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Density and spatial distribution patterns of cetaceans in the Central North Pacific based on habitat models

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ABSTRACT

Habitat-based density models were developed for cetaceans in the Central North Pacific based on cetacean survey data collected by the Southwest Fisheries Science Center in 1997-2006. Cetacean sighting data were collected on systematic line-transect surveys in the temperate eastern Pacific, around Hawaii and other Pacific Islands, and in the eastern tropical Pacific west of 120 degrees longitude. Habitat variables, derived from satellite data, included sea surface temperature, sea surface chlorophyll, sea surface height root-mean-square, primary productivity, distance to land, latitude, and longitude. Models were developed for the pantropical spotted dolphin, spinner dolphin, striped dolphin, rough-toothed dolphin, common bottlenose dolphin, false killer whale, short-finned pilot whale, sperm whale, Bryde's whale, and an "other dolphins" group that included the short-beaked common and Pacific white-sided dolphin. Uniform densities were estimated for species/guilds that had insufficient sightings for modeling, including pygmy killer whale, Risso's dolphin, killer whale, a small beaked whale guild (including Cuvier's beaked whale and beaked whales of the genus *Mesoplodon*), and pygmy/dwarf sperm whale. Although validation using an independent survey was not possible, modeled density estimates for the 10 species/species group were compared to previously published line-transect

density estimates derived within the U.S. Exclusive Economic Zone around Hawaii. The model-based estimates of abundance fall within the 95% confidence limits of the standard line-transect analyses, and they provide greater spatial resolution of the density estimates based on habitat associations. These new models are intended as baseline density estimates for Navy planning and environmental impact statements, to be updated and improved as additional survey data become available in the future.

INTRODUCTION

Recent advances in modeling cetacean densities based on habitat variables have provided new tools for assessing and minimizing impacts of human activities on marine mammals (Ferguson et al. 2006; Barlow et al. 2009; Becker et al. 2012; Forney et al. 2012). These habitat-based density models have provided finer-scale information than traditional line-transect analyses, particularly in the well-surveyed California Current Ecosystem (CCE) and eastern tropical Pacific (ETP). However, the United States (U.S.) Navy and other users of the marine environment also require density estimates for cetaceans in other regions, where survey coverage may be low or the number of sightings is limited. In particular, waters of the Central North Pacific Ocean have been poorly studied but include large geographic regions with potential for naval activity (U.S. Department of the Navy 2008). To ensure compliance with U.S. regulations under the Endangered Species Act and the Marine Mammal Protection Act, the Navy must estimate the number of marine mammals that might be affected by their at-sea training and testing activities. Such quantitative assessments require estimates of species density in specific areas where those activities will occur. Line-transect density estimates have been derived for waters within the U.S. Exclusive Economic Zone (EEZ) around Hawaii (Barlow 2006; Barlow and Rankin 2007); however, these data provide uniform density estimates for a very broad region and provide little information on spatial patterns. Spatially-explicit estimates are needed to better assess potential impacts on cetaceans.

In this study, we have adapted previous modeling methods (Barlow et al. 2009; Forney et al. 2012) to create habitat-based models of cetacean densities within a large area of the Central North Pacific where surveys were conducted in 1997, 2002, and 2005 but sighting rates were low. Additional data from surveys conducted in 1998-2006 within portions of the eastern tropical Pacific were included in the model-building data set to increase sample sizes. One of the goals of this study was to assess the ability to develop habitat-based density models using limited sighting data and coarse-scale habitat predictor variables derived from remotely sensed measures. Given our limited data set available for model development, we also included static measures in our list of potential predictors, including latitude, longitude, and distance to land. Although validation using an independent survey was not possible, modeled abundance for the 10 species/species group was compared to previously published line-transect abundance estimates, derived within the U.S. EEZ around Hawaii from the 2002 and 2005 surveys (Barlow 2006; Barlow and Rankin 2007).

METHODS

Field Methods

The Southwest Fisheries Science Center (SWFSC) has conducted systematic line-transect cetacean and ecosystem ship surveys in regions of the Central North Pacific from 1986 to 2006. Research vessels used for the surveys included the *David Starr Jordan*, *McArthur*, *Endeavor*, and *McArthur II* (Hamilton et al. 2009). The surveys included in this study were conducted along pre-determined transect lines that systematically covered waters in the temperate eastern Pacific, around Hawaii and other Central Pacific islands, and in the ETP. This resulted in an irregularly shaped study area that included regions within and adjacent to our Central North Pacific area of interest (Fig. 1), encompassing the largest possible region around the Hawaiian Islands where some systematic line-transect survey effort had been conducted, while also including survey effort west of 120º W longitude in the ETP to increase sample sizes.

Cetacean sighting data were collected using standard visual line-transect protocols that were consistent on all surveys (Kinzey et al. 2000). In summary, one starboard and one port observer searched for animals using pedestal-mounted 25x150 binoculars while a third observer/data recorder searched from a central position using unaided eye and 7x50 handheld binoculars. A team of six observers rotated every 40 minutes among the three positions, so that each observer received a 2-hour rest period during the rotations. All “on-effort” observations were made from the flying bridge of the ship. When cetaceans were detected within 5.5 km of the trackline, the ship typically diverted from the transect line (“closing mode”) and observers were considered “off-effort” for group size estimation and species identification. Occasionally, operational constraints required the ship to continue along the trackline in "passing mode" while the observers remained on-effort without approaching the sighted animals. Species were identified to the lowest possible taxonomic level. If the observers were not able to confirm species, a higher taxonomic level, e.g., *Mesoplodon* spp., was recorded. In order to increase the number of sightings available for modeling, we used some guilds and grouped species known to have similar distribution patterns within the study area (Table 1).

In addition to sighting information (time, position, species present, and estimates of group size), effort data such as Beaufort sea state and wind speed were entered into a laptop computer connected to the ship's navigation system. Swell height and visibility were recorded within our study area beginning in 1997. Models were therefore limited to 15 surveys conducted between 1997 and 2006 (Table 2), to allow derivation of species-specific detection parameters based on environmental covariates.

Analytical Methods

The analytical methods used to develop Central North Pacific habitat-based density models were adapted from those used to develop models for the CCE and the ETP (Ferguson et al. 2006; Barlow et al. 2009; Becker et al. 2010, 2012; Forney et al. 2012) and are briefly summarized here.

Data Sources. To create samples for modeling, cetacean survey data from the 15 shipboard surveys were separated into continuous on-effort transect segments of approximately 10-km length as described by Becker et al. (2010). We initially evaluated transect segment lengths of 10-km, 20-km, and 30-km using a portion (35%) of our survey data. We selected 10-km segments as our sample size because the majority of resulting segments (75%) were equal to the target length of 10 km (12% were <10 km and 13% were > 10 and <15 km), while only 54% would have been equal to the 20-km target length and 40% equal to the 30-km target length. Only segments with average Beaufort sea states of 0-6 were used to develop models, corresponding to the conditions included in past studies of cetacean density (Barlow 2006; Barlow and Rankin 2007).

Cetacean sighting data for each species/species group were summarized as the total number of groups sighted per segment and the average group size in the segment. Average group size was calculated as the mean "best" group size estimate, averaged over all observers that contributed group size estimates. In cases where there was no "best" estimate, the "low" estimate was used and averaged over all observers (Kinzey et al. 2000). For purposes of estimating distance-detection functions for the habitat models (see "Model Development" below), sighting data were truncated to eliminate the most distant groups observed, following guidelines by Buckland et al. (2001) and consistent with truncation distances used by Barlow et al. (2011). Truncation distances used in this study were 4 km for small whales and 5.5 km for delphinids, large odontocetes, and large baleen whales. Sighting data beyond these distances were eliminated prior to modeling.

Given that much of the physical oceanography is defined by large-scale processes in the study area (Fiedler and Talley 2006) and large-scale cetacean-habitat models have been determined to be most appropriate for the ETP (i.e., 160 km resolution; Redfern et al. 2008), we selected relatively coarse temporal and spatial resolutions for the predictor variables. Dynamic environmental data used as habitat predictor variables in our analysis were derived from remotely sensed measures and included monthly mean values of the following: SST = sea surface temperature (°C), lnCHL = the natural logarithm of sea surface chlorophyll concentration (mg/m^3; we used the log transformation because the range of chlorophyll values differed by more than an order of magnitude), PP = primary productivity (mg C/m^2/day), and SSHrms = sea surface height root-mean-square (m). SST (National Oceanic and Atmospheric Administration/National Environmental Satellite, Data, and Information Service [NOAA/NESDIS]/Pathfinder v5), sea surface chlorophyll concentration (NOAA/NESDIS/Sea-viewing wide Field-of-View Sensor [SeaWiFS]), and primary productivity (NOAA/NESDIS/SeaWiFS) values were obtained at a spatial resolution of 0.2 degree (i.e., a 5x5 pixel box with a single pixel resolution of 5.55 km or approximately 770 km^2). SSHrms (NOAA/NESDIS/Aviso) was calculated within a 2x2 degree box centered on the segment midpoint and was used to provide a measure of mesoscale variability in the project area.

Habitat-based density models built for the CCE (Barlow et al. 2009; Becker et al. 2010, 2012; Forney et al. 2012) purposefully excluded longitude and latitude as predictor variables because the goal was to predict species density based on dynamic environmental variables. However, given the limited number of sightings and coarse transect coverage available for model development in this study, we included several static measures in our list of potential predictors, including latitude, longitude, and distance to land. Distance to land values were estimated at the midpoint of each segment and retrieved using the "near" tool in ArcGIS (Version 9.3, ESRI, Inc.).

Strong correlations (>0.70) were observed between primary productivity and surface chlorophyll concentration (0.71) and longitude and distance to land (0.73). Spatial autocorrelation in these variables is not unexpected because chlorophyll is used to derive estimates of primary productivity and longitude is directly related to distance from the islands within the study area. All variables were included as potential predictors, because the goal for our models was to predict cetacean densities (not to test hypotheses), and such correlations do not bias mean responses or predictions of new observations (Neter et al. 1996).

Model Development. Generalized additive models (GAMs) of species/species group encounter rates (number of sightings per segment) and group size were built using the segment-specific sighting and habitat predictor data described above. A GAM may be represented as

$$g(\mu) = \alpha + \sum_{j=1}^{p} f_j(X_j) \qquad \text{(Eq. 1)}$$

(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 $\mu=E(Y|X_1,\ldots,X_n)$ to the additive predictor $\alpha+\Sigma_j f_j(X_j)$. The components $f_j(X_j)$ can include nonparametric smooth functions (splines) of the predictor variables, allowing for a flexible modeling framework. We used a maximum of three degrees of freedom in our smoothing splines to capture non-linear relationships without adding unrealistic complexity to the functions (Forney 2000; Ferguson et al. 2006). Separate encounter rate and group size GAMs were built using the *step.gam* function in the statistical software package S-PLUS (Professional Edition Version 6.1, Release 1 for Windows, Insightful Corp., 2001). We used a stepwise forward/backward variable selection procedure in which each model was fit three times to ensure that all terms were tested and to improve the dispersion parameter estimate used to assess the final model (Ferguson et al. 2006). The fitting process started with a null model that included only the intercept. The dispersion parameter from the null model was used to test all predictor variables for inclusion in the second model as cubic smoothing splines with two or three degrees of freedom. The third model used the dispersion parameter from the second model to test all predictor variables for inclusion as linear terms or cubic smoothing splines with two or three degrees of freedom. Akaike's

Information Criterion (AIC; Akaike 1973) was used in *step.gam* as the basis for selecting among potential combinations of predictor variables and varying degrees of freedom.

Encounter-rate models were built using all transect segments, regardless of whether they included sightings, while group-size models were built using only those segments that included sightings. Group size models were built using the natural log of group size as the response variable and an identity link function (Ferguson et al. 2006).

The encounter data (number of groups) were fit using Poisson GAMs in which overdispersion was corrected using a quasi-likelihood model. The natural log of the effective area searched (the segment length times twice the effective half-strip width) was included as an offset term to account for varying segment lengths and detection probabilities based on recorded observation conditions. The effective strip half-width in km (ESW; Buckland et al. 2001) is equal to $1/f(0)$, where $f(0)$ is the pdf of the distance-detection function, $g(y)$, evaluated at perpendicular distance $y = 0$ (i.e., on the trackline). ESW values were derived on a segment-specific basis using a multiple-covariate approach and coefficients estimated by Barlow et al. (2011). In that study, species were aggregated into 6 categories with similar sighting characteristics, and, within each category, ESW was modeled as a function of group size, Beaufort sea state, swell height (height of predominant swell in feet), visibility (distance in nmi at which a dolphin could be seen), and (for some species categories) survey vessel, region or year. Species was also included as a covariate to allow for species-specific differences in detection distances within a species category that could not be explained by group size. The ESW values for each segment in our study were based on the average values of Beaufort sea state, swell height, and visibility within that segment. For our species guilds (i.e., small beaked whales and *Kogia* spp.), we used the average ESW value for all species in the guild.

Density Computations. Paired encounter rate and group size predictions were used to estimate segment-specific density by species/species group. Density (number of animals per km^2) for each species was estimated by incorporating the final encounter rate and group size model results into the standard line-transect equation (Buckland et al. 2001):

$$D_i = \left(\frac{n_i}{A_i}\right) \cdot s_i \cdot \frac{1}{g_i(0)} \qquad \text{(Eq. 2)}$$

Where *i* is the segment, *n* is the number of sightings, *A* is the effective area searched on both sides of the vessel in km^2 (accounting for detection probability), *s* is the predicted group size, and *g(0)* is the probability of detecting a group of animals on the trackline. Note that we refer to *n/A* as the encounter rate, although others have used this term to refer to the number of sightings per km of search effort.

Estimates of *g(0)* were derived from previously published studies (see Barlow 2003, 2006). For many species, the published *g(0)* values were stratified by group size and, therefore, we weighted *g(0)* values based on the number of small and large groups recorded in the survey data included in our Central North Pacific study area. For *Kogia* spp. and the species within our small beaked whale guild, *g(0)* values were estimated using search effort in sea state conditions of Beaufort 0-2. To avoid potential bias in our density estimates, we therefore built models and made predictions for *Kogia* spp. and the small beaked whale guild using only segments with average Beaufort conditions ≤2. Survey effort in Beaufort conditions of 0-2 was not distributed uniformly across the study area (Fig. 1), and models built using only segments with these Beaufort conditions may not have captured the full range of habitat types for *Kogia* spp. and the small beaked whale guild in the study area.

Segment density estimates were interpolated to the entire study area using Surfer 9.0 (Version 9, Golden Software, Inc., 2009). Following the methods described in Barlow et al. (2009) but adjusting the resolution to account for coarser transect coverage, initial contour grids were created using inverse distance weighting to the second power and including all data within a search radius of 2,222 km (20 degrees latitude). Density grids were initially created at a resolution of 200 km (except for spinner dolphins, which required a resolution of 150 km to avoid interpolation artifacts) and subsequently interpolated to a higher-resolution grid of 50-km resolution by inserting additional grid nodes using Surfer's *Spline Smooth* function. Sighting locations were plotted on the grids to evaluate model performance visually, as the human eye can be superior to statistics for comparing patterns (Wang et al. 2004). If the sighting plots revealed obvious inconsistencies, we re-examined the models and performed additional analyses to evaluate interaction terms or include predictors expected to be important based on known species distribution patterns. If these additional analyses did not improve the model performance, we concluded that there were insufficient sightings of that species to create a habitat-based density model and created a uniform density 'null' model instead. Our models are considered preliminary, as more rigorous validation should be done when additional data become available.

To examine potential bias in the resulting density models, we compared overall abundance estimates derived from the model-based densities with published line-transect abundance estimates derived from the 2002 and 2005 surveys for two strata within the EEZ around the Hawaiian Islands: a main Hawaiian Islands stratum within about 75 nmi of the islands, and an outer EEZ stratum (Barlow 2006; Barlow and Rankin 2007). For this comparison, the model-based abundance of each species was calculated for each grid cell as the product of the cell density times the cell area (in km^2). Abundance estimates for grid cells partially contained within each stratum were prorated based on the percent of grid area overlapping the stratum. Model-based abundances for grid cells wholly or partially contained within each stratum were then summed to obtain an overall abundance estimate. Area calculations were completed using the R packages *geosphere* and *gpclib* in R (version 2.13.1, The R Foundation for Statistical Computing, 2011).

RESULTS

Barlow (2006) provided information on the search effort, number of species sighted, and associated line-transect abundance estimates for the 2002 shipboard survey of the U.S. EEZ around the Hawaiian Islands. We originally selected 15 species/species groups for habitat modeling based on the number of sightings available and the intent to provide the Navy with spatial density plots for as many species as possible. For most species/species groups, the number of available sightings was far fewer than the 80 or greater recommended by Becker et al. (2010) for the CCE; however, generally larger-scale oceanic processes characterize the study area (Fiedler and Talley 2006) and analyses suggest that larger scale cetacean-habitat models may be considered acceptable for the ETP (i.e., 160 km resolution; Redfern et al. 2008). For our selection of a coarse-scale modeling framework, the sample sizes were sufficient to provide satisfactory model results for 10 of the species/species groups as described below.

Of the total 8,021 segments in our dataset, 11% were eliminated due to missing satellite data. For each species, a small number of sightings beyond the species-specific truncation distances used for detection function estimation were also excluded, to ensure consistency between encounter rate and effective strip width in the line-transect density calculations (Table 1). Models were not developed for species with extremely limited sighting numbers (<15), including northern right whale dolphin, Dall's porpoise, sei whale, fin whale, blue whale, and humpback whale. Although there were only four pygmy killer whale sightings, a uniform density estimate for the entire study area was calculated for this species in order to compare it to a density estimate derived for the Hawaiian EEZ that was based on only two on-effort sightings (Barlow 2006). Models were developed for the remaining 14 species or species guilds, including pantropical spotted dolphin, spinner dolphin, striped dolphin, rough-toothed dolphin, common bottlenose dolphin, Risso's dolphin, false killer whale, short-finned pilot whale, killer whale, sperm whale, a small beaked whale guild, Bryde's whale, and *Kogia* spp. We also created a combined "other dolphins" model for short-beaked common dolphin and Pacific white-sided dolphin, because sample sizes were insufficient for species-specific models. Both species are found in the northern portions of our study area, while only short-beaked common dolphins are found in the southern portion of the study area.

The density of each species was estimated using the weighted *g(0)* estimates shown in Table 3. Density plots derived from models selected based on the AIC stepwise procedure captured observed distribution patterns for pantropical spotted dolphin, spinner dolphin, striped dolphin, common bottlenose dolphin, false killer whale, short-finned pilot whale, sperm whale, and Bryde's whale (Figs. 2-5). For the species/species groups for which the original models were not able to capture observed distribution patterns (i.e., rough-toothed dolphin, Risso's dolphin, the "other dolphins" group, killer whale, the small beaked whale guild, and *Kogia* spp.), we examined results and evaluated the potential for forcing different variables into the models based on known species distribution patterns (e.g., Baird et al. 2008). For example, for rough-toothed dolphin, we increased the degrees of freedom in the distance-to-land variable from 3 to 5 to allow more flexibility in modeling this species' island-associated distribution around Hawaii (Baird et al. 2008). This species is also often associated with flotsam (indicative of small-scale surface convergence features) and relatively colder waters in the study area (J. Cotton and S. Benson, pers. comm. 2010). Based on these observations, we included an interaction term between SST and chlorophyll in the encounter rate model (chlorophyll was used as a proxy for surface convergence, because a direct satellite-derived measure was not available). The group size model for this species was not changed. These additional analyses resulted in models that were more successful at capturing the observed distribution patterns of rough-toothed dolphin in the study area (Fig. 6).

For the "other dolphins" group, we limited the list of potential predictors to SST, longitude, and latitude. This was done in order to capture the temperate range of short-beaked common dolphins and Pacific white-sided dolphins in the north-eastern portion of the study area, while allowing flexibility in the latitude term to capture the additional presence of short-beaked common dolphins in the southeastern portions of the study area. The revised models were able to produce more accurate distribution predictions for the "other dolphins" group (Fig. 6). Additional model adjustments were not able to capture observed distribution patterns for Risso's dolphin, killer whale, the small beaked whale guild, and *Kogia* spp., likely because of sample sizes, and uniform density estimates were calculated for these species instead (Table 4).

Variables that had the greatest effect on encounter rate were SST and chlorophyll (Table 5 and Fig. 7). Latitude was the most prevalent variable in the group size models, followed by chlorophyll and longitude (Table 5 and Fig. 8). The percentage of deviance explained ranged from 4.2 to 29.4% for the encounter rate models and from 0 to 57.5% for the group size models (Table 6). Model-based density estimates for all species within the U.S. EEZ around the Hawaiian Islands were within the 95% confidence limits of previously published standard line-transect estimates (Barlow 2006; Barlow and Rankin 2007; Fig. 9).

DISCUSSION

The models developed in this study represent a first attempt to provide habitat-based density models in this sparsely surveyed region of the Central North Pacific. Despite coarse transect coverage and small sample sizes (i.e., the number of sightings available for modeling ranged from 16 to 149, with the majority <50; Table 1), we were able to develop habitat-based density models for nine cetacean species and one species group. The resulting density estimates are comparable to previously published, uniform line-transect densities, but the models provide greater spatial resolution and take into account gradients with respect to the islands, latitude/longitude, or dynamic habitat variables. The models also identified a previously undocumented higher-density region for false killer whales north of the Northwestern Hawaiian Islands (Fig. 4), which was confirmed through multiple sightings during a recent 2010 survey

(Bradford et al. 2012). Further validation of the model-based densities will be important when these additional survey data have been fully processed and become available for additional analyses.

The amount of deviance explained (Table 6) was comparable to that for habitat based density models developed for the CCE and the ETP (Forney et al. 2012). The percentage of deviance explained by the CCE encounter rate models ranged from 5% (sperm whale) to 42% (Dall's porpoise) and for the group size models ranged from 0% (humpback whale) to 35% (Pacific white-sided dolphin). Explained deviance for the ETP encounter rate models ranged from 6% (Cuvier's beaked whale) to 39% (dwarf sperm whale), and 4% (pantropical spotted dolphin) to 59% (blue whale) for the group size models.

The single year (2002) of survey data within the main Hawaiian Islands EEZ portion of our study area and the sparse transect coverage throughout the remainder of the region prevented any temporal or spatial cross validation of our model estimates as was done for habitat-based density models developed for the CCE and ETP (Barlow et al 2009; Becker et al. 2012; Forney et al. 2012). Further, the data available for the Central North Pacific are too sparse to calculate variances based on interannual variability, as was done in those previous modeling studies. The study area was enlarged to include additional data from surveys within portions of the ETP; while these data did increase sample sizes, high ETP densities also increased the range of the scale bar on the density plots, causing the density patterns for some island-associated species (e.g., pantropical spotted, spinner dolphins, see re-scaled Fig. 10), to be less apparent around the Hawaiian Islands. The addition of the 2010 survey data may help to better distinguish higher densities around the islands by providing additional sighting data near the islands and potentially eliminating the need to include the ETP sighting data in model development.

For Risso's dolphin, killer whale, *Kogia* spp. and the small beaked whale guild, the habitat-based models did not yield accurate density surfaces, as evident from plots of sighting locations, and we estimated uniform densities throughout the study area instead. The lack of accuracy was likely caused by small sample sizes and, particularly for the cryptic beaked whales and *Kogia* spp., by the non-uniform distribution of calm sea conditions (Beaufort sea states 0-2) during the surveys (Fig. 1). In the model, the sparse coverage in calm sea conditions resulted in artificial 'bulls-eyes' of high density where sightings occurred in sea states 0-2 and low density where no sightings were made. It is unlikely that these patterns reflected actual species distributions, and additional survey data will be required to resolve habitat-based density patterns for these species.

The uniform density estimates for the Central North Pacific study area were similar to those estimated by Barlow (2006) within U.S. EEZ waters around Hawaii (Table 4). All the density estimates were within the 95% confidence limits of the standard line-transect estimates derived by Barlow (2006), but there were some apparent differences for Risso's dolphin and *Kogia* spp. These differences may be caused by the larger geographic extent of our study area, or by the inclusion of additional survey data in our study.

The Central North Pacific study area was defined to include as large a region as possible around the Hawaiian Islands that included at least some systematic line-transect survey effort. In areas where survey coverage was particularly sparse, such as in the northeastern corner of our study area, additional survey data will be required to produce more robust habitat models and associated density estimates in the future. The large-scale smoothing required to interpolate between the coarse transect lines also introduced some smoothing artifacts, particularly at the edges of the study area where survey coverage was sparse (e.g. along the northwestern edge of the study area for sperm whales, Fig 5). It may be possible to avoid some of these interpolation artifacts by predicting on a pixel-by-pixel basis, rather than predicting back onto actual transect segments and then interpolating. Additional studies of these modified methods within the Central Pacific study area are planned in the future. Edge effects can also produce mismatches near the borders of two study areas, for example where the eastern edge of our Central North Pacific study area approaches the western edge of the study area used to develop habitat-based density models for the CCE (Barlow et al. 2009; Becker et al. 2012; Forney et al. 2012). Further analyses are needed to explore methods for dealing with these edge effects and creating consistent density surfaces.

Until additional survey data become available, the model-based density estimates presented in this study can help inform assessment of impacts on cetaceans, e.g. by naval activities. The spatially-explicit densities within our larger Central North Pacific study area represent an improvement over past line-transect estimates of uniform density within subsets of this region. Although no models can predict with certainty where and when animals will be seen, the gradients identified, particularly with respect to higher cetacean densities surrounding the main Hawaiian Islands, are important to consider to minimize potential impacts.

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LITERATURE CITED

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. In: Petran BN and Csàaki F (eds) Second International Symposium on Information Theory. Akadèemiai Kiadi, Budapest, Hungary, p 267-281.

Baird, R. W., D.L. Webster, S.D. MaHaffy, D.J. McSweeney, G.S. Schorr, and A.D. Ligon. 2008. Site fidelity and association patterns in a deep-water dolphin: Rough-toothed dolphins (*Steno bredanensis*) in the Hawaiian Archipelago. Mar Mamm Sci 24(3): 535-553.

Barlow, J. 2003. Preliminary estimates of the abundance of cetaceans along the U.S. west coast: 1991-2001. Administrative report LJ-03-03. U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA. 33 p.

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

Barlow, J., and S. Rankin. 2007. False killer whale abundance and density: preliminary estimates for the PICEAS study areas south of Hawaii and new estimates for the US EEZ around

Hawaii. NOAA Administrative Report LJ-07-02. U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA. 15 p.

Barlow, J., M.C. Ferguson, E.A. Becker, J.V. Redfern, K.A. Forney, I.L.Vilchis, P.C. Fiedler, T. Gerrodette, and L.T. Ballance. 2009. Predictive modeling of cetacean densities in the eastern Pacific Ocean. NOAA Technical Memorandum NMFS-SWFSC-444, U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA. 206 p.

Barlow J., L.T. Balance, and K.A. Forney. 2011. Effective strip widths for ship-based line-transect surveys of cetaceans. NOAA Technical Memorandum NMFS-SWFSC-484, U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA. 28 p.

Becker E.A., K.A. Forney, M.C. Ferguson, D.G. Foley, R.C. Smith, J. Barlow, and J.V. Redfern. 2010. Comparing California Current cetacean-habitat models developed using *in situ* and remotely sensed sea surface temperature data. Mar Ecol Prog Ser 413: 163-183.

Becker E.A., D.G. Foley, K.A. Forney, J. Barlow, J.V. Redfern, and C.L. Genteman. 2012. Forecasting cetacean abundance patterns to enhance management. Endang Species Res 16:97-112.

Benson, S., personal communication. 2010. Marine Ecologist, Protected Resouces Division, Southwest Fisheries Science Center, NOAA.

Bradford, A.L., K.A. Forney, E.M. Oleson, and J. Barlow. Line-transect abundance estimates of false killer whales (*Pseudorca crassidens*) in the pelagic region of the Hawaiian Exclusive Economic Zone and in the insular waters of the Northwestern Hawaiian Islands. NOAA Administrative Report H-12-02, U.S. Department of Commerce, National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Honolulu, HI. 23 p.

Buckland, S. T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, Inc., New York, NY. 432 p.

Cotton, J., personal communicatiom. 2010. Senior Marine Mammal Observer/Identification Specialist, Protected Resouces Division, Southwest Fisheries Science Center, NOAA.

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

Fiedler, P.C., and L.D. Talley. 2006. Hydrography of the eastern tropical Pacific: a review. Prog Oceanogr 69:143-180.

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

Forney, K. A., M.C. Ferguson, E.A. Becker, P.C. Fiedler, J.V. Redfern, J. Barlow, I.L. Vilchis, and L. T. Ballance. 2012. Habitat-based spatial models of cetacean density in the eastern Pacific Ocean. Endang Species Res 16:113-133.

Hastie, T.J., and R.J. Tibshirani. 1990. Generalized Additive Models. Monographs on Applied Statistics and Applied Probability 43. Chapman & Hall/CRC, Boca Raton.

Hamilton, T.A., J.V. Redfern, J. Barlow, L.T. Ballance, T. Gerrodette, R.S. Holt, K.S. Forney, and B.L. Taylor. 2009. Atlas of cetacean sightings from Southwest Fisheries Science Center cetacean ecosystem surveys: 1986-2005. NOAA Technical Memorandum NMFS-SWFSC-440. U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA. 70 p.

Kinzey, D., P. Olson, and T. Gerrodette. 2000. Marine mammal data collection procedures on research ship line-transect surveys by the Southwest Fisheries Science Center. Report No. LJ-00-08, Southwest Fisheries Science Center, La Jolla.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied linear statistical models. Irwin, Chicago.

Redfern, J.V., J. Barlow, L.T. Ballance, T. Gerrodette, and E.A. Becker. 2008. Absence of scale dependence in dolphin-habitat models for the eastern tropical Pacific Ocean. Mar Ecol Prog Ser 363:1–14.

U.S. Department of the Navy. 2008. Hawaii Range Complex, Final Environmental Impact Statement/Overseas Environmental Impact Statement (EIS/OEIS). Prepared by Pacific Missile Range Facility.

Wang, Z., A.C. Bovik, H.R. Sheikh, and E.P. Simoncelli. 2004. Image quality assessment: From error visibility to structural similarity. IEEE Transactions on Image Processing 13:600-612.

Table 1. Scientific names, common names, and number of sightings in Beaufort sea states 0-6 in waters within our Central North Pacific study area from the 1997 - 2006 surveys of the temperate eastern North Pacific, around Hawaii and other Pacific Islands, and the eastern tropical Pacific. N_s is the total number of on-effort sightings from transects within our study area. N_m is the total number of sightings available for model development that included segments with the full suite of predictor variables and sightings within the truncation distance used to estimate the probability density function. Models were not developed for all species (N/A), and some species were combined into higher taxonomic categories to increase sample sizes for modeling.

Scientific Name	Common Name	N_s	N_m
Stenella attenuata	pantropical spotted dolphin	174	149
Stenella longirostris	spinner dolphin (includes whitebelly, Hawaiian, and unid. spinner dolphins)	108	98
Stenella coeruleoalba	striped dolphin	139	116
Steno bredanensis	rough-toothed dolphin	36	32
Tursiops truncatus	common bottlenose dolphin	55	49
Grampus griseus	Risso's dolphin	34	25
Lissodelphis borealis	northern right whale dolphin	2	N/A
Feresa attenuata	pygmy killer whale	4	N/A
Pseudorca crassidens	false killer whale	18	16
Globicephala macrorhynchus	short-finned pilot whale	94	84
Orcinus orca	killer whale	26	22
Phocoenoides dalli	Dall's porpoise	1	N/A
Physeter macrocephalus	sperm whale	66	47
Balaenoptera edeni	Bryde's whale	43	40
Balaenoptera borealis	sei whale	9	N/A
Balaenoptera physalus	fin whale	3	N/A
Balaenoptera musculus	blue whale	1	N/A
Megaptera novaeangliae	humpback whale	3	N/A
Other Dolphins		34	30
Delphinus delphis	Short-beaked common dolphin		
Lagenorhynchus obliquidens	Pacific white-sided dolphin		
Small beaked whales		75	63
ziphiid whale	unid. beaked whale		
Mesoplodon spp.	unid. *Mesoplodon*		
Mesoplodon densirostris	Blaineville's beaked whale		
Ziphius cavirostris	Cuvier's beaked whale		
Indopacetus pacificus	Longman's beaked whale		
Pygmy/dwarf sperm whales		22	16
Kogia spp.	unid. *Kogia*		
Kogia breviceps	pygmy sperm whale		
Kogia sima	dwarf sperm whale		

Table 2. Southwest Fisheries Science Center's 1997 - 2006 surveys of the temperate eastern North Pacific, around Hawaii and other Pacific Islands (Central Pacific), and the eastern tropical Pacific (ETP) that included transects within our study area.

SWFSC Cruise Number	Date	Research Vessel	Survey Region
1607	Mar-Jun 1997	McArthur	Temperate North Pacific
1610	Jul-Dec 1998	McArthur	ETP
1611	Jul-Dec 1998	Endeavor	ETP
1612	Jul-Dec 1998	Jordan	ETP
1613	Jul-Dec 1999	Jordan	ETP
1614	Jul-Dec 1999	McArthur	ETP
1615	Jul-Dec 2000	Jordan	ETP
1616	Jul-Dec 2000	McArthur	ETP
1621	Jul-Dec 2002	Jordan	Central Pacific
1622	Jul-Dec 2002	McArthur	Central Pacific
1623	Jul-Dec 2003	McArthur II	ETP
1624	Jul-Dec 2003	Jordan	ETP
1629	Jul-Nov 2005	McArthur II	Central Pacific
1630	Jul-Dec 2006	Jordan	ETP
1631	Jul-Dec 2006	McArthur II	ETP

Table 3. Summary of the weighted average *g(0)* estimates used to calculate densities for this analysis. The original values are those derived from previously published studies as summarized by Barlow (2006) and derived by Barlow (2003) for the "other dolphins" group. These values are weighted based on the number of small and large groups recorded in the 1997-2006 survey data included in our Central North Pacific study area.

	Original *g(0)*, by group size		**Weighted average *g(0)*, for model-derived densities**
Species	**1-20**	**>20**	
Pantropical spotted dolphin	0.76	1.00	0.97
Spinner dolphin guild	0.76	1.00	0.96
Striped dolphin	0.76	1.00	0.95
Rough-toothed dolphin	0.76	1.00	0.81
Common bottlenose dolphin	0.76	1.00	0.83
Risso's dolphin	0.76	1.00	0.83
Pygmy killer whale	0.76	1.00	0.76
False killer whale	0.76	1.00	0.79
Short-finned pilot whale	0.76	1.00	0.86
Killer whale	0.90	0.90	0.90
Sperm whale	0.87	0.87	0.87
Bryde's whale	0.90	0.90	0.90
Other dolphins[1]	0.77	1.00	0.95
Small beaked whale guild	0.23-0.76	0.23-1.00	0.34
Kogia spp.	0.35	0.35	0.35

[1] Includes short-beaked common dolphin and Pacific white-sided dolphin

Table 4. Estimated uniform densities (animals per 1000 km^2) for cetaceans in the Central North Pacific (this study) and the U.S. Exclusive Economic Zone (EEZ) of the Hawaiian Islands, with associated lognormal 95% confidence intervals (Barlow 2006).

	Model-based density estimates for the Central North Pacific	**Line-transect density estimates for Hawaiian EEZ, with 95% confidence limits (Barlow 2006)**		
Common Name	**Animals per 1000 km^2**	**Animals per 1000 km^2**	**Lower 95%**	**Upper 95%**
Pygmy killer whale	0.28	0.39	0.09	1.61
Risso's dolphin	2.05	0.97	0.30	3.11
Killer whale	0.28	0.14	0.03	0.70
Small beaked whales	5.41	7.95	1.33	47.26
Pygmy/dwarf sperm whales	3.25	10.05	3.30	30.63

Table 5. Predictor variables included in the encounter rate (ER) and group size (GS) GAMs for the Central North Pacific cetacean species. The expression s(x,n) indicates a non-parametric spline smoother of the variable x with n degrees of freedom. Variable abbreviations are as follows: lnCHL=ln(chlorophyll concentration), SST = sea surface temperature, SSHrms = sea surface height variation, PP = primary productivity, Dist = distance to land, LAT = latitude, LNG = longitude, offset = offset(ln(effective area searched)).

Common Name	Model	Predictor Variables
Pantropical spotted dolphin	ER	s(lnCHL, 2) + s(LAT, 3) + offset
	GS	s(SST, 2) + s(lnCHL, 3) + s(SSHrms, 3) + Dist
Spinner dolphin	ER	SST + s(lnCHL, 2) + s(LAT, 2) + offset
	GS	s(LAT, 2)
Striped dolphin	ER	SST + SSHrms + s(LAT, 3) + LNG + offset
	GS	lnCHL + LAT + LNG
Rough-toothed dolphin	ER	s(Dist, 5) * + SST:lnCHL* + offset
	GS	s(Dist, 2)
Common bottlenose dolphin	ER	SST + s(lnCHL, 2) + s(Dist, 3) + LNG + offset
	GS	s(PP, 2) + lnCHL + s(LAT, 2) + s(LNG, 2)
Risso's dolphin[1]	ER	Null
	GS	Null
False killer whale	ER	SST + offset
	GS	s(Dist, 2) + LAT + LNG
Short-finned pilot whale	ER	lnCHL + s(Dist, 3) + offset
	GS	Null
Killer whale[1]	ER	null
	GS	null
Sperm whale	ER	PP + lnCHL + Dist + LAT + offset
	GS	s(SSHrms, 3) + s(LAT, 2)
Bryde's whale	ER	SST + s(LAT, 3) + offset
	GS	Null
Other dolphins: short-beaked	ER	s(SST, 3) + s(LNG, 3) + offset
common and Pacific white-sided[2]	GS	s(SST, 2)
Small beaked whale guild[1]	ER	Null
	GS	Null
Kogia spp. [1]	ER	Null
	GS	Null

*Predictor variables forced into model based on known distribution patterns
[1]Modeled density estimates were not able to capture observed distribution patterns so the null model was selected.
[2] The list of potential predictors was limited to SST, longitude, and latitude, the latter term allowing up to 6 degrees of freedom.

Table 6. The percentage of deviance explained by the final encounter rate and group size models for each species.

Species	Encounter Rate Model	Group Size Model
Pantropical spotted dolphin	12.2%	25.0%
Spinner dolphin	17.2%	15.1%
Striped dolphin	9.9%	10.7%
Rough-toothed dolphin	8.7%	18.7%
Common bottlenose dolphin	15.8%	37.6%
False killer whale	5.4%	7.9%
Short-finned pilot whale	4.2%	0%
Sperm whale	8.4%	24.3%
Bryde's whale	10.8%	0%
Other dolphins: Short-beaked common dolphin and Pacific white-sided dolphin	29.4%	57.5%

Figure 1. The transect lines from surveys conducted between 1997 and 2006 in the temperate eastern Pacific, around Hawaii and other Pacific Islands, and in the eastern tropical Pacific that included effort within our Central North Pacific study area.

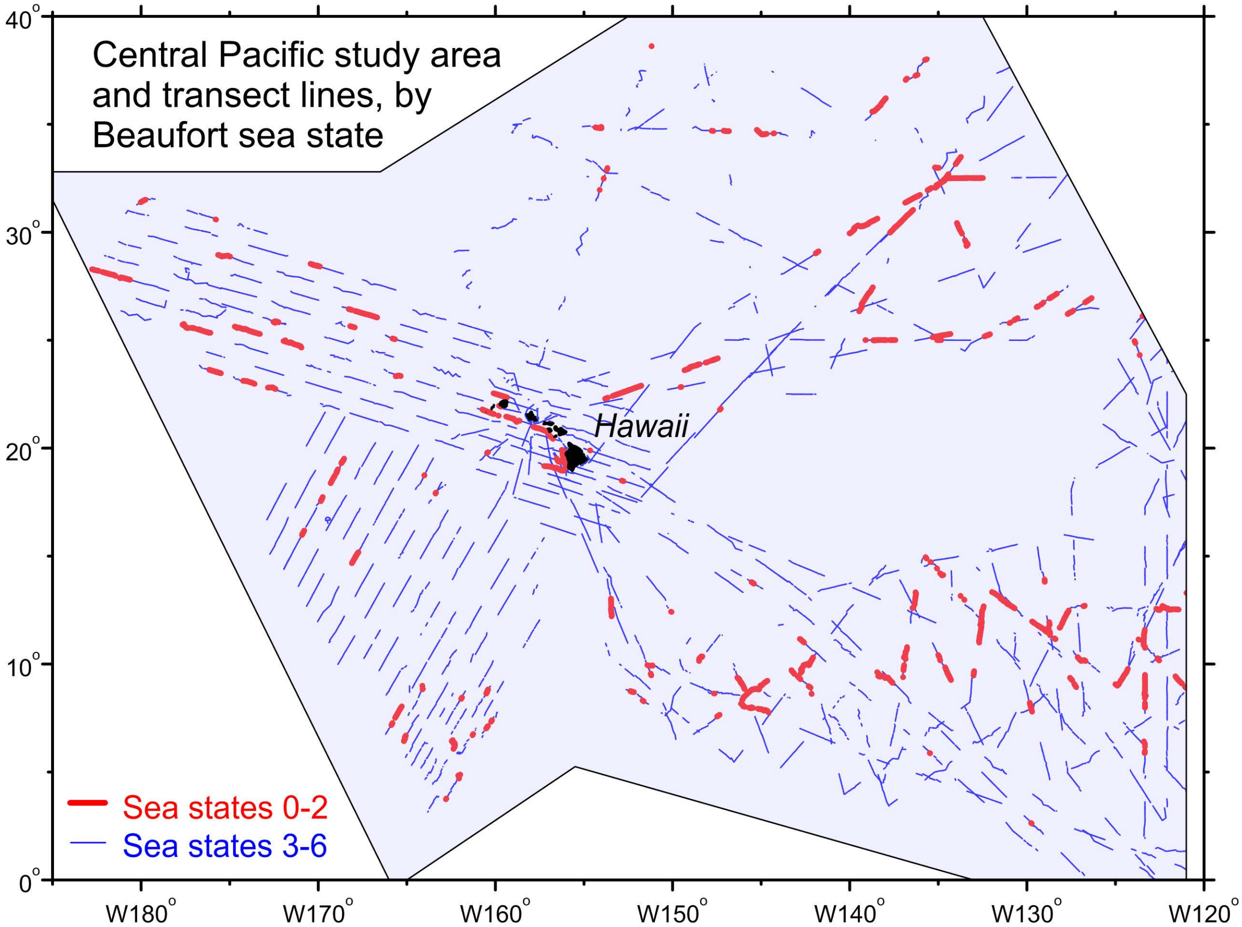


Figure 2. Modeled habitat-based densities of pantropical spotted dolphins (Ste.att) and spinner dolphins (Ste.lon). Black dots are sighting locations, with larger dots representing more animals. Light gray lines show survey effort.

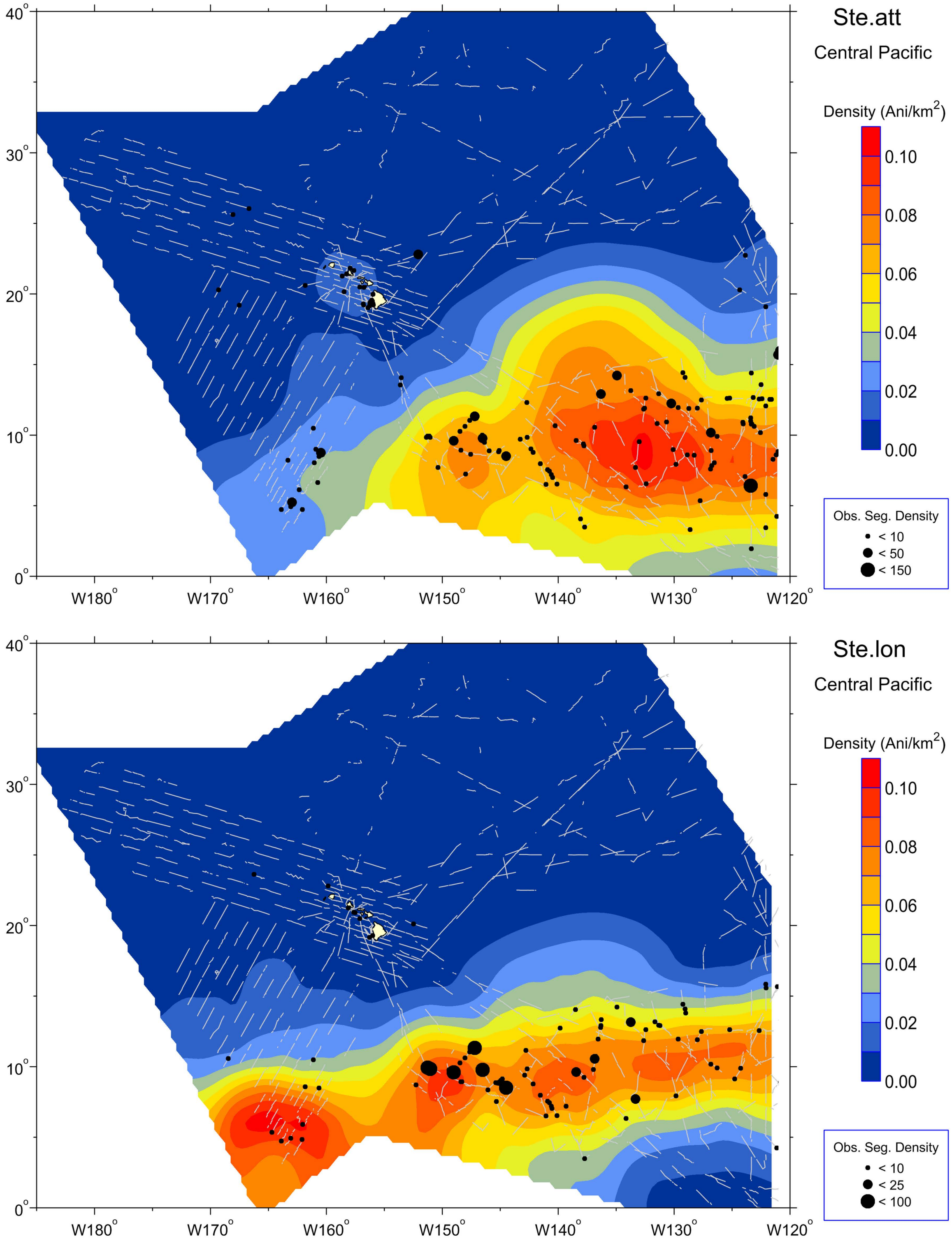


Figure 3. Modeled habitat-based densities of striped dolphins (Ste.coe) and common bottlenose dolphins (Tur.tru). Black dots are sighting locations, with larger dots representing more animals. Light gray lines show survey effort.

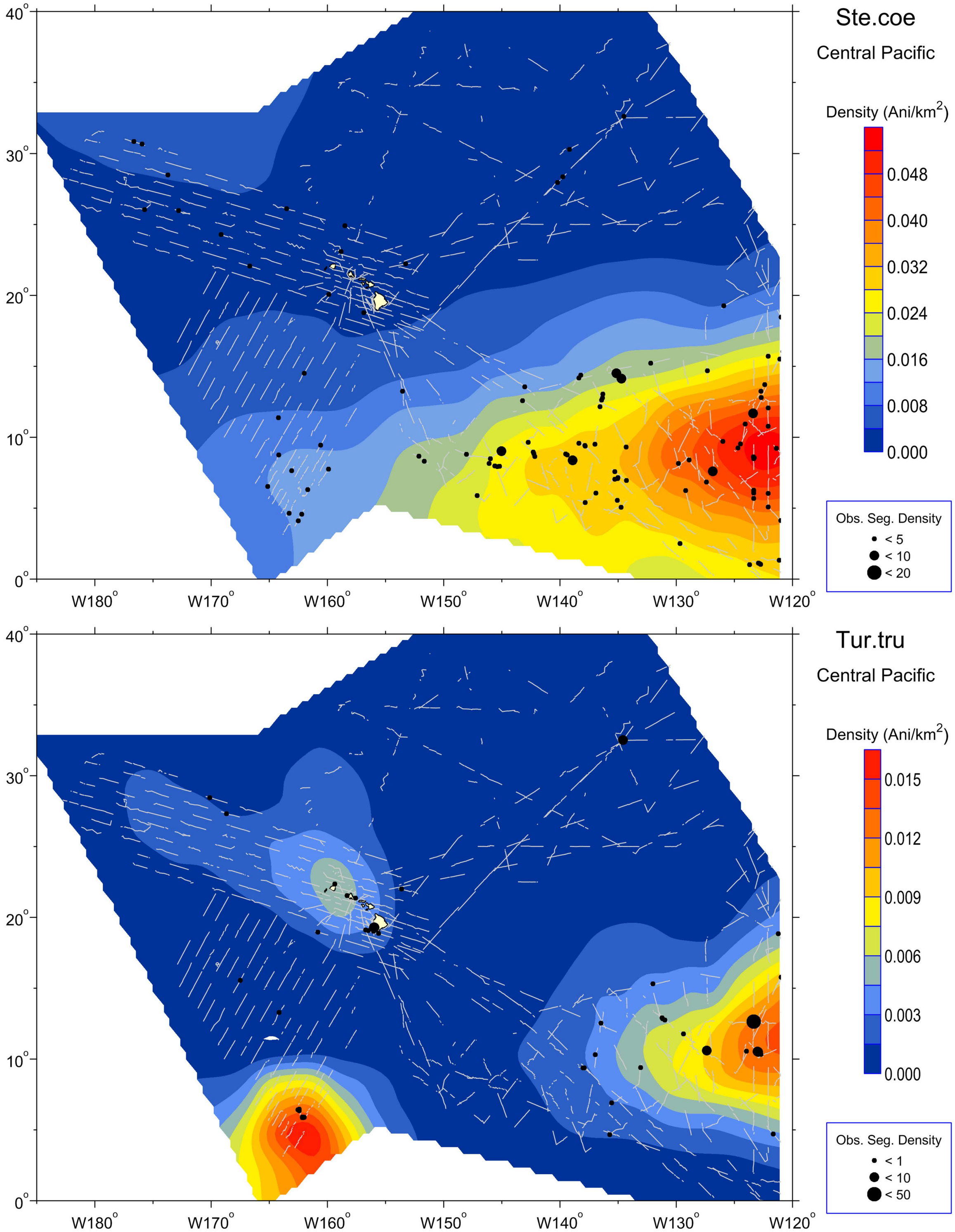


Figure 4. Modeled habitat-based densities of false killer whales (Pse.cra) and short-finned pilot whales (Glo.mac). Black dots are sighting locations, with larger dots representing more animals. Light gray lines show survey effort.

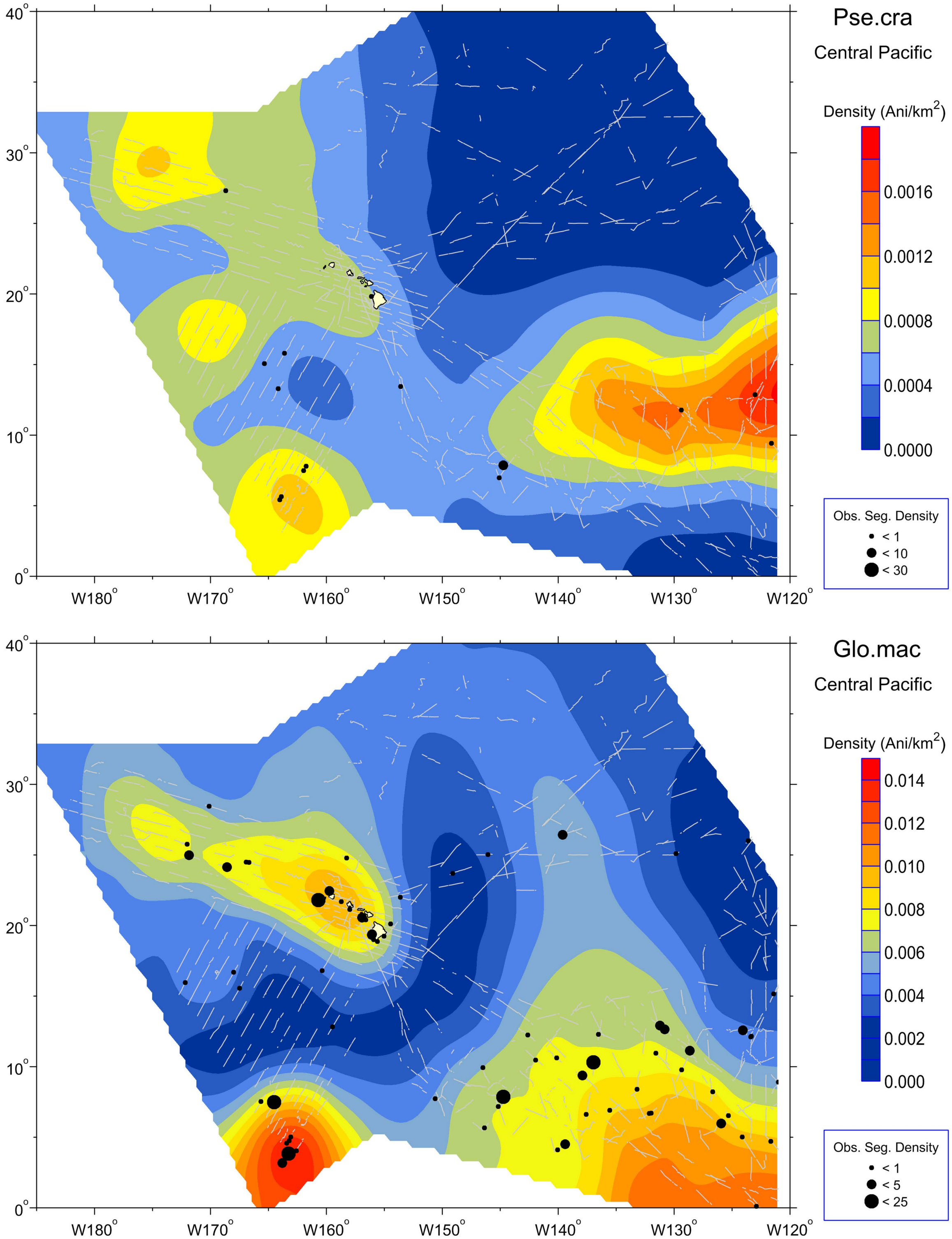
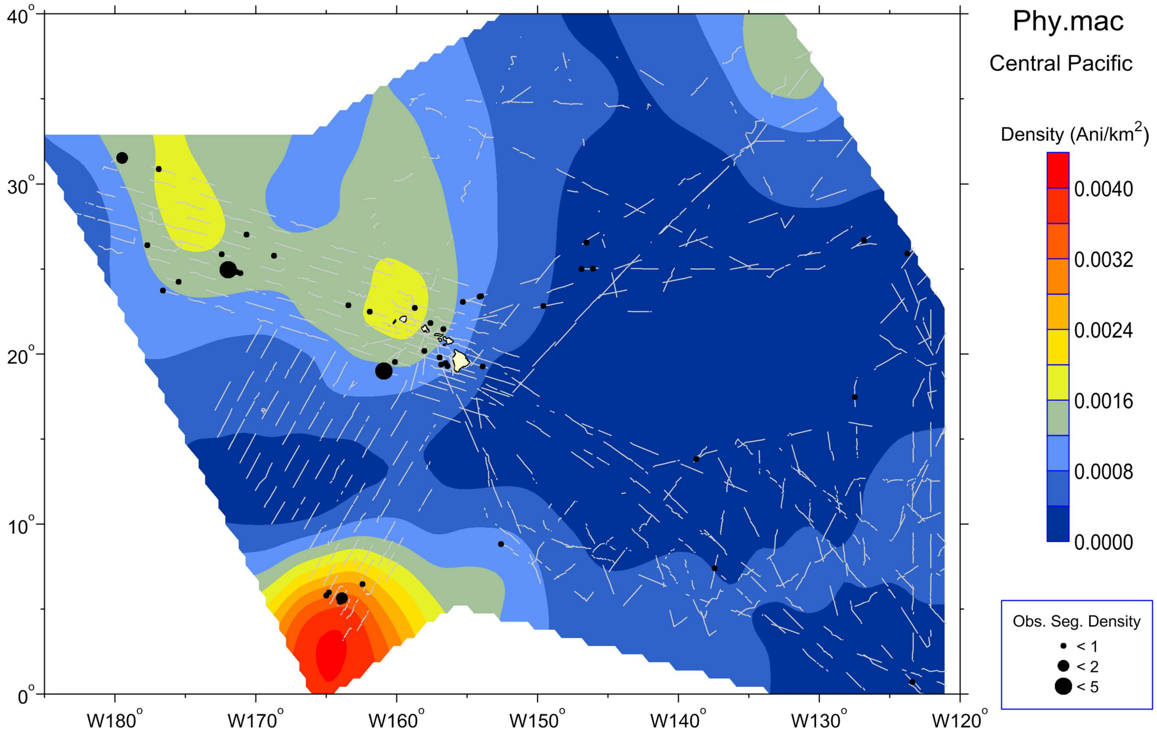


Figure 5. Modeled habitat-based densities of sperm whales (Phy.mac) and Bryde's whales (Bal.ede). Black dots are sighting locations, with larger dots representing more animals. Light gray lines show survey effort.



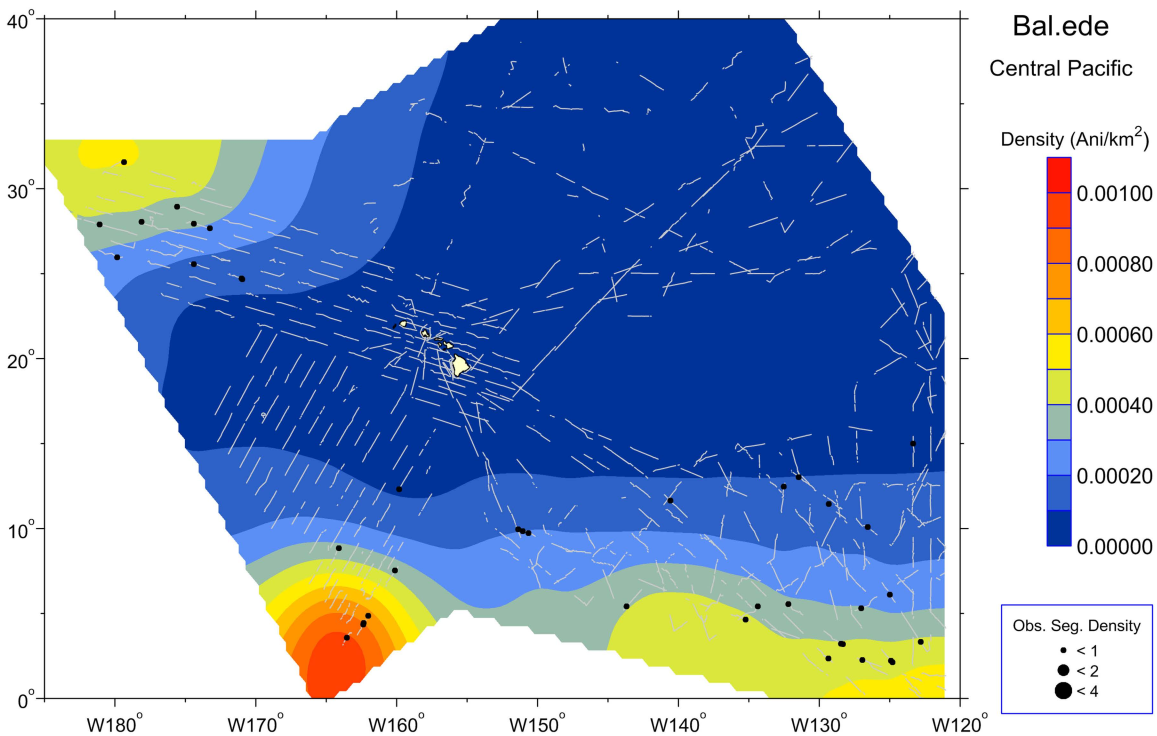


Figure 6. Modeled habitat-based densities of rough-toothed dolphin (Ste.bre) and the dolphin guild including Pacific white-sided and short-beaked common dolphins (Lo & Dd). Areas south of about 20ºN represent only short-beaked common dolphins. Black dots are sighting locations, with larger dots representing more animals. Light gray lines show survey effort.

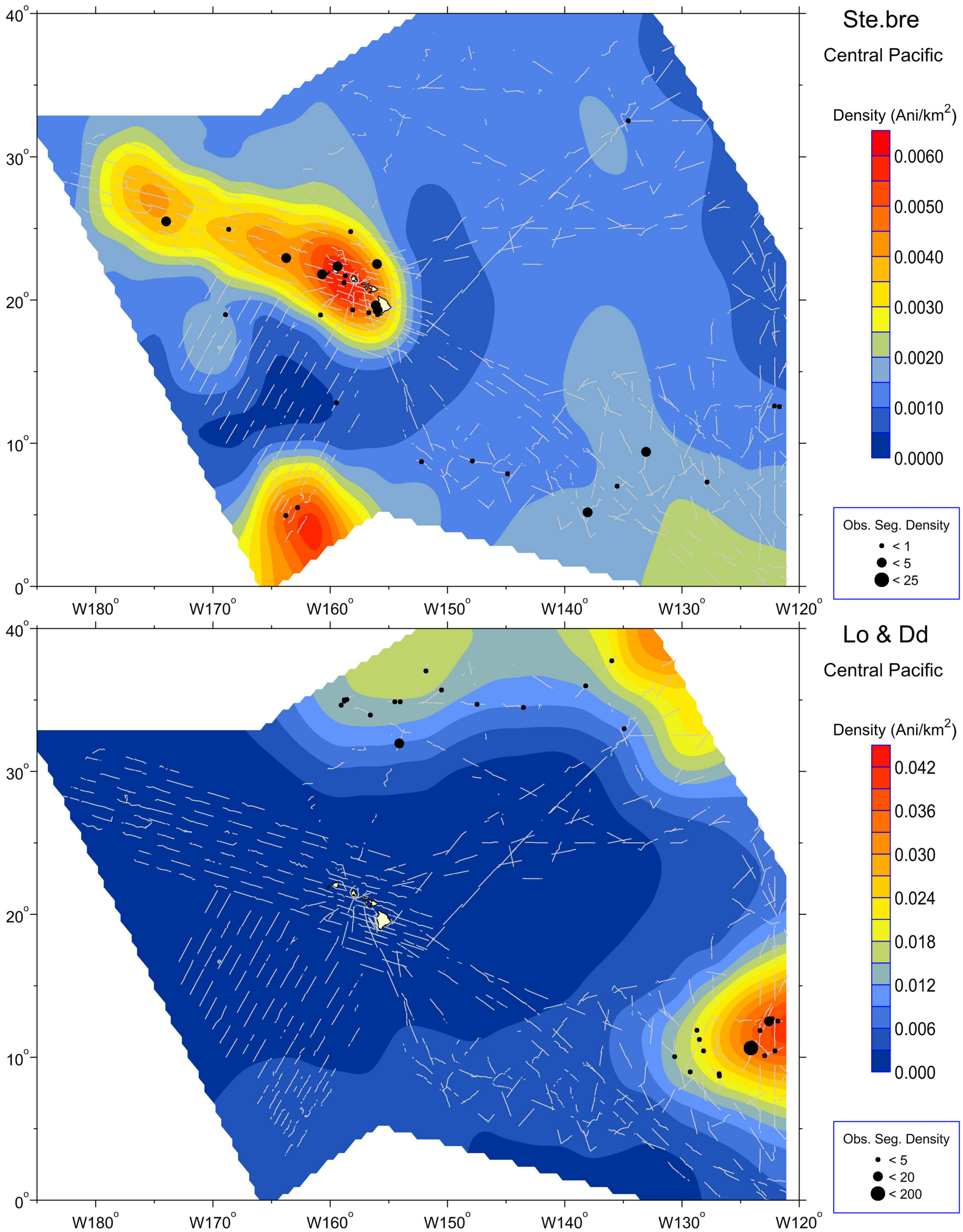


Figure 7. Functional forms for variables included in the encounter rate models for a) pantropical spotted dolphin, b) spinner dolphin, c) striped dolphin, d) rough-toothed dolphin, e) common bottlenose dolphin, f) false killer whale, g) short-finned pilot whale, h) sperm whale, i) Bryde's whale, and j) the "other dolphins" group. Models were constructed with both linear terms and smoothing splines having up to three degrees of freedom. Degrees of freedom for nonlinear fits are in the parentheses on the y-axis. Potential predictor variables included sea surface temperature (SST; °C), the natural logarithm of surface chlorophyll concentration (lnCHL; measured in mg/m^3), primary productivity (PP; mg $C/m^2/day$), sea surface height root-mean-square (SSHrms; m), distance to land (Dist; km), latitude, and longitude. The y-axes represent the term's smoothing spline function. Zero on the y-axes corresponds to no effect of the predictor variable on the estimated response variable (encounter rate). The dashed lines reflect 2x standard error bands (i.e., 95% confidence interval). Scaling of the y-axis varies among predictor variables to emphasize model fit.

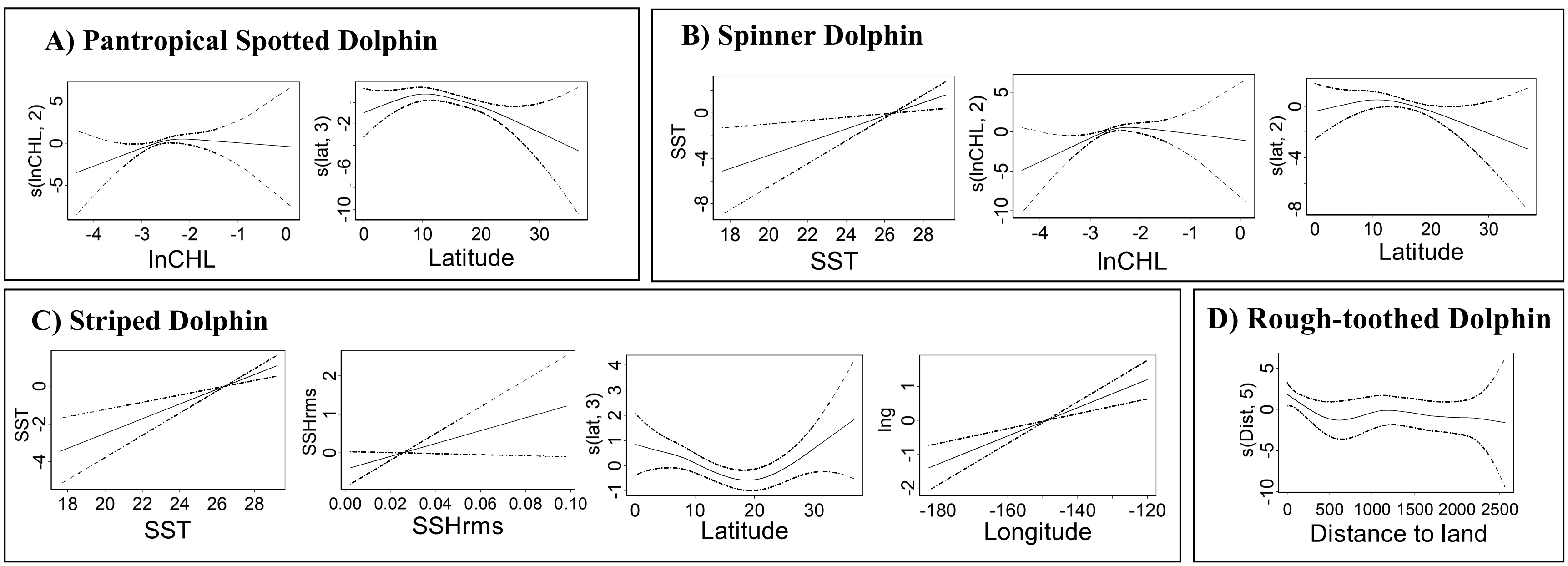


Figure 7.
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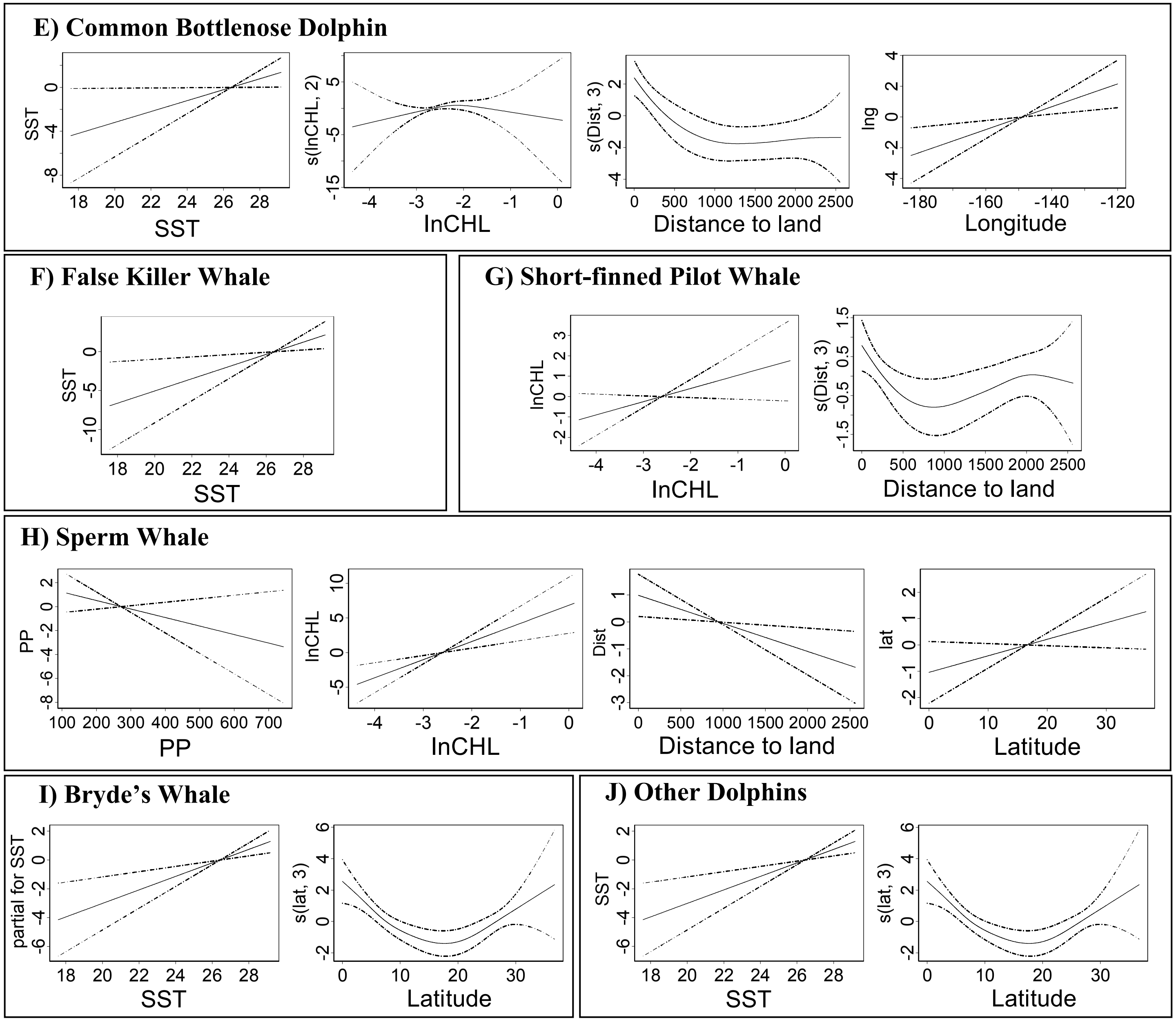


Figure 8. Functional forms for variables included in the group size models for a) pantropical spotted dolphin, b) spinner dolphin, c) striped dolphin, d) rough-toothed dolphin, e) common bottlenose dolphin, f) false killer whale, g) sperm whale, and h) the "other dolphins" group. (The null model was selected for both short-finned pilot whale and Bryde's whale.) Models were constructed with both linear terms and smoothing splines having up to three degrees of freedom. Degrees of freedom for nonlinear fits are in the parentheses on the y-axis. Potential predictor variables included sea surface temperature (SST; °C), the natural logarithm of surface chlorophyll concentration (lnCHL; measured in mg/m^3), primary productivity (PP; mg $C/m^2/day$), sea surface height root-mean-square (SSHrms; m), distance to land (Dist; km), latitude, and longitude. The y-axes represent the term's smoothing spline function. Zero on the y-axes corresponds to no effect of the predictor variable on the estimated response variable (group size). The dashed lines reflect 2x standard error bands (i.e., 95% confidence interval). Scaling of the y-axis varies among predictor variables to emphasize model fit.

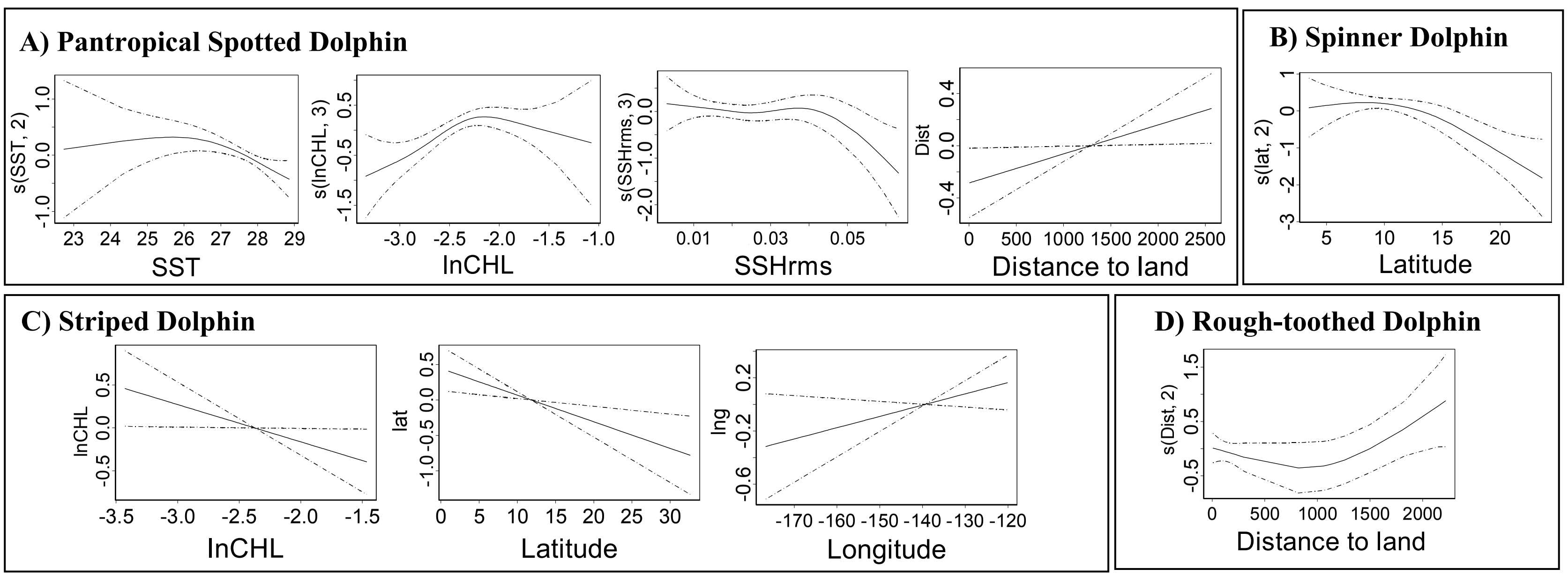


Figure 8. (continued)

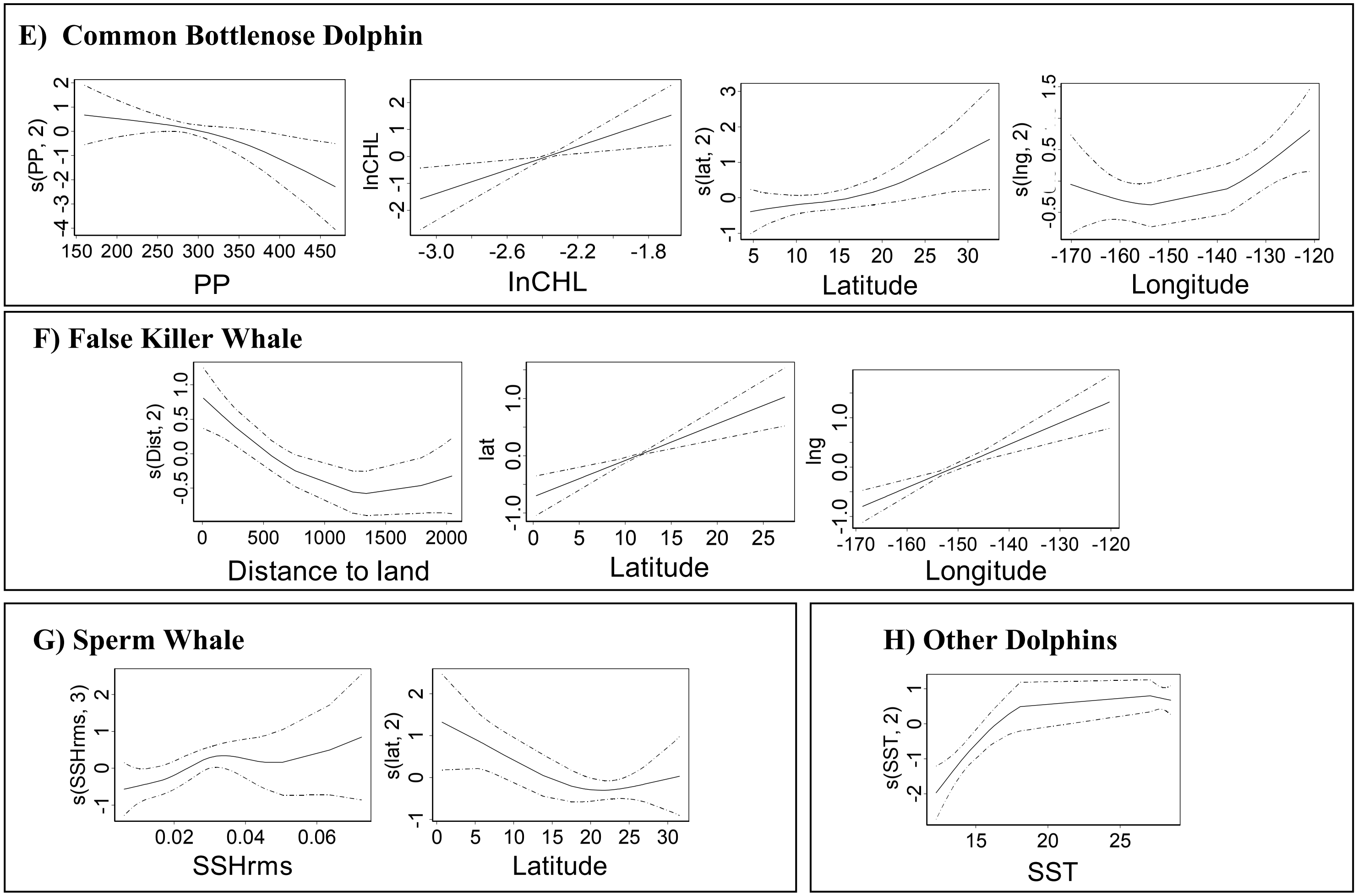


Figure 9. Comparison of model-based abundance estimates ('Model Est') to previously published line-transect abundance estimates ('LT Est') and associated 95% confidence intervals for (A) the Hawaiian EEZ stratum and B) the Main Hawaiian Islands stratum (Barlow 2006, Barlow and Rankin 2007).

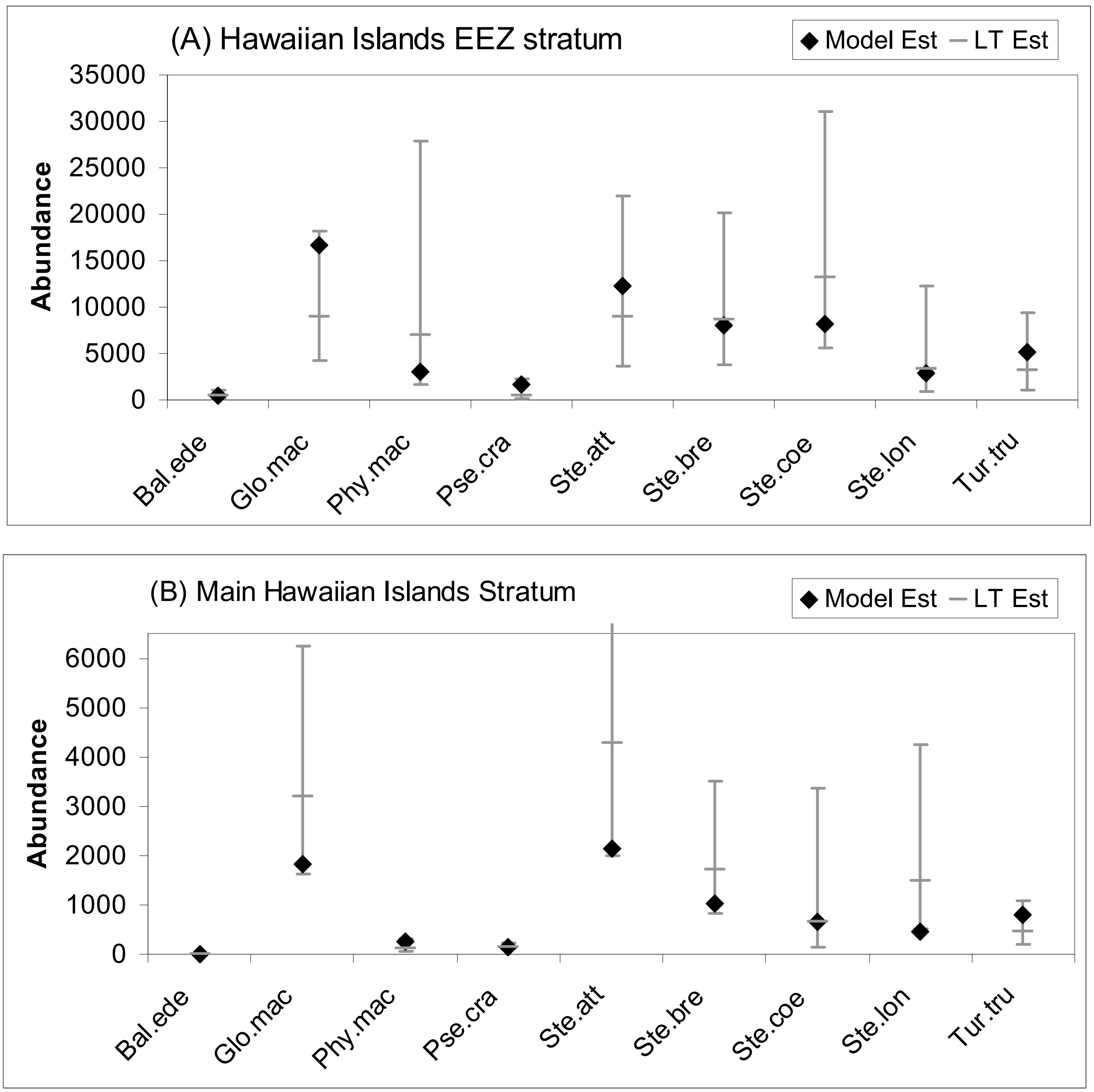
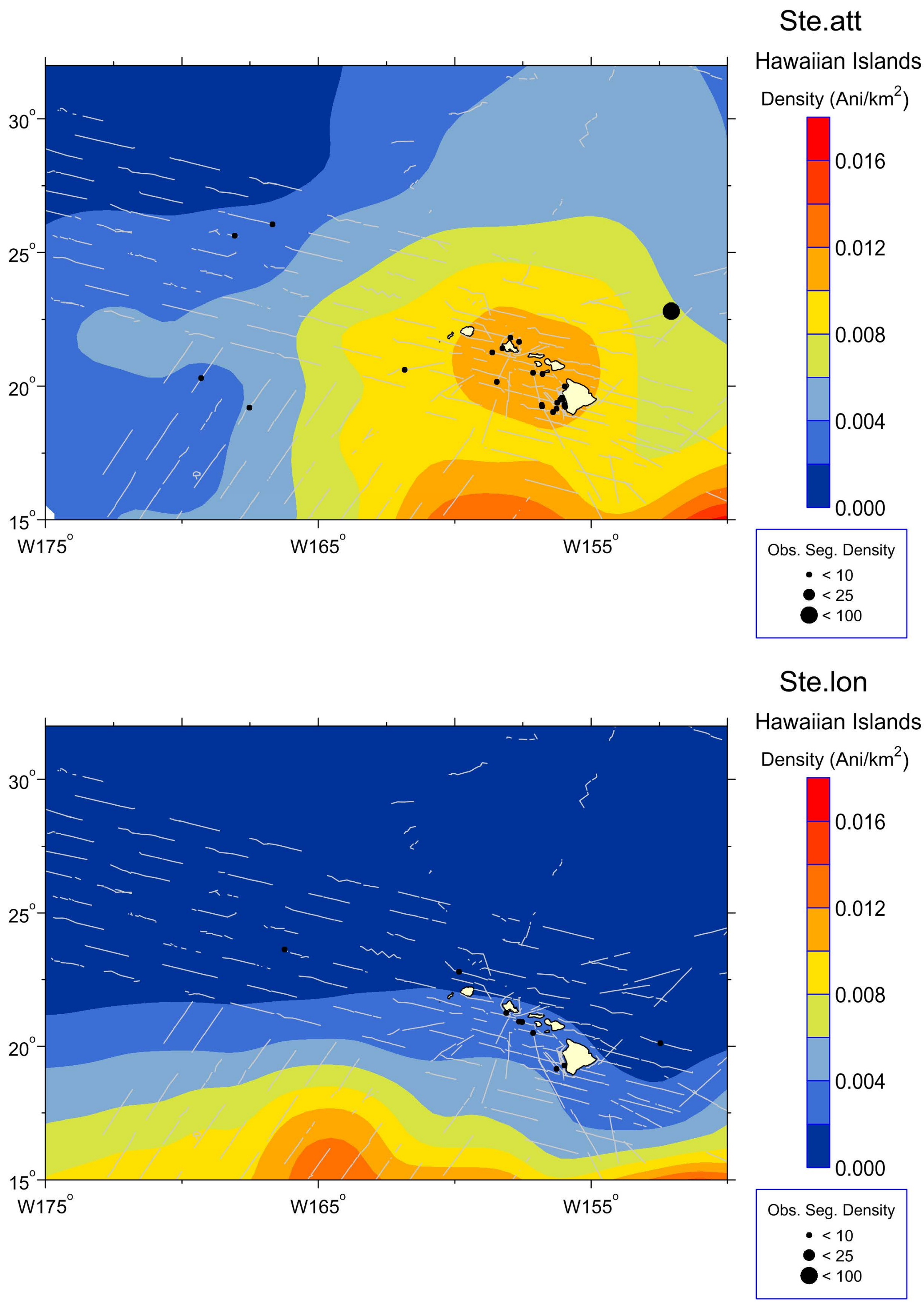


Figure 10. Near-island density patterns for pantropical spotted dolphins (Ste.att) and spinner dolphins (Ste.lon). These plots have been re-scaled to better depict island distributions that were not apparent in the larger scale versions (see Fig. 2).



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