OCS Study
BOEM 2025-009

Year-round and Diel Patterns in Habitat Use of Seabirds off Oregon

U.S. Department of the Interior
Bureau of Ocean Energy Management
Pacific OCS Region, Camarillo, CA

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Authors:
Rachael A. Orben
Jessica Porquez
Robert Suryan

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By
Oregon State University
Hatfield Marine Science Center
2030 SE Marine Science Drive
Newport, OR 97365

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ABOUT THE COVER

Yaquina Head, Newport Oregon. Photo credit: Amanda Gladics.

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Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

2G	second-generation cellular network
3G	third-generation cellular network
4G	fourth-generation cellular network
BBUD	Brownian bridge utilization distributions
BFAL	Black-footed Albatross
BLKI	Black-legged Kittiwake
BOEM	Bureau of Ocean Energy Management
BRAC	Brandt's Cormorant
BRT	Boosted Regression Trees
CAAU	Cassin's Auklet
CATS	Customized Animal Telemetry Solutions
COMU	Common Murre
DOI	U.S. Department of the Interior
DOP	Dilution of Precision
EEZ	Exclusive Economic Zone
GDOP	geometric dilution of precision
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HDOP	Horizontal dilution of precision
LAAL	Laysan Albatross
mamsl	Meters above mean sea level
MT	Microwave Telemetry
nCCS	Northern California Current System
NOFU	Northern Fulmar
OCS	Outer Continental Shelf
OR	Oregon
OSU	Oregon State University
PALO	Pacific Loon
PFSH	Pink-footed Shearwater
PTT	Platform Telemetry Transmitter
RHAU	Rhinoceros Auklet
RST	Residence in Space and Time
RSZ	Rotor Sweep Zone
RTLO	Red-throated Loon
SOSH	Sooty Shearwater
STAL	Short-tailed Albatross
TDOP	time dilution of precision
USGS-WERC	U.S. Geological Survey, Western Ecological Research Center
UVA	University of Amsterdam
VDOP	vertical dilution of precision
VHF	Very high frequency
WEGU	Western Gull

Abstract

Oregon hosts approximately 1.2 million breeding seabirds and even more summer and winter migrants with at-sea residence times of days to months. Common Murres are the most abundant breeding bird, followed by storm-petrels, cormorants, and gulls. Over the course of this project, we filled critical seabird tracking needs of mid-sized species: Common Murres, Western Gull, Pink-footed Shearwaters, and Pacific Loons (Chapter 1). We then compiled available tracking data into the Oregon Seabird Tracking Inventory (a subset of the *California Current Ecosystem Seabird Telemetry Atlas*). We provide a Brownian bridge density framework for analysis and visualization that combines data from multiple location types (Argos, GPS) and summarize the data within the Oregon Exclusive Economic Zone and the northern California Current System (Chapter 2). An understanding of seabird flight heights is needed to estimate collision vulnerability to offshore wind energy development. While many challenges are inherent in using GPS altitude fixes for this purpose, we used bootstrapping methods to estimate the percentage of time spent within the Rotor-Sweep Zone for seabird species (Chapter 3). We then applied boosted regression trees (BRTs) to disentangle environmental, bird behavior, and electronic-based influences on seabird flight heights. While our BRT models only performed moderately well the results provide ecologically plausible insights into the factors that influence seabird flight heights. At-sea observations of seabirds can fill critical gaps in identifying which species are present in Oregon waters. Here we summarize at-sea survey efforts for three surveys (2015-2017) in the northern California Current System and compare the species composition and at sea densities to telemetry-derived utilization distributions (Chapter 4). This study highlights available seabird tracking data off Oregon and critical gaps in our spatial understanding of smaller-bodied seabird species including storm-petrels, Tufted Puffin, and Cassin's Auklet.

1 Oregon Seabird Tracking Efforts (2015-2019)

Oregon hosts approximately 1.2 million breeding seabirds and even more summer and winter migrants with at-sea residence times of days to months. Common Murres are the most abundant breeding bird (50% of breeding population), followed by storm-petrels (37%), cormorants (5%), and gulls (2%). Common Murres along with loons, grebes, and seaducks are the most abundant overwintering species. At times of the year, shearwaters and albatrosses also are abundant. Several species including the Short-tailed Albatross and Marbled Murrelet are federally protected under the U.S. Endangered Species Act. Prior to 2015, limited tracking data existed for larger-bodied, non-resident species (albatrosses, Sooty and Pink-footed Shearwater), but not for the smaller, numerically dominant breeding and overwintering species. The suite of birds that comprise the Oregon seabird community are adapted to a summer upwelling and winter downwelling eastern boundary current system. This community is dominated by diving species most of the year, but at times similar numbers of surface/near-surface feeding species are present.

In order to fill some of these gaps we tracked four species during this project: Common Murres, Western Gulls, Pink-footed Shearwaters, and Pacific Loons. This section details the methods and tags employed to track the four focal species. The tracking data are also included in the Section 2: Oregon Seabird Telemetry Inventory.

1.1 Focal Species

1.1.1 Common Murre (*Uria aalge*)

Common Murres (*Uria aalge*) are a deep diving seabird with high wing loading (Elliott et al. 2013). These characteristics make them especially challenging to tag via biologging devices. Colonies of Common Murres in Oregon are typically located on off-shore sea stacks where they are hard to reach without disturbing breeding birds (Naughton et al. 2007). Therefore, we caught birds at-sea near one of the largest breeding colonies in Oregon, Yaquina Head (Naughton et al. 2007). We deployed tags in the summers of 2015-2017 (Loredo 2018, Loredo et al. 2019). We also attempted to deploy tags in the early spring (March) of 2017, however swell conditions and boat availability never coincided to allow for a capture effort. All tags were attached at-sea to minimize animal handling time.

1.1.1.1 Tagging Effort

In a 2010, a pilot study indicated that birds captured at sea and tagged with very high frequency (VHF) transmitters were likely to attend the colony at Yaquina Head (38%, n=8). In 2015, we chose to deploy 10 platform telemetry transmitters (PTTs) (TAV-2617 PTTs, Telonics Inc., Meza AZ, USA ,17 g) with salt-water switches along with birds just deployed with VHF transmitters (n = 8, Advanced Telemetry Systems, A1000, 3 g) as controls. These PTTs had been used previously on Common Murres in Oregon so the sensor data was comparable (Phillips et al. 2018). We found none of the PTT birds made central-place foraging trips, while 4 of the VHF tagged birds were consistently heard through the summer at Yaquina Head, Oregon (one frequency was consistently noisy and bird attendance was unconfirmed). Thus, in 2016, we tested solar powered GPS tags (11 g, UVA-bits, http://www.uva-bits.nl) that downloaded to a base station on the headland. These tags had been previously used successfully with Common Murres in the Baltic Sea (Evans 2017), however differences in mass were subsequently reported (Evans et al. 2020). Unfortunately, anomalous oceanic conditions coincided with our study years (2014-2017) (Bond et al. 2015, Piatt et al. 2020), and Common Murres had near to complete breeding failure at the Yaquina Head colony (Peterson et al. 2015, McClatchie 2016). Tagged birds did not consistently return to the proximity of the base station. In 2016, we were also able to acquire three 5 g solar powered PTT tags manufactured by Microwave Telemetry Inc. (Columbia MD, USA). It was uncertain if this tag would be resilient at Common Murre foraging depths (up to 200 m), but successful preliminary results allowed us to purchase tags directly from the manufacturer. In fall 2016 and 2017, we deployed these tags (n = 12), with a mean tagging duration of 84 days (max = 128 days) (Loredo et al. 2019) (Figure 1-1). The per unit cost ($3,450) exceeded our original estimates and limited our ability to deploy a larger sample size of this tag type.

Our original goal was to tag Common Murres with a Global Position System (GPS) logger that would transmit data through the cell phone networks (GPS/GSM) and carry a pressure sensor (~10 g) built in collaboration with Customized Animal Telemetry Solutions (CATS, Germany). The switch from 2G to 3G slowed progress and the greater size and power demands of the 3G chips prevented this tag type from being suitable for murres (>20 g), even without pressure sensors, within the timeframe of our project.

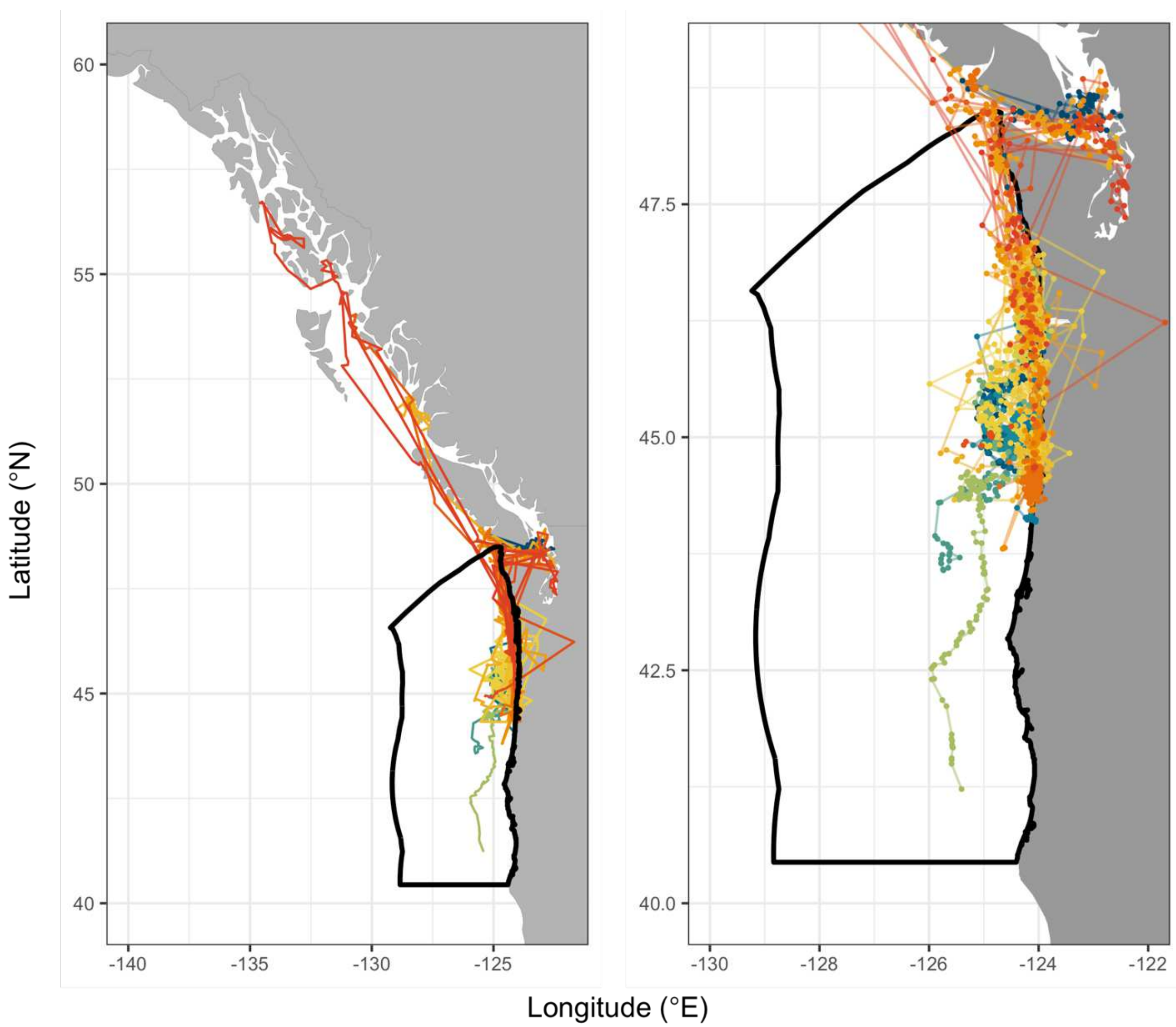


Figure 1-1. Common Murre tracks (2015-2017).
Colors indicate different individuals. The US Exclusive Economic Zone for the northern California Current is show in black on both panels.

1.1.1.2 Murre Capture and Handling

Murres were caught at night from a small boat. First, a handheld spotlight was used to disorient them and then they were caught using a dip-net (Ronconi et al. 2010). All tags were attached to Common Murres using sutures (2-0, Prolene; Newman et al. 1997) (Figure 1-2). This method had previously been used with Marbled Murrelets (*Brachyramphus marmoratus*) (Lorenz et al. 2016), shearwaters (Adams et al. 2012, Felis et al. 2019), and Common Murres (Phillips et al. 2018). The VHF transmitters deployed in 2010 were attached using this method (Suryan, unpublished data), providing evidence that this attachment method might be compatible with Common Murre central-place foraging behavior. Sutures were the preferred method of attachment because they added minimal material to the attachment (little additional weight). We were unable to directly measure the impacts on the birds of this attachment method since birds were not recaptured but see Loredo et al. (2018). We resighted one banded bird attending a chick on the Yaquina Head colony in 2018; but it is unknown if this bird carried a transmitter.

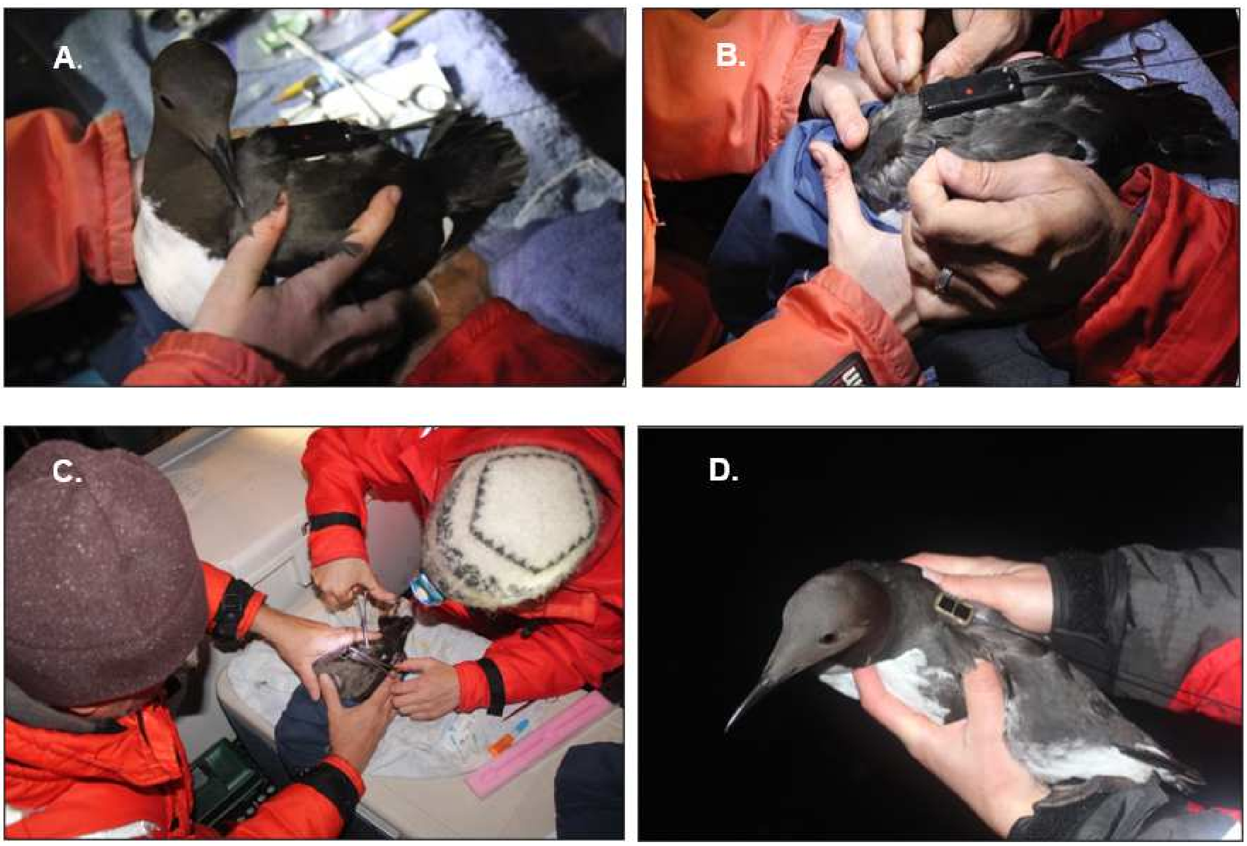


Figure 1-2. Common Murre biologging tag deployments.
A. Common Murre with a 17g Telonics PTT, B. attaching the Telonics PTT, C. attaching a 5g Microwave Telemetry solar powered PTT tag, and D. releasing a Common Murre with a 5g Microwave Telemetry solar powered PTT. Photos: Seabird Oceanography Lab, Oregon State University.

1.1.2 Pacific Loon (*Gavia pacifica*)

In collaboration with USGS Alaska Science Center and the Smithsonian Migratory Connectivity project, in 2016, PTTs (Microwave Telemetry, Columbia MD) were deployed on Pacific Loons breeding at Yukon-Kuskokwim Delta (Harrison et al. 2020). Five of these tags was funded through this project. PTTs were 38-44 g and designed to be surgically implanted in the intra-coelomic. Ducks and loons do not do well with externally attached biologging devices and coelomic implantation of transmitters is a preferred alternative method (e.g., McCloskey et al. 2018).

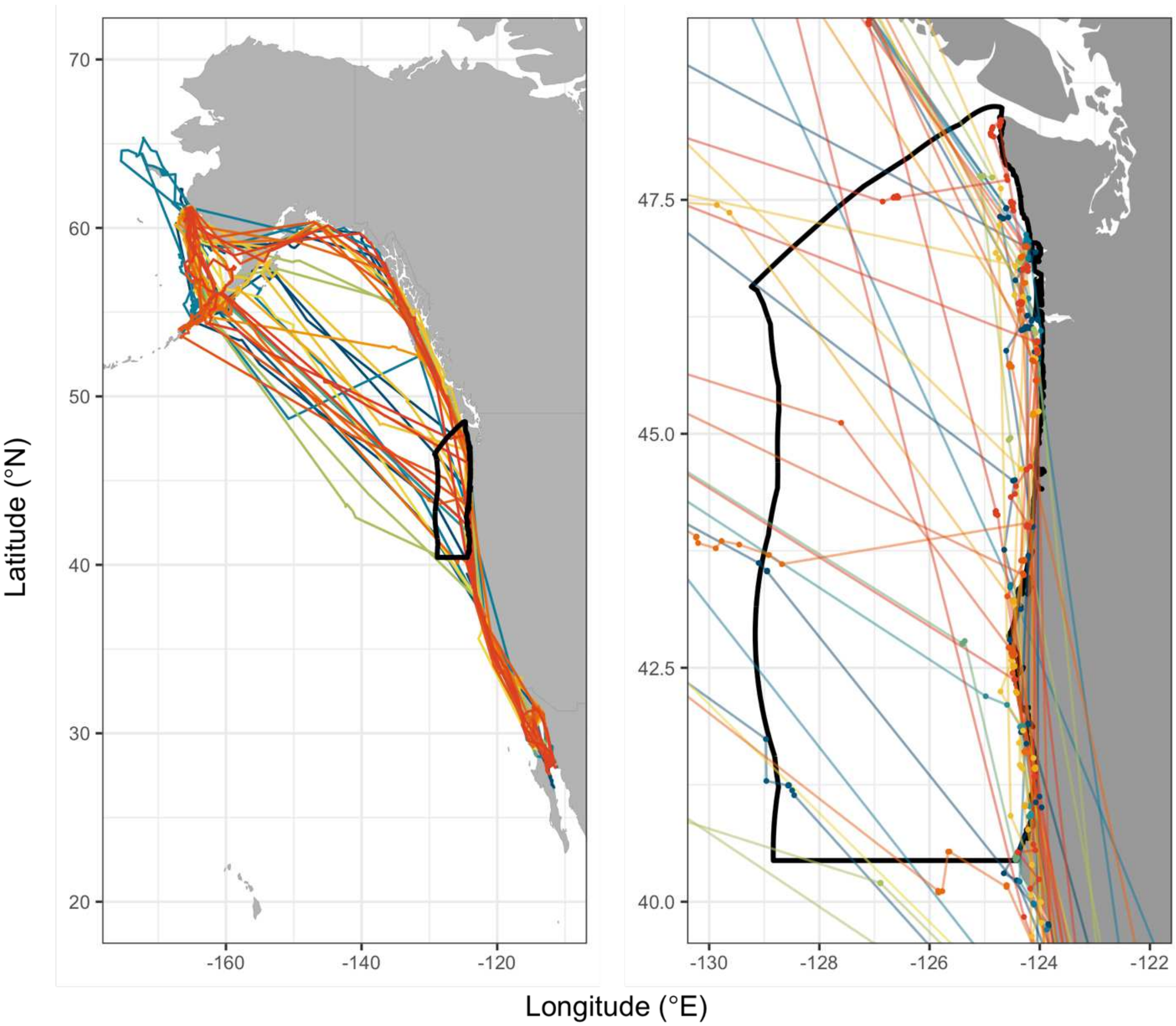


Figure 1-3. Pacific Loon tracks from the Yukon-Kuskokwim Delta, Alaska in 2016.
Colors indicate different individuals. The US Exclusive Economic Zone for the northern California Current is show in black on both panels.

1.1.3 Pink-footed Shearwater (*Ardenna creatopus*)

Pink-footed Shearwaters breed on islands along the coast of central Chile and the Juan Fernandez Islands (Carle et al. 2021). During the non-breeding period some individuals migrate to the US West Coast during the northern hemisphere summer (Baltz and Morejohn 1977, Ainley and Hyrenbach 2010, Felis et al. 2019). With support from BOEM (this project), USGS-WERC and Oikonos, deployed 10 PTTs (Microwave Telemetry; PTT100, 17g) on Pink-footed Shearwaters at Isla Mocha, Chile in 2015 to supplement previously collected tracking data and increase coverage of this species use of Oregon waters (Felis et al. 2019); three of these individuals reached the nCCS (Figure 1-4).

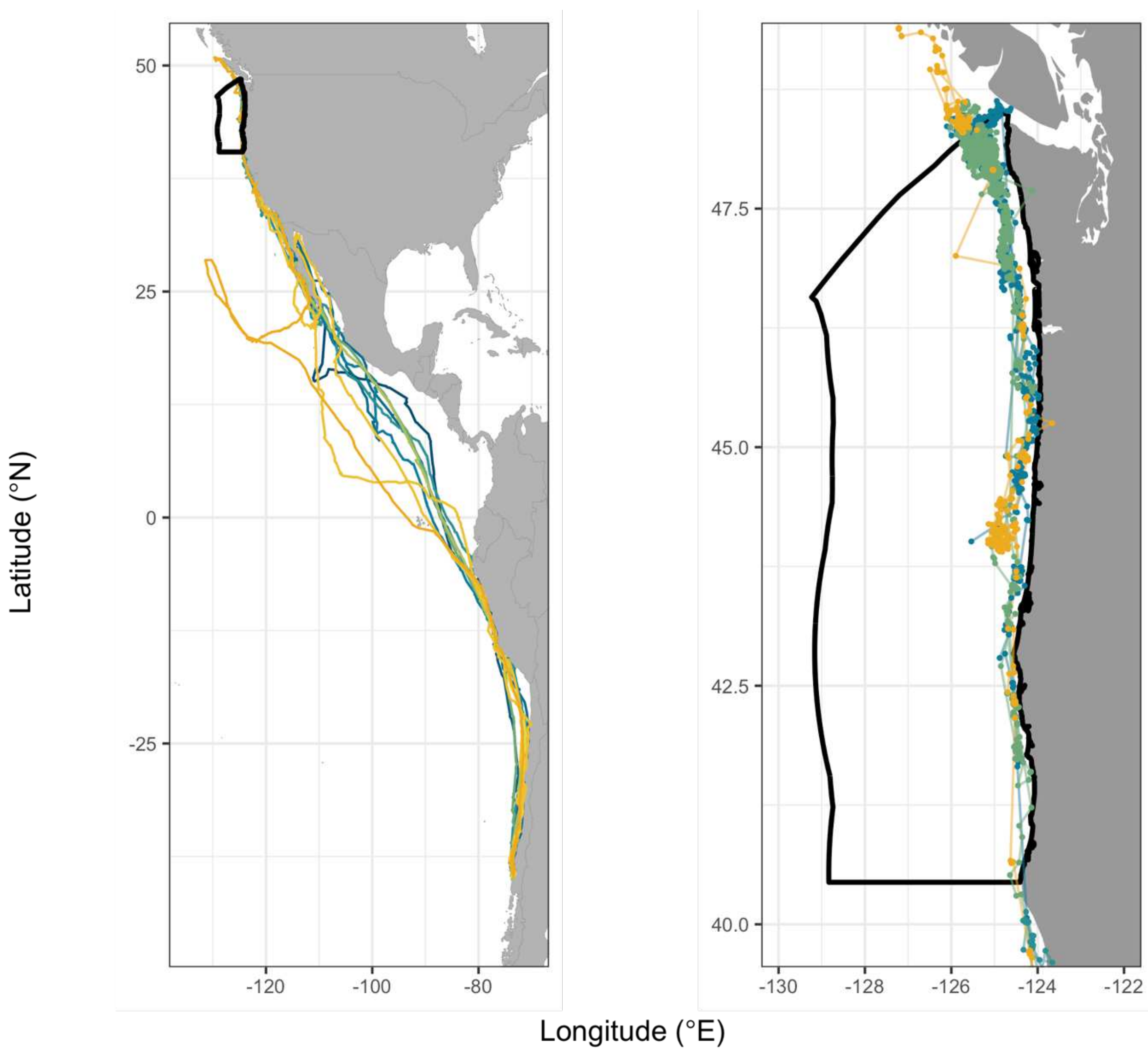


Figure 1-4. Pink-footed Shearwater tracks (2015).
Colors indicate different individuals. The US Exclusive Economic Zone for the northern California Current is show in black on both panels.

1.1.4 Western Gull (*Larus occidentalis*)

Western Gulls are large gulls that breed at numerous locations along the Oregon coast including on off-shore sea stacks and within human population centers on the roof tops of buildings (Naughton et al. 2007). Prior to our efforts there were no available tracking data from Western Gulls on the Oregon coast. In 2015, we used modified GPS dataloggers (i-gotU GT-120 and igotU GT-600) to tag 10 birds from a colony on the central coast of Oregon (Cleft-in-the-Rock, Colony #024.5, Naughton et al. 2007). We caught birds during late incubation and recaptured them (n = 6) during early chick rearing. In 2016, we deployed archival tags again at Cleft-in-the-Rock (n = 11) and Hunter's Island on the southern coast of Oregon (n = 14, Colony #071, Naughton et al. 2007). Archival tags were attached to the central four tail feathers with Tesa tape.

Additionally, we deployed GPS/GSM tags that transmit data to the local cell phone networks. In 2016, we deployed GSM loggers that were originally intended for Common Murres (Customized Animal Telemetry Solutions, CATS, Germany, n = 14). We had little success with the CATS tags. The power management and transmission protocols were a prototype version and generally not reliable. Additionally, most birds lost the tags very quickly. In 2017, we deployed 16 GPS-GSM tags (Ornitela, Ornitrak-25, Lithuania) with barometric pressure sensors to help inform our understand of Western Gull flight heights. These tags were also attached via leg loop harnesses, but they had a smaller and narrower footprint. A few tags were shed and retrieved, and subsequently redeployed in August 2017 (n = 3). In 2018, we deployed GPS dataloggers during late incubation at the Cleft-in-the-Rock (n=10). In 2019, we deployed three GPS/GSM tags during late incubation that had been recovered after birds lost tags in 2016. In total, we had 27 successful archival tag deployments (60% recovery rate) and we deployed Ornitela GPS/GSM tags on 22 individuals.

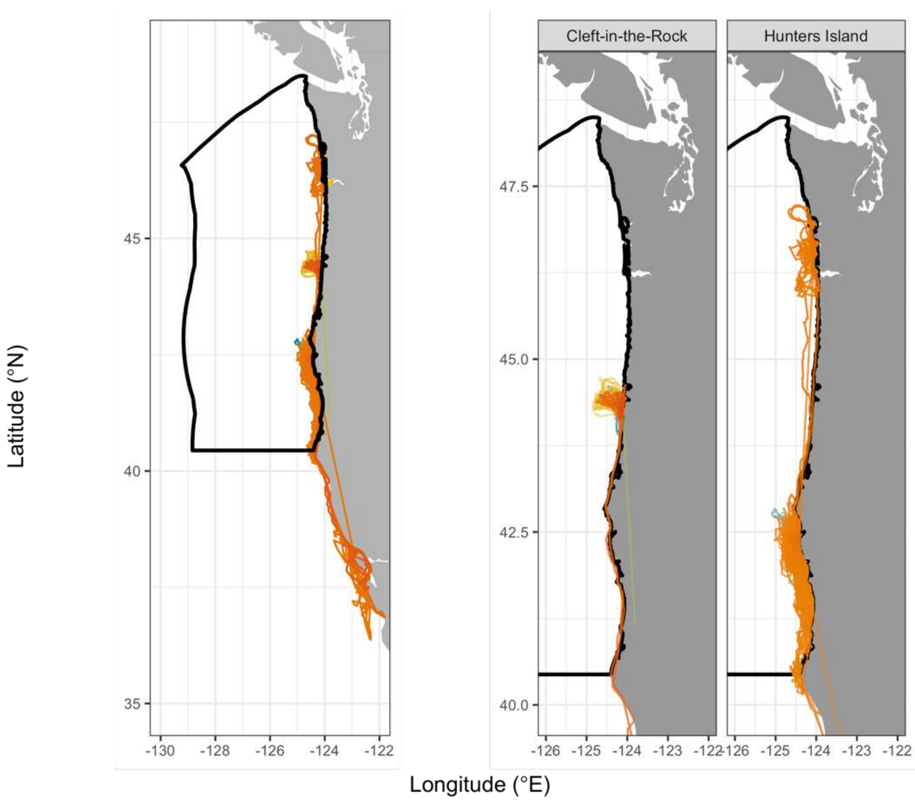


Figure 1-5. Western Gull tracks (2015-2018).
Colors indicate different individuals. The US Exclusive Economic Zone for the northern California Current is show in black on both panels. The track are split by site to help aid in visualization.

1.1.4.1 Tag Attachment Methods

Both the CATS and Ornitela tags were attached via leg-loop harnesses (Thaxter et al. 2015). We chose this type of harness because it appeared easier for birds to shed these than back-pack harnesses attached around the wings. Indeed, we found this to be the case, and retrieved a number of shed Ornitela loggers. The leg-loop harness however places the tags low on the back where the solar panels on the tags can be obscured by the wings of the birds (Thaxter et al. 2015). Generally, tags were able to charge when birds were frequently flying, but many individuals exhibited extremely residential movement strategies post breeding and GPS locations were intermittent from these birds outside the summer months.

Figure 1-6. Western Gull biologging tag deployments.
A. Western Gull with an Ornitela Orn-Track25 GPS/GSM tag, B. A rear profile of a Western Gull in flight with an Ornitela Orn-Track25 GPS/GSM tag, C. Attaching a Ornitela Orn-Track25 GPS/GSM tag, D. preparing to release a western gull with a CATS prototype tag, and E. Attaching a Mr. Lee archival tag to the central tail feathers. Photos: Tim Lawes (A-C), Robert Suryan (D & E), Oregon State University.

2 Oregon Seabird Telemetry Inventory

The Oregon Seabird Telemetry Inventory is a collection of the available seabird tracking data (1998-2019) for species that use the northern California Current System (nCCS) and the US Exclusive Economic Zone (EEZ) off Oregon were generated and shared by multiple collaborators working in the Pacific. The dataset and methods are consistent with those in development for the *California Current Ecosystem Seabird Telemetry Atlas*. These data do not constitute a comprehensive dataset to represent annual seabird habitat use because many gaps remain, both in the species included and in the temporal coverage of existing tracking data. Many of the seabirds breeding in Oregon nest on hard-to-reach offshore sea stacks, are small bodied, or are few in number. Notably, data for several alcid species (e.g., Tufted Puffins, Cassin's Auklet, Rhinoceros Auklet) and Leach's Storm-Petrel are lacking. For several marine birds that use Oregon waters seasonally, tags were deployed at distant breeding locations (e.g., Black-footed Albatross, Pacific and Red-throated Loons, Northern Fulmars) and only a small proportion of tracked individuals used Oregon waters. For some species (e.g., Sooty Shearwaters, some Pink-footed Shearwaters, and some Black-footed Albatrosses), at-sea captures within the CCS provided an important method for tagging seabirds that might otherwise be hard to tag during their residency in the northern CCS due to constraints such as feather molt and species incompatibility with long-term harness attachment methods.

All species from which fine-scale tracking data were available are large bodied (>500 g). Most data are from ARGOS-PTTs which allow locations to be determined remotely via satellites rather than requiring the birds to be recaptured to recover tags with archived data. ARGOS-PTT locations typically have 0.5-10 km accuracy (Costa et al. 2010). Short-tailed Albatross juveniles were tracked with GPS-PTTs allowing for GPS-quality locations (~10 m). More recently, GPS-GSM transmitters allow GPS-quality locations to be transmitted via cell phone networks for large-bodied near-shore species that are challenging to recapture (e.g., Western Gull, Brandt's Cormorant).

Notably, geolocation data derived from light-level geolocation dataloggers (GLS tags) are available for other species that show ranges extending into the waters off of Oregon were not included here (e.g., Black-legged Kittiwake, Arctic Tern, Sabine's Gull, Leach's Storm-Petrel, Fork-tailed Storm-Petrel, Ancient Murrelet, Rhinoceros Auklet, Cassin's Auklet) that show ranges extending into the waters off of Oregon (McKnight et al. 2011, 2013, Orben et al. 2015, Davis et al. 2016, Halpin et al. 2018, Studholme et al. 2019, Johns et al. 2020, Hipfner et al. 2020). We did not include GLS tag data because of their low spatial resolution ~186 km (Phillips et al. 2004, Halpin et al.2021).

2.1 Methods

2.1.1 Biologging tags

2.1.1.1 Platform Telemetry Transmitters

Platform Telemetry Transmitters (PTTs) were first used to track animal movements in the late 1980s (Keating et al. 1991). These transmitters transmit signals that are received by ARGOS modules that are attached to low-orbiting NOAA weather satellites (www.ARGOS-system.org). Locations are triangulated by successive communications typically to a single satellite. A minimum of three communications are required to calculate a location and tag location is calculated using the Doppler effect. Original tagging efforts often applied duty-cycle programming to tag transmissions to increase battery life. For instance, tags might transmit for 8 hours once every 48 hours. This type of programming provides irregular sampling and produces large temporal gaps. Each ARGOS location has a location class (LC) category assigned to it. The standard LCs are 3, 2, and 1 and have estimated errors of <250 m, 250-500 m, and 500-1,,500 m, respectively. However, actual location errors tend to be greater (Costa et al. 2010, Douglas et al. 2012). Moreover, animal tracking data tends to be dominated by less precise LC 0, A, B, and Z locations with errors from 4-10 km (Costa et al. 2010, Douglas et al. 2012).

2.1.1.2 Global Positioning System Tags

Global Positioning System (GPS) tags use satellites in the GPS/GLONASS satellite constellation. These ~27 satellites are in medium Earth orbit. A location is triangulated from the geometry of the satellite constellation and the time of the signal reception. Horizontal accuracy is typically ± 10 m. Locations are calculated on-board the GPS receiving device (or from stored career signal data), thus data need to be retrieved from the device. This means that birds need to be recaptured to retrieve the device or the device needs to have the capability to transmit data via another system. Limited data transmission can occur via the Argos system, through the cell-phone network, or via a base station. Each of these systems are suitable for seabirds, depending on the species, life history stage, and foraging area. Coastal species are especially suited to tags that send data through cell phone networks (e.g., 2G, 3G, 4G), central-place foraging species can reliably download to base stations, and transmission to ARGOS satellites is suitable for wide-ranging pelagic species. The power needed to transmit to the ARGOS satellites substantially limits the quantity of data that it is possible to transmit.

2.1.2 Brownian bridge utilization distributions

Probability density surfaces from animal telemetry locations allow an approximation of home range and high-use areas (Worton 1995). Probability densities can be calculated in numerous ways (Fieberg and Kochanny 2005, Horne et al. 2007, Benhamou and Riotte-Lambert 2012, Fleming and Calabrese 2016). Often, point-based approaches are applied after using a movement model to adjust for inherent error (e.g., ARGOS locations classes). For instance, points are interpolated to regular intervals, and kernel density methods applied (Johnson et al. 2008, Baylis et al. 2019). However, this can be challenging to implement when using locations with variable intervals and accuracy. Additionally, the core areas associated with fixed kernel densities are significantly impacted by the choice of smoothing factor (Lascelles et al. 2016). Brownian bridge densities offer a path-based approach that require little preprocessing before implementation (Horne et al. 2007). Probability density surfaces from Brownian bridge utilization distributions (BBUDs) can be implemented without location interpolation because the probability density connects sequential point locations. We chose this method for visualizing the available tracking data and to display new telemetry data consistent with the methods in development for the *California Current Ecosystem Seabird Telemetry Atlas*.

Prior to calculating the BBUDs, we trimmed each track to the deployment period, eliminated duplicate and missing or erroneous locations (e.g., latitude = 0, longitude = 0), and speed-distance-angle (SDA) filtered each dataset (Table 2-1) (Freitas 2012). For ARGOS PTT data, we calculated the mean locational error for the filtered track by taking the sum of the product of the ARGOS location-class error (as reported in Costa et al. 2010) and the number of locations, for each location class, divided by the total number of relocations (Adams et al. 2012). The resulting mean value was used to estimate a mean circular locational error (this value is approximately 3 km for ARGOS locations). Given our large study region, we assumed that GPS error was ± 10 m and applied this error estimate to the GPS datasets. We used a grid cell size for the entire dataset of 3 km to be consistent with the mean locational error for the ARGOS tags.

BBUDs were calculated for the regions of interest rather than the entire range of the tracking data. The approach is advantageous, because tracking data for many individuals included data from distant locations (e.g., Chile, Alaska, Japan). This approach produced probability density surfaces that highlight the important areas within the study area, but these areas may not be as important as regions outside the study area. For instance, the two species of loons included here nest in Alaska (an important region with long residency time), migrate through Oregon waters, and winter farther south. Therefore, the densities presented here would not be high-use areas when considering the full annual movements of the loons, but the regional densities do indicate important regions within Oregon waters for loons during migration.

Table 2-1. Location filtering parameters for species-tag combinations.
Maximum velocity estimates were approximated following Spear and Ainley (1997). Angles and distance limits were used in speed-distance-angle (SDA) filtering of raw ARGOS locations (see Freitas 2012).

Species	Tag	V max	Angle 1	Angle 2	Distance Limit 1	Distance Limit 2
BFAL	ARGOS	30	15	25	2500	5000
BRAC	GPS	45	15	25	2500	5000
COMU	ARGOS	35	15	25	250	500
LAAL	ARGOS	30	15	25	2500	5000
NOFU	ARGOS	40	15	25	2500	5000
PALO	ARGOS	30	25	40	2500	5000
PFSH	ARGOS	30	15	25	250	500
RTLO	ARGOS	30	25	40	2500	5000
SOSH	ARGOS	35	15	25	2500	5000
STAL	GPS	40	15	25	2500	5000
WEGU	GPS	60	15	25	2500	5000

2.1.3 Processing Scripts and Functions

The Oregon Seabird Telemetry Inventory is based on a series of scripts implemented in R (R Core Development Team 2020) designed to input raw tracking data and run through the methods outlined above (https://github.com/raorben/seabird_tracking_atlas). The scripts are reliant on a metadata table (*STA_metadata.rda*) with information on each individual in the dataset and associated raw tracking file. The scripts are also reliant on a hard-coded file directory system where raw and processed datafiles are stored along with plots useful in assessing the dataset. The data from each tracked individual are stored in a '.csv' file and needs standard column names for date, time, latitude, longitude, and individual identification. When bird metadata (e.g., id, band, capture date and time, file name) are added to the master list (*STA_metadata.rda*), each track gets a unique id. This id is used in the data processing codes. We chose this approach as it is consistent with the current file structure of the *California Current Ecosystem Seabird Telemetry Atlas*. Processed datafiles are stored periodically as '.rda' files to allow users to start in the middle of the workflow and maintain formatting within the R environment. This is convenient for changing grouping variables, polygons, and for plotting. The track pre-processing is done with the script 'STA_TrackPrepFilter.R' that is reliant on a series of functions: 'track_prep_filter', 'tf_filt_sum', 'tf_filt_error' (Figure 2-1).

The second script 'STA_2_BrownianBridges' uses a series of functions to group and segment the tracks depending on the preferred study region polygon (user specified) and grouping variable (e.g., all, year, season). After the segments are identified the individual Brownian bridges are calculated and combined (Figure 2-1). At the individual, level a regional polygon might contain several independent track segments that enters and exits from a polygon of interest. Because BBUDs for segments sum to 1, it is first necessary to weight segments by duration before summing. Once summed, the combined individual utilization distribution must be rescaled to sum to 1 before individuals are combined to represent seasons, years, or any other grouping factor. For example, a group with 30 individuals would be expected to have a summed UD = 30 (i.e., each individual's BBUD sums to 1). The resulting raster outputs can be plotted and are saved as '.rda' and '.asc' files so that they can be imported back into R or GIS software (e.g., ArcGIS, QGIS), respectively.

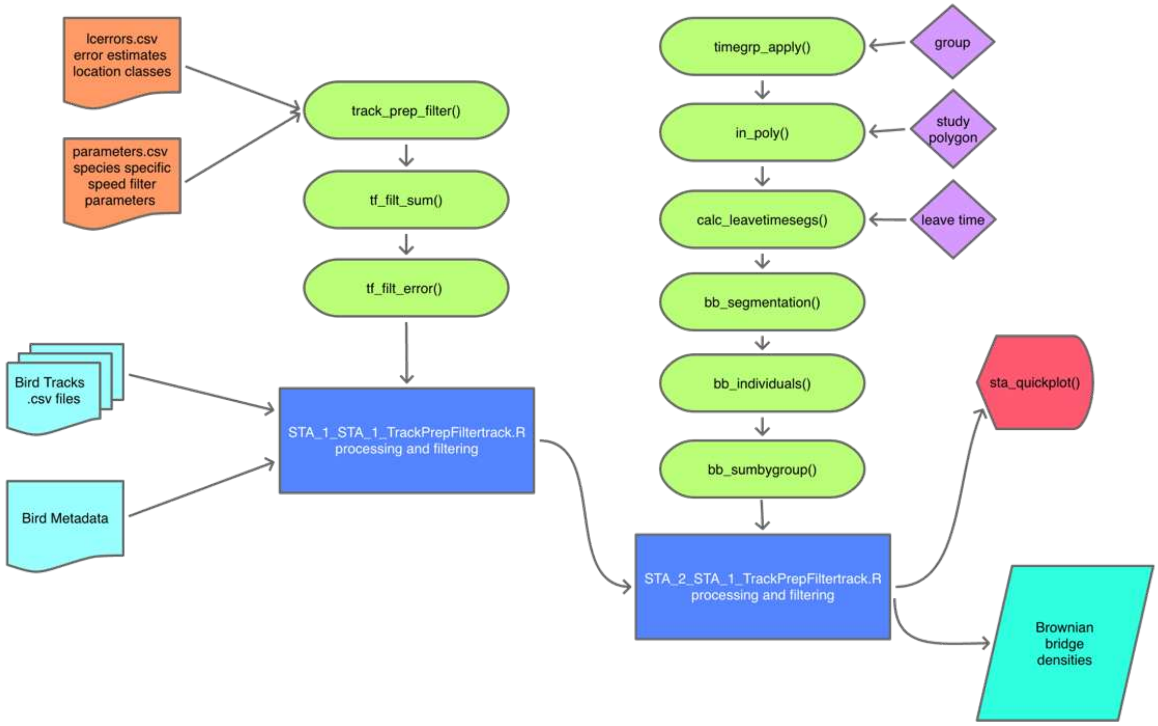


Figure 2-1. Schematic of processing scripts and functions for the Oregon Seabird Telemetry Inventory.
The two processing scripts are shown in dark blue squares with the associated functions in green. The data starts as individual .csv files for each track and bird metadata is added to a master datafile. The user can specify filtering parameters using the two files (orange). Other user inputs are the group (year, all, season), study polygon, and how long an individual can leave the polygon before the track is segmented. The outputs are the raster datafiles and a standard plot showing the filtered tracks, sample sizes, and Brownian bridge utilization distributions.

2.1.4 Species Datasets

Tracking data for eleven species were evaluated here. The data are owned by multiple scientists and entities and were collected over two decades (1999-2019). The practice of routinely publishing animal telemetry data lagged the initial ground-breaking studies, thus older data are less likely to be publicly available. The data sets evaluated here are summarized by year, site, and data owner (Table 2-2). Details of the tracking devices used are either in Chapter 1 of this report or in the published studies or datasets (Table 2-2).

Table 2-2. Oregon Seabird Telemetry Inventory dataset summary.
This is a compilation of available seabird telemetry data that overlap with Pacific waters off OR and the Northern California Current. A dataset was considered to be discrete for each year, site, and data owner/contact provided. The location type is listed as either Argos or GPS to provide an indication of the accuracy of the location data. Only those birds that entered the study region are listed here, but many of these tracking datasets contain additional individuals that did not enter the study region.

Species	Year	Deployment Site	Data Contact	Fix type	# Birds in nCCS	# Birds in OR	References
BFAL	2005	Cordell Bank, CA	Michelle Hester	Argos	2	2	Marrero et al. 2013, Guy et al. 2013
BFAL	2007	Cordell Bank, CA	Michelle Hester	Argos	1	1	Marrero et al. 2013, Guy et al. 2013
BFAL	2008	Cordell Bank, CA	Michelle Hester	Argos	1	1	Marrero et al. 2013, Guy et al. 2013
BFAL	1998	Tern Island, HI	David Anderson	Argos	4	4	Hyrenbach et al. 2002
BFAL	1999	Tern Island, HI	David Anderson	Argos	1	1	Hyrenbach et al. 2002
BFAL	2003	Tern Island, HI	Scott Shaffer	Argos	1	1	Kappes et al. 2010
BFAL	2005	Tern Island, HI	Scott Shaffer	Argos	1	1	Kappes et al. 2010
BFAL	2008	Kure Atoll, HI	Michelle Hester	Argos	1	1	Marrero et al. 2013, Guy et al. 2013
BRAC	2019	Columbia River, OR	Rachael Orben	GPS	17	17	Unpublished dataset[1]
COMU	2012	Columbia River Plume, OR	Josh Adams	Argos	15	15	Phillips et al. 2018, Loredo et al. 2019
COMU	2013	Columbia River Plume, OR	Josh Adams	Argos	15	15	Phillips et al. 2018, Loredo et al. 2019
COMU	2015	Yaquina Head, OR	Rachael Orben	Argos	10	10	Loredo et al. 2019
COMU	2016	Yaquina Head, OR	Rachael Orben	Argos	7	7	Loredo et al. 2019
COMU	2017	Yaquina Head, OR	Rachael Orben	Argos	9	9	Loredo et al. 2019
LAAL	2003	Guadalupe Island, Mexico	Bill Henry	Argos	1	1	Henry et al. 2021
LAAL	2005	Guadalupe Island, Mexico	Bill Henry	Argos	1	1	Henry et al. 2021
NOFU	2002	Chagulak Island, Alaska	Scott Hatch	Argos	1	1	Hatch et al. 2010, Hatch et al. 2020
NOFU	2003	Semidi Islands, Alaska	Scott Hatch	Argos	3	3	Hatch et al. 2010, Hatch et al. 2020
PALO	2016	Yukon-Kuskokwim Delta, AK	Joel Schmutz	Argos	12	11	Harrison et al. 2020
PFSH	2011	Isla Mocha, Chile	Peter Hodum	Argos	2	2	Felis et al. 2019
PFSH	2013	Isla Mocha, Chile	Peter Hodum	Argos	1	1	Felis et al. 2019
PFSH	2015	Isla Mocha, Chile	Josh Adams	Argos	3	3	Felis et al. 2019
PFSH	2009	Santa Barbara Channel, CA	Josh Adams	Argos	2	2	Felis et al. 2019
PFSH	2013	Santa Barbara Channel, CA	Josh Adams	Argos	3	3	Felis et al. 2019
RTLO	2008	Arctic Coastal Plain, AK	Joel Schmutz	Argos	1	0	Uher-Koch et al. 2017, McCloskey et al. 2018
RTLO	2000	Copper River Delta, AK	Joel Schmutz	Argos	3	3	Uher-Koch et al. 2017, McCloskey et al. 2018

Species	Year	Deployment Site	Data Contact	Fix type	# Birds in nCCS	# Birds in OR	References
RTLO	2001	Copper River Delta, AK	Joel Schmutz	Argos	1	1	Uher-Koch et al. 2017, McCloskey et al. 2018
RTLO	2001	Seward Peninsula, AK	Joel Schmutz	Argos	1	0	Uher-Koch et al. 2017, McCloskey et al. 2018
RTLO	2000	Yukon-Kuskokwim Delta, AK	Joel Schmutz	Argos	2	2	Uher-Koch et al. 2017, McCloskey et al. 2018
RTLO	2001	Yukon-Kuskokwim Delta, AK	Joel Schmutz	Argos	1	0	Uher-Koch et al. 2017, McCloskey et al. 2018
SOSH	2005	Columbia River Plume, OR	Josh Adams	Argos	3	2	Adams et al. 2012, Phillips et al. 2018
SOSH	2008	Columbia River Plume, OR	Josh Adams	Argos	7	6	Adams et al. 2012, Phillips et al. 2018
SOSH	2009	Columbia River Plume, OR	Josh Adams	Argos	5	5	Adams et al. 2012, Phillips et al. 2018
SOSH	2004	Monterey Bay, CA	Josh Adams	Argos	1	1	Unpublished data[2]
SOSH	2005	Monterey Bay, CA	Josh Adams	Argos	1	1	Unpublished data[2]
SOSH	2007	Monterey Bay, CA	Josh Adams	Argos	1	1	Unpublished data[2]
SOSH	2008	Monterey Bay, CA	Josh Adams	Argos	5	5	Adams et al. 2012, Phillips et al. 2018
SOSH	2009	Monterey Bay, CA	Josh Adams	Argos	8	8	Adams et al. 2012, Phillips et al. 2018
SOSH	2008	Santa Barbara Channel, CA	Josh Adams	Argos	3	1	Adams et al. 2012, Phillips et al. 2018
SOSH	2009	Santa Barbara Channel, CA	Josh Adams	Argos	6	5	Adams et al. 2012, Phillips et al. 2018
STAL	2009	Mukujima, Japan	Rob Suryan	GPS	3	3	Deguchi et al. 2017, Orben et al. 2018
STAL	2011	Mukujima, Japan	Rob Suryan	GPS	1	1	Deguchi et al. 2017, Orben et al. 2018
STAL	2012	Mukujima, Japan	Rob Suryan	GPS	1	1	Deguchi et al. 2017, Orben et al. 2018
STAL	2009	Torishima, Japan	Rob Suryan	GPS	1	1	Deguchi et al. 2017, Orben et al. 2018
STAL	2010	Torishima, Japan	Rob Suryan	GPS	2	2	Deguchi et al. 2017, Orben et al. 2018
STAL	2012	Torishima, Japan	Rob Suryan	GPS	2	2	Deguchi et al. 2017, Orben et al. 2018
WEGU	2015	Cleft-in-the-Rock, OR	Rachael Orben	GPS	5	5	Unpublished dataset[3]
WEGU	2016	Cleft-in-the-Rock, OR	Rachael Orben	GPS	11	11	Unpublished dataset[3]

Species	Year	Deployment Site	Data Contact	Fix type	# Birds in nCCS	# Birds in OR	References
WEGU	2016	Hunters Island, OR	Rachael Orben	GPS	12	12	Unpublished dataset[3]
WEGU	2016	South Jetty, Newport, OR	Rachael Orben	GPS	1	1	Unpublished dataset[3]
WEGU	2017	Cleft-in-the-Rock, OR	Rachael Orben	GPS	8	8	Unpublished dataset[3]
WEGU	2017	Hunters Island, OR	Rachael Orben	GPS	9	9	Unpublished dataset[3]
WEGU	2017	South Jetty, Newport, OR	Rachael Orben	GPS	1	1	Unpublished dataset[3]
WEGU	2018	Cleft-in-the-Rock, OR	Rachael Orben	GPS	5	5	Unpublished dataset[3]

[1] Brandt's Cormorant Tracking was funded by the Office of Naval Research under Award No. N00014-19-1-2218. Tagging was conducted under USGS Bird Banding Lab Permit 05271, Oregon State University Animal Care and Use Permit 5062, and Oregon State Permit 060-19.

[2] Sooty Shearwaters tagging in Monterrey Bay was supported in part by Moss Landing Marine Laboratories, NOAA Northwest Fisheries Science Center, the US Geological Survey Western Ecological Research Center, the Oiled Wildlife Care Network, Wildlife Health Center, School of Veterinary Medicine at the University of California at Davis, NOAA Monterey Bay National Marine Sanctuary, and UC Santa Cruz, Tagging of Pacific Pelagics and authorized under San Jose State University Research Foundation Institutional Animal Care and Use Committee (J.T. Harvey and J. Adams: 807, 929), USGS-WERC Study Plan Project No. 9370BQ9- TSK1102 and CA Department of Fish and Game, Scientific Collecting Permit 6443.

[3] Western Gull tracking was funded under this award. Refer to the acknowledgments for this report.

2.1.4.1 Black-footed Albatross (*Phoebastria nigripes*)

Black-footed Albatross (BFAL) are one of the three albatross species in the North Pacific. Black-footed Albatross have been tracked from their breeding colonies in the Northwestern Hawaiian Islands (Hyrenbach et al. 2002, Hyrenbach and Dotson 2003, Kappes et al. 2010, Hyrenbach et al. 2017), caught at sea off central California (Marrero et al. 2013, Guy et al. 2013), and in the Aleutians (Fischer et al. 2009). Early data 1998-2008, are from Argos-PTTs deployed during the life-history stages (incubation, chick rearing) when individuals might reach the US West Coast during central place foraging trips (Hyrenbach et al. 2002, Kappes et al. 2010, Hyrenbach et al. 2017). There are more recent GPS tracking data available during breeding, however tracks do not reach the US West Coast (e.g., Orben et al. 2021). Geolocation data from non-breeding Black-footed Albatross include birds that use waters off of the US West Coast (Conners 2015, S.A. Shaffer, unpublished data).

2.1.4.2 Brandt's Cormorant (*Urile penicillatus*)

In 2019, Brandt's Cormorants (BRAC) were tagged with GPS-GSM transmitters in May-September (n = 22, Ornitela, Vilnius, Lithuania, Orni-Track30). Tracking efforts are on-going, but local dispersal along the coast of Washington in the spring and fall indicated some offshore habitat use by this species, though birds predominantly disperse north from the Columbia River. One individual dispersed from the Columbia River and spent time in Gulf of the Farallones, San Francisco Bay, and off Long Beach, California. There are additional GPS tracking data from the Columbia River, but locations are largely within the estuary (Peck-Richardson et al. 2018).

2.1.4.3 Common Murre (*Uria aalge*)

Common Murre (COMU) tracking data on the Oregon coast was limited to Argos quality locations from biologging tags deployed at two locations. Transmitters were deployed in the region of the Columbia River Plume in early spring (n = 26) during 2012 and 2013 (Phillips et al. 2018). Birds were caught and tagged near the Yaquina Head breeding colony in spring (n = 15, 2015-2017) and off Newport in late summer (n = 9, 2016-2017). Tracking duration was contingent on programming, tag type, and attachment duration. Transmitters deployed in 2013, 2014, and 2015 lacked solar panels and were programmed to capture near-complete diving records (Phillips et al. 2018, Loredo et al. 2019), thus tracking data were limited to May-July. Tags deployed in 2016 and 2017, were solar powered and optimized for longer duration deployments and some tracks lasted into the early winter (Loredo 2018).

2.1.4.4 Laysan Albatross (*Phoebastria immutabilis*)

Laysan Albatross (LAAL) breed at multiple colonies in the Hawaiian Islands; however, multiple tracking studies indicated that while breeding, birds nesting there did not venture into the US EEZ along the US West Coast (Kappes et al. 2010, Adams et al. 2019). Laysan Albatross also nest on Guadalupe Island, Mexico and these birds occupied the California Current System (Henry et al. 2021). Laysan Albatross were tracked via Argos PTTs in 2003, 2005, and 2007 resulted in two individuals that entered the US EEZ off of Oregon (Henry et al. 2021). Additional GPS tracking data has occurred on Guadalupe Island since 2014, but these data are not included here (Bird Life International Seabird Tracking Database #964 and #965).

2.1.4.5 Northern Fulmar (*Fulmarus glacialis*)

Northern fulmars (NOFU) were tracked using Argos-PTTs from four major breeding colonies in Alaska during 2002-2004 (Hatch et al. 2010, Hatch at al. 2020). The transmitters were relatively large (18-38 g) and attached either via Teflon harness or by coelomic implantation. Of the 19 birds tagged, one individual from Chagulak Island, Alaska tagged in 2002 and three individuals tagged in the Semidi Islands in 2003 reached the US EEZ off Oregon.

2.1.4.6 Pacific Loon (*Gavia pacifica*)

In 2016, Pacific Loons (PALO, n = 15), were tagged on the Yukon-Kuskokwim Delta (Harrison et al. 2020). The birds from the Yukon-Kuskokwim Delta migrate to the California Current System and Baja for the winter. Twelve of the tagged individuals entered the US EEZ in the nCCS, while eleven of these entered the waters off Oregon. Distributions were largely coastal; however, birds crossed the Gulf of Alaska and this off-shore crossing results in birds crossing the EEZ off of Oregon and Washington to reach the coast of the western US.

2.1.4.7 Pink-footed Shearwater (*Ardenna creatopus*)

Pink-footed Shearwaters (PFSH, n = 42) were tagged with PTTs at breeding colonies in Chile and at-sea off of southern California from 2006-2015 (Felis et al. 2019). Tags after 2006 were attached via sutures for longer-duration deployments (Felis et al. 2019). Of these, 11 individuals reached the Oregon coast. Obtaining tracking data from individuals along the Oregon coast hinges on both attachment duration and the percentage of individuals that venture to the region (Felis et al. 2019).

2.1.4.8 Red Throated Loon (*Gavia stellata*)

Red-throated Loons (RTLO) were tracked from four breeding locations in Alaska. This species uses areas in the Salish Sea and the US West Coast as fall stopover sites and wintering areas, however very few locations were acquired in the US-EEZ off of Oregon from seven individuals (McCloskey et al. 2018).

2.1.4.9 Short-tailed Albatross (*Phoebastria albatrus*)

Data from Short-tailed Albatrosses (STAL) along the Oregon coast were limited to juveniles. This is not unexpected because at-sea observations of this species in Oregon waters are typically juveniles (Carter and Sealy 2014). In August of 2003, three juvenile Short-tailed Albatrosses were caught at-sea in the Aleutian Islands and Argos PTTs were deployed on them (Suryan et al. 2006, 2007). Of these, one individual visited the Oregon coast. From 2008-2012, annually, ~12 fledglings originating from the Bonin Islands (Ogasawara Islands), Japan were equipped with solar powered GPS-Argos linked tags (Deguchi et al. 2017, Orben et al. 2018). The majority of tags (n = 36) were attached with Tesa tape and resulted in attachment durations of 111 ± 45.7 (max 252) days, the remaining tags (n = 15) were attached via Teflon harnesses and tracking durations lasted 726 ± 488 (max 1750) days (Deguchi et al. 2017, Orben et al. 2018). Most fledglings spent time in the Sea of Okhotsk or the Bering Sea prior to traveling farther east, thus only 10 birds were tracked to the US EEZ off of Oregon.

2.1.4.10 Sooty Shearwater (*Ardenna grisea*)

Sooty Shearwaters (SOSH) are transhemispheric migrants that inhabit the greater California Current System during the spring, summer, and fall months. Sooty Shearwaters were captured at-sea off central California, the mouth of the Columbia River, and in the Santa Barbara Channel in 2008 and 2009 (n = 57) (Adams et al. 2012, Phillips et al. 2018). Before 2008, 52 birds were tagged as part of previous study during 2004-2007 (J. Adams USGS unpublished data). Geolocation data from non-breeding Sooty Shearwaters captured on their breeding grounds in New Zealand included birds that used the waters off of the US West Coast (Shaffer et al. 2006), but those lower-resolution data are not included here.

2.1.4.11 Western Gull (*Larus occidentalis*)

Western Gull (WEGU) tracking was initiated in Oregon in 2015. Western Gulls were tracked from two breeding colonies, one in central Oregon (Cleft-in-the-Rock, Colony #024.5) and the other on the south coast (Hunter's Island, Colony #071) (Naughton et al. 2007). Most birds were tagged in late-May during incubation. GPS-GSM tags allowed locations through chick-rearing; after chicks hatch, birds are much more challenging to recapture. Harness-attached tags (n = 36) and an additional deployment in August (n = 2) allowed for some individuals to be tracked during the winter months.

2.2 Results

2.2.1 Brownian bridge utilization distributions: US EEZ off Oregon and the Northern California Current

Weighted and summed Brownian bridge densities within the US EEZ off Oregon and the Northern California Current showed multiple high-use areas on the continental shelf for the eleven species included here (Figure 2-2 to Figure 2-12). However, individual sample size within the Oregon US EEZ (and nCCS EEZ) were less than twenty individuals for eight of these species (Table 2-3, BFAL, BRAC, LAAL, NOFU, PALO, RTLO, STAL). While both PALO and RTLO had coastal hotspots, tracks indicate that these birds transit across the off-shore US EEZ during their migrations.

2.2.2 Brownian bridge utilization distributions: Seasonal changes (selected species)

Seasonal BBUDs were calculated for locally-breeding Common Murres and migratory Pacific Loons, Short-tailed Albatross, and Sooty Shearwaters (Figure 2-13 to Figure 2-15). Common Murres were tagged in May and August, thus little winter tracking data was obtained (Figure 2-13). The movement of individual birds tracked from Oregon indicated that these birds were farther north during early winter. Common Murres returned to the colony at Yaquina Head in February (BLM unpublished data). Pacific

Loons breed in Alaska and typically are not found off the Oregon coast during summer months. This was reflected in the seasonal distributions that included northbound and southbound migratory movements during spring and fall, respectively (Figure 2-14). Short-tailed Albatrosses were tracked as first-year fledglings and typically did not depart from their colony until late May through early June (Deguchi et al. 2014). Most individuals were present in February and March (winter and spring, Figure 2-15). Individual Sooty Shearwaters were present off the Oregon coast during all four seasons (Figure 2-16); however, numbers of tracked individuals were greatest during summer and fall. These seasonal distributions reflected migration and over wintering (austral) off the US West Coast during their annual non-breeding season (Shaffer et al. 2006, Adams et al. 2012).

Table 2-3: Species sample sizes inside polygons.

Species	Sample Size in US EEZ for Northern California Current	Sample Size in Oregon US EEZ
BFAL	12	12
BRAC	17	17
COMU	56	56
LAAL	2	2
NOFU	4	4
PALO	12	11
PFSH	11	11
RTLO	9	7
SOSH	40	35
STAL	10	10
WEGU	52	52

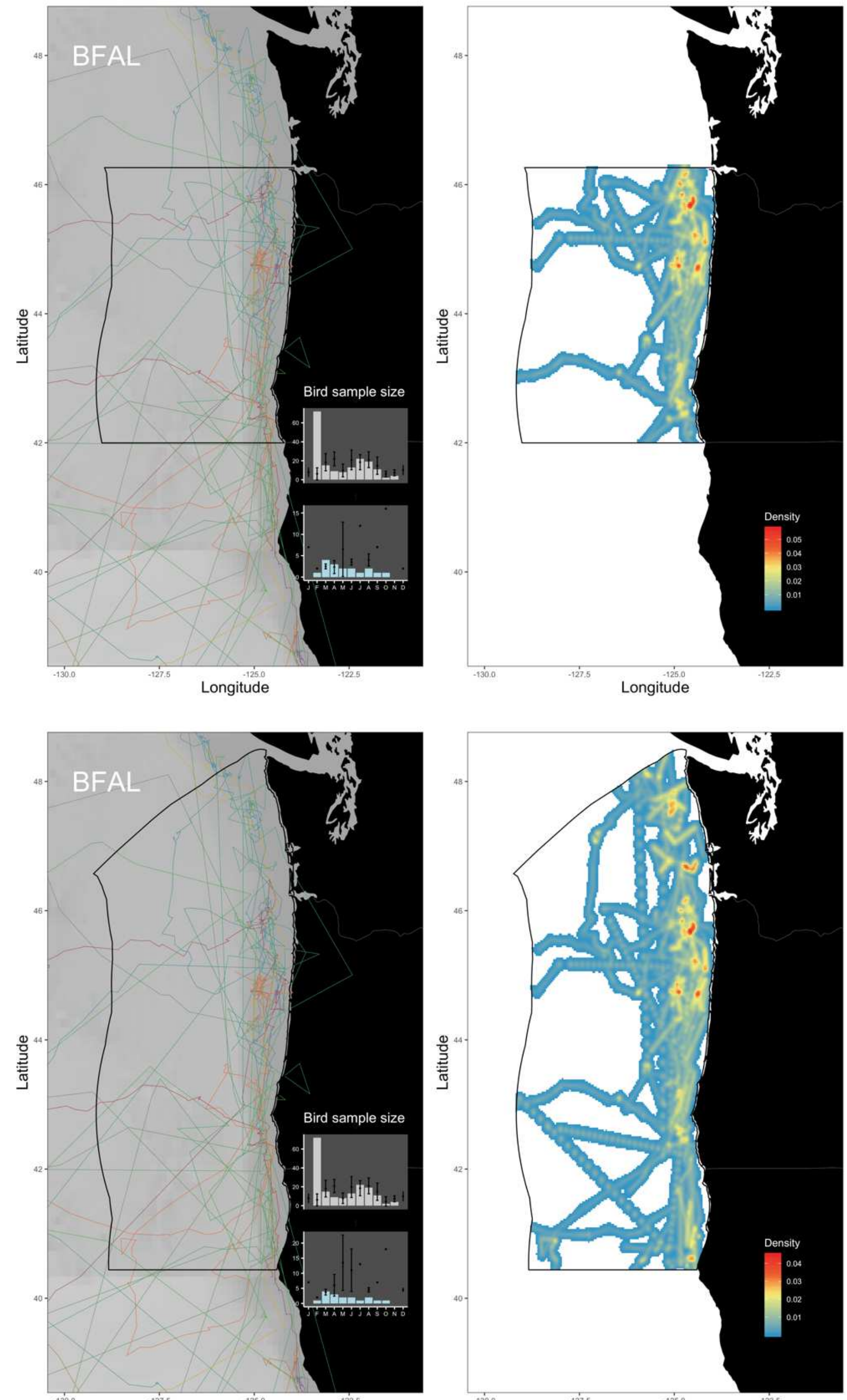


Figure 2-2. Black-footed Albatross Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

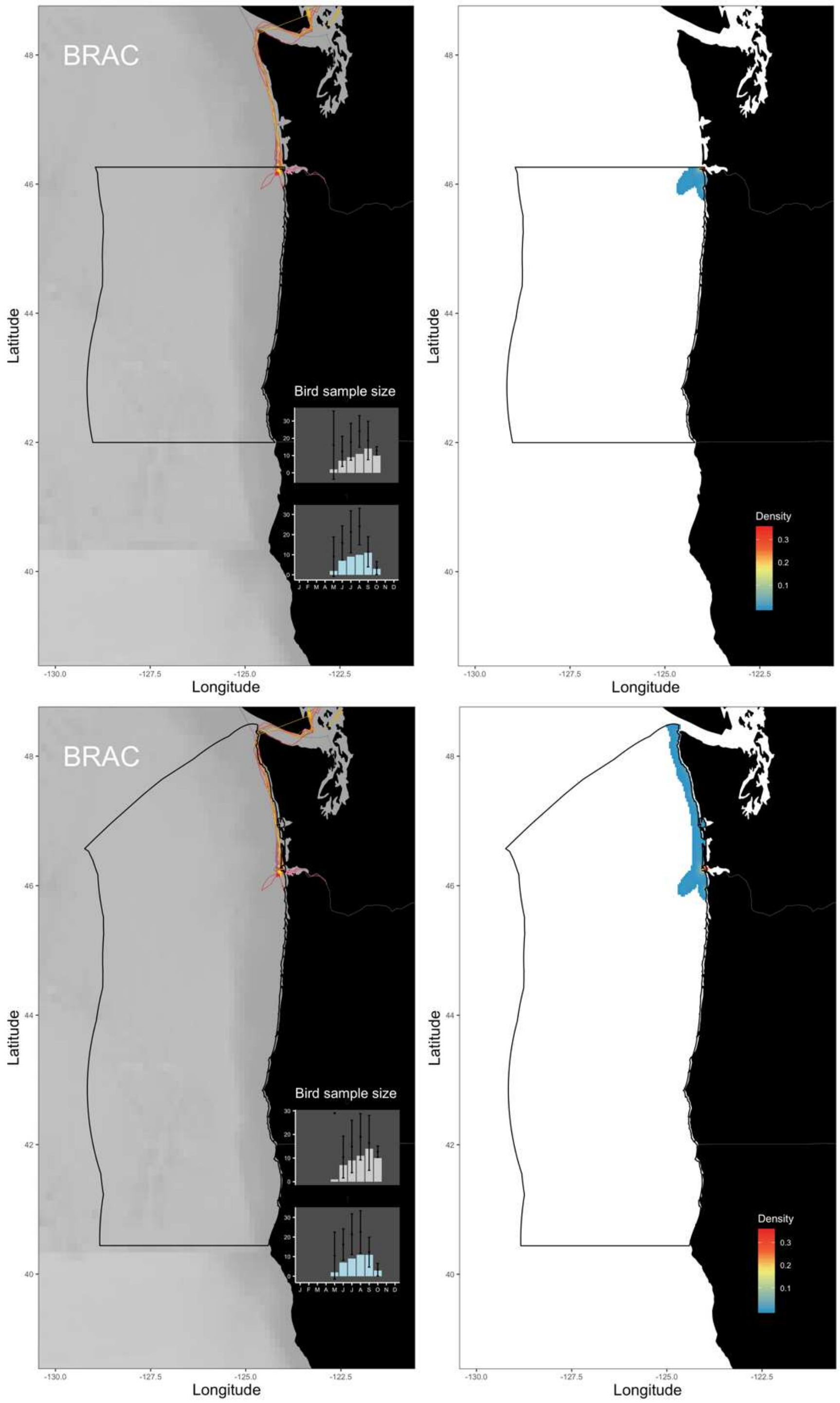


Figure 2-3. Brandt's Cormorant Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.
The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

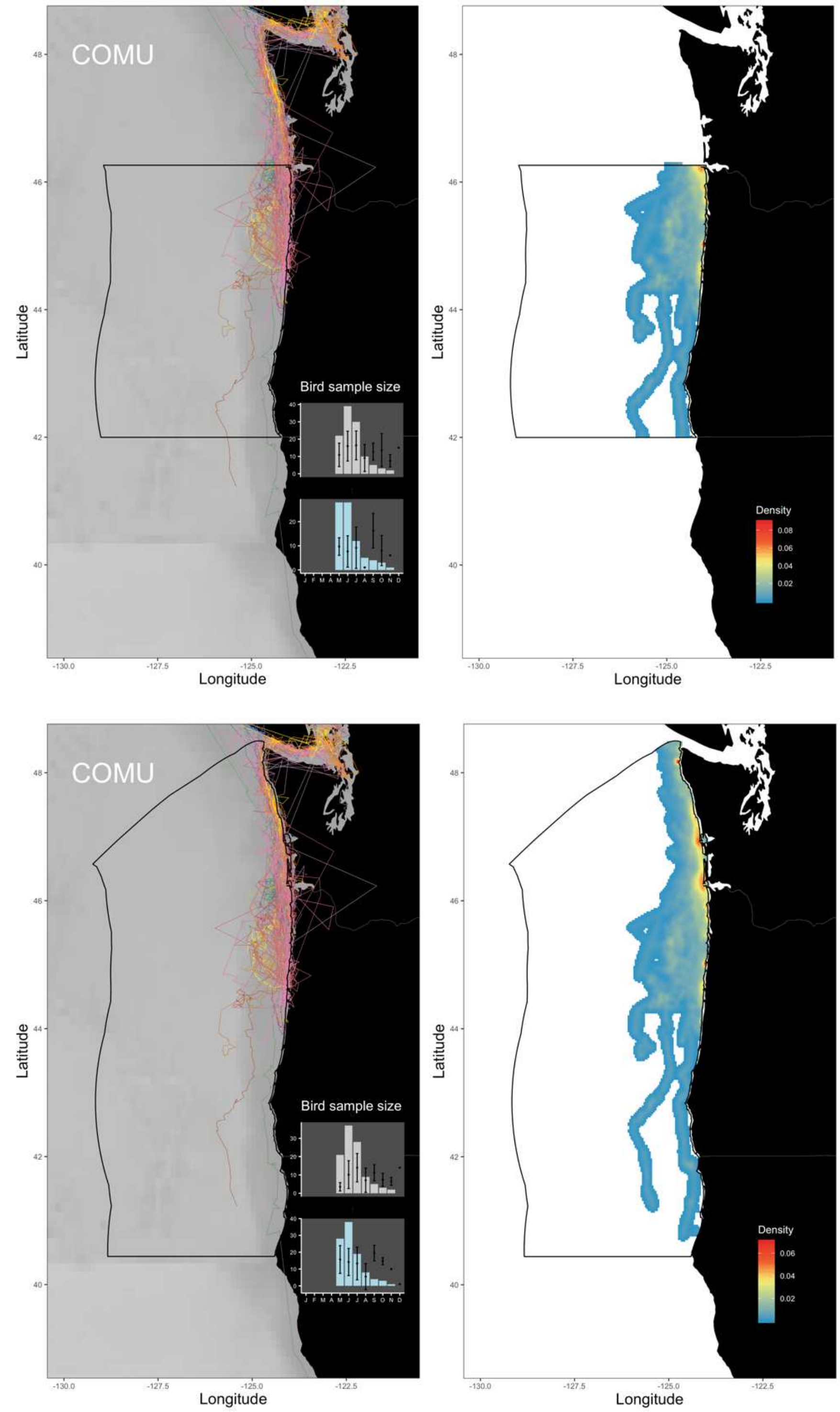


Figure 2-4. Common Murre Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

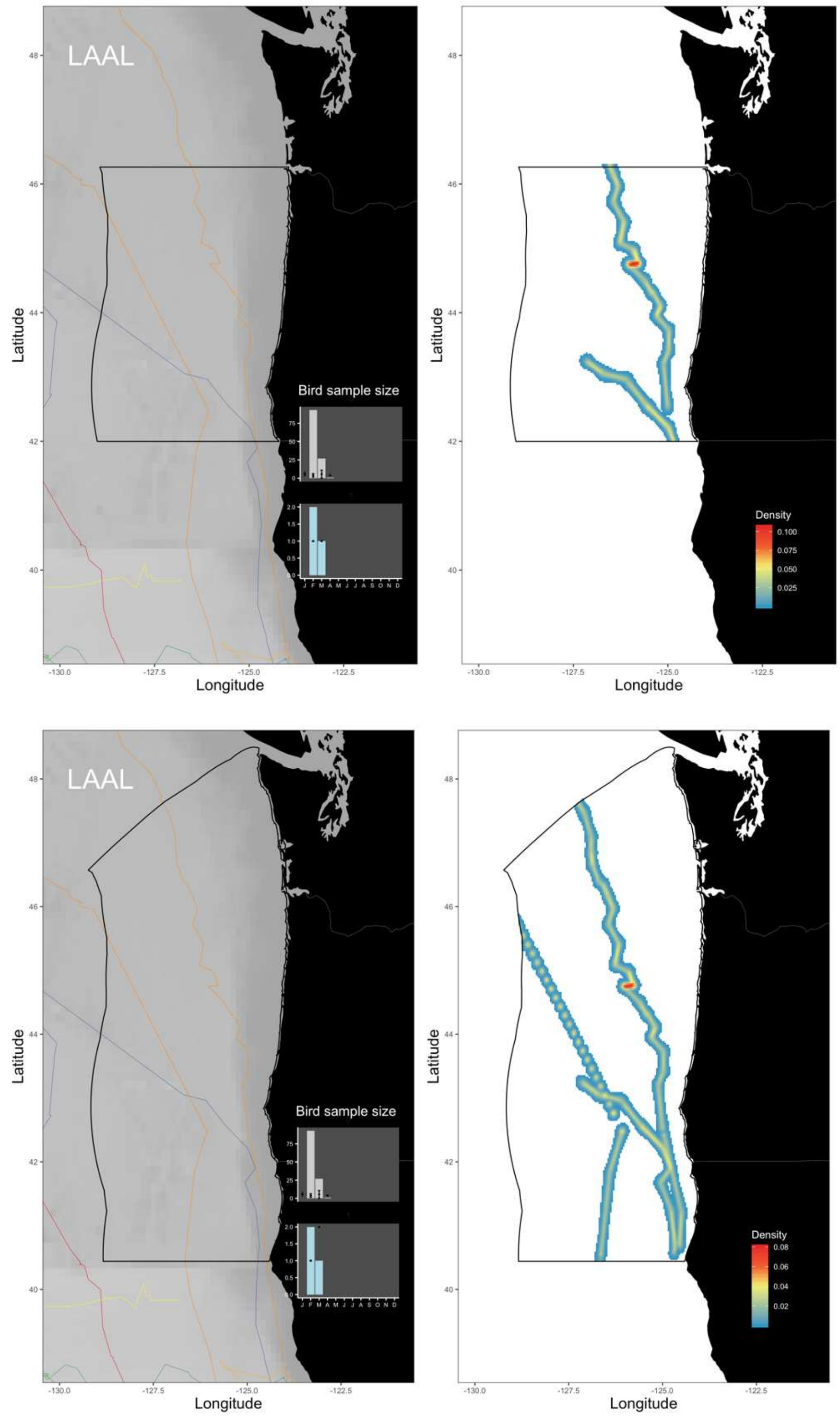


Figure 2-5. Laysan Albatross Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

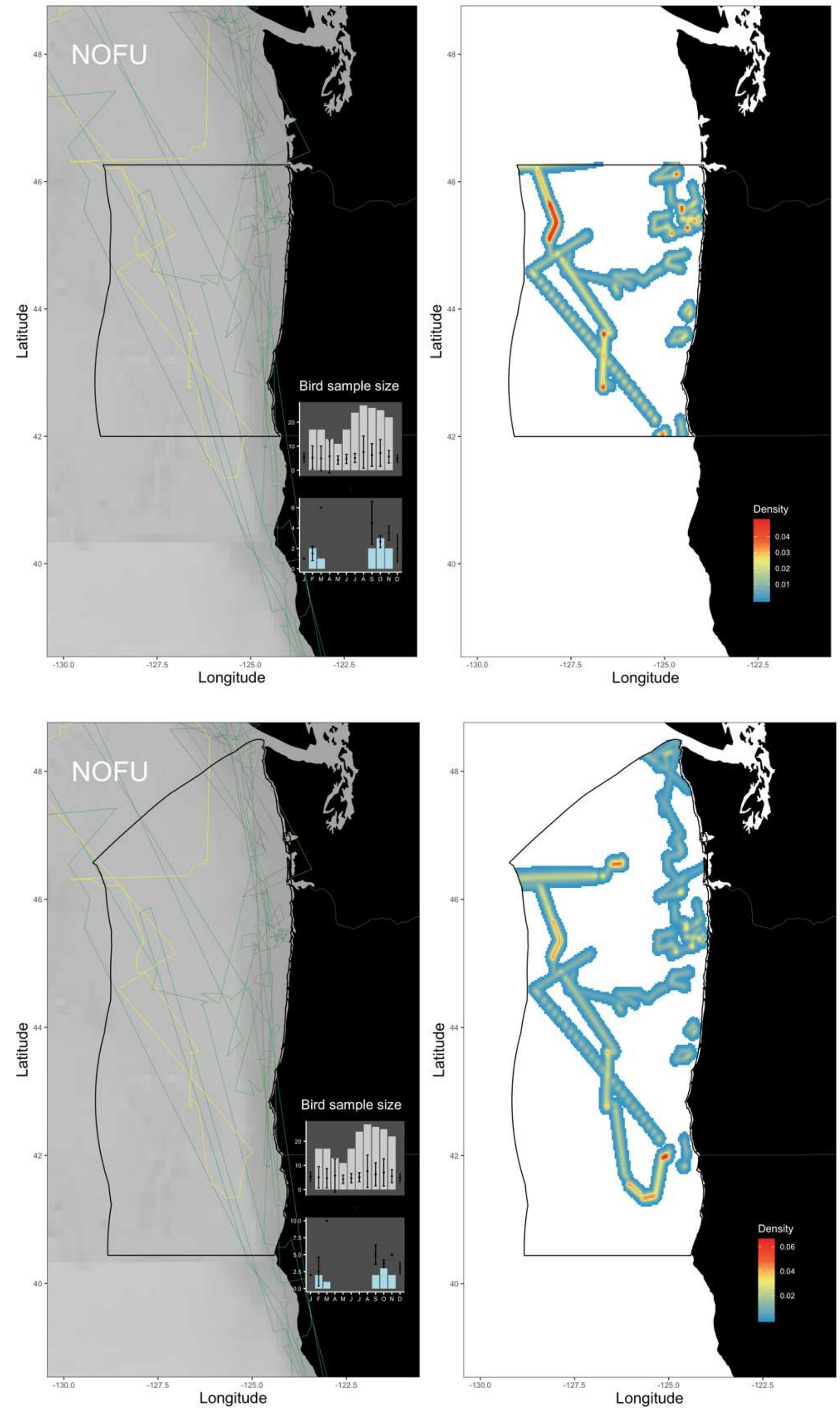


Figure 2-6. Northern Fulmar Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

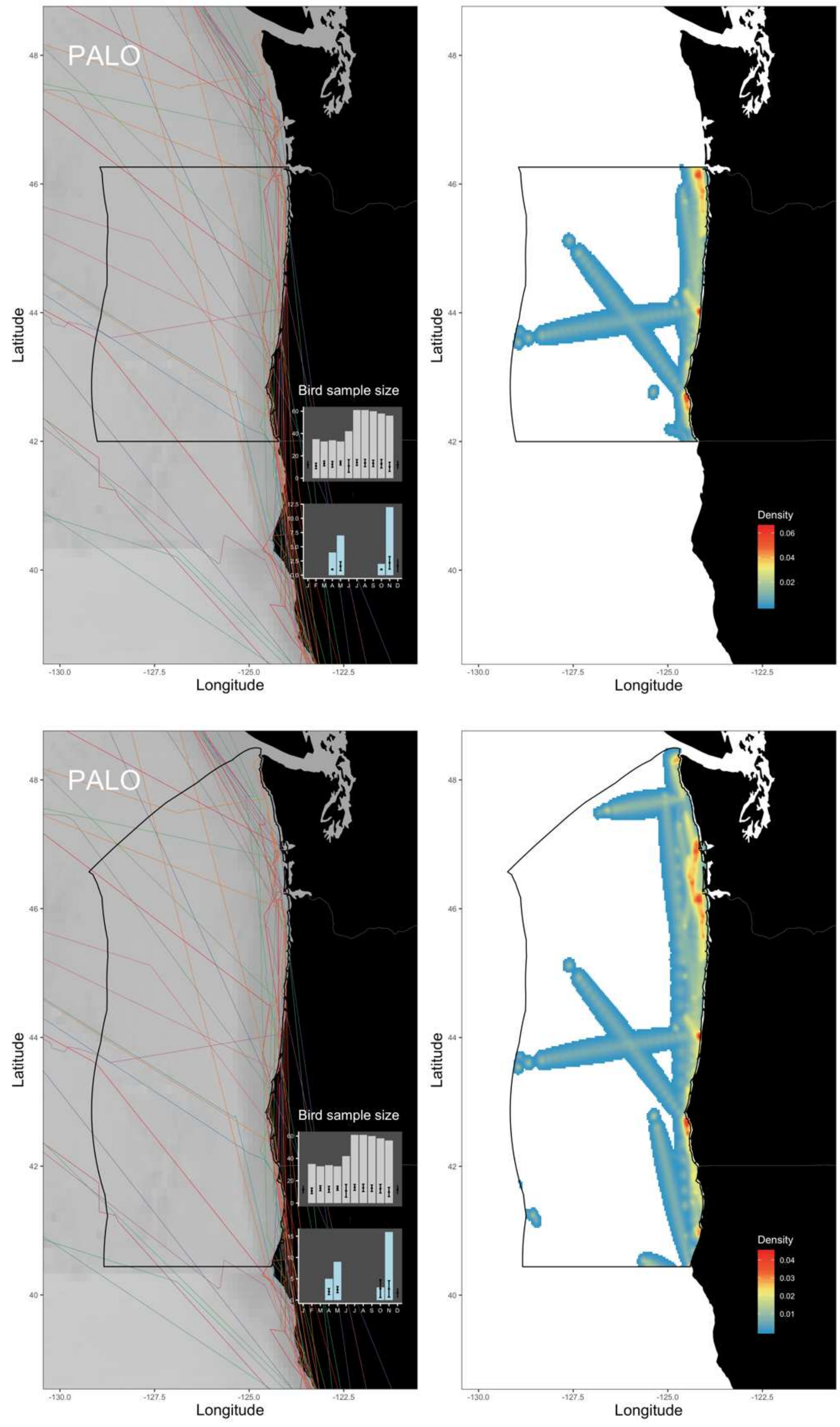


Figure 2-7. Pacific Loon density Brownian bridge utilization distributions the US EEZ off the Oregon coast and the northern California Current.
The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

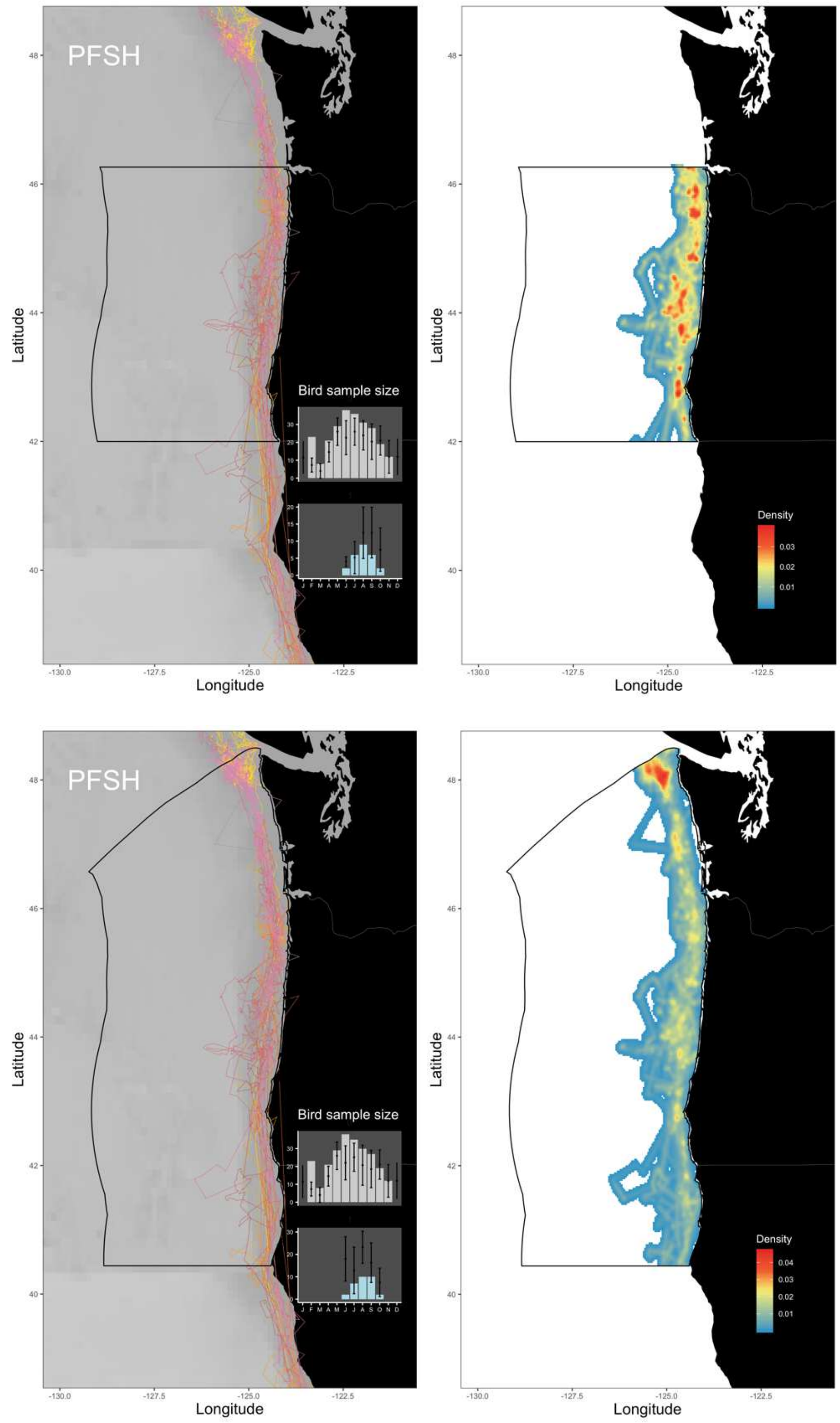


Figure 2-8. Pink-footed Shearwater Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

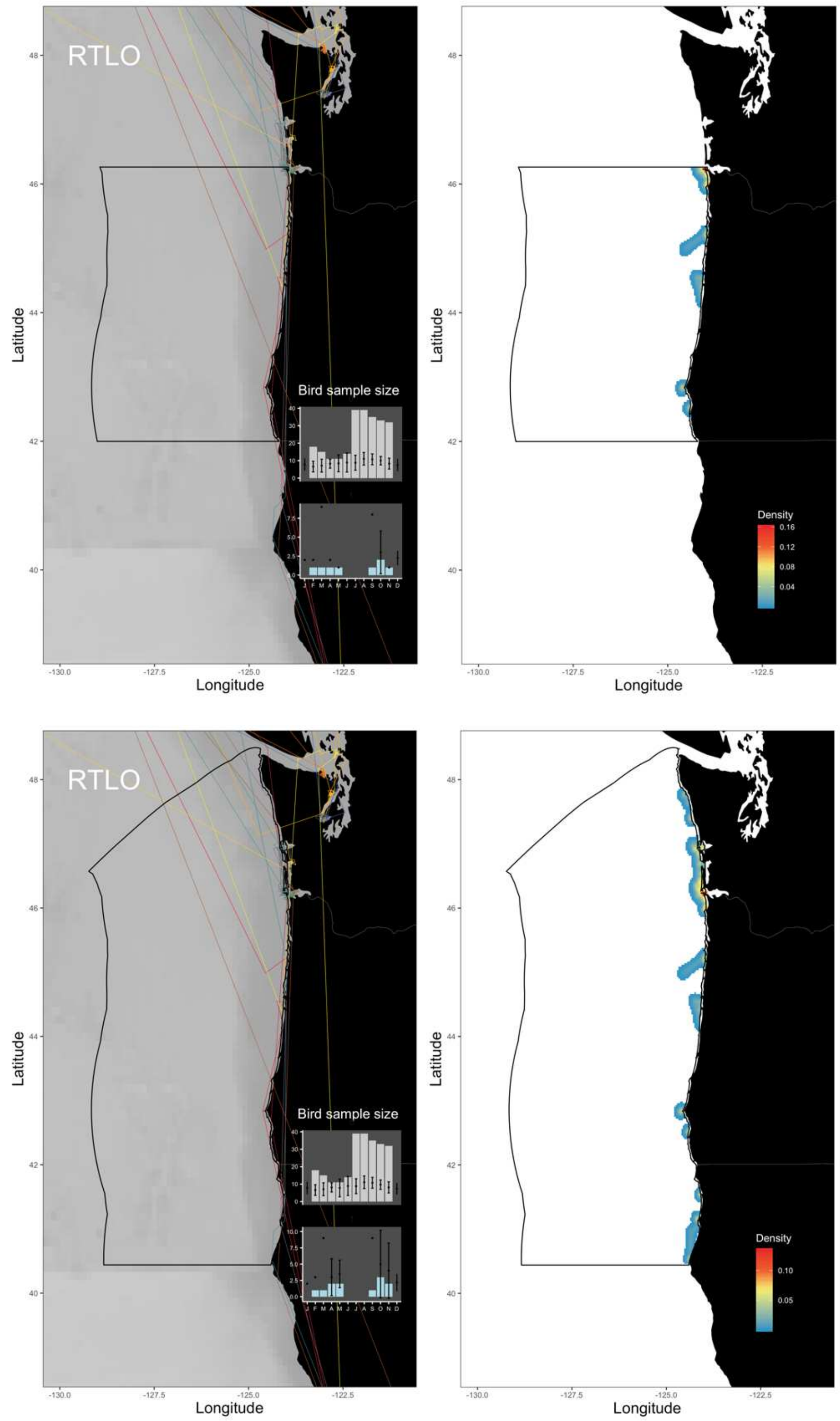


Figure 2-9. Red-throated Loon Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

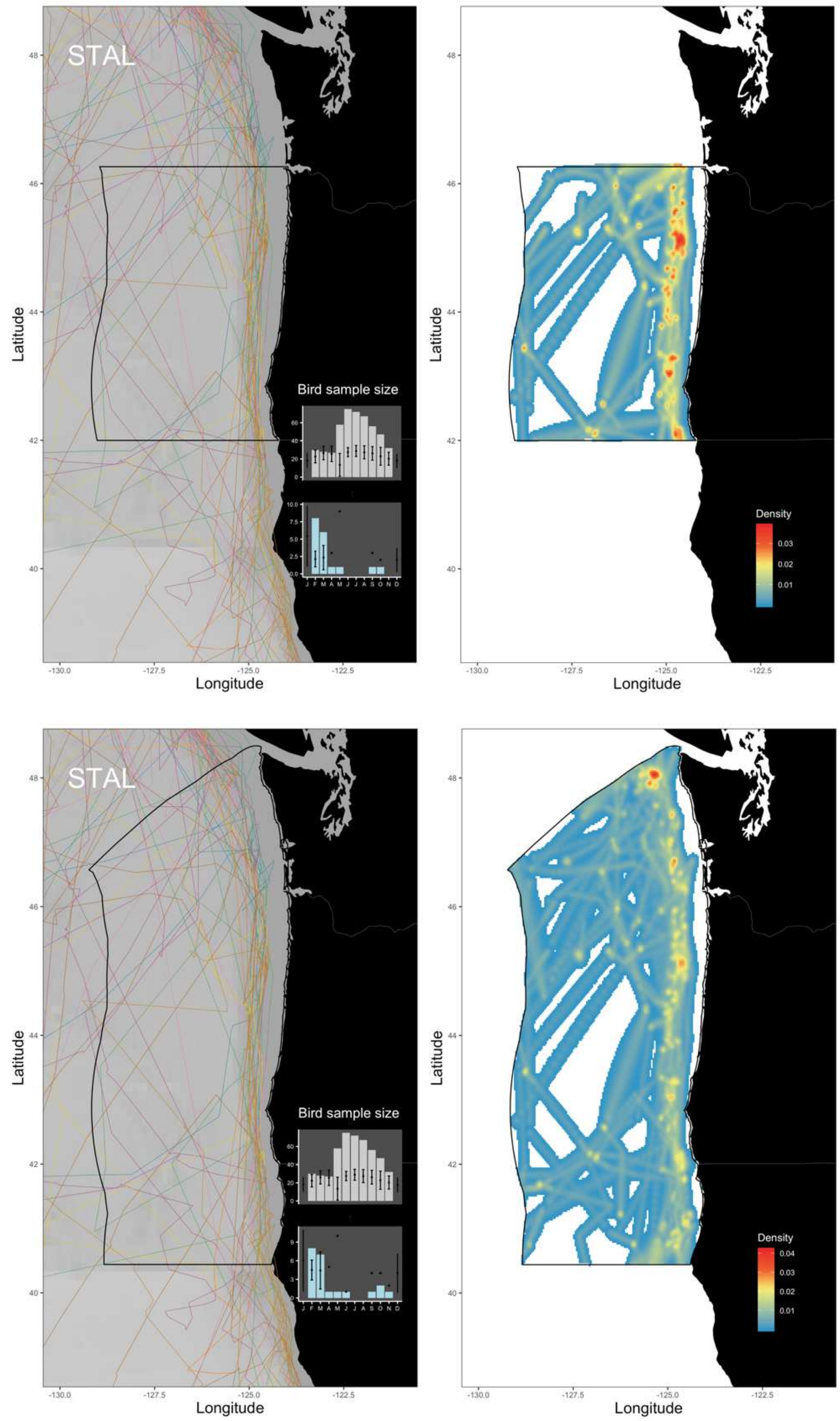


Figure 2-10. Short-tailed Albatross Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

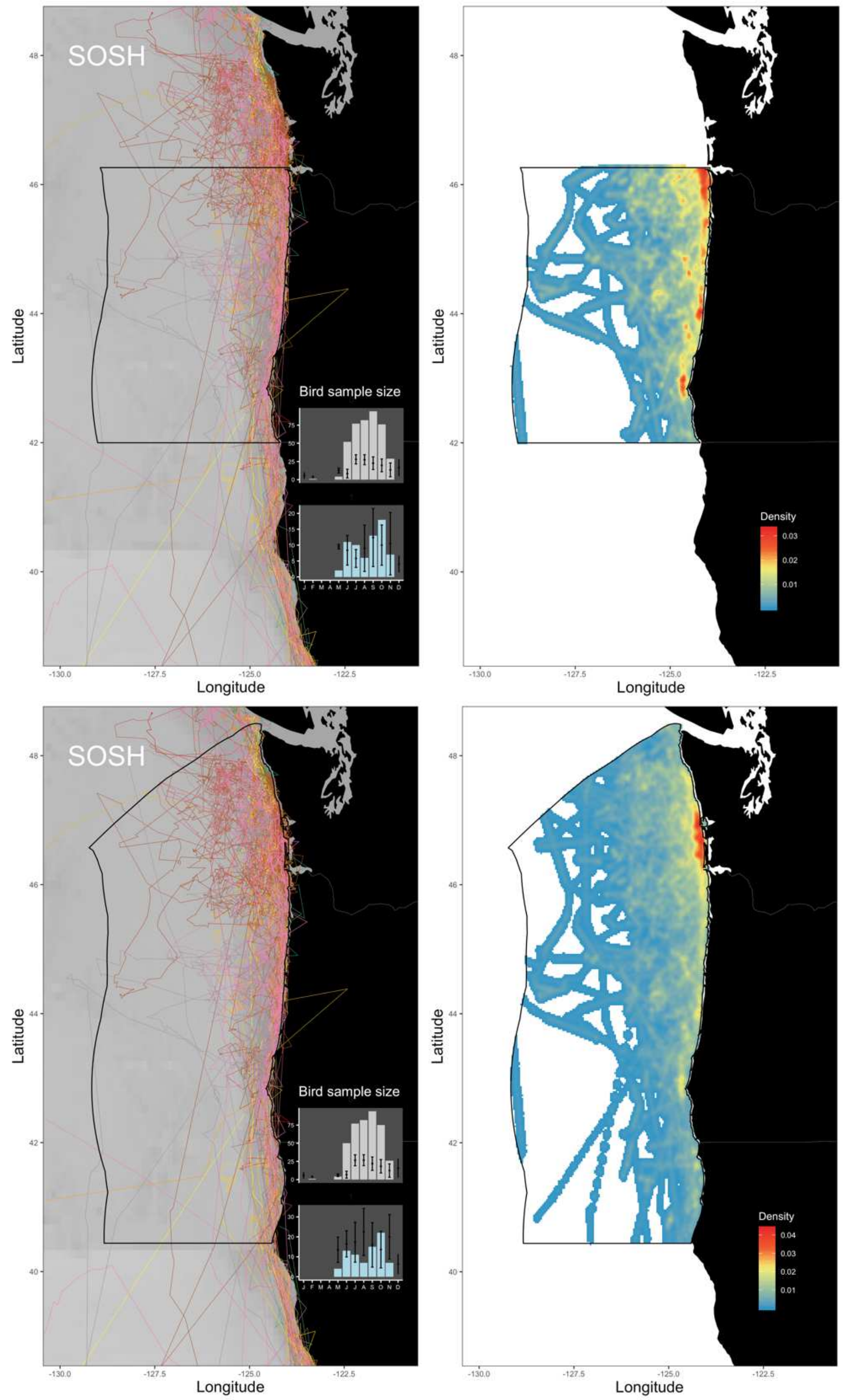


Figure 2-11. Sooty Shearwater Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

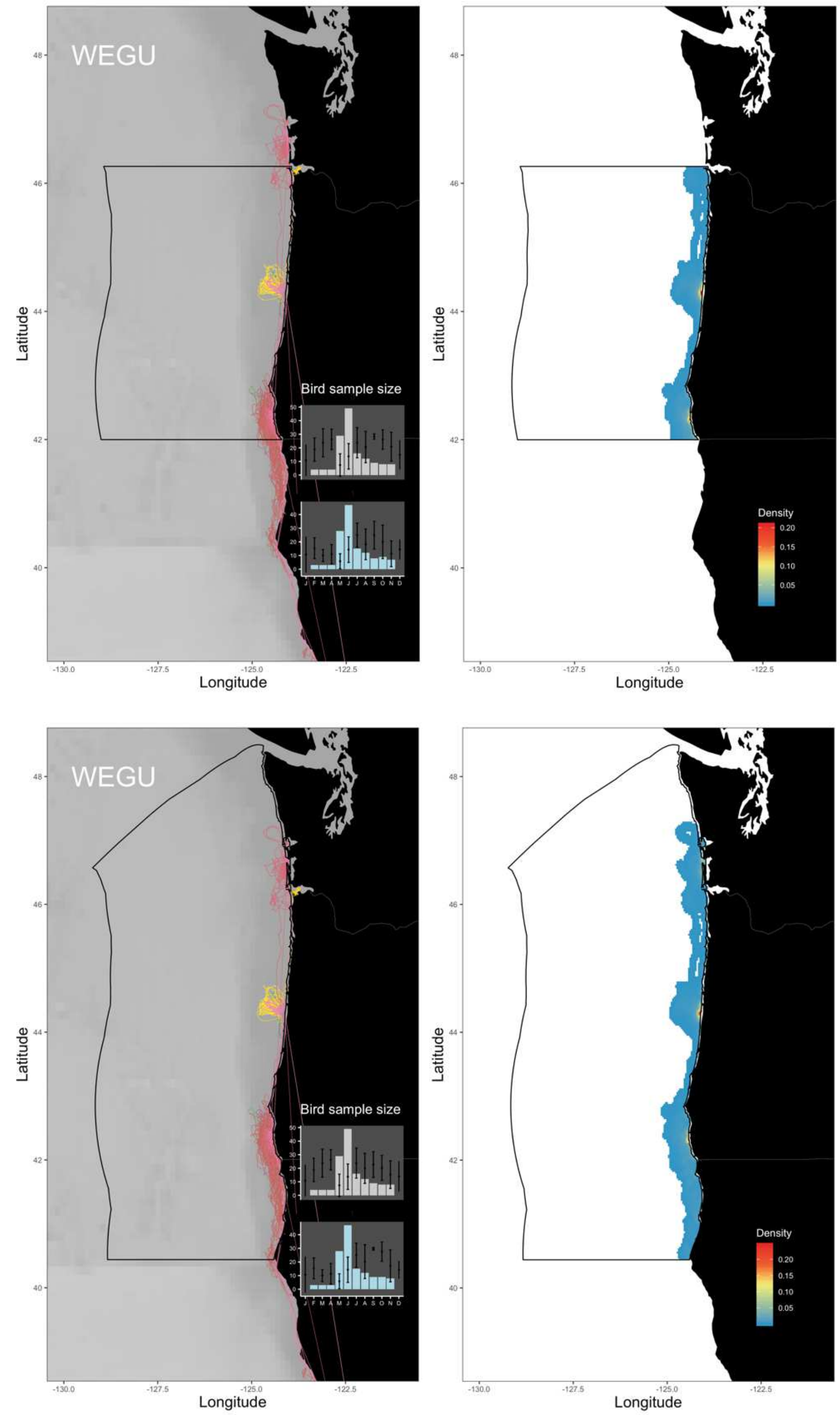


Figure 2-12. Western Gull Brownian bridge utilization distributions within the US EEZ off the Oregon coast and the northern California Current.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

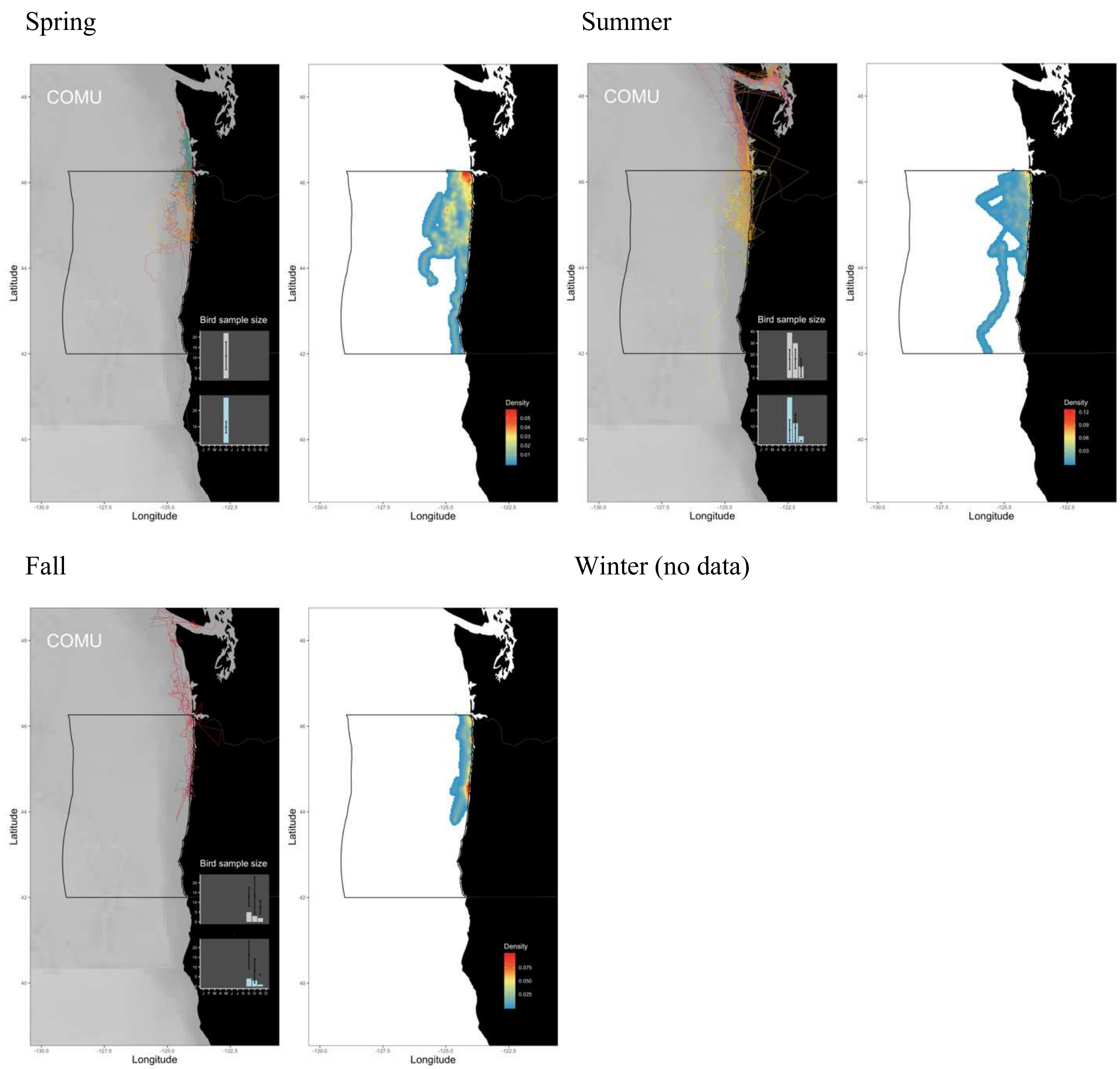
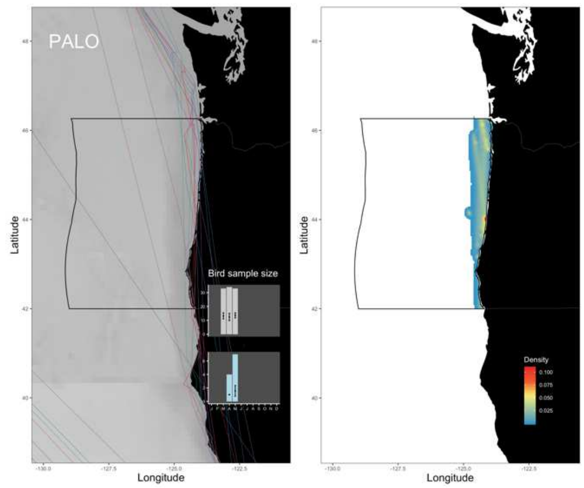


Figure 2-13. Seasonal Common Murre Brownian bridge utilization distributions within the US EEZ off the Oregon coast during spring, summer, and fall.

The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

Spring Summer (none)



Fall Winter

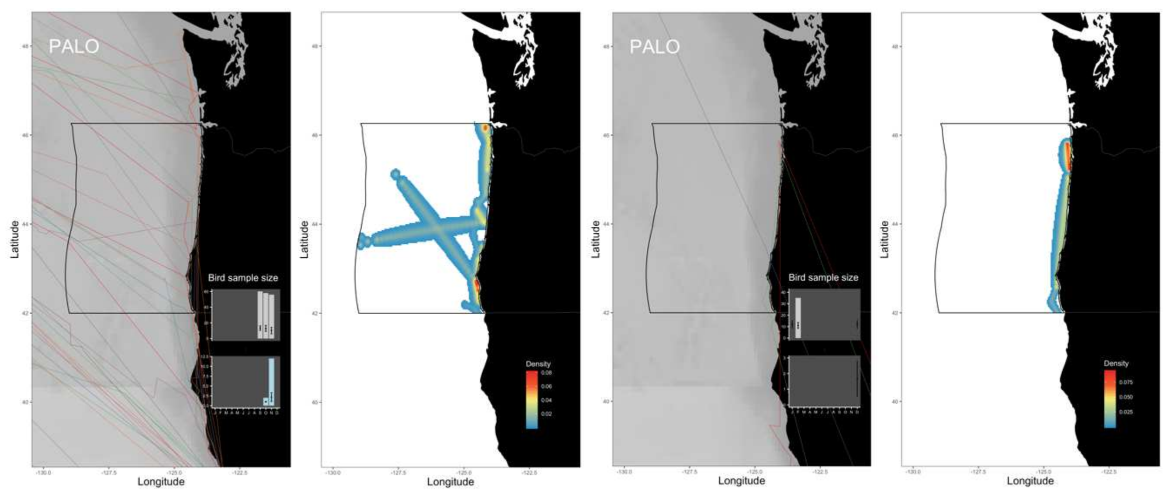
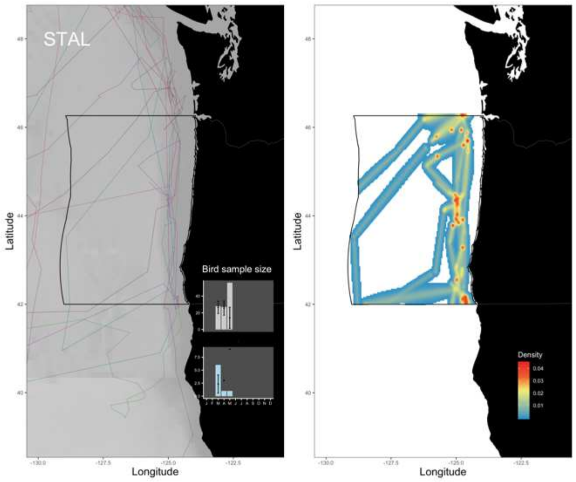


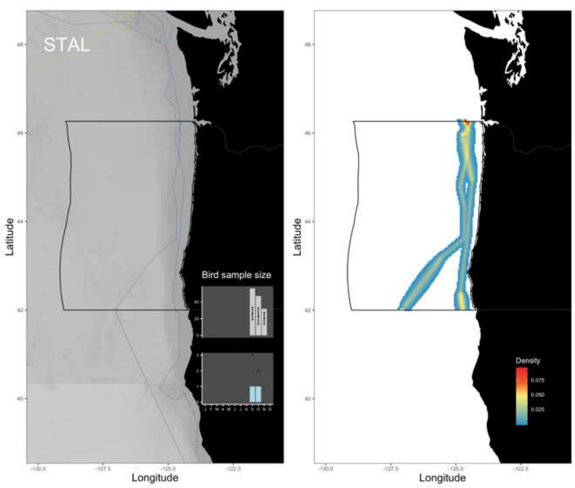
Figure 2-14. Seasonal Pacific Loon Brownian bridge utilization distributions within the US EEZ off the Oregon coast during spring and fall.
The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

Spring

Summer (none)



Fall



Winter

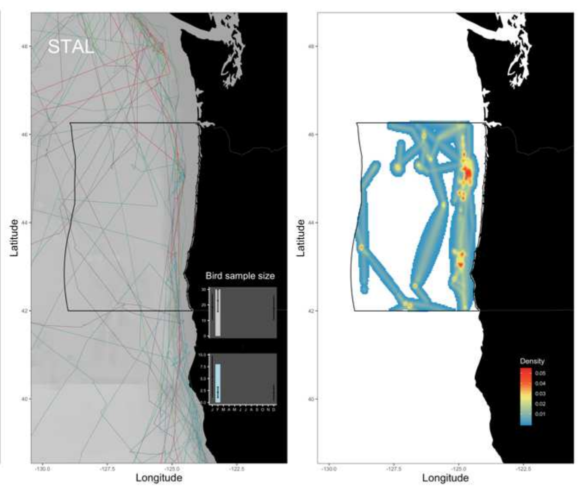


Figure 2-15. Seasonal Short-tailed Albatross Brownian bridge utilization distributions within the US EEZ off the Oregon coast during spring, fall, and winter.
The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

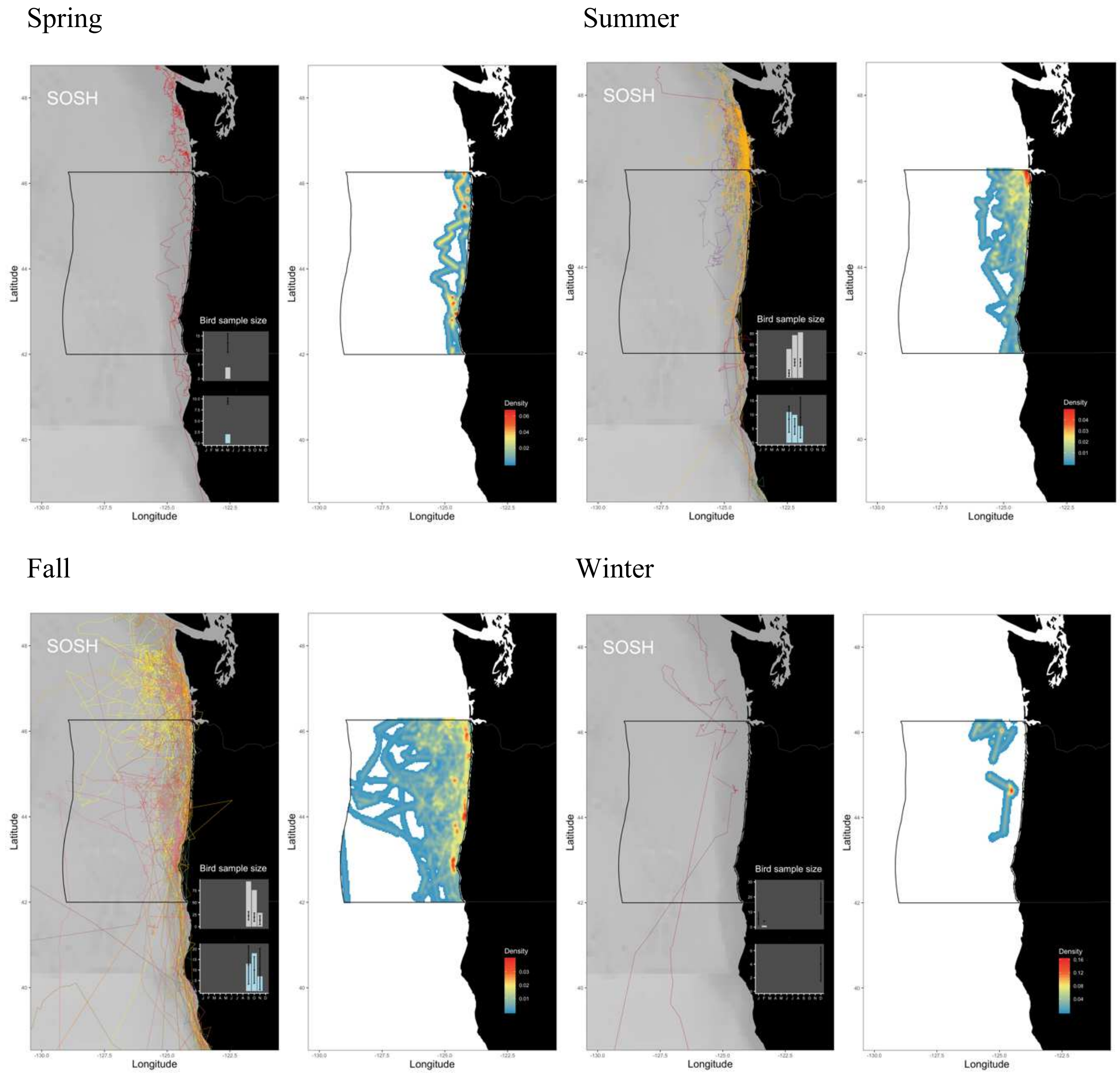


Figure 2-16. Seasonal Sooty Shearwaters Brownian bridge utilization distributions within the US EEZ off the Oregon coast during spring, summer, fall, and winter.
The left map panel shows the tracks colored by individual. The sample sizes of the tracking data are shown in the inset plot with the top panel summarizing all the available data (gray bars) and the bottom panel summarizing the sample size within the polygon (blue bars). The number of tracked birds are shown as a bar plot, while the average number of days tracked within each area during each month are shown with points and standard deviations (black). The right map panel shows the summed and weighted Brownian bridge utilization within the polygon of interest.

2.2.3 Multi-species High-Use Areas

Species-level high-use areas (50% summed BBUD) were calculated to determine areas where the core utilization distributions of multiple species overlapped (Figure 2-17). Although this approach was limited by the availability of tracking data, core areas of the eleven species contained in this dataset mostly spanned the shelf waters off the coast of Oregon. Areas where two species overlapped were dispersed along the coast, but areas where three or four species overlapped were generally concentrated at the mouth of the Columbia River and extending southward (i.e., Columbia River Plume; Figure 2-17). When considering the same approach for the US EZZ within the northern California Current region, again core areas generally covered the extent of the continental shelf (Figure 2-18). Areas where two species overlapped were dispersed across the study region, but areas where three or four species occurred included the mouth of the Columbia River and offshore from Willapa Bay, and along the outer coast off southern WA and northern OR. Species groups that shared common grid cells included STAL-BFAL, COMU-SOSH, PALO-SOSH, and PFSH-SOSH (Figure 2-19). COMU-SOSH-PALO was the three species group that shared the greatest number of grid cells (Figure 2-20).

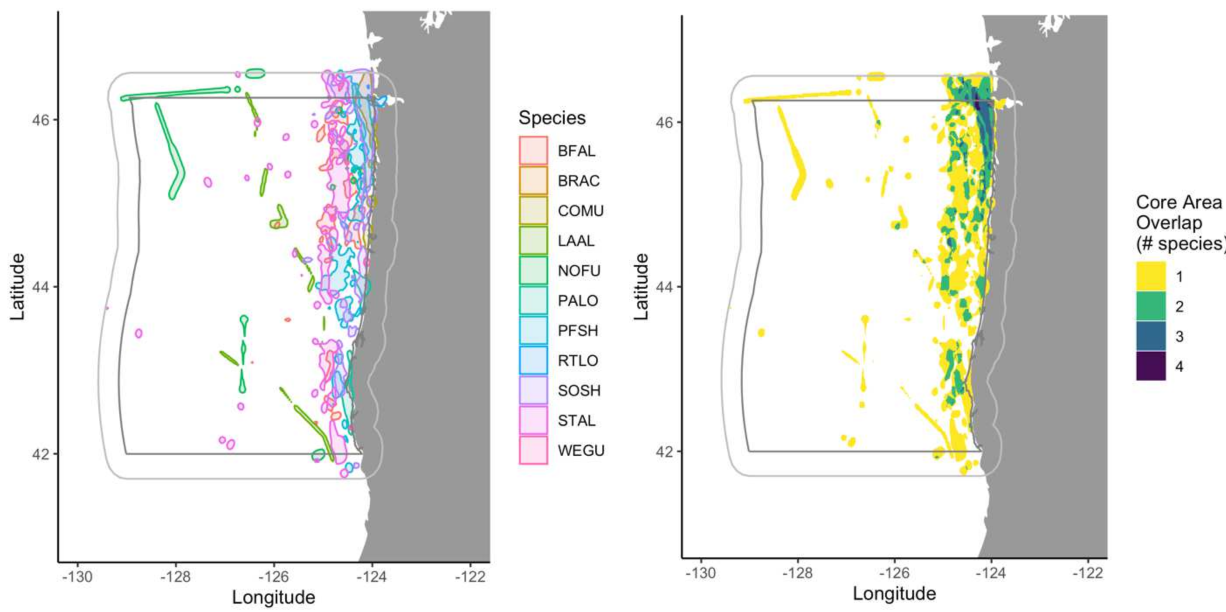


Figure 2-17. Core areas (50% BBUD) for seabird species in this dataset within the US EEZ off Oregon.

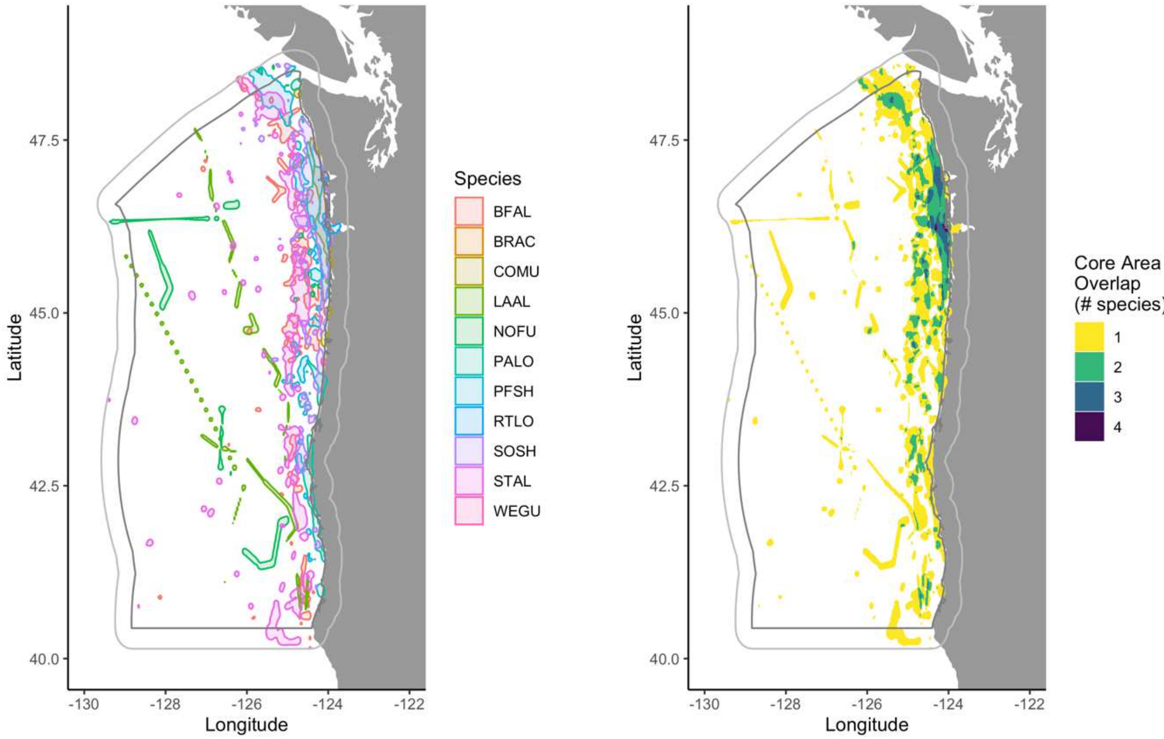


Figure 2-18. Core areas (50% BBUD) for the species in this dataset within the US EEZ in the northern California Current.

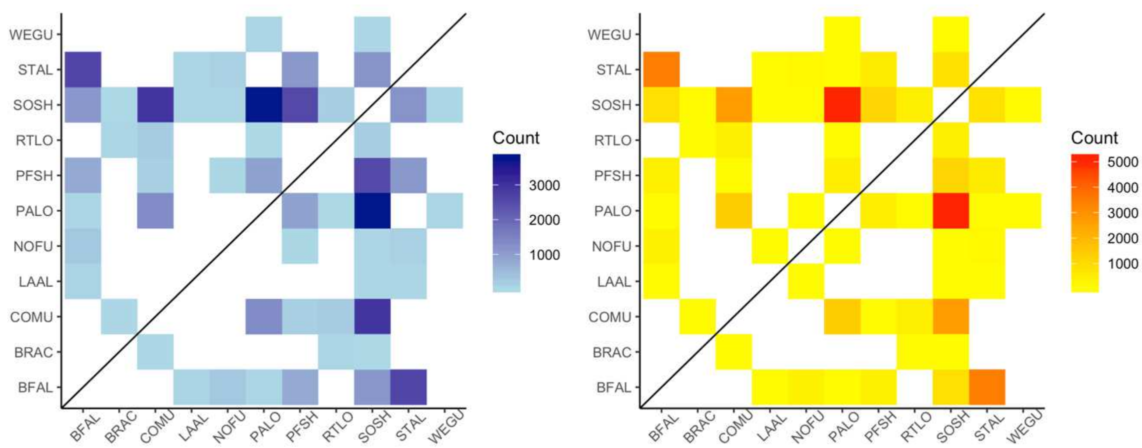


Figure 2-19. Count of grid cell (3 km^2) overlap of species 50% BBUDs.
A. Oregon and B. the Northern California Current.

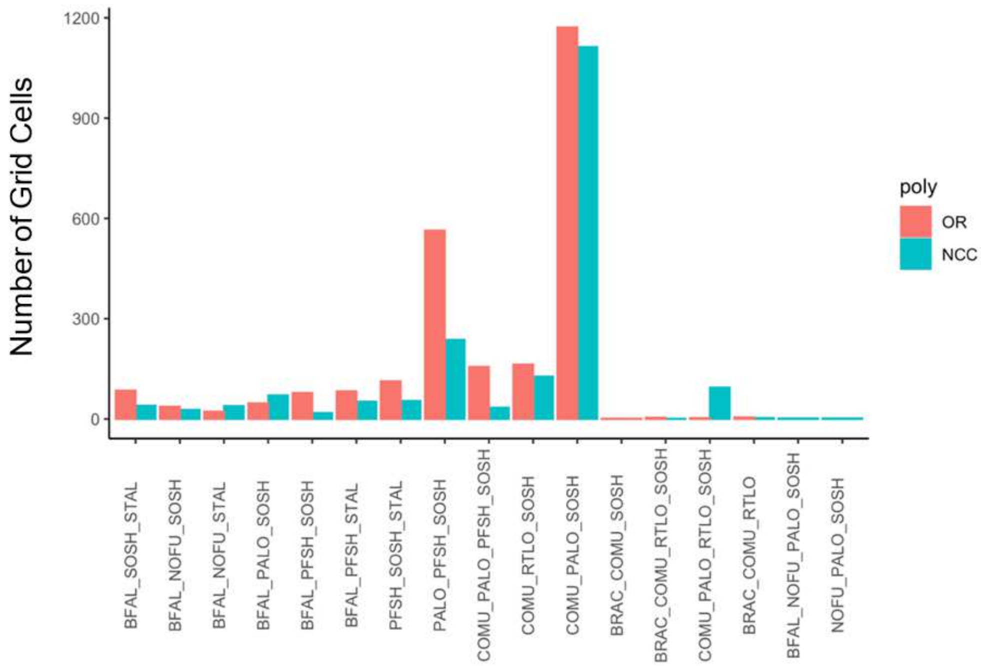


Figure 2-20. Prevalence of three-species overlap in grid cells.
Grid cells are 3km^2. The number of three-species grid cells for Oregon is shown in pink and nCC is shown in teal.

2.3 Discussion

2.3.1 Intended Use and Future Adaptations

The Oregon Seabird Inventory provides a framework for visualizing available seabird tracking data in the Northern California Current. The data management, file structure, processing scrips, and Brownian Bridge utilization distributions are consistent with those in development for the *California Current Ecosystem Seabird Telemetry Atlas*. The processing scrips allow new tracking datasets to be added relatively easily so that densities can be updated and new species added (e.g., Ramey et al. 2020). However, the available tracking data also highlight large gaps in represented species and low individual sample sizes for some important species. For instance, the tracking data from Black-footed Albatrosses was surprisingly limited to only eleven individuals. Despite this, the core areas of use extended over much of the continental shelf. Multi-species hotspots occurred in expected locations (e.g., the Columbia River Plume, the continental shelf off Washington), but other notable areas where seabirds aggregate (e.g., Heceta Bank) were not highlighted by multi-species hotspots.

Future efforts could refine these analytic and mapping techniques to work directly with data repositories (e.g., Animal Telemetry Network: https://atn.ioos.us, MoveBank; https://www.movebank.org) to bridge the gap between tag deployment and data use. Except for the tracking data collected during this project from Common Murres, Western Gulls, Pacific Loons, and Pink-footed Shearwaters, and previous work with Sooty Shearwaters, none of the tracking data were collected with the intended purpose of understanding individual distributions in the northern California Current region. Future efforts are needed to track seabirds using the outer continental shelf region in the northern California Current region to fill the substantial temporal, species, and spatial gaps highlighted by the Oregon Seabird Telemetry Inventory. Though of lower spatial resolution, the additional of geolocation and VHF tracking data would further highlight seasonal abundances and migratory movements among additional species.

3 Seabird Flight Heights

3.1 Flight Heights of Seabirds from GPS Dataloggers

3.1.1 Abstract Summary

An understanding of how high seabirds fly above the water is critical for quantifying seabird collision risk to wind energy turbines. The use of biologging devices provides the opportunity to continuously follow movement trajectories of known individuals as they encounter different environmental conditions. However, estimating flight height from biologging data is not straightforward. Horizontal GPS positions are typically within <10 m of the true location, but vertical errors are on the order of ± >20 m. Herein we use GPS biologging data from seven seabird species to estimate flight heights and the percent time spent in the approximate Rotor Sweep Zone (30–194 m) of off-shore wind turbines. We employed resampling to provide confidence intervals in our estimates, however we found little differentiation between resting and flying altitudes. Then we used Boosted Regression Tree models to disentangle bird, GPS, and environmental predictor variables used to predict seabird flight heights. While our results revealed ecologically plausible trends, the lack of precision in GPS flight heights limited our ability to provide robust estimates. The Boosted Regression Tree models performed poorly (0.169 = average training correlation, maximum = 0.371), but across species faster flight speeds typically led to higher height estimates. GPS metrics (e.g., number of satellites, time between fixes) did not contribute substantially to models (<20%). Altitude measurements from biologging devices could be a powerful method to better understand flight altitudes of seabirds, but more accurate measurement methods and additional and nuanced explanatory variables are needed to improve model performance and identify erroneous values.

3.1.2 Introduction

An understanding of how high seabirds fly above the water is critical for wind energy development and predicting what species are at risk from strikes with wind turbines (Band 2012, Cook et al. 2012, Kelsey et al. 2018). This is especially important in the marine environment because mortalities are likely to be unobserved, unless sophisticated detection equipment is installed on offshore infrastructure (e.g., Flowers et al. 2014). Much of our current knowledge of seabird flight heights, particularly for North Pacific species, is based on observational studies, but these are inherently limited to time periods and conditions under which birds are observable (e.g., Ainley et al. 2015, Borkenhagen et al. 2017). Thus, understanding how flight heights might change at night, during storms or other conditions when observations are obscured is important for refining collision vulnerability. The use of biologging devices provides the opportunity to continuously follow the movement trajectory of known individuals as they encounter different environmental conditions. However, estimating flight height from biologging data is not straightforward.

The Global Positioning System (GPS) is a constellation of ~27 satellites in medium earth orbit. A GPS receiver detects the satellites, and a location is triangulated from the geometry of the satellite constellation and the time of the signal reception. Biologging devices containing GPS receivers are now standard methodology in studies of seabird at-sea distributions, behavior, and ecology (Burger and Shaffer 2008). Though GPS loggers provide information on altitude (height above sea level), these data are less precise than horizontal positions. Essentially, the presence of the Earth obscures the reception of satellites that would be needed to provide high accuracy altitude calculations. Thus, the configuration of the satellites is especially important for these three-dimensional location fixes. Horizontal positions are typically within <10 m of the true location, but often vertical errors are on the order of ± >20 m (Péron et al. 2020). It is possible to apply sophisticated state-space modeling approaches to the GPS altitude data associated with error estimates (Ross-Smith et al. 2016, Pirotta et al. 2018, Péron et al. 2020), but the development and application of these modeling approaches are complex.

Herein, we compared the GPS derived flight heights from five GPS tags made by different manufacturers carried by six seabird species including three dynamic soaring species (Laysan Albatross, Black-footed Albatross, Short-tailed Albatross), one flap-gliding species (Western Gull), and a small- and a large-bodied flapping species with relatively high wing loading (Rhinoceros Auklet and Brandt's Cormorant, respectively). These flight heights were used to estimate the percentage of time spent within the rotor sweep zone (RSZ; 30–194 m) for each species by time of day. When possible we retained negative altitudes, as trimming these can bias flight height estimates (Adams et al. 2019, Péron et al. 2020). Western Gulls were tracked with four types of GPS loggers, and we provide each of these estimates independently. We then modeled the GPS derived flight heights of seabirds relative to day/night, wind conditions, distance to coast, and bathymetric habitat to better understand the contribution of bird, GPS, and environmental predictor variables to the flight height measurement. We feel that this analysis of flight height provides a complementary perspective to at-sea observations, but results should be considered with caution given the short-falls inherent in the accuracy of the flight height data.

3.2 Methods

We limited our analysis of GPS derived flight heights to six species from which GPS tracking data were available: Rhinoceros Auklet (RHAU), Western Gull (WEGU), Laysan Albatross (LAAL), Black-footed Albatross (BFAL), Short-tailed Albatross (STAL), and Brandt's Cormorant (BRAC). Due to the limitations of obtaining GPS tracking data within Oregon waters, we have included tracks from species that occur in Oregon but were collected from other locales where they were more accessible. These included Rhinoceros Auklets tagged at East Farallon Island, in the central California Current (37° 42' N, 123° 00' W) (Wilkinson et al. 2018), Laysan Albatross and Black-footed Albatross tagged at Midway Atoll in the northwestern Hawaiian Islands (28° 15' N, 177° 20' W), and Short-tailed Albatross adults tagged at their colony in Japan (Torishima: 30° 29' N, 140° 18' E). In Oregon, Brandt's Cormorants were tagged at the mouth of the Columbia River (46° 15' N, 123° 59' W), and Western Gulls tagged at two colonies on the Oregon coast (Hunter's Island, 42°18' N, 124°25' W; Cleft-in-the-Rock, 44° 17' N, 124° 6' W).

3.2.1 GPS Processing

Tracks were speed filtered to remove erroneous locations (Table 5-1) (McConnell et al. 1992, Freitas 2012). For the species engaged in central-place foraging during the tracking period (RHAU, WEGU, LAAL, BFAL, STAL) we split each track into foraging trips using a radius of 1 km from the breeding colony and a minimum of 5 locations (Fleishman et al. 2019). For all tracks we determined simple behavior states (transit, search, stationary) using the Residence in Space and Time (RST) algorithm that calculates the difference between the normalized residuals of residence time and residence distance within a given radius (Torres et al. 2017). We applied the dynamic scaling method to each trip independently to identify the radius of inference (Table 3-1). This approach is robust to irregular sampling intervals because it is used to identify simple behavioral states based on time and distance rather than turning angle. However, tracks with larger intervals between locations cannot be used reliably to distinguish between specific behaviors like flight and rest. Similar methods were applied to BRAC, but the entire track was treated as a trip even though birds periodically returned to roost sites.

3.2.2 Model Covariates: Bird, GPS, and the Environment

Bathymetry was extracted from NOAA ETOPO1 (Pante and Simon-Bouhet 2013, Amante and Eakins), and the coast was calculated as the contour at 0 m depth. The minimum distance to the coast was calculated from coordinates projected into the Lambert azimuthal equal-area projection (van Etten 2018). Day, dusk, and night were identified from the timing of sunset, nautical twilight, and sunrise (Bivand and Lewin-Koh 2019). Speeds of <1 m/s were classified as 'rest'. Locations within 1 km of the coast were excluded from altitude calculations due to the tendency of birds (particularly WEGUs) to gain altitude along cliffs, headlands, and bridges and classified as 'land'. Speed (m/s) and the proceeding time gap (s) were calculated for each location.

3.2.3 GPS Flight Height Calculations

GPS dataloggers can have different accuracy tolerances for making fixes, and antenna types can influence satellite reception (Poessel et al. 2018). GPS loggers can calculate and report dilution of precision (DOP) metrics to specify the effects of satellite geometry on positional accuracy. These metrics include Geometric Dilution of Precision (GDOP), Time Dilution of Precision (TDOP), Positional Dilution of Precision (PDOP), Horizontal Dilution of Precision (HDOP), and Vertical Dilution of Precision (VDOP). Low DOP values (<4) indicate good satellite geometry while values >7 indicate less optimal geometry. HDOP values are typically between 1 and 2 and VDOP values are larger than the HDOP due to greater vertical position errors. GDOP is calculated from HDOP, VDOP and TDOP. PDOP is calculated from HDOP and VDOP (eq1):

$$\text{(eq1)} \quad PDOP^2 = HDOP^2 + VDOP^2$$

We used five types of GPS loggers in this study (Table 5-2). Western Gulls were tagged with four types of GPS data loggers: igotU (n = 23), Mr. Lee (n = 8), Ornitela (n = 19), CATS (n = 10, Customized Animal Telemetry Solutions); we processed each dataset separately for a comparison among tag types. The igotU GPS loggers do not natively report the number of satellites, but we extracted the log files and computed the number of satellites used to make each fix (Morris and Conner 2017, Fleishman et al. 2019).

GPS WGS84 altitudes were corrected to mean sea level using the geoid (Earth Gravitational Model 2008, https://earth-info.nga.mil/GandG/update/index.php?action=home). However, there is unresolved uncertainty in the geoid of the igotU and Ornitela GPS fixes and it is unknown if these tags are using the WGS84 geoid. Bootstrapping methods were applied to produce altitude distributions from which the percentage of time in the rotor-sweep zone (30-194 m) was calculated for transiting and searching behaviors (Adams et al. 2019). For tag types that provided satellite number (Table 3-2), we only included locations made with >4 satellites (84% of locations).

3.2.4 Contributing Factors to Flight Heights

We developed species- and tag- specific models using a machine learning method, Boosted Regression Trees (BRTs), to address the question: what factors influence flight heights? We included bird behavior (speed, transit or search), environmental (distance to coast, diel period), and GPS parameters (tag type, satellite number, hour, DOPs, proceeding time gap) as predictor variables. BRTs combines decision tree methods (models that partition predictor data by recursive binary splits) with a boosting algorithm to iteratively optimize model performance by combining a large number of decision trees (Elith et al. 2008). BRT models can model non-linear relationships and can simultaneously assess both continuous and categorical data as predictors in the model, making them well-suited for ecological studies (Leathwick et al. 2006, Elith et al. 2008, Torres et al. 2013). To ensure data coverage of the predictor variables we trimmed outliers in our dataset for flight heights (amsl) above 200 m and below -200 m, proceeding time differences >2,000 s and speeds greater than 35 m/s. For some models, we transformed amsl by dividing by 100. BRTs estimate the relative influence of each predictor variable on the response variable based on the number of times the variable was selected for tree splitting and weighted by model improvement as a result of each split (Friedman and Meulman 2003).

Gaussian BRT models were fit using 'gbm' (Greenwell) and 'dismo' (Hijmans et al. 2017). The bag fraction (proportion of data selected at random for each decision tree at each step) was set to 0.75. The tree complexity (number of interactions between predictor variables allowed) was tested using values between 1 and 4, with final favoring lower tree complexity values for similar performance metrics. Learning rate (contribution of each tree to the model) was initialized at 0.01 and was allowed to increase until the optimal number of trees was reached (>1,000; Elith, Leathwick and Hastie 2008)**.** BRT models were evaluated based on correlation scores between predictions and observed values of withheld data (training correlation). To evaluate the robustness of the predictor variables we fit species specific models (LAAL, BFAL, RHAU, WEGU, BRAC) and two tag specific models (igotu, Ornitela) with species as a predictor. The global WEGU model included tag manufacturer as a predictor and separate models were fit for each of the three tag types that reported the full range of altitude values (igotu, Ornitela, Mr. Lee).

3.3 Results

Most of the tracking data from birds in our study was not located in the Oregon coast study region (Figure 3-1). All of the species were caught and tracked during the summer breeding period. Some tracks lasted through multiple seasons, including tracks from STAL, WEGU, and BRAC. LAAL and BFAL had similar time budgets; both species typically spending a substantial amount of time at night in flight during their chick brooding foraging trips. RHAU showed a distinct pattern of higher flight activity at dusk and WEGU were less active at night (Figure 3-2). All of the study species had <30% of their flight heights in the RSZ (Table 3-3). Microwave Telemetry (MT) and Customized Animal Telemetry Solutions (CATS) tags did not report negative altitude data, thus biasing the estimates presented.

3.3.1 Contributing Factors to Flight Heights

The resulting BRT models performed moderately well to poor (Table 3-4), with training correlation values of 0.371 to 0.010. Model performance was not related to observation number; however, models from igotu loggers had higher correlation values (n = 5, 0.259 ± 0.101), followed by the one model fit with data from Mr. Lee (0.127). Models fit with data from Ornitela tags performed the worst (n = 3, 0.084 ± 0.061).

Of the species-specific models, the models for LAAL and RHAU performed moderately well (Table 3-4). Distance to shore was the top predictor in all models (30.1% - 45.2%) except the RHAU model where it was second (22.1%) (Figure 3-3). Speed was among the top two predictors for all models (32% - 16.4%) except the LAAL model (7.1%). Hour of the day was typically the third strongest predictor (12.1% - 19%), the exception being the WEGU model where it was fourth. The preceding time gap was included in all models, but the trends were stochastic, and the percentage contribution varied from 25.8% (LAAL) to 9.1% (RHAU). Satellite number contributed to all models (7.1% - 16.1%) except the WEGU model. Diel period contributed to the LAAL model, where flight heights were higher during the day and to the RHAU model where flight heights were higher during both the day and dusk periods. The hours variable tended to have a diel pattern, with flight heights higher during the afternoon hours for both WEGU and BRAC. Behavior was only useful in the WEGU model (6.6%), with higher flight heights for transiting and large-scale searching movements. Finally tag type contributed a small percentage to the WEGU model (4.7%).

We ran four models using the data from the WEGUs, because three different GPS loggers were used to collect these data (Figure 3-4). The igotu and Ornitela models produced relatively similar results. The model using the data from the Mr. Lee tags had Hour as the highest predictor, and unlike the other two models it was not resolved in a diel pattern. These tags were the only to report HDOP, PDOP, and VDOP. VDOP and HDOP both contributed to the model (Figure 3-4).

We built two multi-species tag-specific models (Figure 3-5). One for igotu tags (LAAL, BFAL, RHAU, WEGU) that preformed moderately well and one for Ornitela tags (BRAC and WEGU) that performed poorly (Table 3-4). Species contributed to both models. Speed showed a strong linear pattern in both models, with heights increasing as speeds increased. In contrast, distance to shore and time difference also strongly contributed to both models, but the model predictions were stochastic. The igotu model included satellite number as a predictor, with lower heights from fixes with 11 and 12 satellites. The Ornitela model included hour as a predictor with higher flight heights during the daylight hours.

3.4 Discussion

Flight height measurements from biologging devices would be a powerful method to better understand flight altitudes for seabirds; however, the accuracy of GPS altitude measurements lack consistent measurement precision on the scale needed for many species (0-20 m). However, our results reveal plausible ecological patterns that are consistent with observational data. This includes the relative height of each species and behavioral and environmental drivers of flights heights. Though the tags we used for this study included both off the shelf units (igotu, Mr. Lee) and purpose-built bird telemetry devices (Microwave Telemetry, Ornitela, CATS), the error values reported were inconsistent. This makes it more challenging to apply purpose-built state-space models that use DOP values in their estimates (Ross-Smith et al. 2016, Péron et al. 2017, Pirotta et al. 2018). Furthermore, GPS tags rarely reported the VDOP value that would provide the most information about the quality of the vertical fix.

As expected, all of the species in our study fly at relatively low heights when at sea (<50 m) (Spear and Ainley 1997). Previous studies indicate that we should expect the following pattern in relative flight heights: WEGU > BRAC > RHAU = LAAL = BFAL = STAL (Krijgsveld et al. 2005, 2011, Furness et al. 2013). We did find that regardless of tag type WEGU flight heights were consistently high. As expected BRAC flight heights were slightly less, followed by the three albatross species. However, for an alcid, the RHAU flew higher than the expected flight altitude of ~12 m (Krijgsveld et al. 2005, 2011), however at night they tended to fly at lower heights. The same tag type (igotu) was used on WEGU, RHAU, LAAL, and BFAL, thus these flight heights should be comparable, suggesting that RHAU do fly relatively higher than expected (Bradbury et al. 2014, Johnston et al. 2014). The pattern was apparent in both the raw data, the resampled estimate of percent time within the RSZ, and the multi-species igotu BRT model that accounts for contributions of the other predictor variables. The multi-species igotu model performed reasonably well and was our second highest performing model. However, more careful consideration is needed for RHAU to determine collision and displacement vulnerability to wind energy development along the western coast of North America (Kelsey et al. 2018); their nocturnal activity may make them more vulnerable to collision risk than similarly sized alcids that are more active during the day (e.g., puffins and murres).

Though calculated from measurements with a large amount of error, our estimates of the time within the RSZ are consistent with prior studies (Bradbury et al. 2014, Johnston et al. 2014). The median flight altitudes for the three albatross species (-2.9 to 8.7 m) are in the range anticipated for species that employ dynamic soaring. However, the MT tags deployed on incubating STAL trimmed the negative altitude measurement before geoid correction – likely making these values inaccurate (Péron et al. 2020). This could explain the high percent of locations within the RSZ for this species as the geoid ranges from an off-set of more than ± 20 m across their distribution. Our results indicate that there is the potential for these albatross species to spend a small percentage of time within the RSZ. However, this could still be substantial for these species as and small increases in adult mortality can change albatross population trajectories (Bakker et al. 2017). Our estimate for the percent time in the RSZ for the BRAC is very similar to estimates for cormorants and shags in the North Atlantic (Bradbury et al. 2014, Johnston et al. 2014). Finally, our estimates for WEGU are similar to large gulls in the north Atlantic (Bradbury et al. 2014, Johnston et al. 2014).

The five types of GPS tags used in this study all have their advantages and disadvantages. In most cases, these data were collected for other studies and the GPS data were repurposed here for this analysis. The

WEGU were tracked with four different GPS tags. This allows a within species comparison of flight heights and highlights the variation in results that can be caused by differences in GPS quality, antenna, and algorithms. The CATS loggers did not report negative altitudes, biasing results, and will not be discussed further. The igotu dataloggers were used on multiple species in this study (RHAU, LAAL, BFAL, and WEGU. For the WEGU, the estimates of flight heights from the igotu loggers are lower than those from the other two tag types Mr. Lee and Ornitela. This could indicate that our estimates for these other species are also likely to be low. The Ornitela tags are purpose built for animal tracking and should offer the best internal programming to optimize location accuracy; however, typically horizonal accuracy is more important for most applications and our models performed poorly for this tag type.

3.4.1 Recommendations

Our results indicate that species evaluated herein all are relatively low flying seabird species that inhabit the US West Coast. The estimated flight heights are generally in-line with species studied elsewhere, however the results for the RHAU indicate that results for groups, such as alcids, are not necessarily transferable to all species. Future work should attempt to measure flight altitudes in North Pacific species, like the RHAU and Cassin's Auklet that are more active during twilight and darkness. Likewise, more effort should be invested in measuring albatross flight heights. Although they many not often sustain flight at heights in the RSZ, they do engage in gust soaring that can enable significant pull-up heights under strong wind conditions (Pennicuick 2002), and their life history indicates that low chronic adult mortality can be a strong driver of population trends (Zador et al. 2008, Bakker et al. 2017).

Table 3-1. Summary of GPS tracking data and processing parameters.

Species	Birds	Trips	# GPS Points	Days Tracked (mean ± SD, min-max)	Speed Filter (m/s)	Radii Used for RST (km)
RHAU	23	23	7,942	3.1 ± 0.7, 2.5 - 4.1	18	0.27 ± 0.24
WEGU	60	2771	442,506	51 ± 82, 1.9 - 341	23	1.21 ± 1.25
LAAL	18	18	29,411	4.8 ± 2.8, 2.0 - 12.9	27.8	1.61 ± 1.43
BFAL	17	17	64,386	2.6 ± 1.3, 1.2 - 5.8	27.8	0.62 ± 0.96
STAL	57	57	4553	230 ± 76, 109 - 315	28	59.6 ± 59.4
BRAC	16	NA	305,510	87 ± 57, 10 - 163	18	0.29 ± 0.28

Table 3-2. Types of GPS biologging tags used to collect altitude data.

Each GPS tag type offers a different set of variables to assess position accuracy including satellite count and dilution of precision variables (DOP, HDOP, PDOP, VDOP). Microwave Telemetry (MT) and CATS tags did not report negative altitudes.

GPS Tag Type	Tag Model	Altitude Datum	Satellite Count	HDOP	DOP	PDOP	VDOP	EHPE (m)	EVPE (m)
CATS	GPS/GSM	-	No	No	No	No	No	**Yes**	**Yes**
igotu	120 / 600	USGS 84?	**Yes**	No	No	No	No	No	No
Mr. Lee	-	USGS 84	**Yes**	**Yes**	No	**Yes**	Calc	No	No
MT	GPS/PTT-100	-	No	No	No	No	No	No	No
Ornitela	OrniTrack-25, OrniTrack-30	NAC88?	**Yes**	No	**Yes**	No	No	No	No

Table 3-3. Height above sea level derived from GPS tracking.
The percent in the RSZ is based on the percentage of locations within the time period and RSZ. MT and CATS tags did not report negative altitude data biasing the estimates presented. GPS sampling interval prevented identification of flight locations for STAL. LAAL and BFAL were tracked on brooding trips from Midway atoll.

Species	Tag Type	Median Flight Altitude (mamsl)	Median Rest Altitude (mamsl)	% Night in Flight	Day: Flight (%) in RSZ (95% CI)	Dusk: Flight (%) in RSZ (95% CI)	Night: Flight (%) in RSZ (95% CI)
BFAL	igotu	4.2	2.3	86 ± 14	3.1 (2.8, 3.4)	0.8 (0.5, 1.1)	3 (2.7, 3.2)
BRAC	Ornitela	18.0	19.7	21 ± 13	9.3 (8.8, 9.9)	10.2 (7.7, 13)	-
LAAL	igotu	8.7	6.5	71 ± 26	6.3 (5.7, 6.9)	1.8 (1.2, 2.6)	4.2 (3.7, 4.7)
RHAU	igotu	26.5	26.2	6 ± 5	1.6 (0.4, 3.2)	9.9 (5.5, 14.2)	8 (2.6, 14.1)
WEGU	CATS	33.3	27.3	19 ± 22	14 (10.6, 17.7)	-	-
WEGU	igotu	29.0	23.8	23 ± 33	11.4 (10.7, 12.2)	7 (5.1, 8.8)	1.2 (0.4, 2.1)
WEGU	Mr. Lee	33.0	23.3	5 ± 6	28.2 (26.8, 29.7)	17.1 (13.4, 21.4)	30.2 (20.2, 39.3)
WEGU	Ornitela	35.3	25.5	21 ± 22	29.1 (28.5, 29.8)	22.2 (20.6, 23.8)	13.9 (10, 17.8)

Table 3-4. Boosted Regression Tree models.
Model fit statistics of final Boosted Regression Tree models (Model, Tag, GPS Points, Tree Complexity, Bag Fraction, Learning Rate, Tree D, % Deviance Explained) used to identify factors influencing seabird flight heights and the percent contribution of predictor variables related to bird behavior, GPS, or the environment.

Model	Tag	GPS Points	Tree Complexity	Bag Fraction	Learning Rate	Tree (#)	% Deviance Explained	% Bird	% GPS	% Envir.
BFAL	igotu	50,731	3	0.75	0.005	8050	0.127	16.3	31.7	52.0
BRAC	Ornitela	12,563	4	0.75	0.005	1150	0.025	19.4	30.1	50.5
LAAL	igotu	21,729	4	0.75	0.005	8400	0.371	7.1	45.0	47.9
RHAU	igotu	625	3	0.75	0.005	4650	0.227	32.3	36.3	31.4
WEGU	All	42,161	4	0.75	0.005	3100	0.010	34.8	22.1	43.0
WEGU	igotu	11,785	3	0.75	0.005	4500	0.219	27.3	32.5	40.1
WEGU	Mr. Lee	4,219	4	0.75	0.005	3900	0.127	12.9	12.9	74.3
WEGU	Ornitela	24,401	3	0.75	0.005	1950	0.081	45.1	32.3	22.6
igotu	-	84,871	4	0.75	0.005	8200	0.352	18.6	20.9	60.5
Ornitela	-	38,719	3	0.75	0.005	2600	0.146	69.2	7.4	23.4

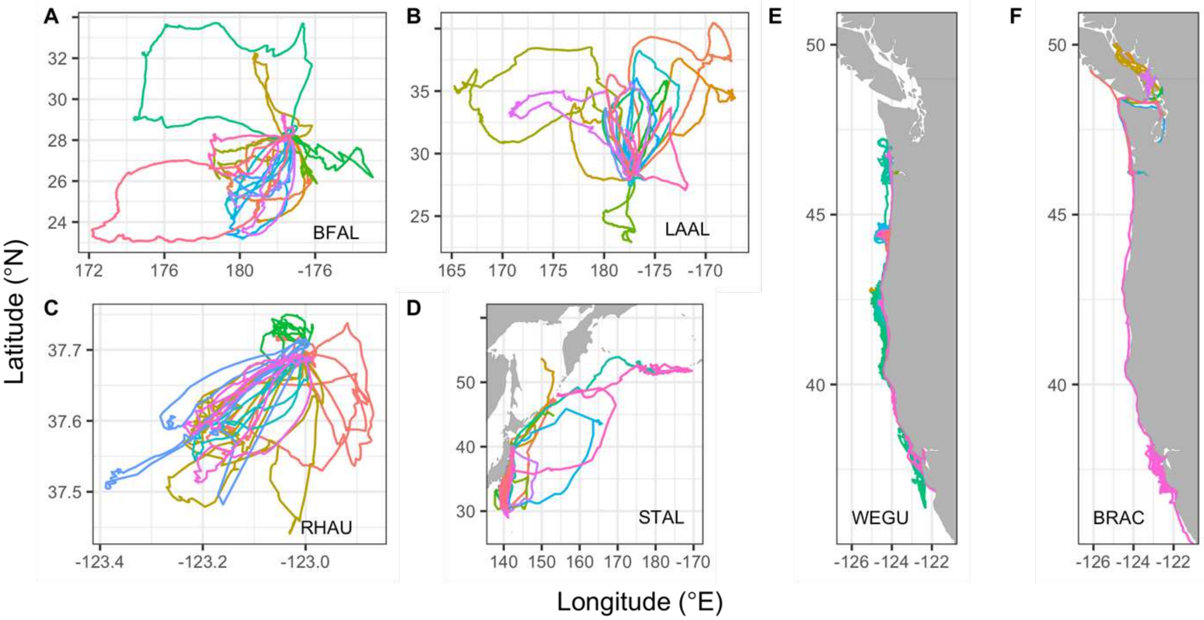


Figure 3-1. Map of GPS tracks.
Panels show each species: A) BFAL, B) LAAL, C) RHAU, D) STAL, E) WEGU, and F) BRAC. Tracks are colored by individual birds.

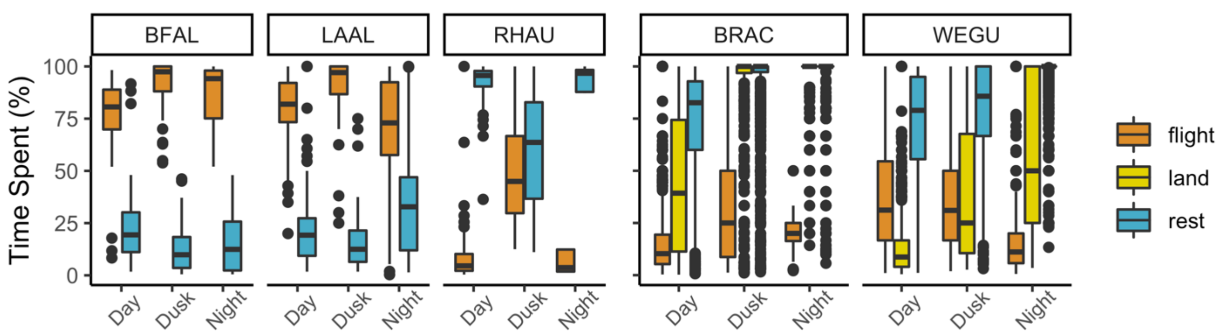


Figure 3-2. Behavioral time budgets from GPS trajectories.
Flight is composed of the two RST states: search and transit. Rest was identified as all points associated with speeds <1 m/s and points with restricted movement.

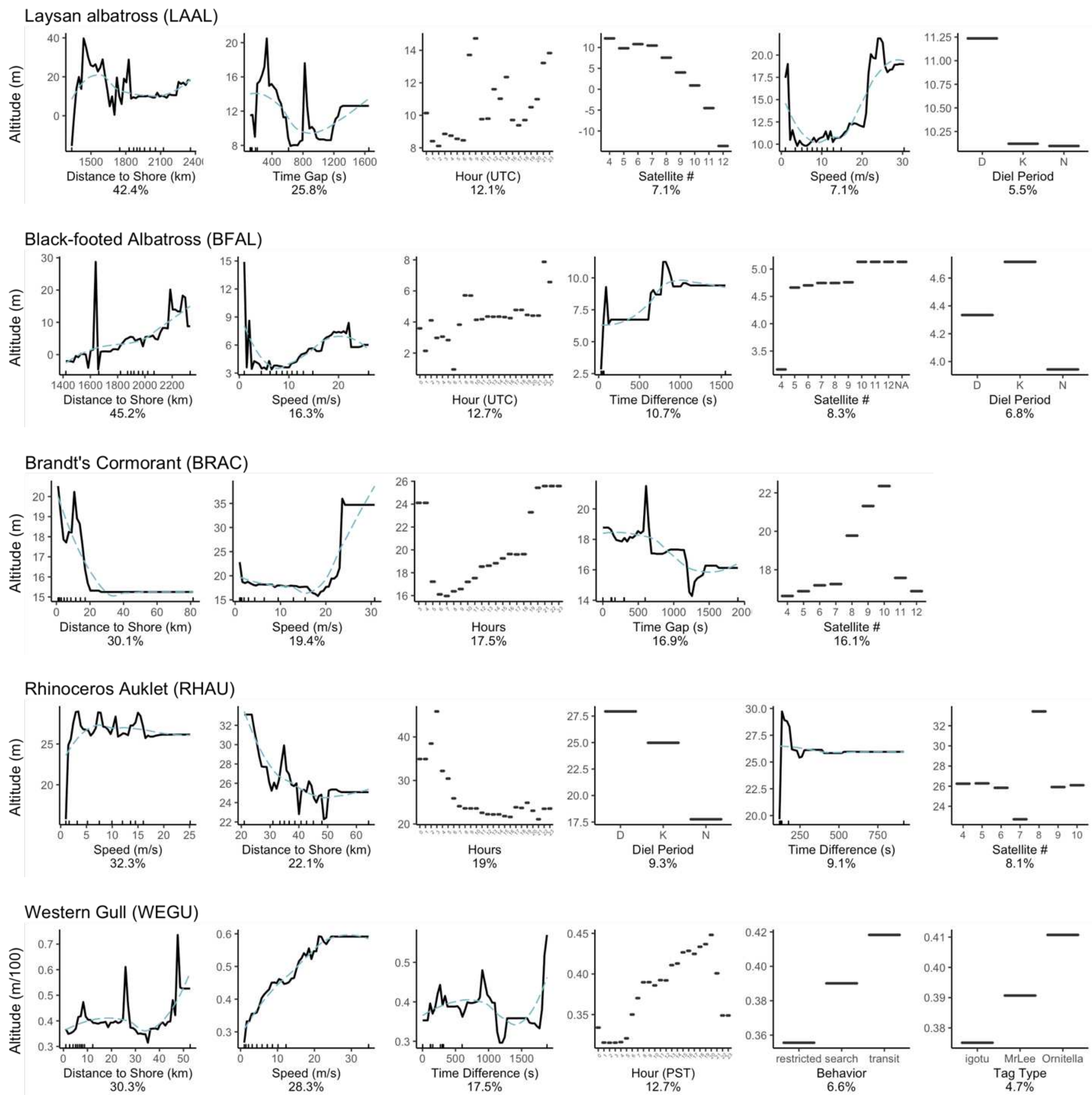


Figure 3-3. Boosted Regression Tree partial dependency plots for multiple species and tag type model.

BRT partial dependency plots for each species model with the predictor variables contributing to flight heights. The model contribution percentage is shown at the bottom of each plot and plots are ordered by model contribution. Panels show the effect of each variable on the probability of an interaction event while fixing other variables at their mean. The functional (black) and smoothed (blue-dashed) response curves are shown. Rug plots show distribution of values, in deciles, and provide a measure of confidence. Plots were constructed with ‘pdp’ (Greenwell 2017).

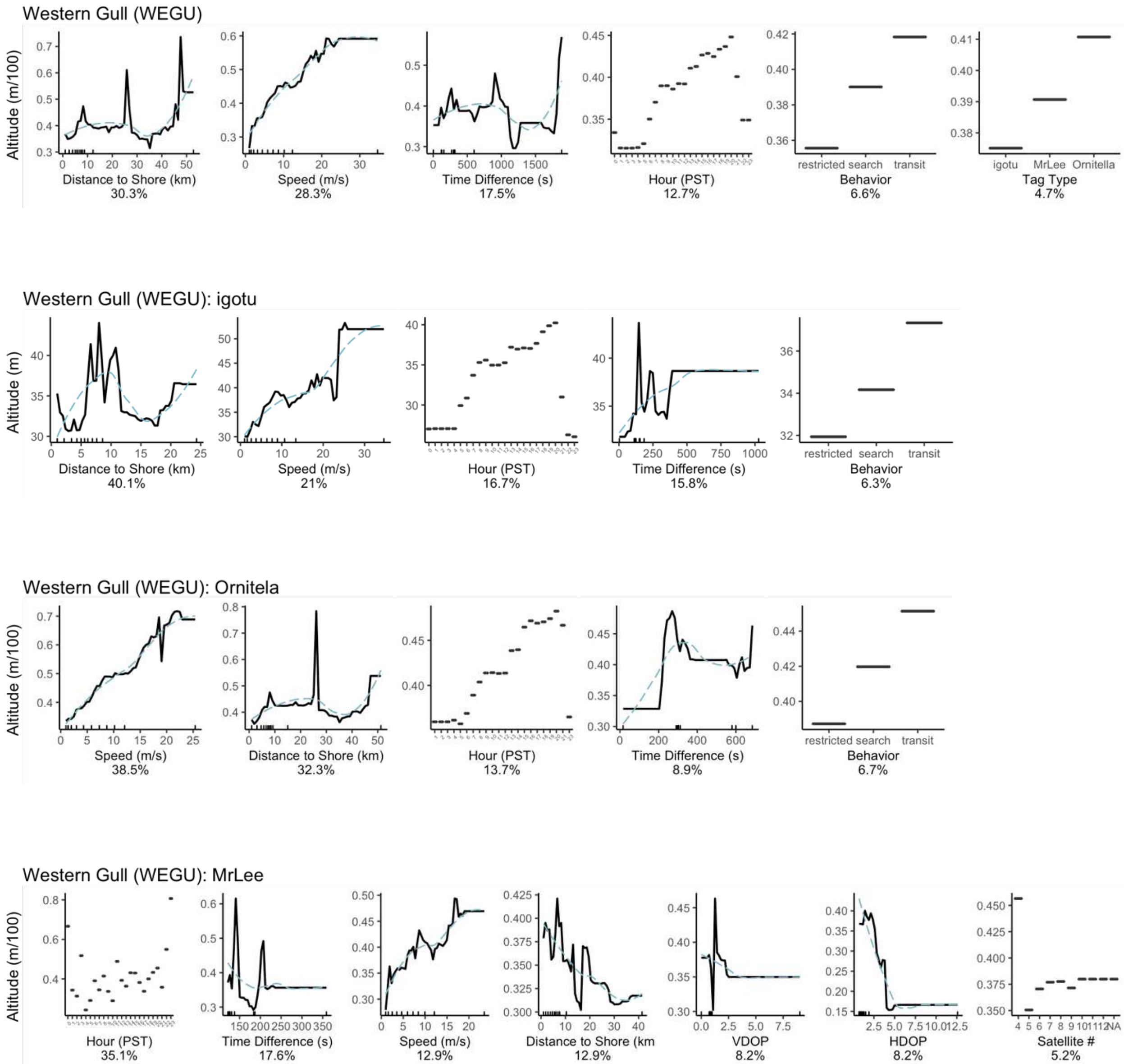


Figure 3-4. Boosted Regression Tree partial dependency plots for Western Gull multiple tag type model.

BRT partial dependency plots for the predictor variables contributing to Western Gull flight heights with the model contribution percentage. Panels show the effect of each variable on flight heights while fixing other variables at their mean. The functional (black) and smoothed (blue-dashed) response curves are shown. Rug plots show distribution of values, in deciles, and provide a measure of confidence. Plots were constructed with ‘pdp’ (Greenwell 2017).

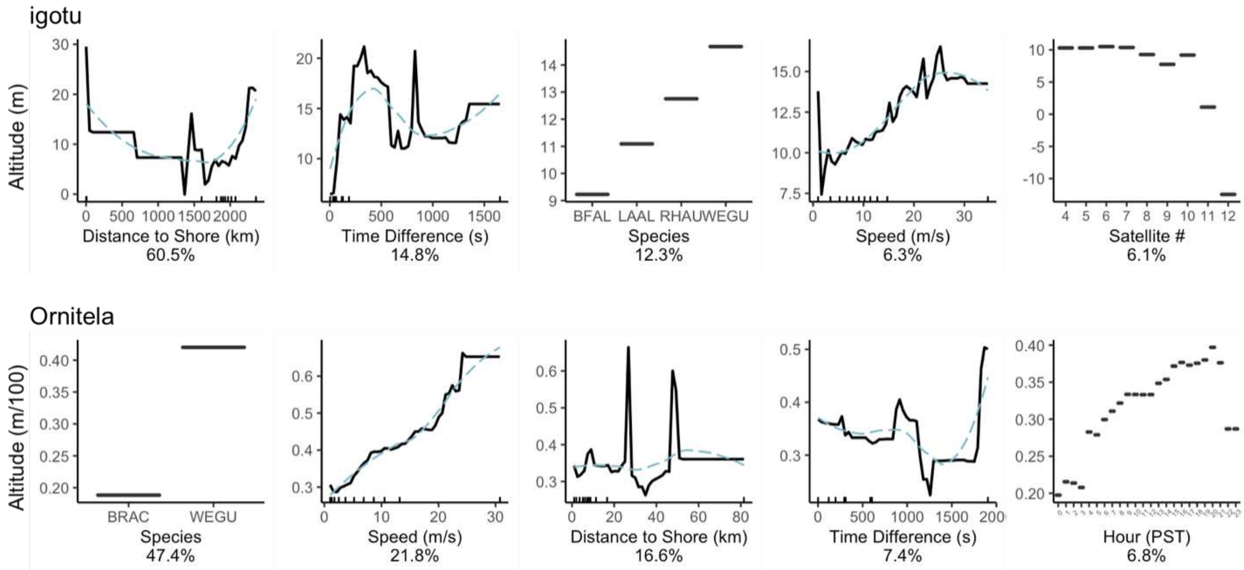


Figure 3-5. Boosted Regression Tree partial dependency plots for tag type models.
BRT partial dependency plots for the predictor variables contributing to seabird flight heights with the model contribution percentage for the two tag types used. Panels show the effect of each variable on flight heights while fixing other variables at their mean. The functional (black) and smoothed (blue-dashed) response curves are shown. Rug plots show distribution of values, in deciles, and provide a measure of confidence. Plots were constructed with 'pdp' (Greenwell 2017).

4 Oregon At-Sea Seabird Surveys

While seabird tracking provides high resolution information about foraging strategies and species-specific vulnerabilities to marine development (e.g., flight height and collision risk), these data are typically limited to larger-bodied seabirds (e.g., albatrosses, gulls). At sea surveys provide broad spatiotemporal distributions of seabirds and at-sea communities and help to fill in gaps in tracking studies. Vessel-based at-sea seabird surveys were conducted off the Oregon coast in the spring (May/June) of 2014, 2015, and 2016. We summarized at-sea distributions for 11 species as available: Black footed and Short-tailed Albatross, Common Murres, Pink-footed and Sooty Shearwaters, Brandt's Cormorants, Pacific and Red throated Loons, Northern Fulmars, Western Gulls, and Black-legged Kittiwakes.

4.1 Methods

4.1.1 Data Collection: At-sea Surveys

Seabird data were collected using vessel based at-sea observations. Observers worked from the vessel's flying bridge or bridge using the strip transect survey method (Tasker et al. 1984, Spear et al. 2004). Seabird and mammal sightings, and flock data within a 300 m strip from one side of the vessel were recorded using SeeBird or SeebirdWinCruz software on a laptop connected to the ships GPS. Sightings were entered using four letter species codes. Weather, observation and sea conditions, and comments were also documented. Observations occurred from sunrise to sunset as vessel conditions allowed. When only one dedicated seabird observer was aboard, comments identified survey breaks (recommended every 4 hours). Although target vessel speed for strip transect surveys is 10 knots, surveys were conducted between 8-12 knot vessel speeds. If the vessel speed dropped below 8 knots snapshot surveys were conducted, however on cruises with one dedicated observer, this also provided break time. Surveys were paused otherwise, with comments noting the reason. Laser range finders were ineffective on sea surface from a moving vessel, so observers constructed personal and vessel specific range finders prior to the start of each cruise. These were used to calibrate observations and strip width estimates.

The 2014 survey was conducted aboard NOAA research vessel Ocean Starr. Seabird and marine mammal observations were made along the Brookings, Gold Beach, Bandon, Heceta Head, Newport transects as well as during nearshore north/southward transits between the transect lines. High winds precluded observations on portions of the Gold Beach transect, otherwise conditions were favorable. Both surveys in 2015 and 2016 were conducted from the NOAA research vessel Bell M. Shimada with coverage including the entire Oregon coast. In 2015, seabird observations were conducted along the Brookings, Gold Beach, Bandon, Coos Bay, Heceta Head, Newport, Lincoln Beach, Tillamook, Astoria, and Willapa Bay (Washington) transects. A special observation effort was made while transiting south through the proposed WindFloat Pacific wind energy development site near Coos Bay, Oregon. In 2016, seabird observations were conducted along the Brookings, Gold Beach, Bandon, Coos Bay, Heceta Head, Newport, Lincoln Beach, Tillamook, and Astoria transects. Conditions were favorable. One dedicated seabird observer conducted surveys in 2014 and 2015, with the help of teachers and students aboard the cruise. In 2016, two dedicated observers conducted seabird surveys.

4.1.2 Data Processing

Observations of focal species over time were fit to generalized linear models with negative binomial distribution in R Statistical Software (R Core Team 2020; Table 4-1). From these models we were able to detect significant changes in species and total abundance along the Oregon coast from 2014-2016, however it is important to note that each model only contains three data points.

To calculate species densities, survey data were converted from text files and combined into a single CSV file. Data fields were added as needed to denote year, month, and cruise identifier. We used a custom program written in R Statistical Software to calculate seabird density (birds/km^2) by species in 3 km sections to minimize autocorrelation in the data (Schneider 1990, Yen et al. 2004). We excluded short transects (<1.5 km) from analysis and only retained 'on effort' observations (vessel cruising between 8-12 knots).

4.1.3 GIS Analysis and Distribution Maps

All distribution maps were produced in ArcGIS Pro 2.6.0 (ESRI 2020) using the Geostatistical Analyst tool. Kernel density maps were generated for total birds observed (per year) and species listed above, except when data were so few that the representation was null or indiscernible. This was true for Brandt's Cormorants, Northern Fulmars and Black-legged Kittiwakes. Maps of 'total birds' were made both including and excluding Sooty Shearwaters, which in some cases was two orders of magnitude denser than other species (2016). Model inputs for all species used species density/km^2 by year for data input, with an exponential kernel function and automatically optimized bandwidth, smoothing factor, and radius; 1 order of polynomial and a ridge of 50.

The heat maps represent proportional density distributions within survey years to illustrate species aggregation within years. It is important to note that there is no correction factor between years and these maps should not be used for interannual comparison. When we applied a correction factor to the heat maps, resulting figures were non-intuitive and species signals were lost between years; therefore, we found these maps more helpful to identify hot spots within (rather than among) years. Due to limited data, maps were not generated for Black-legged Kittiwakes, Brandt's Cormorants, Northern Fulmars, Pacific and Red-throated Loons, or Short-tailed Albatrosses.

4.2 Results

We documented 8,810 independent observations (solitary birds and aggregations) of 34,213 seabirds over 4,472 km^2 of on-effort transit along the Oregon coast from 2014-2016. Our focal seabird species as outlined above accounted for 0.94, 0.84, and 0.97 of total observations in 2014, 2015, and 2016, respectively (Table 4-1). Common Murres and Sooty Shearwaters were the two most abundant species in all years, however Sooty Shearwaters observed at the mouth of the Columbia River in 2016 were an order of magnitude higher than another other species total in any other survey year.

Sooty Shearwaters were the only focal species with statistically significant (p<0.001) change in abundance over our study years. Sooty Shearwater abundance also drove significant changes in overall seabird abundance over our study period. All other focal species abundance did not significantly change from 2014-2016, although it is important to note that the model fit reflects abundance, and there may have been changes in distribution or habitat use by species.

Table 4-1. Summary of at-sea seabird survey observations.
Seabird observations in each survey year by focal species, with total observations noted. Abundance over time was statistically insignificant for all focal species except Sooty Shearwaters, which also drove the focal species and total observation models.

Species	2014	2015	2016
Black-footed Albatross	183	415	251
Black-legged Kittiwake*	0	1	0
Brandt's Cormorant*	4	0	4
Common Murre	2802	1057	2709
Northern Fulmar	11	85	20
Pacific Loon*	0	1	0
Pink-footed Shearwater	152	440	62
Red-throated Loon*	0	0	0
Sooty Shearwater^{+}	1701	4286	16936
Short-tailed Albatross*	0	0	0
Western Gull	410	182	295
Focal spp total^{+}	5263	6466	20277
Total^{+}	5617	7729	20867

$^{+}$ Modeled abundance over time was statistically significant ($p<0.001$)
* Not enough data to fit a model

4.3 Species Summaries

4.3.1 Black-footed Albatross

While Black-footed Albatrosses breed primarily in the Northern Hawaiian Islands or the West Pacific, they frequent the Oregon coast to forage offshore in the early boreal spring through fall. Abundance off Oregon generally increases from spring on, as foraging range increases coincident with chick growth. Presence along the Oregon coast in winter during the nesting period is less common, but birds may make extended trips during incubation that reach with US West Coast (Kappes et al. 2010). The primary threat posed to Black-footed Albatross populations off the Oregon coast is mortality resulting from interactions with demersal long-line commercial fisheries, however management and regulation of fishing practices is expected to decrease mortalities significantly (Gladics et al. 2017). Black-footed Albatrosses are moderately vulnerable to collision, population, and displacement risks with regard to marine renewable energy development (Kelsey et al. 2018).

Black-footed Albatrosses were documented in the study area over all 3 years, with the lowest and highest total sightings in 2014 and 2015, respectively. High densities were concentrated offshore of Cape Blanco in 2014 and 2015, however the highest recorded density (~91 BFAL/km^2) was observed in 2016 further to the north, offshore of the central coast (Figure 4-1).

4.3.2 Brandt's Cormorant

Endemic to the California Current, Brandt's Cormorants are a resident Oregon seabird species with approximately 10,000 nesting pairs along the coast and estuaries (Naughton et al. 2007)(Porquez et al. in press). Brandt's Cormorants are present year-round, typically nearshore or in rivers and estuaries. Although the Oregon population is considered relatively stable, risks include fishing mortality and anthropogenic disturbance (to individuals and nesting habitat). Population vulnerability for Brandt's Cormorants along the outer continental shelf was high (Kelsey et al. 2018), likely as a result of abundance and relatively in-depth understanding of population fluxes and mortality rates (particularly along California); however, this species had very low detection rates over our sea-based surveys.

Brandt's Cormorants were observed in very low frequencies and abundance throughout our study area from 2014-2016. In fact, Brandt's Cormorants were only documented in 2014 and 2016, with fewer than 5 individuals total despite the knowledge that the species is abundant along the coast during nesting in the spring/summer months. This is likely a reflection of the survey/transect design rather than real distributions, as survey transects typically began or ended 3-5 miles offshore, excluding the nearshore region typical of Brandt's Cormorants breeding foraging range. Therefore, we do not recommend these Brandt's Cormorants data are used to make management decisions, rather that future marine spatial planning with respect to Brandt's Cormorants requires further investigation and potential incorporation of nearshore or shore-based surveys.

4.3.3 Common Murre

Common Murres are the most abundant species on the Oregon coast, with approximately 100 known breeding colonies that have been occupied at different rates over the last 30 years. Common Murres are present in Oregon year-round and breed in dense colonies along the coast, with some of the largest breeding colonies in the world historically present off Oregon. Common Murres are commonly sighted nearshore but have also been known to conduct long foraging trips and are regularly observed over the Oregon continental shelf. Common Murres were abundant throughout the study area over all years with a notable northward shift from 2014 to 2016 (Figure 4-2). In 2014, Common Murres appeared randomly dispersed along the Oregon coast, whereas in 2015 they were more concentrated in the central region and south of Cape Blanco. In 2016, Common Murres were documented in the highest densities over our study period at the mouth of the Columbia River. The Mouth of the Columbia River and Columbia River Estuary likely provided more abundant foraging habitat for seabird species during the Pacific Marine Heatwave years when foraging conditions elsewhere along the coast were unfavorable.

The estimated collision risk between Common Murres and marine infrastructure is low; however, estimated displacement vulnerability is higher, primarily driven by macro-avoidance of nearshore structures (Kelsey et al. 2018). Because of the extent of the breeding population of Common Murres along the Oregon coast, this species could be subject to elevated rates of displacement by marine or coastal structures (wind/wave energy) during the nesting season (Spring/April – Fall/August) and may be more vulnerable to development near larger breeding colonies where the population is denser (Suryan et al. 2012).

4.3.4 Northern Fulmar

Northern Fulmars are present over Oregon waters during the boreal winter and are largely absent the rest of the year. Accordingly, Northern Fulmars were observed at a relatively low rate over our study, never exceeding 100 sightings in any survey year. The highest densities were detected in 2014 and 2015, and in both years were concentrated on or south of the southern Oregon border. Our observations, and lack thereof, likely reflected seasonal absence of Northern Fulmars along the Oregon coast in summer.

Primary threats to the species include introduced predators at breeding sites, contaminant ingestion, and mortality from fisheries interaction. Northern Fulmars on the outer continental shelf were moderately vulnerable to collision, and displacement (Kelsey et al. 2018). Winter distributions along the Oregon coast are not well understood, however we would not expect the species to be vulnerable to interaction with seasonal devices (e.g., summer testing at PacWave off Newport, Oregon).

4.3.5 Pacific Loon

Pacific Loons are present briefly as migrants along the Oregon coast in the boreal spring and fall. Pacific Loons are occasionally observed on the Oregon coast during winter but are typically found further south. The rest of the year is spent in more northern latitudes when Pacific Loons are conspicuously absent from Oregon. Likely a reflection of seasonal distribution, Pacific Loons were not observed over the course of our at-sea surveys.

Pacific Loons had high collision and low displacement vulnerability rates across the outer continental shelf (Kelsey et al. 2018). Due to low macro-avoidance rates, collision risk was elevated; however, these values may be lower when considering only Oregon distributions as risks would be largely restricted to short time periods when Pacific Loons are migrating through.

4.3.6 Pink-footed Shearwater

Pink-footed Shearwaters are present along the Oregon continental during their non-breeding period and trans-equatorial migration. Observations primarily occur from boreal spring (April/May through September). Conservation status of Pink-footed Shearwaters is vulnerable primarily due to unknown population sizes, loss of nesting habitat, fisheries bycatch, and predation (Kelsey et al. 2018).

Pink-footed Shearwaters were observed along the Oregon coast throughout our study period, with the highest total observations and aggregations in 2015 (Figure 4-3). Pink-footed Shearwaters were generally observed along the continental shelf, with observations aggregated in the northern half of the Oregon coast in 2014 and shifting further to the south in 2015. In 2016, sightings and species density decreased.

4.3.7 Red-throated Loon

Red-throated Loons are present in Oregon during their non-breeding season, primarily boreal spring and fall. Occasionally present during winter months, however non-breeding Red-throated Loons are more commonly concentrated north (Juan de Fuca Strait) or south (Point Reyes, Arena) during the winter. Red-throated Loons were not observed along the Oregon coast during our at-sea study. Due to low macro-avoidance rates of Red-throated Loons, collision risk is elevated (Kelsey et al. 2018); however, these values may be lower when considering only Oregon distributions as risks would be largely restricted to short time periods when Red-throated Loons are migrating.

4.3.8 Short-tailed Albatross

Short-tailed Albatross were not observed within our study area in any of our study years. Based on low occurrence along the Pacific Outer Continental Shelf, collision and displacement risks related to marine renewable energy are relatively low, however we would expect the impact of these risks to shift and need reevaluation as the population grows (Kelsey et al. 2018).

4.3.9 Sooty Shearwater

Sooty Shearwaters occur in Oregon during their non-breeding season/ boreal spring, summer, and fall on their trans-equatorial migration to foraging grounds in the northern hemisphere. Sooty Shearwaters are one of the most abundant seabird species in the world. Although this population is large, the species is considered near-threatened with recorded decline in both nesting populations and at-sea distributions over the last several decades (Carboneras et al. 2020). Population vulnerability along the outer continental shelf was elevated, although this finding was accompanied by high uncertainty (Kelsey et al. 2018). Further research on this species could better define vulnerability and risks to Sooty Shearwaters.

Sooty Shearwaters were the most abundant seabird species observed over the course of our study (with the exception of 2014 where they were nearly as abundant as resident species Common Murre). In 2014, the highest Sooty Shearwater densities occurred along the northern portion of the Oregon coast; however, they were regularly observed coast-wide (Figure 4-4). In 2015, the species appeared in highest densities at the mouth of the Columbia River and to a lesser extent around Cape Arago/north of Cape Blanco. In 2016, we observed a marked concentration in Sooty Shearwater aggregations at the mouth of the Columbia River with densities exceeding 10,000 birds/km^2.

4.3.10 Western Gull

A portion of Western Gulls breed in Oregon (~5,000 breeding pairs) and can be observed along this coast year-round. Commonly observed near and further offshore, in rivers and estuaries and areas with high anthropogenic activity. Primary mortality risks include injury from collision and anthropogenic disturbance (fisheries entanglement, contaminants, etc.). High collision and low displacement vulnerability is predicted for Western Gulls (Kelsey et al. 2018). Attraction to platforms and structures along the California coast contributed to the elevated collision risk of Western Gulls. Western Gulls were observed at the highest rate in 2014, with decreased sightings in 2015 and 2016 (Figure 4-5). In 2014, Western Gulls were primarily aggregated off of Cape Blanco but were also abundant on the northern Oregon coast. In 2015, Western Gull concentrations appeared to shift south, with a portion of gulls still occurring around the mouth of the Columbia River. In 2016, Western Gulls were more dispersed along the coast in smaller densities overall.

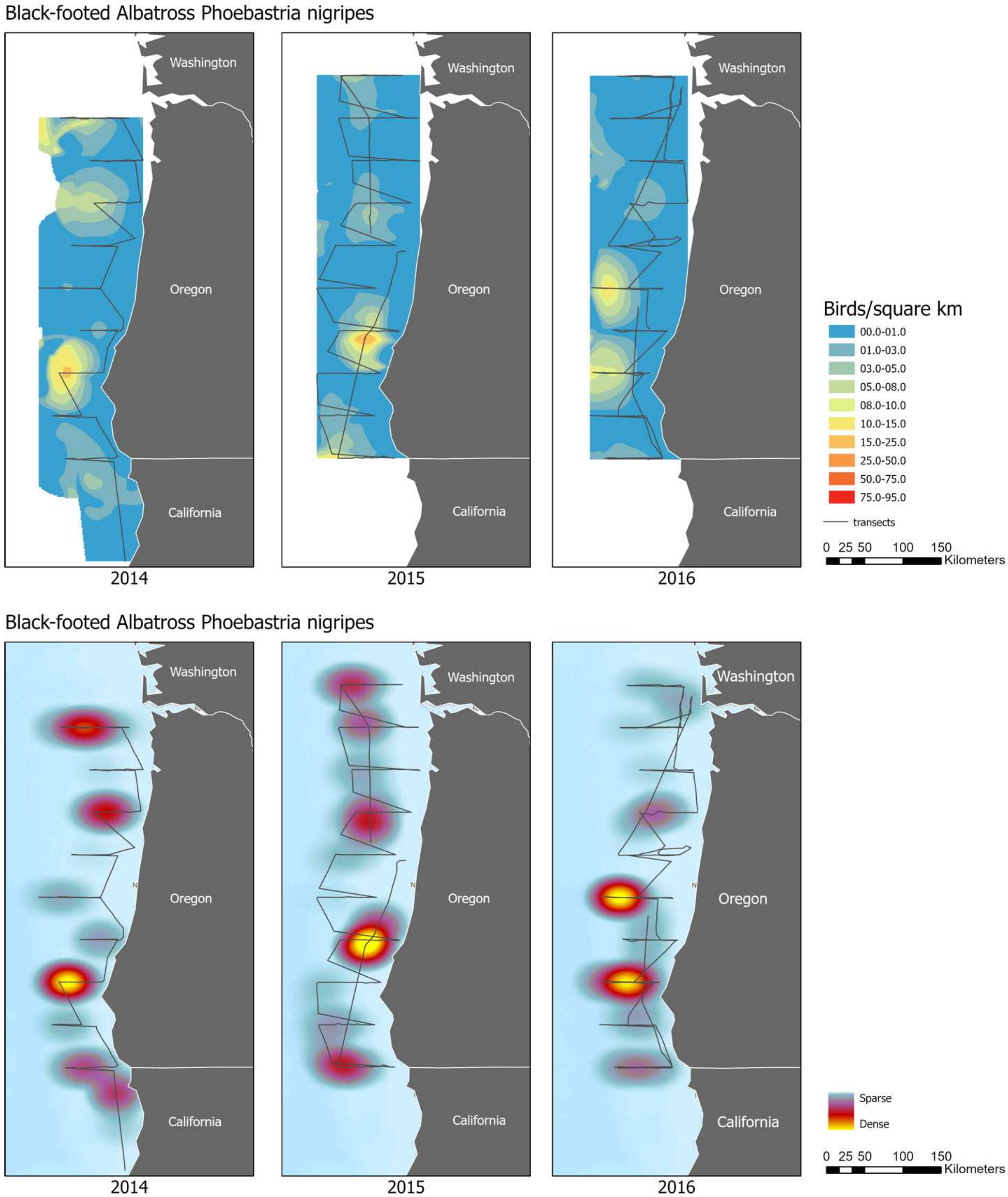


Figure 4-1. At-sea densities per km^2 (A) and relative densities with years (B) of Black-footed Albatross observations May/June 2014-2016.

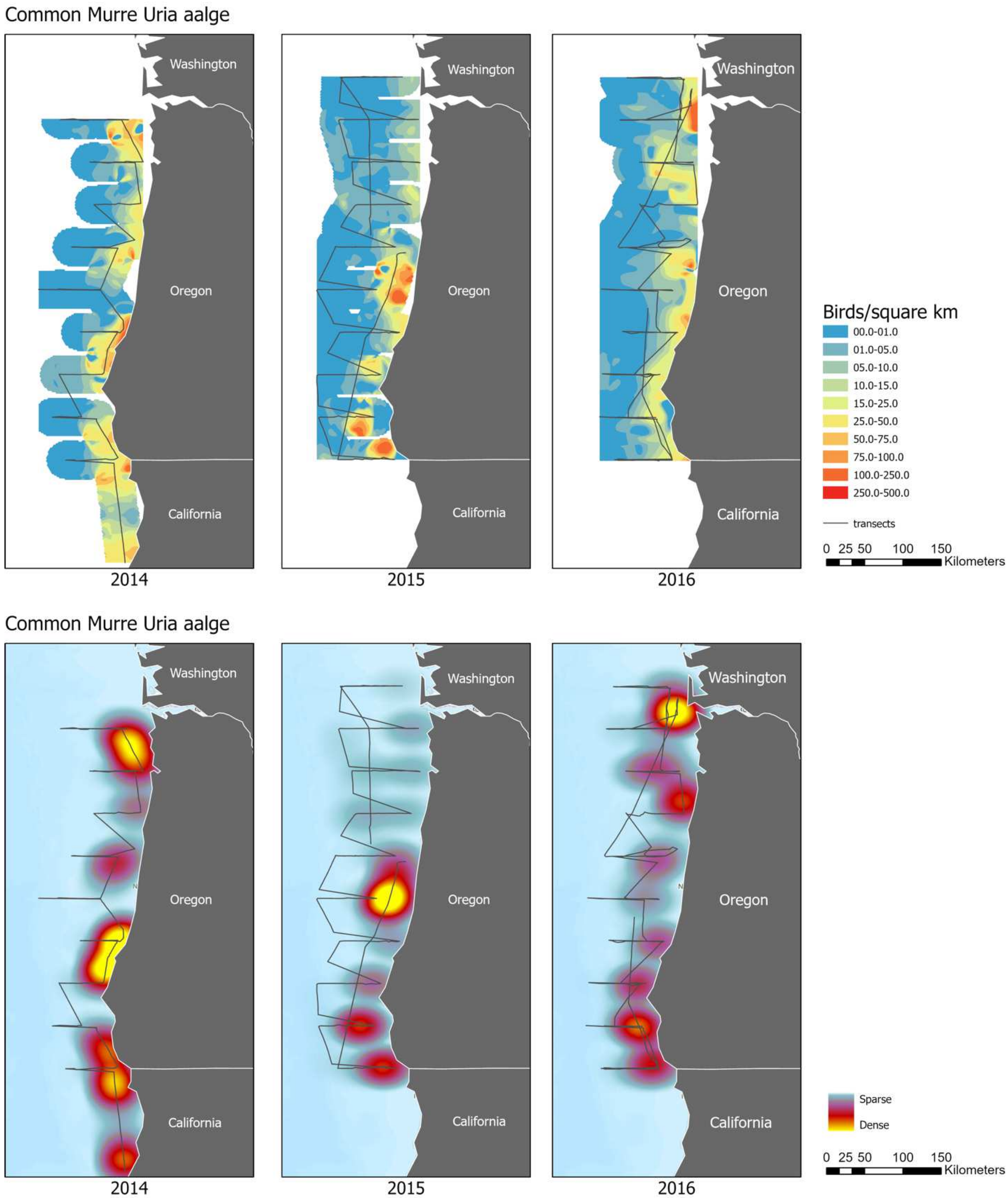
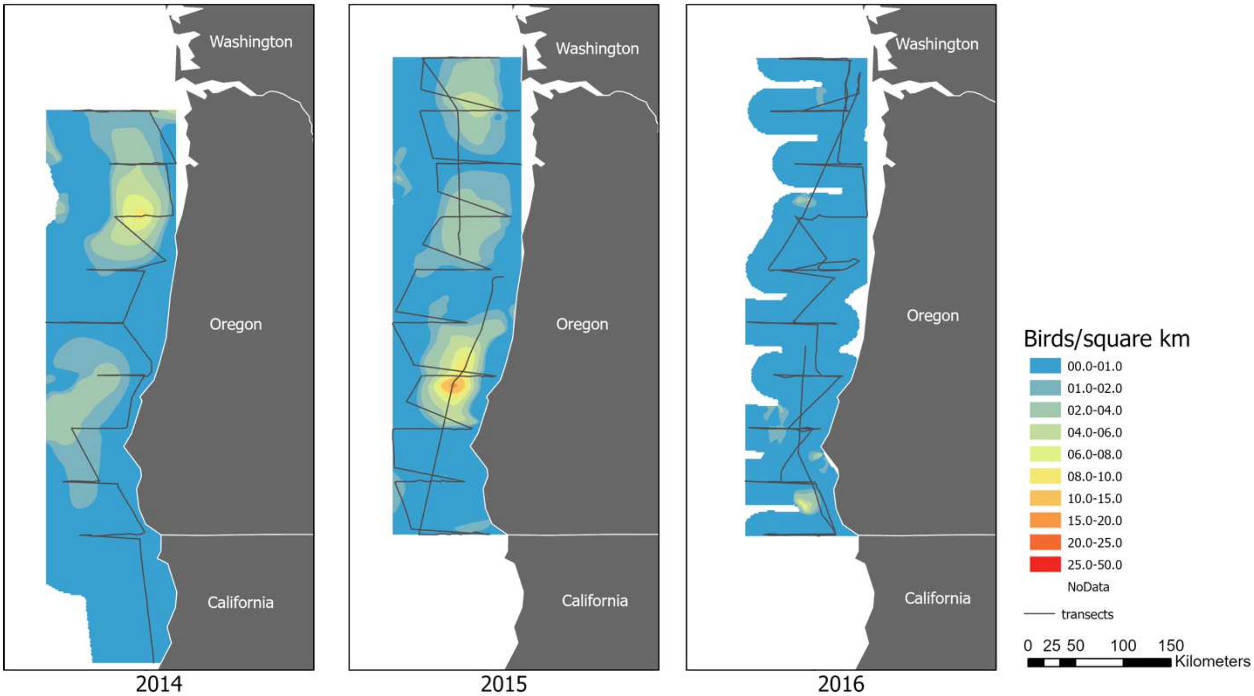


Figure 4-2. At-sea densities per km^2 (A) and relative densities with years (B) of Common Murre observations May/June 2014-2016.

Pink-footed Shearwater Puffinus creatopus



Pink-footed Shearwater Puffinus creatopus

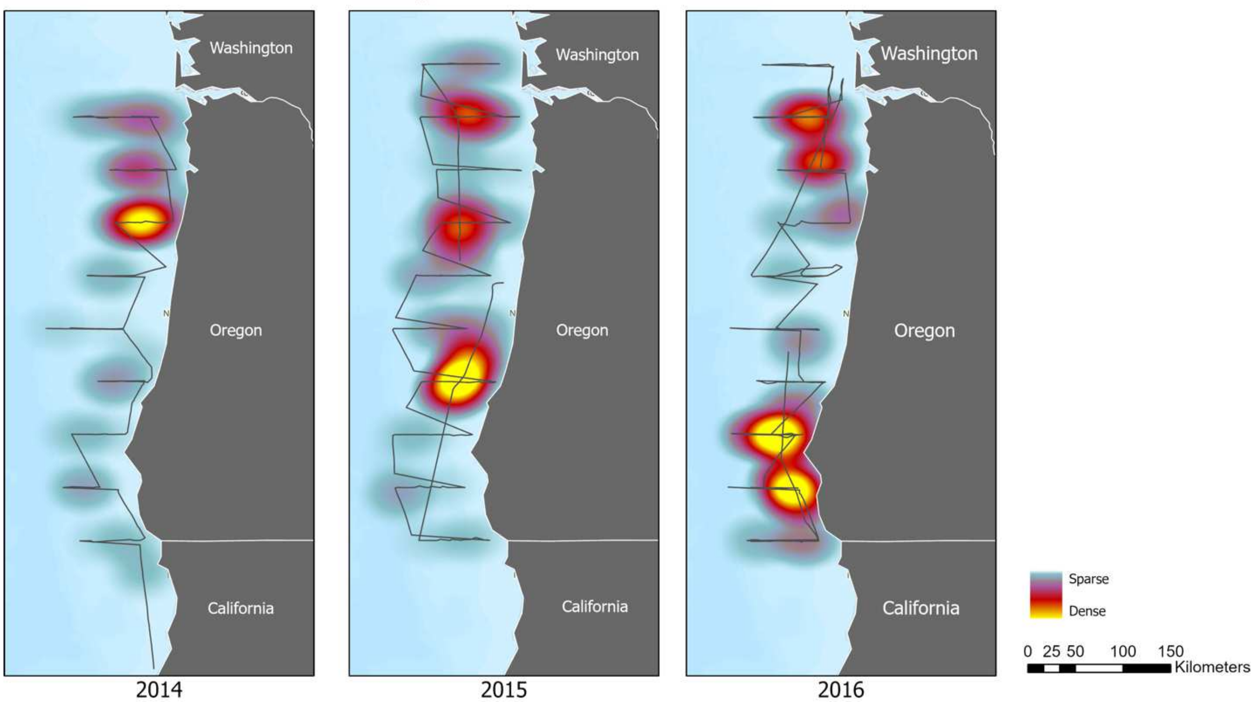


Figure 4-3. At-sea densities per km^2 (A) and relative densities with years (B) of Pink-footed Shearwater observations May/June 2014-2016.

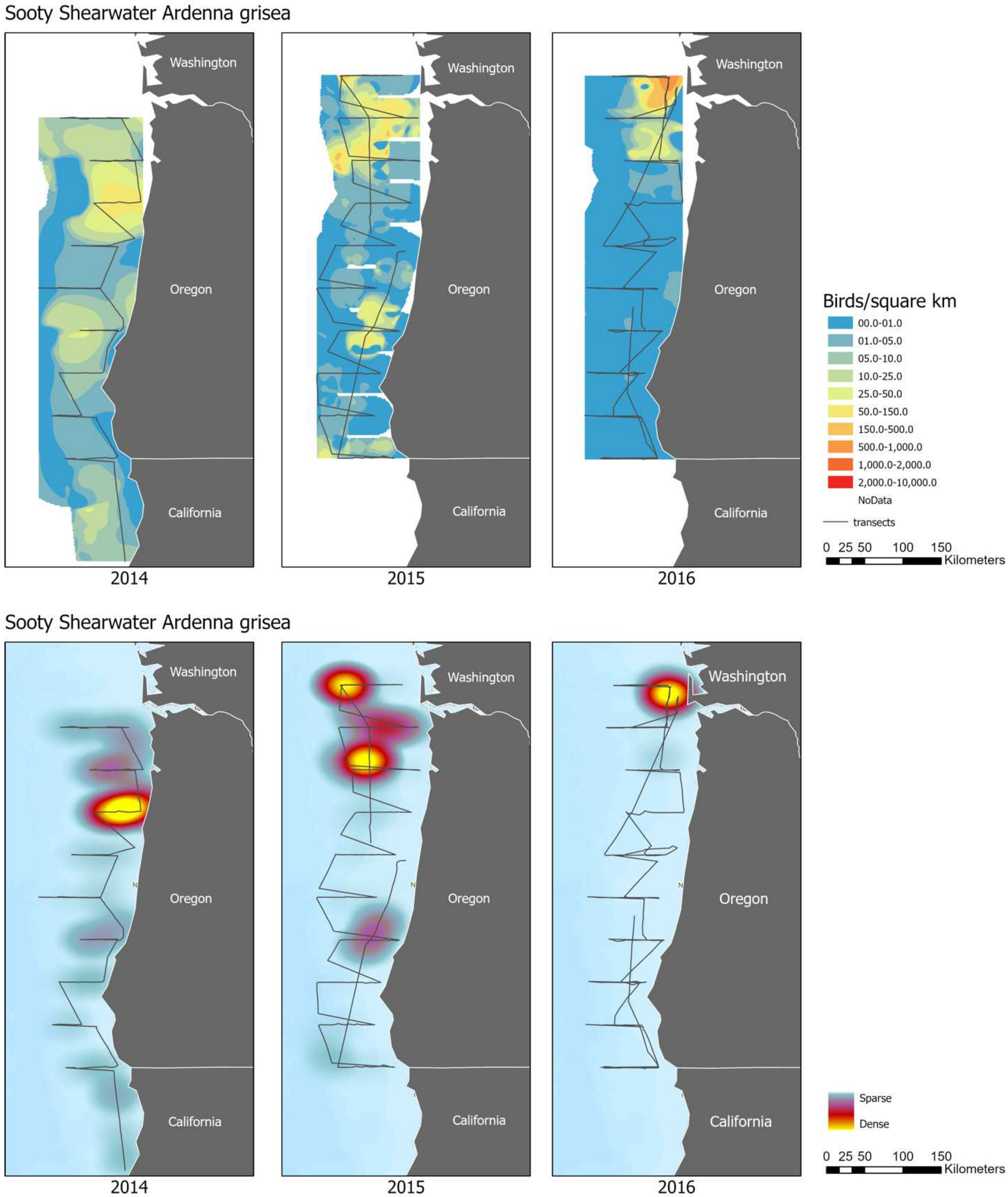


Figure 4-4. At-sea densities per km^2 (A) and relative densities with years (B) of Sooty Shearwater observations May/June 2014-2016.

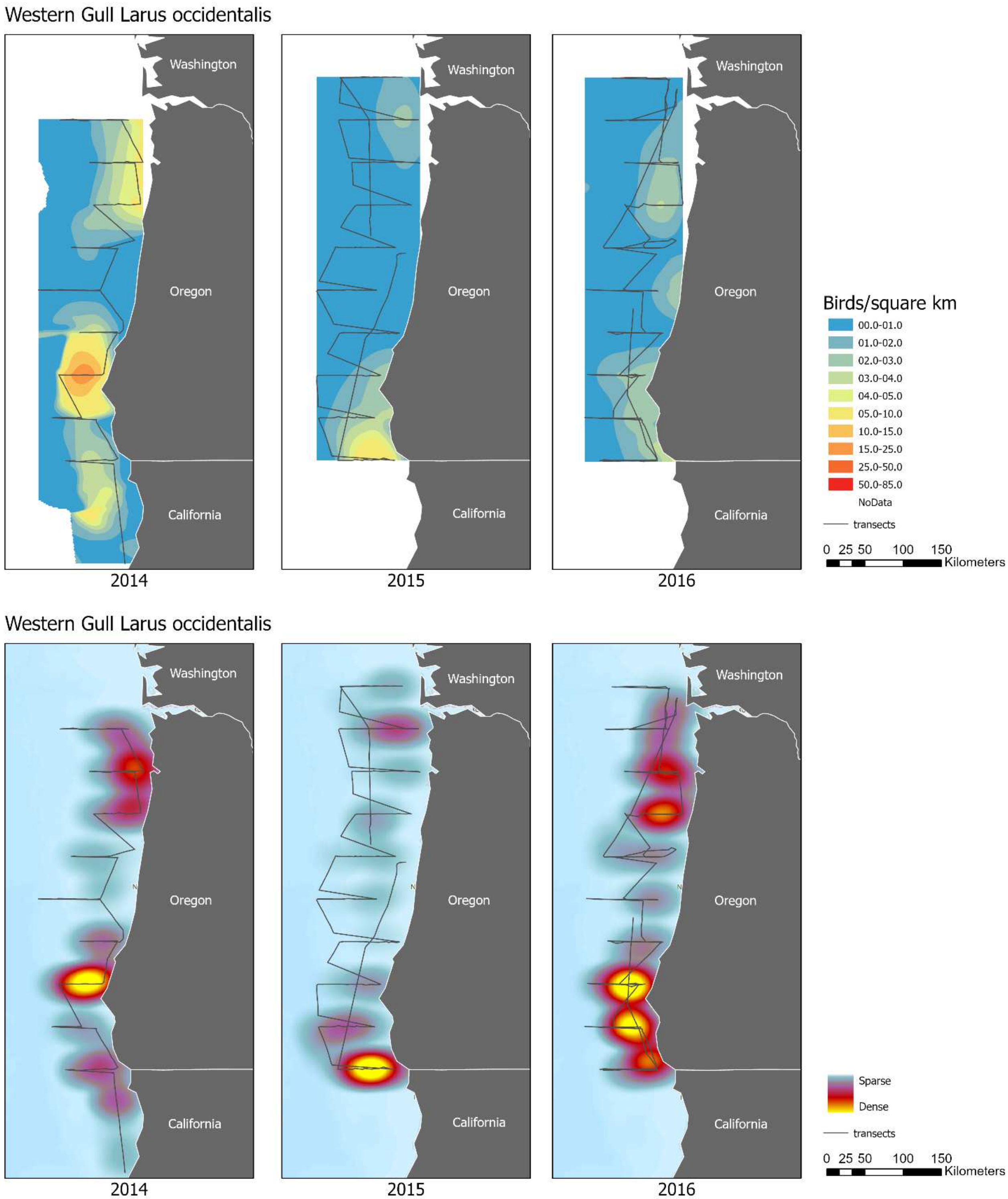


Figure 4-5. At-sea densities per km^2 (A) and relative densities with years (B) of Western Gull observations May/June 2014-2016.

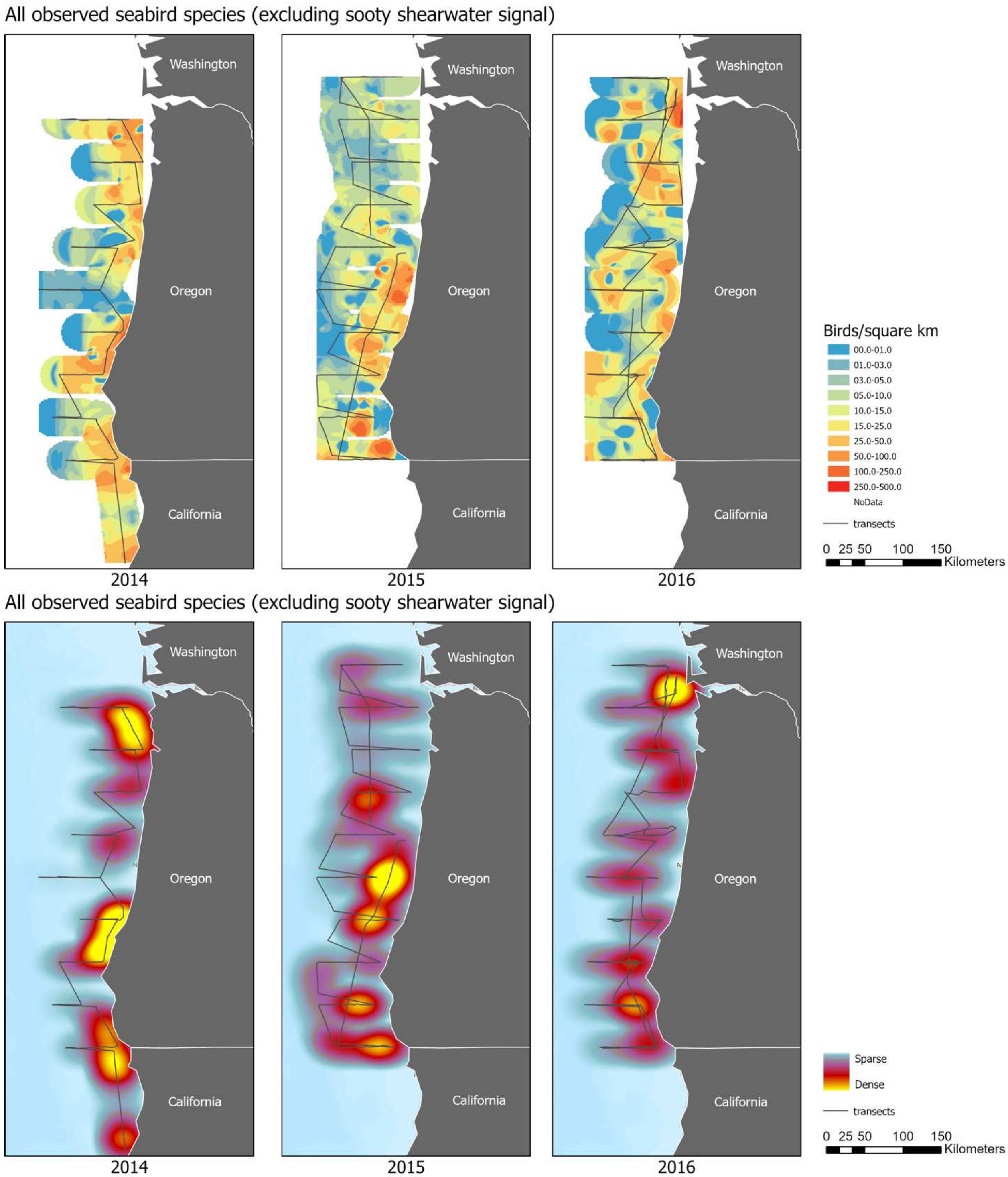


Figure 4-6. At-sea densities per km^2 (A) and relative densities with years (B) of seabird observations May/June 2014-2016 (excluding Sooty Shearwaters).

4.4 Discussion

4.4.1 At-sea and Tracking Data Qualitative Hotspot Comparison

At-sea observations and individual tracking data provide a complimentary understanding of species distributions, though both approaches have inherent biases. At-sea observations are collected in a systematic way, but are limited to the narrow swath of ocean observable, the ship transect coverage, and the limited duration and annual timing of surveys (Watanuki et al. 2016). Tracking data provide an individual perspective on movements of a small number of tagged individuals. The selection of tracked individuals is typically biased to the capture site (e.g., colony) or to the life history phase most easily captures (e.g., breeding adult). Thus, combining both data sources offers additional insight on marine bird distributions across the annual cycle. Generally, density maps from the off-shore survey data and tracking densities did not highlight similar high-use patterns across the northern California Current System. However, the areas off of the mouth of the Columbia River was a noted high use area for tracked Common Murres, and shearwaters and high densities of these species were observed during the summer at-sea surveys.

4.4.2 At-sea and Tracking Data Species Composition Comparison

At-sea surveys and tracking data included a different selection of species. Available tracking data have noticeable gaps in species composition and coverage including most smaller-bodied species that were observed >20 instances in the at-sea surveys (e.g., phalaropes, storm-petrel spp., Rhinoceros Auklets, Cassin's Auklets, Tufted Puffins, and California Gulls). However, at-sea surveys excluded near shore species including Brandt's Cormorants, Pelagic Cormorants, loon spp., and Marbled Murrelets. Additionally, no observations of Short-tailed Albatrosses occurred during our summer at-sea surveys. Similarly, the tracking data from this time period did not include any tracks from Short-tailed Albatrosses, but multiple individuals were present in the study region during the spring, fall, and winter months. Additional empirical data is needed to better understand the year-round distribution of many seabird species in the Northern California Current.

4.4.3 Recommendations for Future Work

Both at-sea survey and tracking data have inherent value in understanding the seasonal distributions and habitat associations of seabirds at-sea. Each sampling technique offers complementary advantages, yet has sampling biases, and challenges related to spatiotemporal coverage. Combining both data collection methods into species distribution modeling approaches offers an analytic approach to overcoming some of these biases (e.g., night habitat associations). While still a relatively new statistical approach combining multiple species distribution models built from these datasets can help complete the picture (Watanuki et al. 2016, Derville et al. 2018, Abrahms et al. 2019). However, seabird-habitat associations may not be universally transferable in space and time due to factors such as dietary flexibility, confounding environmental influences on prey species, and unexpected ecosystem shifts (e.g., Torres et al. 2015). Continued observational data is thus required to reassess both the empirical observations of seabird hotspots and understand their persistence through time.

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Appendix A: Publications, Data, and Other Materials Resulting from Data Collected Under This Study

A.1 Published Peer-reviewed Publications

Clatterbuck C, Lewison R, Orben RA, Ackerman J, Torres LG, Suryan RM, Warzybok P, Jahncke J, Shaffer SA. 2021. Foraging in marine habitats increases mercury concentrations in a generalist seabird. Chemosphere, 279, 130470. http://doi.org/10.1016/j.chemosphere.2021.130470

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A.2 Theses

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A.3 Conference Presentations

Clatterbuck C, Lewison R, Orben RA, Suryan RM, Torres LG, Ackerman J, Young H, Shaffer SA. 2019. Contaminants as ecological tracers: does mercury load reflect foraging habits of a generalist seabird? 46rd PSG, Kaua'i, HI.

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Lawson A, Lyons DE, Orben RA. 2020. Breeding and foraging ecology of Western Gulls nesting in different habitats on the Central Oregon coast. 47th PSG, Portland, OR.

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Orben RA, Shaffer SA, Suryan RM. 2017. Comparative flight height behavior of Hawaiian albatrosses. Annual PSG Meeting, Tacoma, WA.

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A.4 Invited Seminars

Hatfield Marine Science Center, Oregon State University. Ontogenetic changes in at-sea distribution of immature Short-tailed Albatrosses. August 2017.

South Atlantic Environmental Research Institute, Falkland Islands. Ontogenetic changes in at-sea distribution of immature Short-tailed Albatrosses. January 2018.

A.5 Data Releases

Harrison A-L, Uher-Koch BD, Schmutz JA, Douglas DC. 2020, Tracking data for Pacific Loons (*Gavia pacifica*) (ver 1.0, February 2020): U.S. Geological Survey data release. https://doi.org/10.5066/P9NNN2XY

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A.6 Computer Code

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