



## AN ABSTRACT OF THE THESIS OF

Jessica M. Porquez for the degree of Master of Science in Marine Resource Management presented on February 5, 2016.

Title: Spatiotemporal drivers of seabird distribution at the Pacific Marine Energy Center off Newport, Oregon.

Abstract approved:

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Robert M. Suryan

The central Oregon coast was selected as an ideal site for wave energy development and establishment of the Pacific Marine Energy Center (PMEC). PMEC will consist of two nearshore sites, one north (NETS) and one south (SETS) of the Yaquina River, Oregon. Our study aims to assess how the development of wave energy sites might impact marine birds. We used vessel-based strip transect surveys to detect spatial and temporal patterns of seabirds during 28 surveys of NETS and SETS from 2013-2015. We also conducted 29 surveys along the Newport Hydrographic Line (NHL) (2006-2009, 2013-2015), a cross-shelf oceanographic sampling line that extends 40 km west of NETS. We collected *in situ* measurements of surface conductivity, temperature and fluorescence to test correlations between spatial variables and seabird abundance. Common murre (*Uria aalge*) were the most abundant resident species (70%) while sooty shearwaters (*Puffinus griseus*) were the most abundant migratory species (78%). We identified 7 focal species (common murre, sooty shearwaters, Brandt's and pelagic cormorants (*Phalacrocorax penicillatus and pelagicus*), western gull (*Larus*

*occidentalis*), Cassin's auklet (*Ptychoramphus aleuticus*), and red-necked phalaropes (*Phalaropus lobatus*), 5 foraging niches and 3 species of interest for analysis. We used non-metric multidimensional scaling ordinations to assess seasonal shifts in the seabird community at a focal species and foraging group level. Both ordinations depicted strong seasonal gradients with distinct seasonal communities. Focal species were also driven by a distance to shore gradient, while foraging niches were more influenced by foraging type (diving versus surface feeding). The shoreward shift or outward dispersal of species appears driven by a combination of factors, including the diffusion of nearshore concentration of murres and cormorants on Yaquina Head post chick fledging, and the inshore movement of migratory species with the onset of upwelling and greater prey abundance. We employed generalized additive mixed models for the focal species, and tested for correlations with *in situ* data (salinity, temperature and fluorescence), depth, substrate, season, and a random 'site' effect. We identified correlations between several species and measured oceanographic variables, which indicated species' selection of specific water masses. With Inverse Distance Weighted maps we detected high use zones by sooty shearwaters and common murres outside of both site boundaries, except during the spring and summer, when murres occur densely within the NETS. None of our observed species of concern (brown pelicans (*Pelicanus occidentalis*), black footed albatrosses (*Phoebastria nigripes*) and marbled murrelets, (*Brachyramphus marmoratus*)) were detected within either site boundary. Rather, pelicans and murrelets were observed inshore of the SETS and south of the NETS, and albatrosses were all detected west of the sites. We observed overall low abundance of focal species within the sites, relative to adjacent areas, although the whole study area appears to be productive

foraging habitat used by many species. As a baseline characterization of the seabird community off Newport, this work can help inform citing and permitting processes of similar wave energy test facilities and provide a platform for continued monitoring of seabirds in the area.

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Spatiotemporal Drivers of Seabird Distribution at the Pacific Marine Energy Center off  
Newport, Oregon

by  
Jessica M. Porquez

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Jessica M. Porquez, Author

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## **Introduction**

A collective shift away from reliance on fossil fuel energy has increased the focus on alternative energy resources, including marine renewable energy. Off the U.S. west coast in the California Current System, there is increased interest in offshore wind and wave energy development. Within the California Current there are areas of marine renewable wind and wave energy research, with pilot studies aimed at understanding potential ecosystem effects in addition to testing marine renewable energy converters for broad-scale commercial production (Boehlert et al. 2012).

Located within the northern portion of the California Current System (nCCS), the central Oregon coast possesses favorable environmental conditions for the development of wind and wave renewable energy. Subsequently, nearshore waters in Newport, Oregon were selected for the Pacific Marine Energy Center's (PMEC) North and South Energy Test Sites (NETS and SETS, respectively). Established in 2012, the NETS is a site for a non-grid connected platform that allows developers to test scaled versions of wave energy devices. The SETS is a proposed utility-scale wave energy device test site which will be equipped with grid connected wave energy converters (WECs) and will be the first U.S. industrial wave energy test facility with the capacity for up to four testing berths (1-5 WECs per berth) with no more than ten WECs at the SETS at any given time. An increasing diversity of human use of marine waters, such as renewable energy facilities, increases the potential for anthropogenic interactions with marine organisms in the nCCS, particularly with highly mobile species such as seabirds.

The Oregon coast supports approximately 1.3 million nesting seabirds per year (Naughton et al. 2007). Of the 15 seabird species that nest on the Oregon coast, 11 nest along the north-central coast, and most occupy rocky habitat throughout the breeding season (Naughton et al. 2007). The central Oregon coast has long stretches of sandy beach, making nest site availability limited compared to the north and south coast. Consequently, relatively few birds breed in the area; approximately 6% of the total Oregon seabird population (Naughton et al. 2007), with the majority nesting at Yaquina Head, adjacent to the NETS site and approximately 15 km northeast of the SETS site. Prior research has documented high use of Oregon nearshore regions by alcids, cormorants, storm-petrels, shearwaters, gulls, brown pelicans, murrelets and phalaropes during the breeding season, however the broad scale of these studies (Suryan et al. 2012, Adams et al. 2014, Zamon et al. 2014) results in inadequate coverage of the PMEC area.

In the non-breeding season, the nCCS is additionally a high-use migration path that sustains millions of seabirds (Briggs et al. 1987; 1992, Adams et al. 2014). From 2011-2012, results from aerial surveys conducted from shore to the 2000 meter isobath identified the highest densities of seabirds in the nearshore region (<100m depth). Adams et al. (2014) documented the densest aggregations in the fall ( $49.4 \pm 5.0$  birds/km<sup>2</sup>), with lower densities in winter and summer ( $37.4 \pm 4.6$  birds/km<sup>2</sup> and  $37.5 \pm 6.4$  birds/km<sup>2</sup>, respectively). Strong evidence that seabirds occur in highest densities nearshore means that we would also expect high densities within the project area, with species composition changing from nearshore to offshore and seasonally. The NETS and SETS are located entirely within the continental shelf, therefore we included an

additional cross-shelf transect extending 40 km offshore from the P MEC to capture seasonal fluctuations and cross-shelf variation in community composition throughout the year (Fig 1; Hickey & Banas 2003). Prior to our study, our understanding of seabird variation off the central Oregon coast was at a relatively coarse spatial and temporal resolution, with limited applicability to a small, fine scale area like the P MEC.

As a result of physical forcing, coastal upwelling, terrestrial input, and interactions between oceanographic features and nutrient concentrations in the nCCS (Hickey & Banas 2008), the central Oregon coast is a highly productive, nutrient rich marine system that supports many seabirds throughout the year. Various oceanographic conditions lead to increased lower trophic level productivity, greater euphausiid and other zooplankton abundance within the system, which directly supports planktonic seabirds such as auklets and phalaropes. Subsequent trophic transfer of energy to mid trophic level forage fishes supports piscivorous seabirds such as murre, cormorants, gulls, terns, and pelicans.

There is high variability in foraging strategies, diets and habitat specializations of seabird species that regularly occur within the study area. Resident species such as cormorants and various alcids are pursuit divers, meaning that they dive to capture prey (usually one item at a time for piscivores), by using their wings (murre, auklets) or feet (cormorants) for propulsion. Dive depths vary by species, with cormorants and some auklets diving to depths of about 40 meters and common murre up to 150 meters (maximum; murre regularly dive to about 60 meters). Prey preference varies by species, with some species exhibiting greater flexibility or adaptability in diet. Common murre

are considered generalist predators that forage in various habitats across the continental shelf, targeting micro-nekton, forage and schooling fishes (Ainley et al. 1996, Gladics et al. 2015). Gladics et al. (2015) found that 65% to 95% of common murre diets within the study area were comprised of smelts, sand lance or clupeids over 8 years (1998-2002, 2007-11). As a result of this generalist diet, murre forage over various substrates, depending on the prey item. Smelts, sand lance and clupeids are all found in the nearshore region, with associations to different benthos; sand lance are found over sandy bottom while smelts aggregate in kelp forests over rocky bottom. In accordance with prey availability, common murre typically forage near to shore, although as generalists, associations with benthic habitat are variable.

As benthic foragers, pelagic and Brant's cormorants have shown overlap in foraging range (Ainley et al. 1981) although they appear to exploit resources differently. Ainley et al. (1981) found that pelagic cormorants selected individual non-schooling prey items over rocky habitat, while Brandt's cormorants were found to prey on school and non-schooling fishes, over a variety of benthic substrates.

Cassin's auklets are the only regularly occurring seabirds in the study area that are planktonic pursuit divers with euphausiids comprising the majority of their diets (Vermeer 1981, Ainley et al. 1996b). Cassin's auklets' foraging habitat has been linked to coastal upwelling (Ainley et al. 1996b), during which time the lipid (energy) rich euphausiid *Thysanoessa spinifera*, shifts inshore from the outer shelf, where it typically dominates planktonic biomass, and becomes more abundant across the central Oregon coast mid-shelf region (Shaw et al. 2004). Therefore Cassin's auklet distributions within

the nCCS closely reflect *T. spinifera* distributions, which are affected by oceanographic processes, including coastal upwelling.

Gulls are abundant along the Oregon coast, with most species, including the resident western gull, demonstrating opportunistic feeding behaviors that are limited to shallow surface foraging. Gulls may forage around other marine animals (mammals, birds) in order to exploit fish forced to surface waters during deep water foraging by other predators (Harrison 1979). Due to the generalist, opportunistic feeding behavior of gulls, spatiotemporal drivers associated with their foraging distributions remains largely unknown.

Although their presence is highly seasonal, dark shearwaters are abundant along the Oregon coast during their trans-equatorial migration. Species present during this time include sooty (*Puffinus griseus*), flesh-footed (*P. carneipes*), pink-footed (*P. creatopus*) and short-tailed (*P. tenuirostris*), however the sooty shearwater is the most abundant. Shearwaters are procellariiformes that feed on prey fishes, and annual consumption of fishes by sooty shearwaters off of California from 2008-2009 was equivalent to the weight of commercial fisheries landings (Adams et al. 2012). Research has found that sooty shearwaters select highly productive foraging habitats (Jahncke et al. 2005, Shaffer et al. 2006) and take advantage of wind patterns to travel to optimal foraging grounds (Adams et al. 2010).

The variation of flight, prey preference and foraging behaviors of seabird species found on the Oregon coast means that potential interactions with marine energy should be considered with respect to differences between species. Research regarding established

WECs in the United Kingdom has identified several risk factors for seabird interactions with WECs including injury or mortality due to collision, foraging behavior alteration or exclusion from foraging area, disturbances from ship traffic or structures and disruptions in habitat specialization (Furness et al. 2012). Benefits could include use of the WECs as roost platforms, allowing greater range for species that tend to have shorter foraging flights or remain nearshore and the potential of WECs as fish attraction devices. Birds that fly within 30m of the sea surface (alcids, cormorants, storm-petrels, shearwaters, gulls, pelicans and phalaropes) are more susceptible to collision with above-surface structures when visibility is low and winds are high, although birds often avoid structures during high visibility and low wind (Boehlert et al. 2008, Cook et al. 2012). Diving birds such as the abundant common murre (*Uria aalge*) regularly dive between 50-100 m below the surface and may be more susceptible to subsurface collision or entanglement (Grecian et al. 2010). Seabird species are variably regulated by bottom up forcing (Ainley et al. 2009, Thompson et al. 2012, Drew et al. 2013), meaning that changes in habitat or hydrography due to WECs could indirectly impact trophic energy transfer and the subsequent seabird community (Furness et al. 2012). Seasonal and geographic variability of potential risks of WECs remains largely undetermined and may fluctuate depending on weather and ocean conditions, further supporting the need for year-round data from local areas of proposed development (Inger et al. 2009, Langton et al. 2011, Furness et al. 2012).

Due to the innovative nature of renewable wave energy development, research examining potential effects of WECs is limited. The majority of existing WECs and

environmental impact assessments are from the United Kingdom (e.g. Grecian et al. 2010, Langton et al. 2011, Furness et al. 2012), where the marine ecosystem and seabird species composition varies markedly from the nCCS. Although seabird distribution on the Oregon coast has been characterized in several studies (including Ainley et al. 2009, Zamon et al. 2014) some of which include year-round data collection (Adams et al. 2014), these surveys occurred infrequently and do not provide fine-scale coverage of the central Oregon coast and the proposed P MEC site. Our study investigated seasonal use of the NETS and SETS and adjacent waters by seabirds, and assessed how distribution changes in response to spatial and environmental variables at and around the sites. We aimed to establish a baseline assessment of the seabird community at the proposed wave energy development site(s), which can be used for ongoing monitoring and future impact studies. A clearer understanding of the fine-scale mechanisms that drive local seabird assemblages can better inform ecosystem management and marine spatial planning decisions. This is especially true with respect to marine renewable energy development, which has the potential to increase exponentially over the next several decades.

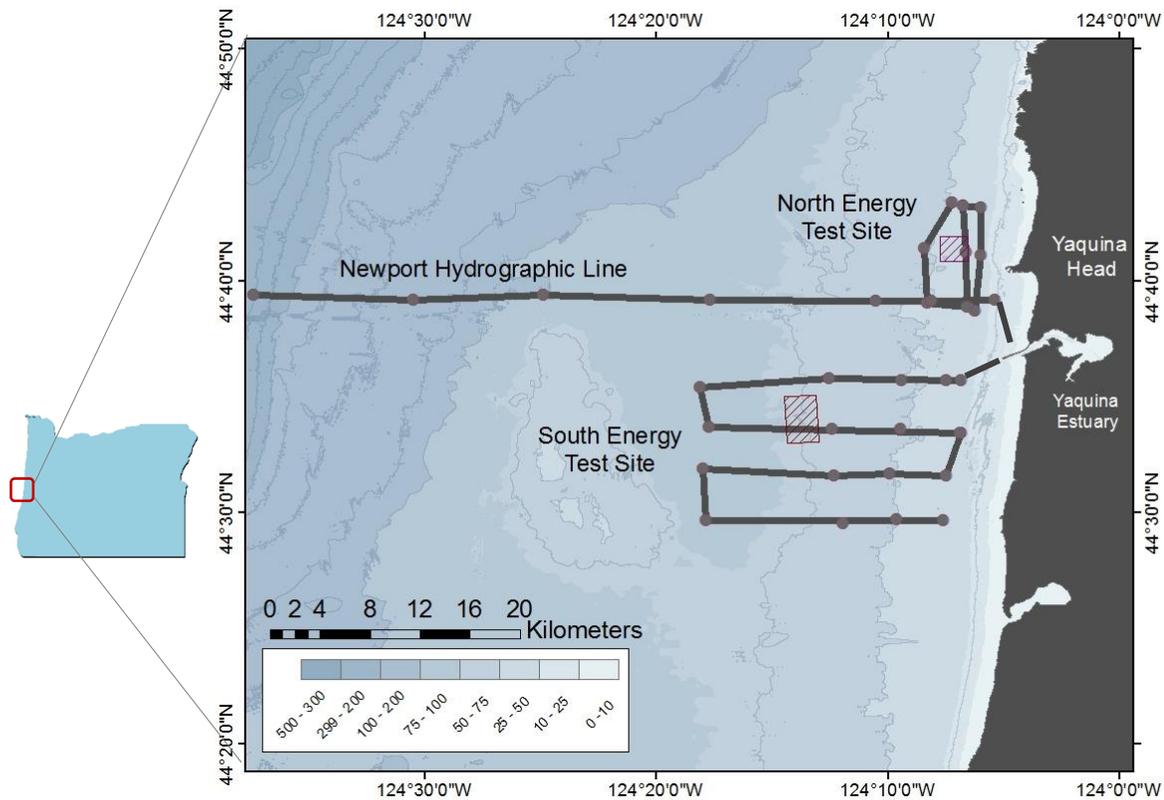


Figure 1. Ship tracks of 3 survey sites. The Newport Hydrographic line extends west from shore 40km, while SETS extends 16km. Grey nodes indicate sampling stations/breaks in continuous surveying effort and the boxes indicate the NETS and the proposed SETS are denoted by hatched boxes.

## Methods

### *Study area*

We surveyed three study sites in neritic waters off the central Oregon coast (Fig. 1) from May 2013 to October 2015 on a total of 44 cruises (table 1). Additionally for one site, the Newport Hydrographic Line, we included data from 13 surveys conducted December 2006 to July 2009.

The NETS and SETS are located north and south of the Yaquina River and extend approximately 5 km and 10 km offshore, respectively (Fig. 1). The NETS is located north of the Yaquina River on the continental shelf, within 7 km of the coastline. NETS is in close proximity to a large common murre breeding colony of up to 80,000 birds in peak breeding season (Naughton et al. 2008). Transects at the NETS ran primarily north-south with a total survey area of approximately 38 km<sup>2</sup>. The SETS is located south of the Yaquina River, extending west 16.5 km from the shoreline. Located approximately 5.5 km south of the NETS, the SETS survey area consisted of 4 major transit lines (each 16.5km) divided into 4 individual segments on each line between sampling stations at the 30, 40, 50 and 60-meter isobaths (Fig. 1). Additionally, we surveyed during transit from one major line to the next along a 3 km north/south transect (total survey area is approximately 160 km<sup>2</sup>). The third site, the Newport Hydrographic Line (NH), is an oceanographic sampling line that bisects NETS nearshore and extends 40 km offshore (Fig. 1), and provided characterization of cross shelf seabird distribution and bio-physical data adjacent to the NETS and SETS. Surveys along the NH line were platforms of opportunity, therefore transects were not modified for seabird observations. NH Line

surveys were conducted in a westward direction between oceanographic sampling stations located 1.6, 4.8, 8, 16, 24, 32 and 40 kilometers from shore. Surveys at NETS and SETS occurred between sunrise and late afternoon, while surveys of the NH line occurred 4 hours before sunset. Return transit from the NH line occurred during darkness to sample zooplankton, and the few nocturnal seabird surveys conducted were not included in these analyses. We also included observations recorded during transit to and from study sites, as well as data collected sporadic trips outside the typical transects to sample at anchors and to retrieve gliders or moorings, etc.

#### *Observational data*

All surveys were conducted aboard the R/V *Elakha* (16.5 m) using the strip transect method (Tasker et al. 1984). The observation bridge was 1.9 m above the water, with an average observer eye height of 3.5 m from the sea surface. Observers surveyed from the port side of the vessel out to 300 m in a 90-degree arc from bow to beam. Sightings were recorded during continuous transit between oceanographic sampling stations when the vessel speed was between 15-22 km/hour.

Observations were recorded using the SeeBird (2006-2013) or SeeBird WinCruz version 3.5+ (2014; Holland 2008) data acquisition software and are geo- and time-referenced with a direct input from the vessel's global positioning satellite receiver (GPS). For every cruise, a designated observer and data recorder alternated duties to avoid fatigue. Environmental sighting conditions included Beaufort sea state, visibility, cloud cover and rain/fog. For analytical purposes we only included data that had a Beaufort Sea state rating  $< 4$ . While previous studies used a Beaufort Sea state cutoff of 5

(Ronconi & Burger 2009, Adams et al. 2014) or 6 (Sigler et al. 2012), our observation platform was lower and we used a cutoff of 4, the point at which detectability of birds on water from the R/V *Elakha* became significantly compromised. For each seabird sighting, observers noted the bird species, number of individuals, distance from ship (<100 m and 100 - 300 m), and multi-species associations.

We calculated seabird density (birds km<sup>-2</sup>) in 3 km sections along transects using a custom program written in R v.3.1.1 (R core team 2014). Sections of continuous transit shorter than 1.5 km were not used for subsequent analysis. We chose 3 km sections in order to account for spatial autocorrelation in the data (Schneider 1991, Yen et al. 2004).

#### *Bio-physical and habitat data*

During seabird surveys we collected continuous surface water conductivity (salinity), temperature, and fluorescence (estimate of chlorophyll a as an indicator of phytoplankton biomass) measurements using a flow-through SeaCat21 thermosalinograph fitted with a Seapoint Ultraviolet fluorometer on 37 of 48 cruises from 2013-2015. Flow-through measurements were recorded every 3 seconds using SBE Seasave V7 software. These data were then converted and processed using the SBE Data Processing program, and binned into 300 m sections in R v.3.1.1 (R core team 2014), providing surface water characterization of the sites. These data were temporally matched to the binned observational data using a custom program written in Matlab (vR2013a).

We obtained benthic habitat data for our study area from the Oregon Department of Fish and Wildlife Nearshore Ecological Data Atlas (NEDA), a spatial planning grid of

nearshore benthic terrain. Surficial geologic habitat for NEDA was classified by the Active Tectonics Lab at Oregon State University into coarse benthic sediment types: sand, rock or mud (Goldfinger 2010; 2014). The data also included general bathymetry classifications of shelf, slope, ridge, basin, nearshore, and channel.

### *Seasonal distributions*

We used PC-ORD v. 6.0 (McCune and Medford 2011) to analyze seasonal shifts in the seabird community. We used non-metric multidimensional scaling (nMDS; Kruskal 1964) to develop community ordinations that reduced species relationships to a specified 2-dimensions over space and time. nMDS ordination was conducted on 7 focal species that were selected using a recommended threshold of 5% of total observations and on 5 foraging niches ecologically important to the area (table 2; McCune and Grace 2002). We calculated density  $\text{km}^{-2}$  for all birds observed and conducted community analysis on the selected 7 focal species and the 5 defined foraging niches. The data sets for the ordinations contained a mean nearshore ( $\leq 18.5 \text{ km}$ ) and offshore ( $> 18.5 \text{ km}$ ) species or group density value for each cruise, derived from the binned observational data. The near- and offshore classifications were selected because of observations that biological indicators and hydrography changed westward of sampling station NH10 and this also corresponded with the westward extent of the P MEC transects, allowing us to compare seabird community composition and abundance at P MEC sites relative to offshore waters. Fewer offshore surveys were conducted, resulting in an uneven number of near- and offshore data points. Final matrices used for ordinations included 74 density values of focal species and 69 foraging group densities from 2007-2015. For all

ordinations we employed Sorensen's distance measure, with a random starting configuration, Monte Carlo test, and 100 runs with real data. Ordinations were evaluated and selected with the use of scree plots, final instability and final stress values (McCune & Grace 2002).

We used inverse distance weighted maps to graphically represent high density areas and overlap with PMEC sites for the most abundant breeding and non-breeding migrant seabird species. We also used these density surfaces to illustrate the seasonal variability in distribution for these two species.

We had a low observation rate of brown pelicans (*Pelicanus occidentalis*), marbled murrelets (*Brachyramphus marmoratus*) and black-footed albatross (*Phoebastria nigripes*), however we included maps of their distributions around the PMEC because of their significance as federally listed endangered species or species of interest. We used black-footed albatross sightings as a proxy for interpreting potential short-tailed albatross (*P. albatrus*) distributions because they use similar habitat within the nCCS (Guy et al. 2013).

### *Spatial distributions*

To assess the relationship between spatial variables and the seabird community, we developed non-linear generalized additive mixed-effects models (GAMMs) using the "mgcv" package in R v. 3.2.2 (Aarts et al. 2008; Wood 2006, 2011; R Core Team 2015). Individual GAMMs allowed us to examine non-parametric species' response to environmental variables and were generated for 7 focal species with abundance greater

than 5% of the total (Fig. 2; Guisan et al. 2002, Elith 2009). For these models we used 3 km transect bins where birds were present and paired the observed densities with environmental/habitat measurements. We define species presence as any observation that yields a mean density/km<sup>2</sup> >0, therefore when the observed density of a given species = 0, the true mean density is unknown. There are numerous intrinsic and extrinsic factors that affect the year-round presence of seabirds in an area, many of which we did not measure, such as prey abundance, variable migration timing, etc. (see Millsbaugh & Martzloff 2001). Therefore, our models address the question of when present in an area, which of our measured variables contributes to increased species density and diversity. We used Spearman's rank correlation to test for correlations among covariates and highly correlated covariates (> 0.7) were not included together in the same model. The bird density data were log transformed and fit using a Gaussian distribution for presence only observations, and the best model was selected based on Akaike's Information Criteria (AIC; Akaike 1973) and generalized cross validation (GCV) scores (Wood 2006, Zuur 2009). Best overall fit was acquired with stepwise methods, AIC and GCV scores for each species and foraging niche. The AIC and GCV values were compared for model selection between the full and null models. We used the autocorrelation function in R and found no spatial autocorrelation among the residuals, therefore we did not apply a correlation factor to any model.

Our explanatory habitat variables; surface salinity, surface temperature, surface fluorescence, and substrate were selected *a priori* due to anticipated effects on seabird distribution from previous studies (Santora et al. 2011, Yen et al. 2004) and available

instrumentation on the vessel. Additionally, we included season, water depth, year and distance to shore as environmental parameters. To control for individual effects over the 3 study areas, *site* was included in the model as a random effect. A mathematical equation to describe species or foraging niche density in response to given environmental variables is:

$$Y_i \sim (\lambda_i, \theta)$$

where  $Y_i$  is the observed species or group density  $\text{km}^{-2}$  given a set of environmental conditions,  $\lambda_i$  is the unobserved true mean density  $\text{km}^{-2}$  of the species, given a set of environmental conditions, and  $\theta$  is the dispersion parameter (Gaussian). Our parameters include:

$$\log(\lambda_i) = \alpha + f_1(\text{fluores}_i) + f_2(\text{salinity}_i) + f_3(\text{temp}_i) + f_4(\text{depth}_i) + f_5(\text{distance}_i) + \beta_1(\text{season}_i) + \beta_2(\text{substrate}_i) + \beta_3(\text{year}_i) + p_k + \varepsilon_i$$

$$\text{where } \varepsilon_i \sim N(0, \sigma^2) \text{ and } p_k \sim N(0, \sigma_p^2) \text{ and } \text{Cov}(p_k, p_{k'}) = 0$$

In the model,  $\lambda_i$  represents the unobserved true mean density/ $\text{km}^2$  of the modeled species, given the observed density  $Y_i > 0$ . The functions  $f_i$  represent smoothing splines applied to explanatory variables fluorescence (fluores), salinity, temperature (temp), depth, and distance to shore (distance). The smooth term varied depending on model fit, but for single parameters we applied either a thin plate or cubic regression smooth spline (Wood 2004; 2006, Zuur et al. 2009). The functions  $\beta_i$  represent coefficients for categorical variables, where a smooth is not applicable, and  $p_k$  is the random effect site.

We examined residuals plots for all models, and equal variance of residuals for all focal species was detected unless otherwise noted.

Table 1. Seasonal cruise frequency by site and month. White boxes indicate = 0 cruises, light grey= 1-2 cruises, dark grey= >3 cruises in a given month. Surveys at the NETS (15 total) and SETS (13 total) all occurred 2013-2015. NH Line surveys include a data set from 2006-2009 (18 cruises) and 2013-2015 (11 cruises).

		Month											
		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
SETS		1			2		4		3	1	1	1	
NETS			1		1	1	6		2	1	3		
NH			1	2	2	4	3	6	4	2	4		1

Table 2. Dominant species selected using a cutoff of a single species representing at least 5% of the total observations. Common murres (*Uria aalge*) were excluded from the cutoff calculation because total sightings were a degree of magnitude larger than the next largest single species sightings. Foraging niches are differentiated by whether a species' diet is comprised primarily of fish (piscivorous) or plankton (planktivorous) and whether they are diving or surface feeder. Observed species with a mixed diet were excluded from foraging niches.

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Species and groups	
<i>Dominant species</i>	
common murre	<i>Uria aalge</i>
sooty shearwaters	<i>Puffinus griseus</i>
Cassin's auklet	<i>Ptychoramphus aleuticus</i>
western gull	<i>Larus occidentalis</i>
Brandt's cormorant	<i>Phalacrocorax penicillatus</i>
pelagic cormorant	<i>Phalacrocorax pelagicus</i>
<i>Foraging niches</i>	
surface piscivores	tern spp., gull spp., kittiwake spp.
diving planktivores	Cassin's auklet ( <i>Ptychoramphus aleuticus</i> )
surface planktivores	phalarope spp., storm petrel spp.
diving piscivores	common murres ( <i>Uria aalge</i> ), cormorant spp., pigeon guillemot ( <i>C. columba</i> ), murrelet spp., rhinoceros auklet ( <i>C. monocerata</i> ), puffins
migratory species	sooty shearwaters ( <i>Puffinus griseus</i> ) and northern fulmars ( <i>Fulmaris glacialis</i> )

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## Results

We surveyed 3533 km<sup>2</sup> during 391 hours of observation and recorded 30,997 birds. Of the 50 species documented through our surveys, common murre were the numerically dominant species, representing 70% of total sightings, while the sooty shearwater was the major component (78%) of the migratory species group. Six additional observed species represented at least 5% of total sightings, and were subsequently included in analysis (table 2).

### *Seasonal distributions*

A two dimensional nMDS ordination (Fig. 2) with orthogonal axes explained 86% of total variance in the species distribution and had an acceptable final stress of 13.3. Axis 1 ( $r^2=0.51$ ) represented a nearshore-offshore gradient, while axis 2 ( $r^2=0.32$ ) captured the effect of resident versus non-resident or migrating species. We detected spring and summer clusters, with low distinction between the near and offshore community, although spring appears more driven by nearshore species, while the summer community appears to be more weighted by the presence of offshore species. Common murre, the dominant species, were densely aggregated nearshore in the spring and summer, dispersing further across the shelf in the fall (Fig. 4). The greatest overlap between common murre and the NETS and SETS occurred in the spring, with a density highest within the NETS (2500-5000 murre/km<sup>2</sup>, Fig. 4). Within the SETS during spring there were between 800-1100 common murre/km<sup>2</sup>, with some higher densities within 2 km of the site. During the summer and fall there was a marked decrease in common murre densities within both sites. The fall community differs distinctly from the

rest of the year, with the offshore community comprised of species found nearshore during the spring and summer while species present offshore during the spring and summer appeared nearshore during the fall. The nearshore fall community was primarily dominated by sooty shearwaters, which were found dispersed further offshore in the spring and summer (Fig. 5). Shearwaters were detected at high densities between the NETS and SETS (100-220 birds/km<sup>2</sup>) during the fall, although density within either site was relatively low throughout the year (Fig. 5).

For foraging groups distributions, a two dimensional NMDS ordination (Fig. 3) described 78% of variance, with orthogonal axes and a final stress of 15.02. nMDS Axis 1 ( $r^2=0.37$ ) represented a seasonal gradient, reiterating a distinctly different community structure in the fall months, while axis 2 ( $r^2=.42$ ) indicated a near/offshore gradient, which can be interpreted in terms of foraging strategies, as diving species occur nearshore and surface feeders offshore.

We quantitatively addressed the spatial distributions of federally listed or endangered species in the area by generating maps of species observations. Brown pelicans were primarily observed in depths <50 meters, and occurred individually and in flocks along the coastal extent of the PMEC study area (Fig. 6). While pelicans were more concentrated at the mouth of the Yaquina River estuary and adjacent to the NETS, they do not occur in the SETS, instead sighted nearer to shore. We recorded a total of 91 brown pelicans over the course of our study. All marbled murrelets were detected within about 17 km of shore with the highest occurrence very near to shore (< 50 m depth, fig. 7). We recorded a total of 35 marbled murrelets sightings, primarily concentrated south

of the NETS and east of the SETS in adjacent nearshore waters near the mouth of the Yaquina River Estuary. We did not observe any murrelets within either of the proposed site boundaries. Nearly all of our black-footed albatross sightings were beyond 20 km from shore along the NH Line, except for one sighting near the SETS, about 16 km from shore (fig. 8). We recorded a total of 41 black-footed albatrosses throughout our study.

#### *Seabird and habitat spatial models*

Common murre densities were highest in the spring, followed by the summer, and comparable decline in the fall and winter (Table 5). Common murre density/km<sup>2</sup> was negatively correlated with depth, with diminished density over deeper water, although there appears to be a peak in higher densities around a depth of 30-40 meters (Fig. 9a). There was a multimodal response to fluorescence, with peaks in densities around 1.1, 1.5 and 4.5 volts (Fig. 9b). Common murre density had a negative response with temperatures exceeding 12°C (Fig. 9c) and salinity (Fig. 9d). Site was retained in the final model, reflecting dense aggregations of murres around Yaquina Head during the breeding season.

Sooty shearwater density was highest in the fall, lower in the spring and summer, and lowest in the winter (Table 5). Depth and distance to shore were both excluded from the final model, as they likely confounded by the seasonal shoreward shift of sooty shearwaters illustrated by the NMDS ordination described in the previous section. Sooty shearwater density had a negative response to salinity, indicating higher densities at lower salinities, although there is high variability in the response to higher salinities (Fig. 10).

Brandt's cormorant density was associated with depth, fluorescence, salinity, and temperature. There was a bimodal response to depth, with peaks in density at 40m and 60m depths (Fig. 11a). There was a positive response to fluorescence (Fig. 11b) and salinity (Fig. 11c). Brandt's cormorant density had a negative response to temperature (Fig. 11d).

Pelagic cormorant density was highest in the fall and lowest in the winter (Table 5), with significantly higher densities over sandy substrate versus mud or rock. The relationship between density and depth was linear and negative (Fig. 12a), with all sightings <70 meters depth. Although there were several larger group densities at deeper depths, there were overall more regular observations over shallower water. The response to temperature was negative (Fig. 12b). Site also had an effect on pelagic cormorants, with higher overall densities at the NETS.

Cassin's auklets were seasonally driven, with the highest densities in summer, with lower densities in the fall (Table 5). Fluorescence was included in the final model, although the response was variable, with a peak around 1.5 volts, and a positive response to fluorescence exceeding 2 volts (Fig. 13a). Density was positively relative to increasing depth (Fig.13b).

Western gulls were present throughout the study area, with no significant effect of season, and the highest densities occurred closer to shore (within 10 km; Fig. 14a). There was a negative response to both salinity (Fig. 14b) and temperature (Fig. 14c), although there was overall higher sighting frequency at higher salinity values.

Red-necked phalarope densities were highest in the summer and fall (Table 5). The response to temperature was unimodal, illustrating increased density response until an optimal temperature of about 14<sup>0</sup>C, at which point warmer temperatures were associated with lower red-necked phalarope concentrations (Fig.15a). Although red-necked phalaropes are distributed throughout the study area, denser aggregations were associated with lower (<33.5 ppt) salinity (Fig. 15b).

Table 3. Three best fit models for each species, with selected model highlighted in grey. X's indicate coefficients included in the model.

Model	Coefficients																
	Spring	Summer	Fall/mud	Winter	Rock	Sand	Salinity	Fluores	Temp	Depth	Dist	2014	2015	Site	$\Delta$ AIC	Adj $r^2$	GCV score
BRCO							X	X	X	X				X	0	0.18	0.86
BRCO.2								X	X	X				X	4	0.17	0.9
BRCO.3	X	X	X	X			X	X	X	X				X	8	0.16	0.94
CAAU	X	X	X	X			X	X		X				X	0	0.5	0.9
CAAU.2	X	X	X	X			X	X		X		X	X	X	0	0.51	1.1
CAAU.3	X	X	X	X				X		X				X	8	0.39	1.1
COMU	X	X	X	X			X	X	X	X		X	X	X	0	0.31	1.2
COMU.2	X	X	X	X	X	X	X	X	X	X				X	0	0.3	1.28
COMU.3	X	X	X	X			X	X		X				X	8	0.27	1.32
PECO	X	X	X	X		X			X	X				X	0	0.26	0.6
PECO.2	X	X	X	X		X		X	X	X				X	2	0.25	0.62
PECO.3	X	X	X	X		X	X		X	X				X	2	0.25	0.62
RNPH	X	X	X				X		X					X	0	0.81	0.6
RNPH.2							X		X					X	10	0.76	0.61
RNPH.3	X	X	X				X		X					X	16	0.61	0.74
SOSH	X	X	X	X			X		X			X	X	X	0	0.26	1.2
SOSH.2	X	X	X	X			X	X	X			X	X	X	1	0.26	1.3
SOSH.3	X	X	X	X			X		X	X		X	X	X	0	0.26	1.3
WEGU			X				X		X					X	0	0.11	0.55
WEGU.2			X		X	X	X		X					X	1	0.12	0.55
WEGU.3			X						X					X	2	0.10	0.55

Table 4. Seasonal mean densities by species, with 95% confidence intervals and standard error.

Species	Season	Lower 95% CI	Mean	Upper 95% CI	SE
common murre	spring	102.4	214.7	327.2	56.8
	summer	51.4	61.6	71.8	5.2
	fall	22.6	40.1	57.5	8.8
	winter	19.8	107.6	195.3	42.1
sooty shearwaters	spring	-1.1	27.3	55.7	13.9
	summer	8.5	14.7	20.8	3.1
	fall	28.3	95.8	163.5	33.9
Brandt's cormorants	winter	3.4	16.9	30.4	6.1
	spring	7.2	18.1	28.9	5.3
	summer	13.9	20.0	26.0	2.9
pelagic cormorants	fall	7.0	17.9	28.9	5.2
	winter	NA	3.9	NA	NA
	spring	11.9	16.9	22.0	2.5
	summer	7.7	12.0	16.2	2.1
Cassin's auklets	fall	-8.2	19.4	46.9	11.7
	winter	3.1	6.9	10.7	1.5
	spring	NA	3.7	NA	NA
western gulls	summer	3.1	25.6	48.1	10.5
	fall	-39.7	67.8	175.3	52.2
	winter	-6.6	23.1	52.9	12.9
	spring	7.0	11.1	15.1	2.0
red-necked phalaropes	summer	8.1	11.5	14.9	1.7
	fall	5.4	6.8	8.3	0.7
	winter	7.5	12.5	17.6	2.4
red-necked phalaropes	spring	-77.0	22.3	121.5	7.8
	summer	5.1	30.1	55.2	10.9
	fall	20.4	37.7	54.9	8.3
	winter	-----	no data	-----	-----

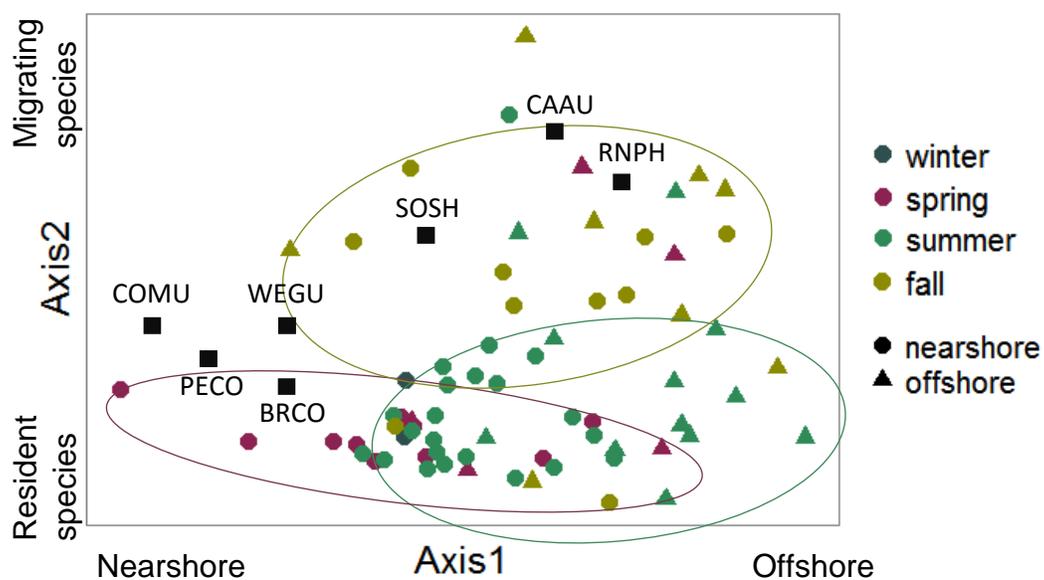


Figure 2. 2-dimensional nMDS ordination of focal species, colored by season, with shapes indicating near- or offshore classification. Species centroids are indicated by black boxes, with species code identifying species position within community. COMU= common murre, PECO= pelagic cormorant, BRCO=Brandt's cormorant, WEGU= western gull, CAAU= Cassin's auklet, and RNPH= red-necked phalarope. Groupings indicate seasonal and distance to shore gradients.

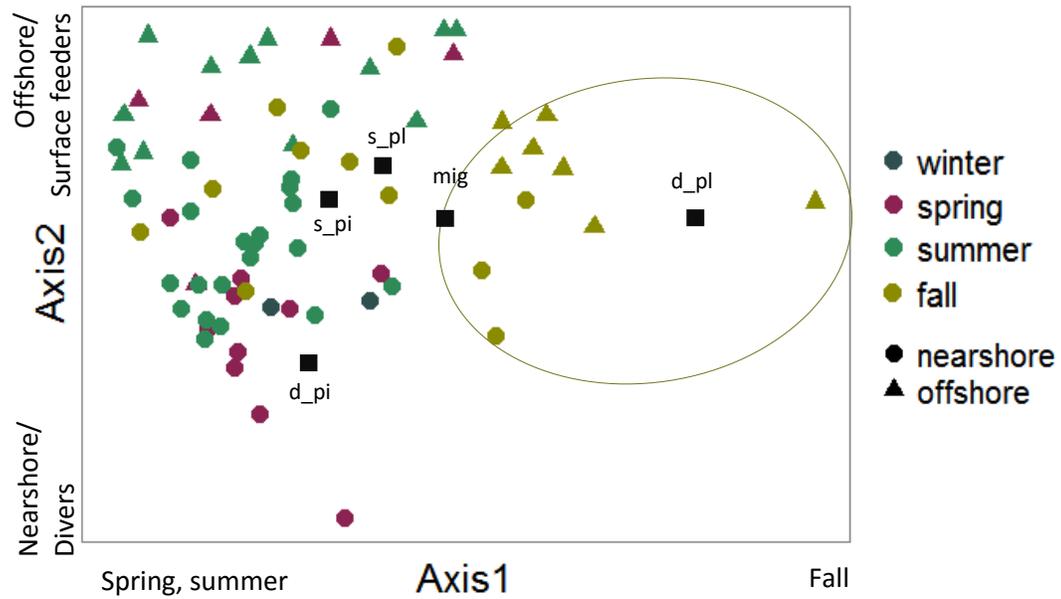


Figure 3. 2-dimensional nMDS ordination of foraging groups, colored by season, with shapes indicating near- or offshore classification. Foraging group centroids indicated by black boxes. Diving piscivores = d\_pi, diving planktivores= d\_pl, surface piscivores= s\_pi, surface planktivores= s\_pl and migratory species group= mig.

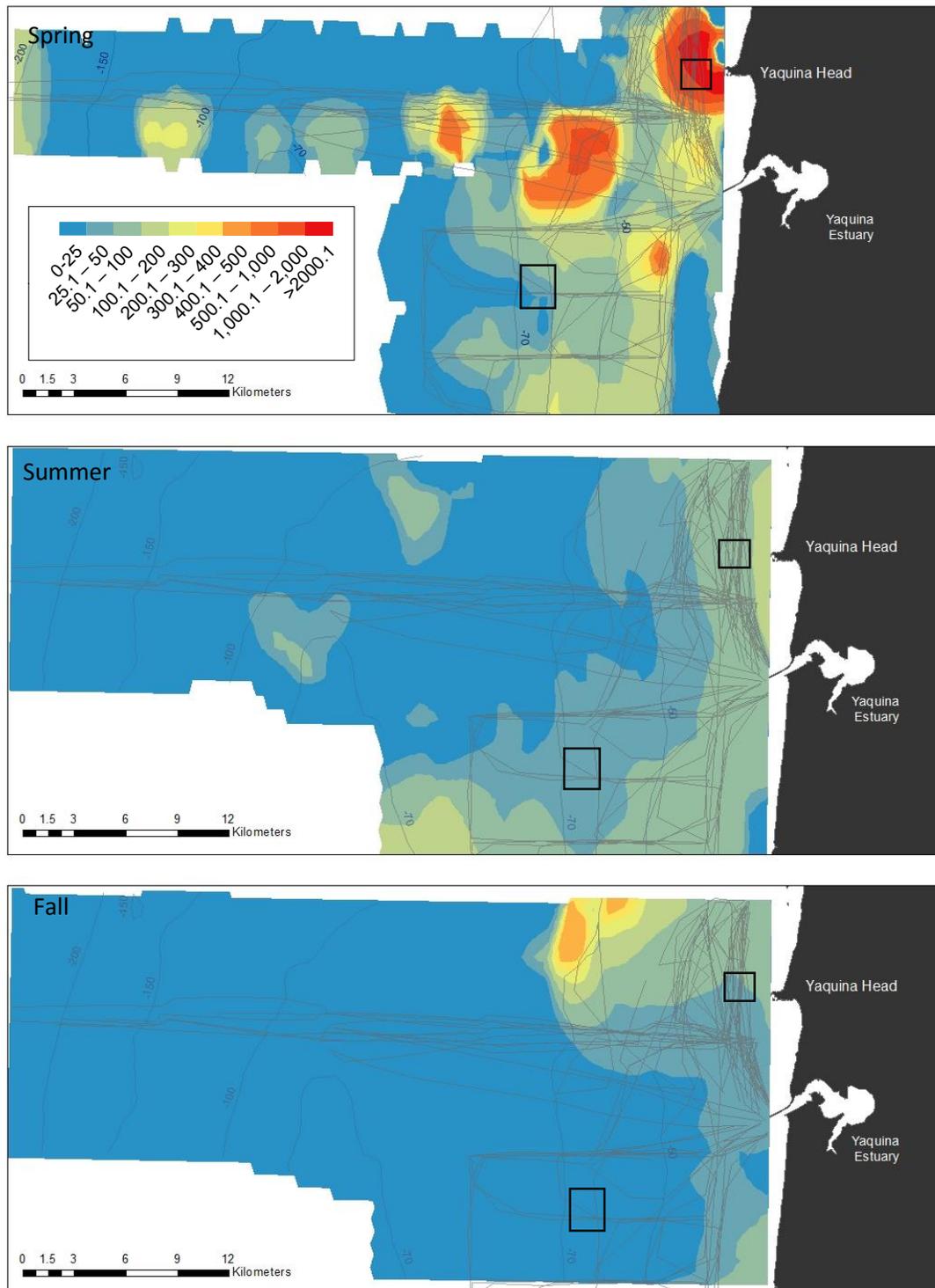


Figure 4. Seasonal common murre density across the three study sites. Kernel density estimates produced in ArcMap 10.2 with constant kernel function and prediction output. A power of 1 and ridge of 50 was applied to all 3 maps. The black boxes identify the NETS and SETS. Ship track lines are in grey, and all densities are standardized to spring panel legend. See appendix 2 for standard error maps.

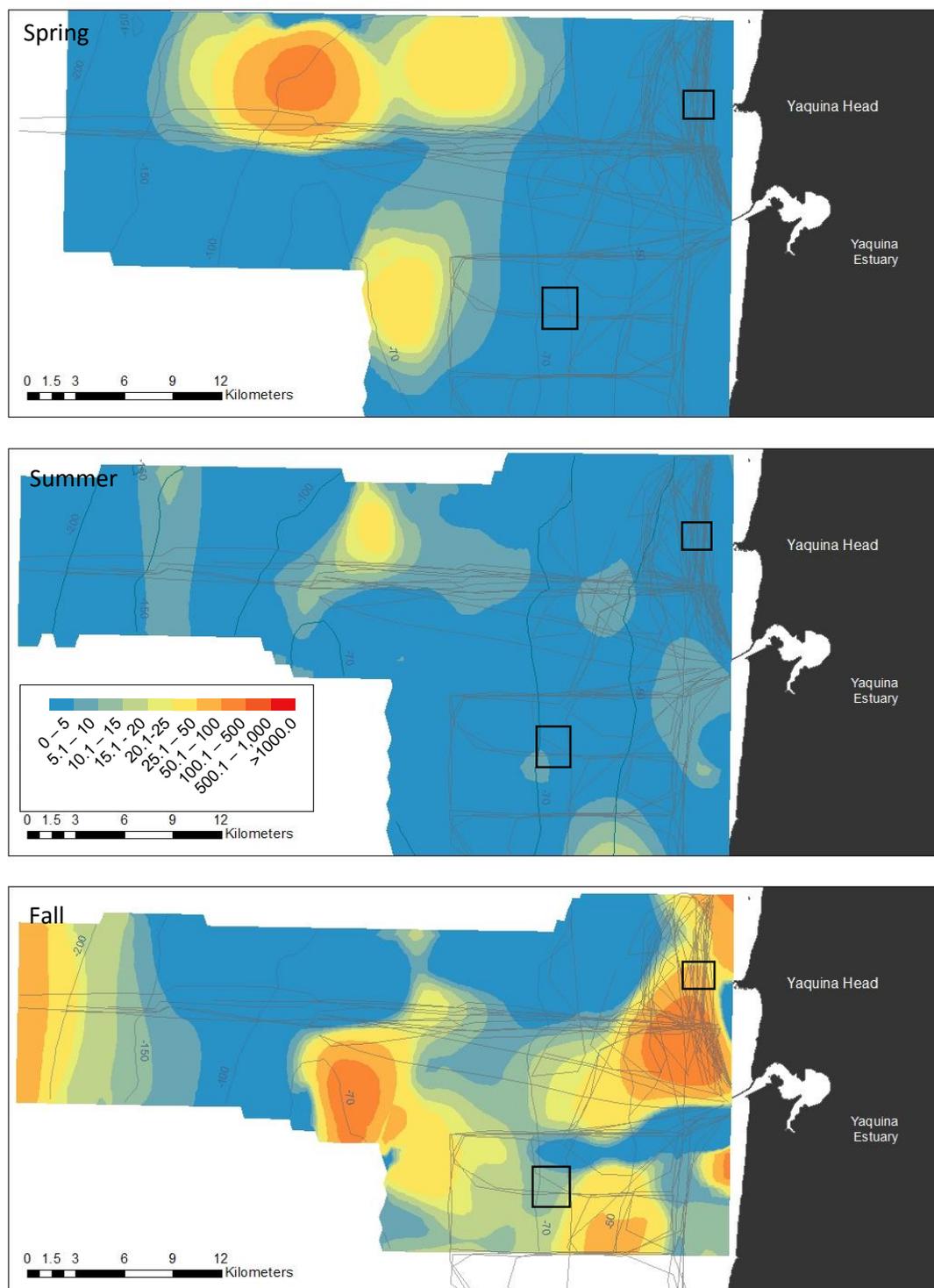


Figure 5. Seasonal sooty shearwater density across the three study sites. Kernel density estimates produced in ArcMap 10.2 with constant kernel function and prediction output. A power of 1 and ridge of 50 was applied to all 3 maps. The black boxes denote the NETS and SETS. Ship track lines are in grey, and all densities are standardized to summer panel legend. See appendix 3 for standard error maps.

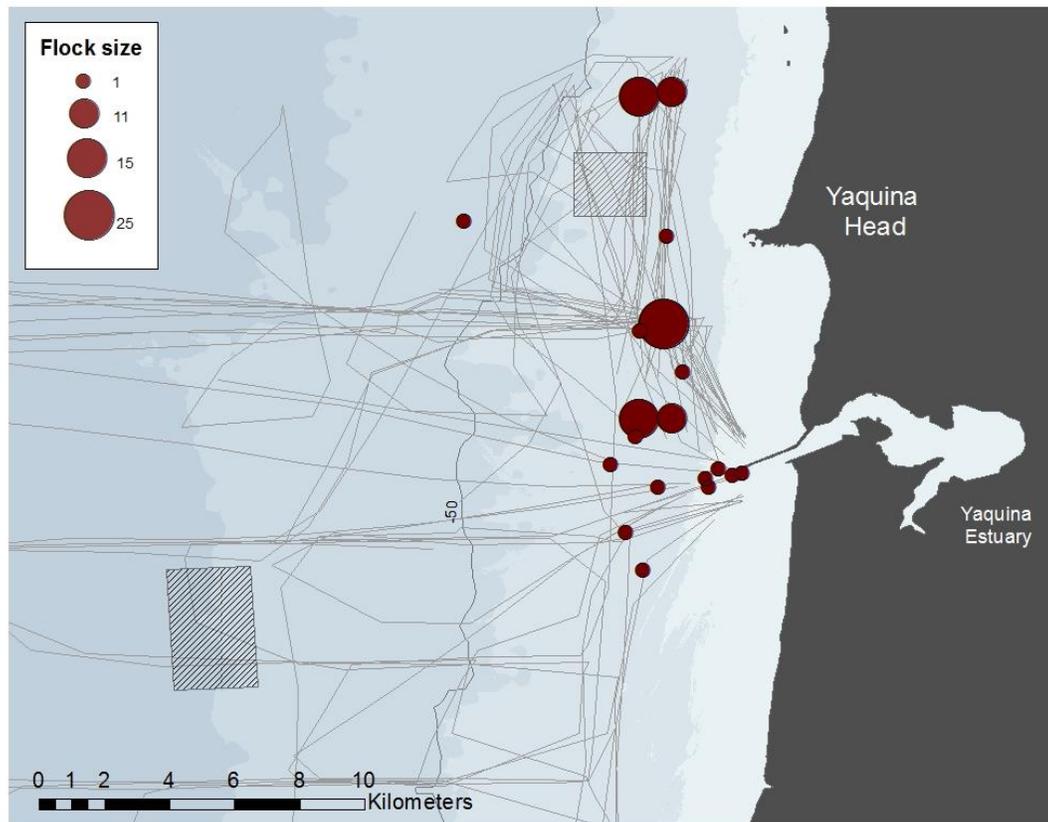


Figure 6. Map of brown pelican observations, with 91 individuals recorded over the course of the study. The PMEC-NETS and SETS are indicated by black hatched boxes, while ship track lines are marked in grey.

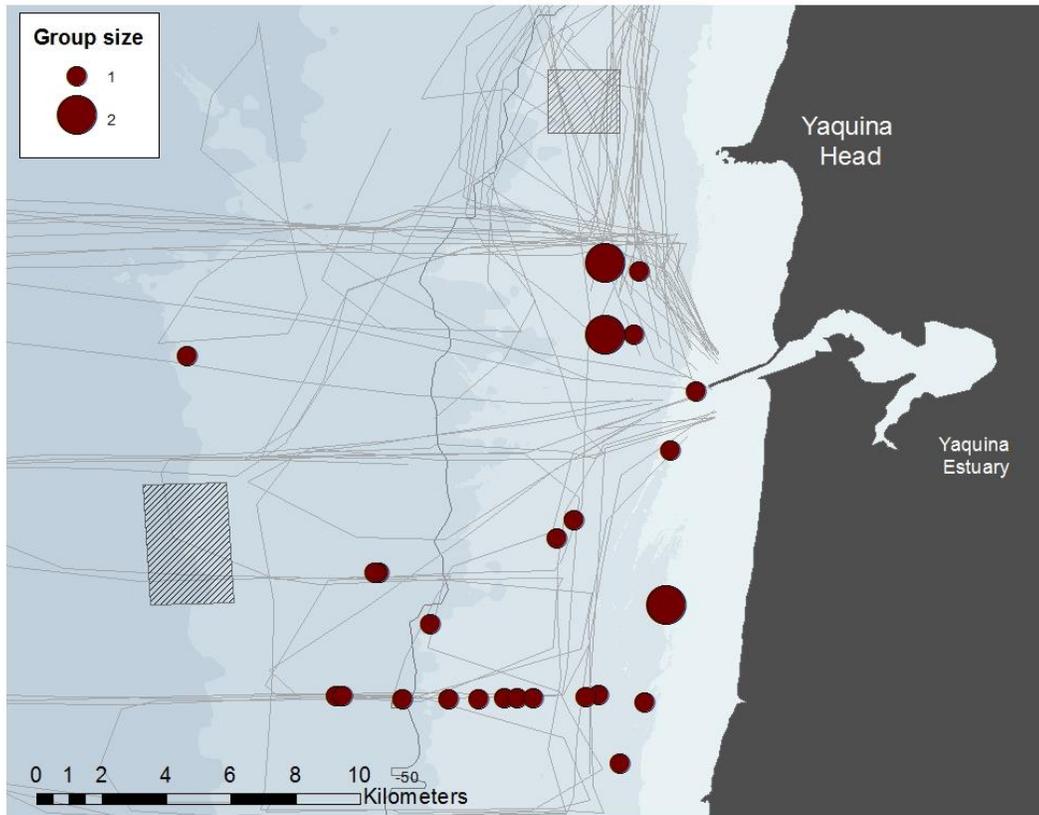


Figure 7. Map of observed marbled murrelets, with 35 individuals recorded over the course of this study. The PMEC-NETS and SETS are indicated by black hatched boxes, while ship track lines are marked in grey.

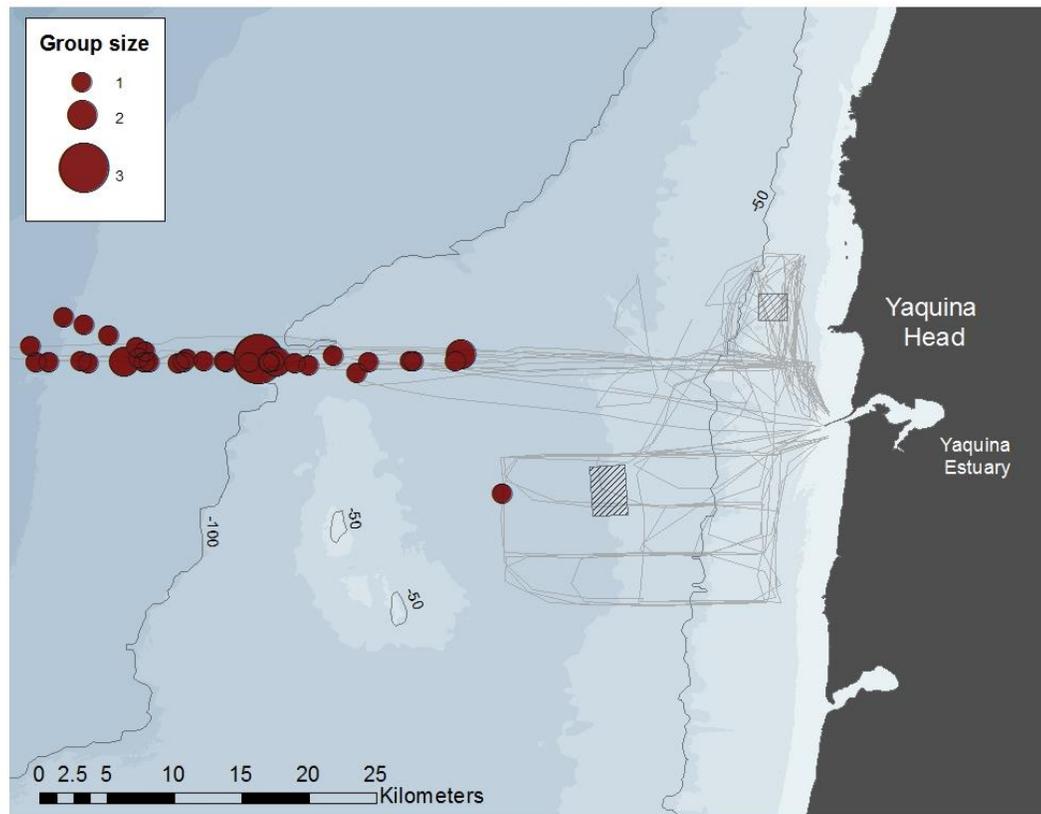


Figure 8. Map of black footed albatross observations, with 41 individuals recorded over the course of this study. The PMEC-NETS and SETS are indicated by black hatched boxes, while ship track lines are marked in grey.

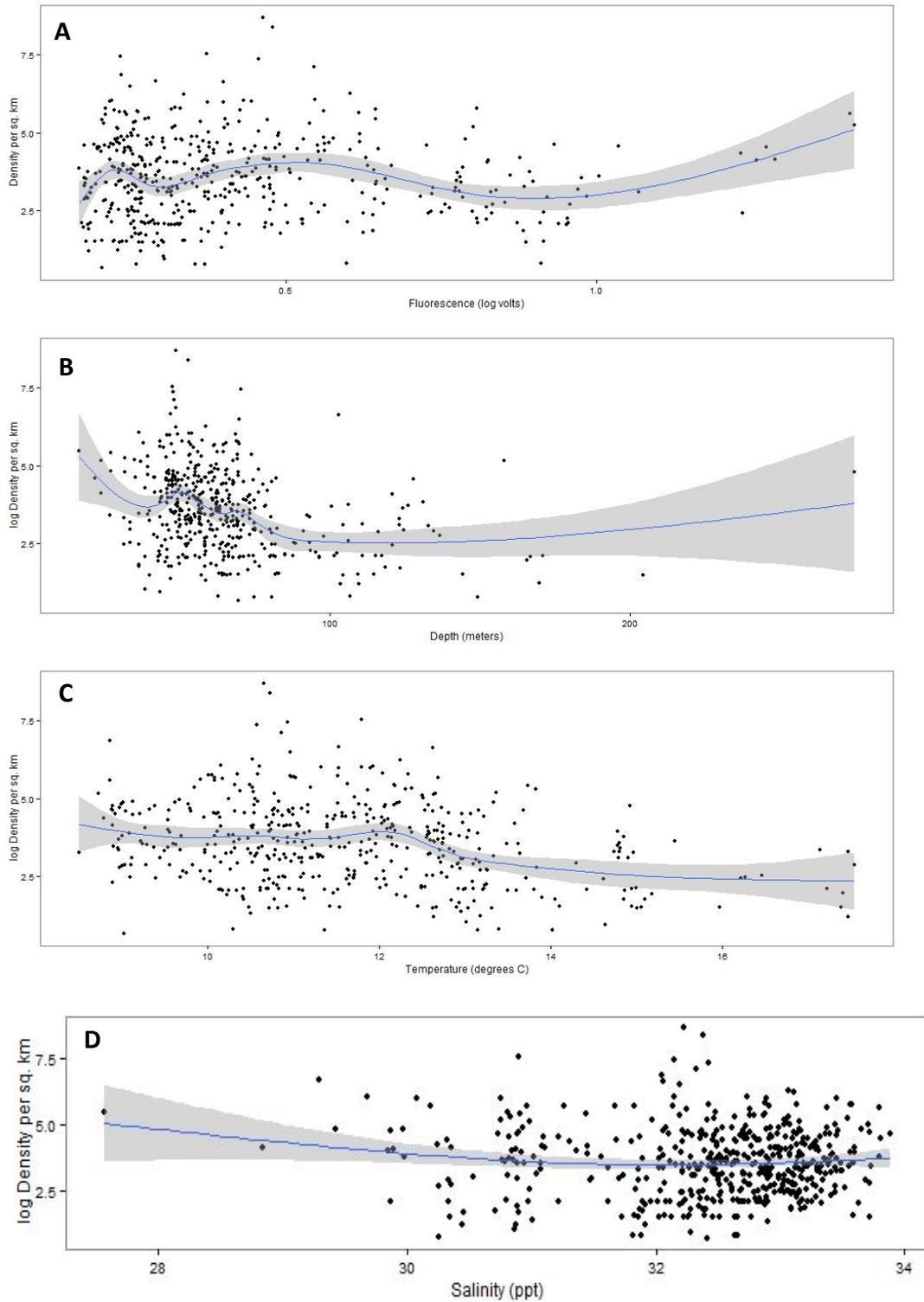


Figure 9. Modeled response of significant factors (A. fluorescence, B. depth, C. temperature, D. salinity) impacting common murre density. Smoothed line indicates trend, with 95% confidence intervals in grey. A thin plate smoothing spline was applied to all three parameters.

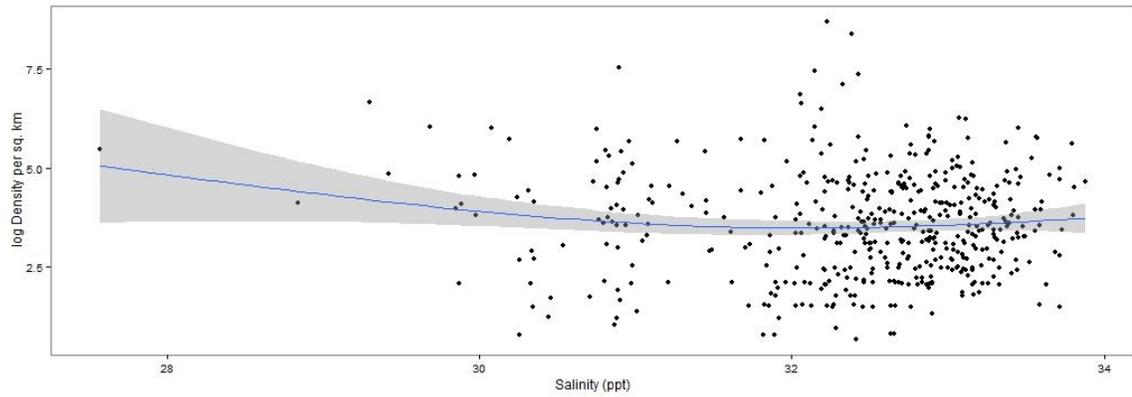


Figure 10. Modeled response of the impact of significant factor salinity) on sooty shearwater density. A thin plate smooth term was applied to the model.

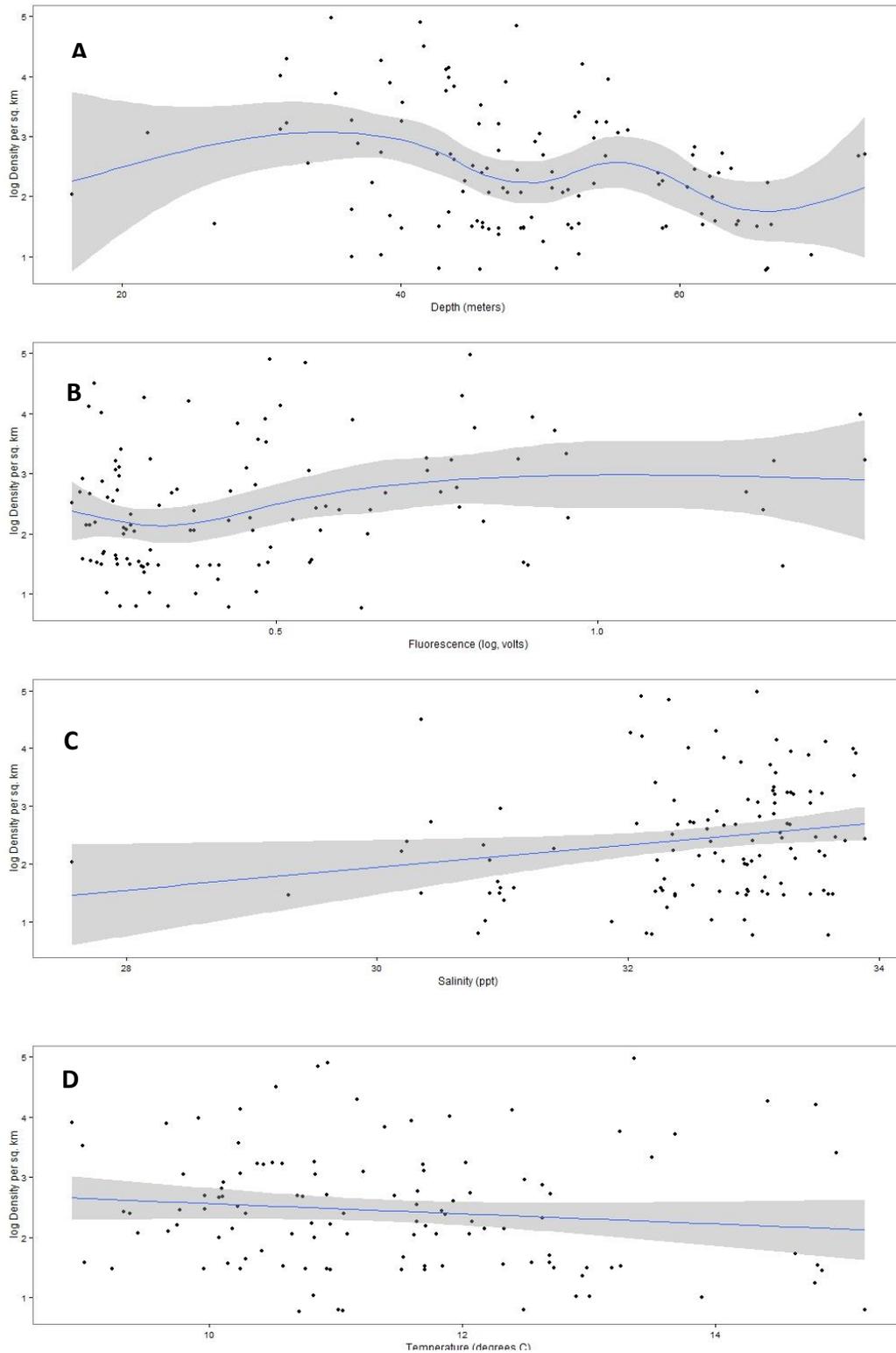


Figure 11. Modeled response of significant factors (A. depth, B. fluorescence, C. salinity D. temperature) impacting Brandt's cormorant density. Smoothed line indicates trend, with 95% confidence intervals in grey. A thin plate smoothing spline was applied to all parameters.

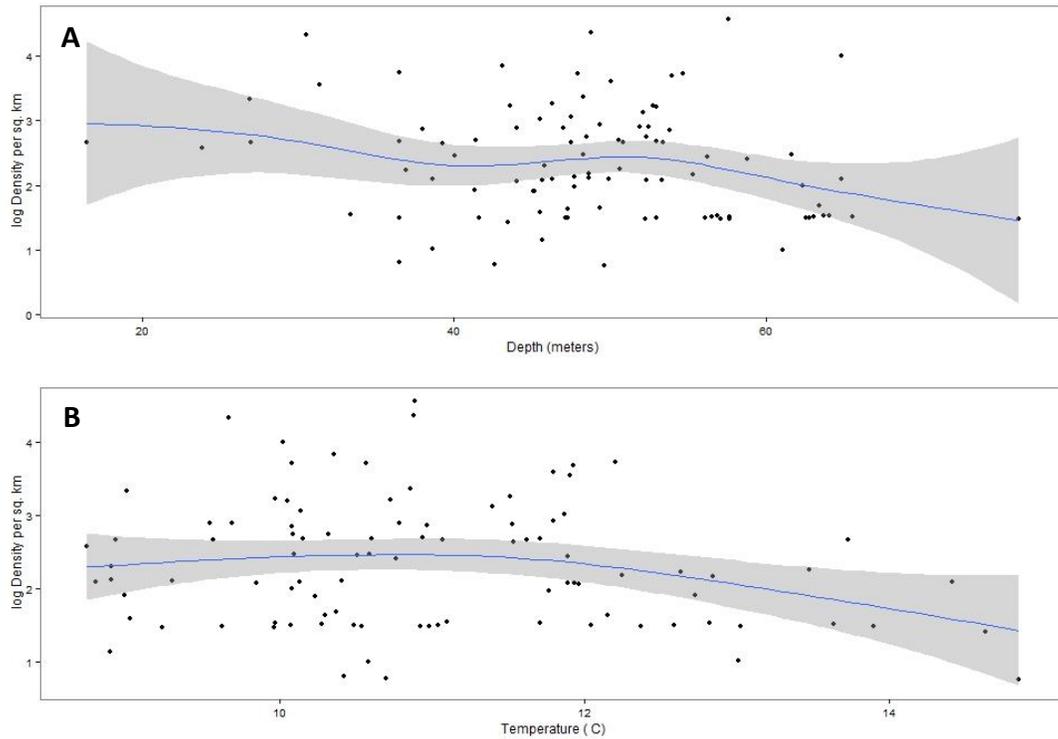


Figure 12. Modeled response of the impact of significant factors (A. depth, B. temperature) on pelagic cormorant density. Smoothed line indicates trend, with 95% confidence intervals in grey. A cubic regression smoothing spline was applied to depth and temperature.

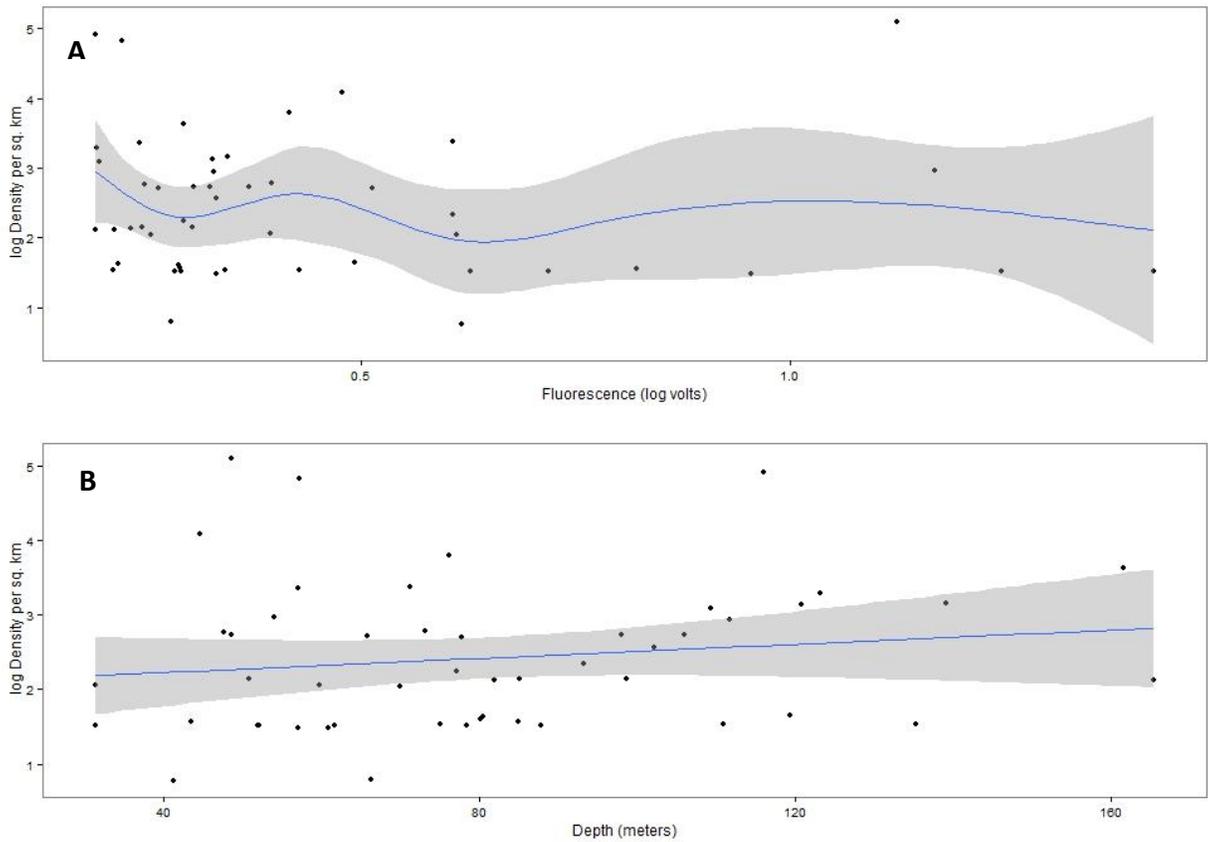


Figure 13. Modeled response of significant factors (A. fluorescence, B. depth) impacting Cassin's auklet density. Smoothed line indicates trend, with 95% confidence intervals in grey. A thin plate smoothing spline was applied to fluorescence.

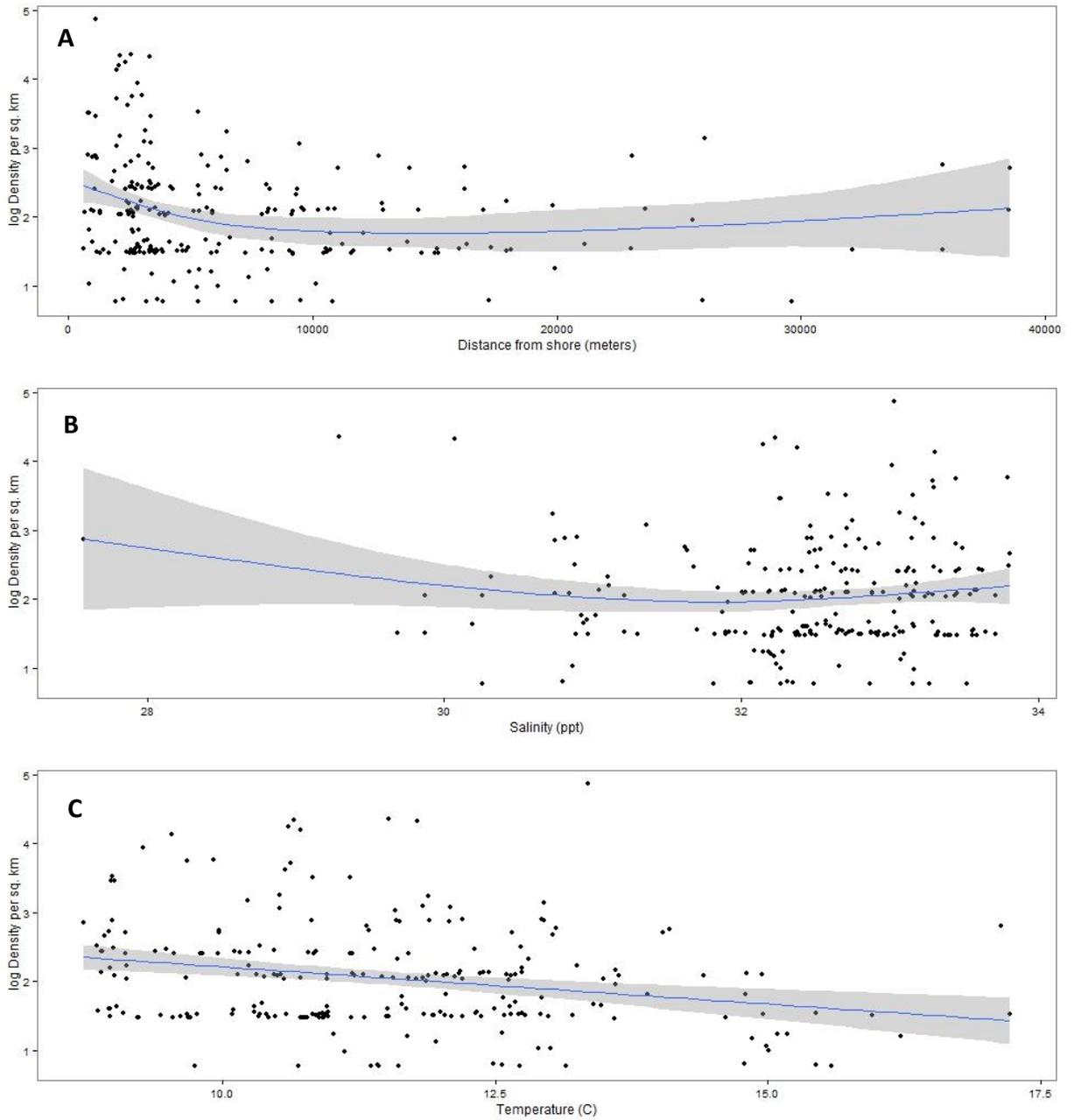


Figure 14. Modeled response of the impact of significant factors (A. distance from shore, B. salinity, C. temperature) on western gull density. Smoothed line indicates trend, with 95% confidence intervals in grey. A cubic regression smoothing spline was applied to all parameters.

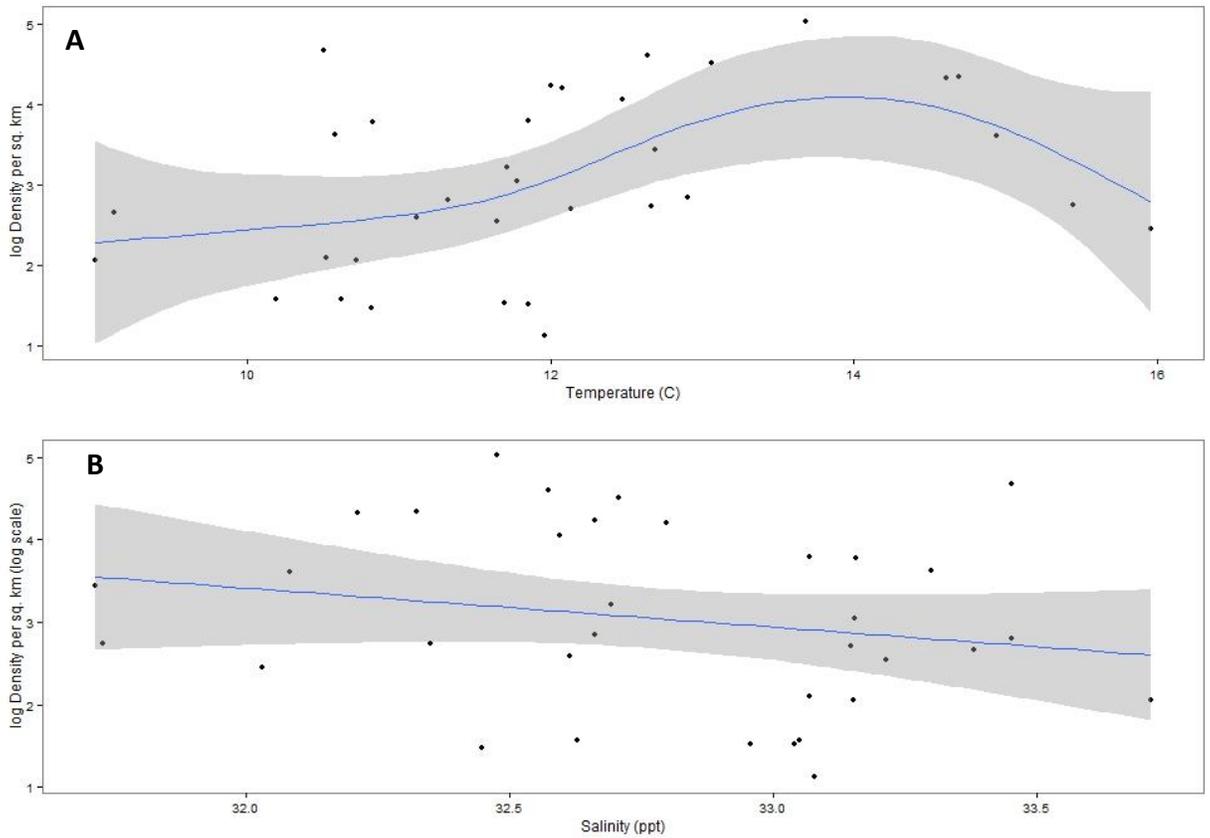


Figure 15. Modeled response of the impact of significant factors (A. temperature, B. salinity) on red-necked phalarope density. Smoothed line indicates trend, with 95% confidence intervals in grey. A cubic regression smoothing spline was applied to temperature and salinity.

## Discussion

### *Fluctuations in seabird community*

The nMDS results indicated that the spring community appeared primarily driven by nearshore species/foraging niches while the summer community was comprised of both near and offshore species/niches. Both the spring and summer nearshore communities were driven by resident species, including common murres, Brandt's and pelagic cormorants. This contradicts Adams et al. (2014), which found the highest densities of common murres and cormorant species during the winter, and could be a result of the fact that all three species nest at the nearby Yaquina Head breeding colony. Common murre and cormorant foraging trips from the breeding colony can be constrained by incubation and chick rearing activities (Orians & Pearson 1979, Cairns et al. 1987), and common murres regularly form rafts in waters around Yaquina Head in response to disturbance and predation at the colony (Horton 2014), explaining the high spring and summer aggregations around the NETS and the greater nearshore region. Evidence that murres are heavily regulated by bottom-up forcing could explain spatial dispersal following chick fledging (fall and winter) as murres' foraging range expanded (Davoren et al. 2003a, Parrish & Zador 2003). Some pursuit divers (alcids such as murres and cormorants), however, appear to be nearshore specialists, which may reflect benthic foraging by some (e.g. cormorants) more than others (e.g. Cassin's auklets). This was especially true with respect to both cormorant species, which rarely occurred beyond 16 km from shore. Prior research has found a negative correlation between cormorants and temperature, suggesting a sensitivity to upper temperature limits (Cairns et al. 2008). The

spatial and foraging overlap of the two species suggests a similar response to environmental parameters, but while we detected a significant relationship between temperature and pelagic cormorants, this parameter was insignificant in our Brandt's cormorant model. Ainley et al. (1981) documented overlap between Brandt's and pelagic cormorant foraging ranges, but distinct habitat preferences and prey consumption between the two species. Ainley et al. (1981) described a correlation between rocky substrate and pelagic cormorants based on stomach samples and identified prey distributions, which we did not detect in our study. Instead, we observed an association between pelagic cormorants and sandy or flat substrate, which could indicate a shift in foraging or prey availability.

In contrast, migratory species, dominated primarily by sooty shearwaters, remained offshore during the spring and summer. The fall community was comprised of both resident and migratory species, capturing the southward migration of sooty shearwaters and northern fulmars during these months. Adams et al. (2014) also detected a trend of higher sooty shearwater density in the nearshore (0-100m depth) region during the summer (June 2012) and fall (September 2012), although they did not identify a shift from or to the offshore region during the spring or winter. The occurrence of coastal upwelling may facilitate greater prey abundance on the continental shelf, prompting the spring and summer offshore community (primarily sooty shearwaters and Cassin's auklets) to shift nearer to shore during this season, as there is strong evidence that sooty shearwaters and Cassin's auklets are positively correlated with upwelling indicators and high euphausiid density (temperature and chlorophyll-a, respectively; Oedekoven 2001,

Yen et al. 2006, Adams et al. 2012). Other studies have found sooty shearwaters associated with warmer temperatures (Shaffer et al. 2009, Hedd et al. 2012), although we found that the effect of temperature is dependent on salinity, with the highest aggregations correlated with high temperature and high salinity, indicating a preference for a specific water mass.

#### *Spatiotemporal overlap with the P MEC*

Common murres and sooty shearwaters were the most abundant species over our study area, consistent with earlier studies for the entire Oregon coast (Strong 2009, Suryan et al. 2012, and Zamon et al. 2014). However, we observed the highest abundance of shearwaters in late summer and fall, (consistent with Adams et al. 2014) rather than spring and summer (Suryan et al. 2012, Zamon et al. 2014), indicating a later peak in shearwater density at the P MEC sites from 2013-2015. Our divergence from these findings could perhaps be attributed to anomalous oceanographic conditions in 2013-2015.

Although they might easily avoid mooring lines, diving birds are at a higher risk of underwater entanglements with marine debris that may accrue on with WEC moorings (Furness et al. 2012), which could be a concern for the dense aggregations of common murres and cormorants observed in our study area. However other than the high densities of common murres staged around Yaquina Head during the breeding season, the highest concentrations of common murres and sooty shearwaters, along with other species, were concentrated outside of the P MEC sites throughout our study period.

We also observed high use of the P MEC area by brown pelicans (NETS) and marbled murrelets (SETS), and further assessment of these species in the area could provide insight into larger conservation issues. Black-footed albatrosses are seldom observed within 16 km of shore, as our study confirmed, and therefore we infer that short-tailed shearwater use of the P MEC area is likely quite low as well. Nonetheless, occasionally conditions exist that draw outer continental shelf and slope species into relatively nearshore regions.

Our study confirmed an influx of shearwaters, northern fulmars, Cassin's auklets, rhinoceros auklets, and brown pelicans to inner shelf waters (<100 m depth) in the fall, consistent with previous findings that did not note the seasonal near/offshore shift, but documented higher overall nearshore densities in the fall (Suryan et al. 2012, Adams et al. 2014). With the NETS and SETS data we were able to capture a broader nearshore community than results from only surveying the NH Line, with greater application to the P MEC and future monitoring of the community. Assuming the persistence or regularity of significant environmental conditions, we might expect these species to have higher rates of exposure to effects of WECs at the SETS and the Ocean Sentinel/anchored platform at NETS.

#### *Habitat selection*

Common murre were negatively correlated with salinity and temperature, with the highest densities detected at low salinities and low temperatures. This possibly indicated a common murre selection for cold, low salinity water masses. Palacios et al. (2013) modeled relationships between temperature, salinity and nitrate, and determined that

water masses with low saline and temperature properties were typically coupled with high levels of nitrate, indicating a fresh water or estuarine component of the water mass. The correlation between these habitat conditions and common murrelets could reflect greater foraging effort in river plumes of nearby estuaries.

Upwelled water is characterized by low temperatures and high salinities, a signal of nutrient rich waters that support euphausiid production and subsequently higher trophic levels.. Our model for Brandt's cormorants detected correlations to typical upwelling indicators; cold, highly saline, nutrient rich water, possibly reflecting greater foraging or foraging potential in upwelled waters. However during anomalous years, (e.g. warm ocean conditions in 2013-2015; Bond et al. 2015) upwelled water may be warmer (higher overall variability in temperatures), with high salinities and poor nutrient content (Mann & Lazier 2006). In our study, we found a correlation between sooty shearwaters and high salinity, but no relationship to temperature. Therefore, while both species appear to be responding to upwelled water, sooty shearwaters appeared to be less sensitive to variable temperatures in their foraging grounds, while Brandt's cormorants displayed a clearer bias for cold temperatures.

#### *Development of the P MEC and future seabird interactions*

Although the use of the P MEC area by focal species is highly seasonal, the semi-permanence (year-round) of the WECs makes our data valuable in providing insight for ongoing monitoring of seabirds at the P MEC sites. The newness of renewable wave energy development leaves seabird/WEC interactions largely unexamined, but with our study we were able to address distributions of breeding and non-breeding species, as well

as use of the area by listed or endangered species. Some distributions (e.g. immature birds) however, are still not well understood, leaving interactions between these seabirds and WECs undefined. Research found that artificial lighting used during construction, installation, or affixed to WECs for navigation purposes might increase the probability of collision for light-attracted seabirds (e.g. shearwaters, petrels, auklets, and murrelets) providing further justification for continued monitoring once the WECs are installed (Montevecchi 2006, Miles et al. 2010).

## Conclusions

Our study confirms our initial hypothesis that the density and distribution of seabirds at the P MEC and adjacent study areas is correlated with both spatial and seasonal variables, however there was variable significance and response among species. While detection of seabirds within the NETS and SETS boundaries was low relative to surrounding areas, there is strong evidence that seabirds aggregate densely adjacent to the proposed development sites. Short and long term variability in oceanographic conditions will likely continue to influence seabird distributions, which could shift nearer or further from the sites as conditions fluctuate.

We identified distinct seasonal communities and seasonal shifts in composition within our study area. The shoreward shift or outward dispersal of species appears driven by a combination of factors, including the diffusion of nearshore concentration of murre and cormorants on Yaquina Head post chick fledging, and the inshore movement of migratory species with the onset of upwelling and greater prey abundance. These community patterns were detected over several years, suggesting similar persistence, pending more dramatic oceanographic changes.

We identified correlations between several species and measured oceanographic variables, which indicated species' preference for specific water masses. This will be important information moving forward, as variable ocean conditions and long term warming may influence hydrographic properties and subsequent productivity, foraging habitat and prey availability for specialized species.

Previous surveys off Newport have omitted the entire SETS (Adams et al 2014, Zamon et al 2014), and instead sampled the NH Line, which provides cross shelf variation in the seabird community in the surrounding P MEC area, but has limited application to the P MEC without the SETS surveys. Our observations include multiple transects through and around both NETS and SETS. While other studies contained transects off Newport, they were not continuous (Ainley et al 2009, Zamon et al 2014), or were at a much broader scale and lesser frequency (Adams et al 2014), making our surveys particularly suited to informing the implementation of the P MEC. Continued survey effort could address questions about interannual variability and species' response to long term shifts in habitat conditions at the P MEC sites, especially concerning displacement effects at the SETS once the WECs are installed, which we were unable to answer with our current data. It is evident that response to environmental variation is species specific and continued monitoring of seabirds would address questions about larger scales shifts over longer periods of time, and attraction or displacement post installation of WECs at the P MEC. As one of the first wave development test sites in the United States, the baseline seabird community at the P MEC sites can inform the siting and permitting process for future wave test facilities and can contribute to informed adaptive ecosystem management. Combined with other studies conducted at the P MEC, the characterization of the ecosystem (seabirds, benthos, mammals, hydrography, etc) provides a robust baseline assessment of the marine community, which can be applied to future policy and ecology studies.

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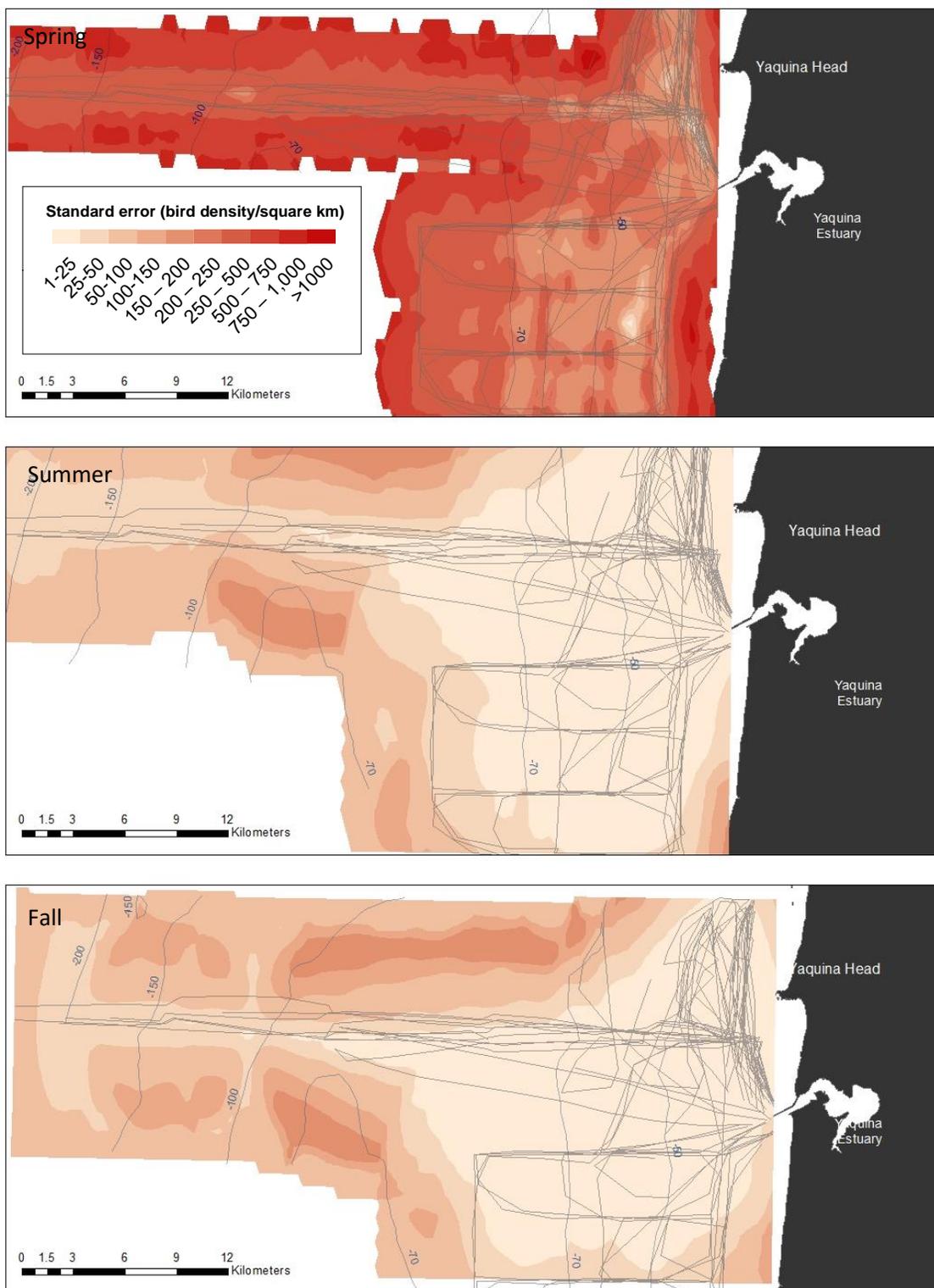
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**APPENDICES**

Appendix 1. Standard error of seasonal common murre distribution, with ship tracks in grey.



Appendix 2. Standard error for seasonal distribution of sooty shearwaters, with ship tracks in grey.

