Fig. 24B). Additional surveys are required to fully characterize environmental variability and improve predictive performance sufficiently to apply these models quantitatively. In particular, model input data must include the full range of conditions for the temporal/spatial period they are predicting, i.e. cold-water conditions during winter. If possible, future seasonal model development and evaluation should also include a broader range of cold-season oceanographic conditions to characterize inter-annual variation. A final complication is that some cetaceans found in the CCE during the warm season are migratory and nearly absent in the cold season. For these reasons, we did not make any predictions of cetacean densities in one season from data that were collected in another.

4.7 Model Validation

Data from the novel 2005 (CCE) and 2006 (ETP) SWFSC cetacean surveys were used to validate the final encounter rate and group size models constructed using data from 1991-2001 for the CCE and from 1986-2003 for the ETP. To assess the models' fit to the validation data set and to examine the inter-annual variability in model predictions, density was predicted separately for each survey year. Methods used to evaluate model fit included visual inspection of geographic contour plots of the annual density predictions and computation of geographically stratified ratios of observed to predicted density.

4.7.1 California Current Ecosystem Models

When the CCE models built using 1991-2001 survey data were used to predict density across all survey years (1991-2005), density ratios (density calculated using standard line-transect methods divided by density predicted by the habitat model) ranged from 0.62 (Baird's beaked whale) to 1.44 (northern right whale dolphin) (Table 18). Density ratios for the novel year (2005) predictions were more variable, ranging from

0.29 (Risso's dolphin) to 3.20 (northern right whale dolphin). The seemingly poor performance of the northern right whale dolphin models was due in part to the small number of sightings (5) available for model validation. The contour plot of the 2005 density predictions from the 1991-2001 models shows that the model did capture the general distribution pattern for this species (Fig. 25).

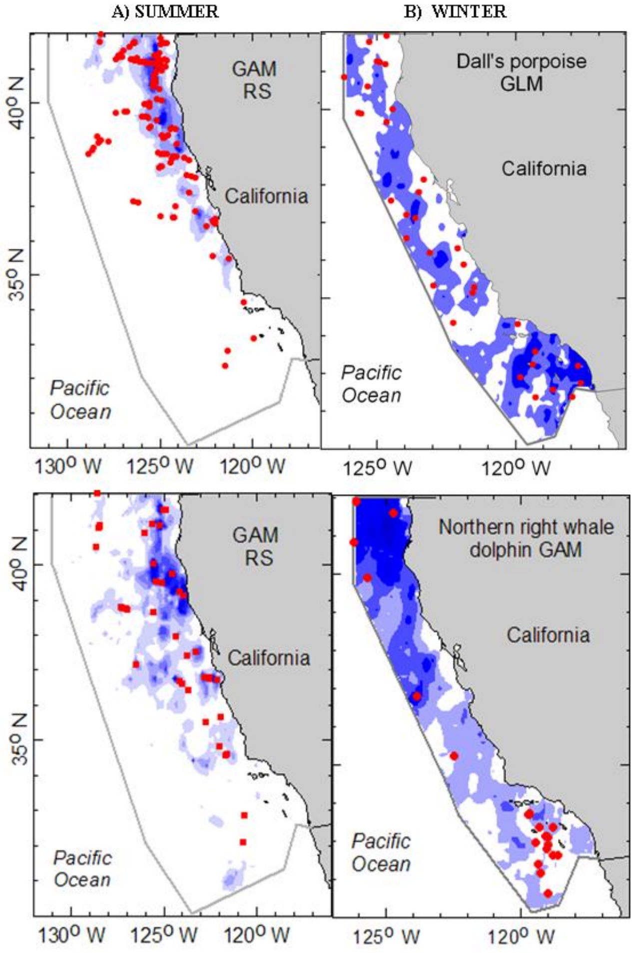


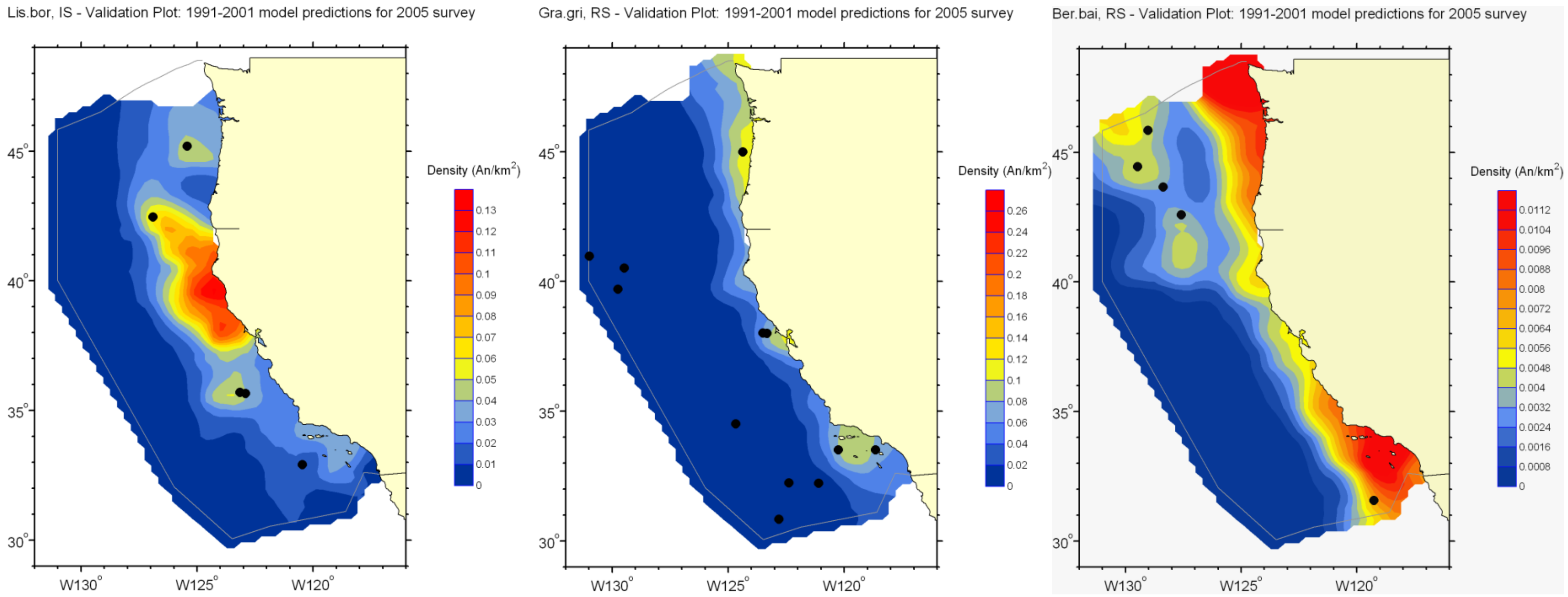
Figure 24. Predicted relative density estimates for Dall's porpoise (top) and northern right whale dolphin (bottom): (A) summer predictions based on the summer shipboard models and (B) winter predictions based on the summer shipboard models. Colors reflect relative density, where white represents the range of lowest density. Density estimates for each segment were interpolated on a grid resolution of approximately 12 km using inverse distance weighting to the second power (Surfer Version. 8 software). Red dots show sighting locations from the summer shipboard (A) and winter aerial (B) surveys.

In contrast, the inability of the Risso's dolphin models to effectively predict distribution patterns for the novel year is clearly reflected in the 2005 predicted density contour plot (Fig. 25). Inspection of the predicted 2005 species density maps overlaid with survey sighting locations revealed that the models for Baird's beaked whale also failed to capture their distribution patterns (Fig. 25). We therefore re-examined the models for both Risso's dolphin and Baird's beaked whale and found that there was only one predictor included in each of the species' models; the encounter rate and group size models for Risso's dolphin included distance to the 2,000 m isobath and slope, respectively, while the encounter rate and group size models for Baird's beaked whale included depth and distance to the 2,000 m isobath, respectively.

Further inspection of the sighting plots suggested that the models for both species might be improved using categorical variables to represent geographic regions rather than the continuous variables included in the models. We therefore included static variables as potential predictors in both the encounter rate and group size models to investigate whether they would be more effective at capturing the two species' distribution patterns. For Risso's dolphin, we used a categorical variable to represent the geographic strata used to evaluate spatial predictive ability (see Section 3.5.1), although we combined the three California offshore strata to increase sample sizes. For Baird's beaked whale we used a binary variable to indicate positions within or outside a 50 km distance from the 2,000 m isobath. Models for both species were substantially improved using the static variables (see Section 4.8and Appendix A). The density contour plots for all other species revealed that the 1991-2001 CCE models were effective at capturing the 2005 general distribution patterns, and were similar to plots generated by the final models that were re-fit to the entire 1991-2005 dataset (Appendix A).

4.7.2 Eastern Tropical Pacific Models

When the initial ETP encounter rate and group size models (built using 1986-2003 data) were used to predict population density across all surveys years (1986-2006), the ratios of stratified line-transect to modeled density estimate (R_D) ranged from 0.999 to 1.3 (Table 18). In general, the models captured the inter-annual variability in cetacean distribution, as evident in the yearly contour plots of density predictions and cetacean sightings (see Figures B-1a-o in appendix B). When the initial models were used to predict on the novel year of data (2006), the R_D values ranged from 0.668 for Cuvier's beaked whale to 5.602 for the blue whale, with most values between 1.1 and 2.5.


Lis.bor, IS - Validation Plot: 1991-2001 model predictions for 2005 survey

Gra.gri, RS - Validation Plot: 1991-2001 model predictions for 2005 survey

Ber.bai, RS - Validation Plot: 1991-2001 model predictions for 2005 survey

Figure 25. Sample 2005 validation plots for models developed using 1991-2001 survey data. Left: northern right whale dolphin, Center: Risso's dolphin, Right Baird's beaked whale. Predicted values were smoothed using inverse distance weighting (see Section 3.5.1 for more details). Black dots show actual sighting locations.

Table 18. Spatial and temporal estimates of the number of animals observed in each geographic stratum, calculated using line-transect methods (LT) and predicted based on results from the 1991-2001 CCE models (Pred). Regional ratios (LT/Pred) and standard errors (SE) of the ratios are also provided. See text (Section 3.5) for region descriptions.

Striped dolphin																		
	1991			**1993**			**1996**			**2001**			**2005**			**ALL years TOTAL**		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.000	0	73	0.000	0	20	0.000	0	35	**0.000**	**0**	**128**
orwaE	NA	NA	NA	NA	NA	NA	0.000	0	0	0.000	0	0	0.000	0	0	**0.000**	**0**	**0**
nocalW	0.430	41	95	1.456	152	105	0.084	14	162	0.000	0	55	4.172	682	163	**1.533**	**888**	**579**
nocalE	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	**0.000**	**0**	**0**
cencalW	0.553	126	229	0.161	11	67	0.244	49	201	0.312	41	131	2.935	423	144	**0.843**	**650**	**772**
cencalE	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	**0.000**	**0**	**0**
socalW	2.576	647	251	1.435	597	416	0.623	206	331	2.532	379	150	0.719	229	319	**1.404**	**2057**	**1466**
socalE	0.000	0	1	0.000	0	1	0.000	0	2	0.000	0	1	0.000	0	1	**0.000**	**0**	**5**
StdyArea	**1.416**	**814**	**575**	**1.292**	**760**	**588**	**0.350**	**269**	**768**	**1.176**	**420**	**357**	**2.015**	**1334**	**662**	**1.219**	**3596**	**2950**
																	SE(ratio)	**0.299**

Short-beaked common dolphin																		
	1991			**1993**			**1996**			**2001**			**2005**			**ALL years TOTAL**		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.000	0	1101	0.005	3	654	1.016	373	368	**0.177**	**376**	**2122**
orwaE	NA	NA	NA	NA	NA	NA	1.405	0	130	0.000	0	89	0.000	0	32	**0.000**	**0**	**251**
nocalW	0.921	1295	1407	2.808	4433	1579	0.000	3015	2146	0.908	1358	1495	2.609	4688	1797	**1.756**	**14789**	**8424**
nocalE	0.793	23	30	0.000	0	51	2.322	0	38	0.000	0	71	0.000	0	8	**0.119**	**23**	**197**
cencalW	0.561	2193	3913	1.887	4232	2243	1.921	8432	0	0.500	1524	3051	1.738	5464	3144	**1.769**	**21846**	**12351**
cencalE	0.000	0	108	1.227	562	458	0.722	316	165	0.000	0	20	0.000	0	26	**1.132**	**879**	**776**
socalW	0.613	1996	3258	0.379	772	2036	0.675	2552	3536	0.941	1885	2004	1.813	4796	2646	**0.890**	**12001**	**13480**
socalE	0.536	2070	3864	1.161	1747	1505	0.675	2594	3842	1.860	3105	1669	4.085	4402	1078	**1.164**	**13918**	**11958**
StdyArea	**0.602**	**7578**	**12579**	**1.492**	**11747**	**7872**	**1.159**	**16909**	**10957**	**0.870**	**7875**	**9054**	**2.168**	**19723**	**9098**	**1.288**	**63833**	**49560**
																	SE(ratio)	**0.303**

Risso's dolphin																		
	1991			**1993**			**1996**			**2001**			**2005**			**ALL years TOTAL**		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.850	104	122	0.666	51	77	0.000	0	57	**0.605**	**155**	**256**
orwaE	NA	NA	NA	NA	NA	NA	1.619	315	195	0.648	95	147	0.076	15	200	**0.786**	**425**	**541**
nocalW	3.839	200	52	0.587	38	65	0.000	0	84	0.000	0	44	0.293	21	71	**0.819**	**259**	**316**
nocalE	0.000	0	25	0.000	0	39	0.000	0	25	0.000	0	26	0.896	29	32	**0.197**	**29**	**147**
cencalW	2.075	150	73	3.547	131	37	0.360	29	80	1.400	67	48	0.599	39	64	**1.378**	**415**	**301**
cencalE	0.000	0	24	0.828	47	56	1.897	150	79	0.186	5	27	0.000	0	37	**0.905**	**202**	**223**
socalW	0.192	9	45	1.385	75	54	0.480	40	83	0.184	8	43	0.664	40	60	**0.600**	**171**	**285**
socalE	1.009	109	108	0.087	5	61	0.901	89	99	1.853	148	80	0.370	33	88	**0.881**	**384**	**436**
StdyArea	**1.434**	**468**	**327**	**0.950**	**296**	**311**	**0.948**	**727**	**767**	**0.760**	**374**	**492**	**0.289**	**176**	**610**	**0.814**	**2041**	**2507**
																	SE(ratio)	**0.206**

Pacific white-sided dolphin																		
	1991			**1993**			**1996**			**2001**			**2005**			**ALL years TOTAL**		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.543	341	628	0.064	20	306	0.839	154	184	**0.461**	**516**	**1119**
orwaE	NA	NA	NA	NA	NA	NA	1.489	765	514	0.777	189	244	0.000	0	154	**1.046**	**954**	**912**
nocalW	0.257	37	145	0.177	18	101	1.360	903	664	0.810	77	96	10.094	1249	124	**2.023**	**2285**	**1129**
nocalE	0.000	0	31	0.869	85	98	0.182	30	166	1.959	113	57	0.000	0	80	**0.526**	**227**	**432**
cencalW	0.000	0	26	0.000	0	33	3.553	568	160	0.000	0	8	0.468	7	15	**2.380**	**575**	**242**
cencalE	0.086	3	35	0.000	0	21	0.000	0	183	0.000	0	8	1.689	17	10	**0.079**	**20**	**256**
socalW	0.000	0	9	0.000	0	4	0.000	0	7	0.000	0	1	0.000	0	8	**0.000**	**0**	**28**
socalE	0.000	0	44	0.322	4	12	0.584	23	39	3.634	65	18	0.000	0	132	**0.374**	**92**	**246**
StdyArea	**0.139**	**40**	**290**	**0.397**	**107**	**268**	**1.114**	**2630**	**2360**	**0.629**	**464**	**738**	**2.018**	**1428**	**707**	**1.070**	**4669**	**4364**
																	SE(ratio)	**0.370**

Table 18. (continued)

Northern right whale dolphin

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	1.123	158.527	141.209721	0.556	75.3196	135.520302	0.323	18.295	56.595104	**0.756**	**252.1416**	**333**
orwaE	NA	NA	NA	NA	NA	NA	0.503	35	69	0.432	24	54	0.000	0	26	**0.389**	**58**	**150**
nocalW	1.224	113	92	0.249	21	86	0.650	107	165	2.474	201	81	0.000	0	91	**0.858**	**443**	**516**
nocalE	1.311	13	10	1.520	31	21	0.461	9	21	0.120	1	11	0.000	0	34	**0.571**	**55**	**96**
cencalW	0.365	9	23	2.926	55	19	1.470	133	90	2.483	140	56	19.329	972	50	**5.470**	**1307**	**239**
cencalE	0.000	0	6	0.000	0	3	1.130	56	50	0.000	0	11	0.000	0	7	**0.723**	**56**	**78**
socalW	0.934	6	6	0.000	0	4	0.866	35	40	0.000	0	15	0.483	12	25	**0.589**	**53**	**90**
socalE	0.000	0	3	0.000	0	1	0.000	0	7	0.000	0	7	0.000	0	23	**0.000**	**0**	**40**
StdyArea	**0.996**	**140**	**141**	**0.807**	**107**	**133**	**0.916**	**534**	**584**	**1.186**	**441**	**372**	**3.204**	**1002**	**313**	1.443	2225	1542
																	SE(ratio)	**0.503**

Dall's porpoise

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	1.158	149	129	0.404	42	104	1.042	57	54	**0.862**	**248**	**287**
orwaE	NA	NA	NA	NA	NA	NA	1.176	187	159	0.792	57	72	0.746	54	73	**0.982**	**299**	**304**
nocalW	1.194	93	78	0.623	29	46	1.415	282	199	1.493	72	49	1.286	71	55	**1.281**	**546**	**426**
nocalE	1.447	13	9	0.448	12	26	1.812	25	14	0.463	8	17	0.894	7	8	**0.873**	**64**	**74**
cencalW	0.126	2	16	0.000	0	13	0.743	32	43	1.461	25	17	1.354	26	19	**0.783**	**85**	**109**
cencalE	0.000	0	6	0.000	0	5	0.782	22	28	0.680	4	6	1.907	11	6	**0.717**	**36**	**51**
socalW	0.000	0	5	0.000	0	2	0.000	0	9	2.013	6	3	0.000	0	7	**0.237**	**6**	**25**
socalE	0.000	0	6	4.551	9	2	0.854	4	5	0.000	0	3	0.228	5	22	**0.482**	**18**	**37**
StdyArea	**0.900**	**107**	**119**	**0.521**	**49**	**94**	**1.197**	**701**	**585**	**0.792**	**214**	**271**	**0.946**	**230**	**243**	0.992	1302	1313
																	SE(ratio)	**0.123**

Sperm whale

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	1.124	31	27	0.511	12	23	2.211	33	15	**1.156**	**75**	**65**
orwaE	NA	NA	NA	NA	NA	NA	2.089	6	3	0.000	0	4	0.000	0	2	**0.661**	**6**	**8**
nocalW	0.000	0	23	5.501	104	19	0.372	12	32	0.774	14	19	4.550	96	21	**1.991**	**226**	**114**
nocalE	0.000	0	1	0.000	0	1	0.000	0	1	0.000	0	1	0.000	0	3	**0.000**	**0**	**7**
cencalW	0.777	13	17	0.000	0	9	0.675	21	32	0.055	1	23	0.000	0	35	**0.310**	**36**	**116**
cencalE	0.000	0	0	0.000	0	0	0.313	1	3	0.000	0	2	0.000	0	1	**0.136**	**1**	**7**
socalW	0.751	6	9	1.237	10	8	0.696	17	24	6.590	78	12	0.789	14	18	**1.764**	**126**	**71**
socalE	1.216	1	1	0.000	0	0	0.000	0	1	0.000	0	1	0.000	0	2	**0.184**	**1**	**5**
StdyArea	**0.410**	**21**	**50**	**3.031**	**114**	**38**	**0.706**	**88**	**124**	**1.242**	**105**	**85**	**1.477**	**143**	**97**	1.196	471	394
																	SE(ratio)	**0.509**

Fin whale

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	0	0.347	7	20	0.607	12	20	1.876	20	11	**0.769**	**39**	**51**
orwaE	NA	NA	NA	NA	NA	0	0.099	2	20	0.328	5	15	0.089	1	11	**0.171**	**8**	**47**
nocalW	0.244	3	12	0.970	11	12	0.510	10	20	1.935	26	13	5.413	68	12	**1.688**	**118**	**70**
nocalE	0.000	0	3	0.000	0	5	0.343	1	3	0.000	0	4	0.000	0	1	**0.067**	**1**	**15**
cencalW	0.427	7	16	4.361	32	7	1.875	34	18	1.830	21	11	3.880	59	15	**2.242**	**152**	**68**
cencalE	2.196	14	6	2.983	12	4	4.399	49	11	0.000	0	4	1.398	6	4	**2.746**	**81**	**30**
socalW	0.179	1	6	0.444	2	5	0.373	5	13	0.000	0	8	0.536	6	11	**0.327**	**14**	**43**
socalE	0.138	1	7	2.007	5	2	2.103	17	8	0.286	3	11	0.916	9	10	**0.910**	**34**	**38**
StdyArea	**0.516**	**26**	**50**	**1.796**	**62**	**34**	**1.098**	**125**	**114**	**0.776**	**67**	**87**	**2.227**	**168**	**75**	1.243	448	360
																	SE(ratio)	**0.357**

Table 18. (continued)

Blue whale															
	1991			1993			1996			2001			2005		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.000	0	2	0.000	0	3	0.346	1	3
orwaE	NA	NA	NA	NA	NA	NA	0.000	0	5	0.105	1	10	0.572	2	3
nocalW	0.000	0	7	1.520	7	4	0.468	5	11	0.665	5	7	0.529	4	7
nocalE	0.509	2	4	0.313	1	3	3.027	23	8	0.764	2	3	0.935	5	5
cencalW	1.050	13	12	1.023	12	12	0.708	14	19	0.670	7	10	0.725	12	17
cencalE	1.870	7	4	1.746	12	7	1.330	28	21	0.000	0	4	0.498	4	7
socalW	1.184	12	10	1.953	15	7	1.946	24	13	0.000	0	4	0.433	4	8
socalE	0.749	13	17	2.085	25	12	1.114	31	27	0.062	1	16	0.403	7	18
StdyArea	**0.865**	**47**	**54**	**1.557**	**70**	**45**	**1.179**	**125**	**106**	**0.273**	**16**	**57**	**0.556**	**38**	**69**

Blue whale			
	ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**
orwaW	**0.129**	**1**	**8**
orwaE	**0.167**	**3**	**18**
nocalW	**0.557**	**20**	**36**
nocalE	**1.449**	**33**	**23**
cencalW	**0.820**	**57**	**70**
cencalE	**1.172**	**51**	**43**
socalW	**1.281**	**55**	**43**
socalE	**0.842**	**76**	**91**
StdyArea	**0.895**	**296**	**331**
		SE(ratio)	**0.253**

Humpback whale															
	1991			1993			1996			2001			2005		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	0	0.000	0	7	0.279	2	7	0.491	3	6
orwaE	NA	NA	NA	NA	NA	0	0.375	12	32	0.515	13	25	0.828	35	42
nocalW	0.000	0	4	1.190	4	3	0.000	0	9	0.000	0	5	0.592	4	6
nocalE	1.811	14	8	0.820	7	9	0.271	2	6	0.172	1	8	0.942	10	10
cencalW	0.000	0	2	0.000	0	1	2.331	14	6	8.036	21	3	3.344	9	3
cencalE	0.702	6	8	6.986	22	3	2.220	57	26	1.272	12	9	3.706	26	7
socalW	3.559	2	1	0.000	0	0	0.000	0	2	0.000	0	2	0.670	1	1
socalE	0.000	0	3	2.972	2	1	0.578	2	3	0.000	0	6	0.360	3	8
StdyArea	**0.860**	**22**	**25**	**2.018**	**34**	**17**	**0.956**	**87**	**91**	**0.763**	**49**	**65**	**1.076**	**90**	**84**

Humpback whale			
	ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**
orwaW	**0.249**	**5**	**20**
orwaE	**0.603**	**60**	**100**
nocalW	**0.271**	**7**	**27**
nocalE	**0.828**	**34**	**40**
cencalW	**2.982**	**44**	**15**
cencalE	**2.296**	**122**	**53**
socalW	**0.503**	**3**	**6**
socalE	**0.337**	**7**	**20**
StdyArea	**1.003**	**282**	**281**
		SE(ratio)	**0.254**

Small beaked whales															
	1991			1993			1996			2001			2005		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	1.556	12	8	0.845	5	6	2.354	9	4
orwaE	NA	NA	NA	NA	NA	NA	1.652	2	1	0.000	0	1	0.000	0	1
nocalW	0.132	1	8	2.461	22	9	0.501	7	14	0.000	0	6	0.703	6	9
nocalE	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	1
cencalW	1.966	24	12	1.255	5	4	1.320	12	9	0.000	0	7	1.160	7	6
cencalE	0.000	0	0	0.000	0	0	0.000	0	1	0.000	0	0	0.000	0	0
socalW	0.934	5	5	1.092	8	8	0.602	6	9	0.793	4	4	0.270	2	7
socalE	0.807	1	1	1.345	1	1	0.000	0	2	4.295	4	1	0.000	0	1
StdyArea	**1.150**	**31**	**27**	**1.656**	**36**	**22**	**0.867**	**39**	**45**	**0.480**	**12**	**26**	**0.836**	**24**	**29**

Small beaked whales			
	ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**
orwaW	**1.491**	**26**	**18**
orwaE	**0.714**	**2**	**3**
nocalW	**0.806**	**36**	**45**
nocalE	**0.000**	**0**	**2**
cencalW	**1.248**	**48**	**39**
cencalE	**0.000**	**0**	**2**
socalW	**0.716**	**25**	**34**
socalE	**0.918**	**6**	**6**
StdyArea	**0.963**	**143**	**148**
		SE(ratio)	**0.219**

Baird's beaked whale															
	1991			1993			1996			2001			2005		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	0	0.420	6	14	0.780	7	8	3.788	25	7
orwaE	NA	NA	NA	NA	NA	0	0.348	4	12	1.137	11	10	0.000	0	12
nocalW	0.000	0	1	5.265	19	4	1.850	11	6	0.000	0	4	0.000	0	5
nocalE	0.000	0	2	0.000	0	4	0.000	0	2	0.000	0	2	0.000	0	1
cencalW	0.000	0	1	13.702	19	1	0.000	0	2	0.000	0	1	0.000	0	1
cencalE	0.000	0	13	2.561	22	9	0.000	0	23	0.000	0	2	0.000	0	2
socalW	0.000	0	1	0.000	0	1	2.829	7	2	0.000	0	1	0.000	0	2
socalE	0.000	0	18	0.000	0	13	0.000	0	14	0.000	0	10	0.890	6	7
StdyArea	**0.000**	**0**	**37**	**1.881**	**61**	**32**	**0.368**	**28**	**77**	**0.468**	**18**	**38**	**0.845**	**31**	**37**

Baird's beaked whale			
	ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**
orwaW	**1.306**	**37**	**28**
orwaE	**0.454**	**16**	**34**
nocalW	**1.476**	**31**	**21**
nocalE	**0.000**	**0**	**11**
cencalW	**2.836**	**19**	**7**
cencalE	**0.457**	**22**	**49**
socalW	**0.843**	**7**	**8**
socalE	**0.097**	**6**	**62**
StdyArea	**0.625**	**137**	**220**
		SE(ratio)	**0.360**

Blue whales had the greatest deviation between stratified line-transect and modeled density estimates across all years pooled (R_D = 1.335) and for any single year (range = 0.222 to 5.602). The highest value of R_D for the annual predictions of blue whales was due to considerably more sightings than predicted during 2006 in the waters of the equatorial cold tongue and off the West coast of the Baja Peninsula. The corresponding lowest value for blue whales was due to higher predictions than sightings for the equatorial cold tongue stratum in 1989. Blue whale distribution is very patchy, even relative to other cetacean species, and it is possible that the apparent discrepancy between the stratified line-transect and the model's predicted estimates of density are due to the inability of the encounter rate or group size models to properly account for this patchiness.

4.8 Final Models for the California Current Ecosystem

Barlow and Forney (2007) provide information on the search effort, number of species sighted, and associated multiple-covariate line-transect abundance estimates for the 1991-2005 shipboard surveys. The 12 species for which we developed final habitat models for the CCE were selected to maximize sample size and included: striped dolphin, short-beaked common dolphin, Risso's dolphin, Pacific white-sided dolphin, northern right whale dolphin, Dall's porpoise, sperm whale, fin whale, blue whale, humpback whale, Baird's beaked whale, and a small beaked whale guild (*Ziphius* and *Mesoplodon*).

A total of 8,956 transect segments from the 1991-2001 CCE surveys were available for model building, the majority of which were 5 km in length (refer to Becker 2007 for a description of data processing). Models were built using only those segments for which all the habitat data were available. Due to persistent cloud cover off the California coast, satellite-derived SST data were available for approximately 86% of the database segments (7,744). Fewer segments were available to develop the combined models (7,426), because additional segments were missing *in situ* data due to instrument failure. To parameterize the final predictive models, the best models were re-fit to the entire 1991-2005 dataset, consisting of 11,252 transect segments, of which 10,005 segments were available for the remotely sensed models and 9,509 segments for the combined models. The number of sightings available for building, validating, and re-fitting the final CCE models also varied, depending on the data sources (Table 19).

Table 19. Data type (remotely sensed [RS] or combined remotely sensed and *in situ* [CB]) and number of sightings used to build, validate, and parameterize the final models for the CCE. The sightings used to build the final models are from the SWFSC's 1991, 1993, 1996, and 2001 surveys of the CCE. Sightings from SWFSC's 2005 survey were used to validate the best models. The best models were re-fit to all years of data (i.e. 1991-2005) to parameterize the final predictive models. Numbers reflect sightings for which remotely sensed SST data were available (remotely sensed models) or for which both the remotely sensed and *in situ* grid data were available (combined models). The numbers reflect sightings in Beaufort sea states 0-5.

Species	**Data Type**	**Total number of sightings**		
		build	**validate**	**re-fit**
Striped dolphin	RS	51	23	74
Short-beaked common dolphin	CB	298	87	385
Risso's dolphin	RS	90	13	103
Pacific white-sided dolphin	CB	49	4	53
Northern right whale dolphin	CB	56	5	61
Dall's porpoise	CB	311	50	361
Sperm whale	CB	47	21	68
Fin whale	RS	152	86	238
Blue whale	CB	157	24	181
Humpback whale	RS	98	52	150
Baird's beaked whale	RS	13	5	18
Small beaked whales	RS	68	11	79

Model validation using the novel 2005 dataset revealed that the models for Risso's dolphin and Baird's beaked whale were not effective at capturing their distribution patterns, indicating that the models required re-examination and subsequent replacement of continuous habitat predictors with static variables (see Section 4.7). Models for both species were substantially improved using the static variables; the final models for all species showed that density estimates were similar to those derived by Barlow (2003) using line-transect analyses (Table 20).

Table 20. Abundance (number of animals) predicted by the final CCE models and calculated using line-transect methods (Barlow 2003). The model-based estimates used data collected on the 1991-2005 SWFSC surveys while the Barlow (2003) estimates were derived from the 1991-2001 survey data. Comparisons provide a general check on overall model performance.

	Abundance	
Species	**Habitat models**	**Barlow (2003)**
Striped dolphin	22,146	13,994
Short-beaked common dolphin	507,660	449,846
Risso's dolphin	19,797	16,066
Pacific white-sided dolphin	33,154	59,274
Northern right whale dolphin	16,890	20,362
Dall's porpoise	66,467	98,617
Sperm whale	1,234	1,233
Fin whale	3,388	3,279
Blue whale	2,862	1,736
Humpback whale	1,373	1,314
Baird’s beaked whale	600	407
Small beaked whales	8,259	5,878

Variables that had the greatest effect on the final encounter rate models for all species were SST, depth, and Beaufort sea state, the latter reflecting this variable’s effect on detection probability (Table 21). The percentage of deviance explained by the final encounter rate models ranged from 5% (sperm whale) to 42% (Dall’s porpoise) (Table 22). Corresponding figures for the final group size models ranged from 0% (humpback whale) to 35% (Pacific white-sided dolphin). Across all years, density ratios (density calculated using standard line-transect methods divided by density predicted by the habitat model, Appendix A) were close to unity for most species (range 0.86 - 1.50), indicating that - on average - model density estimates were similar to line-transect density estimates. Individual annual density ratios were more variable ranging from approximately 0.3 to 3.0, indicating that predictions for any given year were within a factor of three of the standard line-transect density estimates. Density plots reflecting both yearly and averaged predictions in comparison to observed sightings (Appendix A) revealed that the final CCE models were effective at capturing the general distribution patterns of the 12 species. For example, the final model for Dall’s porpoise was effective at capturing the yearly shifts in distribution (Fig. 26). Standard errors and upper and lower lognormal 90% confidence limits show the variance in the average density estimates across all years (Fig. 27).

Table 21. Predictor variables included in the final encounter rate (ER) and group size (GS) GAMs for the CCE. Linear fits are represented by "L1". Smoothing splines are represented by "S#", where # is the associated degrees of freedom. Variables included as potential predictors in all models were: distance to the 2,000-m isobath (Dist 2000), depth, slope, sea surface temperature (SST), the coefficient of variation (CV) of SST, and Beaufort sea state (BF). Additional variables included as potential predictors in the combined models were: mixed layer depth (MLD), the natural log of chlorophyll (ln CHL) and salinity (SAL).

		Predictor Variables								
		All Models						**Combined Models Only**		
Species	**Model**	**Dist 2000**	**Depth**	**Slope**	**SST**	**CV (SST)**	**BF**	**MLD**	**ln CHL**	**SAL**
Striped dolphin	ER		S2		S2		L1			
	GS				L1					
Short-beaked	ER		S3		S3	S2	L1	S3	S3	S3
common dolphin	GS				L1		L1			
Risso's dolphin	ER	CAT[1]					S2			
	GS			L1						
Pacific white-sided	ER		S3		S3		S3	S3	L1	
dolphin	GS		S2				L1			L1
Northern right	ER		S3		S3		S3	L1	L1	S2
whale dolphin	GS						L1	L1		
Dall's porpoise	ER		S3	L1	S3		S3	S3	S3	S3
	GS			S3	S2			L1	S2	
Sperm whale	ER		S2			S3	S2		S3	
	GS	L1			L1					
Fin whale	ER		S3		S3	L1	L1			
	GS	S3				S3				
Blue whale	ER		S3	S3	S3		S3	S3	S3	S3
	GS			L1	L1			L1		
Humpback whale	ER	L1	L1	S2	S3	L1	L1			
	GS									
Small beaked	ER		L1	L1			L1			
whales	GS					L1	S2			
Baird's beaked	ER	CAT[2]								
whale	GS	CAT[2]								

[1] The ER model included a categorical variable representing different regions of the study area (see text for details).

[2] The ER and GS model included a categorical variable to indicate areas within 50 km of the 2,000m isobath (see text for details).

Table 22. Proportion of deviance explained (Expl. Dev.) and average squared prediction error (ASPE) for the final encounter rate (ER) and group size (GS) models for the CCE. For the encounter rate models, ASPE calculations were based on Anscombe residuals to account for the quasi-likelihood error distribution. The large range of ASPE values for the group size models in part reflects the range of species-specific group sizes (e.g., short-beaked common dolphins tend to occur in highly variable groups of up to thousands of animals while blue whales are usually found singly or in small groups).

	Encounter Rate		**Group Size**	
Species	**Expl. Dev.**	**ASPE**	**Expl. Dev.**	**ASPE**
Striped dolphin	0.10	0.04	0.09	4,429
Short-beaked common dolphin	0.13	0.17	0.02	61,267
Risso's dolphin	0.08	0.07	0.05	743.71
Pacific white-sided dolphin	0.28	0.12	0.35	44,405
Northern right whale dolphin	0.18	0.04	0.17	12,423
Dall's porpoise	0.42	0.37	0.11	8.20
Sperm whale	0.05	0.09	0.05	61.95
Fin whale	0.09	0.09	0.06	1.86
Blue whale	0.22	0.14	0.08	0.75
Humpback whale	0.33	0.10	0	2.25
Baird's beaked whale	0.08	0.02	0.35	26.79
Small beaked whales	0.07	0.08	0.14	1.08

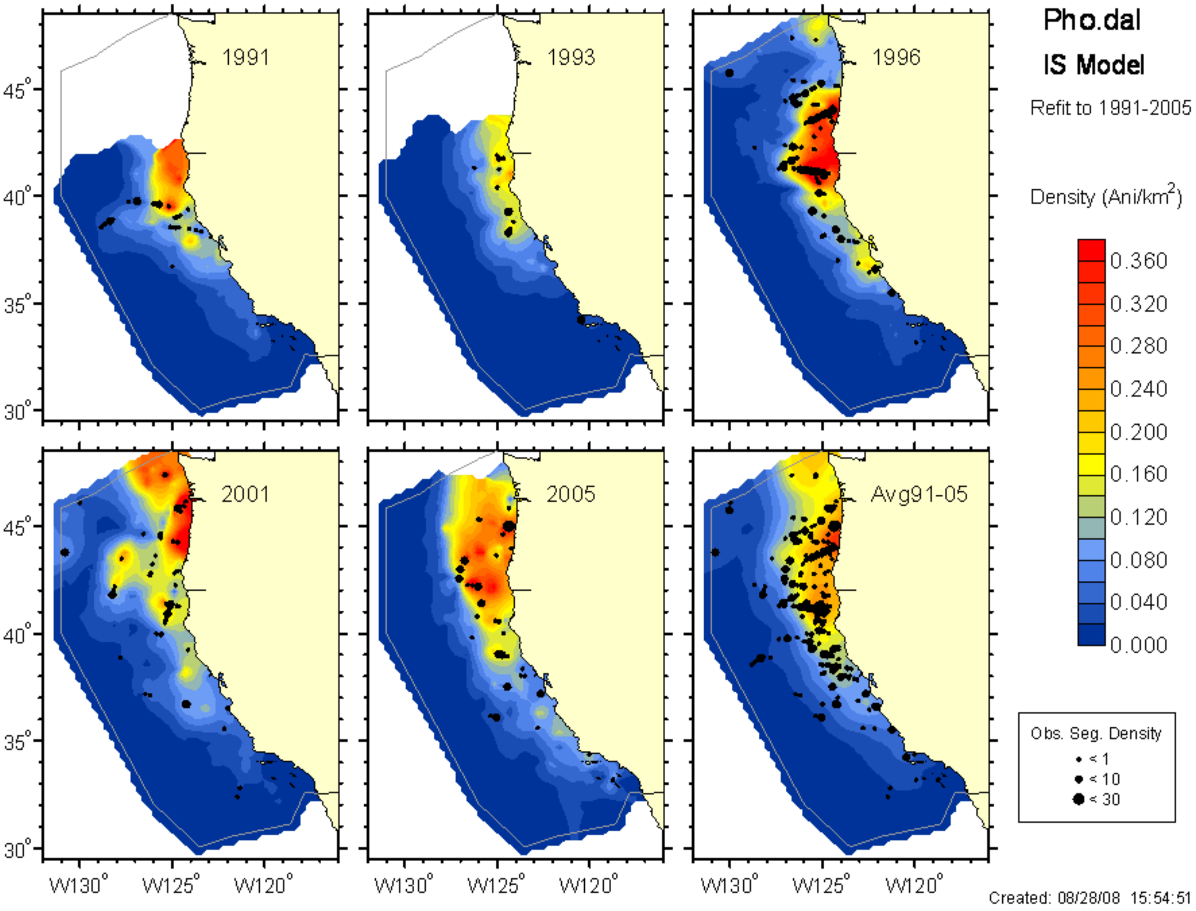


Figure 26. Yearly and averaged densities predicted for Dall's porpoise by the final CCE models. Predicted values were smoothed using inverse distance weighting (see Section 3.5.1 for more details). Black dots show sighting locations.

4.9 Final Models for the Eastern Tropical Pacific

The figures in Appendix B present the predicted distributions of population density for the fifteen ETP species for which cetacean-habitat models were developed. Those plots display predictions for each survey year separately and for all survey years combined. Of the ETP species modeled, striped dolphins included the largest number of sightings (n=1205) and blue whales included the fewest (n=109). The effective degrees of freedom for each term in the final encounter rate and group size models are given in Tables 23 and 24, respectively. A comparison of the simple and complex encounter rate and group size models that were evaluated for each species was presented in Section 4.2 and Tables 10 and 11. The simple encounter rate and group size models were chosen as the final best models for all species except Cuvier's beaked whale.

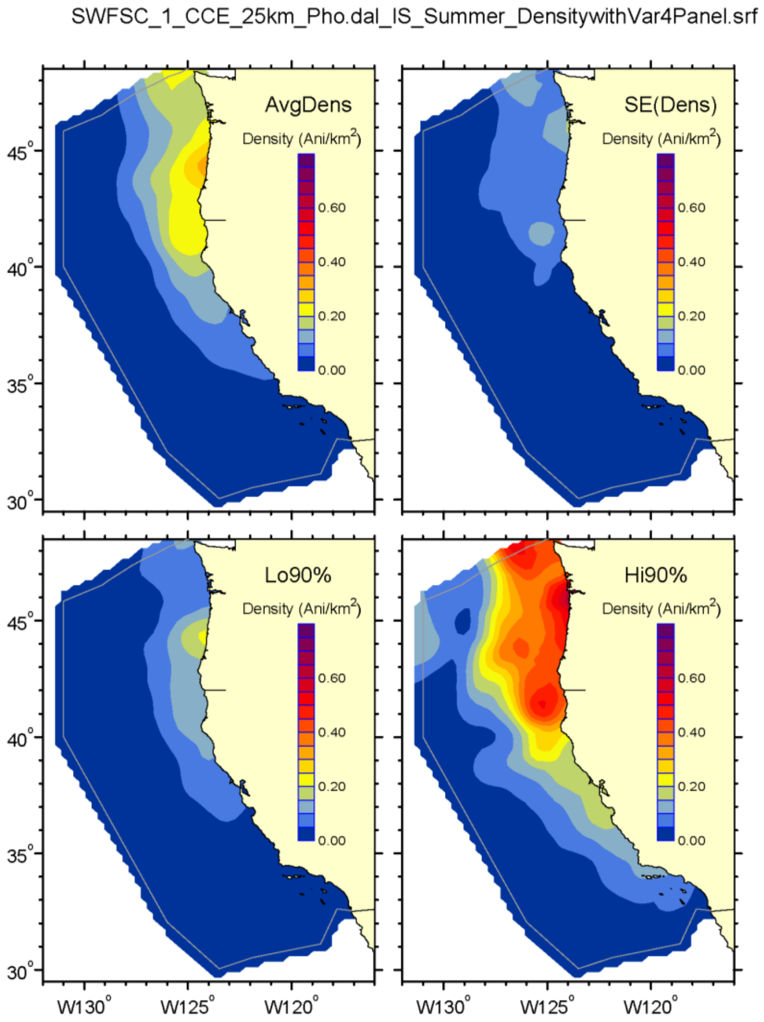


Figure 27. Average density (AveDens), standard error (SE(Dens)), and upper and lower lognormal 90% confidence limits (Lo90% and Hi90%) for Dall's porpoise.

The density predictions for *Mesoplodon* spp. (Fig. B-2n in Appendix B) and small beaked whales (Fig. B-2o in Appendix B) show two general areas of high density: the waters of the equatorial cold tongue that straddle the equator and the coastal waters off central America and Mexico. These areas correspond to known patterns of distribution for Blainville's beaked whale (*M. densirostris*) and the Peruvian beaked whale (*M. peruvianus*), respectively (Pitman and Lynn 2001). Therefore, although sample sizes were not high enough to build separate models for each species of *Mesoplodon*, the genus-level models were able to identify the known patterns of distribution for the dominant species in the genus.

The plots for Bryde's whales (Fig. B-2k in Appendix B) highlight the need to consider survey effort along with the distribution of sightings when interpreting the density plots. Although the Bryde's whale sightings appear to be relatively uniform throughout the study area, there is considerably less survey effort in the southern region, which translates to higher overall densities in these waters.

The encounter rate models for bottlenose dolphins, Cuvier's beaked whales, whitebelly spinner dolphins, and blue whales failed to converge with the default settings in the **mgcv** *gam* algorithm. Convergence was achieved by setting the *irls.reg* parameter in the *gam.control* argument in these models to a value of 1.0. The helpfile for *gam.control* in **mgcv** explains the use of the *irls.reg* parameter as follows:

> For most models this should be 0. The iteratively re-weighted least squares method by which GAMs are fitted can fail to converge in some circumstances. For example, data with many zeroes can cause problems in a model with a log link, because a mean of zero corresponds to an infinite range of linear predictor values. Such convergence problems are caused by a fundamental lack of identifiability, but do not show up as lack of identifiability in the penalized linear model problems that have to be solved at each stage of iteration. In such circumstances it is possible to apply a ridge regression penalty to the model to impose identifiability, and irls.reg is the size of the penalty.

We tried building encounter rate models for these four species using *gam.control(irls.reg=0.5)*, but those models also failed to converge. We did not compare models built with higher values for the *irls.reg* parameter.

Care should be taken in interpreting the predicted density plots for offshore spotted dolphins (Fig. B-2a in Appendix B) and eastern spinner dolphins (Fig. B-2b in Appendix B), both of which show high predicted densities in the far western region of the study area. These waters at the western edge of the study area have relatively little survey effort. The high predicted densities of offshore spotted dolphins in this region are associated with high uncertainty (Fig. B-2a in Appendix B**).** The corresponding high predicted densities of eastern spinner dolphins are also associated with relatively high uncertainty due to inter-annual variability, although the standard errors are much higher towards the east in the eastern Pacific warm pool. It is possible that the waters at the western edge of the study area represent potential eastern spinner habitat, but eastern spinners do not occupy those waters due to some ecological relationship with the whitebelly spinner dolphins. Furthermore, it appears that the tensor product spline with latitude, longitude, and SST that was incorporated into the eastern spinner dolphin could not completely separate the actual from the potential habitat for this species.

Table 23. Effective degrees of freedom for each predictor variable included in the final encounter rate GAMs for the ETP. “Lat x Long x SST” represent an interaction between latitude, longitude and sea surface temperature. Terms with effective degrees of freedom less than 1E-4 are represented as 0.0000.

	Predictor Variables							
Encounter Rate	**Offshore Distance**	**Depth**	**SST**	**Sal**	**Mixed Layer Depth**	**ln(CHL)**	**Beaufort**	**Lat x Long x SST**
Offshore spotted dolphin	0.0000	2.3670	1.7630	1.7850	0.9992	0.0000	NA	NA
Eastern spinner dolphin	2.0133	2.7082	0.9989	0.5715	2.2830	0.5403	3.6295	19.4550
Whitebelly spinner dolphin	3.0030	3.2740	2.5570	7.7890	3.8050	1.0910	1.1090	NA
Striped dolphin	6.9400	4.3010	4.3640	0.0000	1.9430	2.1230	2.8620	NA
Rough-toothed dolphin	0.0000	2.2340	4.4790	0.0000	0.0000	0.4840	1.7170	NA
Short-beaked common dolphin	2.3260	6.3678	2.1058	0.8296	1.3915	2.6880	1.0246	NA
Bottlenose dolphin	1.8115	1.9945	1.4444	5.3406	0.9048	1.8629	0.8815	NA
Risso's dolphin	2.0870	3.2510	2.8250	2.9750	0.0000	1.7870	1.3130	NA
Cuvier's beaked whale	1.1690	2.3100	2.4650	0.0000	0.0000	2.0560	0.9720	NA
Blue whale	3.6030	4.9050	5.5900	3.4240	3.5630	3.1410	0.0000	NA
Bryde's whale	0.0352	2.5409	2.3564	0.9628	0.8652	2.8506	0.6726	NA
Short-finned pilot whale	1.1550	5.8660	1.8060	3.7290	0.0000	1.3760	2.2290	NA
Dwarf sperm whale	0.0000	0.0000	8.9720	0.0000	0.0000	8.9700	8.9790	NA
Mesoplodon spp.	8.9190	8.9510	8.9730	8.7370	0.0000	8.9510	7.7660	NA
Small beaked whales	1.0450	4.6570	2.6490	0.0000	0.0000	3.0080	1.5760	NA

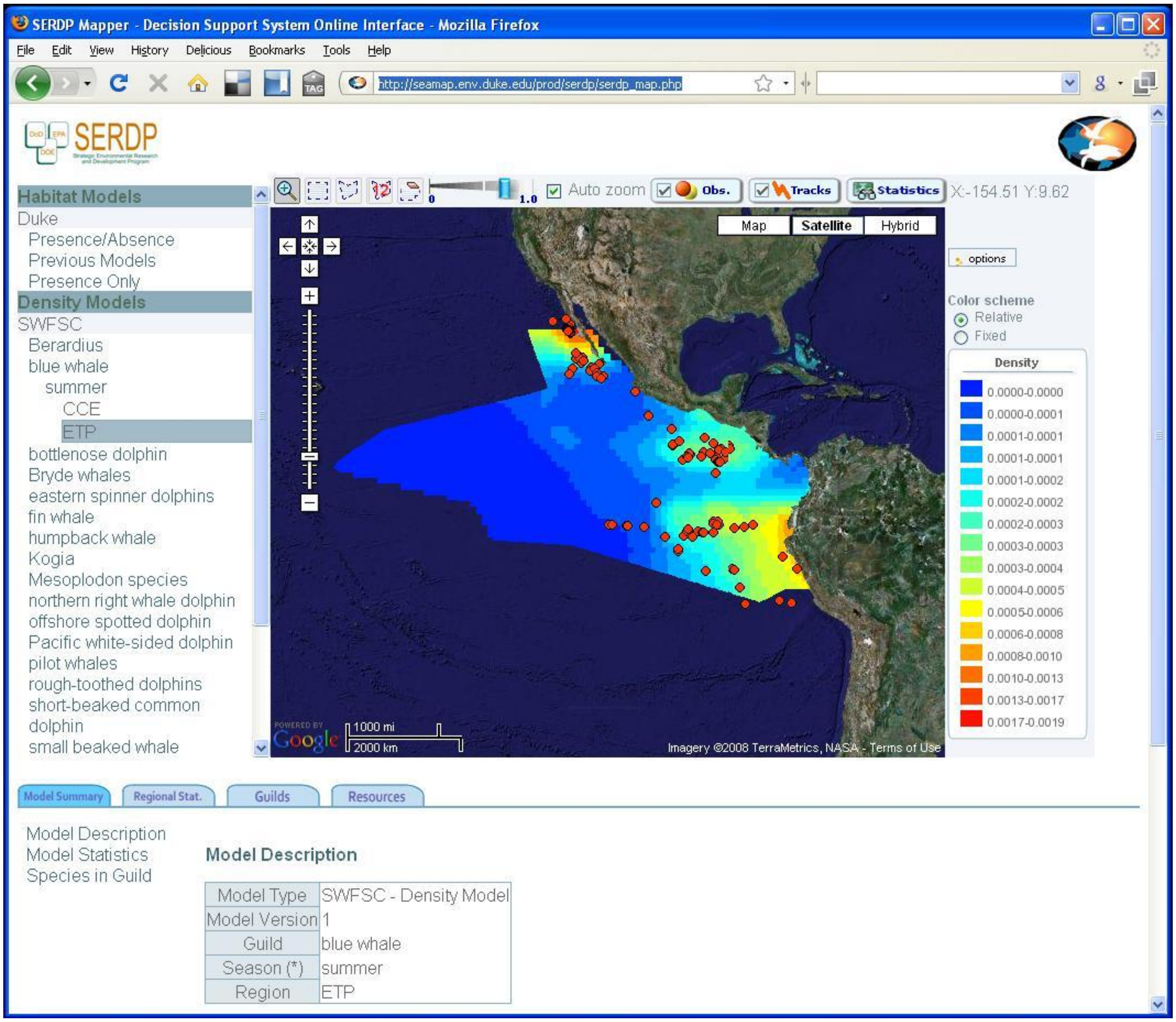
Table 24. Effective degrees of freedom for each predictor variable included in the final group size GAMs for the ETP. Terms with effective degrees of freedom less than 1E-4 are represented as 0.0000.

	Predictor Variables						
Group Size	**Offshore Distance**	**Depth**	**SST**	**Sal**	**Mixed Layer Depth**	**ln(CHL)**	**Beaufort**
Offshore spotted dolphin	1.8900	0.3519	0.0000	0.0000	1.3500	0.2380	NA
Eastern spinner dolphin	4.1060	2.0650	2.1870	2.2800	1.7180	0.0000	0.8673
Whitebelly spinner dolphin	0.0000	0.9765	0.8065	0.0000	0.0000	0.0000	0.0000
Striped dolphin	0.8338	1.2202	0.9656	5.6278	3.8603	0.1212	0.0121
Rough-toothed dolphin	3.0690	0.0000	1.1380	0.6668	0.0000	1.3340	0.5823
Short-beaked common dolphin	0.0000	0.0090	0.4831	0.7816	6.8640	1.1520	1.6840
Bottlenose dolphin	0.6154	4.0630	0.8780	1.6260	0.0000	0.0033	2.9760
Risso's dolphin	1.9350	0.0000	1.4630	0.0000	0.7493	0.0000	0.8842
Cuvier's beaked whale	2.9660	2.2070	2.0600	1.5420	2.4110	2.8430	2.5950
Blue whale	1.2210	0.8051	0.5328	0.0000	2.5930	2.4190	0.0000
Bryde's whale	2.4380	3.7560	0.0000	0.0000	0.0000	0.0000	0.0000
Short-finned pilot whale	2.2060	0.0000	0.8752	0.0000	1.5010	0.0000	0.8456
Dwarf sperm whale	1.0600	0.7869	0.0000	0.0000	0.0000	0.0000	0.0000
Mesoplodon spp.	1.3820	0.4505	1.8970	3.2180	0.0000	0.0000	2.4740
Small beaked whales	0.9845	0.7757	2.1210	0.0000	0.0000	0.5236	0.7121

We attempted to build encounter rate and group size models for sperm whales, killer whales, and coastal spotted dolphins, but the models for these three species failed in one or more ways. The coastal spotted dolphin models would not converge, suggesting that there was a mismatch in the type or scale of the predictor variables used in the model building process and the ecological processes that affect the animals' distribution. In contrast, we were able to construct models for sperm whales, but we did not trust the model predictions; the experts who attended our workshop at SWFSC were also skeptical of the predicted densities from the sperm whale models. The scenario was similar for killer whales: the models converged, but the magnitude and shape of the predictor variables in the final models were suspicious from an ecological perspective. Therefore, the densities incorporated into the SDSS for these three species are from the geographically stratified line-transect estimates reported in Ferguson and Barlow (2001) (see Section 3.5.3).

4.10 Model Output and Visualization Software

Our best-and-final models for the CCE and the ETP have been incorporated into a web-based GIS software system developed by Duke University's SERDP Team in close collaboration with our Southwest Fisheries Science Center (SWFSC) SERDP Team. The web site (http://serdp.env.duke.edu/) is currently hosted at Duke University but needs to be transitioned to a permanent home. The software, called the Spatial Decision Support System (SDSS), allows the user to view our model outputs as color-coded maps of cetacean density (Fig. 28) as well as maps that depict the precision of the models (expressed as point-wise standard errors and log-normal 90% confidence intervals). The user can pan and zoom to their area of interest. To obtain quantitative information about cetacean densities (and their coefficients of variation) the user can define a specific operational area either by choosing one from a pull-down menu, by uploading a shape file defining that area, or by interactively choosing perimeter points. Density estimates for a user-selected area are accompanied by estimates of the uncertainty (coefficient of variation) in those estimates. Detailed metadata describing the model are also available, including: survey years used to fit the model, habitat variables included in the model, type of model used, etc.



Model Description

Model Type	SWFSC - Density Model
Model Version	1
Guild	blue whale
Season (*)	summer
Region	ETP

Figure 28. Screenshot from the SDSS development website of blue whale sightings and predicted density in the eastern tropical Pacific Ocean.

5.0 Conclusion

The field of predictive modeling of cetacean density has advanced considerably during the past few years, in part as a result of our research presented in this report and associated publications (Appendix C). Several new lines of research on model methodology, effects of scale, inclusion of mid-trophic data, comparison of remotely sensed vs. *in situ* data, and seasonal predictive capabilities have provided a robust set of predictive models for cetaceans within a broad region of the eastern Pacific Ocean, spanning both temperate and tropical waters. Our research has confirmed that generalized additive models offer a robust framework for predictive modeling of cetacean density, as long as sufficient observations of each species are available and the surveys adequately characterize the full range of oceanographic variability. Models derived from either *in situ* or remotely sensed environmental data (or a combination thereof) were able to predict cetacean occurrence patterns within the highly dynamic California Current Ecosystem, although a few species were clearly better characterized by one type of data or the other (e.g. striped dolphins in the CCE were better modeled using the remotely sensed data). The use of remotely sensed data will be important for expanding models to include seasonal predictive capabilities as additional years of data become available. Our studies also confirmed that the inclusion of variables related to the abundance of mid-trophic species from net-tow and acoustic backscatter data can improve habitat models for several species in both the ETP and CCE.

As with all research, there is continued room for improvement and expansion of predictive cetacean density models. The Spatial Decision Support Software (SDSS) produced through our research provides users with long-term seasonal average cetacean densities (and uncertainty therein) within any user-specified polygon, based on the range of environmental conditions and species occurrence patterns observed during nearly two decades of SWFSC surveys. While this represents a significant improvement over the previous, constant-density estimates from broad-scale line-transect surveys, a logical next step in model development will be to identify methods of near real-time density prediction based on current or projected oceanographic conditions.

This 'next-generation' of models will likely build upon recent advances in processing and integrating remotely sensed data, ship reports, and buoy data to create new habitat indices and ocean circulation models. Such synoptic measures may improve accuracy of models, allow forecasting based on modeled oceanographic conditions, or allow prediction of oceanographic variables on finer temporal and spatial scales. It may also be possible to develop analytical methods of incorporating alternative data types, such as small-scale line-transect survey, tagging, opportunistic, and acoustic data, into the building and validation of cetacean-habitat models. Currently, the models are based on large-scale line-transect surveys that are limited by weather, funding, and logistics. Expansion of the models to include alternative data types would help overcome some of these limitations. For example, tagging data could be useful in exploring seasonal distribution patterns and developing migration models for large whales. Shore-based surveys and coastal aerial line-transect surveys could be used to develop predictive density models for nearshore marine mammal species, such as harbor porpoise, coastal bottlenose dolphins, gray whales, and pinnipeds.

A final important line of research relates to the scale and extent of cetacean density predictions. The studies completed as part of this project have demonstrated that accurate models are best constructed using input data from the same geographic region, i.e., the CCE or ETP, rather than combined across ecoregions. Therefore, the extrapolation of our models to other areas in different marine ecosystems (e.g. Hawaii) is not reliably possible at this time. However, the seasonal comparison suggests that temporal and/or spatial expansion of models may be possible in the future if we can obtain sufficient input data spanning a broader range of habitat conditions. Thus, the continued collection of integrated marine mammal and ecosystem data throughout a range of marine habitats will be necessary to expand the scope and utility of SDSS in the future.

6.0 Transition Plan

The models of cetacean densities developed for this project are expected to have immediate utility to the Navy and its contractors who are required to conduct Environmental Assessments or prepare Environmental Impact Statements regarding Navy activities that might impact marine mammals. The cetacean habitat models for the Pacific Coast and Eastern Tropical Pacific (our project SI-1391) and for the Atlantic Coast and Gulf of Mexico (Duke University's project SI-1390) are currently accessible online at a web portal maintained by Duke University (http://serdp.env.duke.edu/). Using the web-based Spatial Decision Support System (SDSS) software at that site, users can access our models to view how cetacean densities vary spatially within our two study areas (the CCE and ETP). Users can define an area of interest (either from a pull-down menu of operational areas or by entering or uploading coordinates) and estimate the densities of most cetaceans that are expected to be present. Soon the SDSS will also include stratified estimates so that densities can be estimated for Hawaiian EEZ waters and for those rare species for which small sample size prevented us from modeling densities.

Although this transition should work well in the short-term (roughly through the next year or two), there is a need to transition the SDSS to a permanent web site maintained by the US Government or other entity with a commitment to maintain the software over a longer term. Although the US Navy may be interested in taking on this role, many other potential users have been identified for this software tool. A partial list of potential users was identified at a joint planning meeting between the SWFSC and Duke teams. This list includes: Navy, Air Force, Coast Guard, Army Corps of Engineers, Minerals Management Service, National Science Foundation, National Marine Fisheries Service science centers and regional offices, universities, and oil exploration companies. Basically, any entity that might need a Government permit for any activity that might affect marine mammals is a likely user of the SDSS software.

Because the Navy is not the only likely user of the SDSS, NOAA (a major secondary supporter of this project) will likely insist that the ultimate web host for the system must be willing to make the system publically available to other users. For that reason, NOAA might be a better host than the Navy. Ultimately, information about the potential impacts of Navy activities will submitted to NOAA Fisheries for review. Clearly, to be accepted, that information should be generally recognized by NOAA as the scientifically valid source of the best available information on cetacean densities. That condition is most likely to be achieved if NOAA is, itself, the source of the information by hosting the SDSS software on one of their web sites.

Regardless of who hosts the SDSS software website, the long-term success of this project in solving the Navy's marine mammal information needs will depend on several steps beyond the mere completion of this project. The most critical next steps for full Navy implementation and use of this system include:

1) Obtaining acceptance and buy-in by the regulatory community. For most marine mammals, that means the NOAA Fisheries Office of Protected Resources in Silver Springs, Md. [The U.S. Fish and Wildlife Service has regulatory authority over manatees, sea otters, polar bears, and walruses, but none of those species are included in the current version of the SDSS software.] The lead PI on our SWFSC project (Barlow) has already given two seminars describing our SERDP project at the NOAA Office of Protected Resources and has provided a basic tutorial on the use of the software. To be accepted as the "best available information" on the density of ceteceans, that office needs to be convinced that the scientific basis for the model-based estimates is sound. We have been pursuing that goal by publishing our methods as we develop them (see Appendix C). Furthermore, the developers of our models include some of NOAA's own experts on the estimation of cetacean abundance from line-transect surveys (Barlow, Gerrodette, and Forney). Unfortunately, the NOAA expertise on the SWFSC SERDP team is entirely based on the US West Coast. NOAA experts on line-transect estimation on the US East Coast and Gulf of Mexico were not directly involved in the Duke SERDP modeling project (although they did provide their data). To facilitate NOAA buy-in at all levels, the NOAA cetacean researchers along the East Coast and Gulf of Mexico need to also be convinced that the methods we used are sound and result in scientifically defensible estimates of cetacean density. Again, that might be best facilitated by direct face-to-face meetings, perhaps with a seminar to introduce the methods and a workshop to familiarize them with the SDSS software.

2) Establishing a program for continued development of habitat-based density models for cetaceans in new areas, for other species of marine mammals, and, when new survey data become available, for cetaceans in areas that are already modeled. Although density models are now developed for many areas in the Pacific, many other areas are not covered. Data are currently too sparse to model cetacean densities around Hawaii and the Northern Marianas Islands, two areas with considerable Naval activities. Similar critical gaps in information exist in the Bahamas and Caribbean. Habitat models currently do not include any pinnipeds, sea otters, or manatees. Densities were also not modeled for near-shore cetaceans (harbor porpoises, gray whales (*Eschrichtius robustus*), and coastal bottle-nose dolphins). The methods we have developed here for offshore cetaceans could easily be extended to model the at-sea densities of pinniped species and (with modifications) nearshore cetaceans. Finally, there is a need to continually update habitat models as new information becomes available. A 4-month survey of cetaceans in the CCE was completed by the SWFSC in 2008, and data from that survey will be edited and could be used to improve West Coast models as early as summer of 2009.

NOAA does not have a base-funded program for cetacean habitat modeling. Although SERDP and the Navy may want to continue funding these modeling efforts, a base-funded NOAA program might provide more continuity. However it is funded, new modeling efforts will be needed to ensure that the SDSS remains the source for the best available information on cetacean densities.

3) Continuing development of habitat modeling for marine mammals. Although our program has been able to investigate many previously unexplored aspects of habitat modeling, many areas have not yet been explored. Entirely new approaches are needed to model the continuously changing distributions of migratory species, such as blue, fin, and gray whales. Global ocean circulations models have now reached the state of development where oceanographic conditions can be forecast several months in advance. Those models could be coupled with cetacean habitat models to predict cetacean distributions as well. This information could be used to improve the Navy's ability to predict where negative interactions with marine mammals are likely to occur and allow better planning of naval exercises.

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Appendix A: Detailed Model Results for the California Current Ecosystem

Table A-1. Spatial and temporal estimates of the number of animals observed in each geographic stratum, calculated using line-transect methods (LT) and predicted based on results from the final CCE models (Pred). Regional ratios (LT/Pred) and standard errors (SE) of the ratios are provided for individual years as well as for all years combined. See text (Section 3.5) for region descriptions.

Striped dolphin

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.000	0	86	0.000	0	30	0.000	0	41	**0.000**	**0**	**158**
orwaE	NA	NA	NA	NA	NA	NA	0.000	0	0	0.000	0	0	0.000	0	0	**0.000**	**0**	**1**
nocalW	0.301	41	135	1.092	152	139	0.065	14	210	0.000	0	79	3.372	682	202	**1.161**	**888**	**765**
nocalE	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	**0.000**	**0**	**0**
cencalW	0.403	126	314	0.112	11	96	0.175	49	280	0.219	41	187	1.980	423	214	**0.596**	**650**	**1091**
cencalE	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	**0.000**	**0**	**0**
socalW	2.343	647	276	1.389	597	430	0.542	206	380	2.021	379	187	0.686	229	334	**1.280**	**2057**	**1608**
socalE	0.000	0	1	0.000	0	2	0.000	0	2	0.000	0	1	0.000	0	1	**0.000**	**0**	**7**
StdyArea	**1.121**	**814**	**726**	**1.140**	**760**	**666**	**0.280**	**269**	**959**	**0.866**	**420**	**485**	**1.683**	**1334**	**793**	**0.991**	**3596**	**3629**
																	SE(ratio)	**0.254**

Short-beaked common dolphin

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.000	0	1144	0.004	3	736	0.957	373	390	**0.166**	**376**	**2269**
orwaE	NA	NA	NA	NA	NA	NA	0.000	0	255	0.000	0	171	0.000	0	68	**0.000**	**0**	**494**
nocalW	0.677	1295	1914	2.502	4433	1772	1.119	3015	2694	0.786	1358	1728	2.464	4688	1903	**1.477**	**14789**	**10011**
nocalE	0.349	23	67	0.000	0	127	0.000	0	78	0.000	0	125	0.000	0	14	**0.057**	**23**	**411**
cencalW	0.532	2193	4124	1.644	4232	2574	1.867	8432	4516	0.445	1524	3421	1.441	5464	3792	**1.186**	**21846**	**18427**
cencalE	0.000	0	161	0.829	562	678	0.752	316	421	0.000	0	59	0.000	0	82	**0.627**	**879**	**1401**
socalW	0.636	1996	3137	0.395	772	1957	0.643	2552	3971	0.891	1885	2116	1.630	4796	2942	**0.850**	**12001**	**14122**
socalE	0.568	2070	3642	1.259	1747	1388	0.723	2594	3586	1.965	3105	1580	2.640	4402	1667	**1.173**	**13918**	**11863**
StdyArea	**0.581**	**7578**	**13045**	**1.383**	**11747**	**8495**	**1.015**	**16909**	**16664**	**0.792**	**7875**	**9937**	**1.817**	**19723**	**10857**	**1.082**	**63833**	**58998**
																	SE(ratio)	**0.245**

Risso's dolphin

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	1.069	104	97	0.822	51	63	0.000	0	51	**0.735**	**155**	**211**
orwaE	NA	NA	NA	NA	NA	NA	2.693	315	117	1.080	95	88	0.152	15	100	**1.396**	**425**	**305**
nocalW	3.468	200	58	0.647	38	59	0.000	0	102	0.000	0	60	0.238	21	88	**0.706**	**259**	**366**
nocalE	0.000	0	8	0.000	0	17	0.000	0	11	0.000	0	12	3.355	29	9	**0.516**	**29**	**56**
cencalW	1.891	150	80	3.809	131	34	0.307	29	94	1.211	67	55	0.485	39	80	**1.213**	**415**	**342**
cencalE	0.000	0	12	2.615	47	18	4.087	150	37	0.337	5	15	0.000	0	19	**2.000**	**202**	**101**
socalW	0.150	9	58	1.042	75	72	0.389	40	103	0.135	8	59	0.496	40	80	**0.460**	**171**	**372**
socalE	0.866	109	126	0.046	5	113	0.586	89	152	1.403	148	105	0.325	33	101	**0.643**	**384**	**598**
StdyArea	**1.370**	**468**	**342**	**0.945**	**296**	**313**	**1.021**	**727**	**711**	**0.818**	**374**	**458**	**0.334**	**176**	**527**	**0.868**	**2041**	**2351**
																	SE(ratio)	**0.188**

Pacific white-sided dolphin

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.596	341	573	0.076	20	258	0.826	154	187	**0.506**	**516**	**1018**
orwaE	NA	NA	NA	NA	NA	NA	2.213	765	346	0.987	189	192	0.000	0	93	**1.514**	**954**	**630**
nocalW	0.228	37	164	0.156	18	115	1.482	903	609	0.728	77	106	9.805	1249	127	**2.038**	**2285**	**1121**
nocalE	0.000	0	19	1.161	85	73	0.289	30	104	2.840	113	40	0.000	0	50	**0.793**	**227**	**287**
cencalW	0.000	0	37	0.000	0	43	3.322	568	171	0.000	0	15	0.249	7	28	**1.968**	**575**	**292**
cencalE	0.121	3	25	0.000	0	20	0.000	0	140	0.000	0	8	1.503	17	12	**0.100**	**20**	**204**
socalW	0.000	0	14	0.000	0	5	0.000	0	12	0.000	0	2	0.000	0	9	**0.000**	**0**	**42**
socalE	0.000	0	33	0.395	4	10	0.687	23	33	4.164	65	16	0.000	0	101	**0.476**	**92**	**193**
StdyArea	**0.138**	**40**	**291**	**0.402**	**107**	**265**	**1.323**	**2630**	**1988**	**0.729**	**464**	**636**	**2.355**	**1428**	**606**	**1.233**	**4669**	**3787**
																	SE(ratio)	**0.441**

Table A-1 (continued)

Northern right whale dolphin

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	1.023	159	155	0.530	75	142	0.353	18	52	**0.723**	**252**	**349**
orwaE	NA	NA	NA	NA	NA	NA	0.474	35	73	0.508	24	46	0.000	0	21	**0.415**	**58**	**140**
nocalW	1.190	113	95	0.233	21	92	0.633	107	170	2.495	201	81	0.000	0	79	**0.858**	**443**	**516**
nocalE	1.772	13	7	1.691	31	19	0.541	9	18	0.167	1	8	0.000	0	20	**0.766**	**55**	**72**
cencalW	0.391	9	22	3.079	55	18	1.619	133	82	2.466	140	57	20.008	972	49	**5.764**	**1307**	**227**
cencalE	0.000	0	6	0.000	0	3	1.507	56	37	0.000	0	10	0.000	0	5	**0.926**	**56**	**61**
socalW	1.032	6	6	0.000	0	3	0.906	35	39	0.000	0	12	0.551	12	22	**0.654**	**53**	**81**
socalE	0.000	0	2	0.000	0	0	0.000	0	6	0.000	0	5	0.000	0	21	**0.000**	**0**	**35**
StdyArea	**1.021**	**140**	**137**	**0.799**	**107**	**134**	**0.922**	**534**	**579**	**1.221**	**441**	**361**	**3.730**	**1002**	**269**	**1.502**	**2225**	**1481**
																	SE(ratio)	**0.617**

Dall's porpoise

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	1.205	149	124	0.432	42	98	0.990	57	57	**0.890**	**248**	**278**
orwaE	NA	NA	NA	NA	NA	NA	1.353	187	138	0.832	57	69	0.763	54	71	**1.073**	**299**	**278**
nocalW	1.140	93	81	0.659	29	44	1.398	282	201	1.508	72	48	1.212	71	58	**1.262**	**546**	**433**
nocalE	1.461	13	9	0.499	12	23	1.804	25	14	0.497	8	16	0.697	7	10	**0.894**	**64**	**72**
cencalW	0.131	2	15	0.000	0	13	0.641	32	50	1.218	25	21	1.152	26	23	**0.701**	**85**	**121**
cencalE	0.000	0	6	0.000	0	4	0.758	22	29	0.612	4	6	1.872	11	6	**0.706**	**36**	**51**
socalW	0.000	0	5	0.000	0	2	0.000	0	10	1.863	6	3	0.000	0	7	**0.230**	**6**	**26**
socalE	0.000	0	4	6.032	9	1	0.959	4	4	0.000	0	3	0.241	5	21	**0.533**	**18**	**33**
StdyArea	**0.894**	**107**	**120**	**0.562**	**49**	**87**	**1.229**	**701**	**570**	**0.816**	**214**	**263**	**0.911**	**230**	**253**	**1.007**	**1302**	**1293**
																	SE(ratio)	**0.120**

Sperm whale

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.789	31	39	0.409	12	29	2.148	33	15	**0.908**	**75**	**83**
orwaE	NA	NA	NA	NA	NA	NA	1.747	6	3	0.000	0	5	0.000	0	2	**0.572**	**6**	**10**
nocalW	0.000	0	16	5.861	104	18	0.391	12	31	0.659	14	22	4.259	96	22	**2.080**	**226**	**109**
nocalE	0.000	0	1	0.000	0	1	0.000	0	1	0.000	0	1	0.000	0	2	**0.000**	**0**	**5**
cencalW	0.841	13	16	0.000	0	9	0.824	21	26	0.078	1	16	0.000	0	25	**0.389**	**36**	**92**
cencalE	0.000	0	1	0.000	0	1	0.397	1	3	0.000	0	1	0.000	0	1	**0.152**	**1**	**7**
socalW	0.561	6	11	0.833	10	12	0.617	17	28	4.489	78	17	0.694	14	21	**1.408**	**126**	**90**
socalE	0.575	1	2	0.000	0	1	0.000	0	2	0.000	0	2	0.000	0	2	**0.114**	**1**	**9**
StdyArea	**0.448**	**21**	**46**	**2.765**	**114**	**41**	**0.665**	**88**	**132**	**1.122**	**105**	**94**	**1.583**	**143**	**90**	**1.167**	**471**	**403**
																	SE(ratio)	**0.460**

Fin whale

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.241	7	29	0.463	12	26	1.219	20	16	**0.545**	**39**	**72**
orwaE	NA	NA	NA	NA	NA	NA	0.095	2	21	0.405	5	12	0.099	1	10	**0.184**	**8**	**44**
nocalW	0.153	3	20	0.653	11	17	0.335	10	31	1.338	26	19	3.318	68	20	**1.101**	**118**	**107**
nocalE	0.000	0	2	0.000	0	6	0.330	1	3	0.000	0	3	0.000	0	1	**0.067**	**1**	**15**
cencalW	0.318	7	21	3.052	32	10	1.338	34	25	1.359	21	15	3.048	59	19	**1.658**	**152**	**92**
cencalE	2.789	14	5	2.666	12	4	5.979	49	8	0.000	0	3	1.748	6	3	**3.397**	**81**	**24**
socalW	0.114	1	9	0.264	2	8	0.250	5	20	0.000	0	12	0.375	6	16	**0.218**	**14**	**64**
socalE	0.157	1	6	1.742	5	3	2.180	17	8	0.355	3	8	0.905	9	10	**0.980**	**34**	**35**
StdyArea	**0.408**	**26**	**63**	**1.278**	**62**	**48**	**0.863**	**125**	**145**	**0.671**	**67**	**100**	**1.753**	**168**	**96**	**0.990**	**448**	**453**
																	SE(ratio)	**0.265**

Table A-1 (continued)

Blue whale

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.000	0	2	0.000	0	3	0.311	1	3	**0.117**	**1**	**9**
orwaE	NA	NA	NA	NA	NA	NA	0.000	0	4	0.119	1	8	0.574	2	3	**0.191**	**3**	**16**
nocalW	0.000	0	6	1.631	7	4	0.480	5	11	0.706	5	7	0.539	4	7	**0.587**	**20**	**34**
nocalE	0.559	2	4	0.328	1	3	3.697	23	6	0.793	2	3	0.981	5	5	**1.605**	**33**	**21**
cencalW	1.099	13	12	1.141	12	11	0.809	14	17	0.805	7	8	0.926	12	13	**0.948**	**57**	**61**
cencalE	2.040	7	3	1.781	12	6	1.712	28	17	0.000	0	4	0.613	4	6	**1.404**	**51**	**36**
socalW	1.127	12	11	2.056	15	7	2.300	24	11	0.000	0	3	0.538	4	7	**1.422**	**55**	**38**
socalE	0.749	13	17	2.178	25	11	1.244	31	25	0.061	1	16	0.531	7	14	**0.919**	**76**	**83**
StdyArea	**0.888**	**47**	**53**	**1.654**	**70**	**43**	**1.365**	**125**	**92**	**0.296**	**16**	**52**	**0.661**	**38**	**58**	0.997	296	297
																	SE(ratio)	**0.272**

Humpback whale

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.000	0	7	0.284	2	7	0.450	3	7	**0.242**	**5**	**21**
orwaE	NA	NA	NA	NA	NA	NA	0.333	12	36	0.552	13	24	0.700	35	50	**0.548**	**60**	**110**
nocalW	0.000	0	4	1.187	4	3	0.000	0	10	0.000	0	5	0.573	4	6	**0.258**	**7**	**28**
nocalE	1.999	14	7	0.670	7	10	0.272	2	6	0.185	1	7	1.160	10	8	**0.855**	**34**	**39**
cencalW	0.000	0	2	0.000	0	1	2.198	14	6	7.277	21	3	2.783	9	3	**2.782**	**44**	**16**
cencalE	0.718	6	8	7.089	22	3	2.364	57	24	1.316	12	9	3.288	26	8	**2.350**	**122**	**52**
socalW	3.950	2	1	0.000	0	0	0.000	0	2	0.000	0	2	0.677	1	1	**0.525**	**3**	**6**
socalE	0.000	0	2	3.174	2	1	0.684	2	3	0.000	0	5	0.356	3	8	**0.372**	**7**	**18**
StdyArea	**0.904**	**22**	**24**	**1.839**	**34**	**19**	**0.926**	**87**	**93**	**0.804**	**49**	**61**	**0.981**	**90**	**92**	0.975	282	290
																	SE(ratio)	**0.212**

Small beaked whales

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	1.622	12	8	0.863	5	6	2.498	9	4	**1.549**	**26**	**17**
orwaE	NA	NA	NA	NA	NA	NA	1.699	2	1	0.000	0	1	0.000	0	1	**0.745**	**2**	**3**
nocalW	0.135	1	7	2.484	22	9	0.507	7	14	0.000	0	6	0.731	6	8	**0.823**	**36**	**44**
nocalE	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	0	0.000	0	1	**0.000**	**0**	**2**
cencalW	1.968	24	12	1.304	5	4	1.385	12	9	0.000	0	7	1.266	7	6	**1.292**	**48**	**37**
cencalE	0.000	0	0	0.000	0	0	0.000	0	1	0.000	0	0	0.000	0	0	**0.000**	**0**	**2**
socalW	0.997	5	5	1.150	8	7	0.645	6	9	0.871	4	4	0.289	2	7	**0.766**	**25**	**32**
socalE	0.820	1	1	1.408	1	1	0.000	0	2	4.453	4	1	0.000	0	1	**0.924**	**6**	**6**
StdyArea	**1.172**	**31**	**27**	**1.708**	**36**	**21**	**0.897**	**39**	**44**	**0.500**	**12**	**24**	**0.883**	**24**	**27**	0.998	143	143
																	SE(ratio)	**0.224**

Baird's beaked whale

	1991			1993			1996			2001			2005			ALL years TOTAL		
Region	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**	**LT/Pred**	**LT**	**Pred**
orwaW	NA	NA	NA	NA	NA	NA	0.379	6	15	0.710	7	9	3.750	25	7	**1.207**	**37**	**31**
orwaE	NA	NA	NA	NA	NA	NA	0.948	4	5	3.090	11	4	0.000	0	3	**1.444**	**16**	**11**
nocalW	0.000	0	3	3.475	19	6	1.152	11	10	0.000	0	7	0.000	0	8	**0.910**	**31**	**34**
nocalE	0.000	0	1	0.000	0	1	0.000	0	1	0.000	0	1	0.000	0	1	**0.000**	**0**	**6**
cencalW	0.000	0	2	9.634	19	2	0.000	0	5	0.000	0	3	0.000	0	3	**1.274**	**19**	**15**
cencalE	0.000	0	1	17.951	22	1	0.000	0	2	0.000	0	1	0.000	0	2	**3.037**	**22**	**7**
socalW	0.000	0	2	0.000	0	3	0.890	7	8	0.000	0	4	0.000	0	4	**0.329**	**7**	**21**
socalE	0.000	0	2	0.000	0	2	0.000	0	4	0.000	0	3	2.789	6	2	**0.451**	**6**	**13**
StdyArea	**0.000**	**0**	**11**	**3.848**	**61**	**16**	**0.571**	**28**	**49**	**0.545**	**18**	**32**	**1.089**	**31**	**28**	1.004	137	137
																	SE(ratio)	**0.762**

Figure A-1 Predicted yearly and averaged densities based on the final CCE models for: (a) striped dolphin (*Stenella coeruleoalba*), (b) short-beaked common dolphin (*Delphinus delphis*), (c) Risso's dolphin (*Grampus griseus*), (d) Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), (e) northern right whale dolphin (*Lissodelphis borealis*), (f) Dall's porpoise (*Phocoenoides dalli*), (g) sperm whale (*Physeter macrocephalus*), (h) fin whale (*Balaenoptera physalus*), (i) blue whale (*Balaenoptera musculus*), (j) humpback whale (*Megaptera novaeangliae*), (k) Baird's beaked whale (*Berardius bairdii*), and (l) small beaked whales (*Ziphius and Mesoplodon*). Predicted values were smoothed using inverse distance weighting (see Section 3.5.1 for details). Black dots show actual sighting locations.

Figure A-1a. Striped dolphin

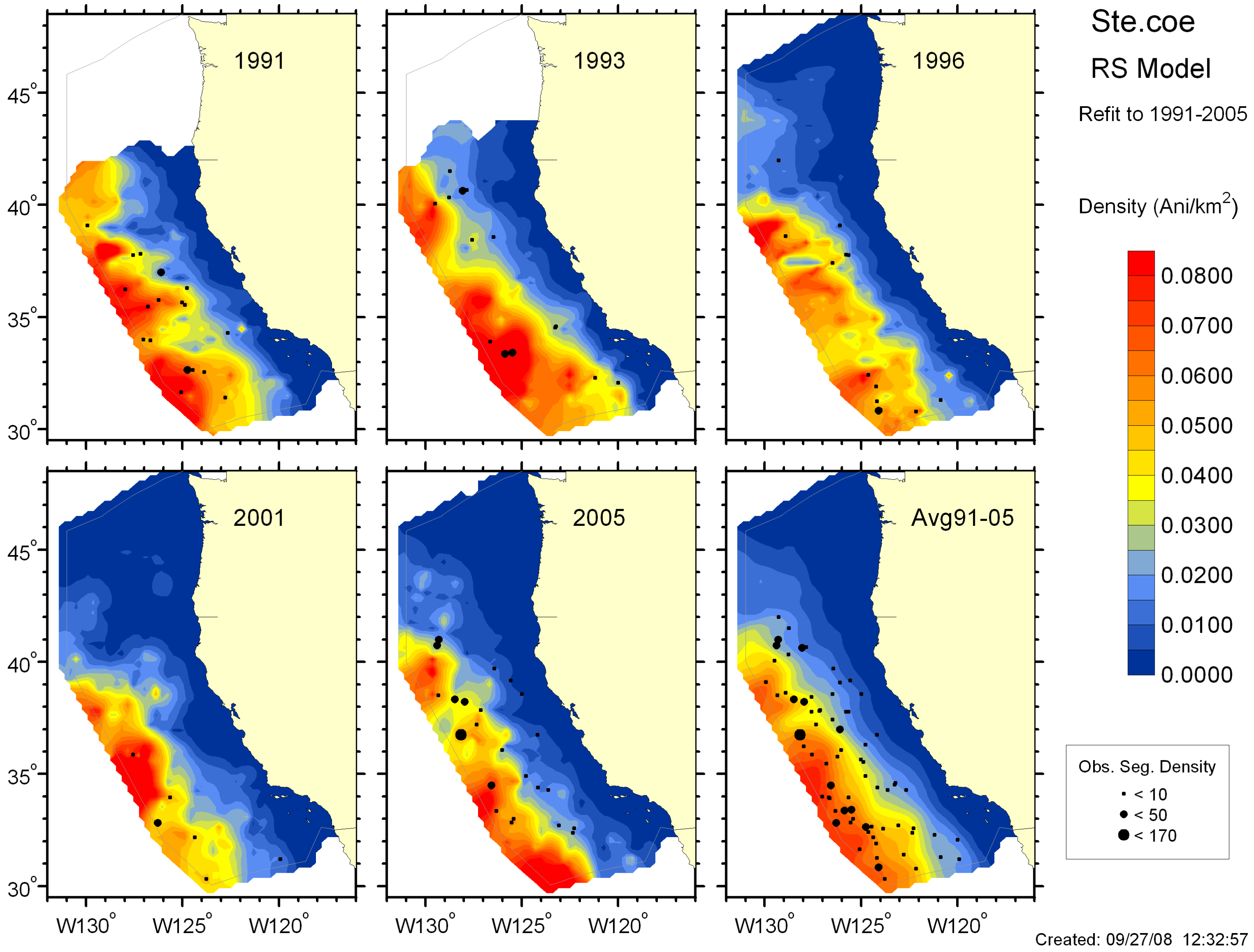

Figure A-1b. Short-beaked common dolphin

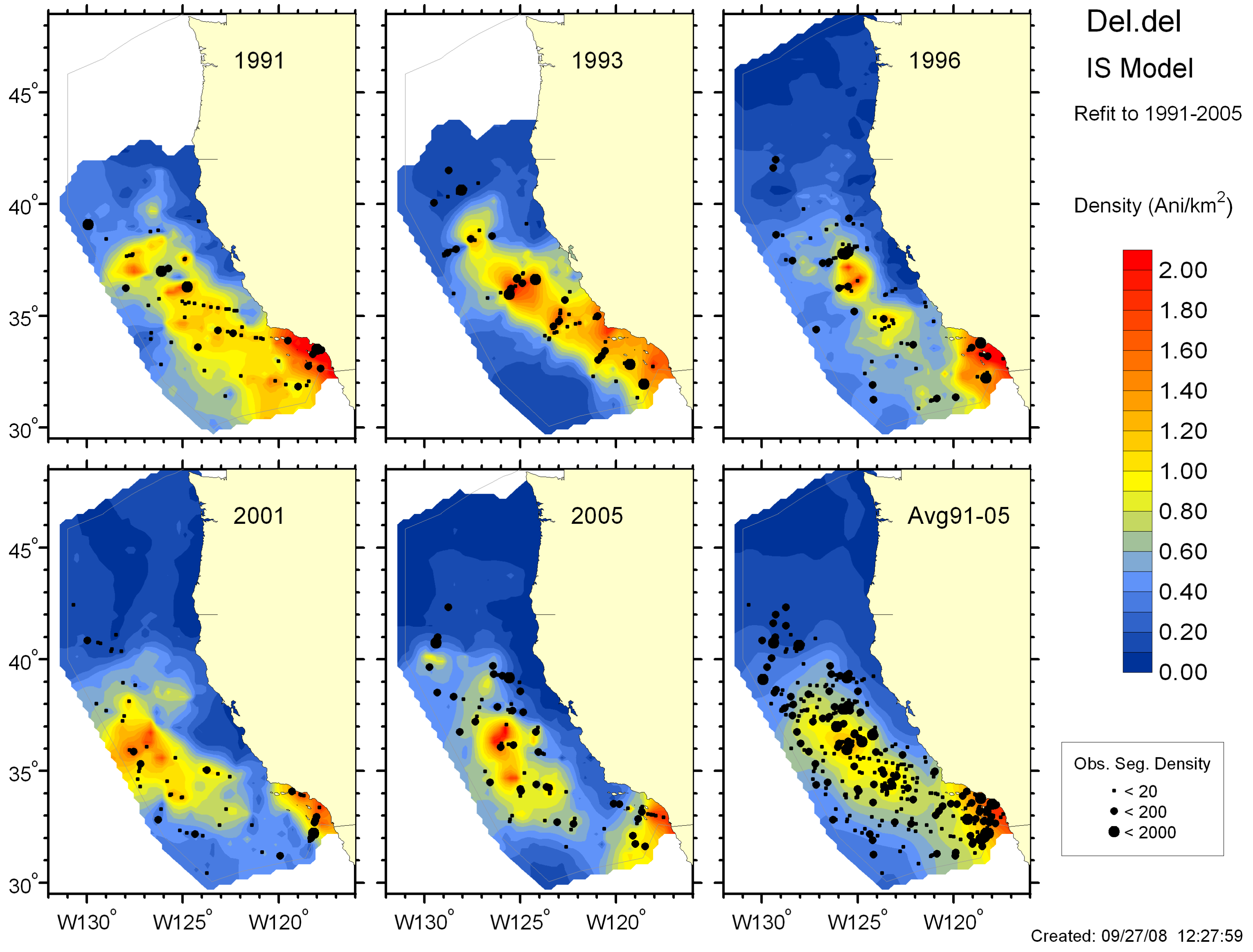

Figure A-1c. Risso's dolphin

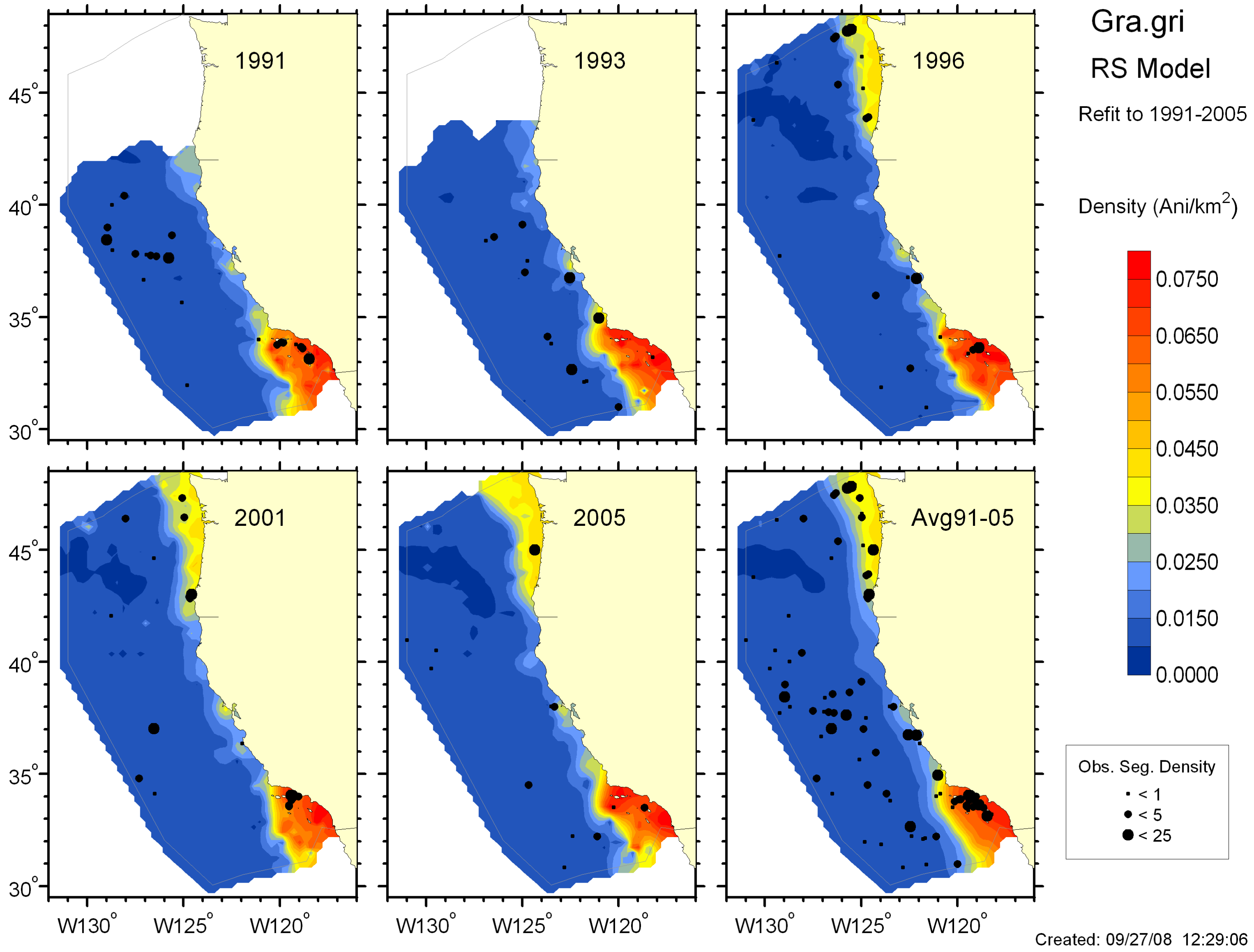

Figure A-1d. Pacific white-sided dolphin

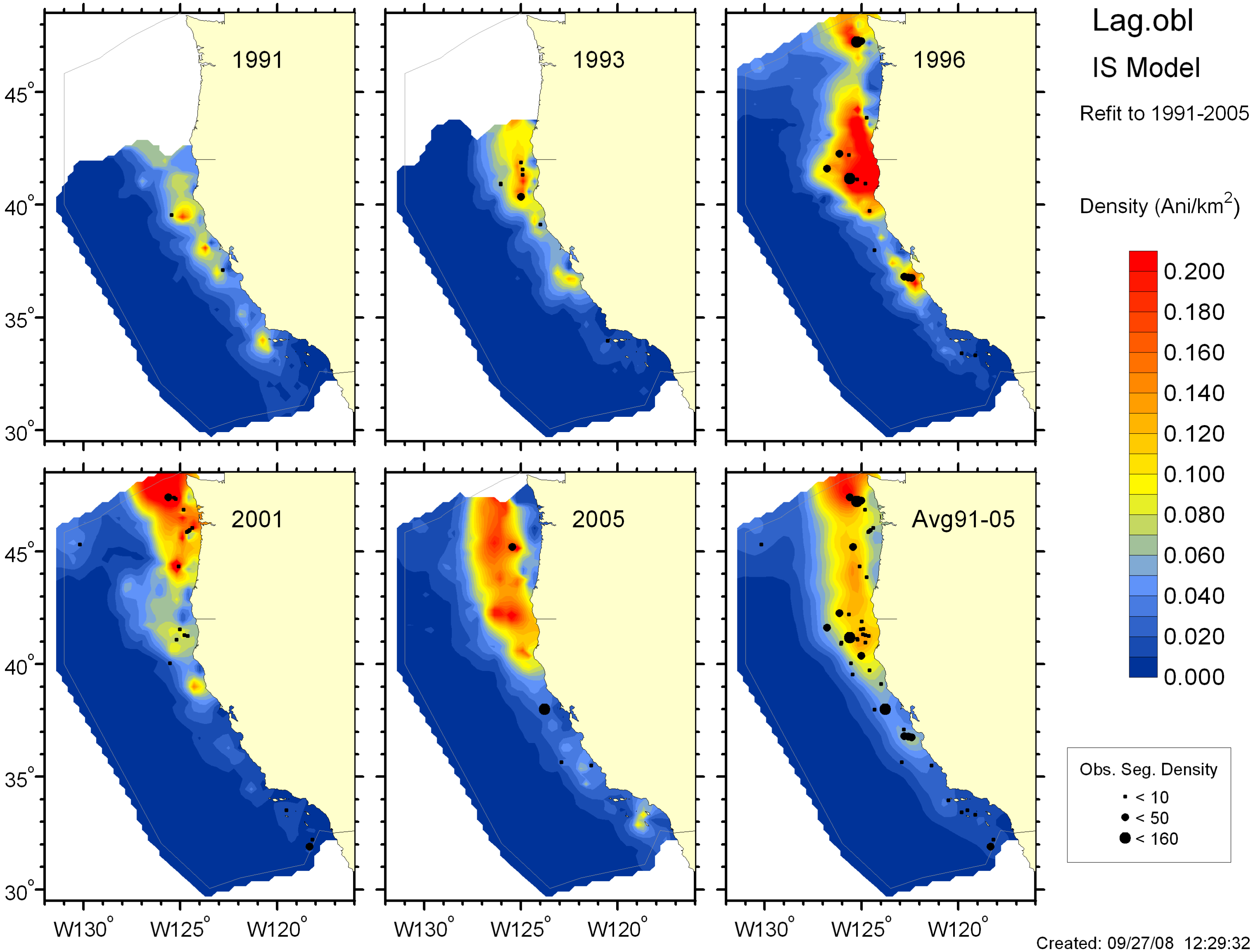

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Figure A-1e. Northern right whale dolphin

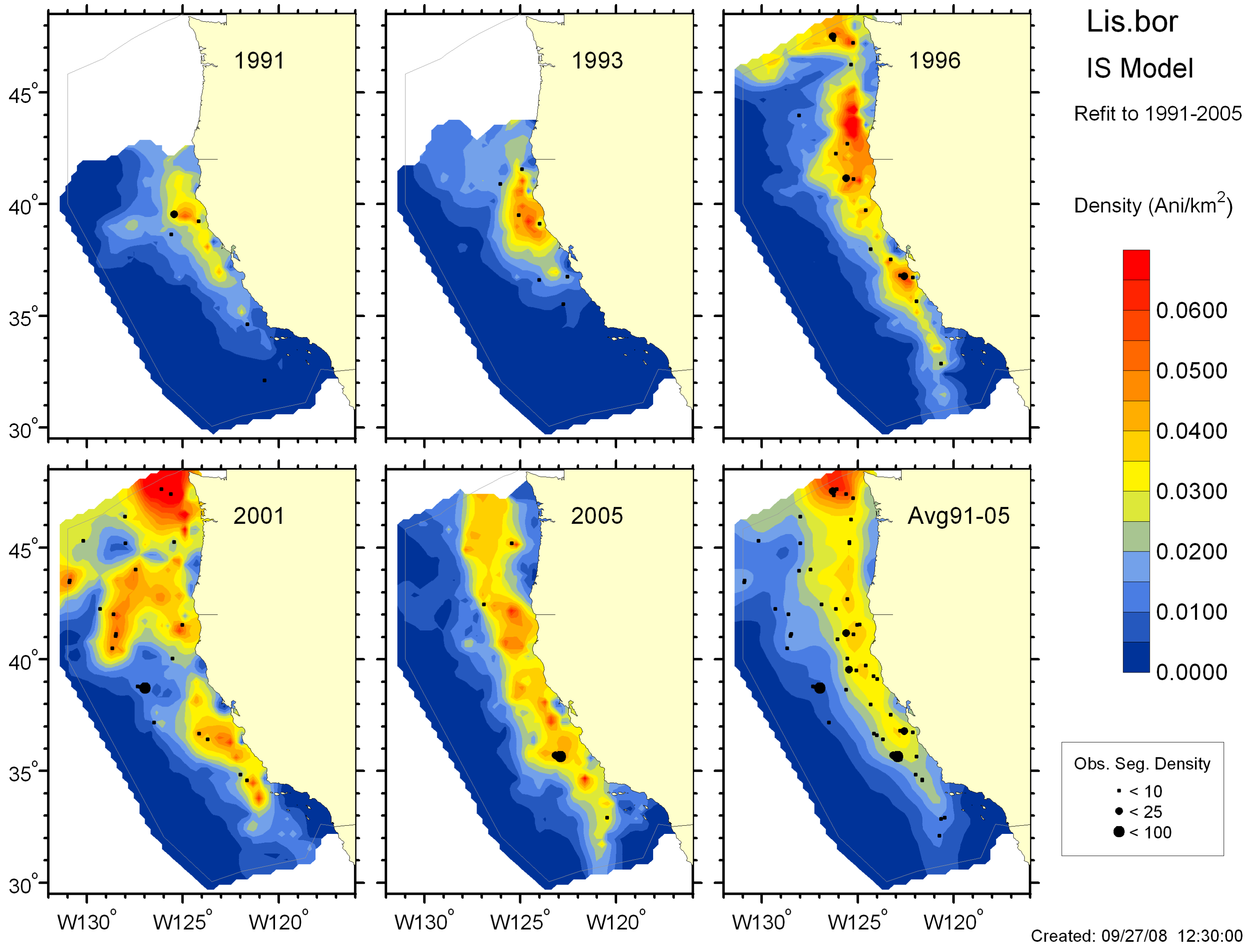


Figure A-1f. Dall's porpoise

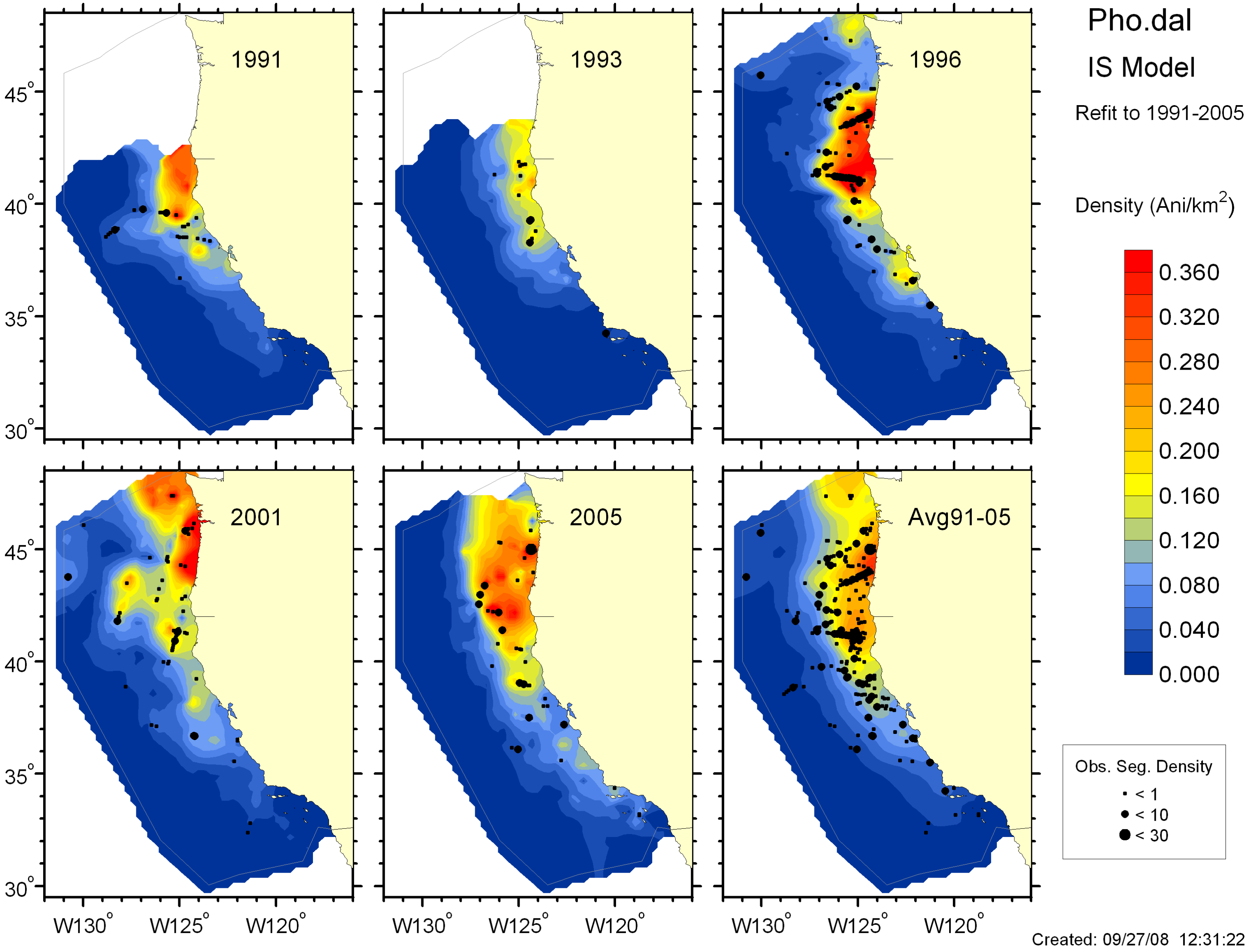


Figure A-1g. Sperm whale

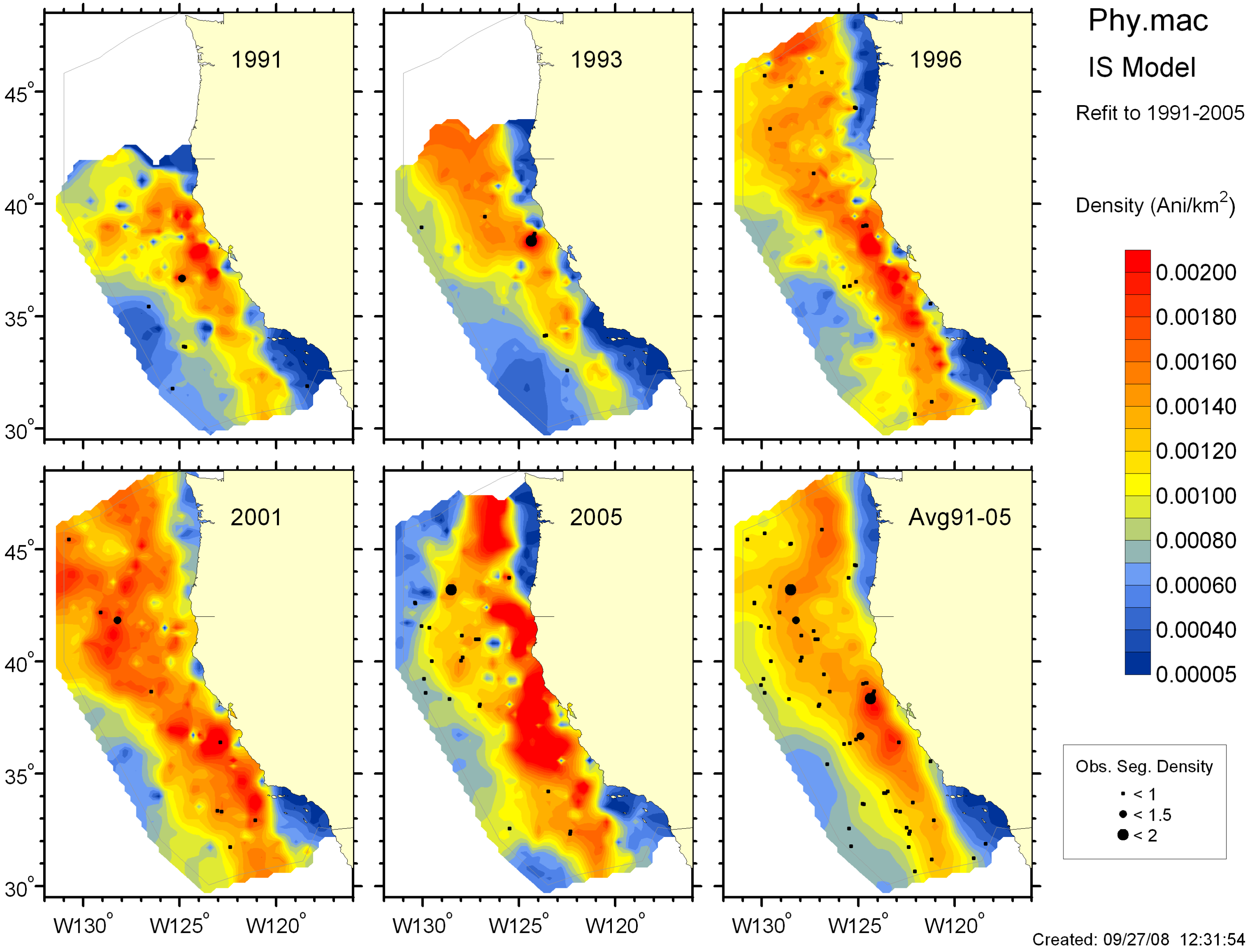


Figure A-1h. Fin whale

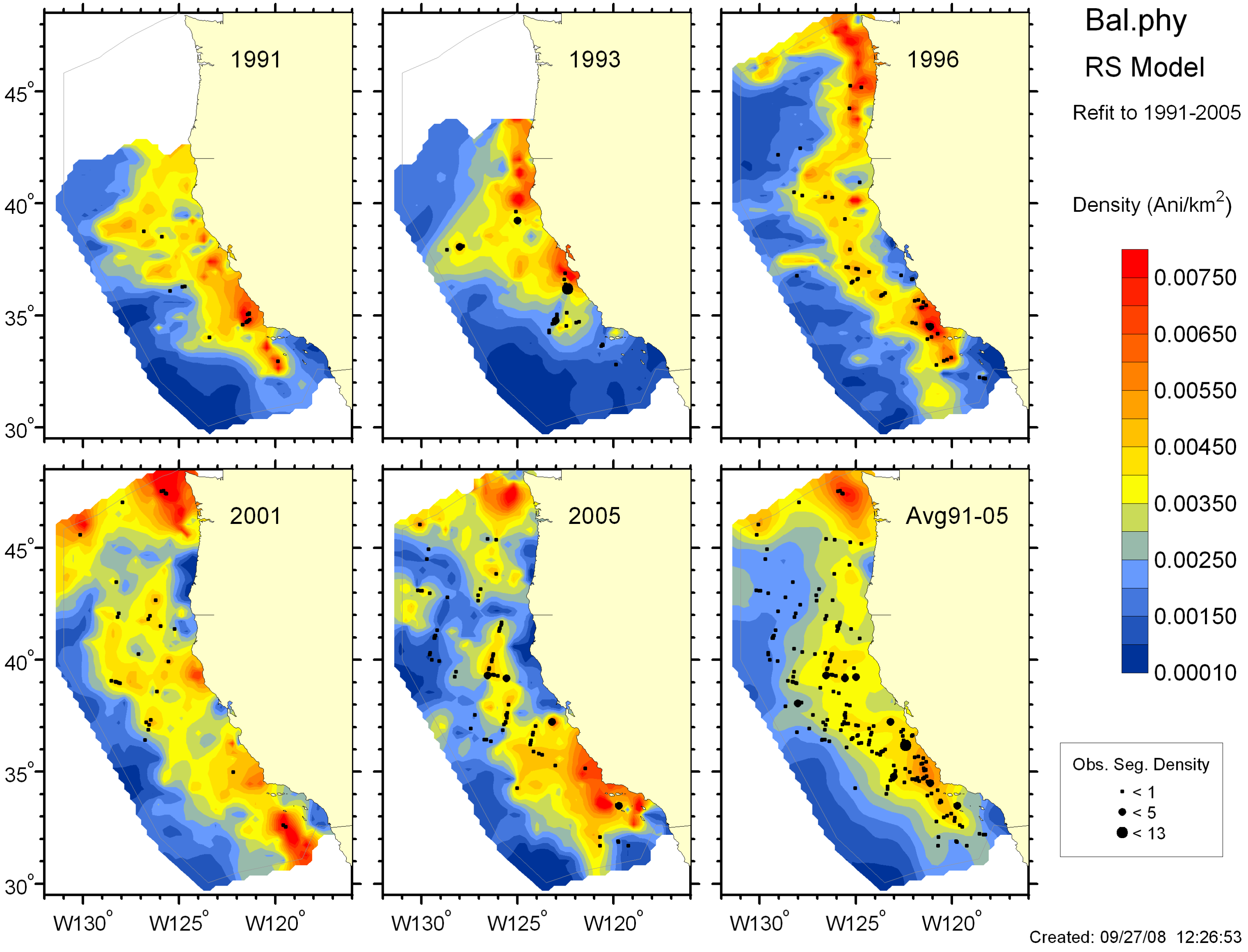


Figure A-1i. Blue whale

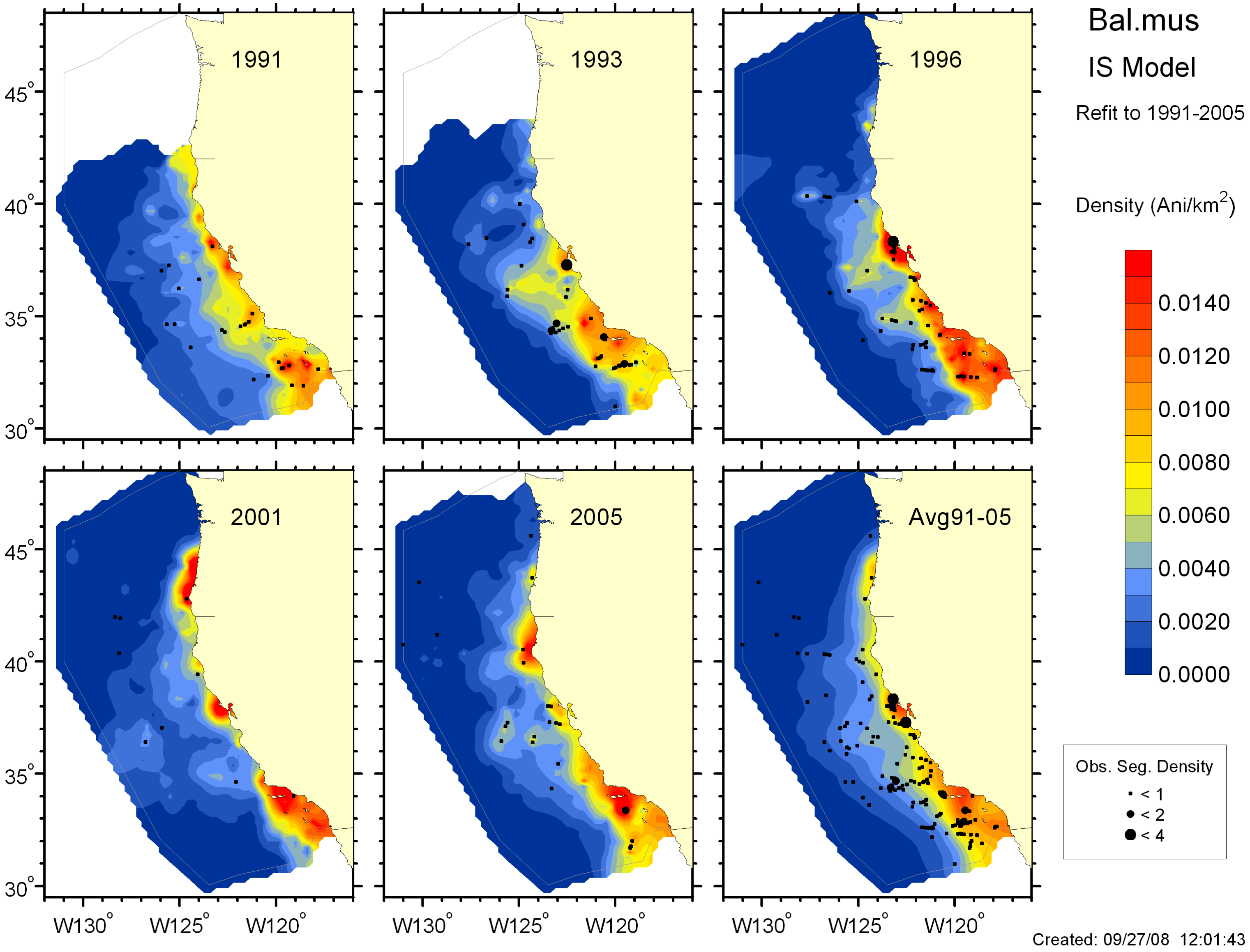


Figure A-1j. Humpback whale

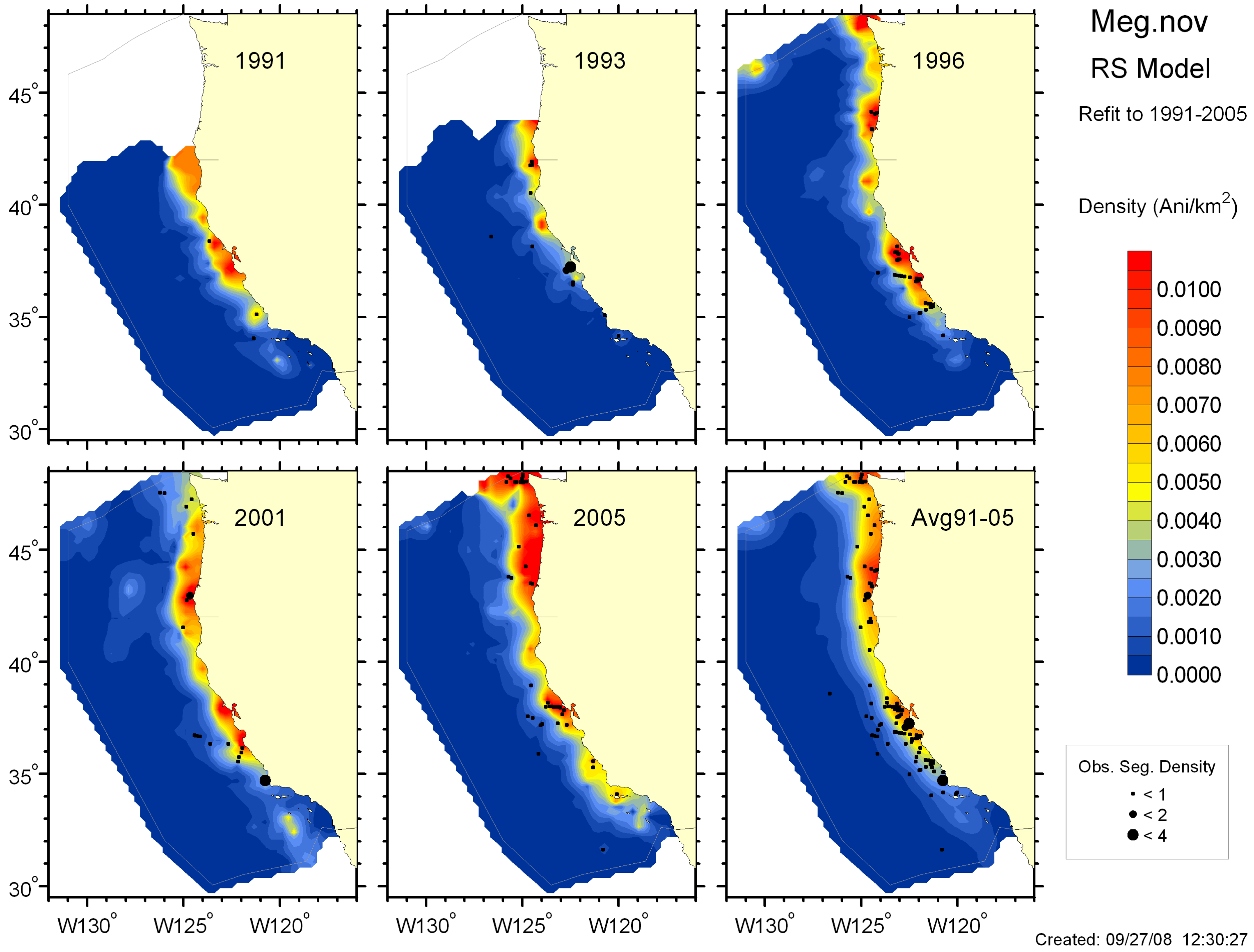


Figure A-1k. Baird's beaked whale

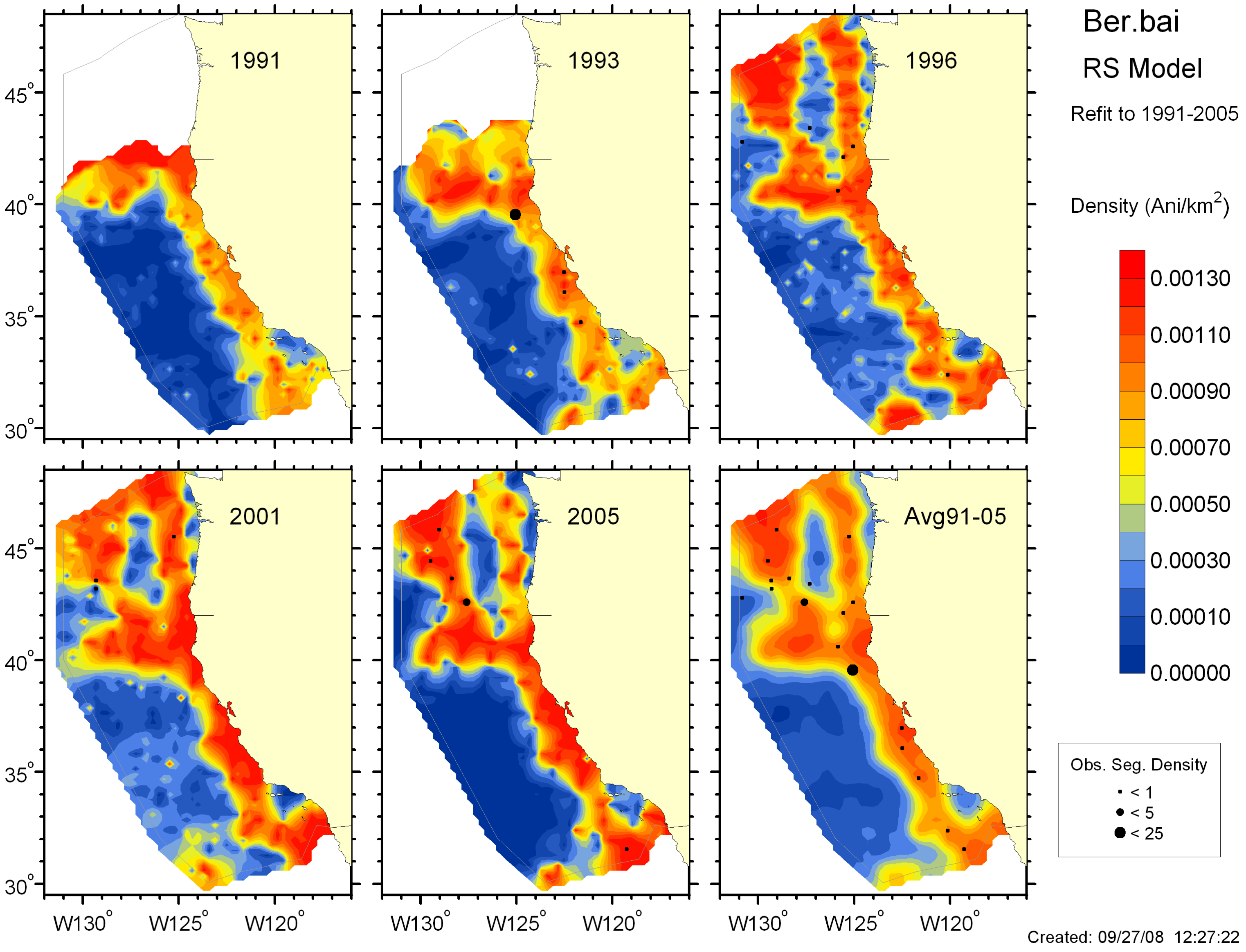


Figure A-1l. Small beaked whales

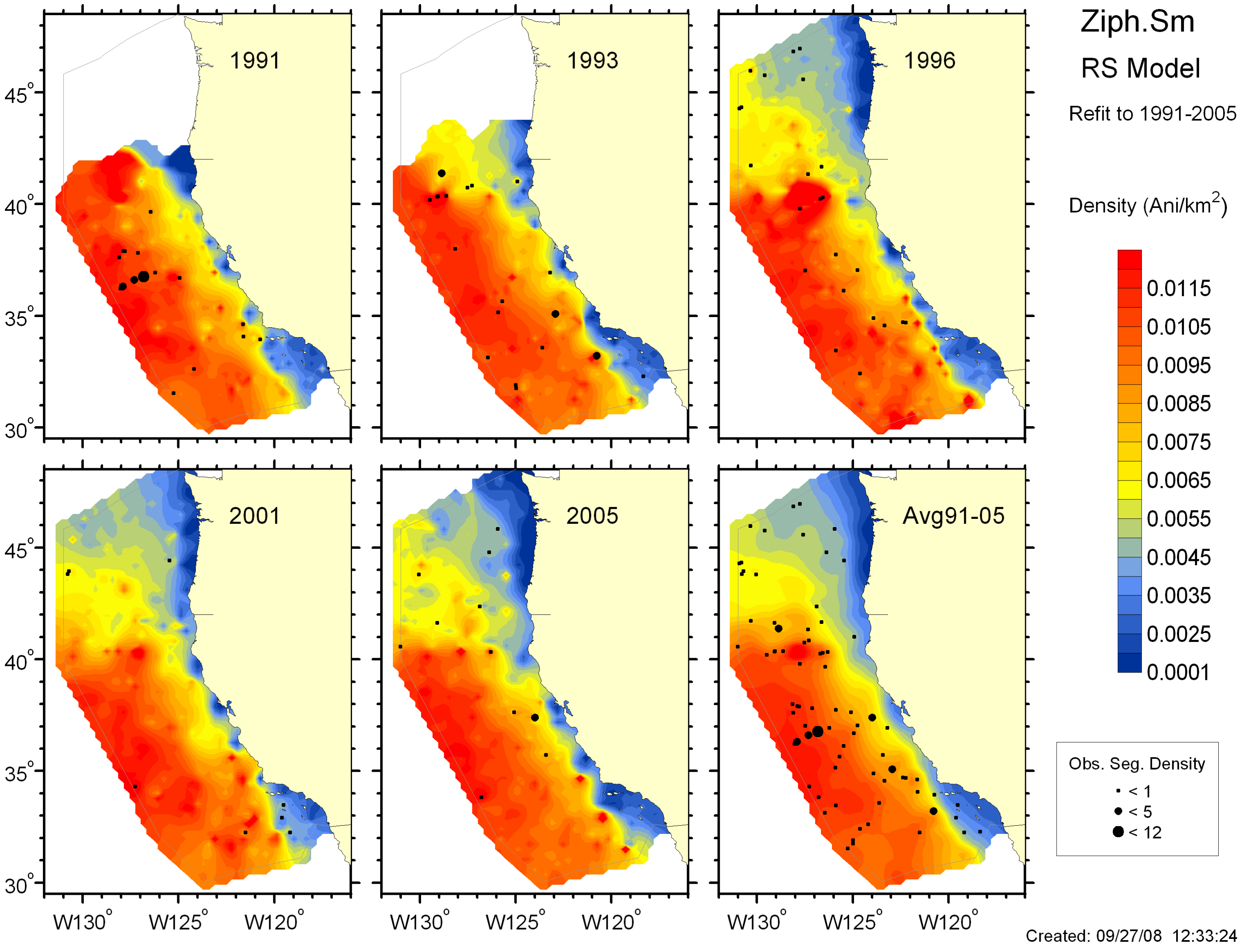


Figure A-2. Predicted average density (AveDens), standard error (SE(Dens), and upper and lower lognormal 90% confidence limits(Lo90% and Hi90%) based on the final CCE models for: (a) striped dolphin (*Stenella coeruleoalba*), (b) short-beaked common dolphin (*Delphinus delphis*), (c) Risso's dolphin (*Grampus griseus*), (d) Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), (e) northern right whale dolphin (*Lissodelphis borealis*), (f) Dall's porpoise (*Phocoenoides dalli*), (g) sperm whale (*Physeter macrocephalus*), (h) fin whale (*Balaenoptera physalus*), (i) blue whale (*Balaenoptera musculus*), (j) humpback whale (*Megaptera novaeangliae*), (k) Baird's beaked whale (*Berardius bairdii*), and (l) small beaked whales (*Ziphius and Mesoplodon*). Grid cells for each of the individual survey years were averaged across all years to calculate average species density; standard errors and upper and lower lognormal 90% confidence limits were calculated from the grid cell averages and variances using standard formulae. Predicted values were then smoothed using inverse distance weighting (see Section 3.5.1 for details).

Figure A-2a. Striped dolphin

SWFSC_1_CCE_25km_Ste.coe_RS_Summer_DensitywithVar4Panel.srf

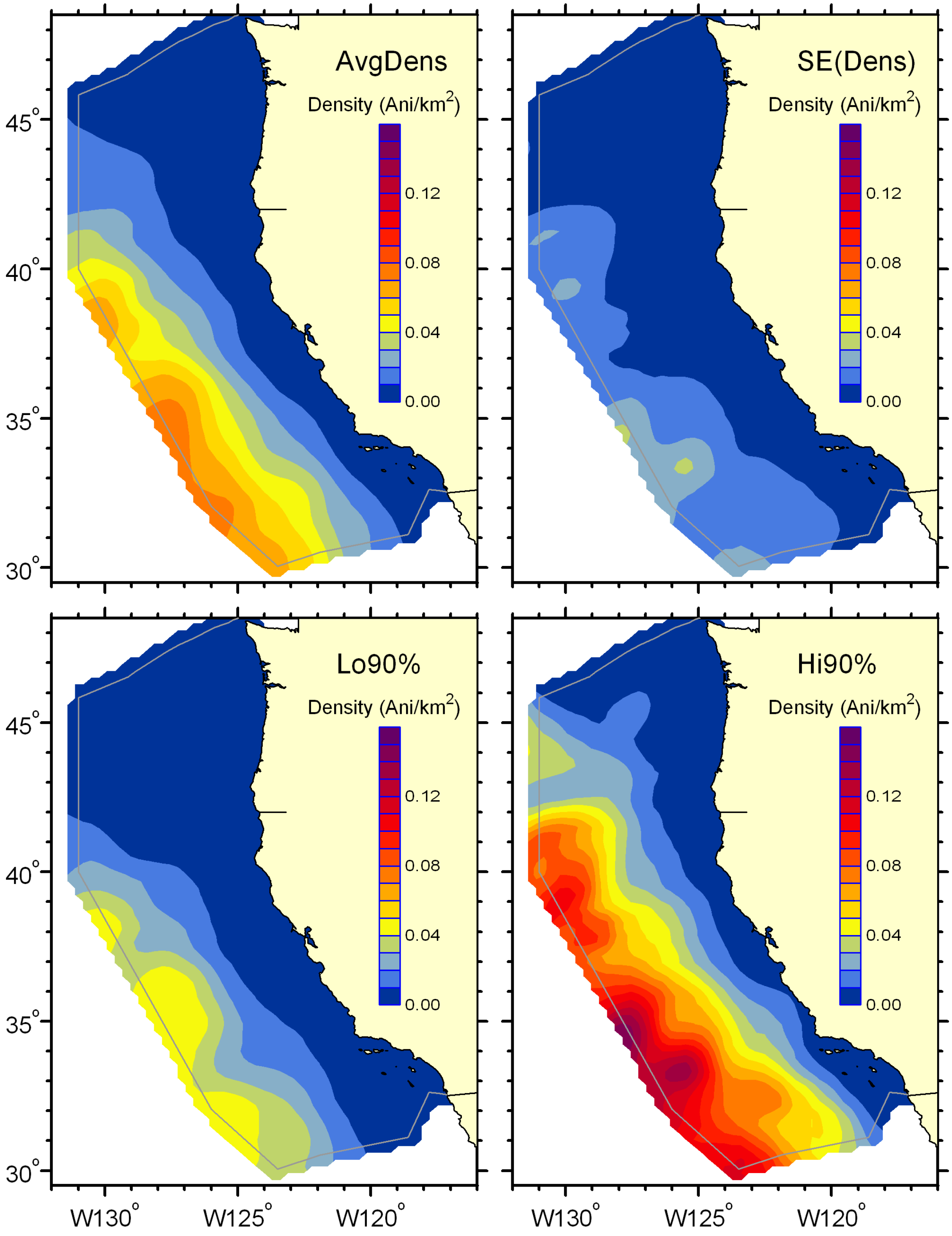


Figure A-2b. Short-beaked common dolphin

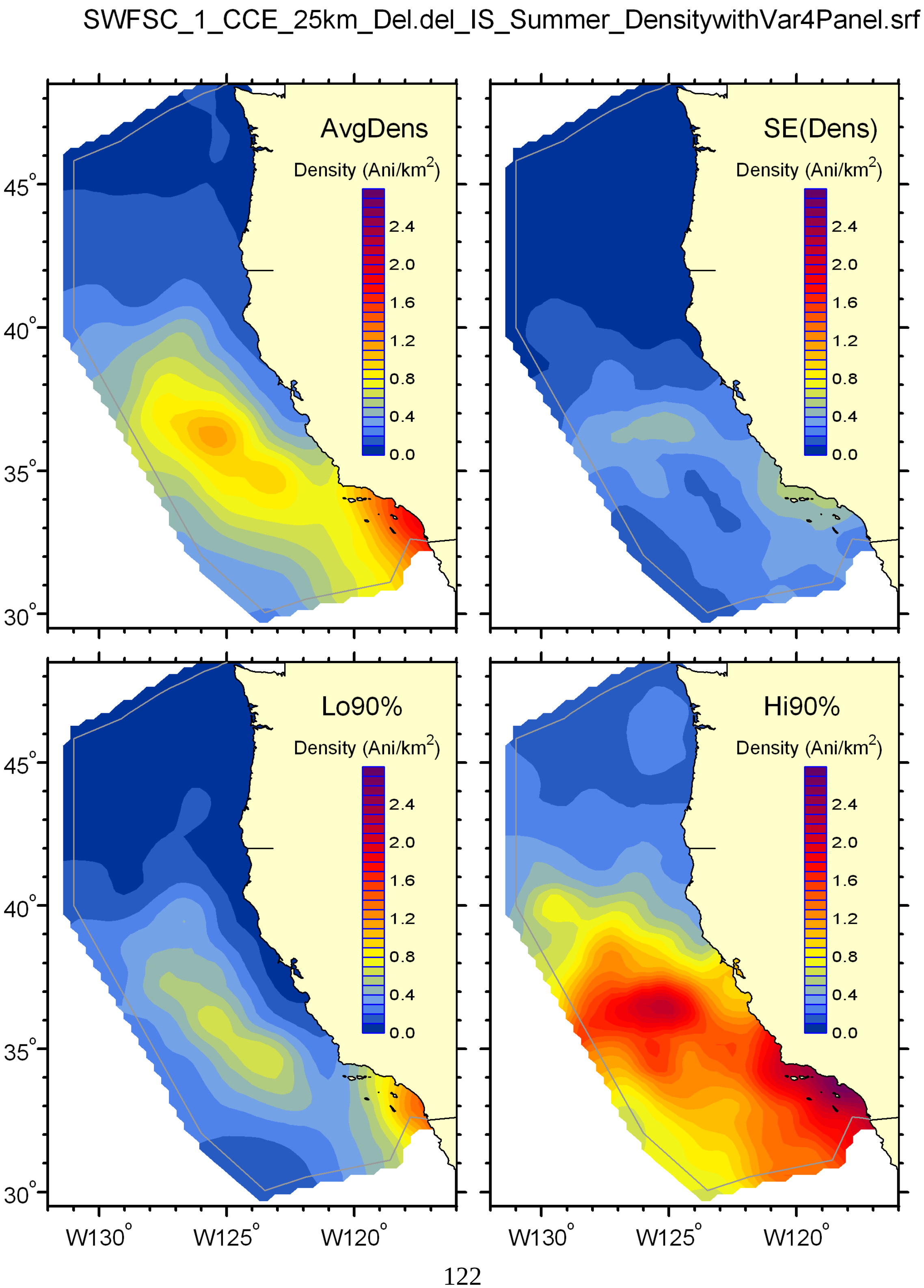


Figure A-2c. Risso's dolphin

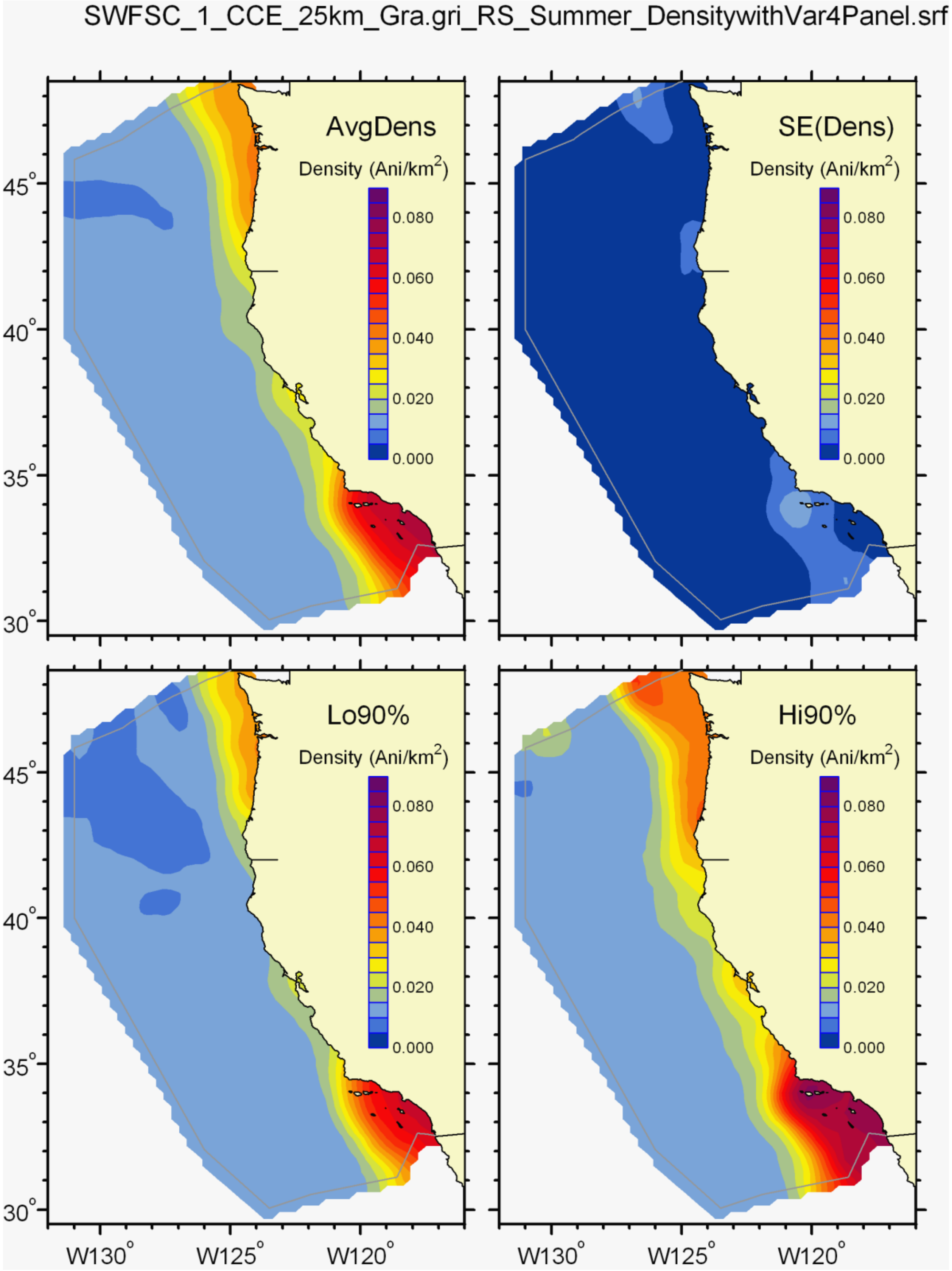


Figure A-2d. Pacific white-sided dolphin

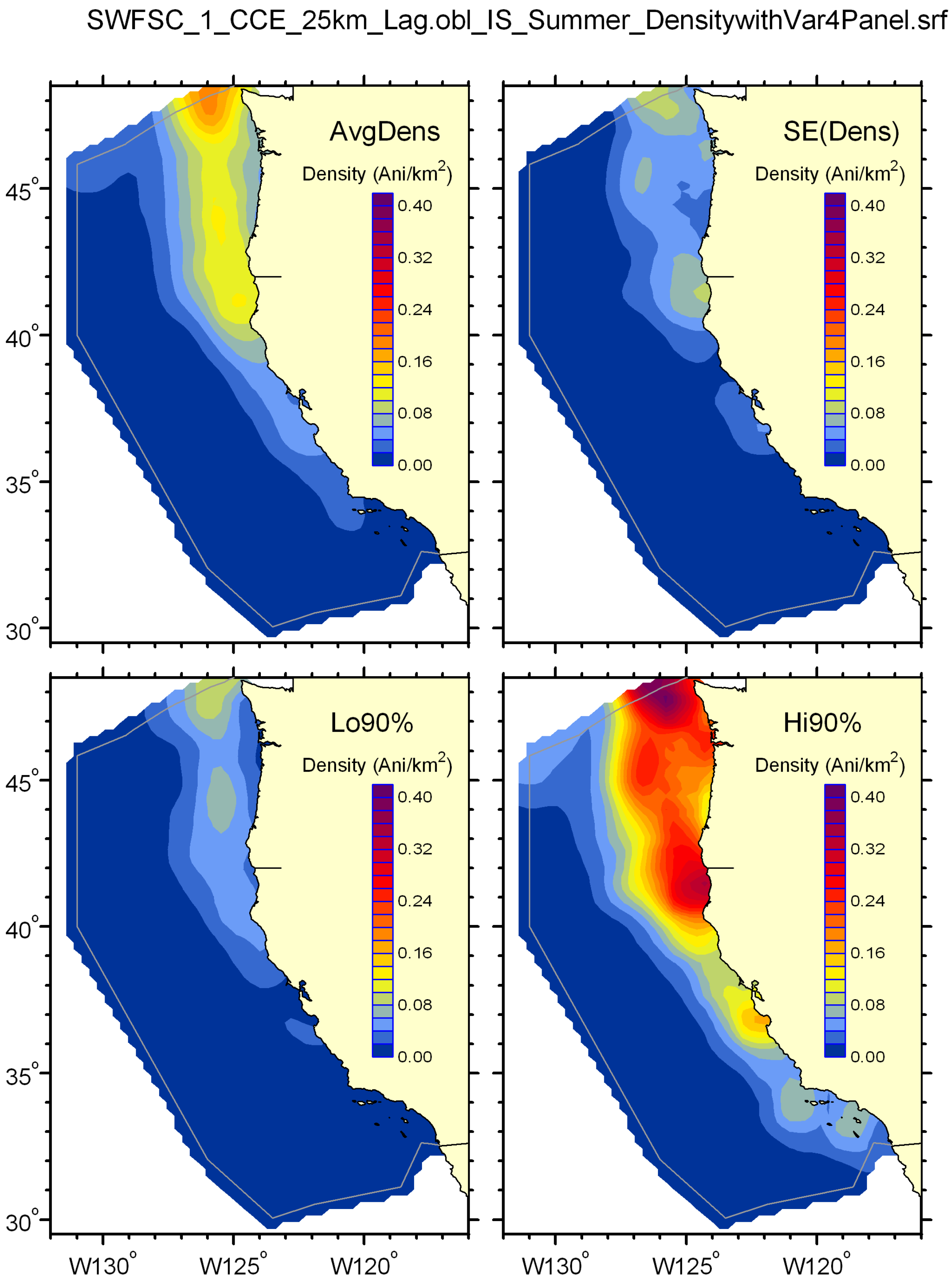


Figure A-2e. Northern right whale dolphin

SWFSC_1_CCE_25km_Lis.bor_IS_Summer_DensitywithVar4Panel.srf

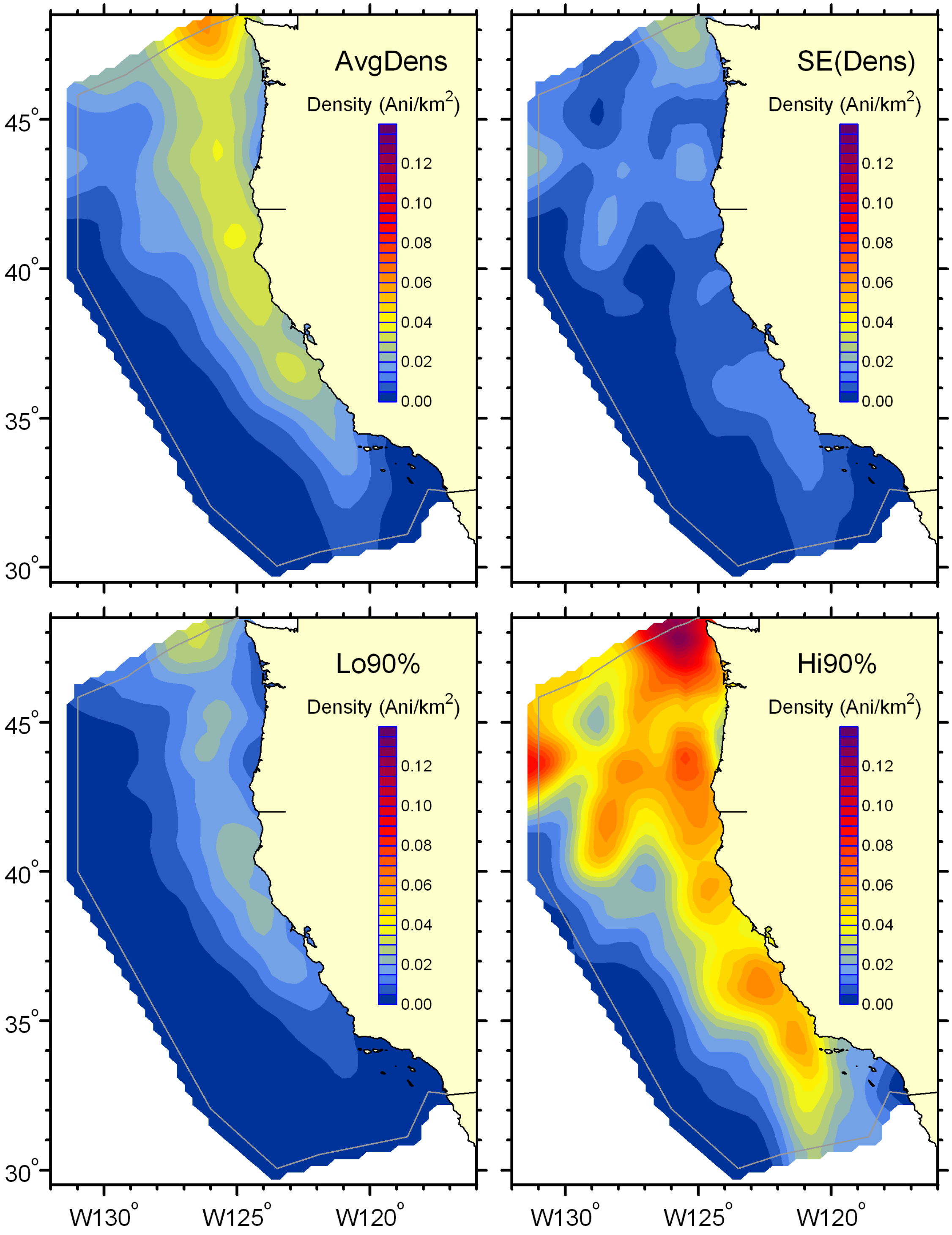


Figure A-2f. Dall's porpoise

SWFSC_1_CCE_25km_Pho.dal_IS_Summer_DensitywithVar4Panel.srf

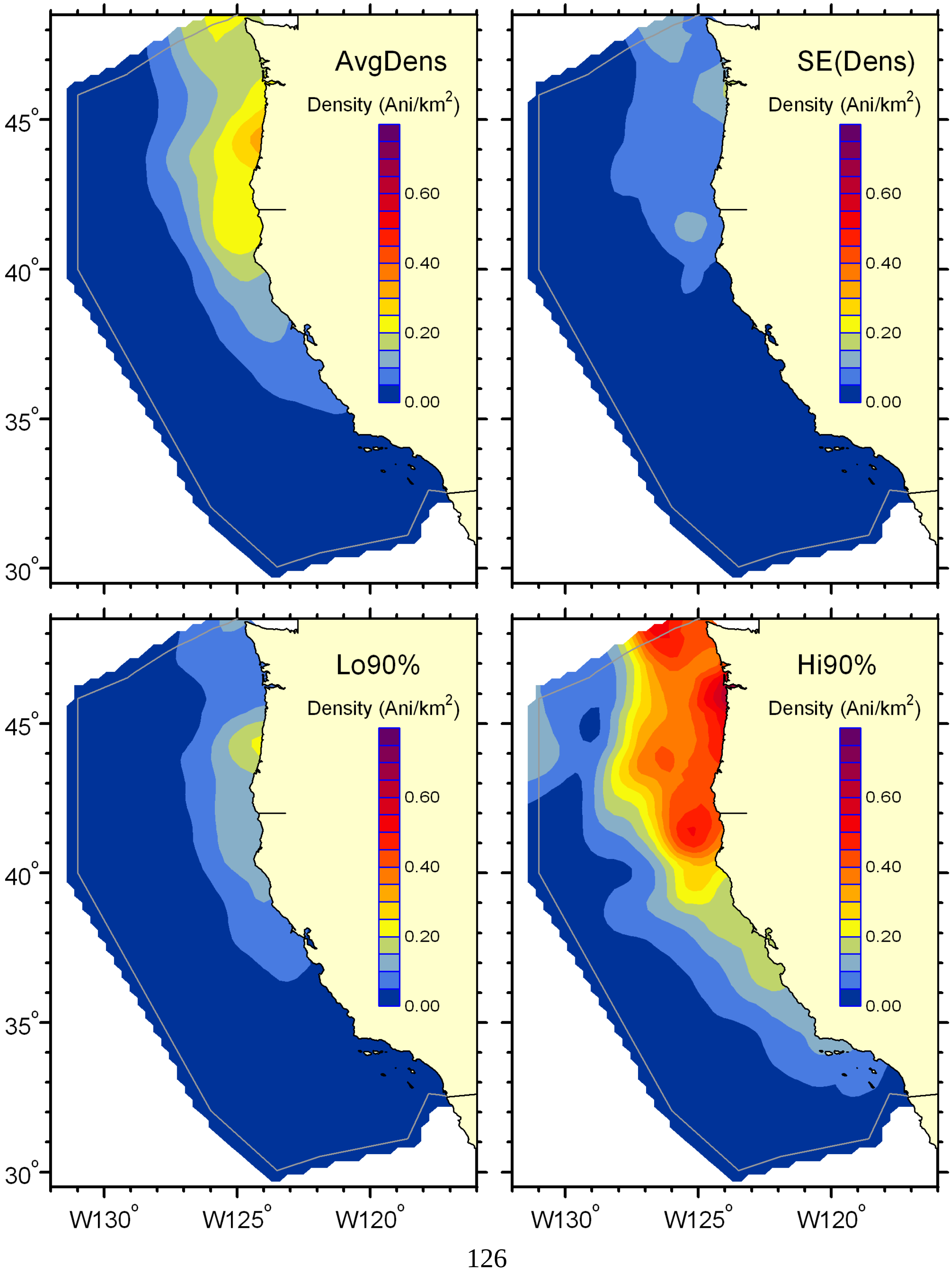


Figure A-2g. Sperm whale

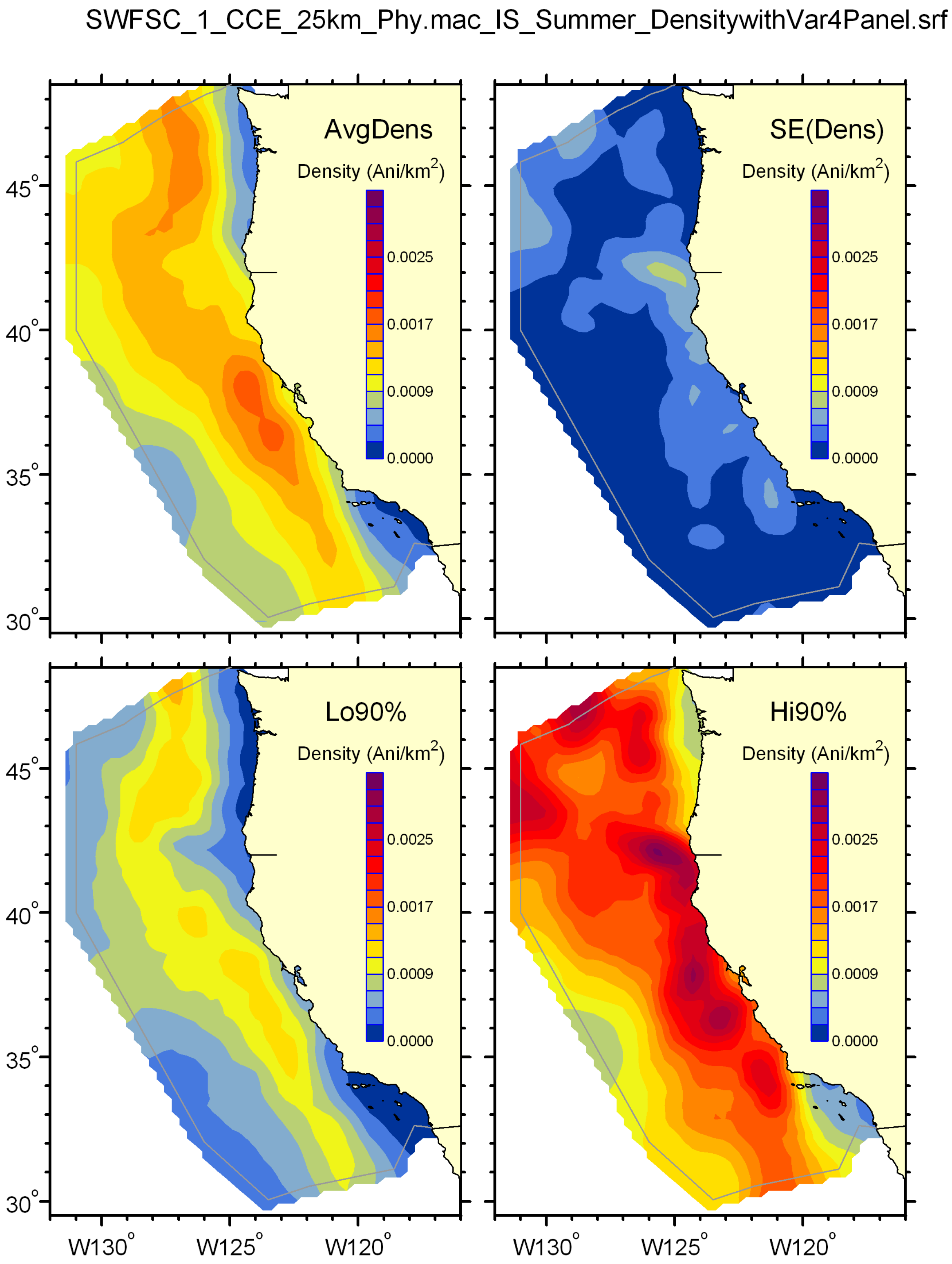


Figure A-2h. Fin whale

SWFSC_1_CCE_25km_Bal.phy_RS_Summer_DensitywithVar4Panel.srf

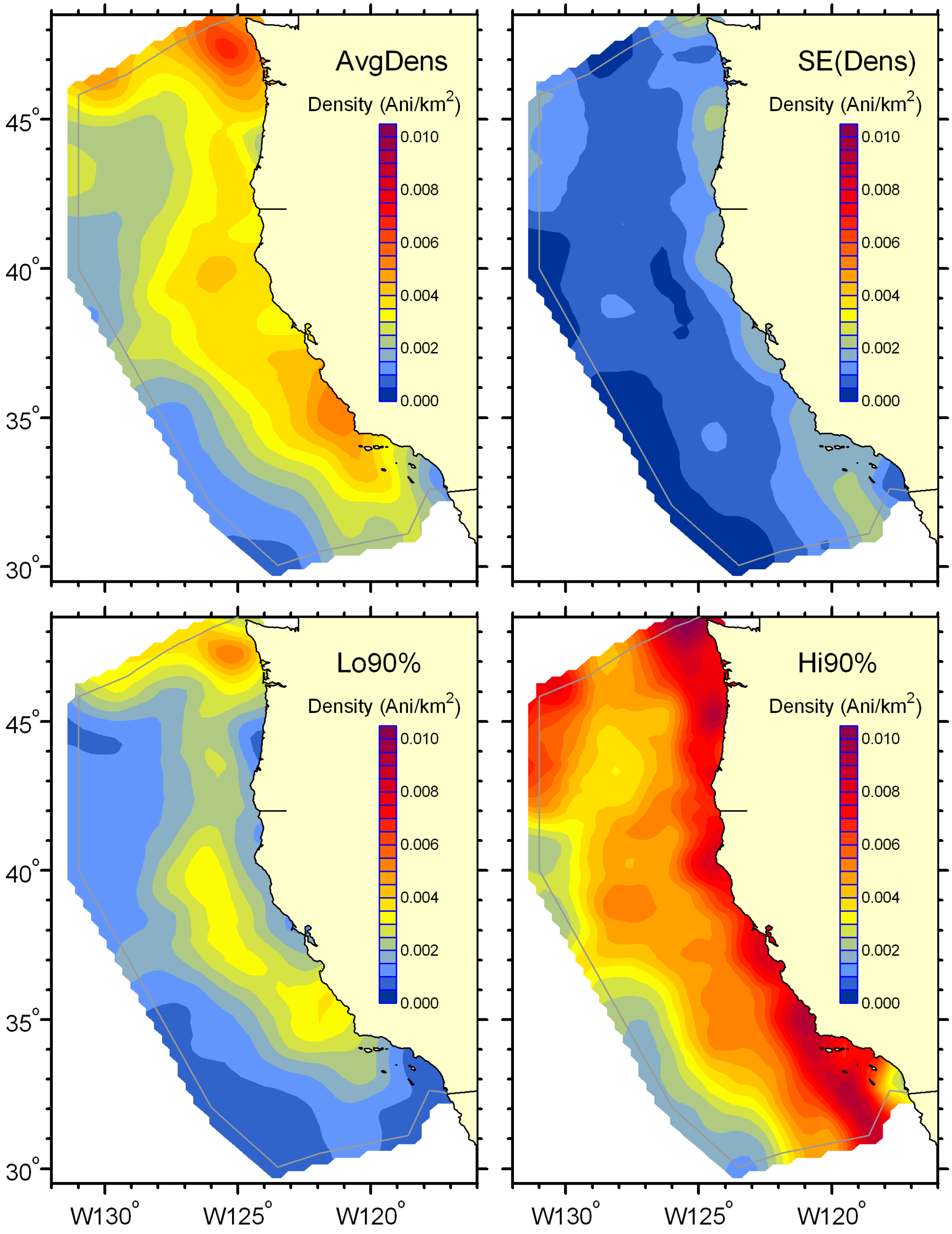


Figure A-2i. Blue whale

SWFSC_1_CCE_25km_Bal.mus_IS_Summer_DensitywithVar4Panel.srf

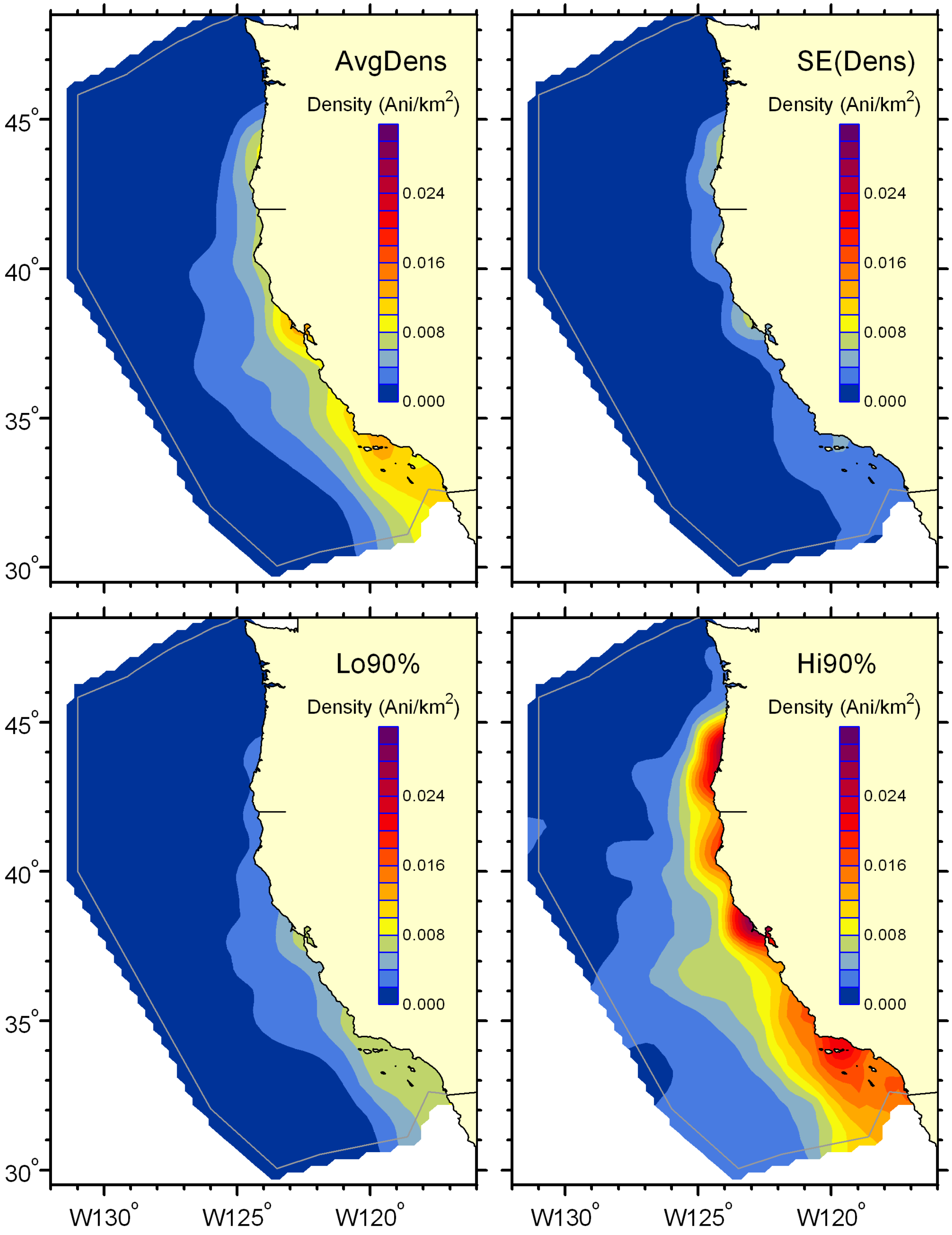


Figure A-2j. Humpback whale

SWFSC_1_CCE_25km_Meg.nov_RS_Summer_DensitywithVar4Panel.srf

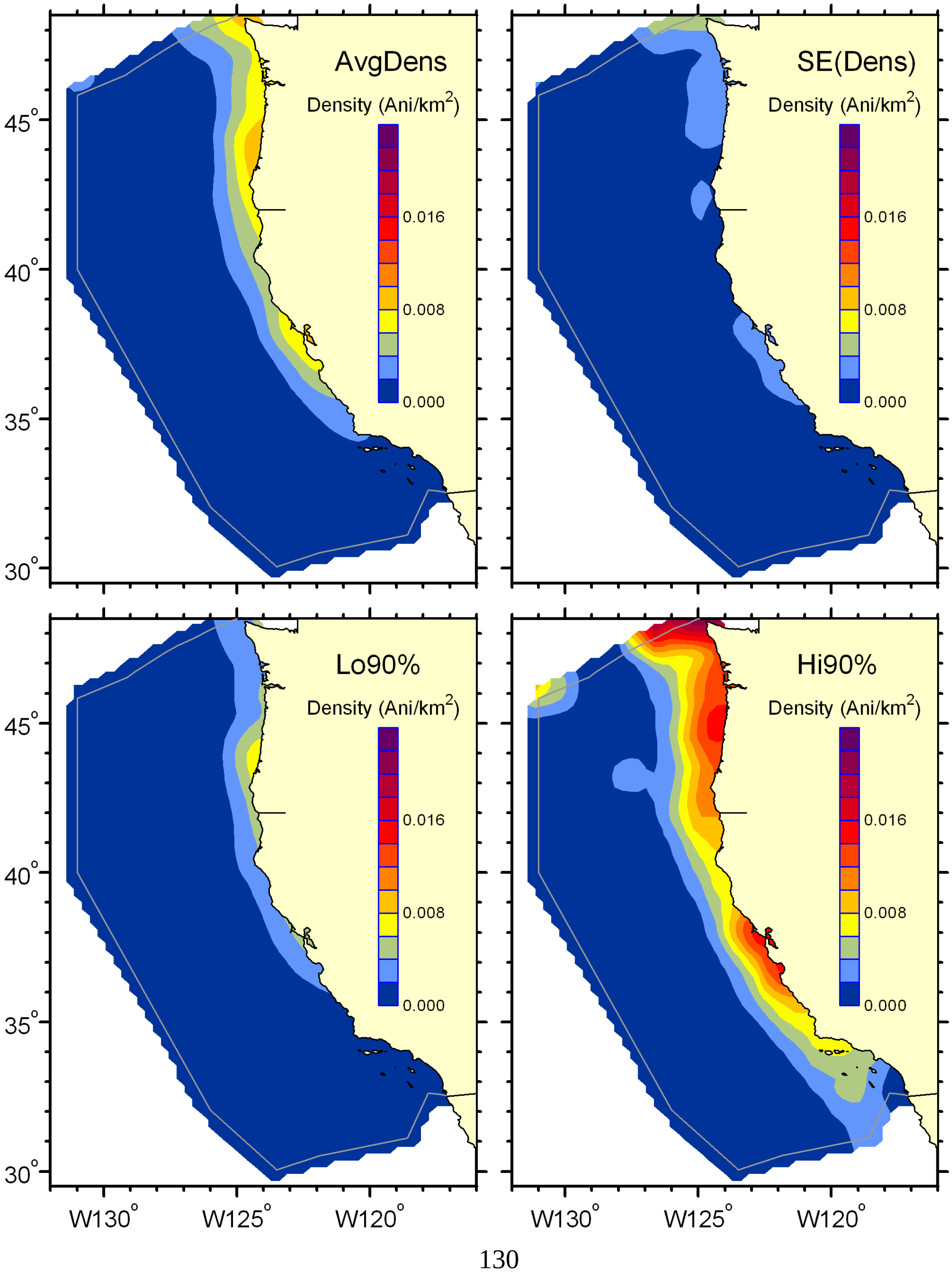


Figure A-2k. Baird's beaked whale

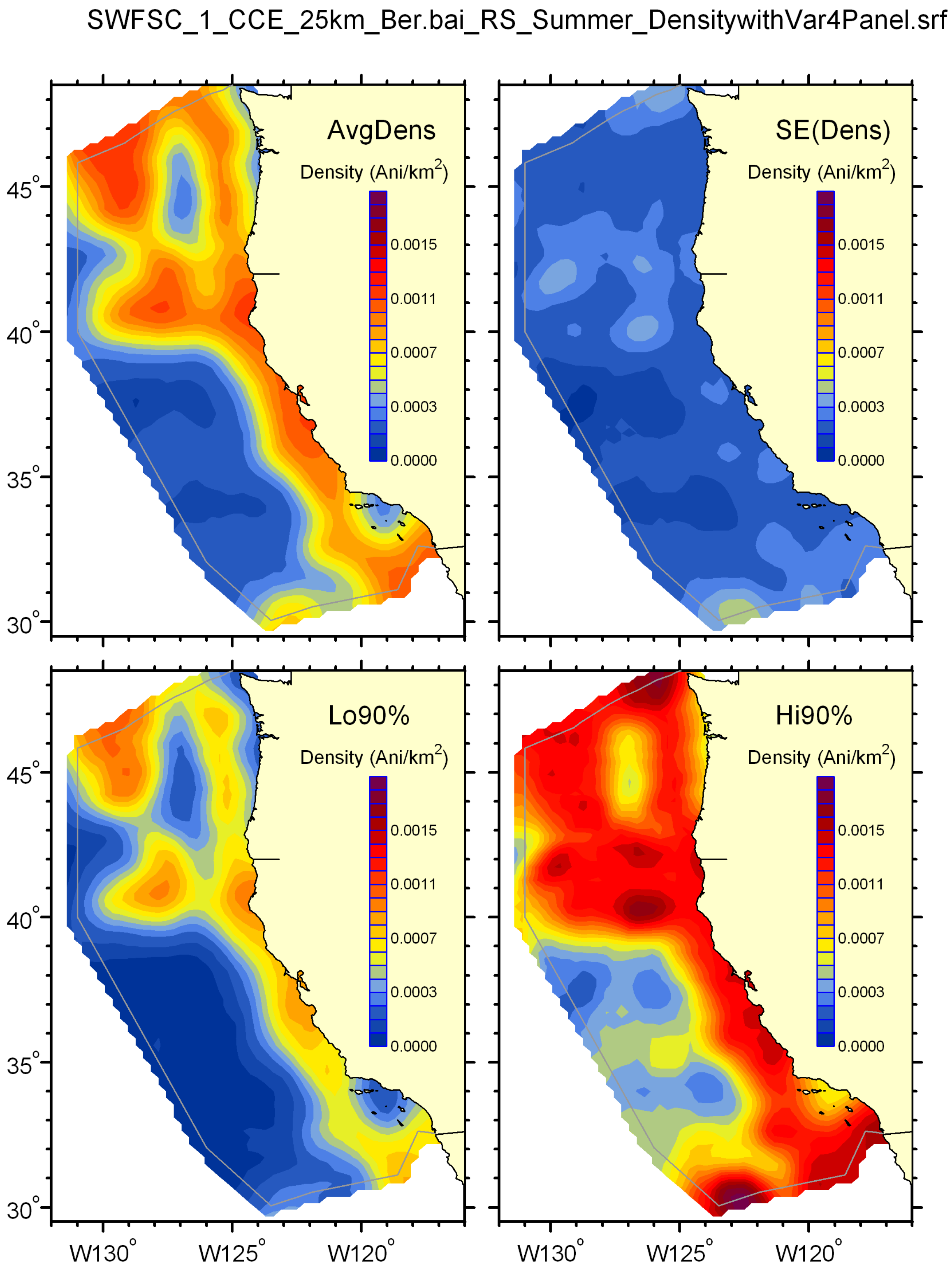
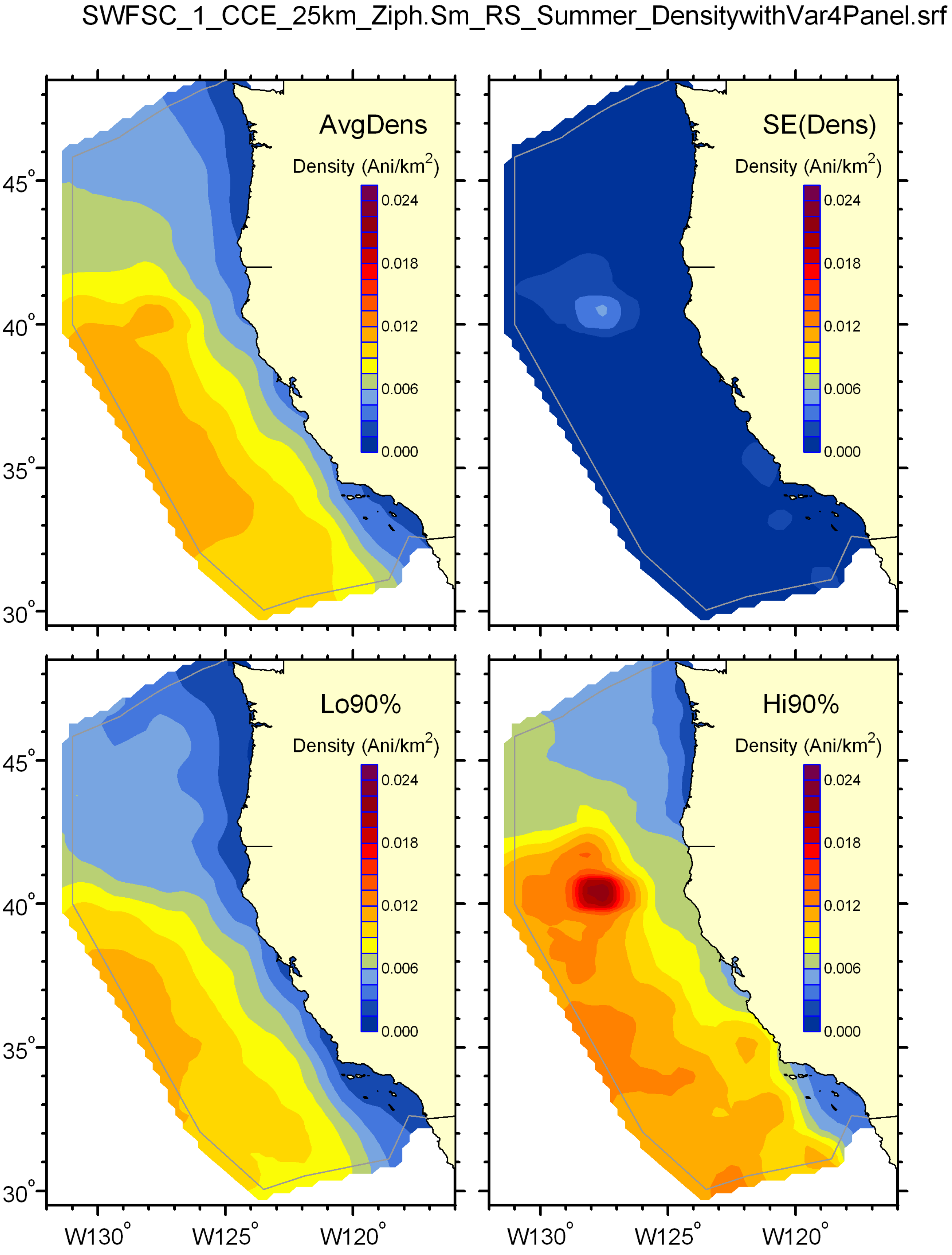


Figure A-2l. Small beaked whales



Appendix B: Detailed Model Results for the Eastern Tropical Pacific

Table B-1. Summary of model validation statistics for final offshore spotted dolphin density models in the ETP built on 1998-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1998			**1999**			**2000**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.576	1891.892	3282.351	0.773	1040.846	1346.893	0.349	676.043	1934.994
West Baja Peninsula	2.060	141.170	68.527	0.000	0.000	48.169	0.000	0.000	118.951
Equatorial Cold Tongue	0.979	1653.173	1688.505	1.007	694.095	689.443	0.758	658.106	868.238
Eastern Pacific Warm Pool	0.835	7764.942	9295.248	0.964	5388.636	5591.076	1.391	8615.090	6191.724
Oligotrophic Offshore	1.061	3144.419	2963.754	1.260	2704.267	2145.824	1.196	2749.437	2299.805
North Equatorial Countercurrent	0.939	2571.694	2737.405	1.377	2419.456	1756.725	1.147	2180.940	1901.450
North Equatorial Current	0.787	2611.924	3320.076	0.647	1512.637	2336.121	1.013	2588.480	2556.186
Study Area	0.823	14761.266	17935.898	1.003	10200.934	10170.228	1.087	12923.546	11884.147

	2003			**2006**			**All Years**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.359	1292.793	951.523	0.408	732.203	1793.012	0.605	5633.777	9308.772
West Baja Peninsula	0.000	0.000	107.592	0.000	0.000	59.872	0.350	141.170	403.110
Equatorial Cold Tongue	1.868	1064.092	569.547	0.690	721.515	1045.159	0.986	4790.981	4860.891
Eastern Pacific Warm Pool	1.218	6303.567	5174.624	1.676	7219.894	4306.944	1.155	35292.129	30559.616
Oligotrophic Offshore	0.268	225.750	843.174	0.934	1718.610	1841.029	1.044	10542.483	10093.586
North Equatorial Countercurrent	0.796	641.340	805.342	1.261	1965.699	1559.164	1.116	9779.129	8760.085
North Equatorial Current	0.471	830.093	1761.382	1.022	2034.319	1990.549	0.801	9577.454	11964.315
Study Area	1.138	8886.202	7811.586	1.102	10650.626	9669.171	0.999	57422.573	57471.029

Table B-2. Summary of model validation statistics for final eastern spinner dolphin density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			1987			1988		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	2.884	2160.047	748.974	0.846	330.287	390.329	0.089	24.000	270.598
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	0.052
Equatorial Cold Tongue	0.000	0.000	42.954	0.000	0.000	56.067	0.000	0.000	28.626
Eastern Pacific Warm Pool	0.590	2094.445	3551.730	1.212	1598.600	1318.601	1.011	1643.102	1625.583
Oligotrophic Offshore	7.928	350.460	44.206	0.361	86.100	238.486	0.000	0.000	131.800
North Equatorial Countercurrent	0.000	0.000	137.006	0.328	109.167	332.839	0.656	172.967	263.651
North Equatorial Current	1.522	1072.337	704.679	2.945	1088.835	369.670	0.223	65.400	292.643
Study Area	1.049	4604.952	4387.864	1.008	2014.987	1999.433	0.810	1667.102	2057.158

	1989			1990			1998		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.478	252.907	529.456	0.569	271.870	477.470	1.875	2961.355	1579.353
West Baja Peninsula	0.000	0.000	8.382	NA	NA	NA	1.828	178.830	97.815
Equatorial Cold Tongue	0.000	0.000	36.126	0.798	34.750	43.545	0.509	37.500	73.736
Eastern Pacific Warm Pool	0.799	3040.564	3807.065	0.717	1351.337	1885.348	0.909	5778.690	6354.898
Oligotrophic Offshore	0.000	0.000	33.181	0.101	23.583	234.067	1.862	553.763	297.379
North Equatorial Countercurrent	0.200	32.667	163.090	0.119	30.983	259.786	0.437	176.743	404.646
North Equatorial Current	0.001	1.000	696.801	0.067	23.583	350.930	1.864	2437.360	1307.296
Study Area	0.746	3293.471	4414.213	0.637	1681.540	2640.548	1.132	9510.137	8404.327

	1999			2000			2003		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.409	247.346	604.597	0.880	898.855	1021.253	0.854	729.339	853.671
West Baja Peninsula	0.000	0.000	9.881	0.000	0.000	32.260	0.000	0.000	56.165
Equatorial Cold Tongue	0.000	0.000	17.041	0.000	0.000	11.727	0.000	0.000	11.861
Eastern Pacific Warm Pool	0.985	4364.758	4432.719	1.124	5091.692	4531.250	1.531	6232.128	4069.902
Oligotrophic Offshore	0.000	0.000	117.464	0.000	0.000	234.035	2.394	342.583	143.120
North Equatorial Countercurrent	0.152	33.000	217.445	0.470	142.750	304.038	2.112	439.417	208.064
North Equatorial Current	0.821	549.947	669.467	0.703	589.050	838.028	3.291	2287.533	695.138
Study Area	0.888	4612.104	5193.253	1.027	5990.547	5831.324	1.423	7304.050	5134.433

Table B-2 cont. Summary of model validation statistics for final eastern spinner dolphin density models in the ETP.

Stratum	2006			All Years		
	Obs/Pred	Obs	Pred	Obs/Pred	Obs	Pred
Costa Rica Dome	1.393	1131.250	812.208	1.236	9007.256	7287.909
West Baja Peninsula	0.000	0.000	2.677	0.863	178.830	207.232
Equatorial Cold Tongue	0.000	0.000	21.343	0.211	72.250	343.026
Eastern Pacific Warm Pool	2.632	6784.450	2578.031	1.112	37979.766	34155.128
Oligotrophic Offshore	6.558	1438.560	219.347	1.651	2795.049	1693.086
North Equatorial Countercurrent	4.099	1820.673	444.162	1.082	2958.367	2734.727
North Equatorial Current	4.124	2081.537	504.763	1.586	10196.582	6429.416
Study Area	2.573	9354.260	3635.110	1.145	50033.150	43697.662

Table B-3. Summary of model validation statistics for final whitebelly spinner dolphin density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			1987			1988		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.000	0.000	57.913	0.000	0.000	16.453	0.000	0.000	31.464
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	5.455
Equatorial Cold Tongue	4.230	1321.945	312.535	2.193	846.227	385.954	1.038	609.640	587.575
Eastern Pacific Warm Pool	0.274	49.250	179.959	0.102	17.160	168.887	0.591	174.866	295.964
Oligotrophic Offshore	1.220	693.970	568.837	0.784	545.317	695.529	1.661	1918.831	1154.962
North Equatorial Countercurrent	1.486	419.500	282.296	0.675	205.393	304.363	0.930	360.570	387.816
North Equatorial Current	0.770	274.470	356.667	0.694	357.084	514.432	1.678	1661.961	990.626
Study Area	1.839	2065.165	1123.023	1.078	1408.704	1307.320	1.276	2871.533	2251.218

	1989			1990			1998		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.000	0.000	39.586	0.000	0.000	36.252	0.460	36.333	79.063
West Baja Peninsula	0.000	0.000	9.994	NA	NA	NA	0.000	0.000	1.801
Equatorial Cold Tongue	4.012	1609.096	401.054	0.647	611.243	944.464	0.393	269.950	687.371
Eastern Pacific Warm Pool	0.000	0.000	195.962	0.242	44.667	184.844	0.068	33.433	490.753
Oligotrophic Offshore	0.000	0.000	88.446	0.793	1019.497	1286.059	0.495	876.148	1769.777
North Equatorial Countercurrent	0.000	0.000	87.902	0.924	554.067	599.334	0.438	474.494	1084.056
North Equatorial Current	0.000	0.000	98.276	0.615	510.097	829.768	0.396	401.654	1014.724
Study Area	2.139	1609.096	752.208	0.652	1675.407	2568.073	0.359	1215.864	3389.146

	1999			2000			2003		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.000	0.000	84.612	0.000	0.000	71.586	4.353	144.160	33.118
West Baja Peninsula	0.000	0.000	6.343	0.000	0.000	16.120	0.000	0.000	4.379
Equatorial Cold Tongue	0.153	52.000	338.965	0.980	362.730	370.294	0.342	70.775	207.011
Eastern Pacific Warm Pool	0.967	559.537	578.898	1.409	697.816	495.296	0.024	5.267	219.046
Oligotrophic Offshore	1.147	2405.578	2098.109	1.293	2230.803	1725.042	0.000	0.000	276.172
North Equatorial Countercurrent	1.850	1785.096	964.904	1.934	1872.246	968.292	0.000	0.000	187.773
North Equatorial Current	0.678	1016.645	1500.073	0.959	1056.373	1101.867	0.000	0.000	244.314
Study Area	1.138	3919.198	3444.664	1.084	3323.549	3065.891	0.273	220.202	805.484

Table B-3 cont. Summary of model validation statistics for final whitebelly spinner dolphin density models in the ETP.

	2006			All Years		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.000	0.000	33.984	0.373	180.493	484.029
West Baja Peninsula	0.000	0.000	7.118	0.000	0.000	51.211
Equatorial Cold Tongue	0.598	205.967	344.180	1.301	5959.574	4579.402
Eastern Pacific Warm Pool	2.404	545.835	227.077	0.701	2127.831	3036.686
Oligotrophic Offshore	4.318	3076.210	712.363	1.230	12766.354	10375.296
North Equatorial Countercurrent	3.183	1088.537	341.933	1.298	6759.903	5208.668
North Equatorial Current	4.732	2473.533	522.690	1.081	7751.817	7173.438
Study Area	2.782	4564.682	1640.598	1.124	22873.400	20347.626

Table B-4. Summary of model validation statistics for final striped dolphin density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			**1987**			**1988**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.084	1277.749	1178.568	2.072	590.269	284.830	1.398	1030.246	736.730
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	53.452
Equatorial Cold Tongue	1.366	2285.165	1672.728	1.013	1302.177	1285.939	1.478	3969.308	2684.924
Eastern Pacific Warm Pool	0.554	840.793	1518.053	0.731	504.750	690.837	1.236	1794.593	1452.379
Oligotrophic Offshore	0.687	155.837	226.697	0.077	20.334	263.532	1.153	763.485	661.965
North Equatorial Countercurrent	0.140	36.667	262.725	1.134	252.584	222.762	1.184	543.097	458.532
North Equatorial Current	0.815	363.696	446.016	0.203	69.500	342.406	0.886	820.651	925.968
Study Area	0.987	4559.544	4621.747	0.948	2633.862	2778.770	1.323	8245.881	6234.015

	1989			**1990**			**1998**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.927	799.083	861.799	1.053	874.833	831.014	1.764	2701.253	1531.057
West Baja Peninsula	0.000	0.000	102.628	NA	NA	NA	0.355	18.000	50.768
Equatorial Cold Tongue	1.403	2706.237	1928.433	0.629	1817.895	2889.431	0.846	2508.851	2964.764
Eastern Pacific Warm Pool	0.811	1688.053	2081.866	1.237	1450.081	1172.051	0.674	2024.141	3004.527
Oligotrophic Offshore	0.000	0.000	41.970	1.449	997.916	688.691	1.577	1065.422	675.480
North Equatorial Countercurrent	1.354	187.667	138.645	2.112	1240.080	587.034	1.541	950.032	616.470
North Equatorial Current	0.253	138.467	546.278	0.925	654.083	706.967	0.753	1013.524	1345.103
Study Area	1.057	5390.373	5100.379	0.846	5318.725	6289.412	0.956	8617.885	9018.313

	1999			**2000**			**2003**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.683	966.086	1414.785	0.778	921.659	1184.599	1.506	691.665	459.334
West Baja Peninsula	0.229	25.000	108.947	0.182	41.000	224.944	0.848	139.250	164.236
Equatorial Cold Tongue	1.313	1698.800	1293.596	1.067	1122.507	1052.297	1.875	1069.663	570.606
Eastern Pacific Warm Pool	0.701	2442.887	3486.596	1.111	3486.594	3139.155	0.805	1362.263	1692.440
Oligotrophic Offshore	0.731	396.768	542.546	1.264	591.984	468.362	0.692	120.000	173.408
North Equatorial Countercurrent	0.741	421.605	569.019	1.245	476.000	382.434	1.503	350.832	233.383
North Equatorial Current	0.593	819.581	1383.257	1.082	1361.486	1258.673	0.949	691.332	728.456
Study Area	0.851	6299.263	7398.012	0.970	6403.411	6601.520	1.126	3894.174	3457.912

Table B-4 cont. Summary of model validation statistics for final striped dolphin density models in the ETP.

	2006			All Years		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	2.212	1681.111	759.983	1.248	11533.954	9242.699
West Baja Peninsula	0.714	115.000	161.060	0.391	338.250	866.036
Equatorial Cold Tongue	0.845	917.749	1086.551	1.113	19398.352	17429.270
Eastern Pacific Warm Pool	1.281	2053.329	1603.280	0.889	17647.484	19841.185
Oligotrophic Offshore	2.087	839.573	402.198	1.195	4951.318	4144.849
North Equatorial Countercurrent	2.627	762.507	290.307	1.388	5221.072	3761.311
North Equatorial Current	1.042	981.316	941.680	0.802	6913.636	8624.803
Study Area	1.420	6343.432	4466.927	1.031	57706.550	55967.007

Table B-5. Summary of model validation statistics for final rough-toothed dolphin density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			**1987**			**1988**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.173	10.000	57.639	0.000	0.000	19.386	0.325	6.000	18.461
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	1.807
Equatorial Cold Tongue	0.313	14.600	46.602	0.557	18.450	33.141	3.467	167.217	48.233
Eastern Pacific Warm Pool	0.618	110.206	178.386	0.000	0.000	76.943	1.088	83.283	76.554
Oligotrophic Offshore	0.581	7.000	12.048	1.142	22.500	19.705	0.765	22.333	29.194
North Equatorial Countercurrent	0.522	7.000	13.419	0.442	15.000	33.971	0.555	9.333	16.821
North Equatorial Current	0.150	7.750	51.660	0.371	7.500	20.205	0.804	31.933	39.702
Study Area	0.480	141.806	295.296	0.261	40.950	156.819	1.484	278.833	187.882

	1989			**1990**			**1998**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.632	47.000	28.803	2.577	71.047	27.567	1.205	102.787	85.294
West Baja Peninsula	0.000	0.000	3.708	NA	NA	NA	0.000	0.000	5.109
Equatorial Cold Tongue	0.329	13.000	39.531	1.695	110.100	64.954	1.375	85.430	62.134
Eastern Pacific Warm Pool	1.155	210.240	181.992	0.757	66.700	88.142	0.735	176.046	239.547
Oligotrophic Offshore	0.000	0.000	1.355	0.056	2.000	35.951	0.527	24.786	47.056
North Equatorial Countercurrent	1.267	7.920	6.252	0.304	8.333	27.400	0.000	0.000	41.629
North Equatorial Current	0.120	4.000	33.385	0.000	0.000	35.315	1.698	111.072	65.394
Study Area	1.050	270.240	257.445	1.134	260.179	229.449	0.840	389.049	463.297

	1999			**2000**			**2003**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.646	22.550	34.898	1.350	70.897	52.500	0.869	22.600	25.994
West Baja Peninsula	0.000	0.000	3.764	0.000	0.000	7.271	0.522	4.000	7.666
Equatorial Cold Tongue	0.974	24.373	25.026	0.364	8.848	24.321	1.075	17.000	15.816
Eastern Pacific Warm Pool	1.602	255.216	159.322	1.127	226.858	201.271	1.178	190.594	161.783
Oligotrophic Offshore	0.000	0.000	20.918	2.121	80.583	37.991	0.000	0.000	7.351
North Equatorial Countercurrent	1.851	39.333	21.245	4.993	98.083	19.644	0.000	0.000	8.773
North Equatorial Current	0.639	32.000	50.084	0.968	77.346	79.894	1.259	42.333	33.635
Study Area	1.193	304.140	254.938	1.153	387.186	335.833	1.030	234.194	227.359

Table B-5 cont. Summary of model validation statistics for final rough-toothed dolphin density models in the ETP.

Stratum	2006			All Years		
	Obs/Pred	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	5.336	241.464	45.254	1.502	594.345	395.797
West Baja Peninsula	0.000	0.000	4.852	0.117	4.000	34.176
Equatorial Cold Tongue	1.244	31.995	25.715	1.274	491.012	385.474
Eastern Pacific Warm Pool	1.201	121.806	101.394	0.983	1440.950	1465.333
Oligotrophic Offshore	2.636	43.350	16.445	0.888	202.552	228.015
North Equatorial Countercurrent	2.312	43.350	18.753	1.098	228.353	207.907
North Equatorial Current	1.669	72.166	43.240	0.853	386.100	452.516
Study Area	2.061	438.614	212.770	1.047	2745.192	2621.089

Table B-6. Summary of model validation statistics for final short-beaked common dolphin density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			1987			1988		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.201	335.000	1666.554	0.000	0.000	429.826	2.524	3630.160	1438.164
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	364.739
Equatorial Cold Tongue	1.392	4264.733	3064.243	0.075	87.333	1171.341	1.517	8628.689	5686.308
Eastern Pacific Warm Pool	0.962	1028.163	1069.008	0.174	67.067	384.749	0.280	407.500	1456.628
Oligotrophic Offshore	0.699	25.500	36.497	0.000	0.000	70.465	0.203	98.333	485.337
North Equatorial Countercurrent	0.000	0.000	60.038	0.000	0.000	51.059	0.000	0.000	256.507
North Equatorial Current	0.090	25.500	284.295	0.516	67.067	129.975	0.541	505.833	935.469
Study Area	0.968	5653.396	5840.838	0.211	473.150	2237.549	1.150	12764.682	11104.108

	1989			1990			1998		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.358	1812.830	1334.591	1.146	1817.115	1585.904	1.599	5438.810	3402.288
West Baja Peninsula	0.000	0.000	639.841	NA	NA	NA	1.197	696.257	581.565
Equatorial Cold Tongue	1.177	7756.277	6588.362	0.622	3747.533	6025.472	0.546	3855.170	7065.950
Eastern Pacific Warm Pool	0.394	887.867	2251.008	0.210	212.667	1012.556	0.827	2554.160	3088.527
Oligotrophic Offshore	0.193	7.000	36.209	0.000	0.000	234.118	1.331	252.267	189.508
North Equatorial Countercurrent	0.000	0.000	77.160	0.000	0.000	135.550	0.000	0.000	170.247
North Equatorial Current	0.819	637.000	777.554	0.426	212.667	499.369	0.813	953.261	1172.319
Study Area	0.961	10463.974	10893.430	0.689	7513.975	10902.537	0.906	15481.747	17094.360

	1999			2000			2003		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.300	3540.026	2723.377	1.717	3865.747	2251.982	1.107	1033.666	933.844
West Baja Peninsula	1.246	1667.497	1338.797	1.068	3178.484	2975.042	0.493	545.340	1105.703
Equatorial Cold Tongue	1.059	3897.084	3678.269	1.943	5021.097	2583.774	1.243	1438.330	1156.697
Eastern Pacific Warm Pool	0.545	1855.754	3404.788	0.738	2113.921	2863.983	0.443	1100.099	2483.641
Oligotrophic Offshore	1.445	352.670	244.003	0.000	0.000	137.384	5.843	540.000	92.412
North Equatorial Countercurrent	0.000	0.000	225.207	0.602	75.667	125.617	5.898	632.330	107.204
North Equatorial Current	0.531	826.337	1556.914	1.241	1407.261	1133.732	0.292	342.617	1172.263
Study Area	1.276	17618.475	13803.493	1.275	15797.079	12387.238	0.735	5501.269	7484.061

Table B-6 cont. Summary of model validation statistics for final short-beaked common dolphin density models in the ETP.

	2006			All Years		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	5.943	9532.351	1603.906	1.785	31005.705	17370.437
West Baja Peninsula	0.896	887.330	990.171	0.872	6974.908	7995.857
Equatorial Cold Tongue	1.297	1953.653	1506.721	1.055	40649.900	38527.138
Eastern Pacific Warm Pool	1.159	2231.170	1925.011	0.625	12458.368	19939.900
Oligotrophic Offshore	0.162	43.667	269.031	0.735	1319.437	1794.964
North Equatorial Countercurrent	0.440	70.917	161.129	0.569	778.914	1369.718
North Equatorial Current	0.778	870.580	1118.833	0.666	5848.123	8780.723
Study Area	2.183	15128.921	6930.793	1.078	106396.669	98678.408

Table B-7. Summary of model validation statistics for final bottlenose dolphin density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			1987			1988		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.990	170.168	171.858	1.587	179.767	113.267	1.084	189.339	174.623
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	10.374
Coast	1.732	566.026	326.837	1.104	96.850	87.713	0.396	28.063	70.817
Equatorial Cold Tongue	0.731	243.763	333.638	0.994	205.450	206.722	0.514	163.105	317.327
Equatorial Warm Pool	0.665	253.935	381.650	0.401	56.834	141.815	0.198	57.783	292.522
Oligotrophic Offshore	0.053	1.000	18.737	0.372	12.600	33.877	0.000	0.000	70.282
North Equatorial Countercurrent	0.030	1.000	32.902	0.276	12.600	45.666	0.000	0.000	63.300
Study Area	0.999	1234.891	1235.604	0.894	567.691	635.152	0.635	681.229	1072.708

	1989			1990			1998		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.820	168.124	204.909	0.830	181.404	218.591	1.018	355.465	349.332
West Baja Peninsula	0.000	0.000	44.883	NA	NA	NA	0.450	122.333	271.609
Coast	0.444	68.450	154.195	1.276	198.734	155.801	1.158	2132.641	1842.241
Equatorial Cold Tongue	0.733	277.356	378.537	0.276	101.940	369.255	0.395	192.274	486.988
Equatorial Warm Pool	0.228	111.253	488.211	0.326	93.909	288.172	1.058	720.399	680.588
Oligotrophic Offshore	0.000	0.000	5.144	0.508	41.165	81.089	0.000	0.000	72.086
North Equatorial Countercurrent	0.697	18.250	26.180	0.023	2.000	85.397	0.000	0.000	98.776
Study Area	0.495	636.383	1284.964	0.702	861.006	1227.235	0.892	3735.779	4188.649

	1999			2000			2003		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.695	202.361	291.247	2.384	848.353	355.778	1.237	128.303	103.707
West Baja Peninsula	0.393	83.332	212.236	1.196	350.168	292.837	0.754	162.962	216.028
Coast	0.983	838.262	853.074	0.896	1124.296	1254.850	0.524	670.899	1280.668
Equatorial Cold Tongue	0.629	120.355	191.300	0.640	78.662	122.859	0.478	48.333	101.072
Equatorial Warm Pool	0.482	299.169	620.559	0.457	294.242	643.846	1.038	411.708	396.659
Oligotrophic Offshore	0.040	2.245	55.955	2.396	191.133	79.778	2.048	48.750	23.799
North Equatorial Countercurrent	0.170	12.917	75.935	1.553	127.783	82.308	0.000	0.000	43.952
Study Area	0.707	1733.148	2451.076	0.981	3058.088	3117.795	1.963	4919.173	2506.393

Table B-7 cont. Summary of model validation statistics for final bottlenose dolphin density models in the ETP.

	2006			All Years		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	2.940	594.449	202.166	1.381	3017.733	2185.478
West Baja Peninsula	0.117	7.892	67.275	0.652	726.687	1115.242
Coast	1.595	847.682	531.361	1.002	6571.901	6557.558
Equatorial Cold Tongue	1.741	385.757	221.570	0.666	1816.994	2729.268
Equatorial Warm Pool	0.721	265.770	368.673	0.596	2565.003	4302.695
Oligotrophic Offshore	3.214	148.917	46.332	0.915	445.810	487.079
North Equatorial Countercurrent	1.815	132.917	73.235	0.490	307.467	627.651
Study Area	1.502	2335.354	1555.211	1.025	19762.741	19274.788

Table B-8. Summary of model validation statistics for final Risso's dolphin density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			**1987**			**1988**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.189	16.667	87.964	1.078	36.350	33.732	0.581	13.000	22.361
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	7.141
Equatorial Cold Tongue	1.280	83.407	65.176	1.398	55.000	39.343	1.070	111.599	104.296
Eastern Pacific Warm Pool	1.221	184.791	151.366	1.077	53.333	49.508	0.361	32.186	89.070
Oligotrophic Offshore	0.000	0.000	14.035	1.180	20.000	16.942	1.647	55.500	33.689
North Equatorial Countercurrent	0.000	0.000	14.579	2.158	52.000	24.098	2.905	53.500	18.416
North Equatorial Current	0.453	17.500	38.606	0.568	8.000	14.080	0.105	5.000	47.655
Study Area	0.891	284.865	319.548	1.106	171.183	154.752	0.995	306.453	308.083

	1989			**1990**			**1998**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.485	25.996	53.561	0.457	14.667	32.117	1.109	197.925	178.394
West Baja Peninsula	0.000	0.000	11.086	NA	NA	NA	0.000	0.000	16.505
Equatorial Cold Tongue	0.412	29.833	72.328	0.952	96.267	101.172	0.641	69.415	108.329
Eastern Pacific Warm Pool	1.206	193.547	160.426	0.131	12.333	94.024	1.104	318.423	288.321
Oligotrophic Offshore	0.000	0.000	1.781	0.142	8.000	56.247	0.000	0.000	49.012
North Equatorial Countercurrent	0.000	0.000	6.831	0.183	8.000	43.713	0.000	0.000	43.742
North Equatorial Current	0.174	6.000	34.507	0.000	0.000	38.319	0.000	0.000	66.034
Study Area	0.827	249.376	301.608	1.397	489.350	350.253	0.817	612.500	750.013

	1999			**2000**			**2003**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	2.504	177.676	70.963	2.544	267.613	105.180	1.641	123.806	75.449
West Baja Peninsula	2.216	35.000	15.794	0.112	6.500	57.889	0.000	0.000	18.541
Equatorial Cold Tongue	0.147	8.563	58.257	3.136	132.494	42.245	0.863	22.647	26.243
Eastern Pacific Warm Pool	0.633	131.000	207.031	0.810	166.283	205.198	0.884	176.774	200.065
Oligotrophic Offshore	2.610	73.922	28.319	0.579	28.350	48.946	0.000	0.000	8.412
North Equatorial Countercurrent	0.427	12.667	29.666	0.158	5.250	33.211	0.000	0.000	11.245
North Equatorial Current	1.396	106.589	76.333	1.367	110.799	81.030	0.175	6.540	37.339
Study Area	0.985	497.012	504.526	1.221	691.103	565.987	1.052	453.556	431.309

Table B-8 cont. Summary of model validation statistics for final Risso's dolphin density models in the ETP.

Stratum	**2006**			**All Years**		
	Obs/Pred	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.985	176.143	88.731	1.403	1049.843	748.452
West Baja Peninsula	0.000	0.000	9.424	0.304	41.500	136.381
Equatorial Cold Tongue	1.086	43.000	39.596	0.993	652.224	656.986
Eastern Pacific Warm Pool	1.772	186.344	105.163	0.939	1455.013	1550.172
Oligotrophic Offshore	0.000	0.000	21.410	0.666	185.772	278.793
North Equatorial Countercurrent	0.000	0.000	27.083	0.520	131.417	252.582
North Equatorial Current	1.716	72.001	41.962	0.699	332.429	475.864
Study Area	1.318	419.087	317.983	1.043	4174.485	4004.063

Table B-9. Summary of model validation statistics for final Cuvier's beaked whale density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			**1987**			**1988**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.184	5.500	4.646	1.565	2.000	1.278	0.000	0.000	2.136
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	0.320
Equatorial Cold Tongue	1.398	8.000	5.724	1.821	8.000	4.393	1.262	12.000	9.510
Eastern Pacific Warm Pool	1.559	19.500	12.506	0.000	0.000	5.374	0.000	0.000	6.821
Oligotrophic Offshore	0.845	1.000	1.184	2.650	4.750	1.792	0.000	0.000	3.089
North Equatorial Countercurrent	0.000	0.000	1.603	1.171	3.000	2.563	0.000	0.000	1.972
North Equatorial Current	0.296	1.000	3.376	0.880	1.750	1.989	0.000	0.000	4.613
Study Area	1.407	34.000	24.168	1.037	14.750	14.226	0.867	22.000	25.368

	1989			**1990**			**1998**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.973	3.000	3.084	1.428	4.000	2.800	0.384	2.000	5.213
West Baja Peninsula	2.126	1.000	0.470	NA	NA	NA	4.156	1.000	0.241
Equatorial Cold Tongue	0.000	0.000	6.658	1.165	12.800	10.986	1.239	11.400	9.201
Eastern Pacific Warm Pool	0.662	8.000	12.085	0.621	4.667	7.521	0.806	15.000	18.614
Oligotrophic Offshore	0.000	0.000	0.223	1.780	7.333	4.119	0.000	0.000	5.153
North Equatorial Countercurrent	0.000	0.000	0.832	1.994	6.667	3.344	0.224	1.000	4.470
North Equatorial Current	1.260	4.000	3.176	0.658	2.667	4.053	0.000	0.000	7.791
Study Area	0.526	12.000	22.824	1.061	31.800	29.980	0.853	37.400	43.862

	1999			**2000**			**2003**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.326	4.333	3.267	1.827	7.333	4.014	0.000	0.000	1.829
West Baja Peninsula	0.000	0.000	0.413	1.778	3.000	1.687	0.000	0.000	0.596
Equatorial Cold Tongue	2.344	12.000	5.119	2.063	7.167	3.474	1.025	2.333	2.276
Eastern Pacific Warm Pool	0.468	7.667	16.365	0.836	13.667	16.345	1.152	12.833	11.138
Oligotrophic Offshore	1.172	3.000	2.561	0.000	0.000	2.535	4.863	4.667	0.960
North Equatorial Countercurrent	1.059	3.000	2.833	0.456	1.000	2.194	2.587	3.000	1.160
North Equatorial Current	0.683	5.000	7.321	0.000	0.000	7.711	0.416	1.667	4.003
Study Area	1.025	34.000	33.171	0.997	32.167	32.249	0.964	19.833	20.579

Table B-9 cont. Summary of model validation statistics for final Cuvier's beaked whale density models in the ETP.

	2006			**All Years**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.564	5.000	3.196	1.054	33.167	31.463
West Baja Peninsula	0.000	0.000	0.496	1.184	5.000	4.223
Equatorial Cold Tongue	0.887	3.667	4.136	1.258	77.367	61.478
Eastern Pacific Warm Pool	0.342	3.000	8.777	0.730	84.333	115.544
Oligotrophic Offshore	1.469	3.000	2.043	1.004	23.750	23.658
North Equatorial Countercurrent	1.460	3.000	2.055	0.898	20.667	23.026
North Equatorial Current	0.441	2.000	4.535	0.372	18.083	48.568
Study Area	0.668	14.667	21.949	0.941	252.617	268.376

Table B-10. Summary of model validation statistics for final blue whale density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			**1987**			**1988**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.176	2.000	1.701	0.000	0.000	0.507	1.210	4.000	3.305
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	0.184
Equatorial Cold Tongue	0.894	2.250	2.518	0.000	0.000	1.225	0.990	5.000	5.051
Eastern Pacific Warm Pool	0.000	0.000	1.184	0.000	0.000	0.719	0.000	0.000	1.723
Oligotrophic Offshore	0.000	0.000	0.006	0.000	0.000	0.048	0.000	0.000	0.459
North Equatorial Countercurrent	0.000	0.000	0.079	0.000	0.000	0.124	0.000	0.000	0.351
North Equatorial Current	0.000	0.000	0.200	0.000	0.000	0.147	0.000	0.000	0.827
Study Area	0.775	4.250	5.486	0.000	0.000	2.949	0.639	9.000	14.087

	1989			**1990**			**1998**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.000	0.000	2.627	0.569	2.000	3.516	0.877	3.000	3.421
West Baja Peninsula	0.000	0.000	0.356	NA	NA	NA	0.192	1.000	5.222
Equatorial Cold Tongue	0.000	0.000	6.884	0.607	5.600	9.230	1.360	13.167	9.679
Eastern Pacific Warm Pool	0.843	3.000	3.558	0.976	2.500	2.561	0.825	3.000	3.638
Oligotrophic Offshore	0.000	0.000	0.033	0.000	0.000	0.141	0.000	0.000	0.403
North Equatorial Countercurrent	0.000	0.000	0.201	0.000	0.000	0.275	0.000	0.000	0.372
North Equatorial Current	1.053	1.000	0.950	2.703	2.500	0.925	2.352	3.000	1.276
Study Area	0.222	3.000	13.538	0.608	11.100	18.268	0.704	20.167	28.665

	1999			**2000**			**2003**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	2.558	10.000	3.909	1.471	4.400	2.991	0.000	0.000	1.736
West Baja Peninsula	0.241	1.000	4.149	2.663	23.823	8.947	4.157	33.917	8.158
Equatorial Cold Tongue	0.000	0.000	3.214	0.000	0.000	3.797	1.034	1.750	1.692
Eastern Pacific Warm Pool	0.208	1.000	4.815	2.070	9.200	4.445	0.508	2.000	3.935
Oligotrophic Offshore	0.000	0.000	0.220	0.000	0.000	0.131	0.000	0.000	0.091
North Equatorial Countercurrent	0.000	0.000	0.470	0.000	0.000	0.260	0.000	0.000	0.131
North Equatorial Current	0.000	0.000	1.592	1.565	2.000	1.278	0.740	1.000	1.351
Study Area	0.667	13.000	19.503	1.637	39.423	24.083	2.262	48.500	21.444

Table B-10 cont. Summary of model validation statistics for final blue whale density models in the ETP.

	2006			All Years		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	2.897	6.353	2.193	1.226	31.753	25.907
West Baja Peninsula	12.722	22.000	1.729	2.844	81.740	28.744
Equatorial Cold Tongue	14.582	25.650	1.759	1.186	53.417	45.049
Eastern Pacific Warm Pool	2.356	6.967	2.957	0.937	27.667	29.534
Oligotrophic Offshore	0.000	0.000	0.308	0.000	0.000	1.840
North Equatorial Countercurrent	0.000	0.000	0.295	0.000	0.000	2.559
North Equatorial Current	2.247	2.967	1.321	1.264	12.467	9.865
Study Area	5.602	64.640	11.539	1.335	213.080	159.562

Table B-11. Summary of model validation statistics for final Bryde's whale density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			**1987**			**1988**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.730	3.000	4.111	0.000	0.000	0.895	0.000	0.000	2.983
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	0.154
Equatorial Cold Tongue	0.598	9.430	15.781	0.481	5.000	10.395	0.756	16.333	21.616
Eastern Pacific Warm Pool	0.517	4.000	7.739	0.000	0.000	3.041	0.598	5.333	8.920
Oligotrophic Offshore	0.000	0.000	1.671	0.000	0.000	1.999	0.976	6.000	6.148
North Equatorial Countercurrent	0.000	0.000	1.815	0.000	0.000	1.523	1.746	7.333	4.200
North Equatorial Current	0.924	2.000	2.165	0.000	0.000	1.970	0.407	3.000	7.371
Study Area	0.553	16.430	29.699	0.262	5.000	19.052	0.709	33.667	47.470
	1989			**1990**			**1998**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.000	0.000	3.213	0.000	0.000	3.984	1.182	9.000	7.615
West Baja Peninsula	0.000	0.000	1.189	NA	NA	NA	1.335	6.000	4.493
Equatorial Cold Tongue	0.923	17.000	18.415	0.775	24.167	31.191	1.703	46.148	27.091
Eastern Pacific Warm Pool	0.093	1.000	10.801	1.006	7.000	6.960	0.958	20.200	21.085
Oligotrophic Offshore	2.958	1.750	0.592	0.422	3.000	7.104	1.129	6.667	5.907
North Equatorial Countercurrent	0.000	0.000	1.125	0.177	1.000	5.660	1.153	5.667	4.916
North Equatorial Current	0.502	1.750	3.486	1.537	8.000	5.205	1.308	13.200	10.090
Study Area	0.591	20.750	35.082	0.720	41.500	57.647	1.208	100.014	82.797
	1999			**2000**			**2003**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.318	2.000	6.291	1.090	6.000	5.507	1.726	6.667	3.862
West Baja Peninsula	2.168	9.490	4.378	1.191	5.667	4.759	4.740	23.655	4.990
Equatorial Cold Tongue	1.735	19.000	10.953	1.008	11.833	11.734	3.479	34.200	9.831
Eastern Pacific Warm Pool	0.660	12.667	19.192	1.348	22.280	16.530	0.652	9.600	14.719
Oligotrophic Offshore	0.647	4.333	6.695	1.806	5.000	2.769	3.180	6.750	2.123
North Equatorial Countercurrent	0.661	4.333	6.560	1.286	3.800	2.955	2.742	5.417	1.975
North Equatorial Current	0.301	3.000	9.974	1.236	9.000	7.284	0.951	6.933	7.288
Study Area	1.083	61.490	56.771	1.201	64.447	53.651	1.782	84.872	47.634

Table B-11 cont. Summary of model validation statistics for final Bryde's whale density models in the ETP.

	2006			All Years		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.582	2.000	3.438	0.684	28.667	41.897
West Baja Peninsula	2.767	3.000	1.084	2.272	47.812	21.046
Equatorial Cold Tongue	1.183	17.000	14.368	1.168	200.111	171.375
Eastern Pacific Warm Pool	0.462	5.000	10.834	0.727	87.080	119.822
Oligotrophic Offshore	0.506	2.500	4.937	0.901	36.000	39.945
North Equatorial Countercurrent	0.000	0.000	3.240	0.811	27.550	33.969
North Equatorial Current	0.886	6.500	7.338	0.859	53.383	62.171
Study Area	1.029	42.847	41.649	0.999	471.016	471.452

Table B-12. Summary of model validation statistics for final short-finned pilot whale density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			**1987**			**1988**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.429	132.878	93.006	1.345	35.067	26.080	3.734	371.651	99.544
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	5.234
Equatorial Cold Tongue	0.819	147.010	179.508	2.282	291.350	127.691	0.428	137.558	321.177
Eastern Pacific Warm Pool	0.450	41.595	92.431	0.617	29.666	48.083	0.428	48.101	112.310
Oligotrophic Offshore	0.000	0.000	40.862	0.523	15.067	28.789	0.345	29.687	85.929
North Equatorial Countercurrent	0.000	0.000	27.273	1.205	27.400	22.747	0.928	48.101	51.809
North Equatorial Current	0.000	0.000	40.427	0.000	0.000	26.352	0.322	29.687	92.125
Study Area	0.785	321.483	409.634	1.486	387.293	260.551	0.910	657.892	723.041

	1989			**1990**			**1998**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.846	60.860	71.932	2.056	164.097	79.816	1.433	220.243	153.735
West Baja Peninsula	0.000	0.000	13.013	NA	NA	NA	0.000	0.000	10.440
Equatorial Cold Tongue	1.323	315.257	238.355	1.190	433.642	364.462	1.057	373.813	353.525
Eastern Pacific Warm Pool	1.091	143.627	131.635	0.482	49.167	102.028	0.216	47.679	220.672
Oligotrophic Offshore	0.000	0.000	5.898	0.179	21.574	120.322	2.192	241.967	110.378
North Equatorial Countercurrent	3.649	49.590	13.591	0.341	32.667	95.669	1.730	170.383	98.503
North Equatorial Current	0.000	0.000	32.756	0.384	29.074	75.639	0.981	98.917	100.862
Study Area	1.141	536.211	470.061	0.967	738.980	763.888	0.954	983.336	1030.526

	1999			**2000**			**2003**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.583	84.376	144.697	1.712	214.224	125.137	0.659	34.901	52.979
West Baja Peninsula	0.000	0.000	16.006	0.904	37.667	41.652	3.616	58.200	16.095
Equatorial Cold Tongue	0.910	134.686	148.035	1.909	238.495	124.905	1.160	88.340	76.126
Eastern Pacific Warm Pool	0.566	154.454	272.829	0.430	107.833	250.602	1.107	177.320	160.150
Oligotrophic Offshore	1.412	125.033	88.522	1.247	118.637	95.123	1.085	25.296	23.324
North Equatorial Countercurrent	1.563	128.783	82.391	0.434	32.637	75.249	1.099	30.300	27.563
North Equatorial Current	0.249	31.667	126.985	0.781	100.667	128.931	0.627	49.983	79.693
Study Area	0.759	599.024	789.061	1.128	839.673	744.241	1.105	493.563	446.575

Table B-12 cont. Summary of model validation statistics for final short-finned pilot whale density models in the ETP.

Stratum	2006			All Years		
	Obs/Pred	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	2.569	194.674	75.779	1.640	1512.971	922.704
West Baja Peninsula	4.626	101.286	21.893	1.586	197.153	124.333
Equatorial Cold Tongue	5.711	764.185	133.808	1.414	2924.334	2067.592
Eastern Pacific Warm Pool	1.057	134.180	126.920	0.615	933.622	1517.661
Oligotrophic Offshore	2.698	105.317	39.033	1.070	682.579	638.181
North Equatorial Countercurrent	5.242	170.067	32.442	1.309	689.928	527.238
North Equatorial Current	0.290	19.750	68.108	0.466	359.745	771.877
Study Area	2.892	1383.918	478.523	1.135	6941.373	6116.101

Table B-13. Summary of model validation statistics for final dwarf sperm whale density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			1987			1988		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.943	19.000	9.780	0.000	0.000	2.330	8.424	7.000	0.831
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	0.318
Equatorial Cold Tongue	0.673	1.000	1.486	4.995	4.500	0.901	1.744	4.000	2.293
Eastern Pacific Warm Pool	0.778	9.337	11.996	1.112	4.000	3.596	0.000	0.000	7.131
Oligotrophic Offshore	0.000	0.000	1.123	0.715	1.000	1.398	1.220	3.250	2.663
North Equatorial Countercurrent	0.000	0.000	1.020	1.789	5.000	2.795	0.000	0.000	1.087
North Equatorial Current	0.000	0.000	3.138	0.000	0.000	0.845	0.966	3.250	3.363
Study Area	1.203	29.337	24.390	1.113	9.500	8.535	1.317	18.250	13.854

	1989			1990			1998		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.416	6.000	4.237	0.721	1.000	1.387	0.144	1.000	6.945
West Baja Peninsula	0.000	0.000	0.092	NA	NA	NA	0.000	0.000	0.517
Equatorial Cold Tongue	0.000	0.000	0.705	0.000	0.000	1.135	0.000	0.000	2.831
Eastern Pacific Warm Pool	0.979	14.000	14.306	0.221	1.000	4.529	1.847	23.000	12.454
Oligotrophic Offshore	0.000	0.000	0.028	0.889	4.000	4.498	1.275	6.000	4.707
North Equatorial Countercurrent	3.066	1.000	0.326	1.403	3.000	2.139	0.620	2.000	3.226
North Equatorial Current	0.000	0.000	1.673	0.621	2.000	3.222	1.240	4.000	3.226
Study Area	1.031	20.000	19.391	0.505	6.000	11.889	1.074	30.000	27.928

	1999			2000			2003		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.896	3.333	3.721	1.237	6.000	4.850	0.000	0.000	3.936
West Baja Peninsula	0.000	0.000	0.226	0.000	0.000	1.150	2.159	2.000	0.927
Equatorial Cold Tongue	0.000	0.000	0.829	0.000	0.000	0.356	0.000	0.000	0.278
Eastern Pacific Warm Pool	0.161	2.000	12.411	2.253	28.167	12.502	0.488	6.000	12.290
Oligotrophic Offshore	0.823	1.000	1.215	0.407	1.000	2.454	0.000	0.000	0.220
North Equatorial Countercurrent	0.880	1.000	1.136	0.000	0.000	0.699	0.000	0.000	0.367
North Equatorial Current	0.398	1.000	2.510	0.247	1.000	4.055	0.000	0.000	0.961
Study Area	0.494	9.333	18.902	1.601	35.167	21.961	0.445	8.000	17.996

Table B-13 cont. Summary of model validation statistics for final dwarf sperm whale density models in the ETP.

	2006			All Years		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.274	5.000	3.924	1.152	48.333	41.941
West Baja Peninsula	0.000	0.000	0.096	0.601	2.000	3.326
Equatorial Cold Tongue	0.000	0.000	0.381	0.849	9.500	11.196
Eastern Pacific Warm Pool	2.618	13.667	5.220	1.049	101.170	96.435
Oligotrophic Offshore	0.000	0.000	0.637	0.858	16.250	18.944
North Equatorial Countercurrent	7.322	9.000	1.229	1.497	21.000	14.025
North Equatorial Current	0.000	0.000	2.232	0.446	11.250	25.226
Study Area	1.726	18.667	10.815	1.049	184.253	175.661

Table B-14. Summary of model validation statistics for final *Mesoplodon* spp. density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			**1987**			**1988**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.410	2.000	4.879	0.000	0.000	1.491	0.000	0.000	1.182
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	0.126
Equatorial Cold Tongue	0.199	1.000	5.038	2.035	8.000	3.932	1.569	20.917	13.330
Eastern Pacific Warm Pool	0.492	4.000	8.137	1.853	5.000	2.698	0.381	2.000	5.254
Oligotrophic Offshore	0.000	0.000	1.114	7.413	5.333	0.719	0.000	0.000	3.034
North Equatorial Countercurrent	0.000	0.000	0.889	13.219	8.333	0.630	1.026	2.000	1.949
North Equatorial Current	0.000	0.000	1.238	0.000	0.000	0.444	0.000	0.000	2.949
Study Area	0.364	7.000	19.215	2.174	20.333	9.353	1.289	32.917	25.530

	1989			**1990**			**1998**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.409	5.000	3.548	0.912	2.000	2.193	1.114	8.500	7.633
West Baja Peninsula	0.000	0.000	0.202	NA	NA	NA	7.072	2.000	0.283
Equatorial Cold Tongue	0.000	0.000	6.806	1.626	23.000	14.148	0.758	8.467	11.165
Eastern Pacific Warm Pool	0.699	8.000	11.450	1.517	9.500	6.264	0.481	8.000	16.647
Oligotrophic Offshore	0.000	0.000	0.067	1.105	8.000	7.239	1.120	2.000	1.786
North Equatorial Countercurrent	0.000	0.000	0.319	1.481	9.000	6.075	1.034	2.000	1.934
North Equatorial Current	0.000	0.000	1.121	0.000	0.000	2.650	0.000	0.000	2.314
Study Area	0.583	13.000	22.303	1.245	42.500	34.147	0.838	33.967	40.535

	1999			**2000**			**2003**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.636	2.000	3.144	0.879	3.000	3.412	0.000	0.000	2.207
West Baja Peninsula	0.000	0.000	0.182	0.000	0.000	0.695	0.000	0.000	0.945
Equatorial Cold Tongue	1.938	20.500	10.580	0.230	1.000	4.353	0.000	0.000	2.633
Eastern Pacific Warm Pool	0.923	11.000	11.916	0.981	14.333	14.617	1.558	25.333	16.255
Oligotrophic Offshore	1.025	4.000	3.902	0.677	2.000	2.955	1.010	1.000	0.990
North Equatorial Countercurrent	1.015	4.000	3.941	1.218	4.000	3.284	3.136	3.000	0.956
North Equatorial Current	0.000	0.000	3.479	0.000	0.000	1.737	2.186	4.000	1.830
Study Area	1.074	37.500	34.918	0.782	22.333	28.569	1.145	29.333	25.617

Table B-14 cont. Summary of model validation statistics for final *Mesoplodon* spp. density models in the ETP.

Stratum	2006			All Years		
	Obs/Pred	Obs	Pred	Obs/Pred	Obs	Pred
Costa Rica Dome	2.453	11.833	4.824	0.995	34.333	34.514
West Baja Peninsula	0.000	0.000	0.186	0.764	2.000	2.619
Equatorial Cold Tongue	0.715	3.333	4.665	1.125	86.217	76.649
Eastern Pacific Warm Pool	1.849	10.500	5.677	0.987	97.667	98.916
Oligotrophic Offshore	0.000	0.000	3.847	0.871	22.333	25.652
North Equatorial Countercurrent	0.910	3.500	3.847	1.504	35.833	23.824
North Equatorial Current	0.000	0.000	2.040	0.202	4.000	19.802
Study Area	1.350	27.667	20.501	1.022	266.550	260.687

Table B-15. Summary of model validation statistics for final small beaked whale density models in the ETP built on 1986-2003 SWFSC survey data and tested on 2006 SWFSC survey data. Obs/Pred = ratio of stratified line-transect to model predicted density estimates. Obs = observed number of groups multiplied by the observed average group size. Pred = predicted number of groups multiplied by the predicted group size. Statistics are provided for each year separately and for all years pooled, and for each stratum separately and the study area as a whole.

	1986			**1987**			**1988**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	1.120	12.500	11.163	0.000	0.000	3.409	1.215	5.000	4.114
West Baja Peninsula	NA	NA	NA	NA	NA	NA	0.000	0.000	0.554
Equatorial Cold Tongue	0.437	5.000	11.433	1.102	8.000	7.263	1.559	34.417	22.080
Eastern Pacific Warm Pool	0.874	16.167	18.495	0.974	7.000	7.186	0.532	7.000	13.155
Oligotrophic Offshore	0.000	0.000	2.325	2.142	5.333	2.489	0.000	0.000	5.974
North Equatorial Countercurrent	0.000	0.000	2.249	2.754	8.333	3.026	0.560	2.000	3.572
North Equatorial Current	1.407	5.167	3.673	0.000	0.000	1.913	0.000	0.000	6.974
Study Area	0.773	33.667	43.573	1.019	22.333	21.919	1.147	58.417	50.935

	1989			**1990**			**1998**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.683	5.000	7.321	1.974	11.000	5.573	0.817	12.500	15.301
West Baja Peninsula	0.000	0.000	0.889	NA	NA	NA	2.889	2.000	0.692
Equatorial Cold Tongue	0.079	1.000	12.651	1.414	30.000	21.224	0.860	17.467	20.305
Eastern Pacific Warm Pool	0.361	9.000	24.919	0.912	12.500	13.713	0.934	31.500	33.727
Oligotrophic Offshore	0.000	0.000	0.390	0.766	8.000	10.444	0.782	6.000	7.677
North Equatorial Countercurrent	0.000	0.000	1.197	1.100	9.000	8.185	1.026	7.000	6.826
North Equatorial Current	0.000	0.000	3.775	0.000	0.000	5.894	0.801	6.500	8.119
Study Area	0.365	17.000	46.581	1.189	69.000	58.036	0.873	75.467	86.400

	1999			**2000**			**2003**		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	0.786	6.333	8.058	0.590	6.000	10.178	0.413	2.000	4.846
West Baja Peninsula	2.223	2.000	0.899	0.610	2.500	4.095	0.617	1.000	1.621
Equatorial Cold Tongue	2.981	40.500	13.588	0.731	5.000	6.836	0.000	0.000	4.091
Eastern Pacific Warm Pool	1.056	27.667	26.207	1.800	50.333	27.964	1.131	29.333	25.943
Oligotrophic Offshore	0.995	5.000	5.023	1.130	6.000	5.307	0.560	1.000	1.785
North Equatorial Countercurrent	1.856	9.667	5.209	1.568	7.000	4.464	2.280	5.000	2.193
North Equatorial Current	0.234	2.000	8.553	0.507	4.000	7.895	0.707	4.000	5.655
Study Area	1.413	88.500	62.620	1.247	76.167	61.059	0.798	36.333	45.542

Table B-15 cont. Summary of model validation statistics for final small beaked whale density models in the ETP.

	2006			All Years		
Stratum	**Obs/Pred**	**Obs**	**Pred**	**Obs/Pred**	**Obs**	**Pred**
Costa Rica Dome	2.013	18.833	9.358	0.998	79.167	79.321
West Baja Peninsula	0.000	0.000	0.927	0.775	7.500	9.678
Equatorial Cold Tongue	1.410	9.833	6.973	1.196	151.217	126.443
Eastern Pacific Warm Pool	1.054	15.500	14.703	1.000	206.000	206.012
Oligotrophic Offshore	0.000	0.000	4.025	0.690	31.333	45.440
North Equatorial Countercurrent	0.803	3.500	4.359	1.248	51.500	41.279
North Equatorial Current	0.182	1.000	5.490	0.391	22.667	57.941
Study Area	1.162	47.167	40.584	1.013	524.050	517.248

Figure B-1. Predicted yearly and averaged densities (animals per km^2) based on the final ETP models for: (a) offshore spotted dolphin (*Stenella attenuata*), (b) eastern spinner dolphin (*Stenella longirostris orientalis*), (c) whitebelly spinner dolphin (*Stenella longirostris longirostris*), (d) striped dolphin (*Stenella coeruleoalba*), (e) rough-toothed dolphin (*Steno bredanensis*), (f) short-beaked common dolphin (*Delphinus delphis*), (g) bottlenose dolphin (*Tursiops truncatus*), (h) Risso's dolphin (*Grampus griseus*), (i) Cuvier's beaked whale (*Ziphius cavirostris*), (j) blue whale (*Balaenoptera musculus*), (k) Bryde's whale (*Balaenoptera edeni*), (l) short-finned pilot whale (*Globicephala macrorhynchus*), (m) dwarf sperm whale (*Kogia sima*), (n) *Mesoplodon* beaked whales (including *Mesoplodon* spp., *Mesoplodon densirostris*, and *Mesoplodon peruvianus*), and (o) small beaked whales (*Mesoplodon* beaked whales plus "unidentified beaked whale"). Offshore spotted dolphins were not distinguished from coastal spotted dolphins in the early surveys (1986-1990), so yearly density plots are shown for 1998-2006 only (see text for details). Predicted values were smoothed using inverse distance weighting (see Section 3.5.1 for details). Black dots show actual sighting locations.

Figure B-1. a) Offshore spotted dolphin

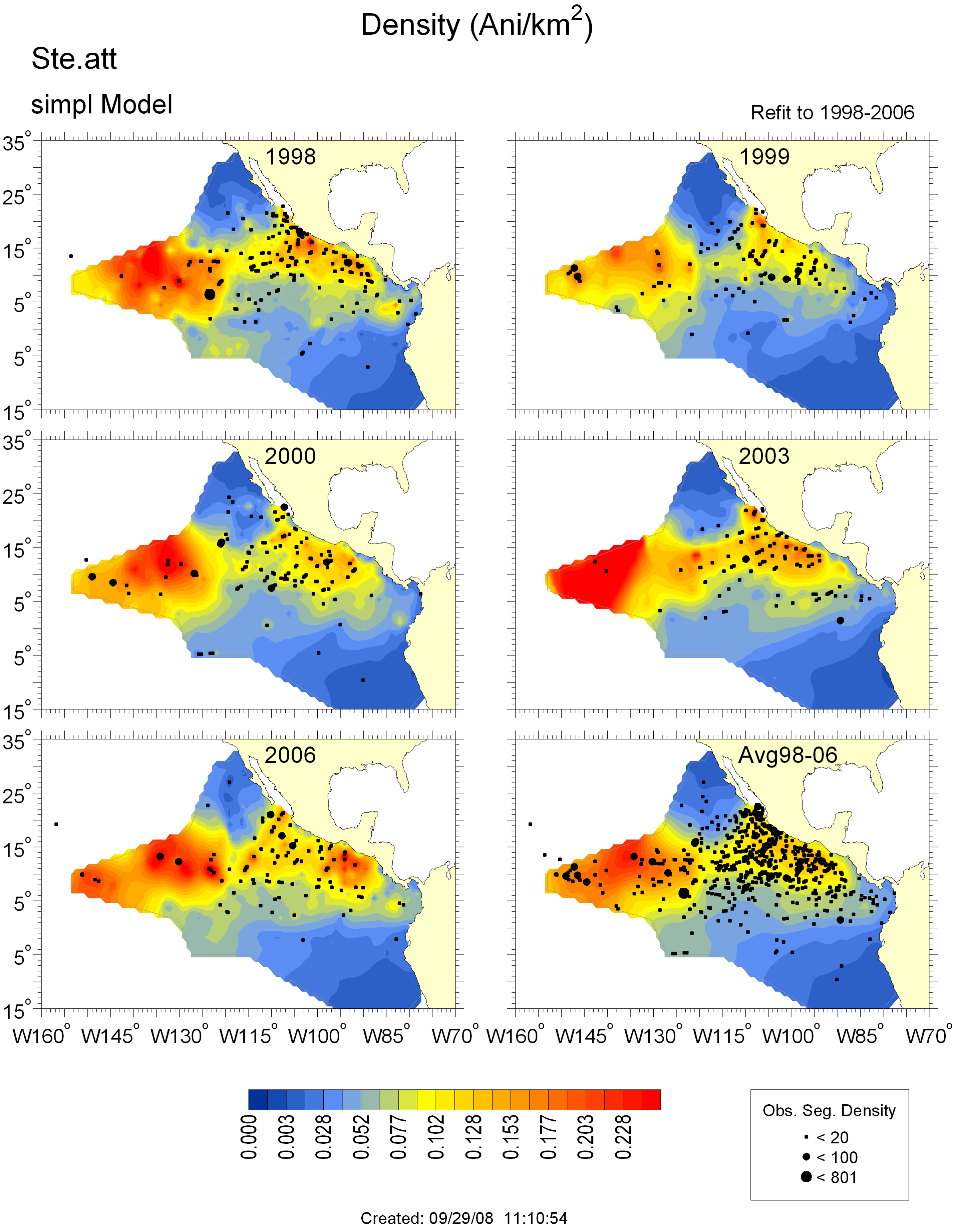


Figure B-1. b) Eastern spinner dolphin

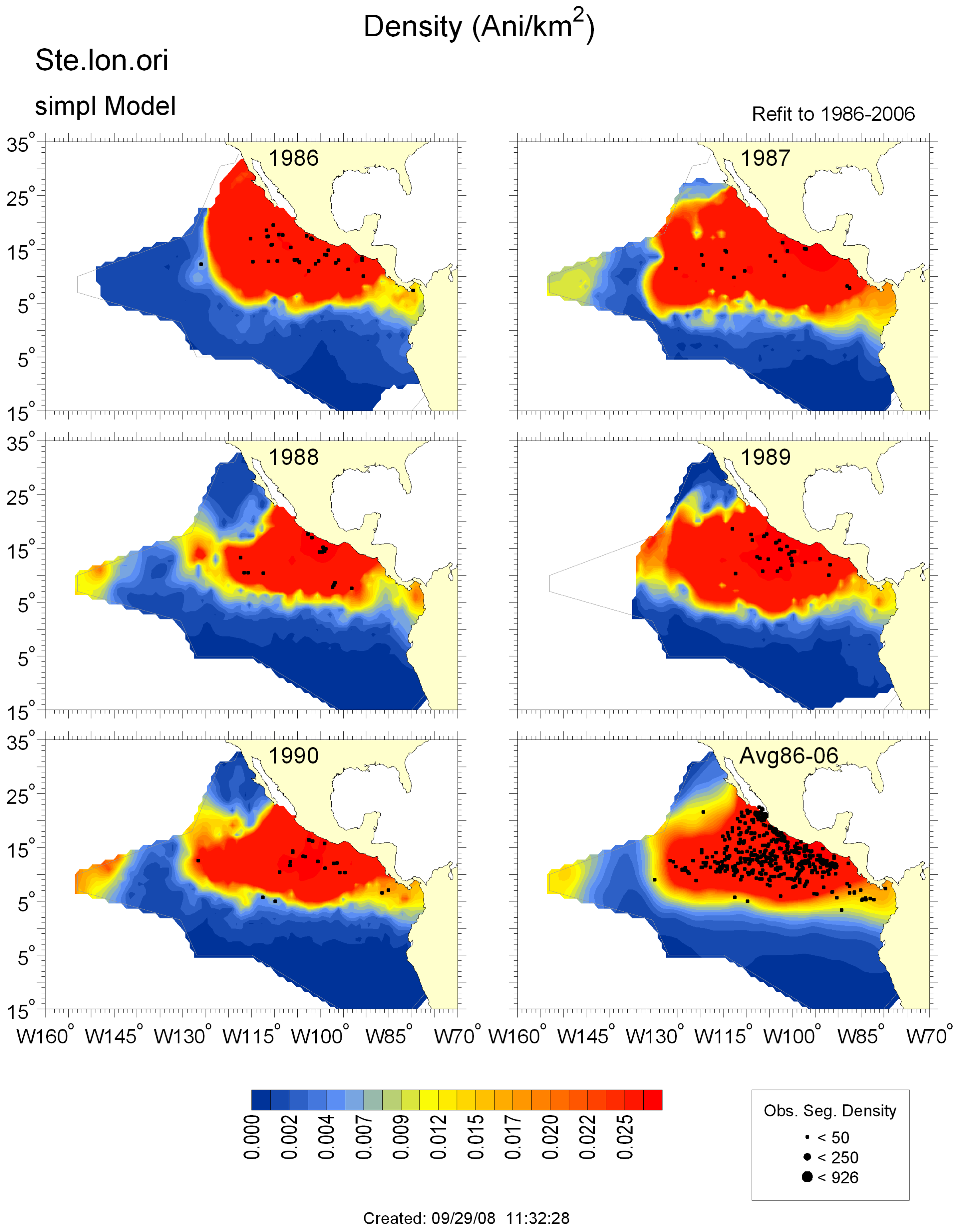


Figure B-1. b) Eastern spinner dolphin (cont.)

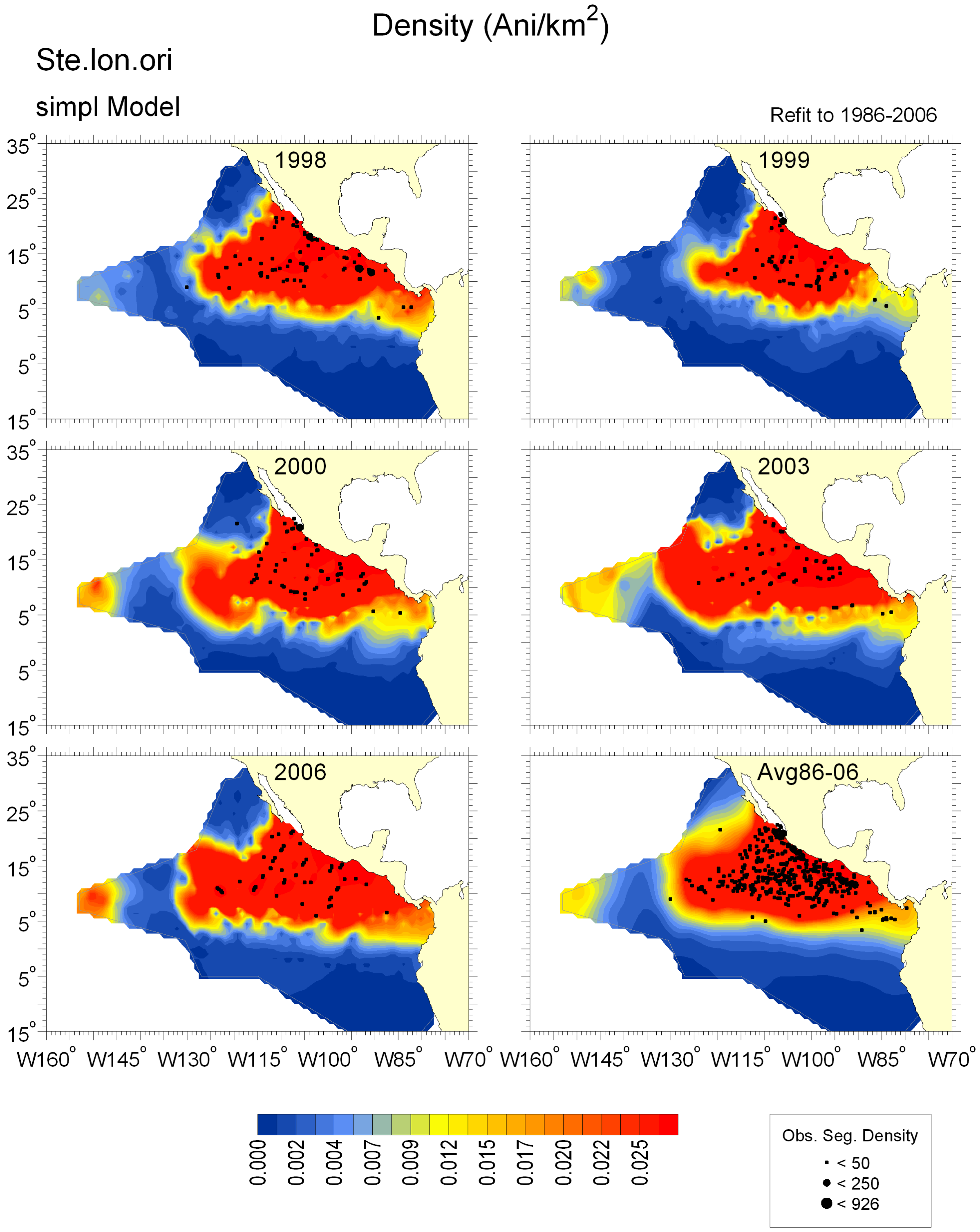


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Figure B-1. c) Whitebelly spinner dolphin

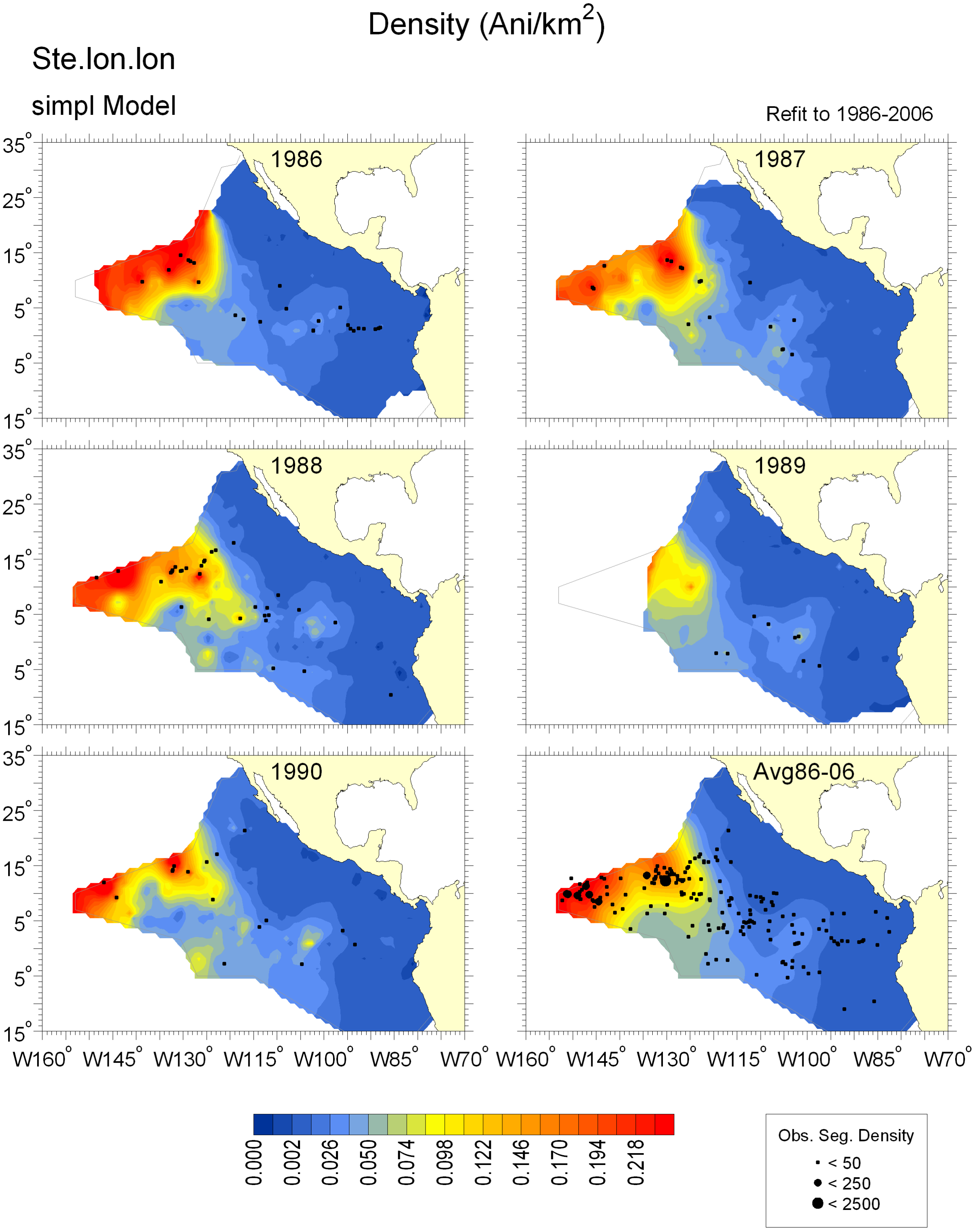

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Figure B-1. c) Whitebelly spinner dolphin (cont.)

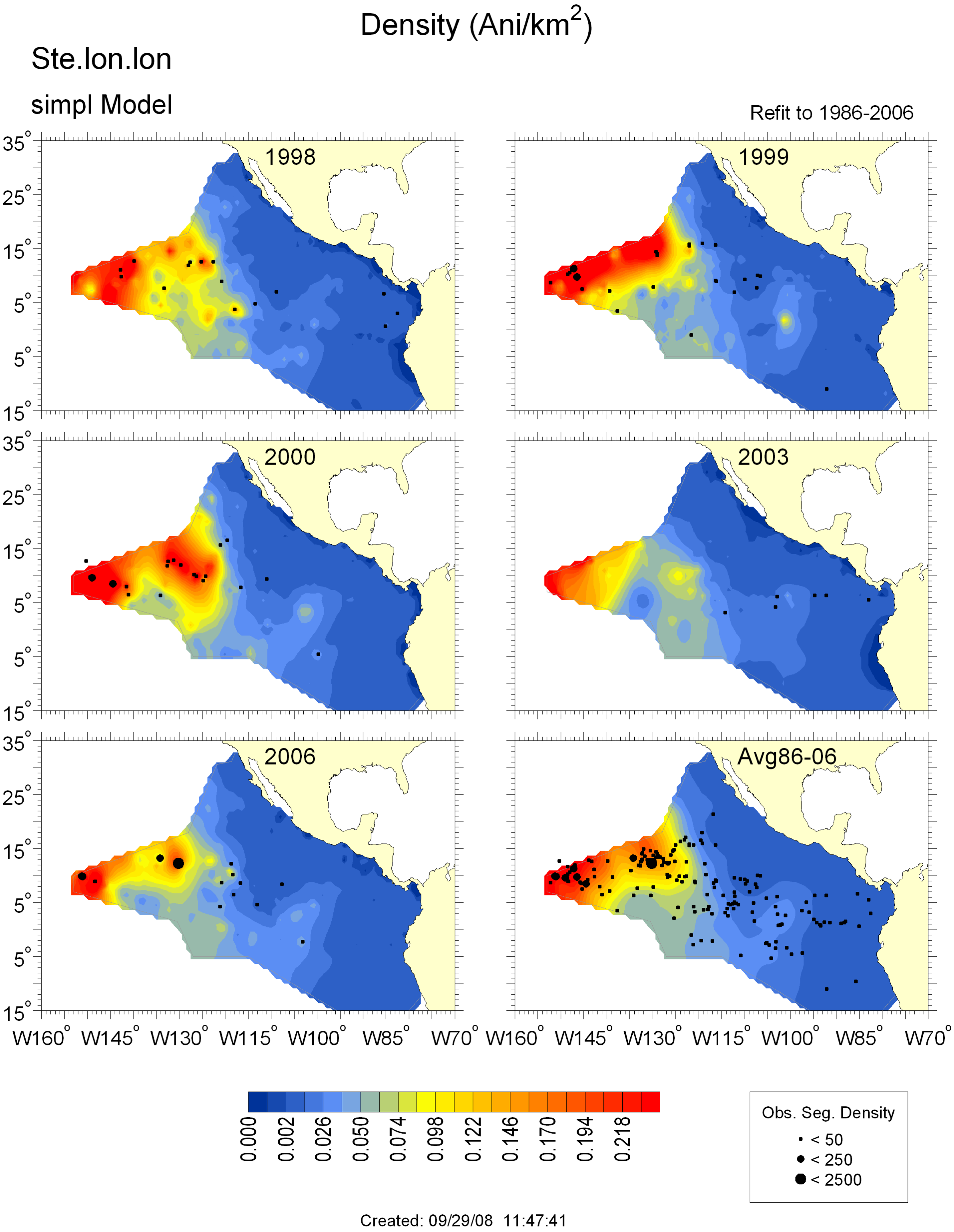

Figure B-1. d) Striped dolphin

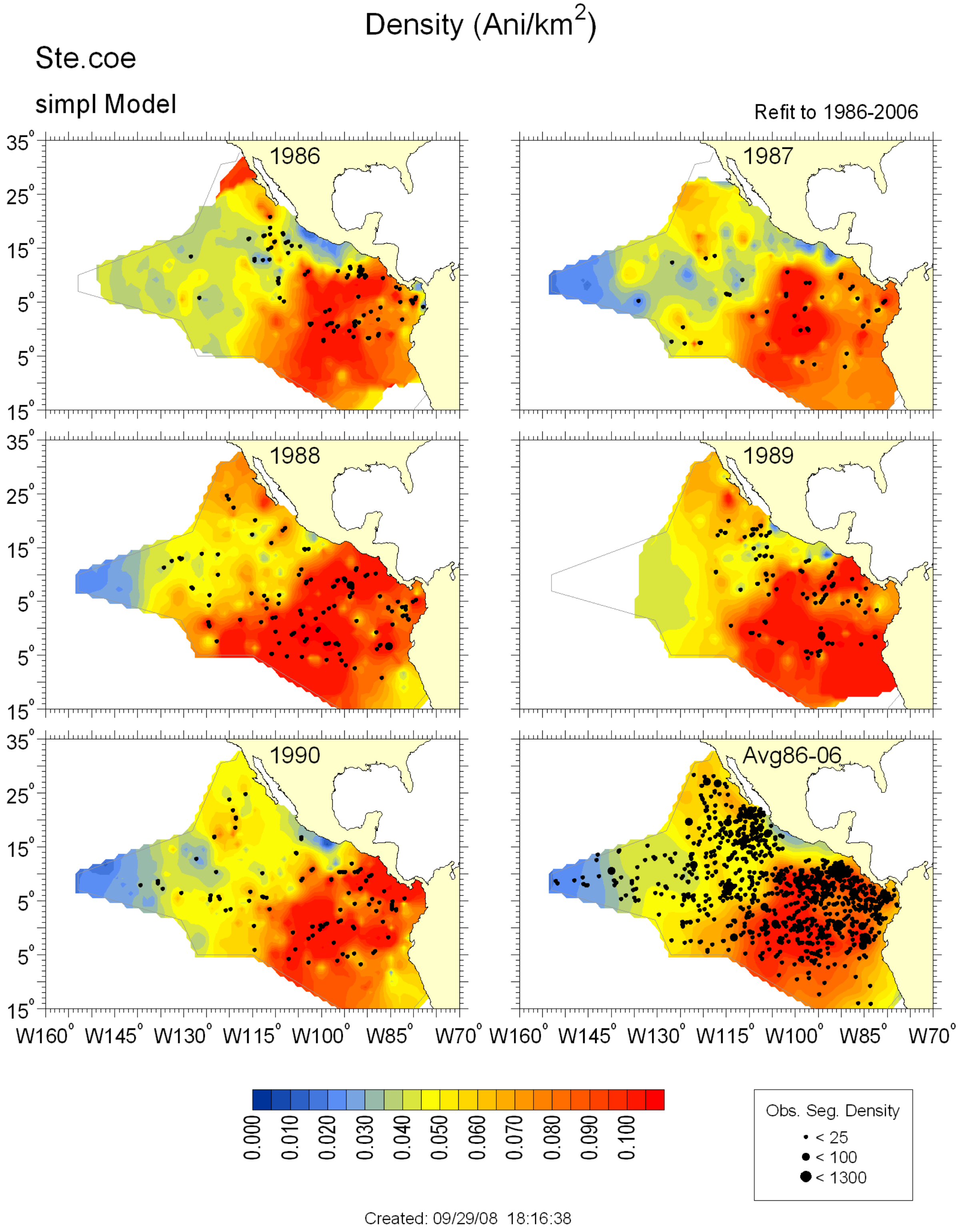

Figure B-1. d) Striped dolphin (cont.)

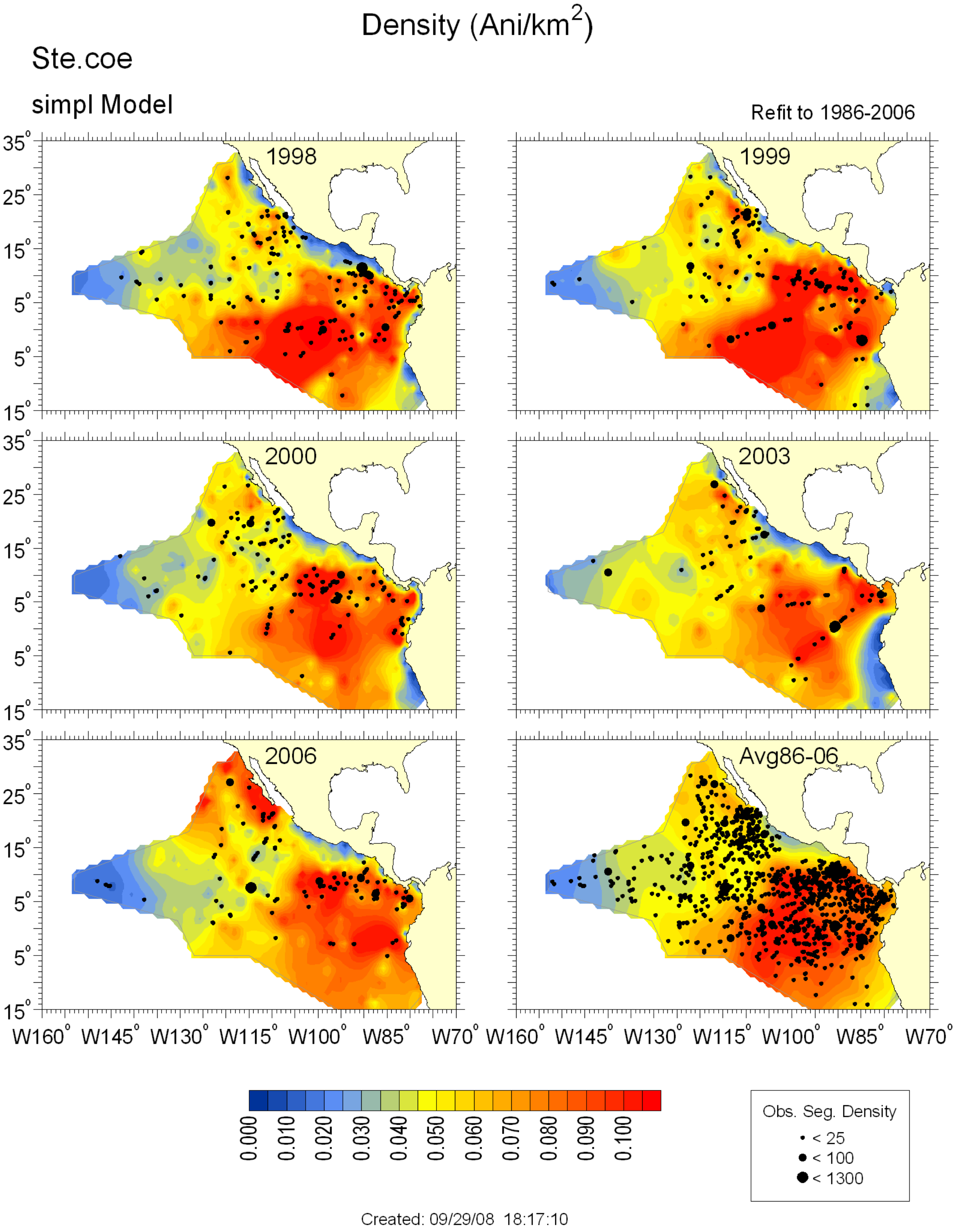

Figure B-1. e) Rough-toothed dolphin

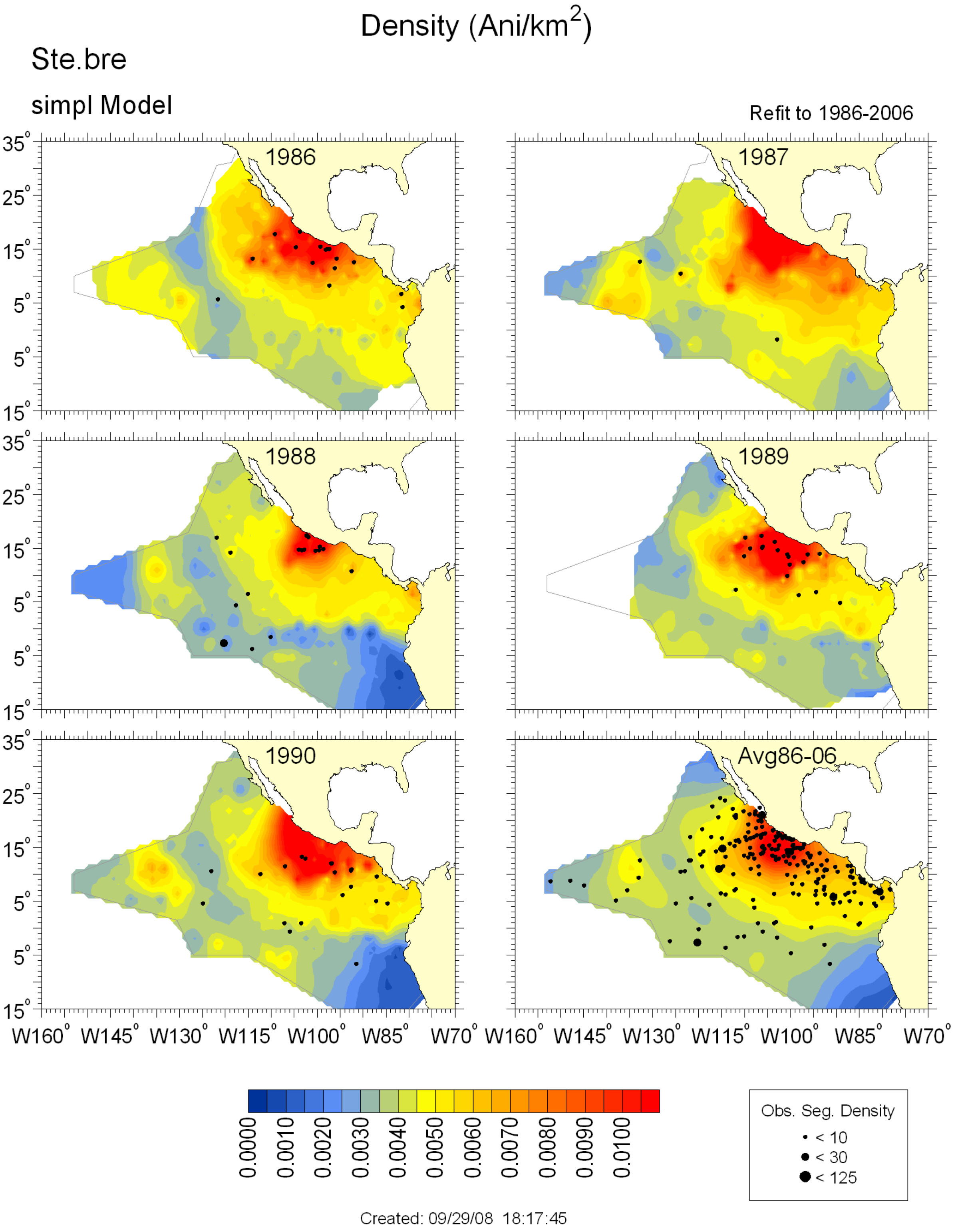

Figure B-1. e) Rough-toothed dolphin (cont.)

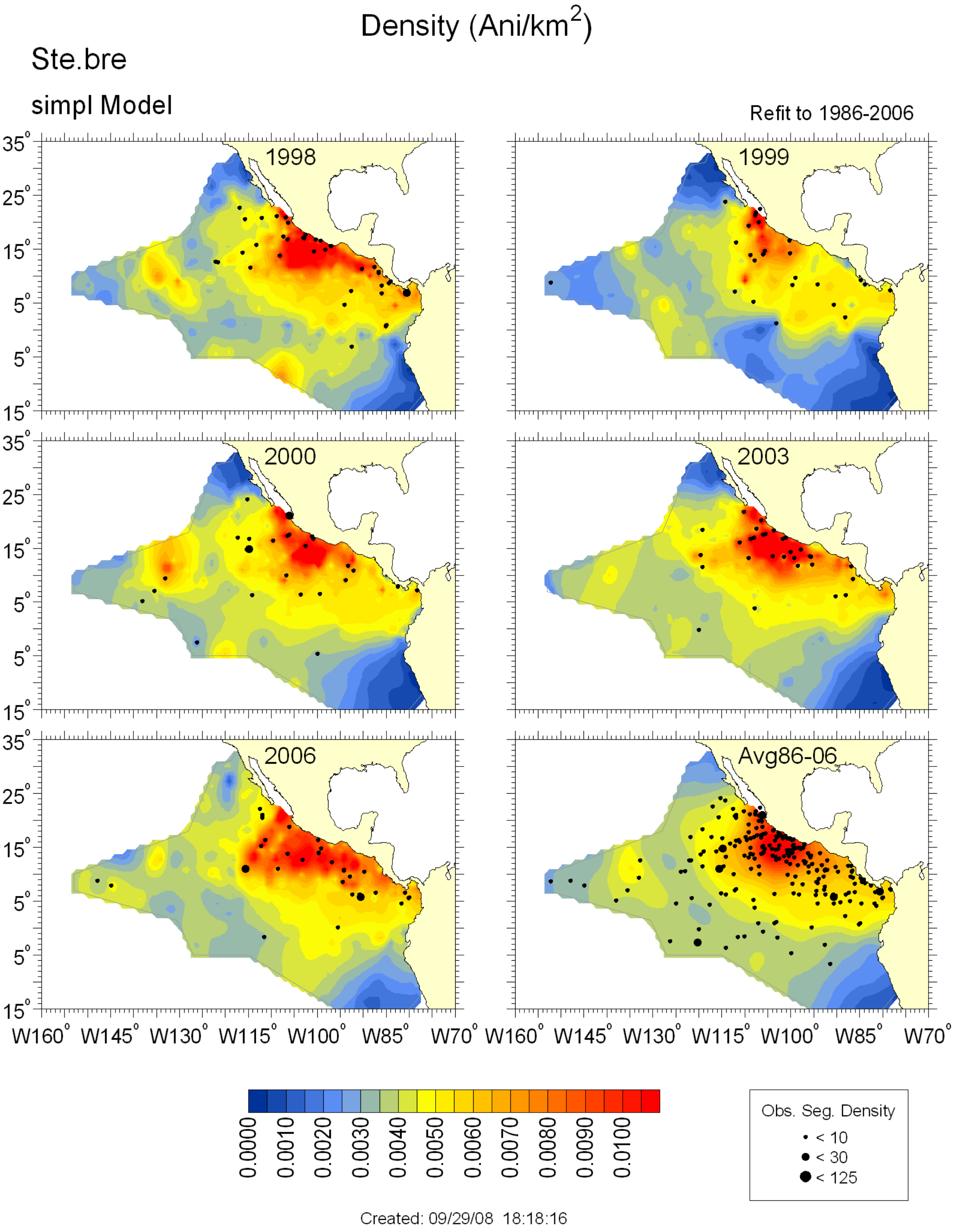

Figure B-1. f) Short-beaked common dolphin

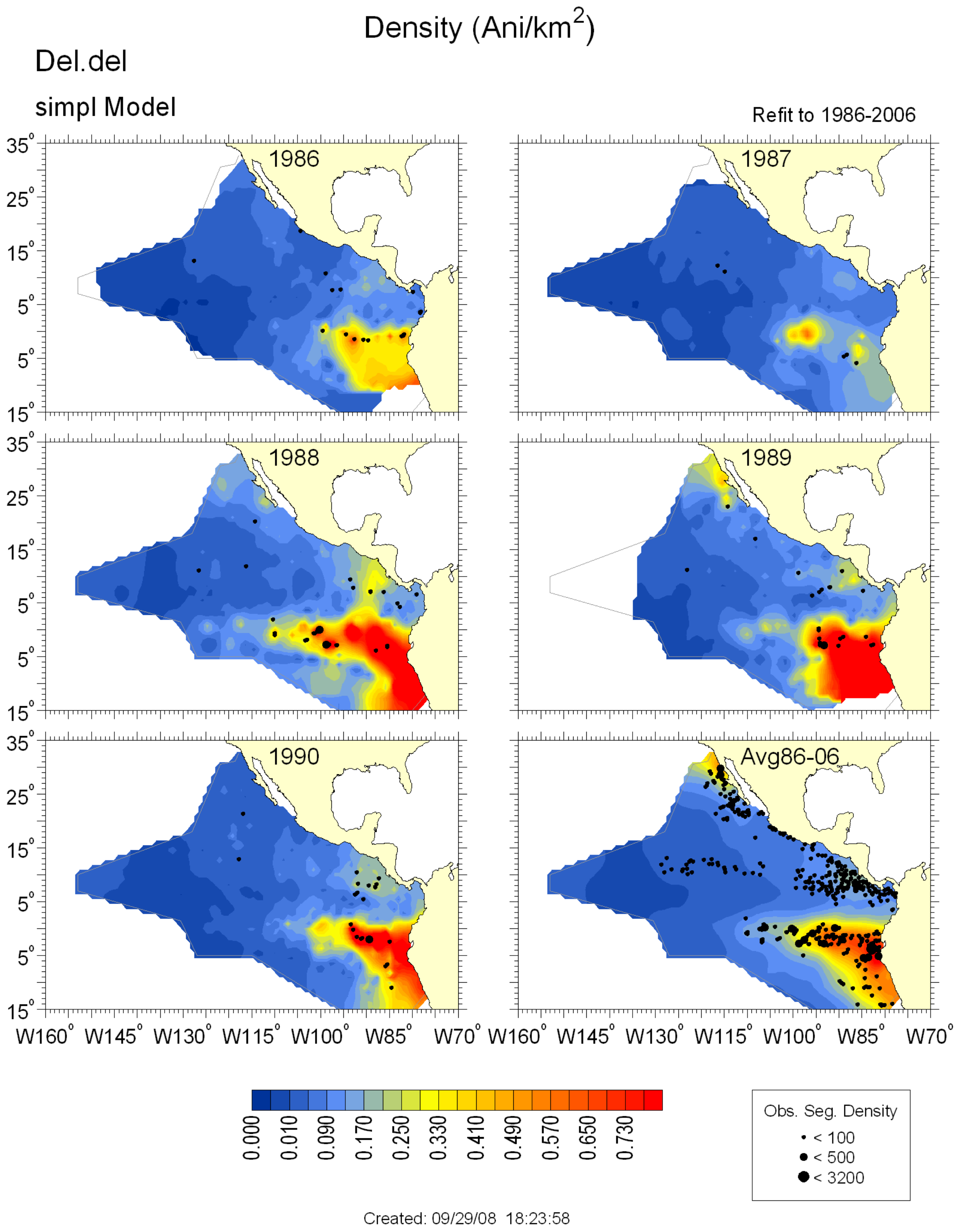

Figure B-1. f) Short-beaked common dolphin (cont.)

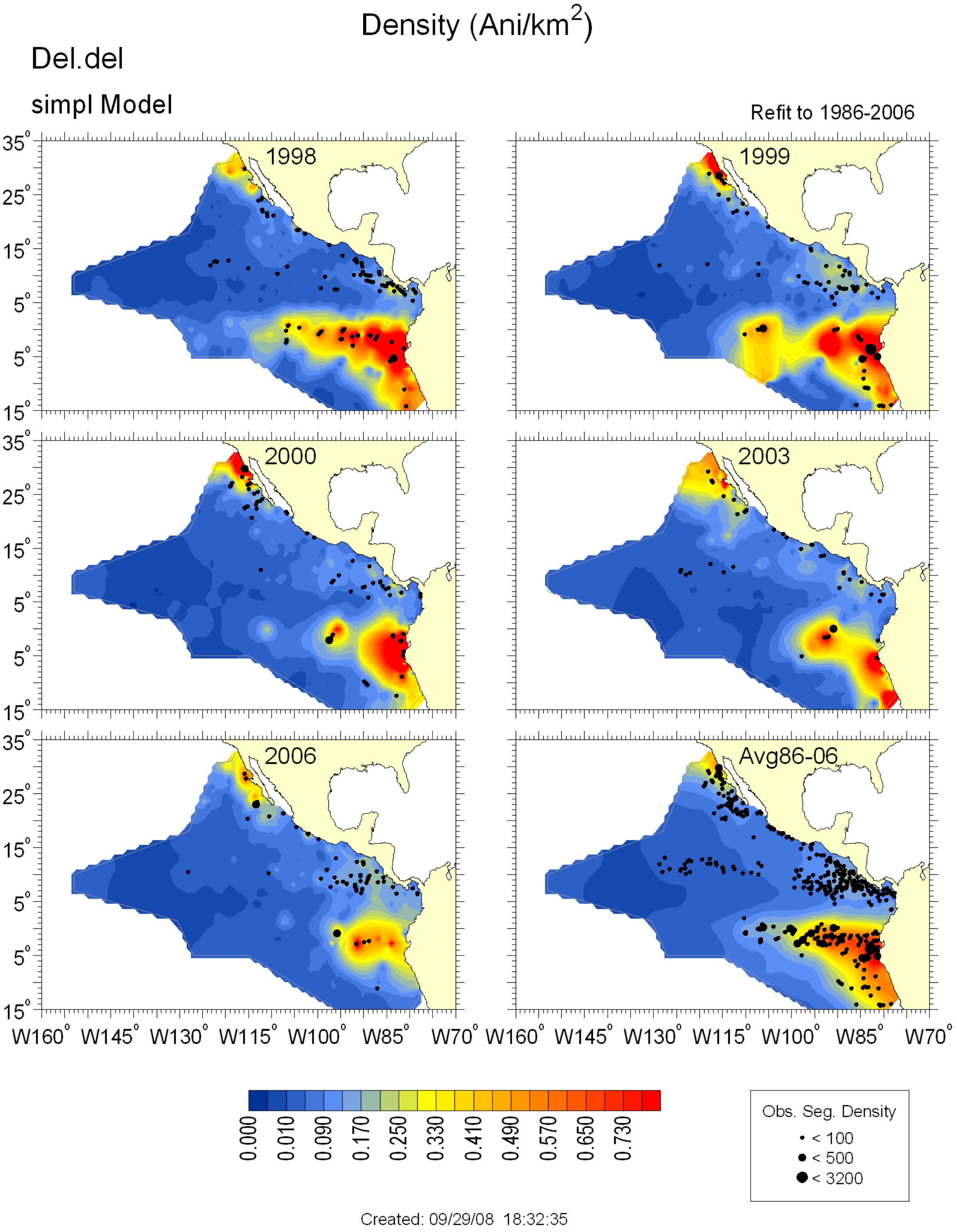

Figure B-1. g) Bottlenose dolphin

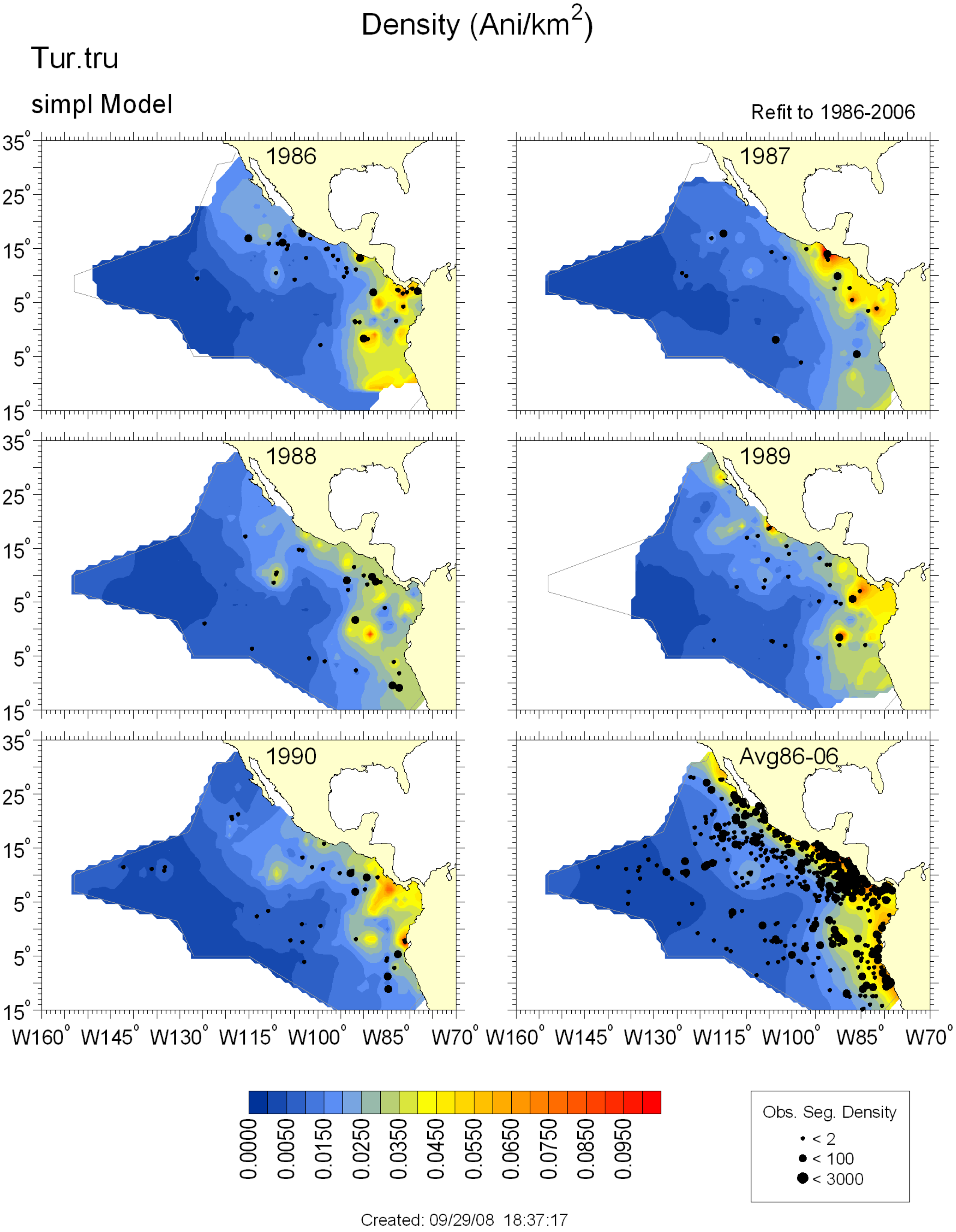

Figure B-1. g) Bottlenose dolphin (cont.)

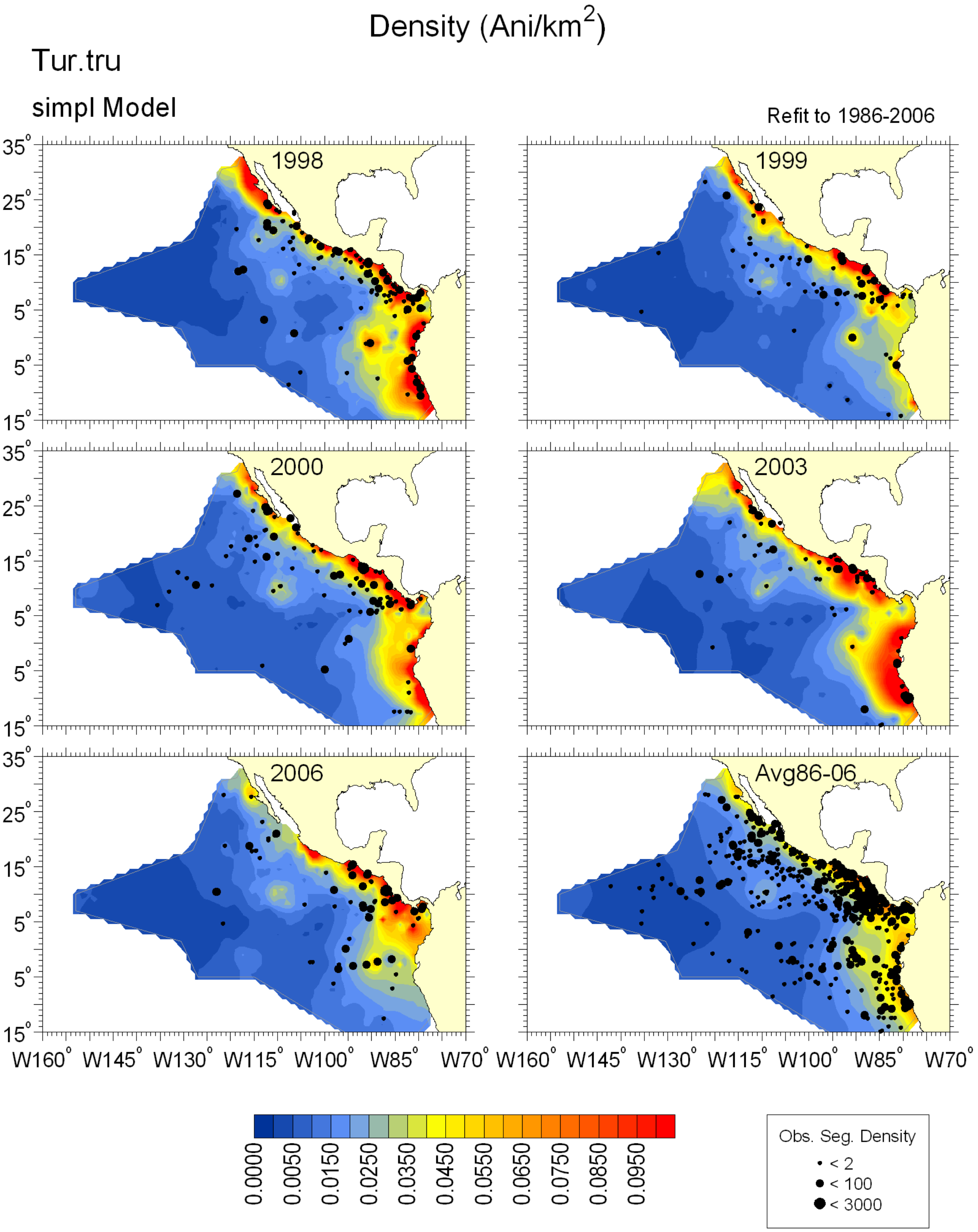

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Figure B-1. h) Risso's dolphin

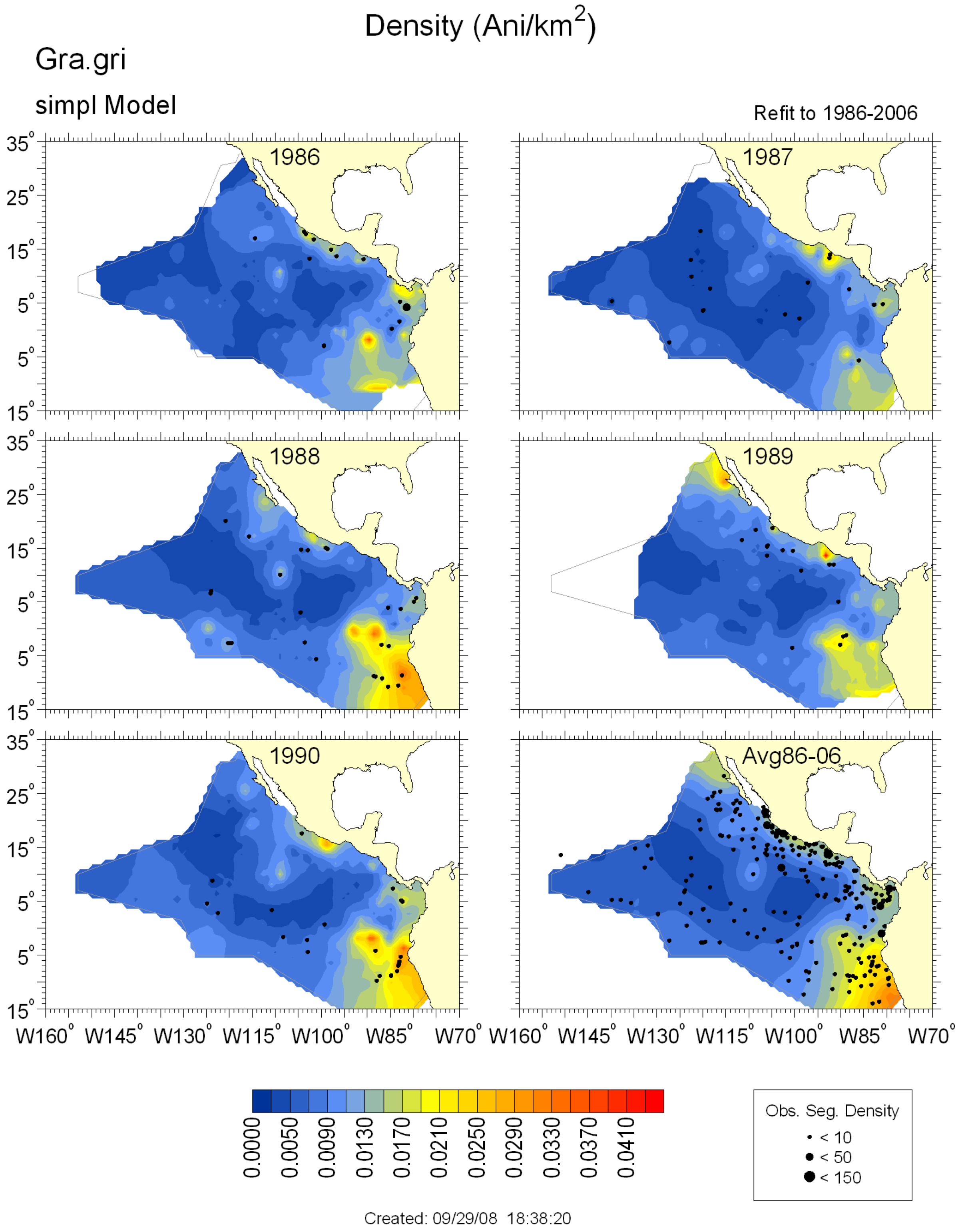

Figure B-1. h) Risso's dolphin (cont.)

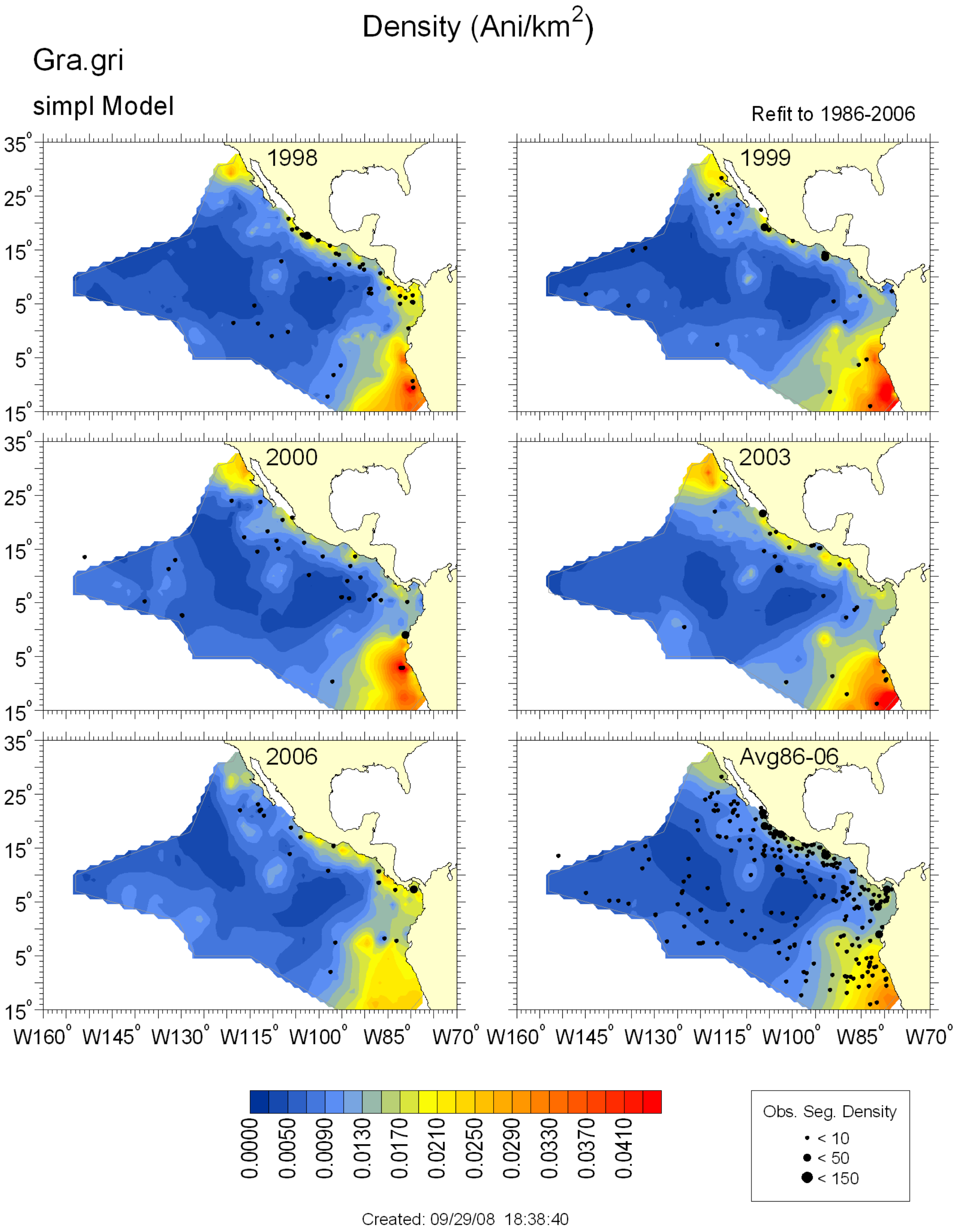

Figure B-1. i) Cuvier's beaked whale

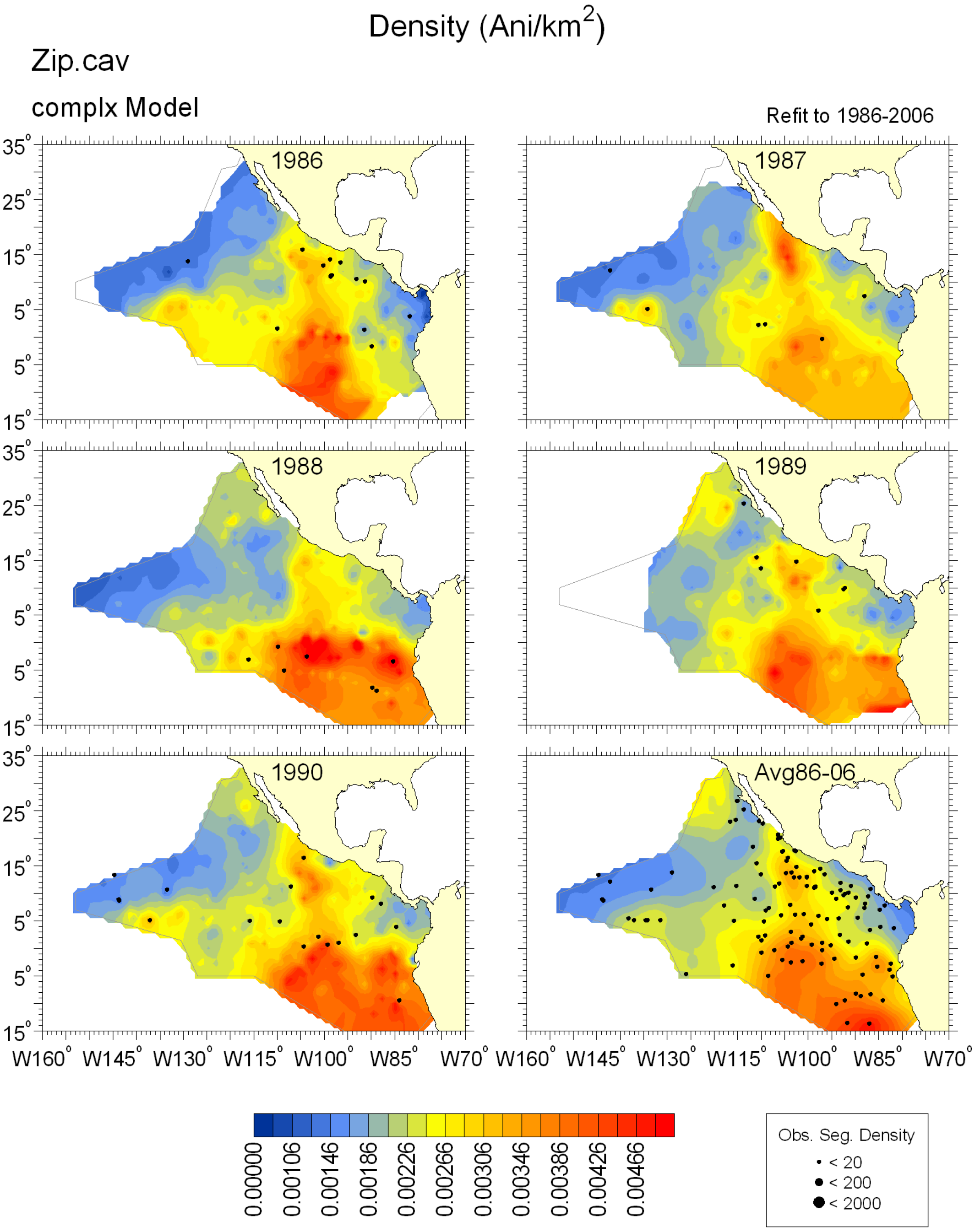

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Figure B-1. i) Cuvier's beaked whale (cont.)

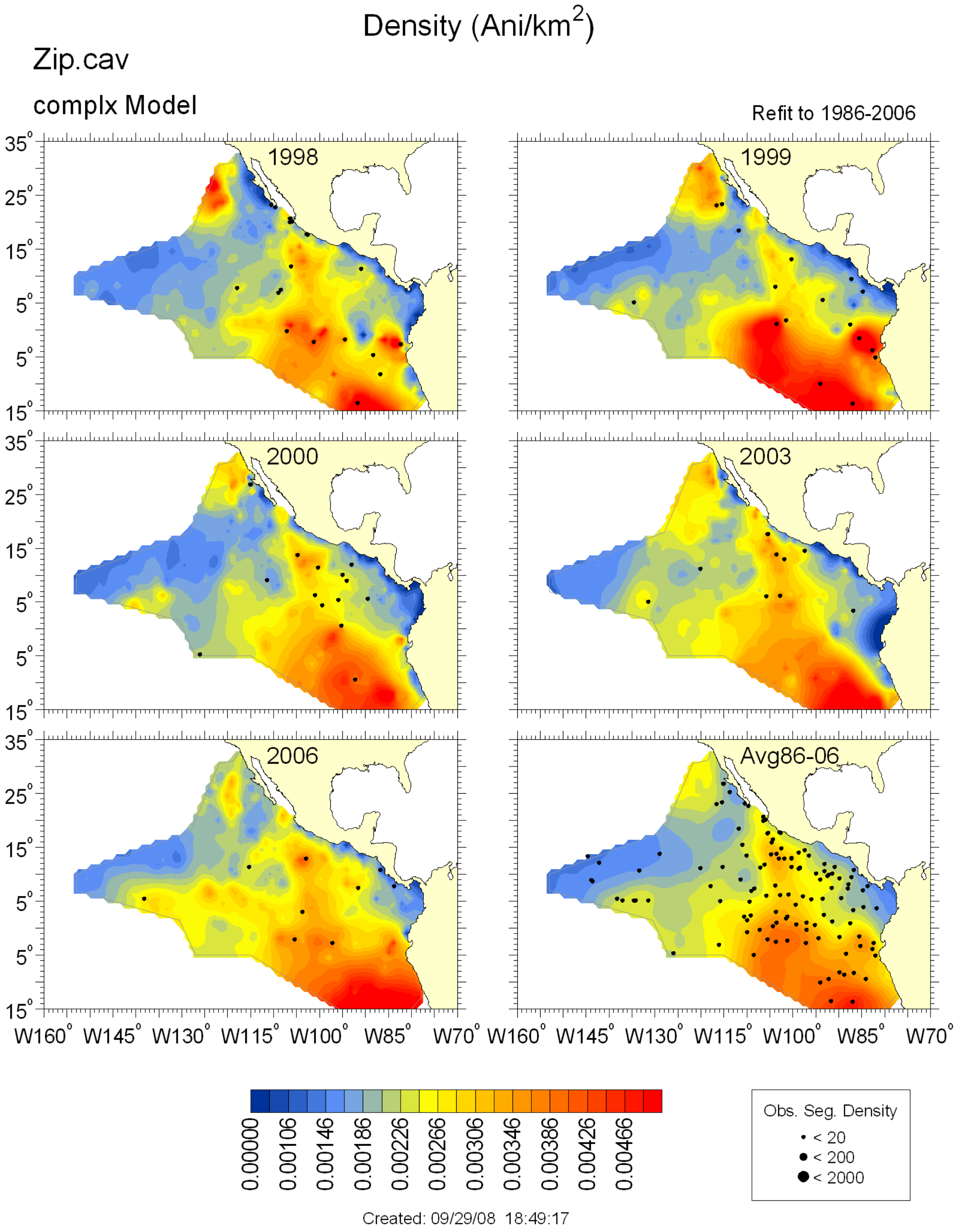


Figure B-1. j) Blue whale

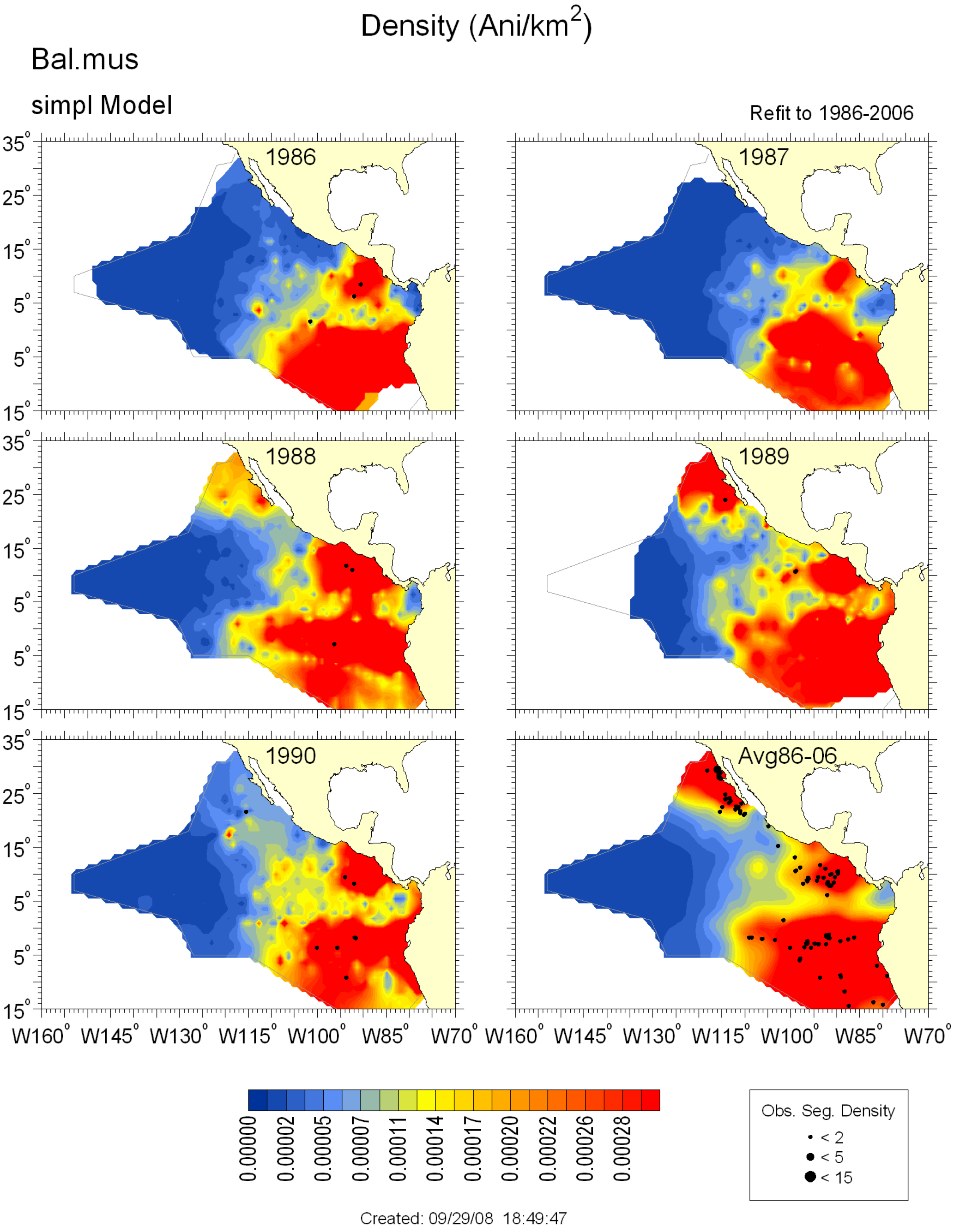


Figure B-1. j) Blue whale (cont.)

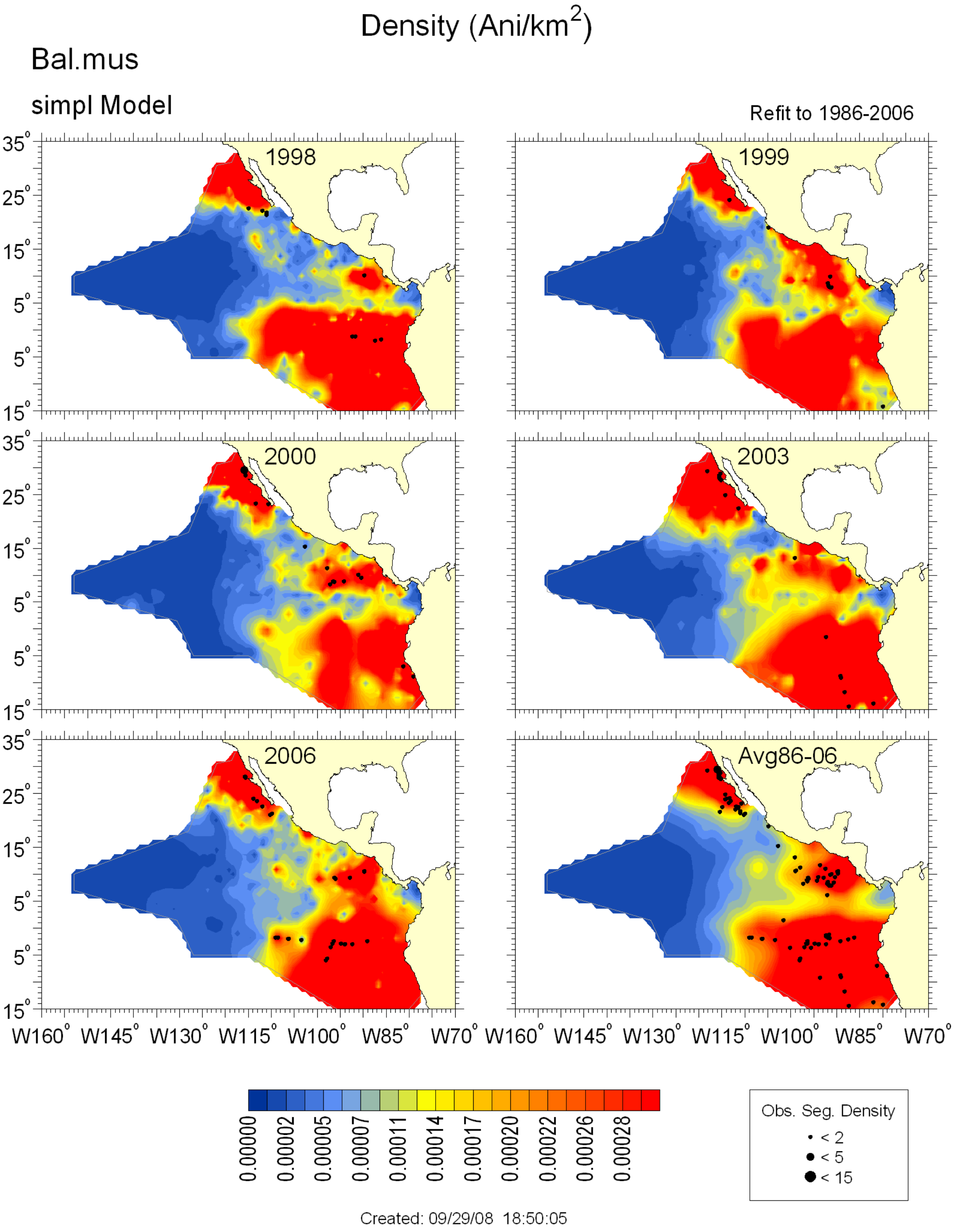


Figure B-1. k) Bryde's whale

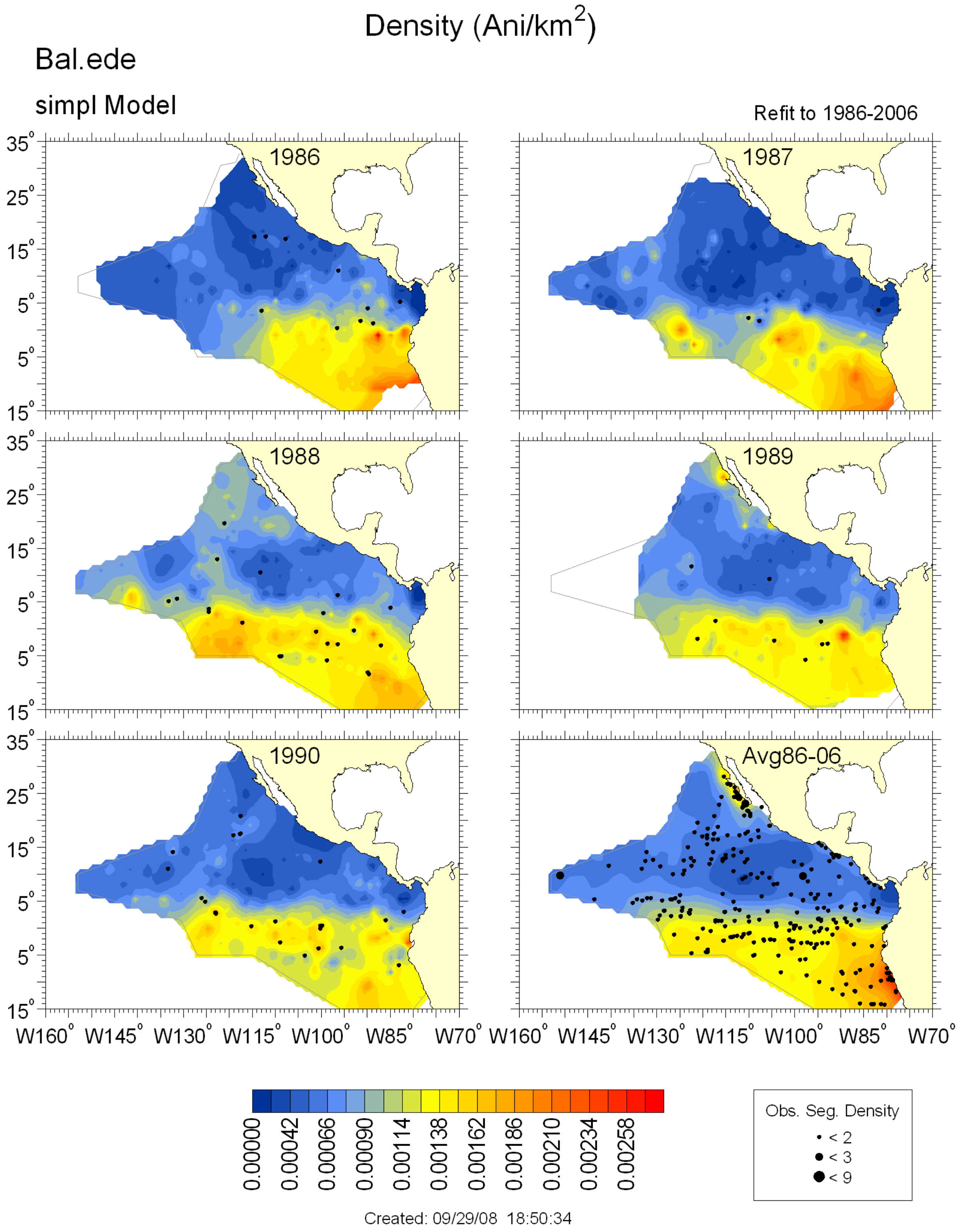


Figure B-1. k) Bryde's whale (cont.)

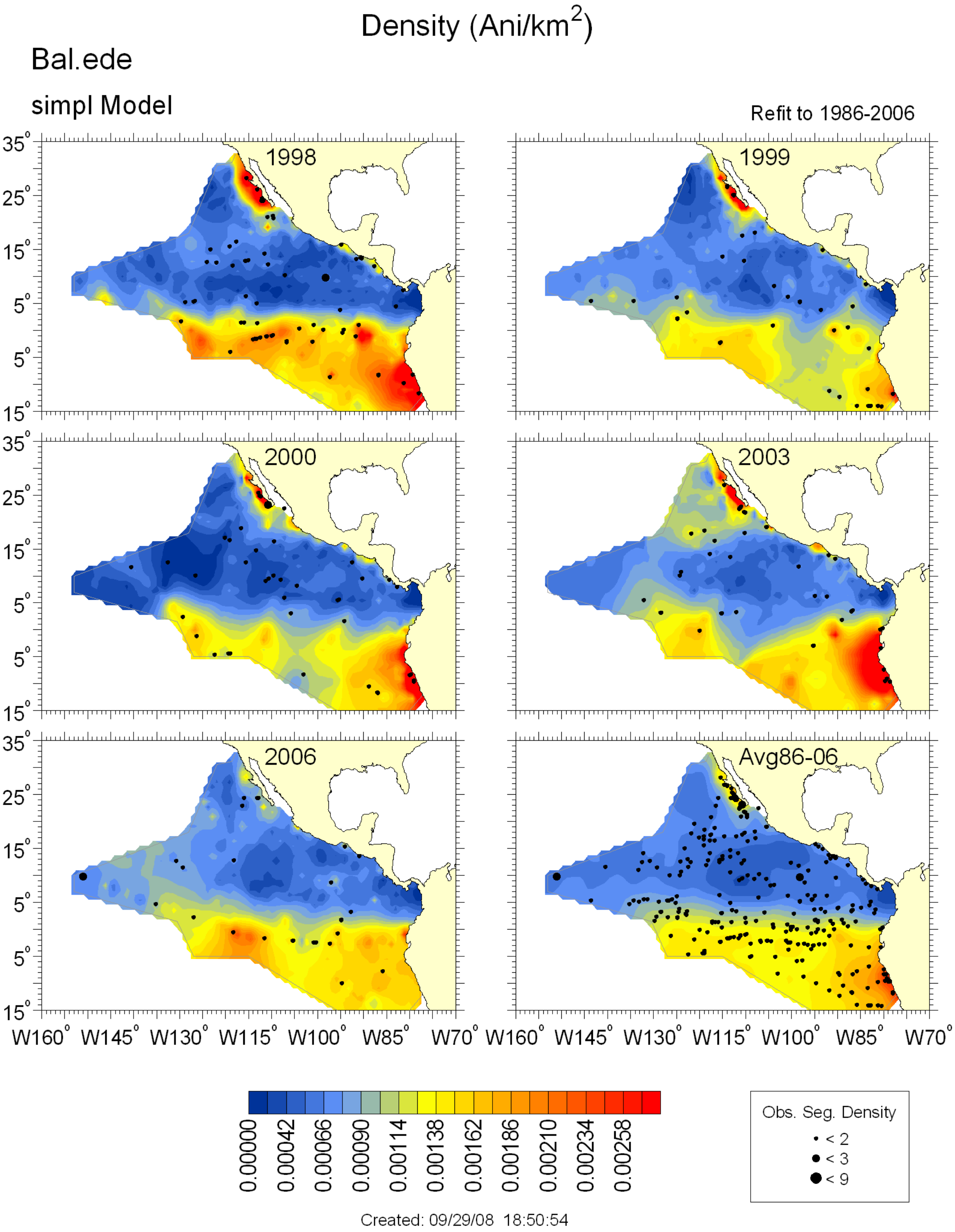


Figure B-1. l) Short-finned pilot whale

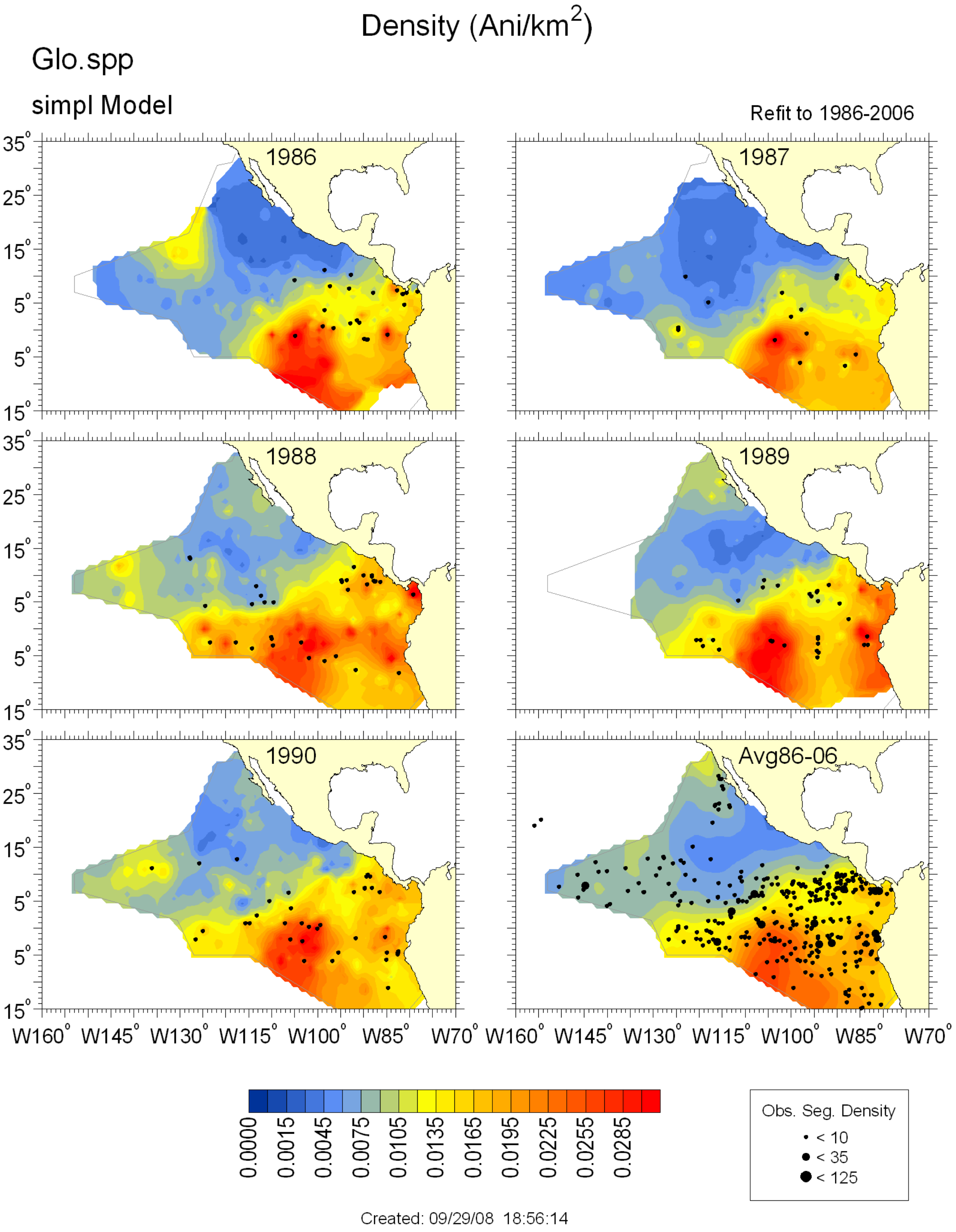


Figure B-1. l) Short-finned pilot whale (cont.)

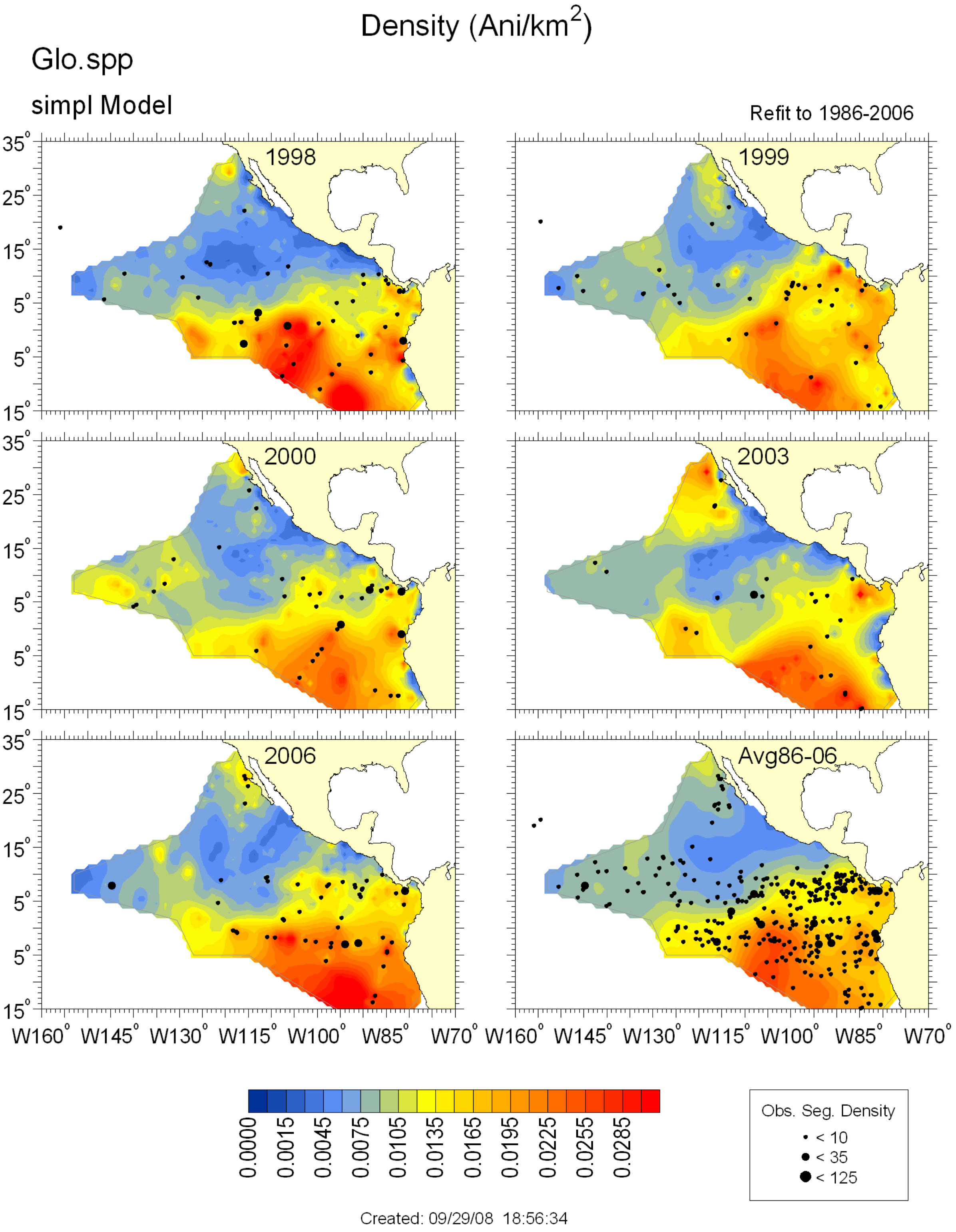


Figure B-1. m) Dwarf sperm whale

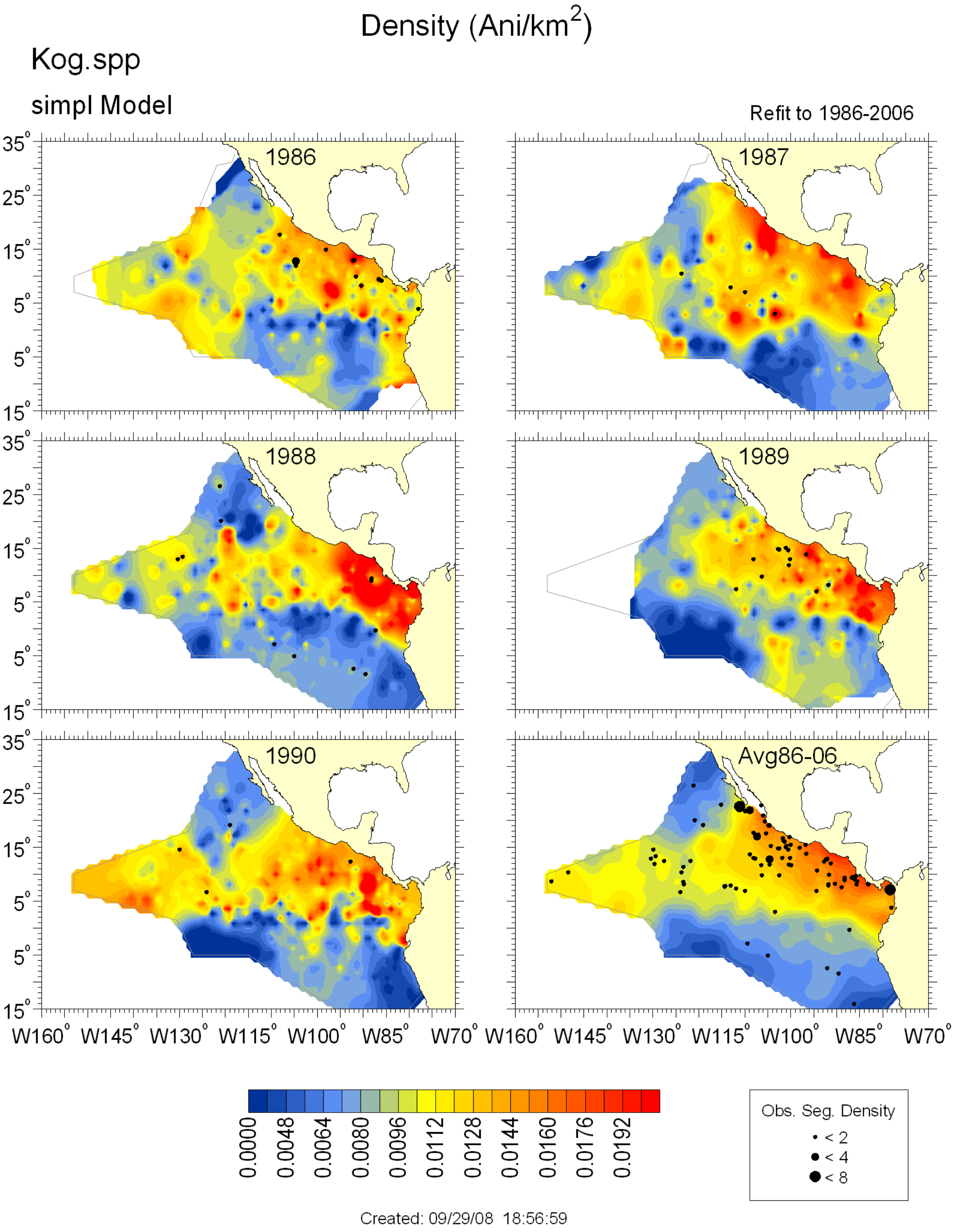


Figure B-1. m) Dwarf sperm whale (cont.)

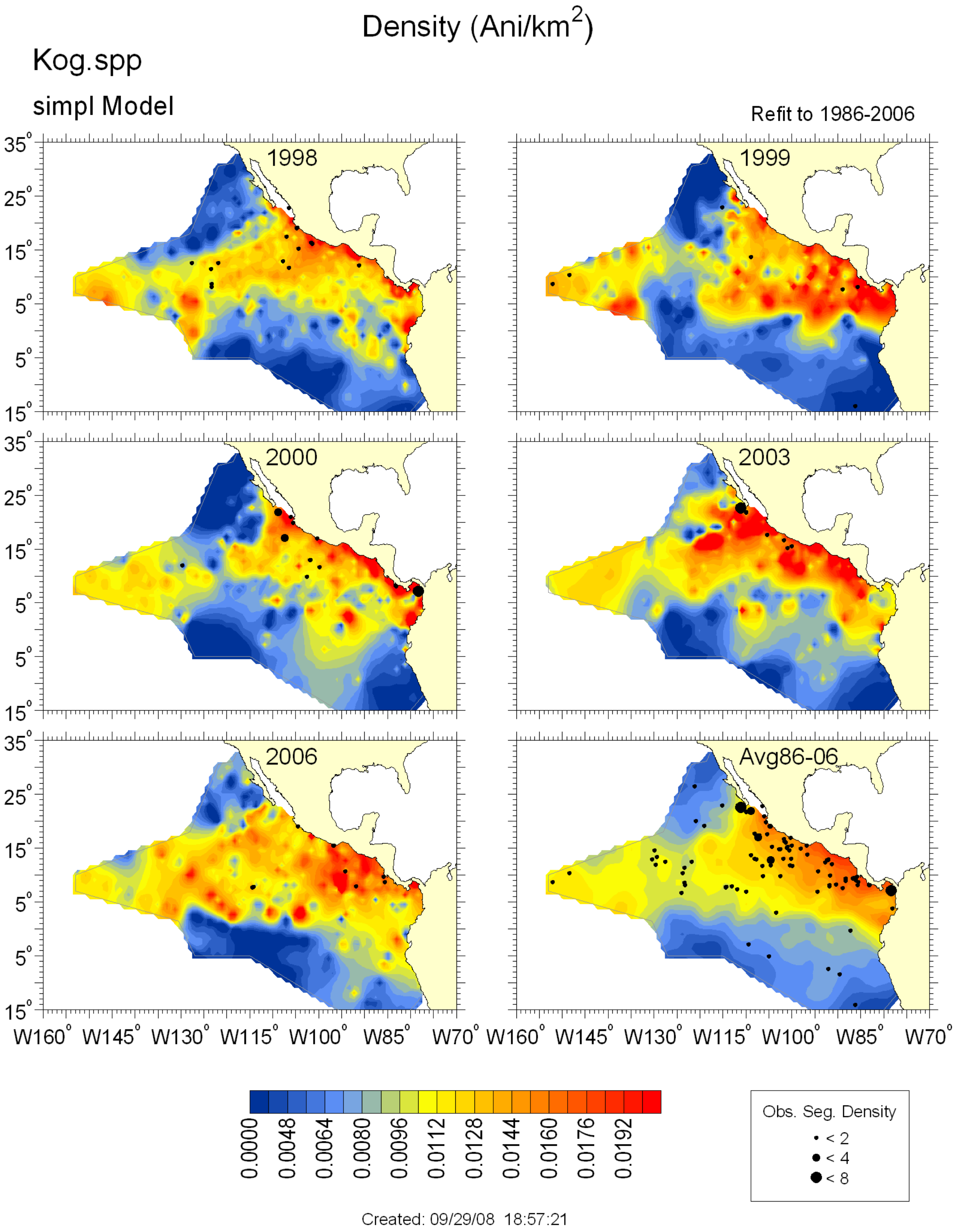


Figure B-1. n) *Mesoplodon* beaked whales

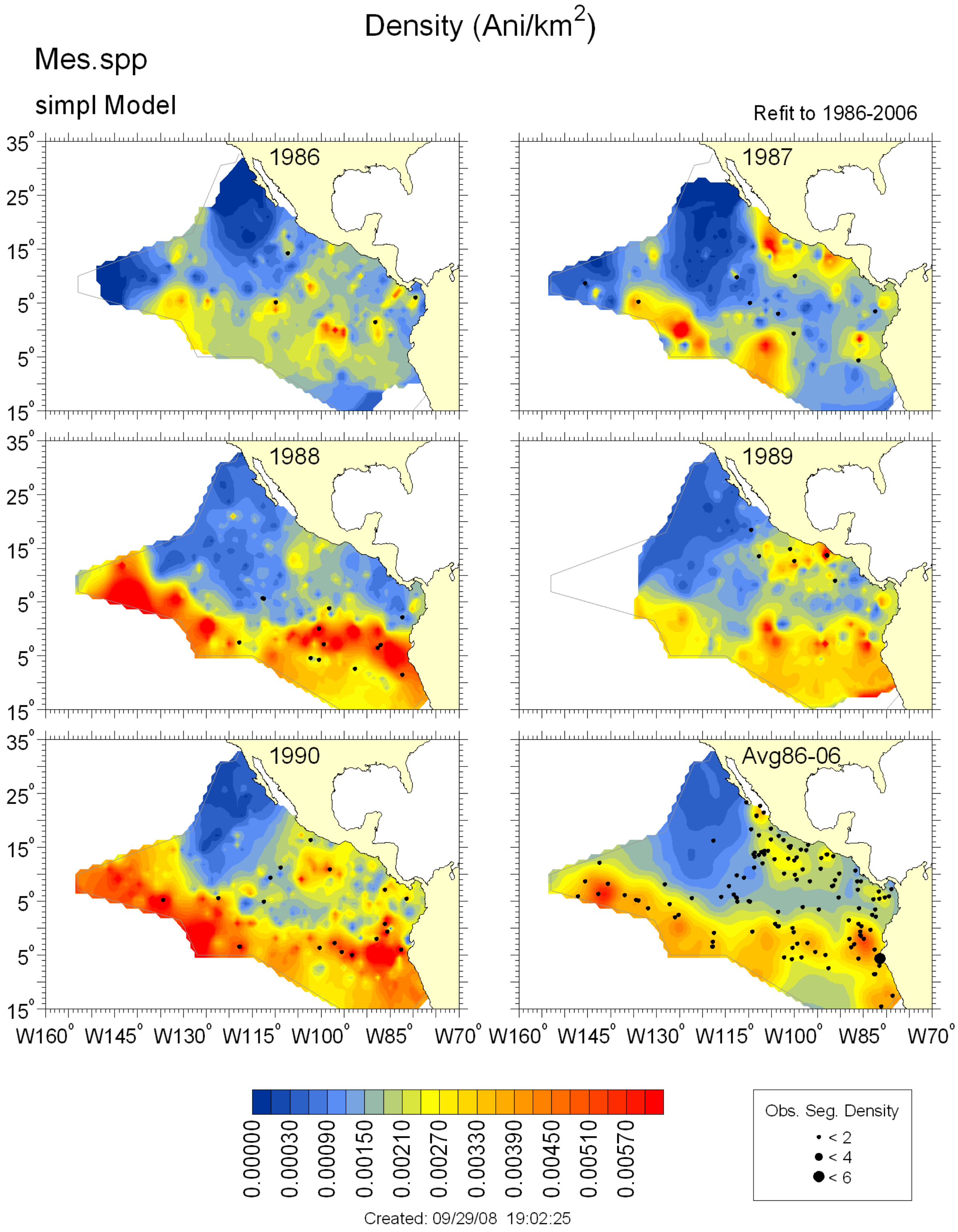


Figure B-1. n) *Mesoplodon* beaked whales (cont.)

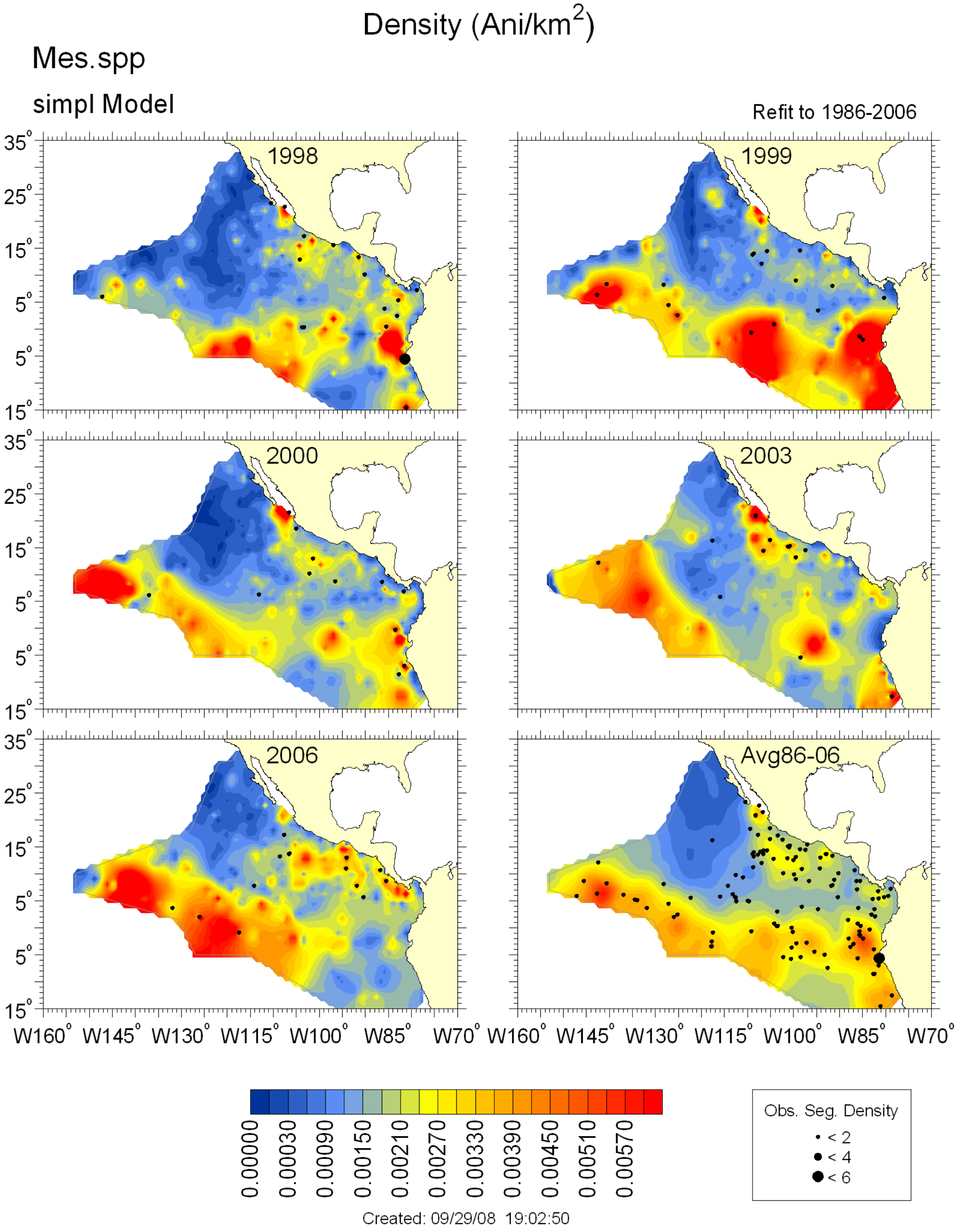


Figure B-1. o) Small beaked whales

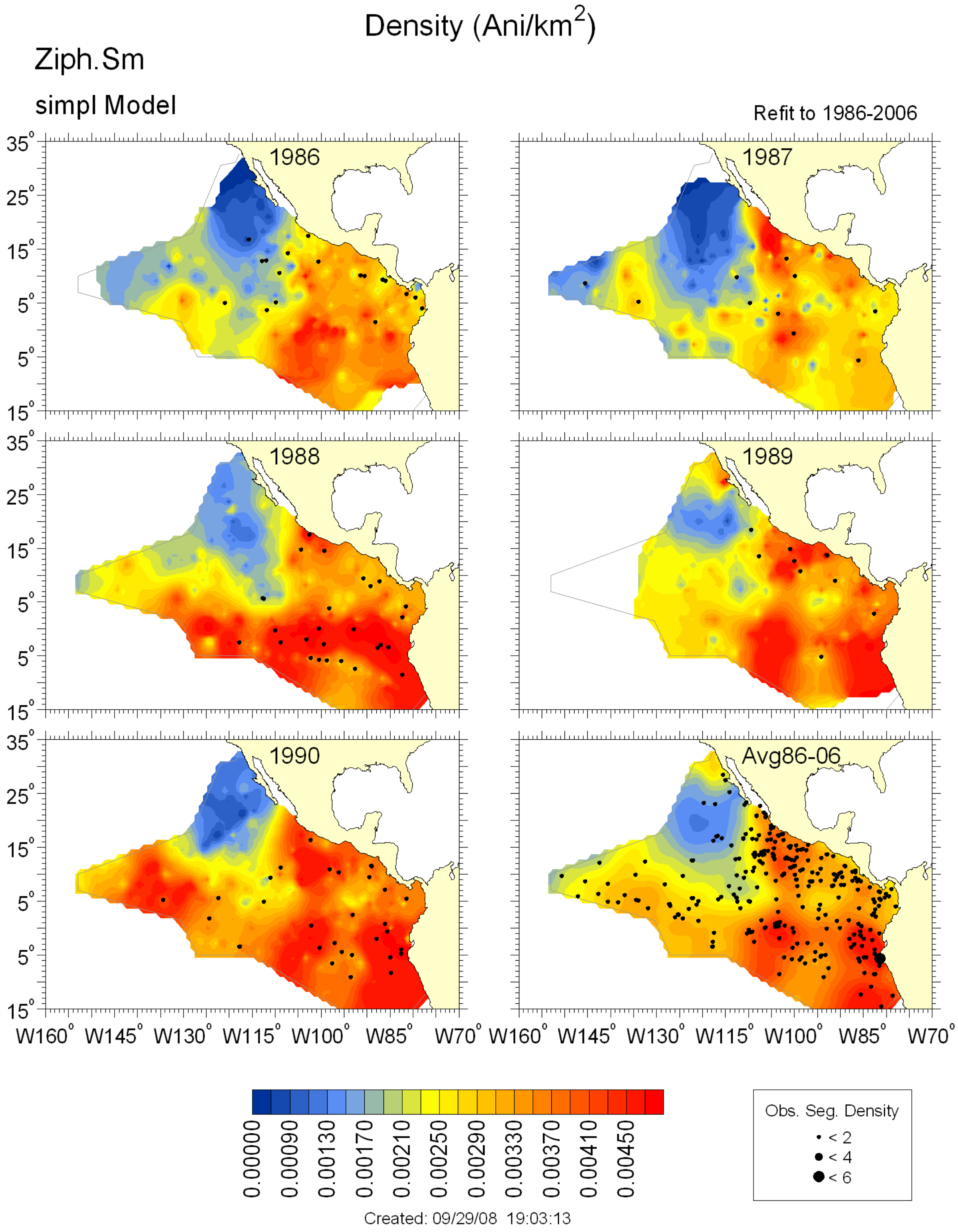


Figure B-1. o) Small beaked whales (cont.)

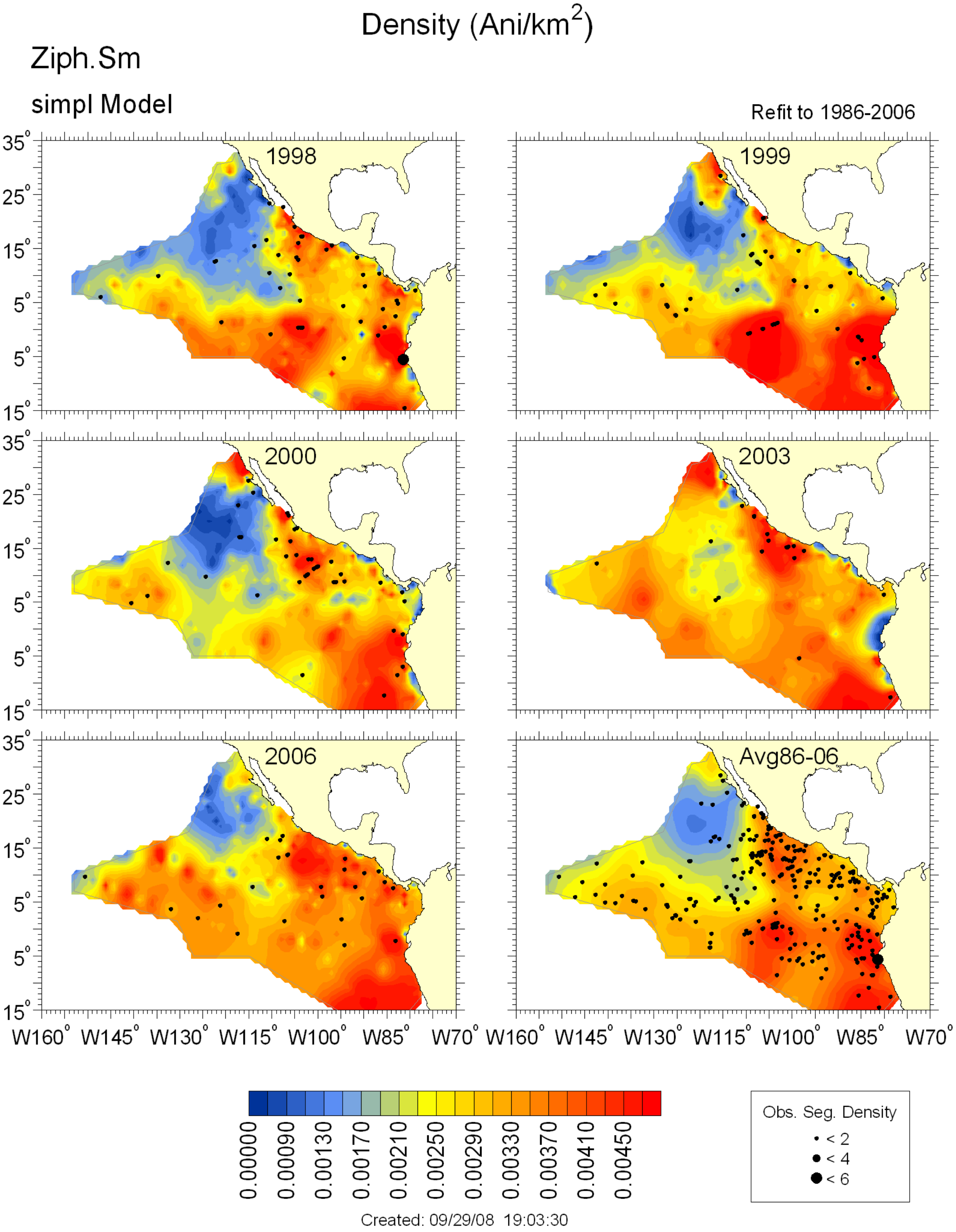
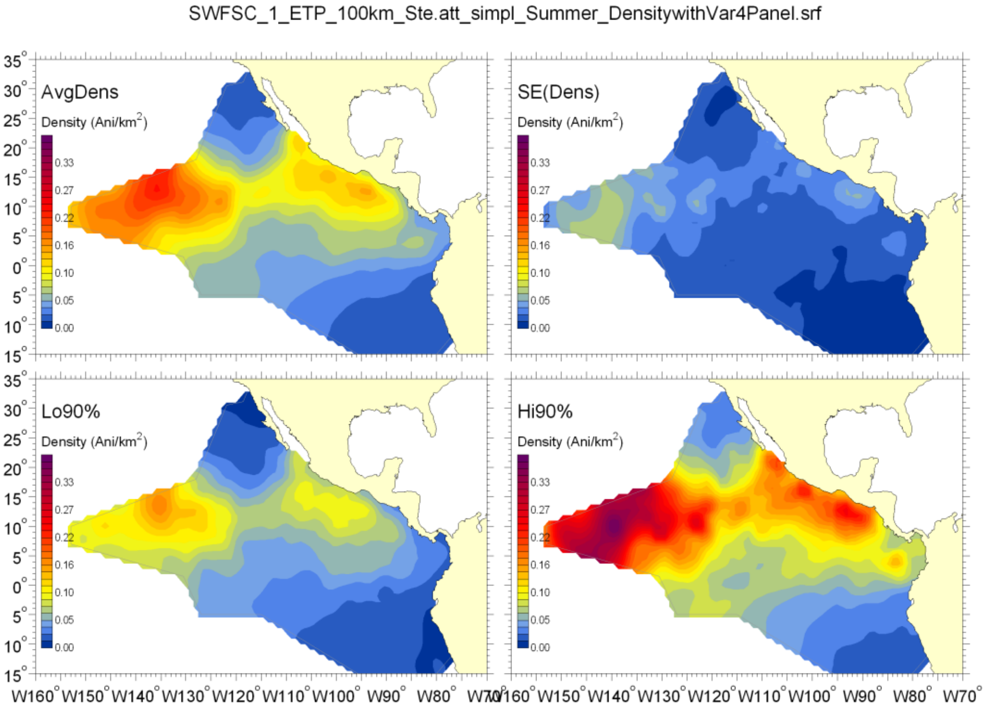


Figure B-2. Predicted average density (AveDens), standard error (SE(Dens)), and lower and upper lognormal 90% confidence limits(Lo90% and Hi90%) based on the final ETP models for: (a) offshore spotted dolphin (*Stenella attenuata*), (b) eastern spinner dolphin (*Stenella longirostris orientalis*), (c) whitebelly spinner dolphin (*Stenella longirostris longirostris*), (d) striped dolphin (*Stenella coeruleoalba*), (e) rough-toothed dolphin (*Steno bredanensis*), (f) short-beaked common dolphin (*Delphinus delphis*), (g) bottlenose dolphin (*Tursiops truncatus*), (h) Risso's dolphin (*Grampus griseus*), (i) Cuvier's beaked whale (*Ziphius cavirostris*), (j) blue whale (*Balaenoptera musculus*), (k) Bryde's whale (*Balaenoptera edeni*), (l) short-finned pilot whale (*Globicephala macrorhynchus*), (m) dwarf sperm whale (*Kogia sima*), (n) *Mesoplodon* beaked whales (including *Mesoplodon* spp., *Mesoplodon densirostris*, and *Mesoplodon peruvianus*), and (o) small beaked whales (*Mesoplodon* beaked whales plus "unidentified beaked whale"). Grid cells for each of the individual survey years were averaged across all years to calculate average species density; standard errors and upper and lower lognormal 90% confidence limits were calculated from the grid cell averages and variances using standard formulae. Predicted values were then smoothed using inverse distance weighting (see Section 3.5.1 for details).

Figure B-2.

a) Offshore spotted dolphin



b) Eastern spinner dolphin

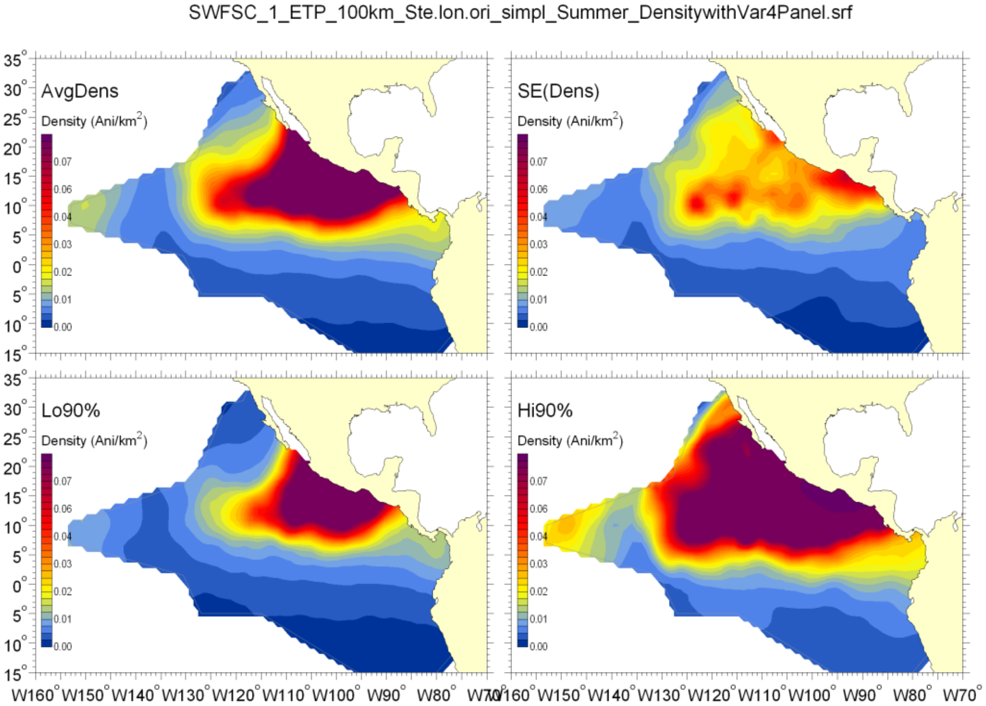
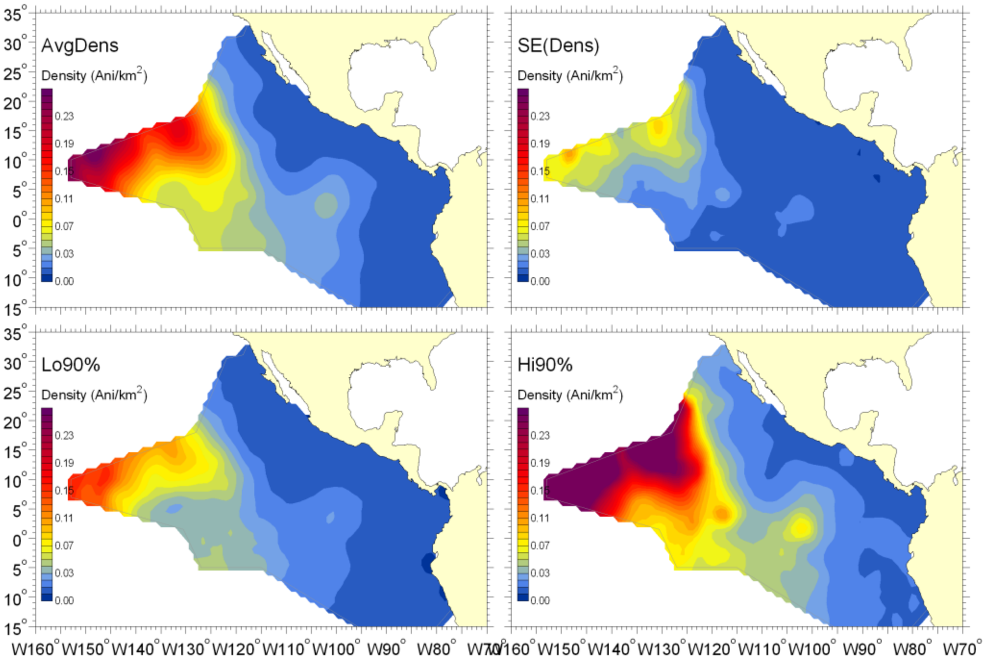


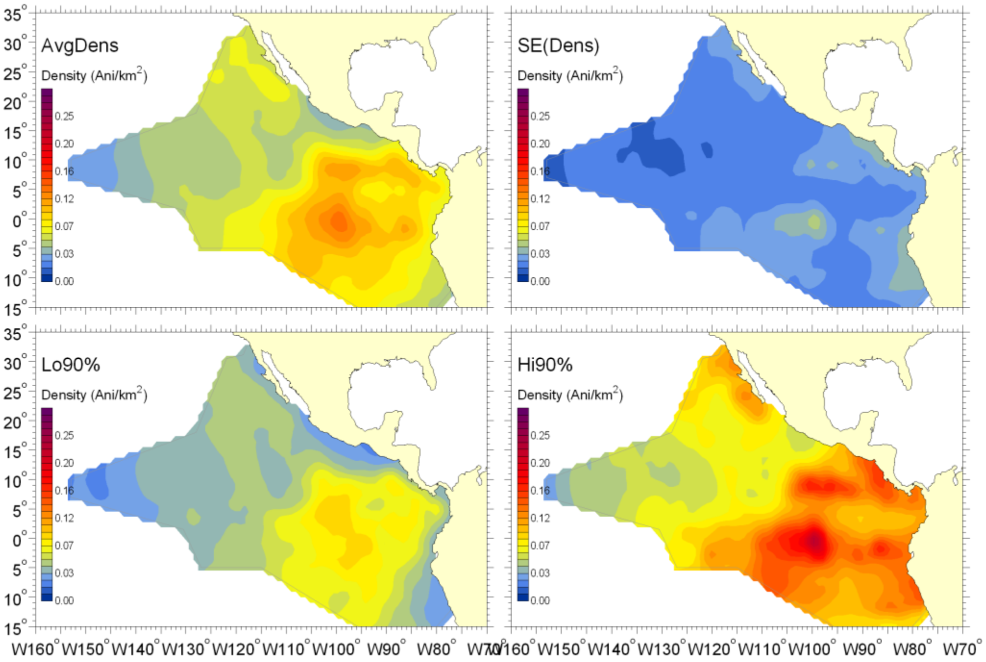
Figure B-2. (cont.)

c) Whitebelly spinner dolphin



SWFSC_1_ETP_100km_Ste.lon.lon_simpl_Summer_DensitywithVar4Panel.srf

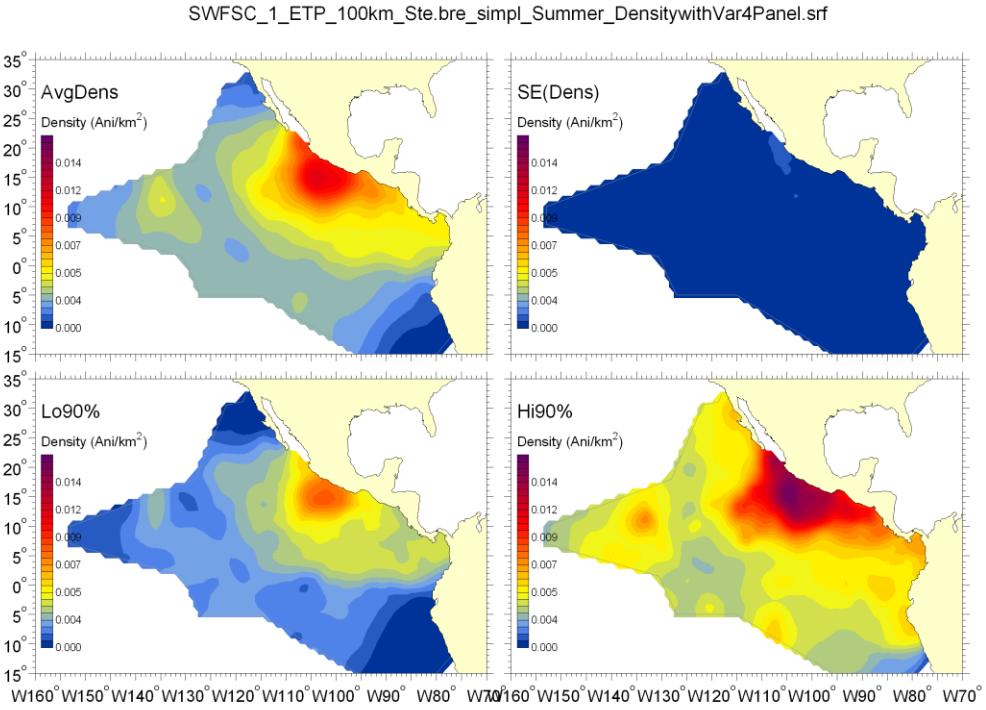
d) Striped dolphin



SWFSC_1_ETP_100km_Ste.coe_simpl_Summer_DensitywithVar4Panel.srf

Figure B-2. (cont.)

e) Rough-toothed dolphin



f) Short-beaked common dolphin

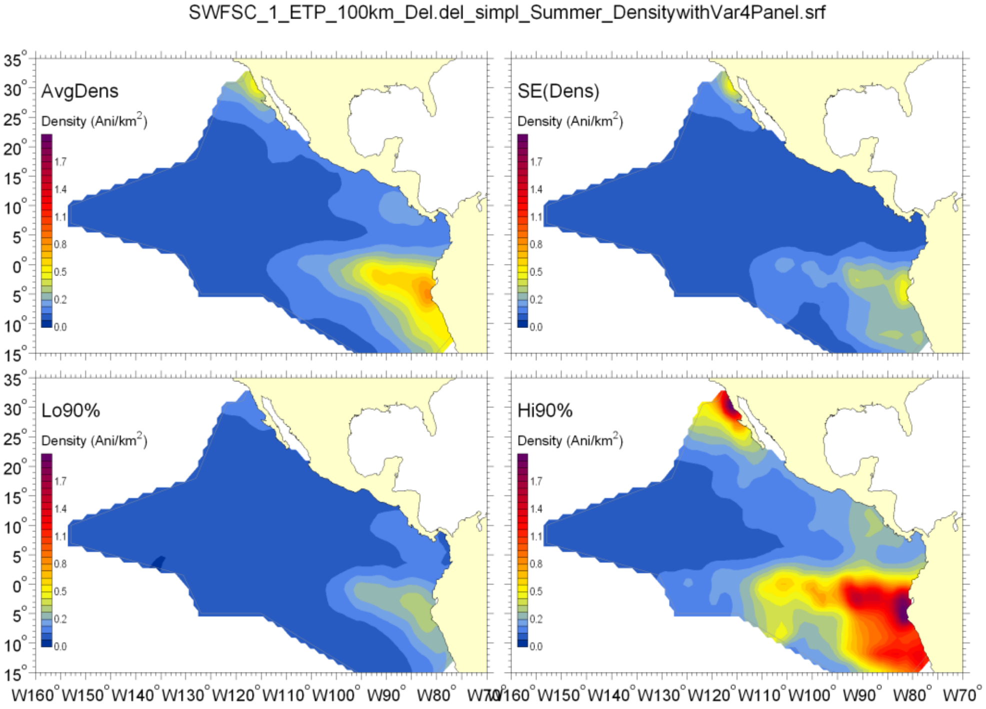
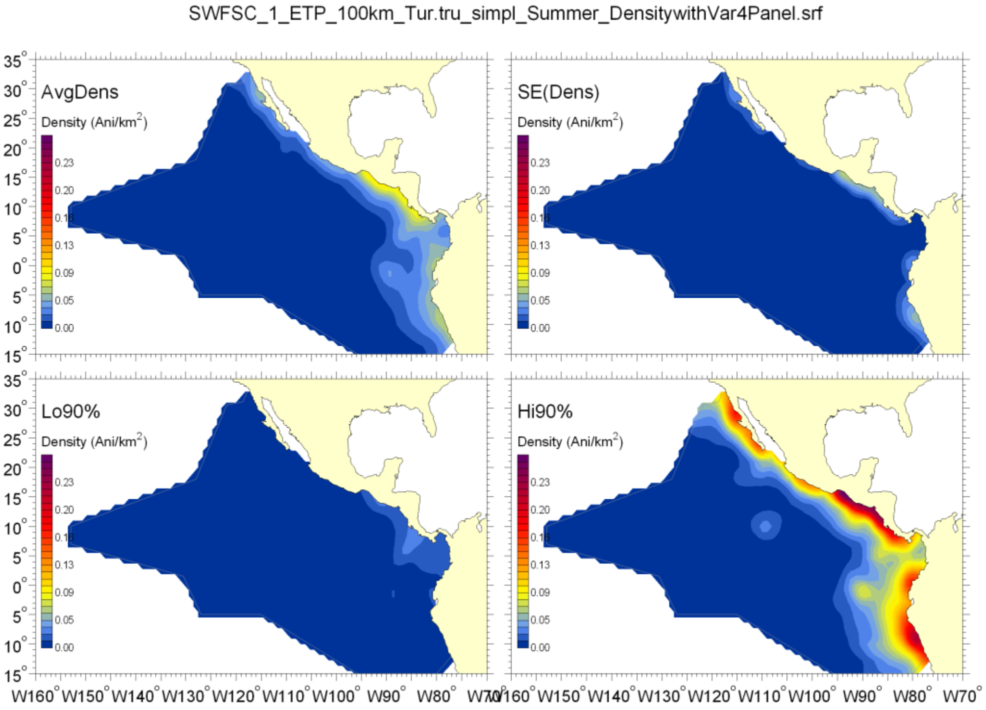


Figure B-2. (cont.)

g) Bottlenose dolphin


SWFSC_1_ETP_100km_Tur.tru_simpl_Summer_DensitywithVar4Panel.srf

h) Risso’s dolphin

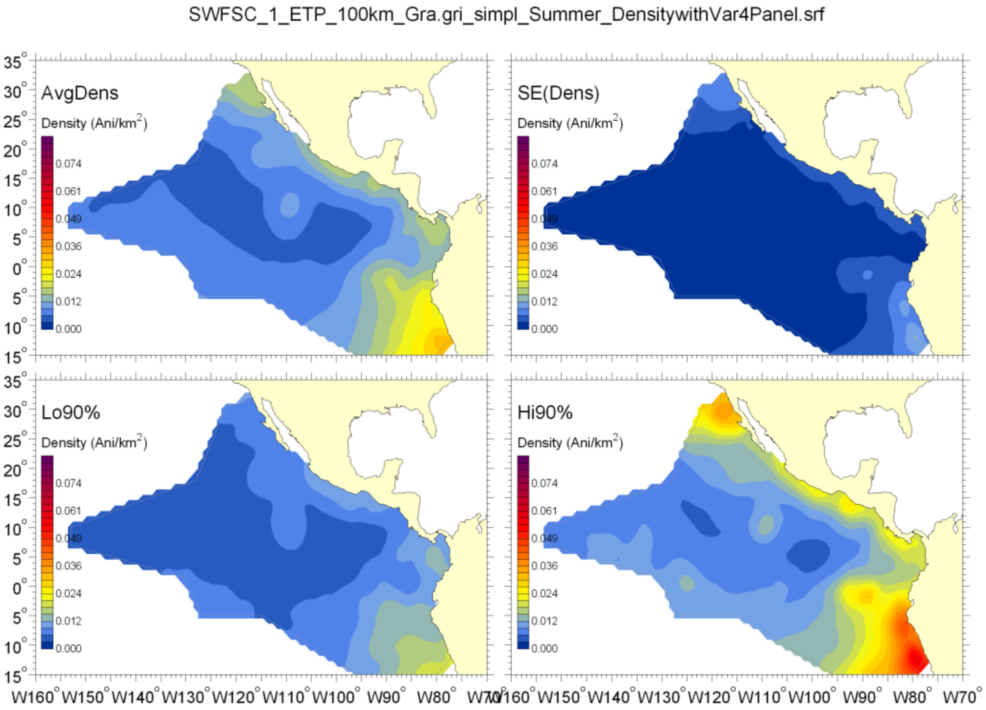

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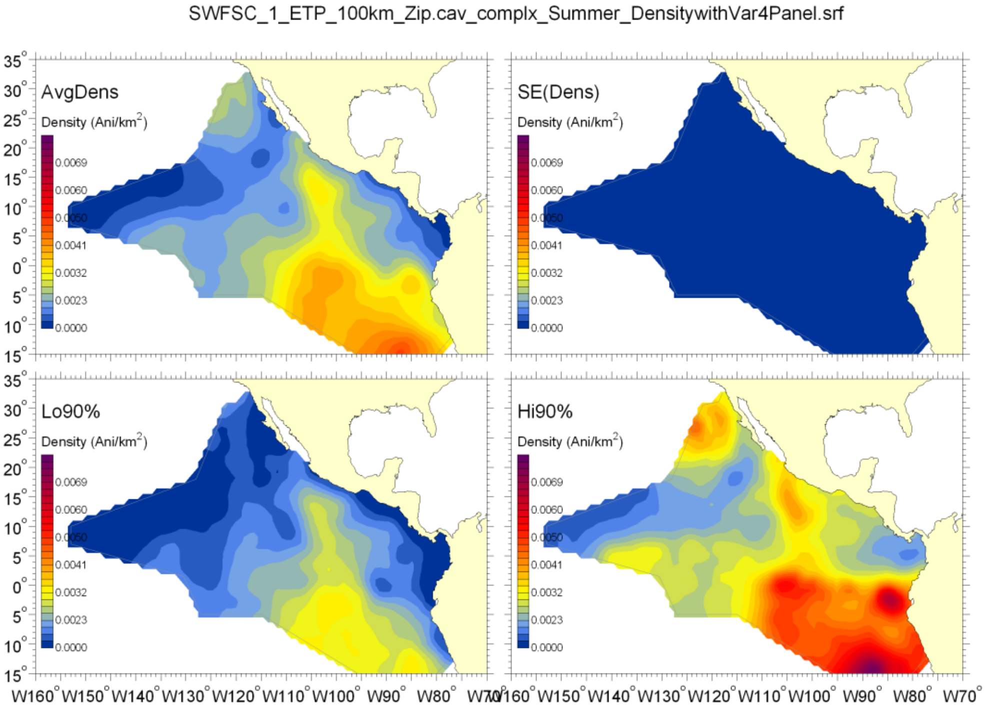
Figure B-2. (cont.)

i) Cuvier’s beaked whale



j) Blue whale

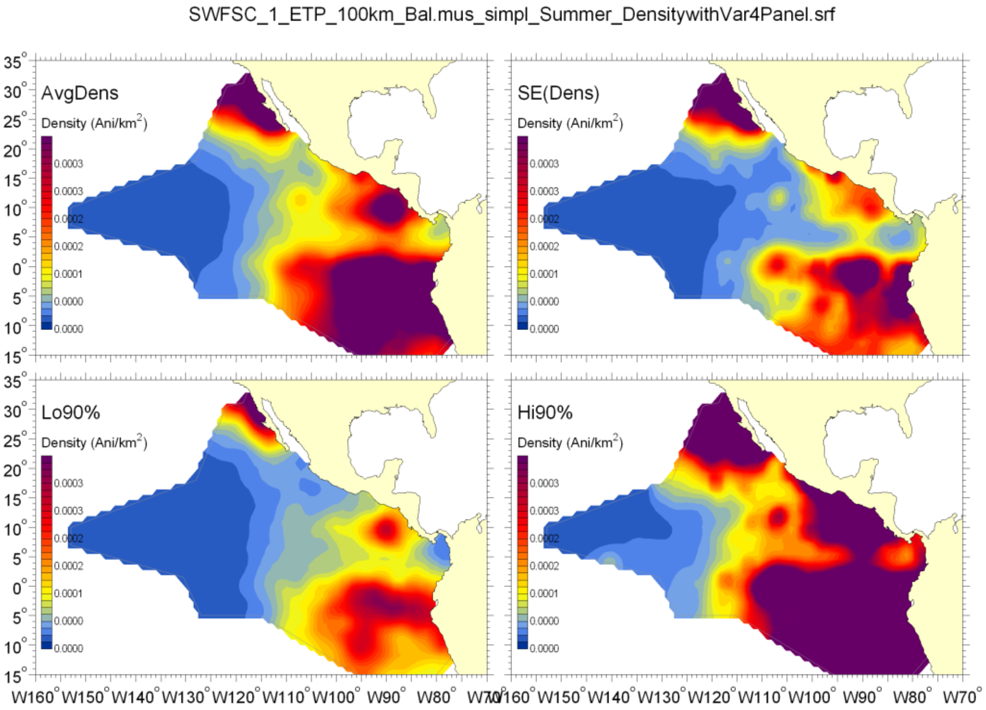
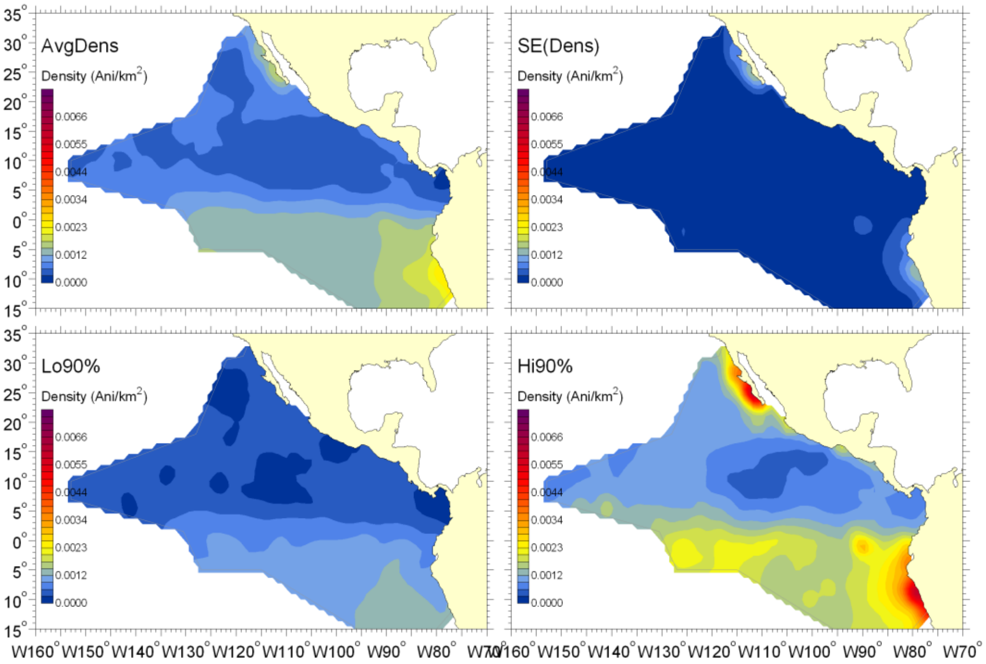


Figure B-2. (cont.)

k) Bryde's whale

SWFSC_1_ETP_100km_Bal.ede_simpl_Summer_DensitywithVar4Panel.srf



l) Short-finned pilot whale

SWFSC_1_ETP_100km_Glo.spp_simpl_Summer_DensitywithVar4Panel.srf

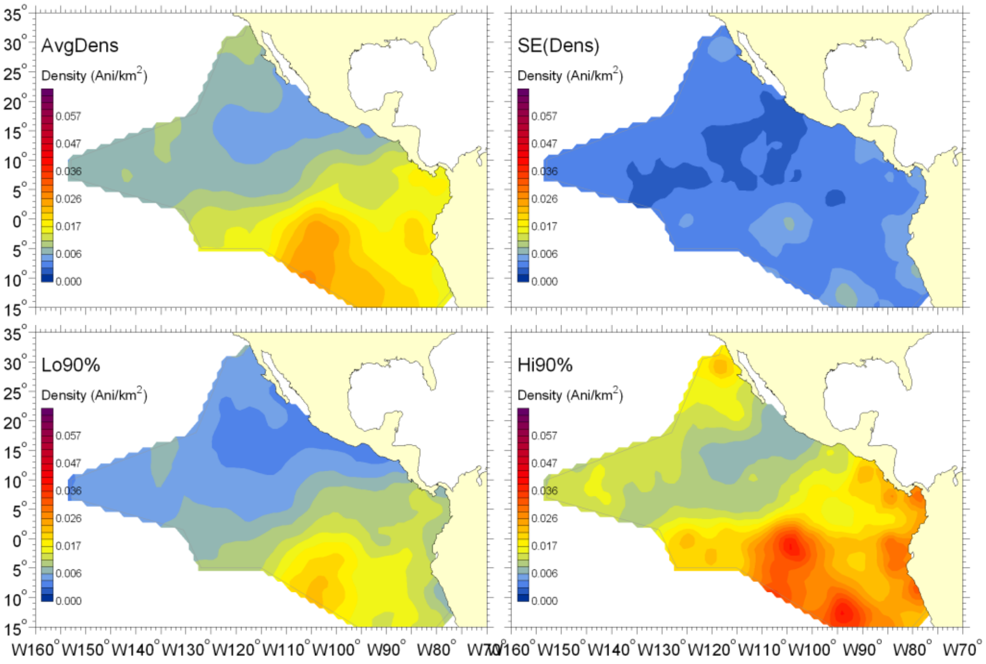
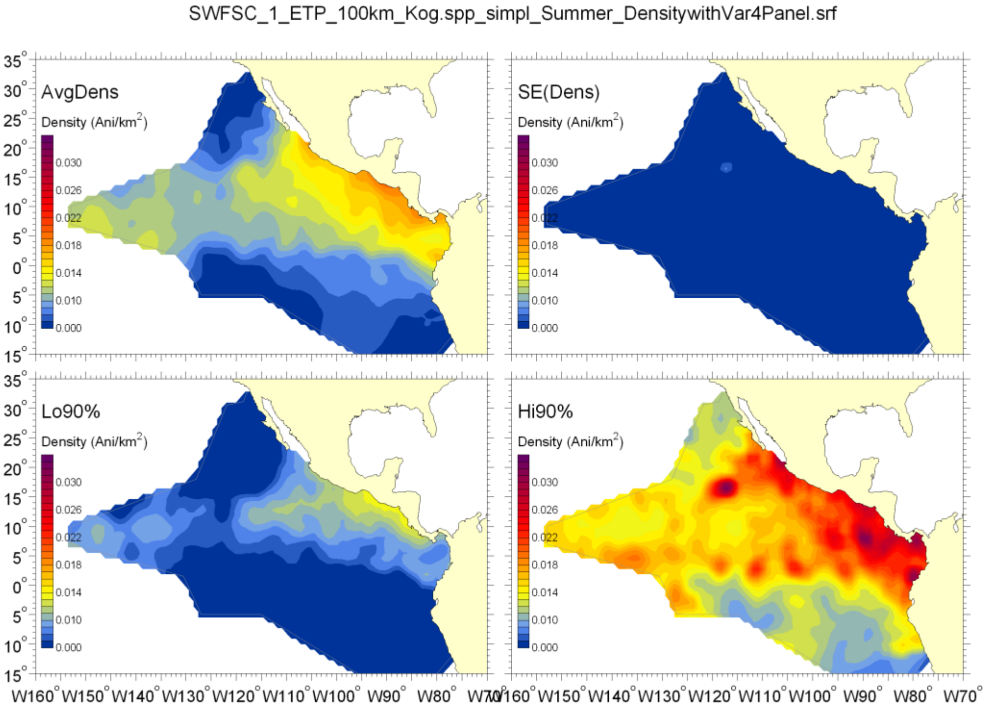


Figure B-2. (cont.)

m) Dwarf sperm whale



n) *Mesoplodon* beaked whales

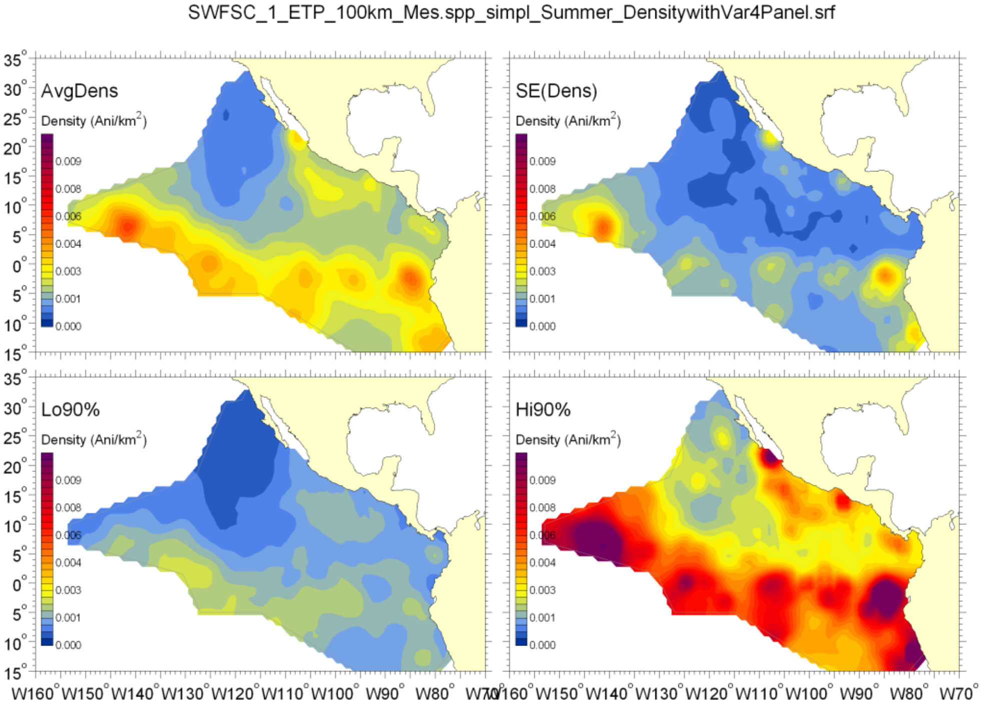
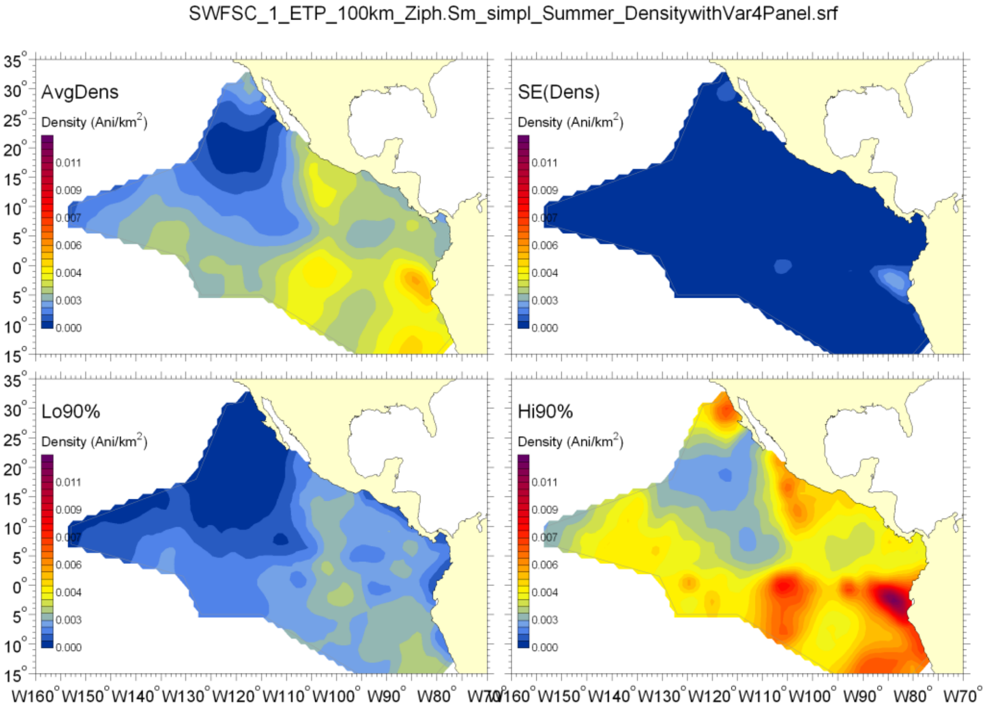


Figure B-2. (cont.)

o) Small beaked whales



Appendix C: List of Technical Publications

C.1 Journal Publications

Ballance LT, Pitman RL, **Fiedler** PC (2006) Oceanographic influences on seabirds and cetaceans of the eastern tropical Pacific: a review. Prog Oceanogr 69:360-390

Barlow J, **Forney** KA (2007) Abundance and density of cetaceans in the California Current Ecosystem. Fish Bull 105:509-526

Barlow J (2006) Cetacean abundance in Hawaiian waters estimated from a summer/fall survey in 2002. Mar Mamm Sci 22: 446-464

Becker EA, **Forney** KA, **Ferguson** MC, Foley DG, Smith RC, **Barlow** J, **Redfern** JV (In prep) A comparison of California Current cetacean-habitat models developed using in situ and remotely sensed sea surface temperature data.

Ferguson MC, **Barlow** J, **Fiedler** P, **Reilly** SB, **Gerrodette** T (2006) Spatial models of delphinid (family Delphinidae) encounter rate and group size in the eastern tropical Pacific Ocean. Ecol Model 193:645-662

Ferguson MC, **Barlow** J, **Reilly** SB, **Gerrodette** T (2006) Predicting Cuvier's (*Ziphius cavirostris*) and Mesoplodon beaked whale population density from habitat characteristics in the eastern tropical Pacific Ocean. Journal of Cetacean Research and Management 7:287–299

Redfern JV, **Barlow** J, **Ballance** LT, **Gerrodette** T, **Becker** EA (2008) Absence of scale dependence in dolphin-habitat models for the eastern tropical Pacific Ocean. Mar Ecol Prog Ser 363:1–14

Redfern JV, **Ferguson** MC, **Becker** EA, Hyrenbach KD, Good C, **Barlow** J, Kaschner K, Baumgartner MF, **Forney** KA, **Ballance** LT, Fauchald P, Halpin P, Hamazaki T, Pershing AJ, Qian SS, Read A, **Reilly** SB, Torres L, Werner F (2006) Techniques for Cetacean-Habitat Modeling: A Review. Mar Ecol Prog Ser 310:271-295

C.2 PhD Dissertations

Becker EA (2007) Predicting seasonal patterns of California cetacean density based on remotely sensed environmental data. Ph.D. Dissertation, University of CA, Santa Barbara

Ferguson MC (2005) Cetacean Population Density in the Eastern Pacific Ocean: Analyzing Patterns with Predictive Spatial Models. Ph.D. Dissertation, University of California San Diego, Scripps Institution of Oceanography

C.3 Technical Reports

Charter SR, MacCall BS, Charter RL, Manion SM, Watson W, **Ballance** L (2006) Ichthyoplankton, paralarval cephalopod, and station data for oblique (bongo) plankton net tows from the Oregon, California, and Washington line-transect expedition (ORCAWALE) in 2001. Report No. NOAA Technical Memorandum NMFS-SWFSC-TM-393, U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA

Forney KA (2007) Preliminary estimates of cetacean abundance along the U.S. West Coast and within four National Marine Sanctuaries during 2005. Report No. NOAA Technical Memorandum NMFS-SWFSC-TM-406, U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA

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