

Chapter 7 Seabirds

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Laysan Albatross at Kaena Point, O'ahu. Photo credit: Arliss Winship (NOAA NOS/NCCOS)

ABSTRACT

This chapter describes an assessment of the at-sea distribution of seabirds around the Main Hawaiian Islands (MHI). We analyzed at-sea visual sighting data collected by the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) Southwest Fisheries Science Center (SWFSC) on shipboard surveys conducted during May and August-December between 1989 and 2012. We present the locations of sightings of 24 species, and for 14 of these species we develop spatial predictive models of relative density throughout the study area. Model predictions are presented with associated measures of precision and statistical fit in terms of a suite of performance metrics. Spatial distributions varied across species, with the majority of sightings occurring relatively close to land, occurring in particular parts of the study area, or occurring more evenly throughout the study area. Predicted spatial distributions for species that were modeled broadly aligned with the distributions of sightings. Some of the most important model predictor variables across species were day of the year, distance to shore or nearest terrestrial site, depth, sea surface height and projected longitude/latitude. Our assessment provides broad-scale spatial information that can aid marine spatial planning around the MHI. Importantly, our assessment also highlights gaps and limitations in the available data, which can guide future data collection efforts. In addition to our assessment, we discuss other studies and available datasets on the at-sea distribution of seabirds around the MHI.

Citation for chapter

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7.1. INTRODUCTION

Seabirds are a group of species that have a large potential for being negatively affected by offshore wind energy development (Garthe and Hüppop, 2004). Seabirds may avoid areas with temporary or permanent structures, possibly being displaced from areas they would normally use for foraging, migrating, etc. (May 2015). There is also a potential mortality risk from collisions with man-made structures, such as wind turbines. Collisions of birds with wind turbines have been well documented in North America and Europe and can result in non-negligible mortality at the population level (Drewitt and Langston, 2006; Erickson et al., 2014). The probability of collision will likely vary with a species' typical flight height (Robinson Willmott, 2013; Cleasby et al., 2015). Seabird mortality from collisions with other man-made structures has been documented in the Hawaiian Islands (Cooper and Day, 1998).

At least 22 species of seabirds breed in the Hawaiian Archipelago, 20 of which are documented as or suspected of breeding in the Main Hawaiian Islands (MHI; Table 7.1). Two endemic species that are federally listed under the U.S. Endangered Species Act, Hawaiian Petrel (*Pterodroma sandwichensis*; Federal Register, 1967) and Newell's Shearwater (*Puffinus newelli*; Federal Register, 1975), breed only in the MHI. Many species of non-breeding, migratory seabirds can also be found in waters around the MHI.

Seasonal timing of presence of each species in the MHI (Table 7.1, Figure 7.1) is dictated by the timing of life history events, like breeding, juvenile dispersal, and migration. The spatial distributions of birds at sea are a result of interactions between behavior (e.g., foraging) and the environment. Important environmental variables that may affect habitat use include distance to breeding colonies, wind speed and direction, thermocline depth and gradient, primary productivity, water temperature, salinity, fronts, and meso- and large-scale ocean features (King, 1970; Ballance et al., 1997; Ribic and Ainley, 1997; Spear et al., 2001; Ballance et al., 2006; Kappes et al., 2010). The relative importance of these variables may differ among species (e.g., planktivores versus piscivores; Spear et al., 2001). Behaviors like multi-species flocking and inter-specific competition, foraging in association with tunas and dolphins, and following fishing vessels (e.g., Black-footed Albatross [*Phoebastria nigripes*]) may also influence spatial distributions (King, 1970; Ballance et al., 1997; Ballance and Pitman, 1999; Hebshi et al., 2008). Inter-annual environmental variability and extreme events (e.g., El Niño) may influence both habitat use and the timing and success of breeding (USFWS, 1983; Vandenbosch, 2000; Ballance et al., 2006; Devney et al., 2009; Thorne et al., 2015).

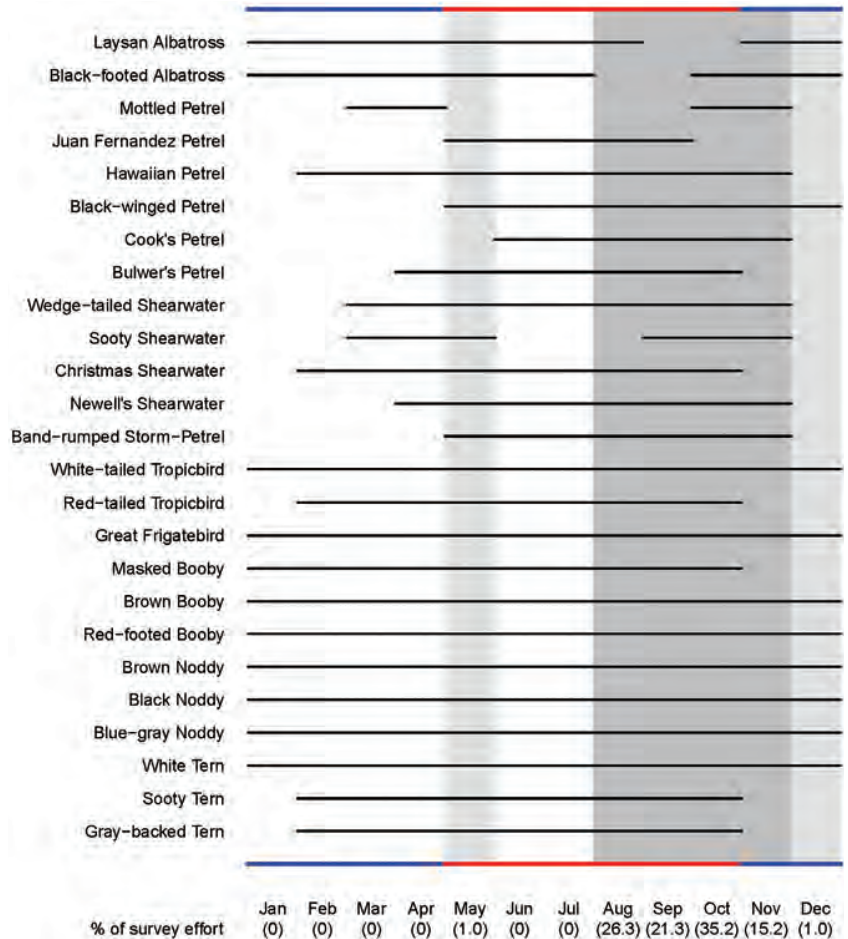


Figure 7.1. Monthly presence of seabird species in the Main Hawaiian Islands. Black lines indicate months present, based on a literature review. Blue and red lines indicate winter and summer (as defined in Chapter 2), respectively. Dark grey shading indicates months with 98 percent of the survey effort, light grey shading indicates months with the remaining 2 percent of the survey effort, and no shading indicates no survey effort.

Table 7.1. Seabird species considered in assessment. Birds are mainly present in the Main Hawaiian Islands (MHI) during the indicated month ranges but can occur at other times. Conservation statuses are BCC (bird of conservation concern), V (vulnerable), NT (near threatened), T (threatened), E (endangered), C (candidate for listing), Y (yellow Watch List) and R (red Watch List) according to the U.S. Endangered Species Act (ESA), State of Hawai'i endangered species legislation (HI), U.S. Fish and Wildlife Service (USFWS), International Union for Conservation of Nature (IUCN) and State of the Birds U.S.A. (SB; Rosenberg et al., 2014). Estimates of maximum breeding foraging range, if they were available, are only presented for breeding species that were not modeled.

Family	Common Name	Scientific Name	Breeds In MHI	Months Present ^{1,2,3}	Conservation Status	Model	Maximum Breeding Foraging Range (km)
Diomedeiidae	Laysan Albatross	<i>Phoebastria immutabilis</i>	yes	Nov – Aug	BCC (USFWS), NT (IUCN), Y (SB)	no	3,929 ⁴
	Black-footed Albatross	<i>Phoebastria nigripes</i>	yes	Oct – Jul	T (HI), BCC (USFWS), NT (IUCN), Y (SB)	no	3,779 ⁴
Procellariidae	Mottled Petrel	<i>Pterodroma inexpectata</i>	no	Mar – Apr, Oct – Nov	NT (IUCN)	yes	N/A
	Juan Fernandez Petrel	<i>Pterodroma externa</i>	no	May – Sep	V (IUCN)	yes	N/A
	Hawaiian Petrel	<i>Pterodroma sandwichensis</i>	yes	Feb – Nov	E (ESA, HI), V (IUCN), R (SB)	yes	model
	Black-winged Petrel	<i>Pterodroma nigripennis</i>	no	May – Dec		yes	N/A
	Cook's Petrel	<i>Pterodroma cookii</i>	no	Jun – Nov	V (IUCN)	yes	N/A
	Bulwer's Petrel	<i>Bulweria bulwerii</i>	yes	Apr – Oct	Y (SB)	yes	model
	Wedge-tailed Shearwater	<i>Puffinus pacificus</i>	yes	Mar – Nov		yes	model
	Sooty Shearwater	<i>Puffinus griseus</i>	no	Mar – May, Sep – Nov	NT (IUCN)	yes	N/A
	Christmas Shearwater	<i>Puffinus nativitatis</i>	yes	Feb – Oct	BCC (USFWS), Y (SB)	no	unknown
Hydrobatidae	Band-rumped Storm-Petrel	<i>Oceanodroma castro</i>	yes	May – Nov	C (ESA), E (HI), BCC (USFWS), Y (SB)	no	unknown
Phaethontidae	White-tailed Tropicbird	<i>Phaethon lepturus</i>	yes	year round	Y (SB)	yes	model
	Red-tailed Tropicbird	<i>Phaethon rubricauda</i>	yes	Feb – Oct	Y (SB)	no	1,034 ⁵
Fregatidae	Great Frigatebird	<i>Fregata minor</i>	suspected	year round	Y (SB)	no	612 ⁵
Sulidae	Masked Booby	<i>Sula dactylatra</i>	yes	Jan – Oct	Y (SB)	no	158 ³
	Brown Booby	<i>Sula leucogaster</i>	yes	year round	Y (SB)	yes	model
	Red-footed Booby	<i>Sula sula</i>	yes	year round		yes	model
Laridae	Brown Noddy	<i>Anous stolidus</i>	yes	year round		no	163 ³
	Black Noddy	<i>Anous minutus</i>	yes	year round	Y (SB)	no	80 ⁶
	Blue-gray Noddy	<i>Procelsterna cerulea</i>	suspected	year round	Y (SB)	no	9 ⁵
	White Tern	<i>Gygis alba</i>	yes	year round	T (HI)	yes	model
	Sooty Tern	<i>Onychoprion fuscatus</i>	yes	Feb – Oct		yes	model
	Gray-backed Tern	<i>Onychoprion lunatus</i>	yes	Feb – Oct	Y (SB)	no	unknown

¹USFWS, 1983; ²Pyle and Pyle, 2009; ³Keller et al., 2009; ⁴Fernandez et al., 2001; ⁵Maxwell and Morgan, 2013; ⁶USFWS, 2005

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This chapter describes an assessment of the at-sea distributions of seabirds around the Main Hawaiian Islands (MHI; Figure 7.2). Data on the at-sea distributions of seabirds around the MHI have mainly been collected two ways, vessel-based sighting surveys (Table 7.2) and electronic tracking (Table 7.3). For our assessment we focused on sighting data, specifically the most comprehensive, scientific at-sea survey dataset for seabirds in the MHI in recent decades, which was collected by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) Southwest Fisheries Science Center (SWFSC). We present the locations of sightings of 24 species: all 19 breeding species with sightings in the dataset and five non-breeding visitors with the greatest numbers of sightings in the survey data. For nine of the breeding species and all five non-breeding visitors, we develop spatial predictive models of relative density throughout the study area.

Our assessment was designed to provide broad-scale spatial information that can be used to guide future data collection efforts and aid marine spatial planning around the MHI. The results of our assessment represent spatial distributions of seabird sightings and relative density around the MHI averaged over time. Our assessment was not designed to provide precise predictions of the absolute number of individuals of a given species that would be expected in a specific location at a specific time. Our assessment was also not designed to determine the ecological drivers of seabird spatial distributions around the MHI, although our modeling results provide related hypotheses for future research.

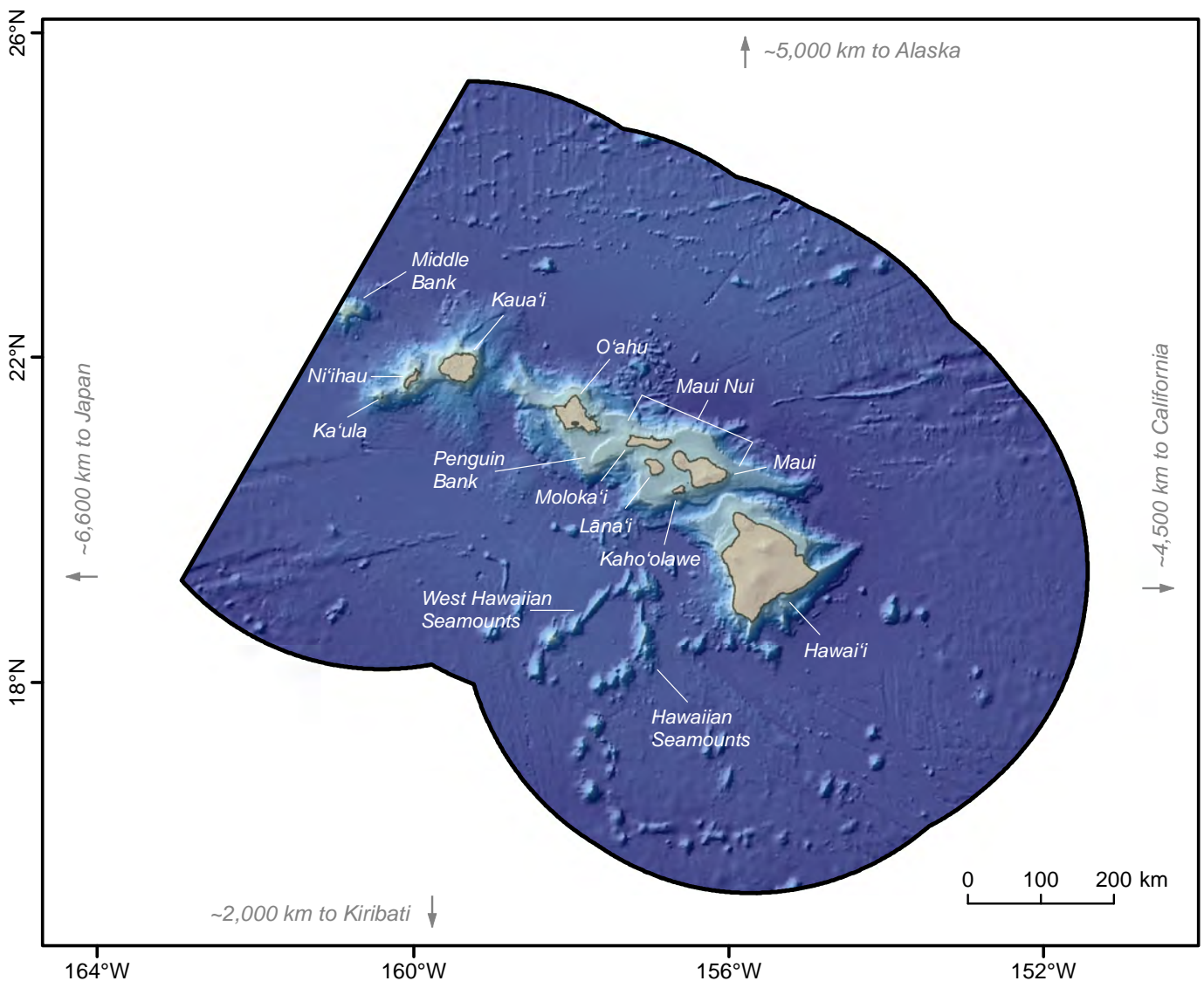


Figure 7.2. Map of the study area with place names referred to in the text.

Table 7.2. Seabird sighting surveys and datasets with survey effort in the MHI not analyzed in our assessment. We did not analyze data from these surveys for several reasons, including data availability, limited spatial coverage, limited spatial resolution, or lack of associated effort data.

Survey/Dataset	At Sea/Terrestrial	Source
Western Pacific	at sea	Dixon and Starrett, 1952
Smithsonian Institution Pacific Ocean Biological Survey Program	at sea	King, 1970; King, 1974
Southeastern Hawaiian Waters	at sea	Spear et al., 1999
South Of O'ahu	at sea	VanderWerf et al., 2005
Cascadia Research Collective	at sea	Robin Baird (Cascadia Research Collective, Olympia, WA) http://www.cascadiaresearch.org
NOAA NMFS/PIRO Observer Program	at sea	NOAA National Marine Fisheries Service Pacific Islands Regional Office, Honolulu, HI (e.g, NOAA NMFS, 2014)
eBird	both	http://ebird.org
Audubon Christmas Bird Count	terrestrial	http://www.audubon.org/conservation/science/christmas-bird-count

Table 7.3. Electronic tracking studies of seabirds in the Hawaiian Islands.

Species	Source
Laysan Albatross	Fernandez et al., 2001; Hyrenbach et al., 2002; Kappes et al., 2010; Conners et al., 2015; Kappes et al., 2015; Josh Adams (USGS, Santa Cruz, CA) ¹
Black-footed Albatross	Fernandez et al., 2001; Hyrenbach et al., 2002; Kappes et al., 2010; Conners et al., 2015; Kappes et al., 2015
Hawaiian Petrel	Josh Adams (USGS, Santa Cruz, CA) ¹
Wedge-tailed Shearwater	Josh Adams (USGS, Santa Cruz, CA) ¹
Newell's Shearwater	Josh Adams (USGS, Santa Cruz, CA) ¹ ; Andre Raine (Kaua'i Endangered Seabird Recovery Project, HI)
Red-tailed Tropicbird	Josh Adams (USGS, Santa Cruz, CA) ¹
Masked Booby	Young et al., 2015
Brown Booby	Josh Adams (USGS, Santa Cruz, CA) ¹
Red-footed Booby	Young et al., 2015; Josh Adams (USGS, Santa Cruz, CA) ¹
Brown Noddy	Harrison and Stone-Burner, 1981

¹ BOEM-funded project PC-13-03



Red-footed Booby, *Sula sula* (left; Robin W. Baird, Cascadia Research Collective); and Black-footed Albatross, *Phoebastria nigripes* (right; David Pereksta, BOEM).

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7.2. METHODS

7.2.1. At-sea survey data

Our assessment focused on at-sea survey data collected by SWFSC. These data were visual sightings on shipboard surveys conducted between 1989 and 2012 (Figure 7.3). The majority of these data were collected on two ship surveys in 2002 and 2010 (Figure 7.4), the Hawaiian Islands Cetacean and Ecosystem Assessment Surveys (HICEAS), that covered the study area with widely spaced transects. There were also data from other shipboard surveys that transited in and out of the study area en route to other survey locales. Most of the survey effort was from August–November, with smaller amounts of effort in May and December (Figure 7.5). The monthly timing of surveys was chosen for historical reasons and consistency over time. Sighting data were collected continuously using strip transect sampling methodology (Ballance et al., 2002). Strip transects were generally 300 m wide, but were sometimes narrower depending on the sighting conditions and species. For analysis, survey transects were divided into 1.2 km ‘segments’ (Appendix B), and species-specific counts were summed for each segment. The mid-point of a segment was used as the location of the summed counts.

Other surveys have been conducted partially or entirely in waters around the MHI (Table 7.2). We did not analyze sighting data from those surveys for several reasons, including data availability, limited spatial coverage, limited spatial resolution, or lack of associated effort data. Nevertheless, those surveys provide a supplementary source of information about the at-sea distributions of seabirds in the MHI.

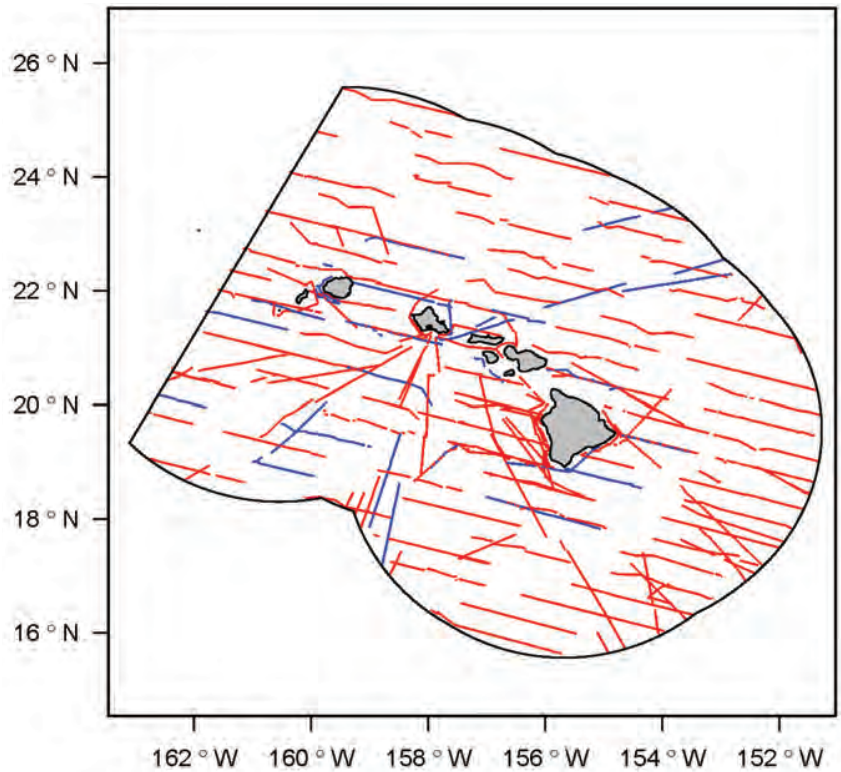


Figure 7.3. Seabird survey transects by NOAA NMFS/SWFSC from 1989–2012. Survey effort was 16,377 1.2-km transect segments during May and August–October (summer; shown in red) and 3,168 during November–December (winter; shown in blue).

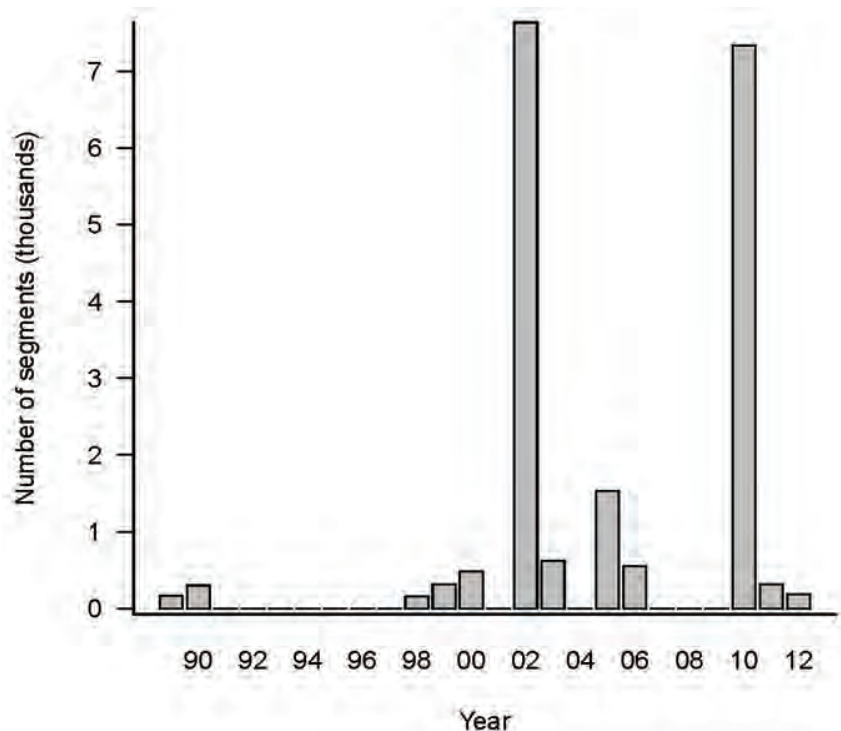


Figure 7.4. Number of survey transect segments by year. Data were collected by NOAA NMFS/SWFSC. Most segments were 1.2 km.

7.2.2. Terrestrial site data

While our assessment was focused on the at-sea distribution of seabirds, we also compiled data on the locations of terrestrial sites used by seabirds in the MHI (e.g., breeding colonies, roosting sites) for two purposes. First, we used the terrestrial site data to develop distance-to-nearest-terrestrial-site predictor variables for use in modeling of relevant species (Section 7.2.3). Second, we used the terrestrial site data to develop potential maximum foraging areas for breeding species that were not modeled (Section 7.2.4).

Many terrestrial and coastal surveys and other studies have provided information about the locations of seabird breeding colonies and roosting sites in the MHI (e.g., Hirai, 1978; USFWS, 1983; Day and Cooper, 1995; Reynolds and Ritchotte, 1997; Cooper and Day, 2003; Day et al., 2003; VanderWerf, 2003; Wood et al., 2003; Kozar et al., 2007; VanderWerf et al., 2007; Wood and Bily, 2008; Pepi et al., 2009; Anders et al., 2011; Fujimoto, 2011; Fujimoto and Juola, 2012; Welch et al., 2012; Wiley et al., 2013; VanderWerf and Young, 2014). Harrison (1990), USFWS (2005) and Pyle and Pyle (2009) provide overviews of terrestrial sites used by seabirds throughout the Hawaiian Islands. There is also at least one publicly available dataset on terrestrial sites and nearshore areas used by seabirds in the Hawaiian Islands (Environmental Sensitivity Index [ESI] database produced by NOAA National Ocean Service Office of Response and Restoration, <http://response.restoration.noaa.gov/maps-and-spatial-data/environmental-sensitivity-index-esi-maps.html>). We consulted all of these sources, as well as multiple local experts (A. Dikken-Young, T. Joyce, S. Judge, S. Plentovich, A. Raine, and E. VanderWerf), and developed a compilation of terrestrial site location data for seabirds in the MHI. It is important to note that this dataset is almost certainly incomplete, and the nature of what was considered an individual terrestrial site varied considerably (e.g., isolated occurrence of breeding, large breeding colony, roosting site), as did the precision of the location information. Nevertheless, the dataset provided a useful and reasonably comprehensive representation of terrestrial sites used by seabirds in the MHI that could be used as a predictor for at-sea distributions.

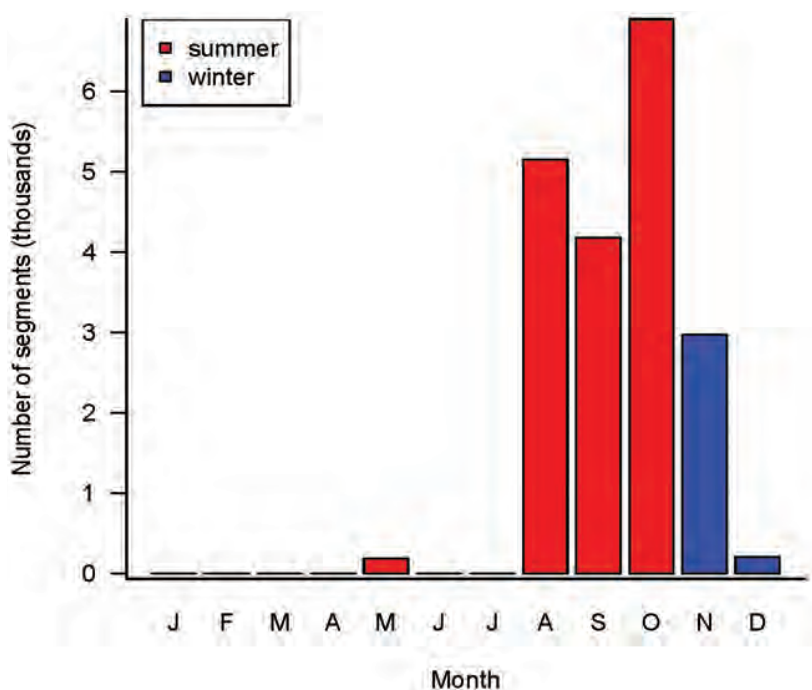


Figure 7.5. Number of survey transect segments by month. Data were collected by NOAA NMFS/SWFSC. Most segments were 1.2 km.

In addition to the sources that we consulted, at least two other terrestrial survey datasets exist for the MHI: eBird and the Audubon Christmas Bird Count (Table 7.2). These datasets are a result of citizen science. We did not incorporate those data in our terrestrial site compilation because they do not specifically identify terrestrial sites used by seabirds. Nevertheless, those datasets provide a supplementary source of information about terrestrial and nearshore areas in the MHI where seabirds have been observed.

Current estimates of the number of birds using each terrestrial site were not available for every species and site. As a result, we developed the distance-to-nearest-terrestrial-site predictor variables by treating every site equally. However, to the extent that locations of terrestrial sites influence at-sea distributions, it is likely that areas near terrestrial sites with larger numbers of birds will exhibit higher relative densities at sea. This effect was not captured by our distance-to-nearest-terrestrial-site predictor variables. Had the requisite data been available, it may have been more useful to weight proximity to terrestrial sites by the numbers of birds using each site.

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7.2.3. Spatial predictive modeling

For species with sufficient numbers of sightings in the at-sea survey dataset, we conducted spatial predictive modeling (Figure 1.5). For our Biogeographic Assessment, environmental predictor variables were characterized as summer (May-October) and winter (November-April) climatologies (Chapter 2), but the sighting data were from May and August-December. To maintain consistency between the environmental predictors and the sighting data, we limited the models to the summer time frame and used the sighting data from May and August-October, along with the summer environmental predictors. Fourteen species had sufficient numbers of sightings to model during these months (≥ 48 transect segments with sightings of ≥ 1 individual; Table 7.1). Nine of these species breed in the MHI and the remaining five species were non-breeding migratory visitors. It is important to recognize that the models apply to specific months of the year and may not be applicable to other months.

A Boosted Zero-inflated Count (BZIC) statistical modeling framework was used to relate the survey count data to a range of temporal and spatial environmental predictor variables (Appendix B). The estimated relationships between the counts of the modeled species and the predictor variables were then used to predict the relative density of these species across the entire study area. Relative density was defined as the expected number of individuals that would be counted per km² observed. It is important to recognize that the model predictions do not represent absolute density because during visual surveys, individual birds may be missed, and animal movement can bias estimates of density. Our model predictions should only be interpreted as indices of density.

7.2.4. Species that were not modeled

For breeding species with insufficient numbers of sightings in the at-sea survey dataset, we characterized their spatial distributions by mapping the locations of survey transect segments with sightings of ≥ 1 individual. Of these 11 species (Table 7.1), only Gray-backed Tern (*Onychoprion lunatus*) had no sightings in the at-sea survey dataset, which is perhaps not surprising given this species' limited breeding range and population size in the MHI.

To indicate potential foraging areas for breeding individuals of these non-modeled species on maps of the MHI, we reviewed the literature for estimates of the maximum foraging ranges of individuals of each species, and overlaid circular areas centered on the species' terrestrial sites with radii equal to these estimates (Soanes et al., 2016). This methodology was also applied to seabirds in a previous Biogeographic Assessment of the Northwestern Hawaiian Islands (Keller et al., 2009). Maximum foraging range estimates were available for eight of the 11 non-modeled breeding species (Table 7.1).



Gray-backed Tern, *Onychoprion lunatus*. Photo credit: Cascadia Research Collective.

There are several important caveats associated with these potential foraging areas. First, the foraging areas are only applicable to individuals that are coming and going from terrestrial sites (e.g., breeding individuals); they are not necessarily applicable to non-breeding individuals of breeding species (e.g., immatures). Second, the foraging range estimates reflect the maximum foraging ranges of individuals and do not necessarily reflect the average or typical foraging range. Third, there can be directional bias in foraging trips so that a circular area around terrestrial sites encapsulates much more area than the actual foraging area. The two albatross species are a good example of this directional bias, where individuals usually forage northward of the Hawaiian Islands (King, 1970; Kappes et al., 2010; Connors et al., 2015). In general, many seabirds (e.g., procellariids) make directed movements influenced by wind direction (Adams and Flora, 2010).

7.3. RESULTS AND DISCUSSION

7.3.1. Spatial distributions

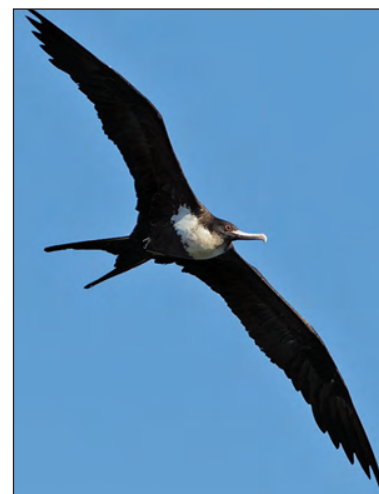
The spatial distributions of sightings varied across species (Figures 7.6-7.21). The majority of sightings for some species were relatively close to land, for example Black Noddy (*Anous minutus*), Brown Noddy (*Anous stolidus*) and Brown Booby (*Sula leucogaster*). The majority of sightings for some other species occurred in particular parts of the study area, for example most Juan Fernandez Petrel (*Pterodroma externa*) and Mottled Petrel (*Pterodroma inexpectata*) sightings were in the southeast. Sightings of other species were more evenly distributed throughout the study area, for example Great Frigatebird (*Fregata minor*), Sooty Tern (*Onychoprion fuscatus*) and Wedge-tailed Shearwater (*Puffinus pacificus*). It is important to note that the distributions of sightings partially reflect the amount and distribution of effort in each season. Differences in the distribution of sightings for a single species between seasons, or in the number of sightings between areas within a season, do not necessarily indicate differences in the distribution of relative abundance of that species.



Masked Booby, *Sula dactylatra*. Photo credit: David Pereksta (BOEM).

When available, potential maximum foraging areas for breeding species that were not modeled captured most, but not necessarily all, of the sightings (Figures 7.6-7.7). There were many Masked Booby (*Sula dactylatra*) sightings outside of the potential maximum foraging area suggesting that the estimated foraging range for this species may have been too small for the MHI. The estimated maximum foraging area for four species (Black-footed Albatross, Laysan Albatross [*Phoebastria immutabilis*], Great Frigatebird and Red-tailed Tropicbird [*Phaethon rubricauda*]) exceeded the study area.

Predicted spatial distributions for species that were modeled broadly aligned with the distributions of sightings (Figures 7.8-7.21). When most sightings were relatively close to land (e.g., Brown Booby), or when most sightings were in a particular part of the study area (e.g., Juan Fernandez Petrel), the pattern of predicted relative density matched. Predicted areas of high relative density for breeding species tended to be more centered near land than for non-breeding, migratory species. Some offshore areas of high predicted relative density for multiple species included west and southwest of the island of Hawai'i (Bulwer's Petrel [*Bulweria bulwerii*], Black-winged Petrel [*Pterodroma nigripennis*], Hawaiian Petrel, Juan Fernandez Petrel, Sooty Tern, and Wedge-tailed Shearwater), north of Kaua'i (Cook's Petrel [*Pterodroma cookii*], Hawaiian Petrel, Newell's Shearwater, Sooty Shearwater [*Puffinus griseus*], and White-tailed Tropicbird [*Phaethon lepturus*]), and the southwest corner of the study area (Black-winged Petrel, Red-footed Booby [*Sula sula*], Sooty Tern, and White-tailed Tropicbird).



Great Frigatebird, *Fregata minor*. Photo credit: David Pereksta (BOEM)

For modeled species, predictions of relative density are accompanied by estimates of the statistical uncertainty in those predictions, specifically the coefficient of variation (CV; Figures 7.8-7.21). CVs were highly variable across species and across the study area for individual species. In many cases, the CV of predictions was higher when predicted relative density was higher, but not always. Some of the predictions had very high CVs (>1), indicating substantial statistical uncertainty and variability associated with the corresponding predictions of relative density, so these predictions should be interpreted cautiously.

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Certain model predictions of high relative density are particularly questionable. In some cases, estimated relationships between relative density and environmental predictor variables may apply in certain areas, but extrapolations to other areas are questionable. For example, the Brown Booby model suggests high relative density near the Hawaiian and West Hawaiian seamounts, but there were few if any sightings in those areas. It is possible that these predictions are an artifact of a relatively nearshore distribution and a resulting estimated negative relationship between relative density and depth.

Other questionable predictions of high relative density may partially reflect large temporal and spatial aggregations of birds coinciding with survey effort rather than average spatial patterns per se. For example, Sooty Shearwaters migrate through the study area in large numbers during short periods of time (March-May and September-November). The predicted area of high relative density for this species north of Kaua'i corresponds to a large number of sightings on a single survey cruise. Similarly, the predicted area of high relative density of Black-winged Petrel southwest of the island of Hawai'i arose from a few transects on which a large number of sightings occurred. In the case of Cook's Petrel, the predicted area of high relative density in the northwest corner of the study area may have been driven by a limited number of transects combined with a less constrained model near the edge of the data extent. In general, predictions near the edges of the data extent should be interpreted more cautiously, as with most models. While our spatial predictive modeling framework theoretically accounts for effort and attempts to account for the aggregated nature of animal distributions and sightings, limited sample size combined with extreme aggregations can unduly influence model predictions.



Cook's Petrel, *Pterodroma cookii*.
Photo credit: David Pereksta (BOEM).

For some modeled species there were many sightings in areas where the predicted relative density was low; e.g., Black-winged Petrel and Wedge-tailed Shearwater. However, low relative density does not imply low absolute density. In other words, the minimum predicted relative density (Figures 7.8-7.21) may still correspond to a substantial number of birds and therefore a substantial number of sightings.

The potential foraging areas (unmodeled species) and predicted areas of high relative density (modeled species) identified in this assessment can help inform marine spatial planning around the MHI by indicating areas where human activities could affect relatively larger numbers of seabirds. That being said, there is also the potential to affect birds in other areas, particularly during months not covered by the data analyzed here. At a finer temporal scale, there are large short-term aggregations of birds that might not have been reflected in the survey data. For example, large numbers of birds staging nearshore prior to returning to breeding colonies each day may have been missed depending on the specific timing of surveys in those areas. Similarly, regular movements of large numbers of birds through specific areas could have been missed. Model predictions of relative density in particular will not necessarily reflect areas that are used by birds regularly but for only short periods of time (e.g., movement corridors).

Interpretation of our model predictions of relative density to inform spatial planning should be at the regional scale (i.e., 10-100 km). Large variations in model predictions of relative density at a finer spatial scale may not be realistic. Several models exhibited narrow strips or features of predicted high relative density; e.g., Brown Booby around the islands and Juan Fernandez Petrel and Sooty Tern west and southwest of the island of Hawai'i. Other times modeled patterns of relative density were patchy; e.g., Mottled Petrel in southeast part of study area. Such large variation in average long-term relative density at such fine spatial scales is likely unrealistic in many cases. These patterns in modeled relative density arose because of strong estimated correlations between counts and environmental predictor variables that exhibited fine scale variation (e.g., bathymetry) or patchiness (e.g., chlorophyll-*a*). Management applications should not assume that fine-scale variation in model predictions of relative density (i.e., 1-10 km) is realistic.

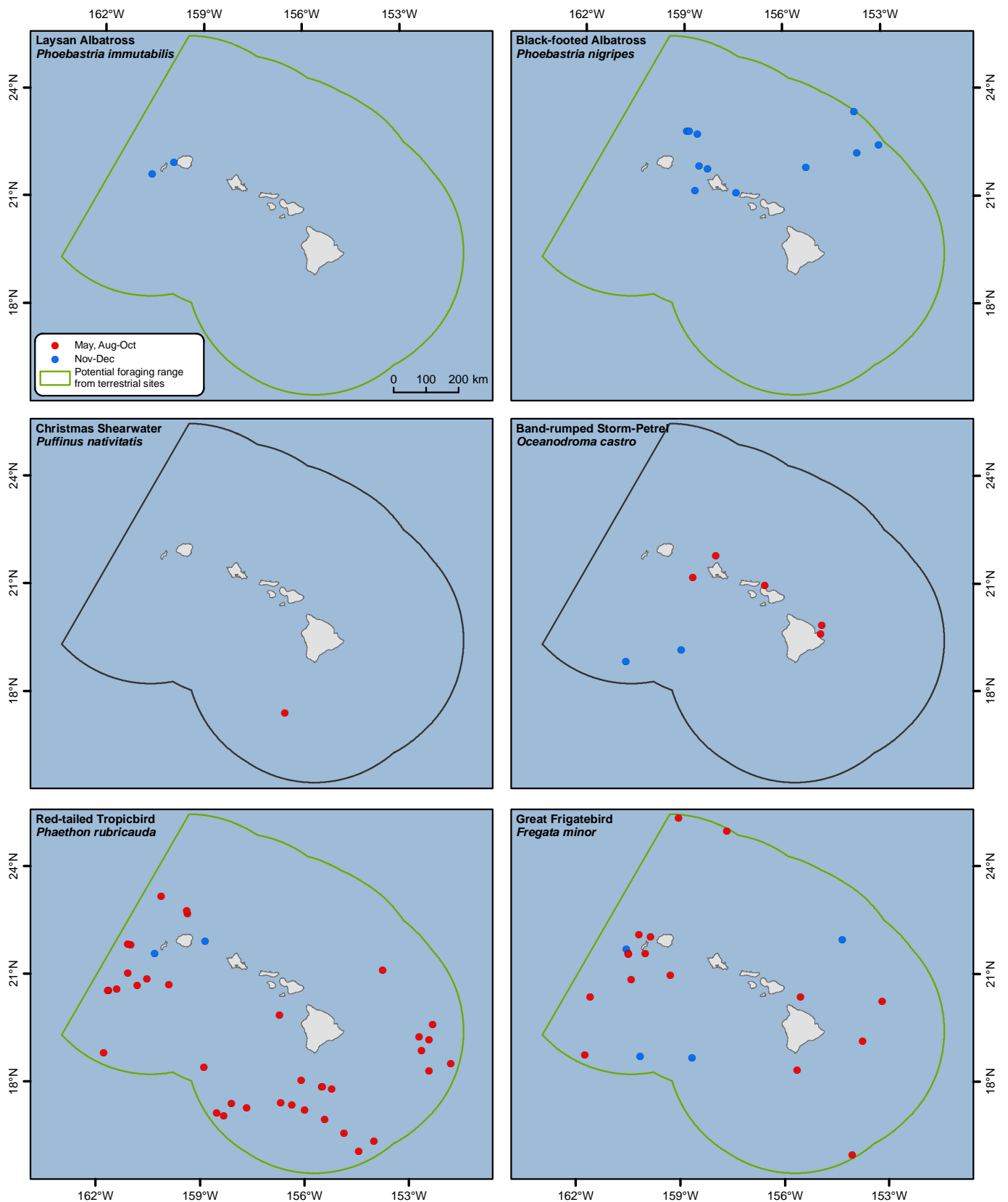


Figure 7.6. Locations of sightings of unmodeled seabird species. Survey data span 1989-2012 (most from 2002 and 2010) and were provided by NOAA NMFS/SWFSC. Survey effort was 16,377 transect segments during May and August-October (summer) and 3,168 during November-December (winter), and the distribution of survey effort differed between seasons (Figure 7.3), so seasonal differences in the number and distribution of sightings do not necessarily reflect differences in relative abundance. Potential foraging ranges only apply to breeding individuals. Foraging ranges were clipped to the study area, and are not displayed if foraging range estimates were not available.

Seabirds

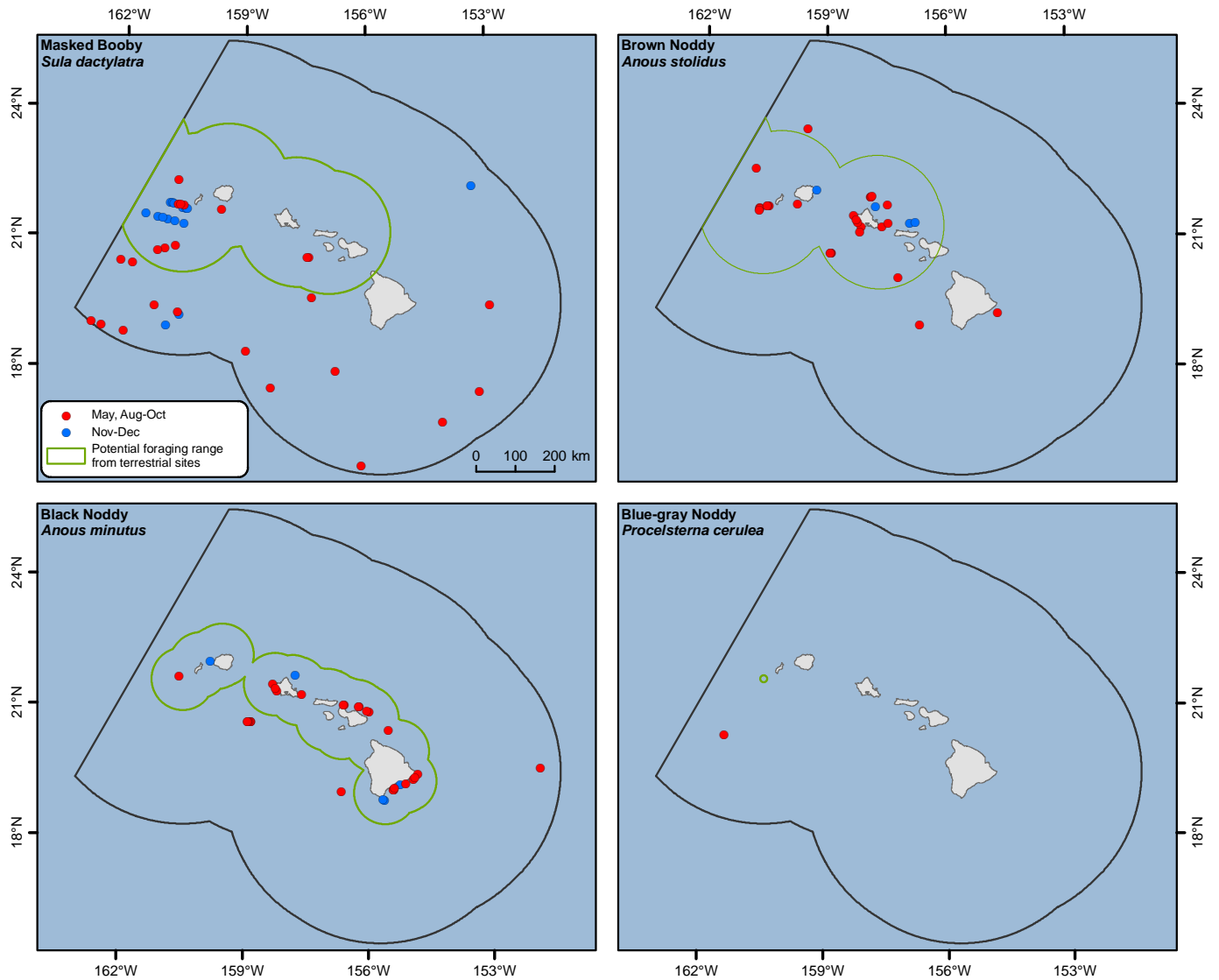


Figure 7.7. Locations of sightings of unmodeled seabird species. Survey data span 1989-2012 (most from 2002 and 2010) and were provided by NOAA NMFS/SWFSC. Survey effort was 16,377 transect segments during May and August-October (summer) and 3,168 during November-December (winter), and the distribution of survey effort differed between seasons (Figure 7.3), so seasonal differences in the number and distribution of sightings do not necessarily reflect differences in relative abundance. Potential foraging ranges only apply to breeding individuals. Foraging ranges were clipped to the study area, and are not displayed if foraging range estimates were not available.



Juan Fernandez Petrel, *Pterodroma externa*, and Red-tailed Tropicbird, *Phaethon rubricauda* (left and middle; Daniel Webster, Cascadia Research Collective) and Brown Booby, *Sula leucogaster* (right; David Pereksta, BOEM).

Mottled Petrel

Pterodroma inexpectata

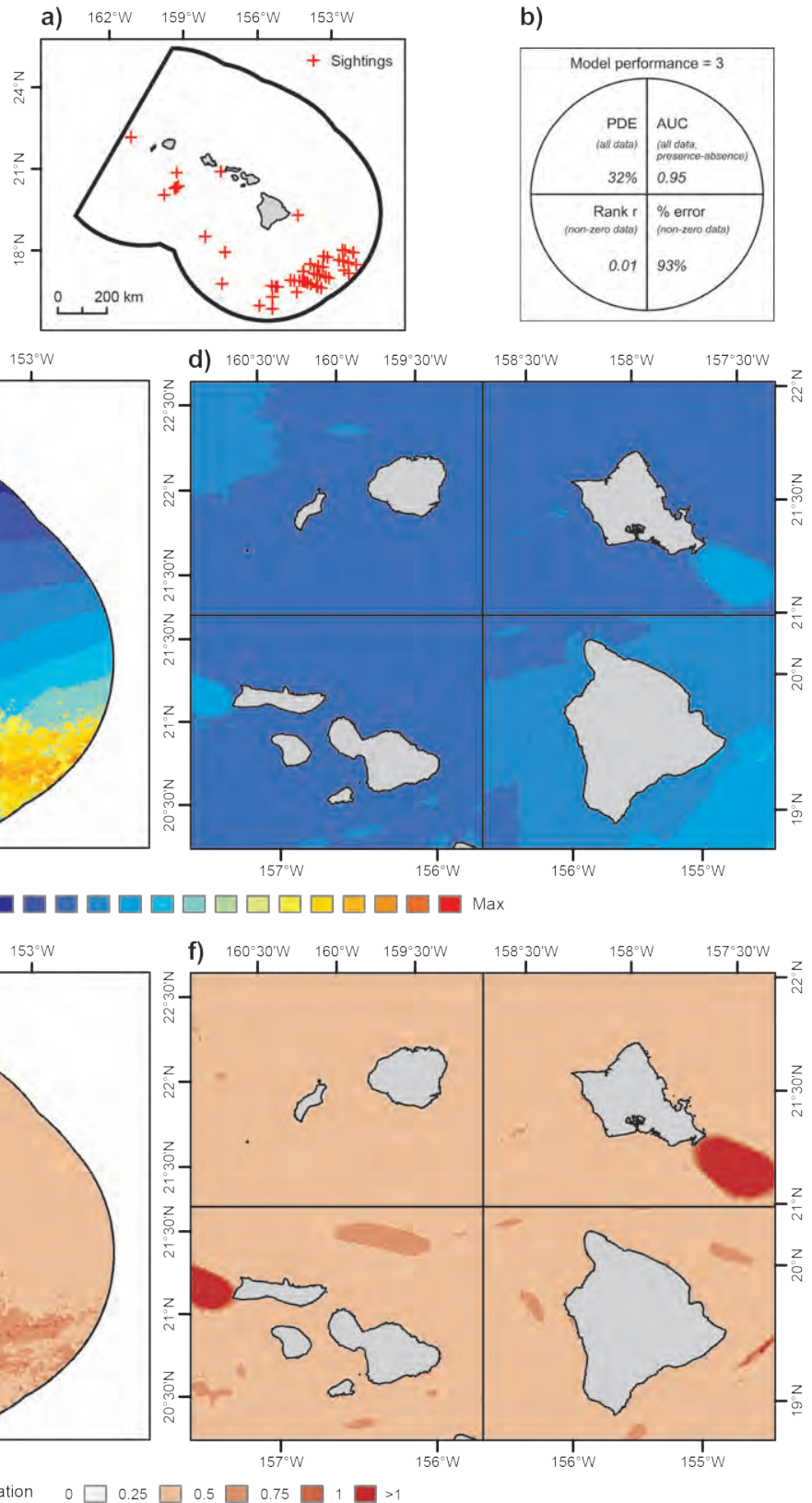


Figure 7.8. Modeled relative density of Mottled Petrel (*Pterodroma inexpectata*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 55 of which this species was sighted for a total of 56 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c,d) median bootstrapped estimates of relative density; and e,f) bootstrapped coefficients of variation. Photo credit: Daniel Webster (Cascadia Research Collective)

Seabirds

Juan Fernandez Petrel

Pterodroma externa

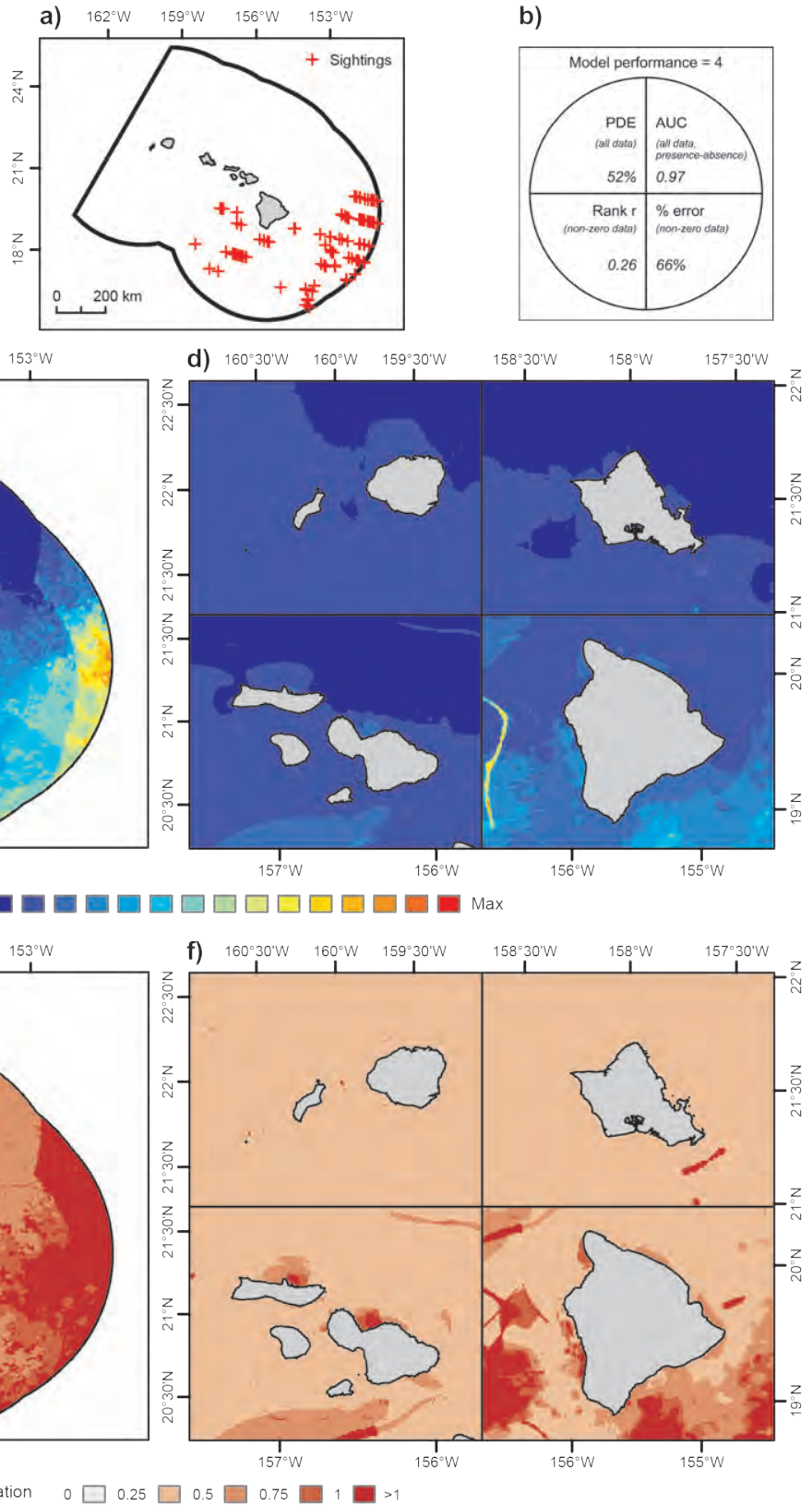
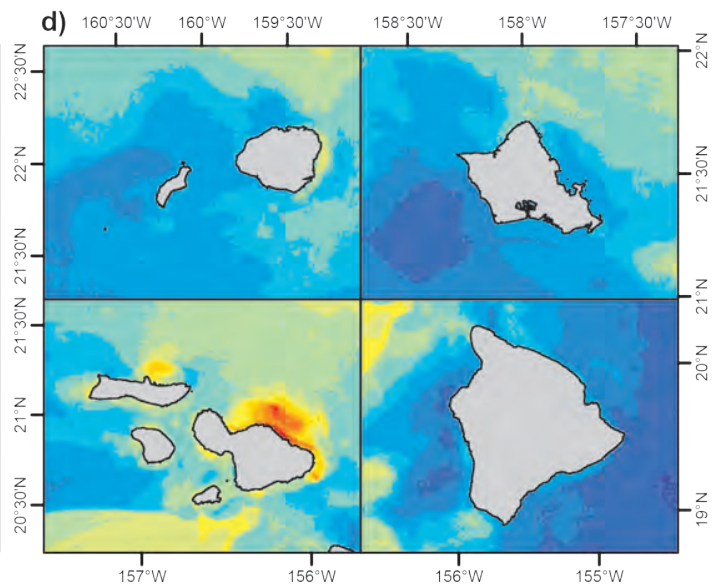
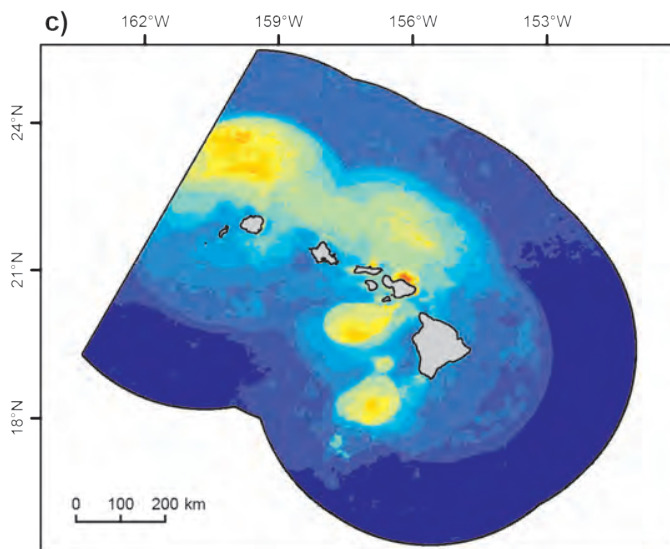
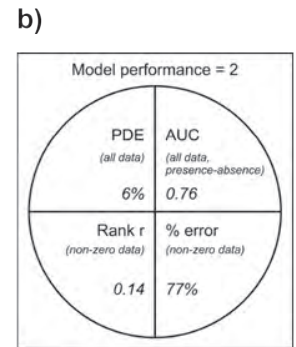
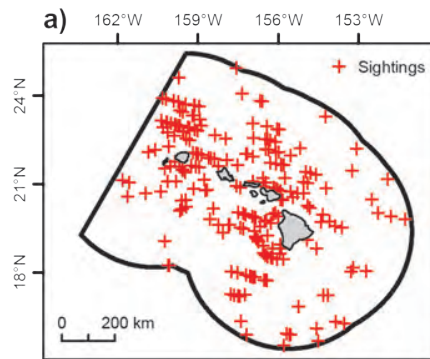
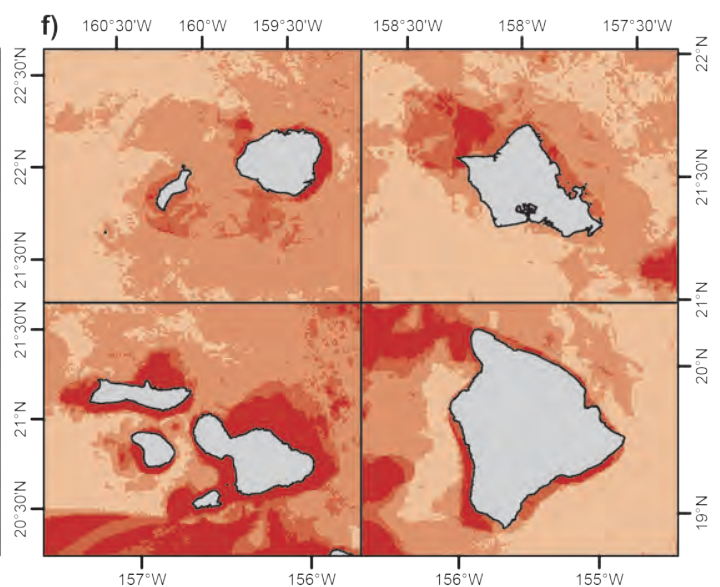
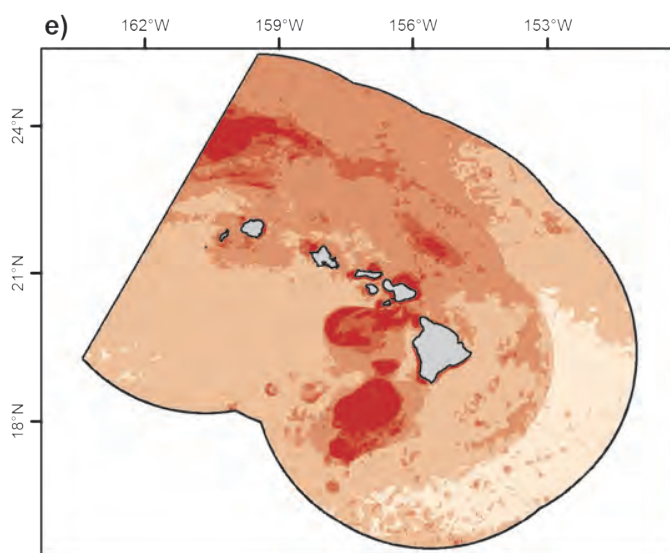


Figure 7.9. Modeled relative density of Juan Fernandez Petrel (*Pterodroma externa*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 108 of which this species was sighted for a total of 157 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c, d) median bootstrapped estimates of relative density; and e, f) bootstrapped coefficients of variation. Photo credit: Daniel Webster (Cascadia Research Collective)

Hawaiian Petrel *Pterodroma sandwichensis*



Relative density Min Max



Coefficient of variation 0 >1

Figure 7.10. Modeled relative density of Hawaiian Petrel (*Pterodroma sandwichensis*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 230 of which this species was sighted for a total of 292 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c,d) median bootstrapped estimates of relative density; and e,f) bootstrapped coefficients of variation. Photo credit: Daniel Webster (Cascadia Research Collective)

Seabirds

Black-winged Petrel

Pterodroma nigripennis

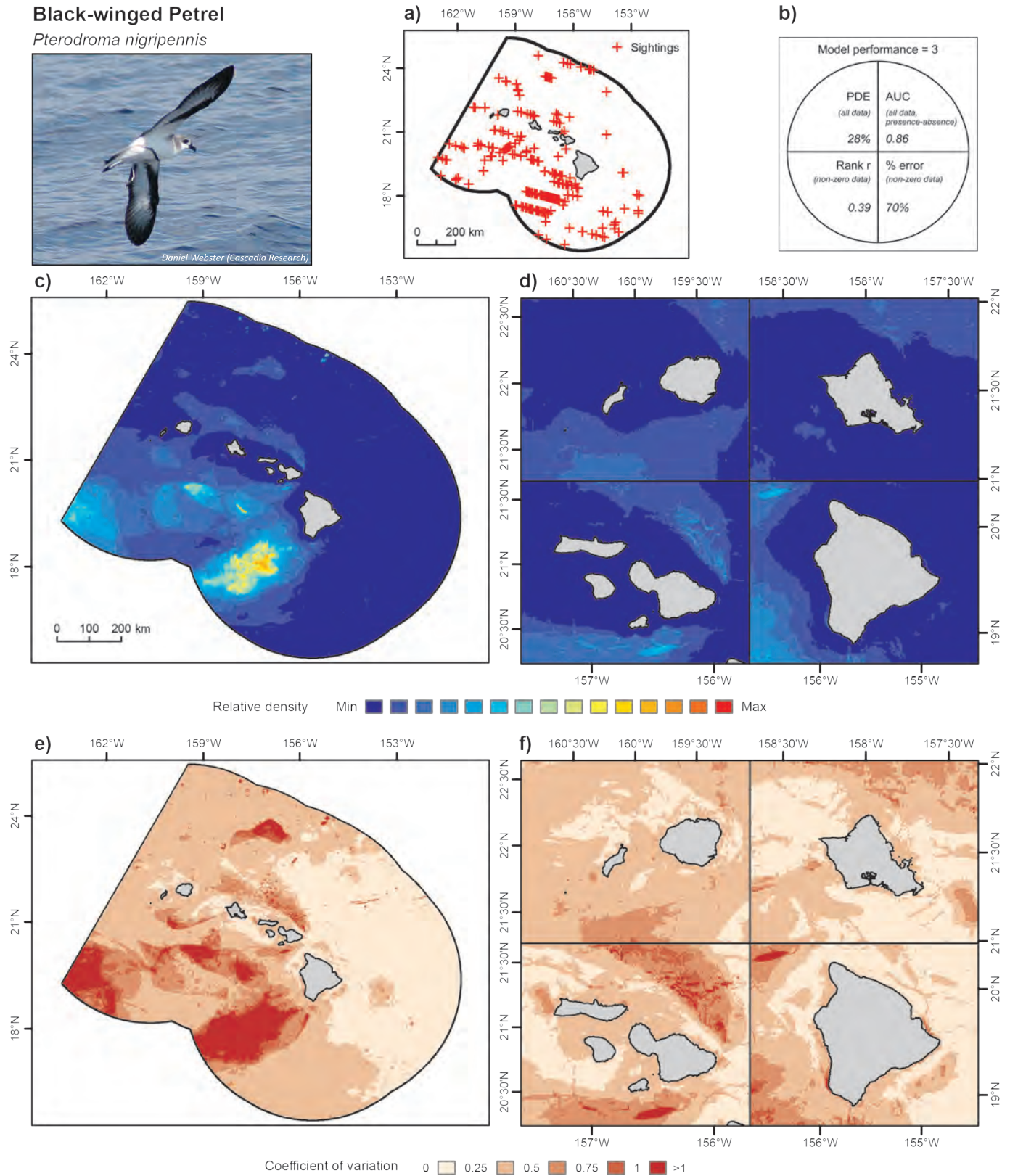


Figure 7.11. Modeled relative density of Black-winged Petrel (*Pterodroma nigripennis*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 243 of which this species was sighted for a total of 337 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c, d) median bootstrapped estimates of relative density; and e, f) bootstrapped coefficients of variation. Photo credit: Daniel Webster (Cascadia Research Collective)

Cook's Petrel

Pterodroma cookii

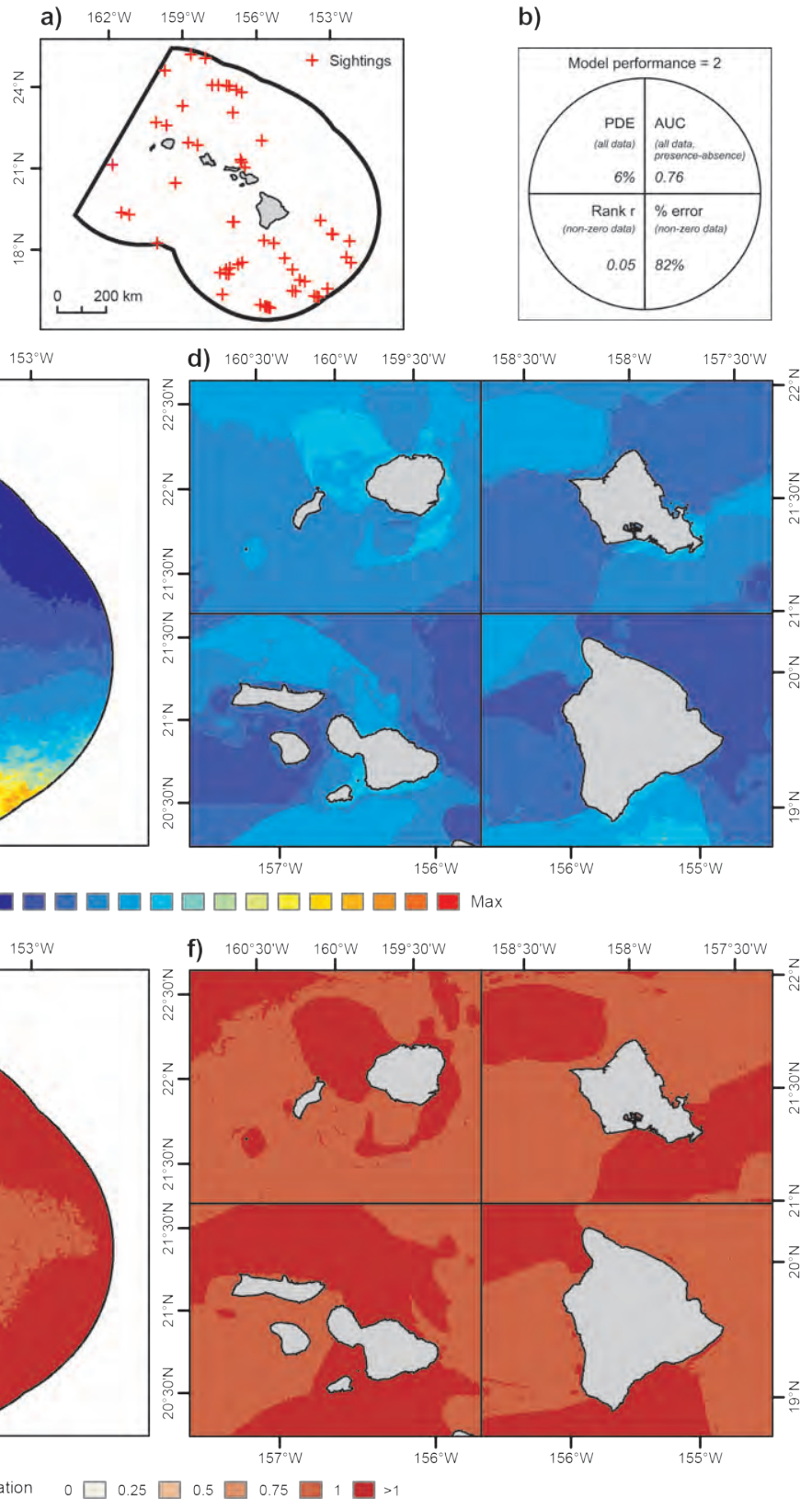
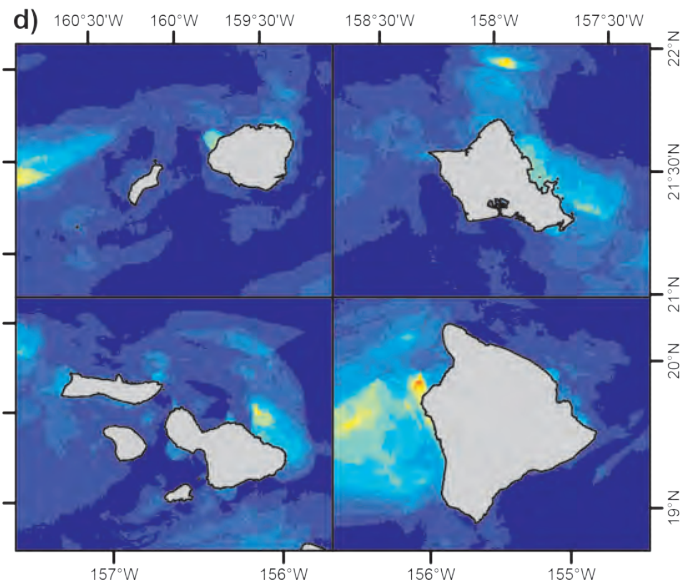
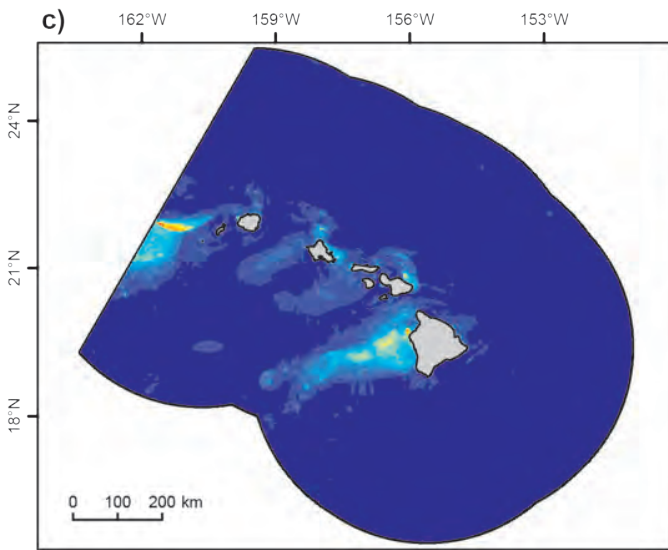
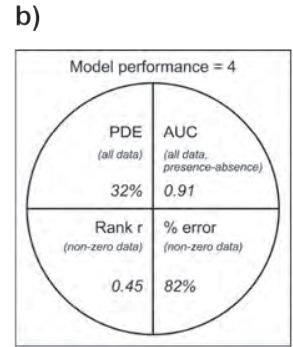
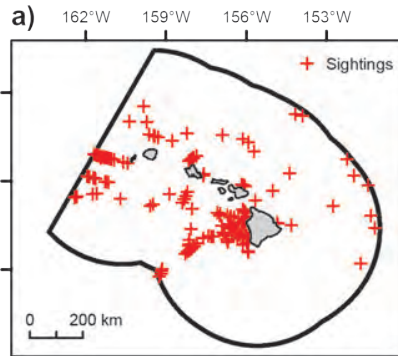


Figure 7.12. Modeled relative density of Cook's Petrel (*Pterodroma cookii*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 62 of which this species was sighted for a total of 75 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c,d) median bootstrapped estimates of relative density; and e,f) bootstrapped coefficients of variation. Photo credit: David Pereksta (BOEM)

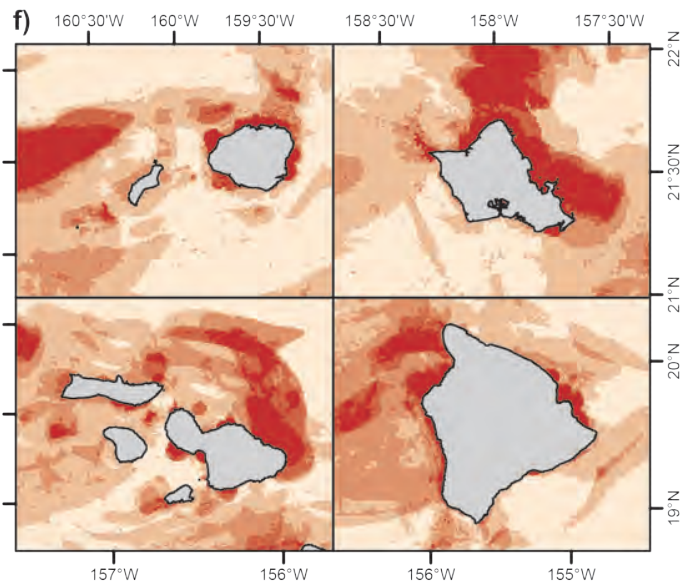
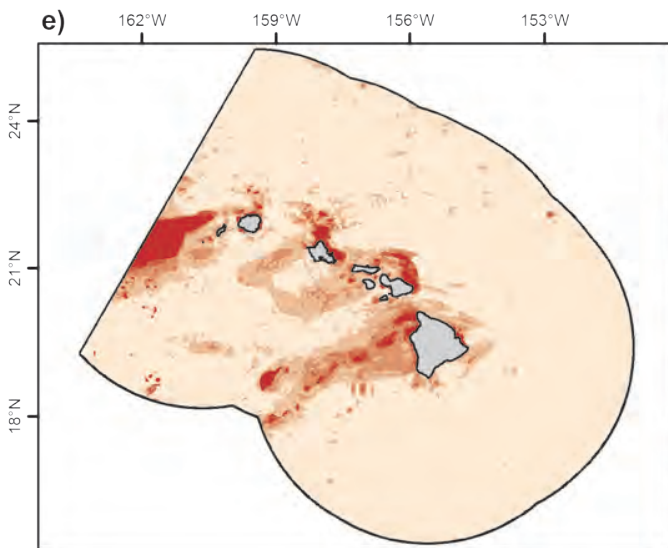
Seabirds

Bulwer's Petrel

Bulweria bulwerii



Relative density Min Max



Coefficient of variation 0 0.25 0.5 0.75 1 >1

Figure 7.13. Modeled relative density of Bulwer's Petrel (*Bulweria bulwerii*). Predictive modelling was applied to at-sea sightings data spanning 1989–2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August–October with some additional data from May. A total of 16,377 transect segments were analyzed, on 194 of which this species was sighted for a total of 230 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c, d) median bootstrapped estimates of relative density; and e, f) bootstrapped coefficients of variation. Photo credit: Daniel Webster (Cascadia Research Collective)

Wedge-tailed Shearwater

Puffinus pacificus

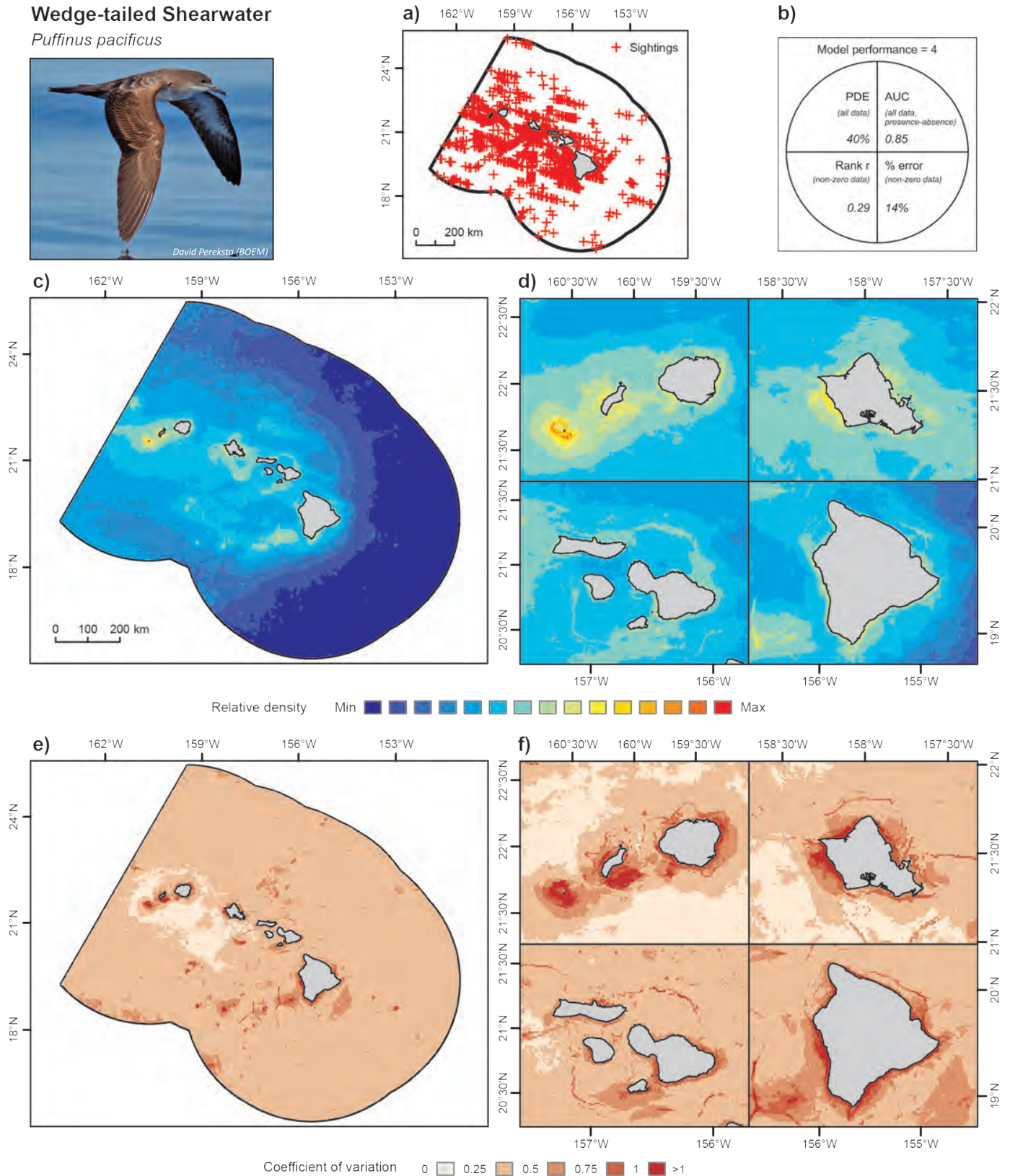


Figure 7.14. Modeled relative density of Wedge-tailed Shearwater (*Puffinus pacificus*). Predictive modelling was applied to at-sea sightings data spanning 1989–2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August–October with some additional data from May. A total of 16,377 transect segments were analyzed, on 1375 of which this species was sighted for a total of 6442 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c,d) median bootstrapped estimates of relative density; and e,f) bootstrapped coefficients of variation. Photo credit: David Pereksta (BOEM)

Seabirds

Sooty Shearwater

Puffinus griseus

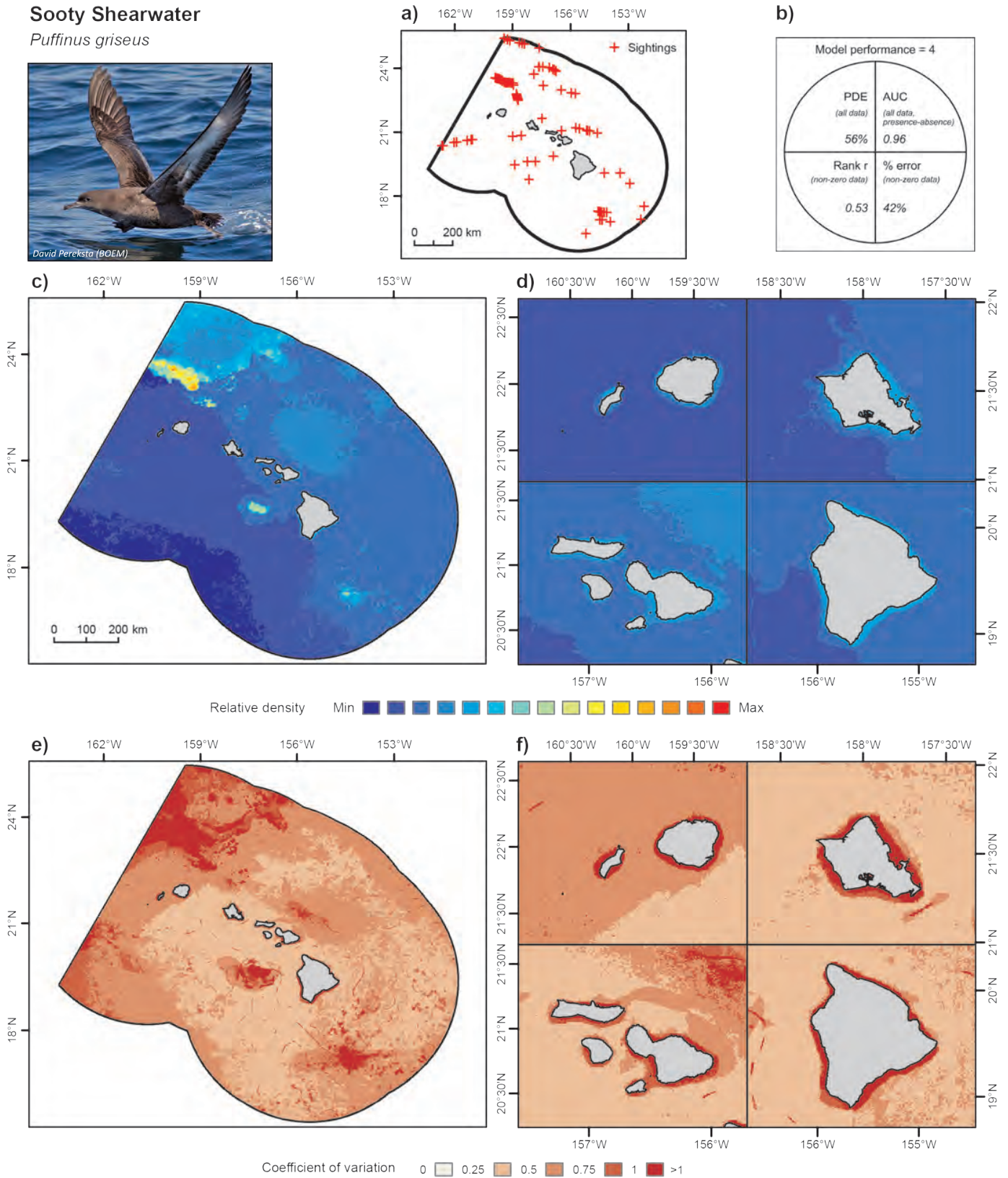


Figure 7.15. Modeled relative density of Sooty Shearwater (*Puffinus griseus*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 115 of which this species was sighted for a total of 268 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c,d) median bootstrapped estimates of relative density; and e,f) bootstrapped coefficients of variation. Photo credit: David Pereksta (BOEM)

Newell's Shearwater

Puffinus newelli

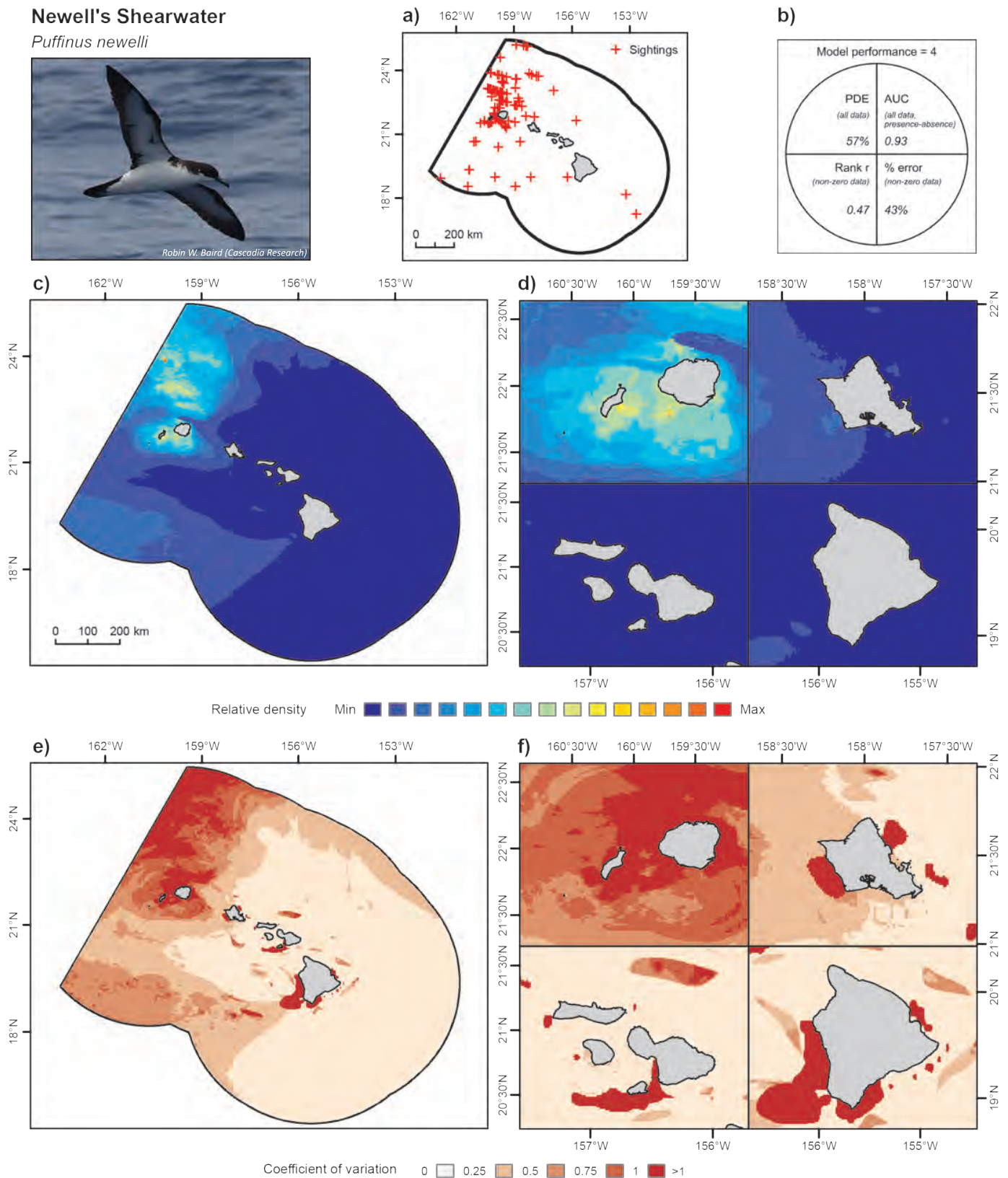


Figure 7.16. Modeled relative density of Newell's Shearwater (*Puffinus newelli*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 105 of which this species was sighted for a total of 235 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c,d) median bootstrapped estimates of relative density; and e,f) bootstrapped coefficients of variation. Photo credit: Robin W. Baird (Cascadia Research Collective)

Seabirds

White-tailed Tropicbird

Phaethon lepturus

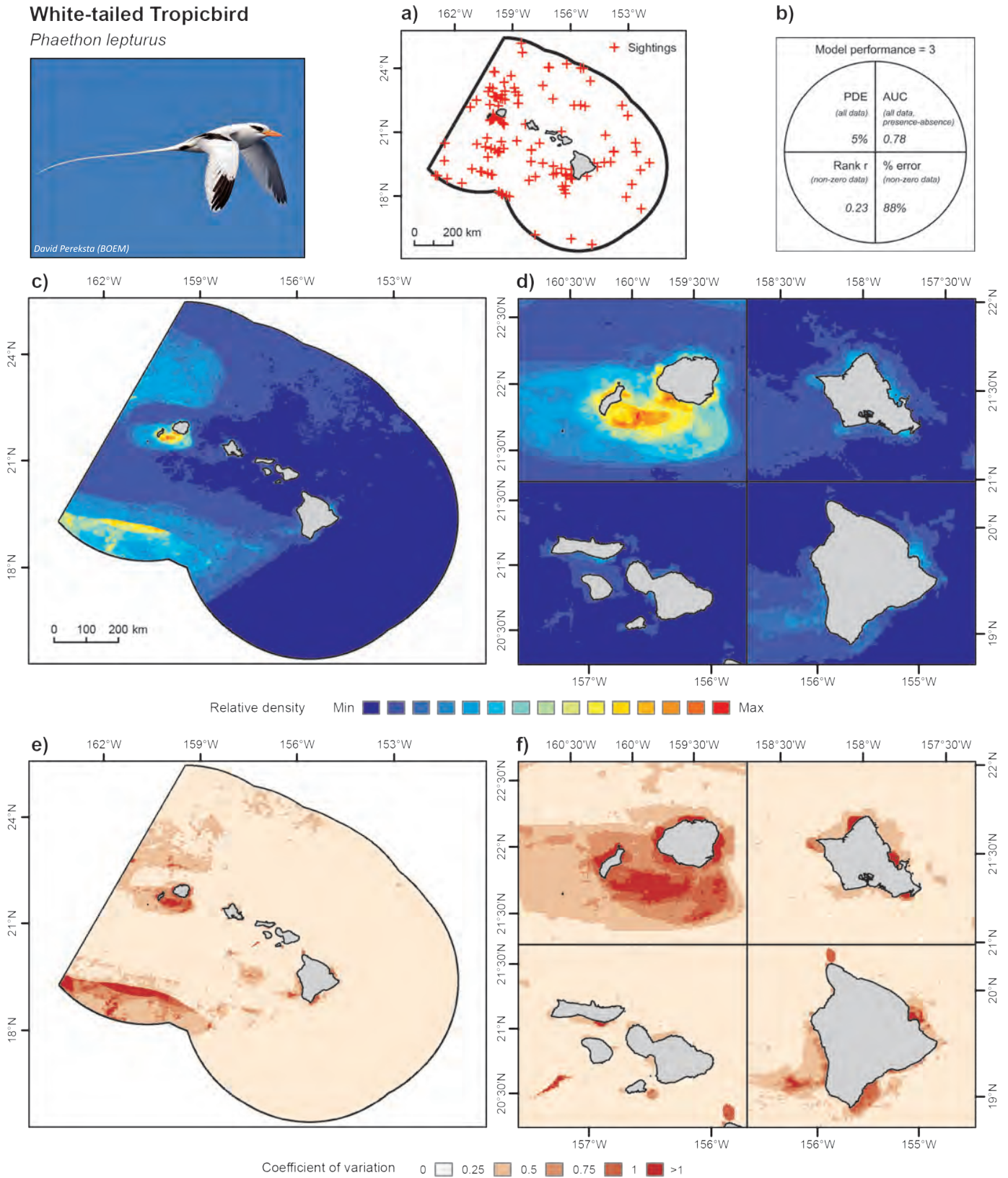


Figure 7.17. Modeled relative density of White-tailed Tropicbird (*Phaethon lepturus*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 128 of which this species was sighted for a total of 144 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c,d) median bootstrapped estimates of relative density; and e,f) bootstrapped coefficients of variation. Photo credit: David Pereksta (BOEM)

Brown Booby *Sula leucogaster*

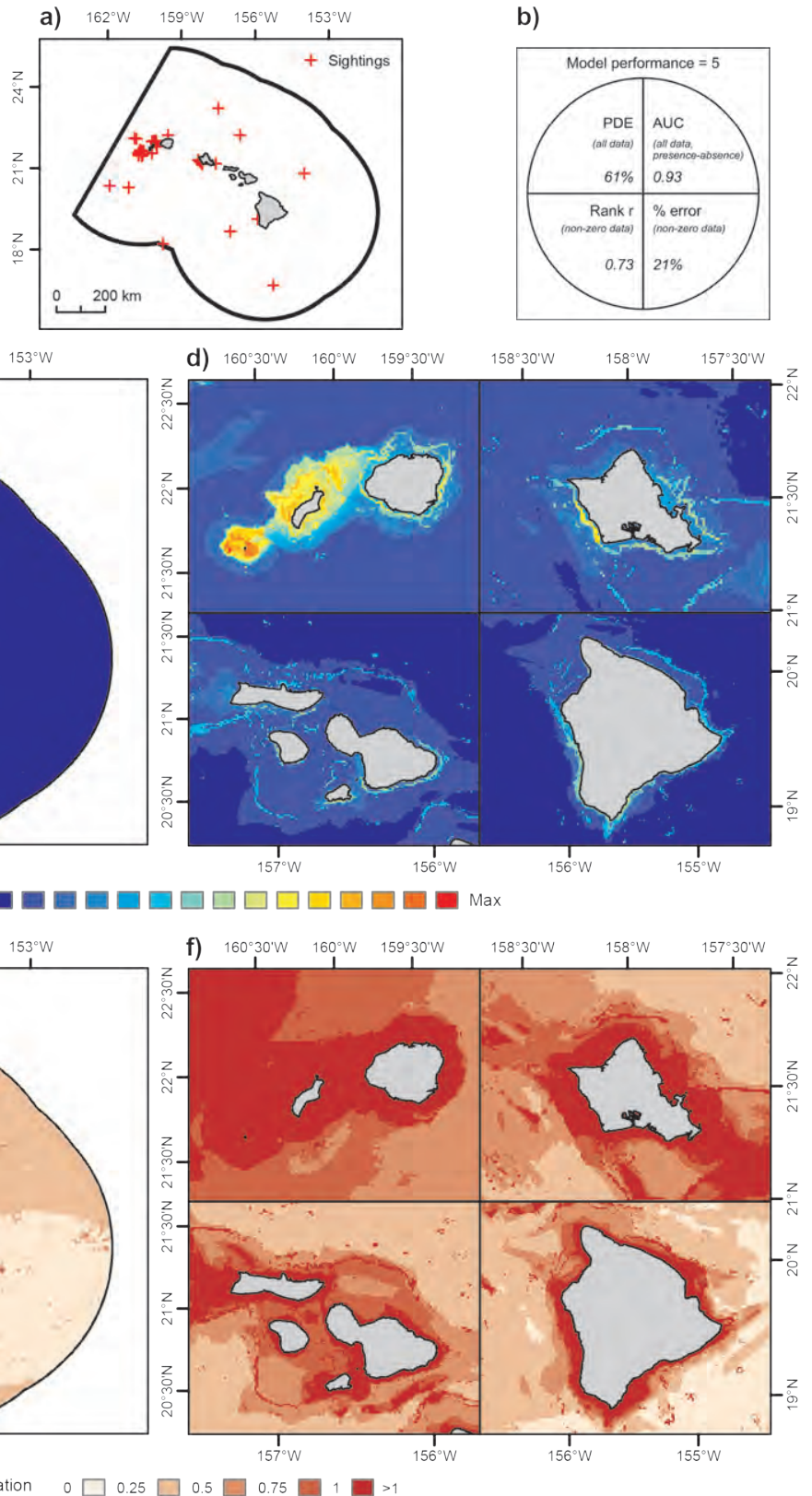
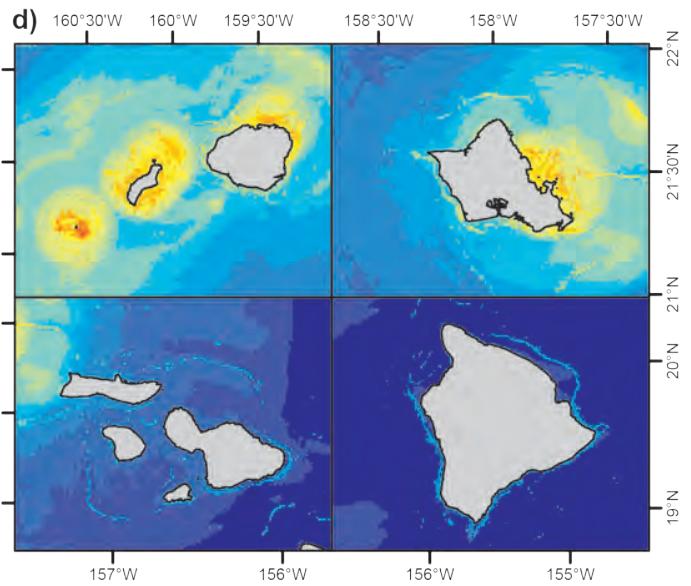
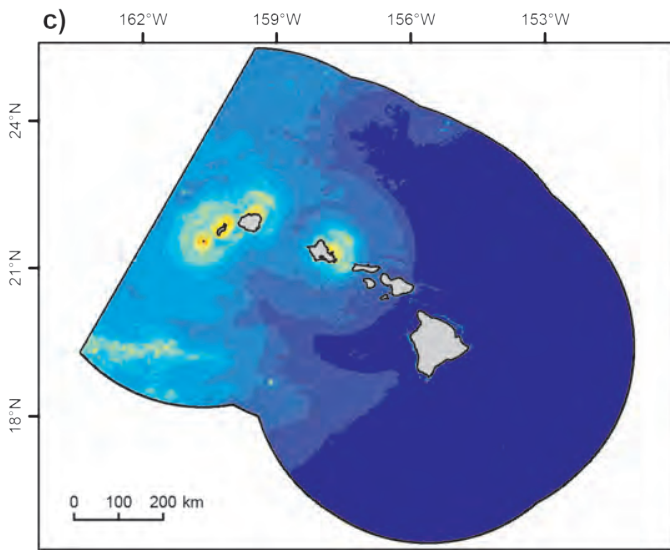
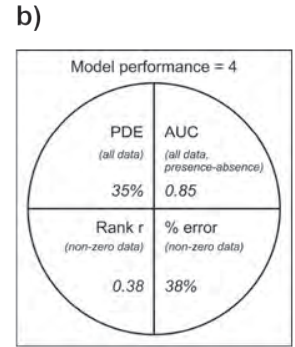
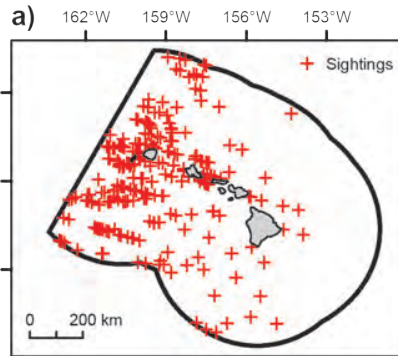


Figure 7.18. Modeled relative density of Brown Booby (*Sula leucogaster*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 48 of which this species was sighted for a total of 232 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c,d) median bootstrapped estimates of relative density; and e,f) bootstrapped coefficients of variation. Photo credit: David Pereksta (BOEM)

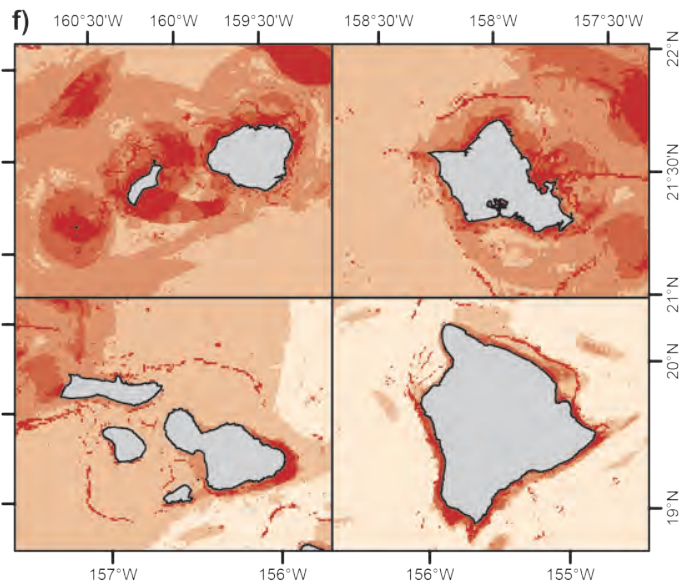
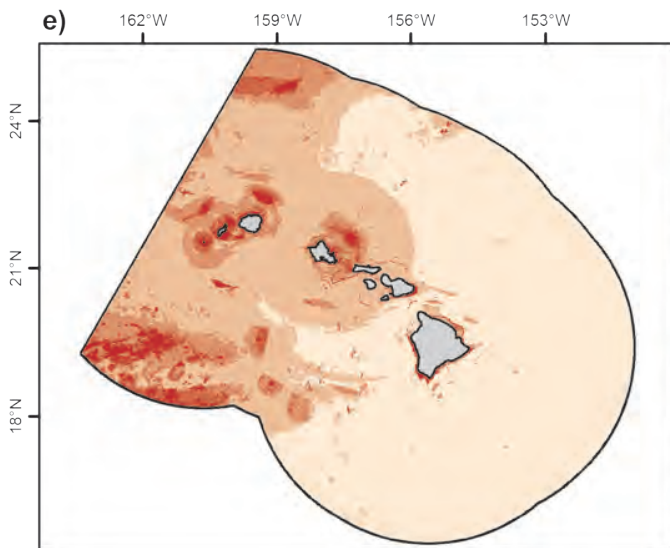
Seabirds

Red-footed Booby

Sula sula



Relative density Min Max



Coefficient of variation 0 >1

Figure 7.19. Modeled relative density of Red-footed Booby (*Sula sula*). Predictive modelling was applied to at-sea sightings data spanning 1989–2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August–October with some additional data from May. A total of 16,377 transect segments were analyzed, on 271 of which this species was sighted for a total of 669 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c, d) median bootstrapped estimates of relative density; and e, f) bootstrapped coefficients of variation. Photo credit: David Pereksta (BOEM)

White Tern

Gygis alba

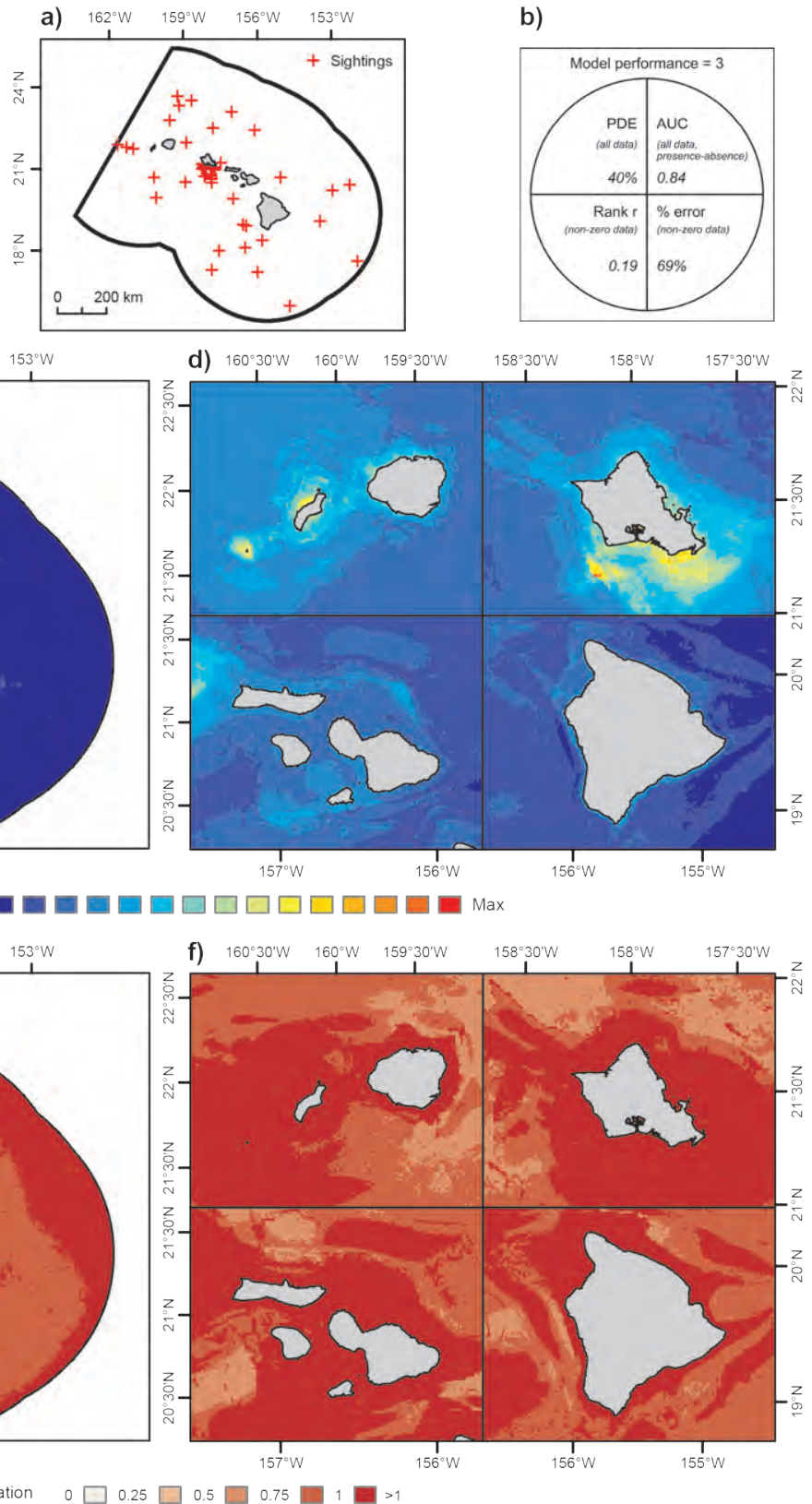


Figure 7.20. Modeled relative density of White Tern (*Gygis alba*). Predictive modelling was applied to at-sea sightings data spanning 1989-2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August-October with some additional data from May. A total of 16,377 transect segments were analyzed, on 60 of which this species was sighted for a total of 86 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c, d) median bootstrapped estimates of relative density; and e, f) bootstrapped coefficients of variation. Photo credit: David Pereksta (BOEM)

Seabirds

Sooty Tern

Onychoprion fuscatus

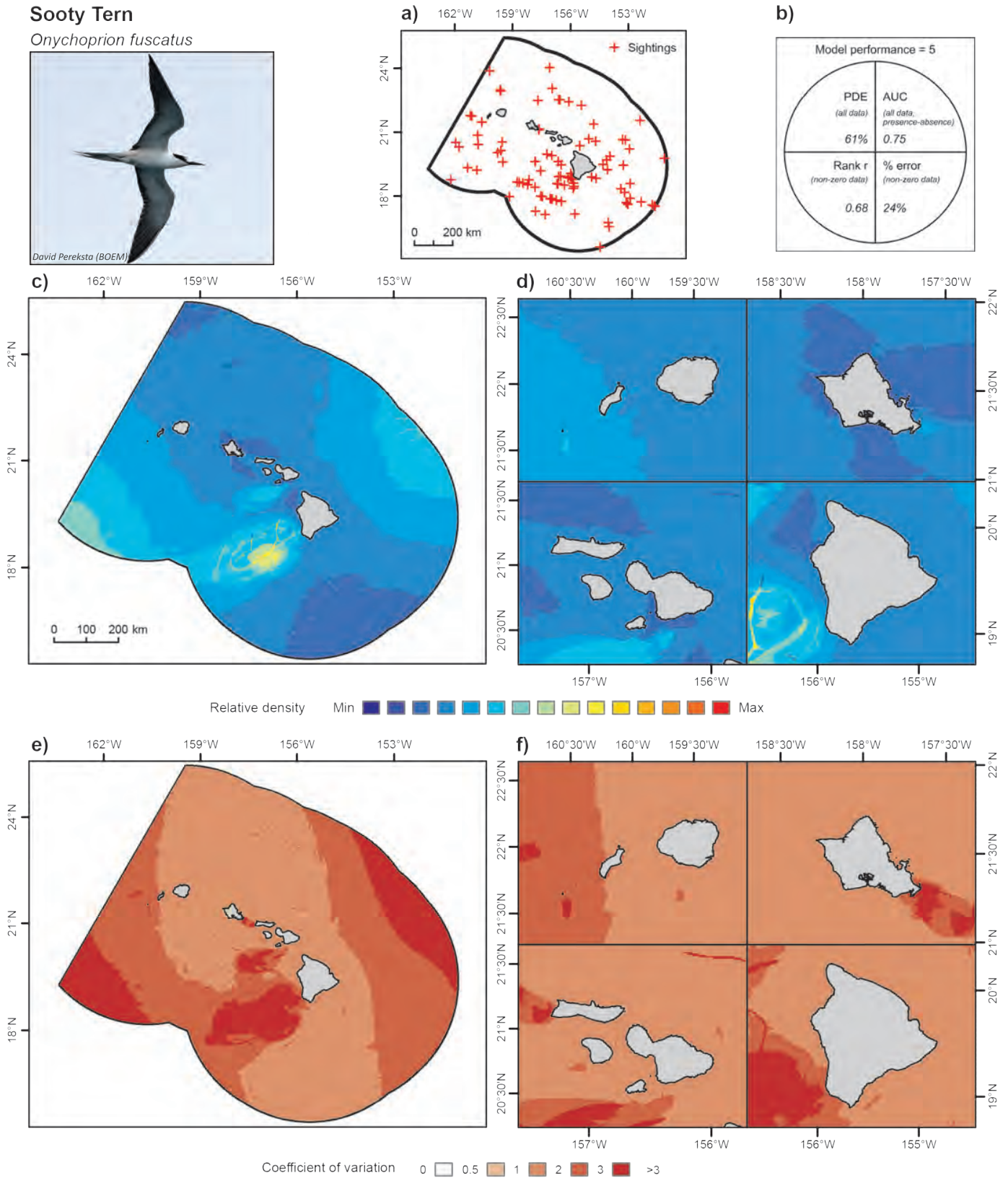


Figure 7.21. Modeled relative density of Sooty Tern (*Onychoprion fuscatus*). Predictive modelling was applied to at-sea sightings data spanning 1989–2012 (most data from 2002 and 2010) provided by NOAA NMFS/SWFSC. Modeled data were mainly from August–October with some additional data from May. A total of 16,377 transect segments were analyzed, on 94 of which this species was sighted for a total of 734 individuals sighted. Figure panels are: a) locations of sightings; b) model quality as a function of four performance metrics (Table B.4); c,d) median bootstrapped estimates of relative density; and e,f) bootstrapped coefficients of variation. Photo credit: David Pereksta (BOEM)

7.3.2. Model statistical performance

Of the eight candidate models for each of the 14 species (Appendix B), no one model was consistently selected as the best model. Over half of the selected final models converged well before the allowed maximum number of boosting iterations, but four models reached near the maximum number of iterations before converging.

Final model statistical performance was highly variable across species and performance metrics. Percent deviance explained (PDE) ranged from 5-61 percent. The Brown Booby and Sooty Tern models had the highest PDE (60-61%), indicating that those models explained substantially more of the variation in the survey count data than did a simpler model with no predictor variables. The models for Cook's Petrel, Hawaiian Petrel and White-tailed Tropicbird had the lowest PDE (5-6%). Area under the receiver operating characteristic curve (AUC) ranged from 0.75-0.97, indicating that all models predicted presence/absence better than random. The models for Juan Fernandez Petrel, Mottled Petrel and Sooty Shearwater had the highest AUC (0.95-0.97), while the models for Cook's Petrel, Hawaiian Petrel, Sooty Tern and White-tailed Tropicbird had AUC between 0.7 and 0.8. The Gaussian rank correlation coefficient (r) ranged from 0.01-0.73. The models for Brown Booby and Sooty Tern had r between 0.68 and 0.73, indicating that the observed and predicted non-zero counts of these species were fairly correlated. The models for Cook's Petrel, Hawaiian Petrel and White Tern (*Gygis alba*) had $r < 0.2$, and the model for Mottled Petrel had the lowest r . Percent error ranged from 0.14-0.93, indicating that the median absolute difference between predicted and observed non-zero counts ranged from 14-93 percent of the average non-zero count. Brown Booby, Sooty Tern and Wedge-tailed Shearwater had the lowest percent error (0.14-0.24), while Mottled Petrel and White-tailed Tropicbird had the highest percent error (0.88-0.93).



Sooty Tern, *Onychoprion fuscatus*. Photo credit: Daniel Webster (Cascadia Research Collective)



White Tern, *Gygis alba*. Photo credit: David Pereksta (BOEM)

Considering all four performance metrics, the final models for Brown Booby and Sooty Tern had the best overall performance (Class 5), while the models for Hawaiian Petrel and Cook's Petrel had the worst performance (Class 2). The performance of all other models was intermediate (Classes 3 and 4).

It is important to recognize that the model performance metrics and badge mainly reflect *the statistical fit of the models to the data*. They reflect only the data that were analyzed, and they do not reflect the quality of model predictions away from the data. For example, the survey data were primarily from two years and three months. The performance metrics do not necessarily indicate how accurate the model predictions may be for other years and months. Similarly, survey data did not cover everywhere within the study area, so some model predictions are essentially interpolations/extrapolations from data in other parts of the study area. The accuracy of those predictions is not necessarily reflected by the model performance metrics. Data from additional years, months, and areas would be required to fully evaluate the accuracy of model predictions outside of the observed data coverage. Nevertheless, the performance metrics and overall performance class give a relative indication of how accurately a model was able to predict the observed data, and better performance provides a measure of confidence in the model predictions, especially within the temporal and spatial coverage of the observed survey data.

Seabirds

7.3.3. Potentially important ecological predictors for modeled species

Our spatial predictive modeling framework was designed to provide the best estimates of at-sea distributions. It was not designed to determine which environmental predictors were most ecologically relevant in determining the distributions of birds, nor was it designed to determine the functional relationships between environmental predictors and the distributions of birds. Correlations between at-sea distributions and environmental variables do not necessarily indicate direct or even indirect connections between behavior and those variables. For example, Sooty Shearwaters pass through the study area during their trans-equatorial migrations (Shaffer et al., 2006), and the degree to which their distribution in waters surrounding the MHI reflects local environmental conditions may be small. Ecological inference from our model results should be cautious. Nevertheless, our correlative results may suggest interesting hypotheses for future research.

Some of the most important predictor variables across modeled species and model components were day of the year, distance to shore/nearest terrestrial site, depth, sea surface height, and projected longitude/latitude (Figures 7.22-7.23). Day of the year effects accounted for changes in the overall number of individuals of a given species in the study area during the modeled time frame. The effect was especially important for many of the non-breeding migratory species (Black-winged Petrel, Cook's Petrel, Mottled Petrel and Sooty Shearwater), some of whom pass through the study area during relatively short periods of time (Mottled Petrel and Sooty Shearwater). Distance to the nearest terrestrial site was frequently an important variable for breeding species (e.g., Hawaiian Petrel, Newell's Shearwater, Red-footed Booby, White Tern and Wedge-tailed Shearwater), with predicted relative density generally decreasing with increasing distance from terrestrial sites. Depth was also an important variable in the models for a few species (Brown Booby, White Tern and Wedge-tailed Shearwater), with predicted relative density generally decreasing with increasing depth. Given the high correlation between depth and distance to land it is difficult to say how important of a driving factor depth is. Sea surface height was a relatively important predictor in the models for several species, especially Newell's Shearwater, Red-footed Booby and White-tailed Tropicbird, with predicted relative density generally increasing with sea surface height. This relationship is most evident in the southwest part of the study area where sea surface height was high and the predicted density of these species was also relatively high. The relative importance of projected longitude/latitude in many of the models indicated that there was additional spatial variability in the distributions of these species that was not explained by the other environmental predictor variables.



Hawaiian Petrel, *Pterodroma sandwichensis*. Photo credit: Daniel Webster (Cascadia Research Collective)



Sooty Shearwater, *Puffinus griseus*. Photo credit: David Pereksta (BOEM)

Some other environmental predictor variables that were important in some models were sea surface temperature (SST), standard deviation (SD), surface chlorophyll-*a* concentration, and the probability of an anticyclonic eddy ring (Figures 7.22-7.23). SST SD was important in the models for Hawaiian Petrel, Newell's Shearwater and Sooty Shearwater with predicted relative density generally increasing with increasing SST SD.

The predicted spatial distributions of these species reflected this relationship with higher relative density in areas where SST was more variable, like the northwest part of the study area (Newell's Shearwater and Sooty Shearwater) and west of the island of Hawai'i/south of Maui Nui (Hawaiian Petrel). Surface chlorophyll-*a* was an important predictor in the Juan Fernandez Petrel and Mottled Petrel models, with predicted relative density decreasing with increasing chlorophyll-*a*. This apparent negative correlation may be more a result of geographic correspondence than a negative relationship between chlorophyll-*a* and the relative density of these species per se. Chlorophyll-*a* tended to increase from south to north within the study area, while the predicted relative density of these species tended to decrease from south to north. Probability of an anticyclonic eddy ring was an important predictor variable in the Sooty Tern model, and was somewhat important in the models for other species (e.g., Black-winged Petrel, Juan Fernandez Petrel and Wedge-tailed Shearwater). Predicted relative density of these species generally increased with increasing probability of an anticyclonic eddy ring. These species had areas of relatively high predicted density overlapping with the area of frequent anticyclonic eddy activity extending southwest from the island of Hawai'i.

Other predictor variables were relatively less important across models (Figures 7.22-7.23). Climate index variables were not very important predictors for any modeled species. Chlorophyll-*a* and SST front strength and probability also did not stand out as especially important predictors. Chlorophyll-*a* front strength in the Wedge-tailed Shearwater model, and SST front strength in the Bulwer's Petrel model, were two of the largest effects, relatively speaking. In both cases, predicted relative density increased with increasing front strength.



Brown Booby, Sula leucogaster. Photo credit: Daniel Webster (Cascadia Research Collective)

Seabirds

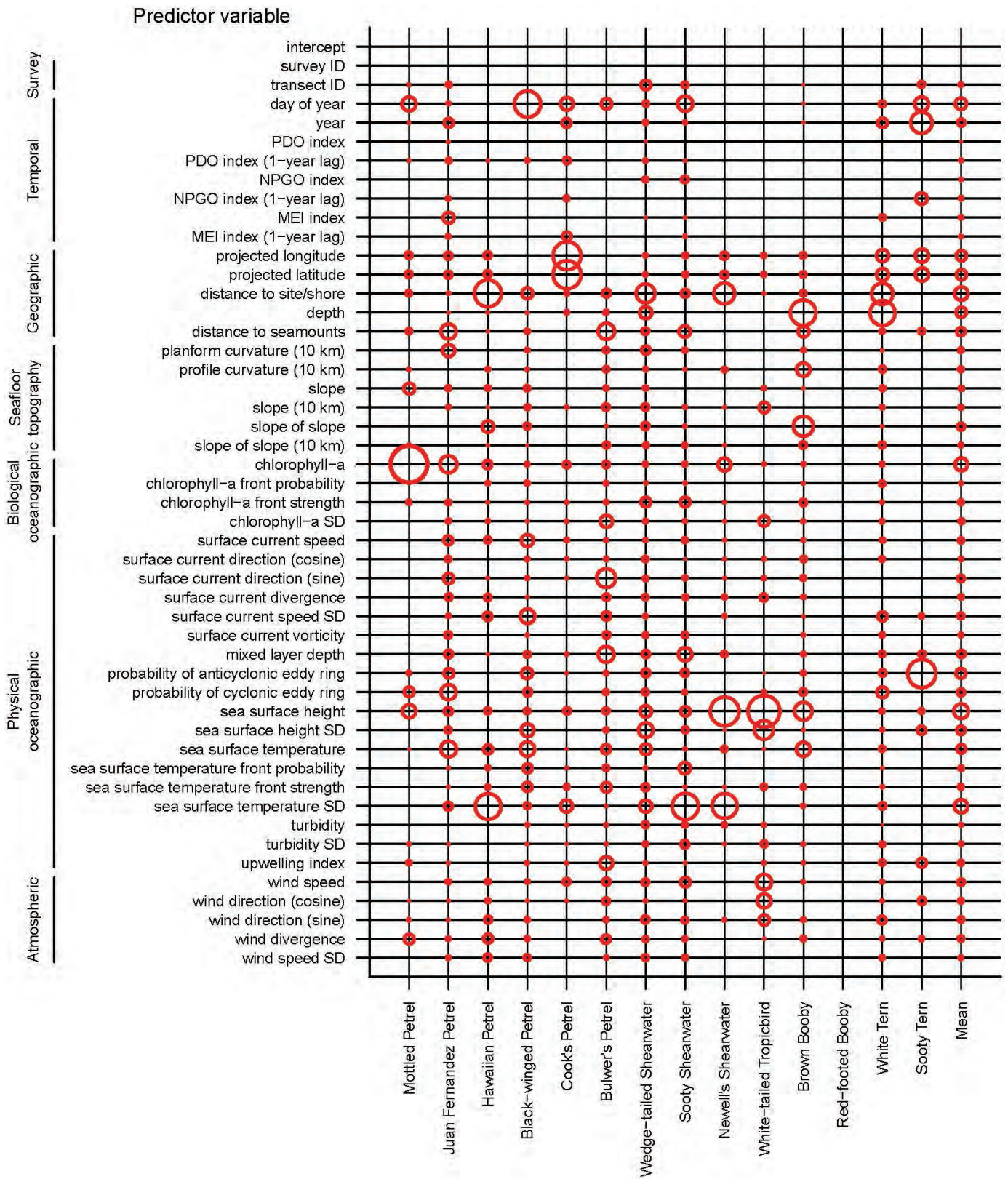


Figure 7.22. Predictor variable importance for the 'zero-inflation' component of each species' model. The area of a circle is proportional to relative variable importance. Models had two components: a zero inflation and a count component (Appendix B). This figure displays the relative importance of each predictor variable for modeling the probability of zero inflation in the former component. The probability of zero inflation in the Red-footed Booby model converged to a single value, so there were no predictor effects for this component.

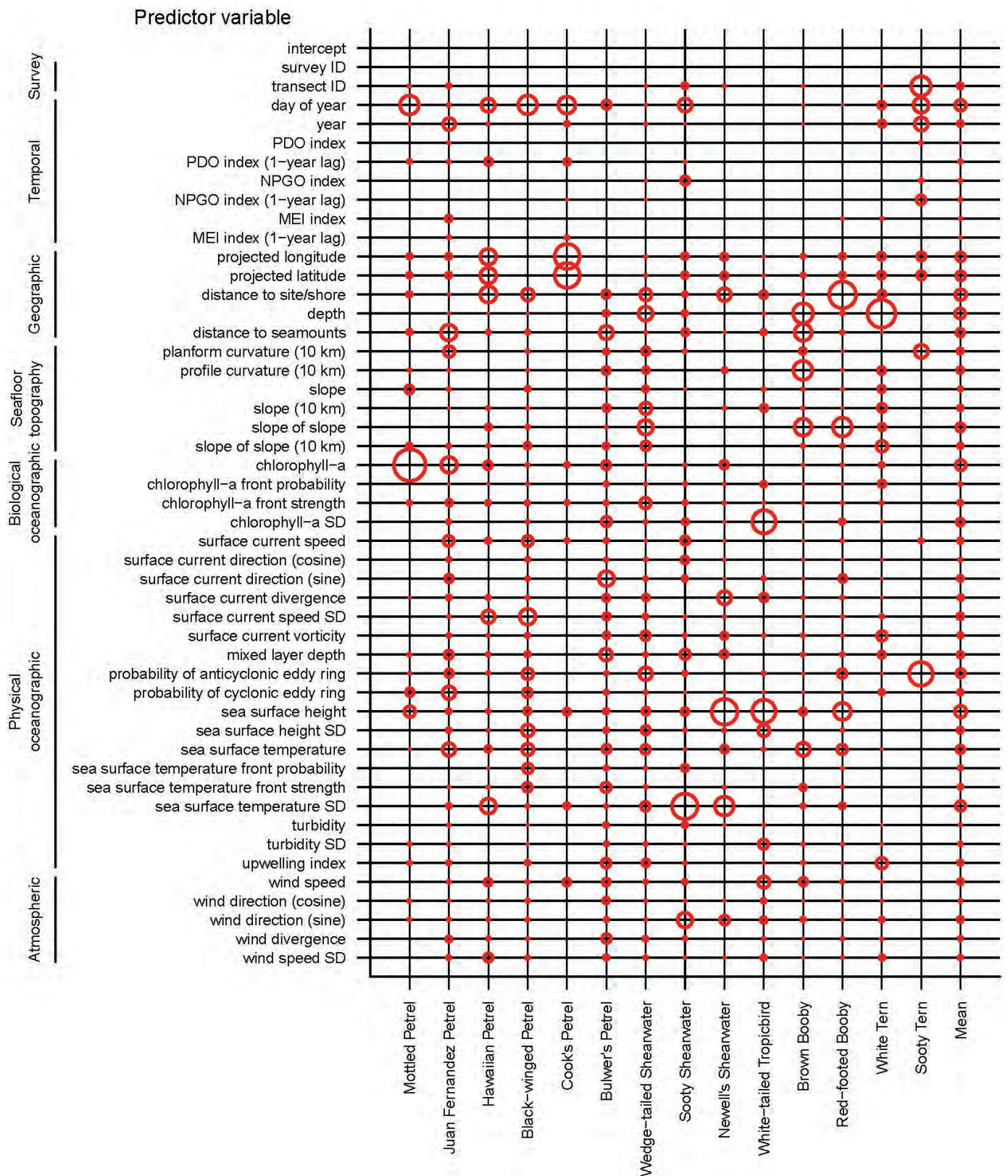


Figure 7.23. Predictor variable importance for the 'mean count' component of each species' model. The area of a circle is proportional to relative variable importance. Models had two components: a zero inflation and a count component (Appendix B). This figure displays the relative importance of each predictor variable for modeling the mean count in the latter component.

Seabirds

7.4. DATA LIMITATIONS AND INFORMATION GAPS

Our assessment of the at-sea distribution of seabirds in the MHI focused on the best available, most recent sighting dataset. The data covered the entire study area and spanned more than two decades. However, due to the expense and logistics required to conduct ship surveys, there were some limitations to the data.

The majority of the sighting data were collected during two years, 2002 and 2010. Seabird distributions can vary substantially from year to year, in part because of environmental variation over time (Ballance et al., 2006), so our results may not be representative of long-term average distributions. For instance, to the extent that seabird distributions in the MHI are influenced by the El Niño Southern Oscillation (ENSO; Ribic et al., 1992), the sighting data that contributed to our assessment mainly reflect ENSO conditions during the latter half of 2002 and 2010. The last seven months of 2002 were characterized as a warm period with respect to the Oceanic Niño Index (3.4 region), while the last half of 2010 was characterized as a cool period (Chapter 2, Figure 2.12). Additional survey effort from more years covering a range of environmental conditions would improve the ability to assess the long-term distributions of seabirds in the MHI.

The sighting data were collected in May and August-December, with the majority from August-November. Our spatial predictive modeling was further limited to only data from May and August-October. For species that are present in the MHI during other months (Figure 7.1), our results may not be representative of their average distribution around the MHI. Additional survey effort from December-July would improve the ability to assess the average annual distributions of seabirds in the MHI.

At-sea sighting surveys are an effective means for collecting data on all species simultaneously across a wide geographic area. Future survey effort during all months of the year would improve the ability to assess the average long-term distributions of seabirds in the MHI. That being said, at-sea surveys can be expensive and logistically challenging, and traditional strip transect methodology may not be especially well-suited for estimating the density and distribution of flocking species associated with sub-surface predators (Ballance and Pitman, 1999).

There is a large, growing online database of global bird sightings contributed by the public, eBird (Sullivan et al., 2014; <http://ebird.org>), that provides some information about at-sea sightings of seabirds in the MHI. Data from eBird were excluded from our analysis given their limited offshore coverage, often opportunistic nature, and lack of documentation of effort. Nevertheless, eBird now has a Pelagic Protocol, and as this database grows and appropriate analytical techniques develop (e.g., Fink et al., 2010) we would encourage the exploration of the usefulness of these data for providing additional information about the at-sea distribution of seabirds in the MHI.

Electronic tracking studies (Table 7.3) provide a complementary source of information about the at-sea distribution of seabirds, and we would encourage current and future efforts in the MHI, especially those with large sample sizes and wide species coverage. Tracking data provide detailed information about behavior and space use of individuals through time, although it can be difficult to track some species (e.g., small birds), and the number of individuals tracked is sometimes small so results may not be representative of the population.

A supplementary type of information that our assessment relied on was data on the locations of terrestrial sites used by seabirds in the MHI (e.g., breeding colonies and roosting sites). We did not find a comprehensive, up-to-date dataset on terrestrial sites, so we compiled information from several sources and consulted local seabird biologists. The information that we compiled is almost certainly incomplete, and the nature of what was considered an individual terrestrial site varied considerably, as did the precision of the location information. We would encourage any efforts to compile the locations of terrestrial sites used by seabirds in the MHI into a single, publicly available atlas or database. Furthermore, estimates of the number of birds of each species using each site would be a valuable addition to such a database.

For many species that were not modeled, estimates of potential foraging areas for breeding individuals were based on limited data or data from other geographic locations. Continued electronic tracking of breeding seabirds in the MHI would help improve estimates of their foraging areas.

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LITERATURE CITED

Seabirds

Adams, J. and S. Flora. 2010. Correlating seabird movements with ocean winds: linking satellite telemetry with ocean scatterometry. *Marine Biology* 157: 915-929.

Anders, A.D., R.K. Uyeyama, and S.F. Hanser. 2011. Kaula Island ship-based seabird and marine mammal surveys, 26-28 June 2010. Prepared by Naval Facilities Engineering Command Pacific for Commander, Pacific Fleet. Department of the Navy.

Ballance, L.T. and R.L. Pitman. 1999. Foraging ecology of tropical seabirds. pp. 2057-2071. In: N.J. Adams and R.H. Slotow (eds.), *Proceedings of the 22nd International Ornithological Congress*, Durban. Johannesburg, South Africa.

Ballance, L.T., R.L. Pitman, and S.B. Reilly. 1997. Seabird community structure along a productivity gradient: importance of competition and energetic constraint. *Ecology* 78(5): 1502- 1518.

Ballance, L.T., R.L. Pitman, L.B. Spear, and P.C. Fiedler. 2002. Investigations into temporal patterns in distribution, abundance and habitat relationships within seabird communities of the Eastern Tropical Pacific. NOAA NMFS Southwest Fisheries Science Center, Administrative Report LJ-02-17. 79 pp.

Ballance, L.T., R.L. Pitman, and P.C. Fiedler. 2006. Oceanographic influences on seabirds and cetaceans of the eastern tropical Pacific: A review. *Progress in Oceanography* 69: 360-390.

Cleasby, I.R., E.D. Wakefield, S. Bearhop, T.W. Bodey, S.C. Votier, and K.C. Hamer. 2015. Three-dimensional tracking of a wide-ranging marine predator: flight heights and vulnerability to offshore wind farms. *Journal of Applied Ecology* 52: 1474-1482.

Connors, M.G., E.L. Hazen, D.P. Costa, and S.A. Shaffer. 2015. Shadowed by scale: subtle behavioral niche partitioning in two sympatric, tropical breeding albatross species. *Movement Ecology* 3: 28.

Cooper, B.A. and R.H. Day. 1998. Summer behavior and mortality of Dark-rumped Petrels and Newell's Shearwaters at Power Lines on Kauai. *Colonial Waterbirds* 21: 11-19.

Cooper, B.A. and R.H. Day. 2003. Movement of the Hawaiian Petrel to inland breeding sites on Maui Island, Hawai'i. *Waterbirds* 26: 62-71.

Day, R.H. and B.A. Cooper. 1995. Patterns of movement of Dark-rumped Petrels and Newell's Shearwaters on Kauai. *Condor* 97: 1011-1027.

Day, R.H., B.A. Cooper, and R.J. Blaha. 2003. Movement patterns of Hawaiian Petrels and Newell's Shearwaters on the Island of Hawai'i. *Pacific Science* 57: 147-159.

Devney, C.A., M. Short, and B.C. Congdon. 2009. Sensitivity of tropical seabirds to El Niño precursors. *Ecology* 90(5): 1175-1183.

Dixon, K.L. and C. Starrett. 1952. Offshore observations of tropical sea birds in the Western Pacific. *Auk* 69: 266-272.

Drewitt, A.L. and R.H.W. Langston. 2006. Assessing the impacts of wind farms on birds. *Ibis* 148: 29-42.

Erickson, W.P., M.M. Wolfe, K.J. Bay, D.H. Johnson, and J.L. Gehring. 2014. A comprehensive analysis of small-passerine fatalities from collision with turbines at wind energy facilities. *PLoS ONE* 9: e107491.

Federal Register. 1967. Native fish and wildlife: Endangered species. 32 Fed. Reg. 4001 (February 24, 1967). U.S. Fish and Wildlife Service. Online: <http://www.nmfs.noaa.gov/pr/pdfs/fr/fr32-4001.pdf> (Accessed 14 June 2016).

Federal Register. 1975. Endangered and threatened wildlife: Listing of endangered and threatened fauna. 40 Fed. Reg. 44149 (September 25, 1975). U.S. Fish and Wildlife Service.

Fernández, P., D.J. Anderson, P.R. Sievert, and K.P. Huyvaert. 2001. Foraging destinations of three low-latitude albatross (*Phoebastria*) species. *Journal of Zoology* 254: 391-404.

Fink, D., W.M. Hochachka, B. Zuckerberg, D.W. Winkler, B. Shaby, M.A. Munson, G. Hooker, M. Riedewald, D. Sheldon, and S. Kelling. 2010. Spatiotemporal exploratory models for broad-scale survey data. *Ecological Applications* 20: 2131-2147.

Fujimoto, J. 2011. Kaula ship-based surveys, 30 June 2011. Prepared by Naval Facilities Engineering Command Pacific for Commander, Pacific Fleet. Department of the Navy.

Fujimoto, J. and F. Juola. 2012. Kaula Island ship-based seabird survey, July 6, 2012. Prepared by Naval Facilities Engineering Command Pacific for Commander, Pacific Fleet. Department of the Navy.

Garthe, S. and O. Hüppop. 2004. Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. *Journal of Applied Ecology* 41: 724-734.

Harrison, C. S. and D.L. Stone-Burner. 1981. Radiotelemetry of the Brown Noddy in Hawaii. *Journal of Wildlife Management* 45: 1021-1025.

Harrison, C.S. 1990. *Seabirds of Hawaii: Natural history and conservation*. Cornell University Press. Ithaca, NY. 249 pp.

Hebshi, A.J., D.C. Duffy, and K.D. Hyrenbach. 2008. Associations between seabirds and subsurface predators around Oahu, Hawaii. *Aquatic Biology* 4: 89-98.

Hirai, L.T. 1978. Native birds of Lanai, Hawaii. *Western Birds* 9: 71-77.

Hyrenbach, K.D., P. Fernández, and D.J. Anderson. 2002. Oceanographic habitats of two sympatric North Pacific albatrosses during the breeding season. *Marine Ecological Progress Series* 233: 283-301.

Kappes, M.A., S.A. Shaffer, Y. Tremblay, D.G. Foley, D.M. Palacios, P.W. Robinson, S.J. Bograd, and D.P. Costa. 2010. Hawaiian albatrosses track interannual variability of marine habitats in the North Pacific. *Progress in Oceanography* 86: 246-260.

Kappes, M.A., S.A. Shaffer, Y. Tremblay, D.G. Foley, D.M. Palacios, S.J. Bograd, and D.P. Costa. 2015. Reproductive constraints influence habitat accessibility, segregation, and preference of sympatric albatross species. *Movement Ecology* 3: 34.

Keller, K.E., A.D. Anders, S.A. Shaffer, M.A. Kappes, B. Flint, and A. Friedlander. 2009. Seabirds. pp. 235-274. In: A. Friedlander, K. Keller, L. Wedding, A. Clarke, and M. Monaco (eds.). 2009. A marine biogeographic assessment of the Northwestern Hawaiian Islands. NOAA Technical Memorandum NOS NCCOS 84. Silver Spring, MD. Online: <https://coastalscience.noaa.gov/datasets/e98/docs/nwhi-2009.pdf> (Site Accessed 8 June 2016).

King, W.B. 1970. The Trade Wind Zone Oceanography Pilot Study Part VII: Observations of Sea Birds March 1964 to June 1965. U.S. Fish and Wildlife Service Special Scientific Report – Fisheries No. 586. Washington, DC.

King, W.B. (ed.) 1974. Pelagic studies of seabirds in the central and eastern Pacific Ocean. Number 158 in Smithsonian contributions to zoology. Smithsonian Institution Press, Washington, DC.

Seabirds

Kozar, K., R. Swift, and S. Marshall. 2007. Shoreline bird inventories in three National Parks in Hawai'i : Kalaupapa National Historical Park, Haleakala National Park and Hawaii Volcanoes National Park. Pacific Cooperative Studies Unit, University of Hawai'i at Manoa and National Park Service, Inventory and Monitoring Program. Technical Report 149. 34 pp.

Maxwell, S.M. and L.E. Morgan. 2013. Foraging of seabirds on pelagic fishes: implications for management of pelagic marine protected areas. *Marine Ecology Progress Series* 481: 289-303.

May, R.F. 2015. A unifying framework for the underlying mechanisms of avian avoidance of wind turbines. *Biological Conservation* 190: 179-187.

NOAA NMFS. 2014. Seabird interactions and mitigation efforts in Hawaii longline fisheries: 2013 Annual Report. NOAA National Marine Fisheries Service, Pacific Islands Regional Office. Honolulu, HI. 12 pp.

Pepi, V.E., A. Kumar, M.E. Laut, J. Hallman, J. Kim, and A.D. Anders. 2009. Kaula Island ship-based seabird and marine mammal surveys, 21-22 July 2009. Prepared for Commander, Pacific Fleet. NAVFAC Pacific. Department of the Navy.

Pyle, R.L. and P. Pyle. 2009. *The Birds of the Hawaiian Islands: Occurrence, history, distribution, and status*. B.P. Bishop Museum. Honolulu, HI. Version 1. Online: <http://hbs.bishopmuseum.org/birds/rlp-monograph/> (Site Accessed 8 June 2016).

Reynolds, M.H. and G.L. Ritchotte. 1997. Evidence of Newell's Shearwater breeding in Puna District, Hawaii. *Journal of Field Ornithology* 68: 26-32.

Ribic, C.A., D.G. Ainley, and L.B. Spear. 1992. Effects of El Niño and La Niña on seabird assemblages in the Equatorial Pacific. *Marine Ecology Progress Series* 80: 109-124.

Ribic, C.A. and D.G. Ainley. 1997. The relationships of seabird assemblages to physical habitat features in Pacific equatorial waters during spring 1984-1991. *ICES Journal of Marine Science* 54: 593-599.

Robinson Willmott, J.C., G. Forcey, and A. Kent. 2013. The relative vulnerability of migratory bird species to offshore wind energy projects on the Atlantic Outer Continental Shelf: An assessment method and database. Final Report to the U.S. Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs. OCS Study BOEM 2013-207. Herndon, VA.

Rosenberg, K.V., D. Pashley, B. Andres, P.J. Blancher, G.S. Butcher, W.C. Hunter, D. Mehlman, A.O. Panjabi, M. Parr, G. Wallace, and D. Wiedenfeld. 2014. The State of the Birds 2014 Watch List. North American Bird Conservation Initiative, U.S. Committee. Washington, DC. Online: <http://www.stateofthebirds.org/2014/extinctions/watchlist.pdf> (Site Accessed 8 June 2016).

Shaffer, S.A., Y. Tremblay, H. Weimerskirch, D. Scott, D.R. Thompson, P.M. Sagar, H. Moller, G.A. Taylor, D.G. Foley, B.A. Block, and D.P. Costa. 2006. Migratory shearwaters integrate oceanic resources across the Pacific Ocean in an endless summer. *Proceedings of the National Academy of Sciences* 103: 12799-12802.

Soanes, L.M., J.A. Bright, L.P. Angel, J.P.Y. Arnould, M. Bolton, M. Berlincourt, B. Lascelles, E. Owen, B. Simon-Bouhet, and J.A. Green. 2016. Defining marine important bird areas: Testing the foraging radius approach. *Biological Conservation* 196: 69-79.

Spear, L.B., D.G. Ainley, and P. Pyle. 1999. Seabirds in southeastern Hawaiian waters. *Western Birds* 30:1-32.

Spear, L.B., L.T. Ballance, and D.G. Ainley. 2001. Response of seabirds to thermal boundaries in the tropical Pacific: the thermocline versus the Equatorial Front. *Marine Ecology Progress Series* 219: 275-289.

Sullivan, B.L., J.L. Aycrigg, J.H. Barry, R.E. Bonney, N. Bruns, C.B. Cooper, T. Damoulas, A.A. Dhondt, T. Dietterich, A. Farnsworth, D. Fink, J.W. Fitzpatrick, T. Fredericks, J. Gerbracht, C. Gomes, W.M. Hochachka, M.J. Iliff, C. Lagoze, F.A. La Sorte, M. Merrifield, W. Morris, T.B. Phillips, M. Reynolds, A.D. Rodewald, K.V. Rosenberg, N.M. Trautmann, A. Wiggins, D.W. Winkler, W.K. Wong, C.L. Wood, J. Yu, and S. Kelling. 2014. The eBird enterprise: An integrated approach to development and application of citizen science. *Biological Conservation* 169: 31-40.

Thorne, L.H., E.L. Hazen, S.J. Bograd, D.G. Foley, M.G. Conners, M.A. Kappes, H.M. Kim, D.P. Costa, Y. Tremblay, and S.A. Shaffer. 2015. Foraging behavior links climate variability and reproduction in North Pacific albatrosses. *Movement Ecology* 3: 27.

USFWS. 1983. Atlas of Hawaiian seabird colonies. U.S. Fish and Wildlife Service. Honolulu, HI.

USFWS. 2005. Regional seabird conservation plan, Pacific Region. U.S. Fish and Wildlife Service, Migratory Birds and Habitat Programs, Pacific Region. Portland, OR.

Vandenbosch, R. 2000. Effects of ENSO and PDO events on seabird populations as revealed by Christmas Bird Count data. *Waterbirds* 23: 416-422.

VanderWerf, E.A. 2003. Distribution, abundance, and breeding biology of White Terns on Oahu, Hawaii. *Wilson Bulletin* 115: 258-262.

VanderWerf, E.A., L. Elliott, and J.S. Fretz. 2005. Observations on the abundance and behavior of seabirds south of O'ahu during the *F/V Ehime Maru* relocation and fuel spill. *'Elepaio* 65: 25-29.

VanderWerf, E.A., K.R. Wood, C. Swenson, M. LeGrande, H. Eijzenga, and R.L. Walker. 2007. Avifauna of Lehua Islet, Hawai'i: Conservation value and management needs. *Pacific Science* 61: 39-52.

VanderWerf, E.A. and L.C. Young. 2014. Breeding biology of Red-tailed Tropicbirds *Phaethon rubricauda* and response to predator control on O'ahu, Hawai'i. *Marine Ornithology* 42: 73-76.

Welch, A.J., R.C. Fleischer, H.F. James, A.E. Wiley, P.H. Ostrom, J. Adams, F. Duvall, N. Holmes, D. Hu, J. Penniman, and K.A. Swindle. 2012. Population divergence and gene flow in an endangered and highly mobile seabird. *Heredity* 109: 19-28.

Wiley, A.E., P.H. Ostrom, A.J. Welch, R.C. Fleischer, H. Gandhi, J.R. Southon, T.W. Stafford Jr., J.F. Penniman, D. Hu, F.P. Duvall, and H.F. James. 2013. Millennial-scale isotope records from a wide-ranging predator show evidence of recent human impact to oceanic food webs. *Proceedings of the National Academy of Sciences* 110: 8972-8977.

Wood, K.R., D. Boynton, E. VanderWerf, L. Arnold, M. LeGrande, J.W. Slotterback, and D. Kuhn. 2003. The distribution and abundance of the Band-rumped Storm-Petrel (*Oceanodroma castro*): A preliminary survey of Kaua'i, Hawai'i 2002. Report to the U.S. Fish and Wildlife Service, Pacific Islands Office. Honolulu, HI.

Wood, K.R. and P. Bily. 2008. Vegetation description of a nesting site for Newell's Shearwater (*Puffinus auricularis newelli*), Pi'ina'au Stream, East Maui, Hawai'i. *'Elepaio* 68: 63-66.

Young, H.S., S.M. Maxwell, M.G. Conners, and S.A. Shaffer. 2015. Pelagic marine protected areas protect foraging habitat for multiple breeding seabirds in the central Pacific. *Biological Conservation* 181:226-235.