OCS Study
BOEM 2017-011

Seasonality of Seabird Distribution in Lower Cook Inlet

US Department of the Interior
Bureau of Ocean Energy Management
Headquarters

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Final Report

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Seasonality of Seabird Distribution in Lower Cook Inlet

Contents

List of Figures

List of Tables

Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
CTD	Conductivity-Temperature-Depth probe
COR	Contracting Officer's Representative
DOI	Digital Object Identifier
ESP	Environmental Studies Program
ESPIS	Environmental Studies Program Information System
GPS	Global Positioning System
GWA	Gulf Watch Alaska
IA	Interagency Agreement
KBRR	Kachemak Bay Research Reserve
LCI	Lower Cook Inlet
MBM	Migratory Bird Management
MMS	Minerals Management Service
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NPPSD	North Pacific Pelagic Seabird Database
OCS	Outer Continental Shelf
PI	Principal Investigator
SE	Standard Error
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey

1 Introduction

Observer-based at-sea surveys of seabirds and marine mammals remain the universally accepted method to estimate densities of all marine bird species utilizing a specific area. As such, a detailed knowledge of the year-round densities and species composition is essential to any assessment of potential impacts of human activities, such as fisheries, vessel traffic, oil-and-gas, or wind power developments (e.g. Bradbury et al. 2014, Renner and Kuletz, 2015). Kachemak Bay and Lower Cook Inlet (LCI) are near the main human population centers in Alaska (Anchorage and Kenai Peninsula) and therefore critically important to the regional economy, much of which is based on commercial fisheries and extraction of oil and gas.

While important to humans in the region, LCI is also rich in natural resources. The area supports several large seabird colonies (Stephensen and Irons, 2003) and migratory seabirds from as far away as Australia and New Zealand (West et al., 2011). Among the marine birds is a sea duck listed under the federal Endangered Species Act (Steller's eider, *Polysticta stelleri*) and significant populations of two species of particular conservation concern (marbled and Kittlitz's murrelet, *Brachyramphus marmoratus* and *B. brevirostris;* Kuletz et al., 2011). The natural resources use, in particular fishing (recreational and commercial) and wildlife viewing are important attractions for the tourism industry, a major contributor to the economy in the region (Colt et al., 2002). There is a limited amount of native subsistence harvesting of marine mammals (sea otters (*Enhydra lutris)*, and in the past beluga whales (*Delphinapterus leucas);* http://www.kfsk.org/wp-content/uploads/2013/11/Oct-2013-reported-AK-sea-otter-harvest.pdf).

In 1989, contamination from the Exxon Valdez Oil Spill in nearby Prince William Sound reached the southern portions of LCI, where seabird and marine mammal carcasses were retrieved (Piatt et al. 1990). Assessing the full extent of the impact of the oil spill has been hampered by incomplete data. The only available pre-spill data on seabird demography in the area was collected prior to a major change in ocean conditions. "Bottom-up" effects of a regime change in ocean climate and forage food web community prior to the spill may have had an even greater impact on the populations of top predators (Anderson and Piatt, 1999). Increasing ocean temperatures, increasing freshwater inflow from melting glaciers, and increasing erosion from rising sea levels are all be expected due to global climate change and can be expected to be a prominent factor affecting upper trophic levels in the region in the near future (Henson, 2017).

1.1 Study Chronology

The National Oceanic and Atmospheric Administration (NOAA) and the Kachemak Bay Research Reserve (KBRR) have conducted oceanographic sampling in the outer Kachemak Bay and LCI since 2010, with repeat sampling of 5 transects (Figure 5) across 3 to 4 seasons. During 2012 and 2013 the USFWS conducted marine bird and mammal surveys in conjunction with the NOAA/KBRR oceanic research. Funding for the KBRR-USFWS marine bird and mammal surveys was guaranteed for 2014 and 2015 through the current project. Because logistics and conditions limited our ability to conduct all of the 2015 surveys, we conducted additional surveys in spring and late summer 2016 and integrated 2016 results into this report.

1.2 History of research and available datasets

Here, we review published and unpublished information on the status and population trends of marine birds and mammals in LCI. Published information on population size and population trends is currently sparse for most marine bird and mammal species. West et al. (2011) provide qualitative information on abundance and seasonal occurrence of marine bird species within Kachemak Bay, which are particularly useful for assessing the status of rare species, that may have been missed in systematic surveys. The Alaska Maritime National Wildlife Refuge (AMNWR) maintains an annual monitoring camp on East Amatuli Island in the Barren Islands, located at the mouth of Cook Inlet for monitoring population trends and demography of most accessible marine bird species (Dragoo et al., 2012). Prior work on the Barren Islands focused on the fork-tailed storm-petrel (*Oceanodroma furcata),*chick growth, incubation and breeding behavior (Boersma, 1986; Boersma et al., 1995; Boersma and Wheelwright, 1979; Boersma and Parrish, 1998). A study of the winter diets of alcids was conducted in Kachemak Bay in 1977-78 (Sanger 1987).

At-sea surveys in the LCI were conducted in 1975-76 by Alaska Department of Fish and Game (Erickson 1977, archived in the NPPSD, U.S. Geological Survey et al., 2015) and established a baseline and start of a time series of marine bird and mammal distribution data in LCI. The first comprehensive marine bird surveys in LCI were conducted during summer of 1993 and winter of 1994 (Agler et al. 1995); these randomly selected transects (n= 411) provided a baseline of population estimates for all species of marine birds and sea otters for LCI. Other projects were initiated in the 1980s and 1990s following the Exxon Valdez Oil Spill (EVOS) and on-going development of oil and gas resources, especially in Upper Cook Inlet. Minerals Management Service (MMS) funding following the oil spill sparked a series of projects on the linkage of seabirds and forage fish (including Piatt, ed. 2002, Abookire and Piatt 2005, Speckman et al. 2005). To date, studies of seabirds at-sea have resulted in a publication on the status and trend of Kittlitz's murrelet (Kuletz et al., 2011), and an integral study of ecological gradients in LCI (Speckman et al., 2005).

Land-based studies, within the umbrella of a MMS-funded LCI project "Response of Seabirds to Fluctuations in Forage Fish Density" (Piatt, ed., 2002) examined the biology of pigeon guillemot (*Cepphus columba*, Litzow, 2002, 2003, Litzow et al., 2004), and stable isotopes and diet (one sample from Kachemak Bay, Hobson et al., 1994). Comparisons of demographics and breeding parameters between black-legged kittiwakes (*Rissa tridactyla*) and common murres, (*Uria aalge)*, at seabird colonies on the west and east side of Cook Inlet revealed striking regional differences (Zador and Piatt, 1999), that mirrored the findings of Speckman et al. (2005). Phenology and time-mismatch of kittiwakes and murres with their prey (Shultz et al., 2009), and their flexibility to rely on different prey species (Harding et al., 2007) have also been studied. Ongoing research in LCI (2016-2018), funded by the United States Geological Survey (USGS), focuses on the status of forage fish and marine birds, monitoring populations, productivity, physiology, and diet on Gull and Chisik Islands (Arimitsu and Piatt, 2016; Piatt, pers. com.).

An isolated population of beluga whales in Cook Inlet were more common and widespread in the 1970s and 1980s, but currently occurs primarily in upper Cook Inlet (Speckman and Piatt, 2000; Rugh et al., 2010). The decline of this population has prompted listing under the Endangered Species Act in 2008 and drove a considerable amount of research (incl. O'Corry-Crowe et al., 1997; Lerczak et al., 2000; Hobbs et al., 2000; Becker et al., 2000; Ferrero et al., 2000; Speckman and Piatt, 2000; Vos, 2003; Shelden et al., 2003; Rugh et al., 2005; Vos et al., 2005; Goetz et al., 2007; Hobbs et al., 2010; Rugh et al., 2010; Carter and Nielsen, 2011; Goetz et al., 2012; Norman et al., 2015). Organo-chlorine contaminants have been studied in killer whales, (*Orcinus orca),* in addition to beluga whales (Krahn et al., 2004). Little has been published regarding trends and status of other marine mammal species in LCI. Harbor porpoise,(*Phocoena phocoena),* is abundant in upper Kachemak Bay (Boveng et al. 2011), but little information exists on population trends. Several stranding and die-off events of marine mammals in the Cook Inlet area have been attributed to infectious disease (Goldstein et al. 2009, Goldstein et al. 2011), but population-level consequences are poorly known.

Knowledge on the seasonal distribution and abundance of marine birds and marine mammals in the LCI has numerous applications. Seabirds are vulnerable to accidental oil spills, therefore risk assessments of oil and gas exploration, extraction, and transport will rely on accurate and current information of the local natural resources. Similarly, permitting processes for potential alternative energy developments, like wind and tidal power, might require assessments on the impact of developments on local bird and mammal populations. Seabirds are also valuable as bioindicators, signaling changes in the ecosystem that may have profound impacts on local fisheries (Anderson and Piatt, 1999, Piatt et al. 2007).

2 Project Objectives

The overall goal of this study was to support an at-sea survey program for seabird observations in LCI. This vessel based study was in collaboration with the Exxon Valdez Oil Spill Trustee Council- Gulf Watch Alaska Program. These surveys provide seasonal and inter-annual information on the distribution, timing, and abundance of marine birds in coordination with concurrent oceanographic, plankton, and forage fish surveys, conducted by KBBRR/NOAA. The objectives were as follows:

- Place seabird observers on vessels conducting oceanographic transects in Lower Cook Inlet as part of the Gulf Watch Alaska program. Include at minimum one observer across 4 seasons.
- Using ships of opportunity, conduct marine bird and mammal surveys
- Estimate the spatial distribution, species composition and species relative abundance for marine birds in designated and potential planning areas from previous years of observations in the Gulf Watch Alaska program.
- Process the data for entry into the North Pacific Pelagic Seabird Database for future accessibility and to facilitate management decisions for marine bird use of planning areas.
- Coordinate with Ecological Processes Work group members and BOEM to discuss synthesis of bird observation data coupled with other physical and biological data.

3 Methods

3.1 Study area

Cook Inlet is a large subarctic fjord, measuring approximate 350 km from the head of the bay, about 90 km across, to the mouth which is about 200 km at its widest extent. The inlet waters are affected by numerous land-locked glaciers feeding streams and four major rivers discharging from the head of the inlet. Three major bays branch off Cook Inlet: Kachemak Bay in the south-east corner near the entrance, and the two major branches, Turnagain Arm and Knik Arm at the head of the inlet (Karlstrom, 1964).

Lower Cook Inlet borders the Katmai coast in the West, Kalgin Island in the North, the Kenai Peninsula in the East and the Barren Islands in the South. The bathymetry is relatively shallow with depths ranging from < 50 m to 100 m at the main channel. The oceanographic circulation is characterized by strong tidal currents a counter-clockwise flow (Figure 1). Ocean water entering Cook Inlet east of the Barren Islands is highly saline. After mixing with glacial melt water, waters exit the inlet along two major tidal rips along the center and western part of the inlet (Burbank, 1977; Trasky and Burbank, 1977; confirmed by recent satellite drifter studies, A. Doroff, pers. com. Figure 1).

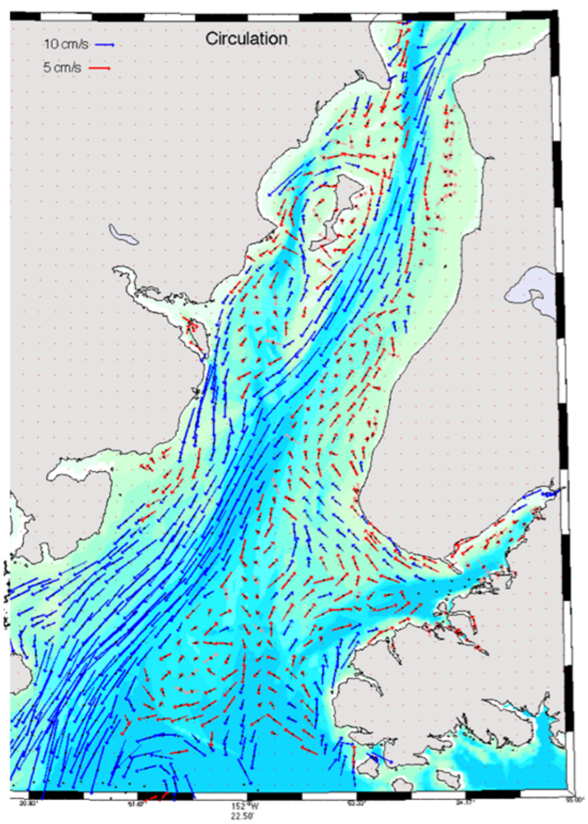

Figure 1. Circulation patterns of surface water modeled after the patterns from satellite drifters (Figure supplied by Angela Doroff, KBRR). These patterns largely match those described by Burbank (1977).

An interpolation of salinity/temperature profiles (from CTD casts) across LCI shows the warm, oceanic water on the east, and cold outflowing water on the west (Figure 2). Heating of the upper water layers during summer causes stratification, the layering of water bodies of different with different densities, which limits the exchange of bottom and surface water. There is a seasonal build-up and break-down of stratification (Figure 3), with particularly high temperatures observed since 2014 compared to previous years.

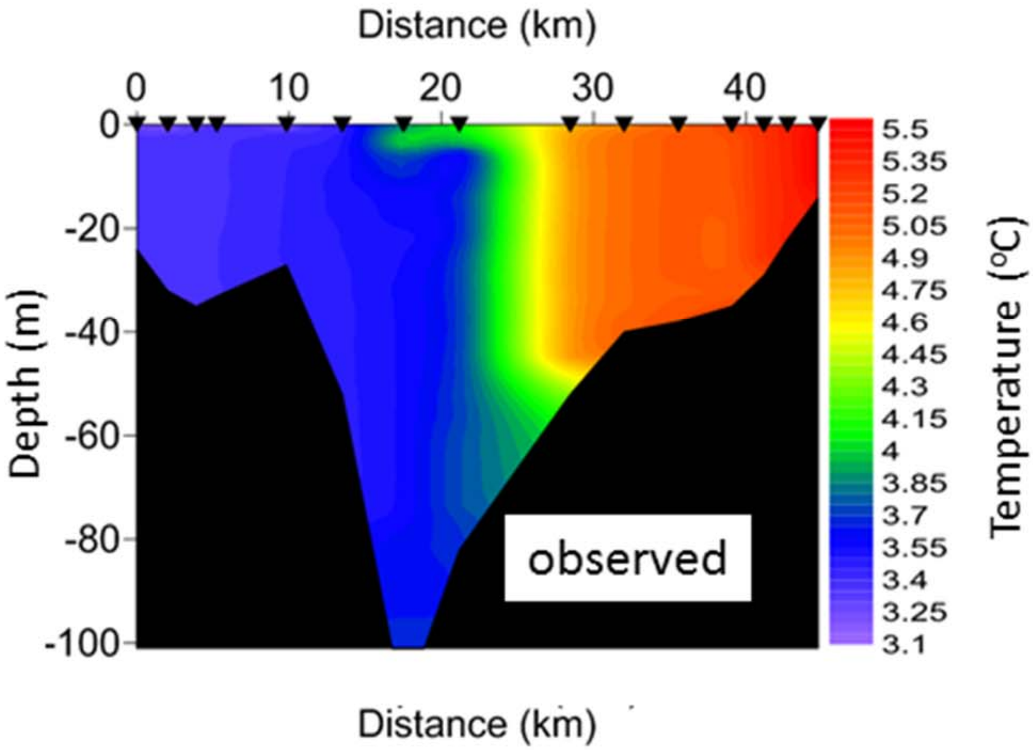

Figure 2. Interpolation of CTD casts along the Anchor Point line, across Lower Cook Inlet, 2 May 2012, going west (left) to east (right). Warm, oceanic water (reds) entering the inlet is visible on the right and cold inlet water (blues) flowing south can be seen on the left. No stratification is apparent, indicating that the water column is still well mixed. Unpublished figure, provided by Kris Holderied, NOAA.

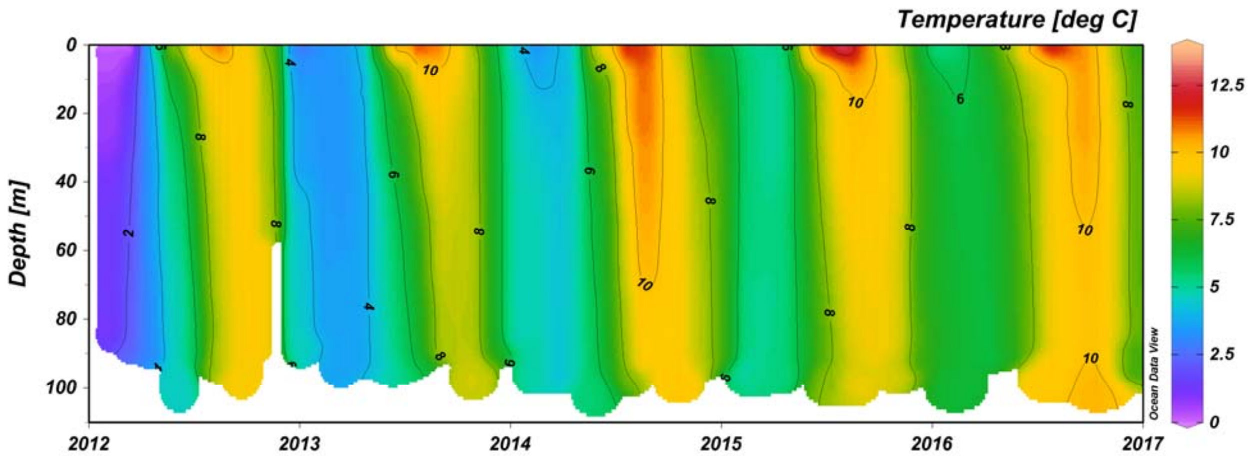

Figure 3. Interpolation of CTD casts in the middle of Kachemak Bay, 2012-2016. The build-up of stratification during summer (warm surface water, cooler bottom water) and the unusually high temperatures seen since 2014 are evident. Unpublished figure, provided by Kris Holderied, NOAA.

Human activities are concentrate along the east side, around the densely populated areas of Kenai Peninsula on the eastern shore of LCI and Anchorage, at the junction between Turnagain and Knik arms. The western shore of Cook Inlet is less populated. A small refinery and natural gas facility exists in Nikiski, which receives some traffic from oil and gas tankers (Robards et al. 2016). Important commercial and sport fisheries occur in Cook Inlet, primarily for halibut and salmon. To investigate this east-west contrast, previously identified based on summer data (Speckman et al. 2005), we examined our data with respect to the western and eastern sides of LCI (Figure 4).

Within the LCI, the Homer Spit divides Kachemak Bay into an inner and outer bay (Figure 4). The southern coastline of Kachemak Bay is rugged, bordered by steep, rocky boreal rainforest. In contrast, the north side beaches are shallow, characterized by large exposed tidally influenced mudflats. Several glacier-fed rivers on the south side discharge large amounts of suspended sediments into the bay, particularly the inner bay.

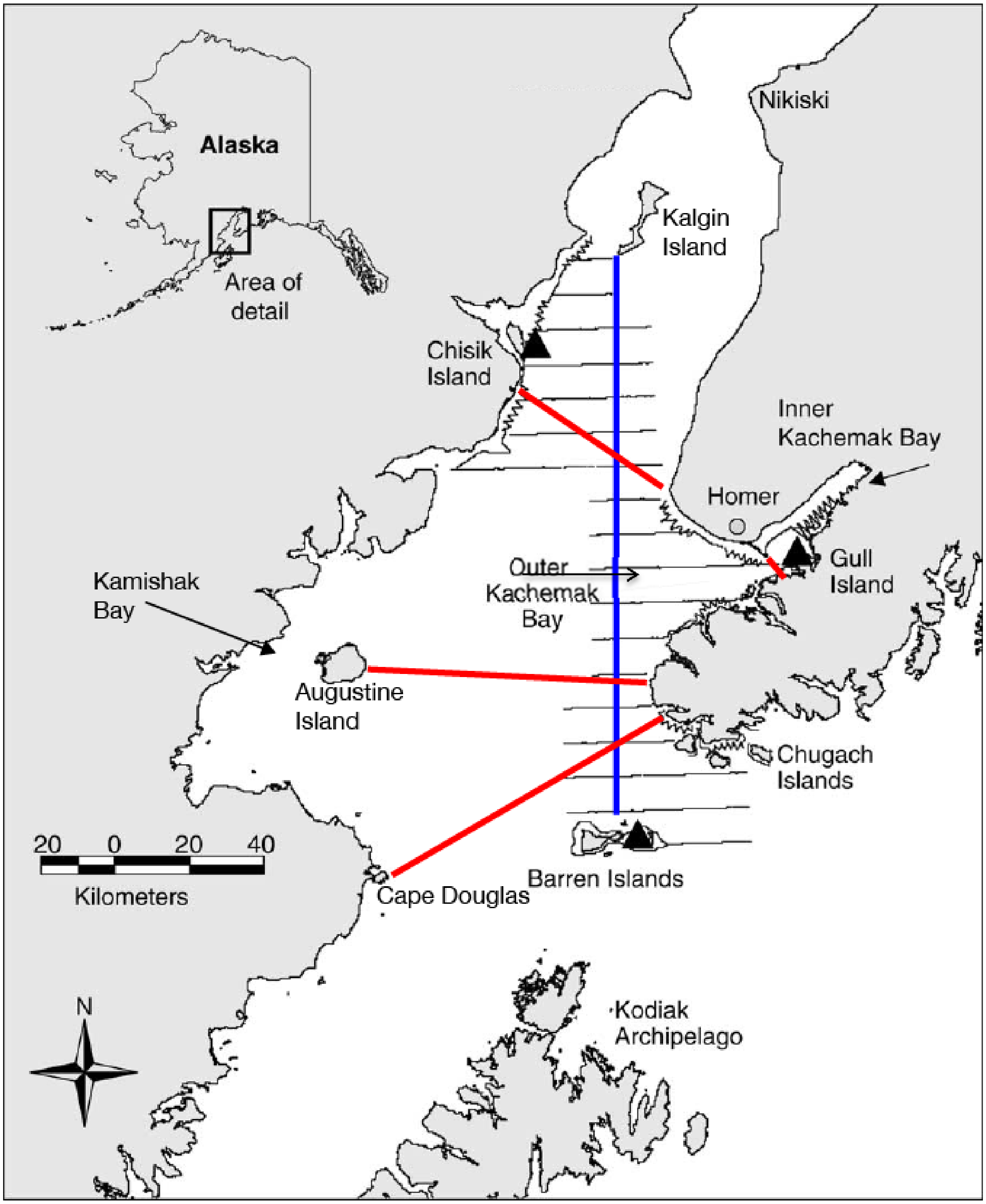

Figure 4. Study area in LCI, showing key geographic locations and location of major seabird colonies (triangles; based on Beringian Seabird Colony Catalog, Stephensen and Irons, 2003). Red lines mark NOAA and KBRR transects for the Lower Cook Inlet (LCI) monitoring project. Black lines mark survey tracks from previous coordinated studies (Piatt, ed., 2002, Speckman et al. 2005). The blue line separates the western and eastern portions of LCI, corresponding to inflowing water (east) and outflowing water (west). Map based on Speckman et al. (2005).

3.2 Data collection

The USFWS coordinated with NOAA and KBRR to place seabird observers on 14 research cruises from 2012 to 2016. During 2012 and 2013, the USFWS used funds from the Migratory Bird Management (MBM) to conduct seabird surveys. During at-sea surveys, the observer collected survey data from the bridge of the vessel. The survey was conducted along a 90° quadrants as the vessel traversed along a 300 m wide strip transect. Flying bird observations were recorded using the snap-shot method, and standard protocol (Gould and Forsell, 1989, Kuletz et al. 2008). The snap-shot method used to avoid a bias introduced by flying birds moving fast compared to the survey vessel. Instead of counting birds continuously, flying birds are only recorded at predefined intervals, equivalent to the time it takes for the survey vessel to advance 300 m. The observer collected observation data from the vessel at 4 m above sea level. Marine birds and mammals were recorded along pre-defined transects and opportunistically while transitioning between transects (Figure 5). However, because this protocol has been designed specifically for marine birds, the data for marine mammals should be viewed largely as descriptive. Observations were entered directly into a laptop computer using dLOG software (Ford, 2004), linked to a hand-held GPS, recording positions every 20 seconds.

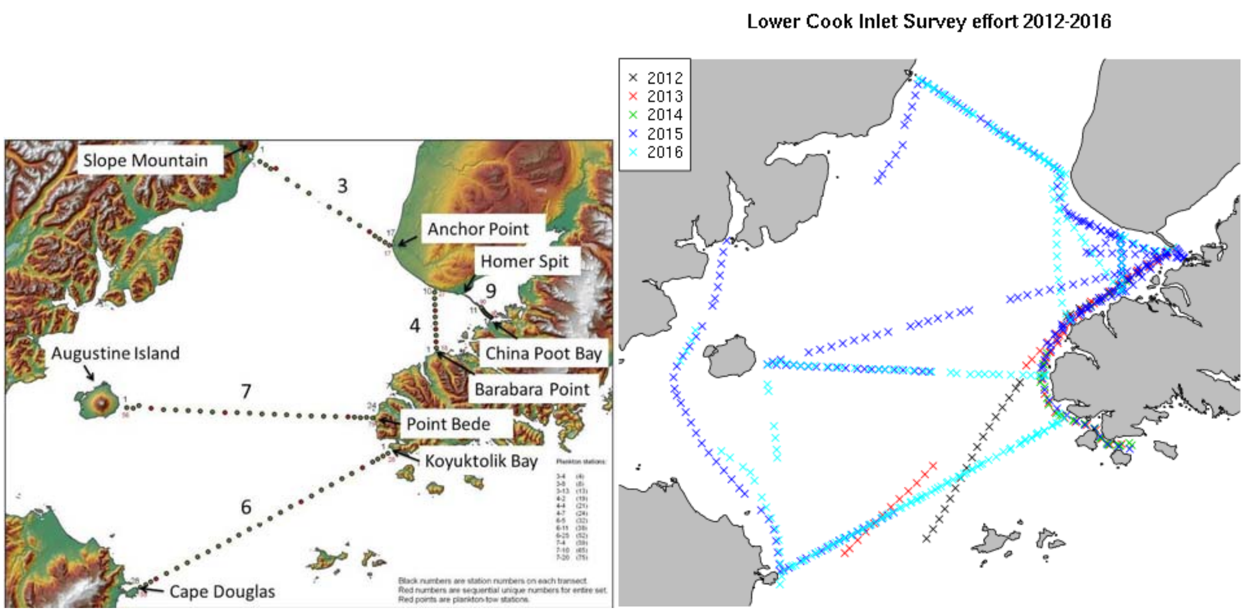

Figure 5. Pre-defined NOAA/KBRR transects for the Lower Cook Inlet monitoring project (left) and actual USFWS marine bird and marine mammal transects 2012–2016, conducted in conjunctions with NOAA/KBRR surveys (right).

Kachemak Bay surveys were conducted 27–29 July 2016 from the 7.7 m *R/V Sandlance* (AMNWR), a 25 foot Boston whaler with cabin, using USFWS protocol for small-vessel surveys (Agler et al. 1995). This protocol is similar to the protocol described above, used for pelagic transects, but is tailored towards smaller vessels. These surveys use two observers, one placed on the port and starboard sides, and a driver. The observers were placed about 2 m above sea level. An observer was positioned on the port and one on the starboard sides of the vessel. A dedicated recorder entered observations into a laptop computer. All birds and mammals within 100 m to either side of the vessel were counted. Species, number of individuals, and their behavior at the time of observation (on water, flying, on land, foraging) were recorded, with flying birds counted continuously, rather than using the snap-shot method. We surveyed the entire Kachemak Bay, following the transect lines established in previous studies (Kuletz et al. 2011, Figure 6). Because it was impractical to complete census of the more than ten-thousand colonially nesting birds, we used GIS to create a 400 m radius buffer around the colonies on Gull Island and Sixty-foot Rock and excluded those sections from density calculations. Because Kachemak Bay surveys used different methods from LCI surveys, we report results from Kachemak Bay separately.

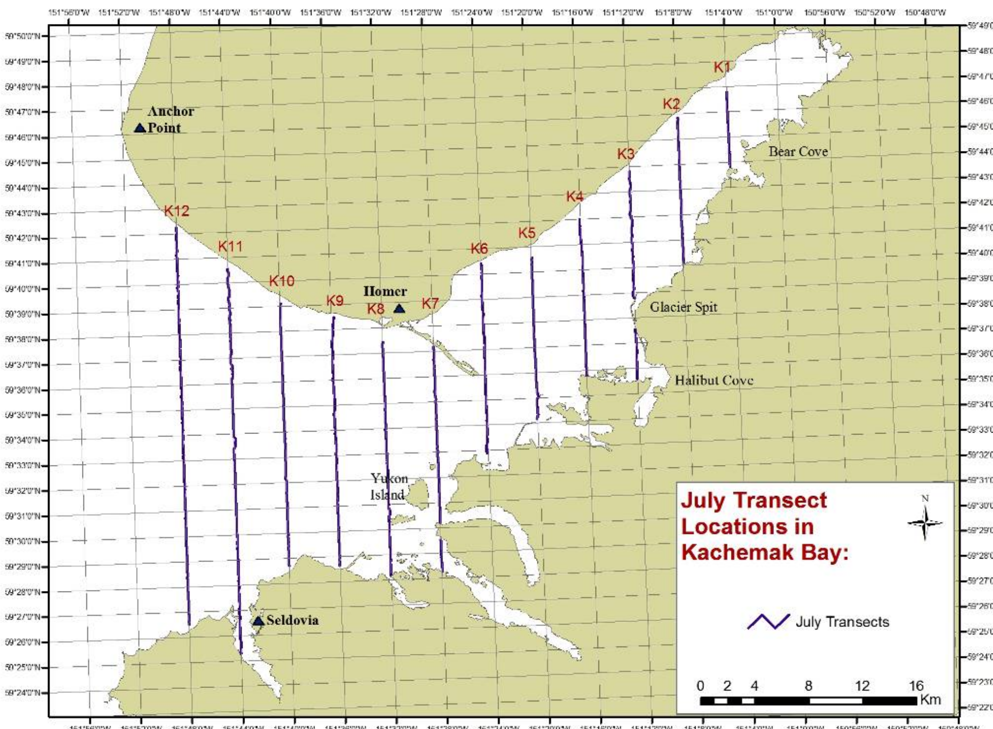

Figure 6. Kachemak Bay transects surveyed in July 2016. These survey transects were initially used in July 2005-2007 and 2011.

3.3 Survey effort

Seabird surveys were conducted from 2012-2016 in LCI (Table 1), totaling 1434 km of transects. Seasonal survey coverage was most complete in 2015 with most of the effort occurring in 2015 and 2016. Constraints due to availability of vessels, observers, or weather meant that not all seasons could be covered in every year. Neither could all transects be covered during every cruise.

Table 1. Survey effort, expressed as total distance [km] of surveyed transect segments per year and season.

Year	Winter	Spring	Summer	fall
2012		23		47
2013		77		87
2014		79		10
2015	427	154		80
2016			230	

Survey data collected from 2012 to 2014 was edited, processed, and submitted to the North Pacific Pelagic Seabird Database (NPPSD) and is on the Gulf Watch Alaska AOOS workspace. The new surveys updated existing knowledge and extended the available time series considerably (Figure 7), which is now extending from the mid-1970s to the mid-2010s (forty years).

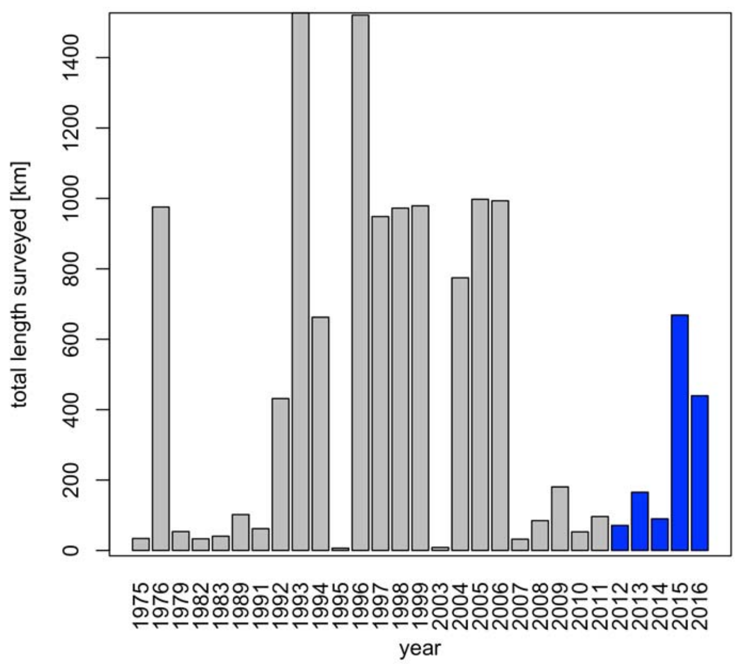

Figure 7. Annual distribution of marine bird surveys, 1975-2016 in Lower Cook Inlet. Data archived in the NPPSD (gray) and BOEM-funded survey effort, submitted to NPPSD (blue).

Geographic and seasonal survey coverage for LCI was also expanded by this study. Previous survey work in LCI was focused on summer months, especially for eastern LCI (Figure 8). Surveys from this project added substantially to the spatial and seasonal coverage, close to doubling the total survey effort in many season/region. Most significantly, winter in the western portion of LCI was not represented in previous studies at all. Previous work also did not cover the southwestern or northeastern part of the study area, which were covered multiple times during this study.

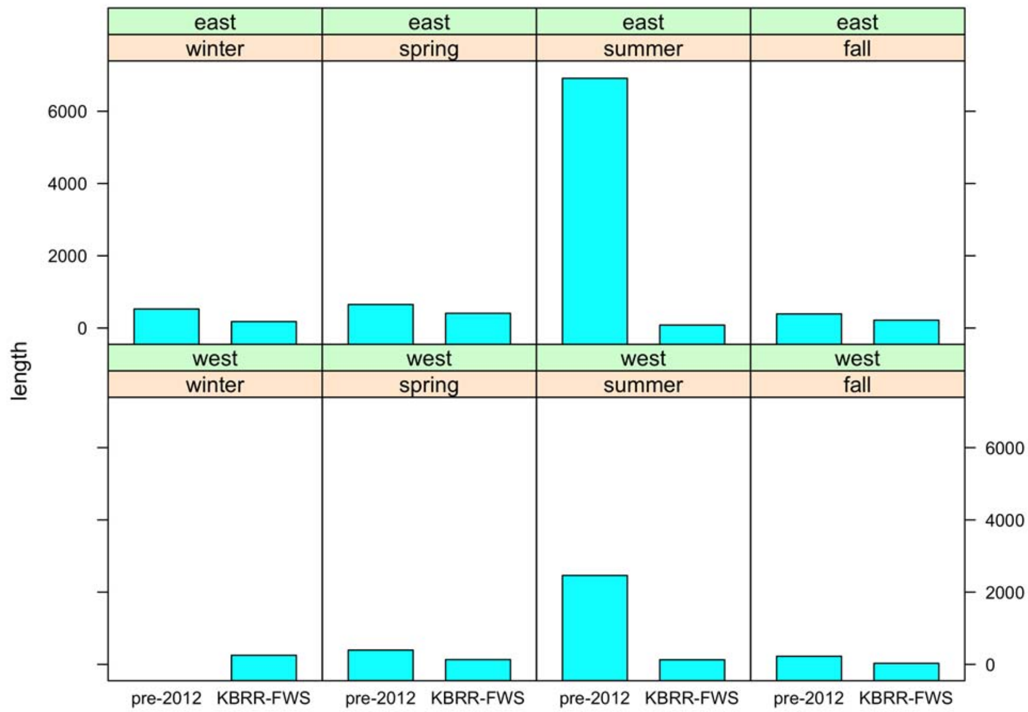

Figure 8. Survey effort (length [km] surveyed) by season and west/east portion of LCI, comparing effort for the KBRR-FWS with previous surveys archived in the NPPSD.

3.4 Data processing

Raw data files underwent quality control to account for data entry and GPS-errors. To calculate densities, we divided transects into segments up to 3-km long, approximately equivalent to the 10 minute in standardized at-sea surveys of marine birds (Tasker et al. 1984, Gould and Forsell, 1989). For comparative LCI historic data extracted from the NPPSD, only ship-based surveys were used, excluding aerial surveys. We calculated apparent densities using transect-width and length. Birds observed outside the 0–300 m survey strip, or the snapshot window, were excluded from density analysis.

3.5 Data analysis

Marine bird densities were summarized using means and standard errors (SE) in tables organized by west/east distribution (Table 2, Table 3) and season (Table 4). We also mapped the distribution of species of particular interest (most abundant species per season and species of conservation concern). Seasons were defined by month: winter (December to February), spring (March to May), summer (June to

August), and fall (September to November).

Appendix C provides maps for all species using the KBRR-USFWS survey data. In addition we calculated Shannon's diversity index, a combined measure of the species richness (number of species) and evenness (similar densities across species). This index is less susceptible than simple species richness to differences in sampling effort. All processing and analysis was completed using R v. 3.3.2 (R Development Core Team, 2016).

4 Results

4.1 Spatial and seasonal patterns of marine birds

Overall, total marine bird densities were similarly high in winter, spring, and summer (18-20.2 birds km^{-2}), but only about half as dense in fall (Table 2). Densities were higher on the east side of LCI, especially in the shallow waters close to shore, whereas there are less marked differences between northern and southern parts of LCI (Figure 9). Bird densities on the east side of LCI were higher in all seasons except in spring, when the east and west sides were nearly equal in seabird density. Differences between east and west sides were most pronounced in winter and summer (Table 2). Densities in western LCI were highest during the breeding season, in spring and summer (Table 2). The eastern part of LCI had highest seabird densities in winter and summer, with approximately three times the densities found in fall (Table 2). Species diversity, as estimated with Shannon's diversity index, was similar on both sides of the inlet, but low in winter and spring compared to summer and fall (Table 3).

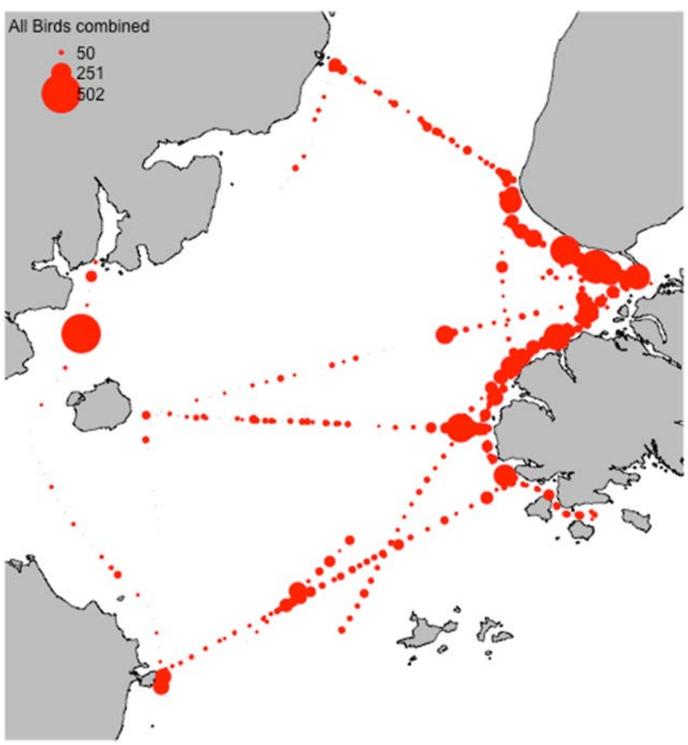

Figure 9. Observed apparent densities [birds km^{-2}] of all marine bird species combined from 2012-2016 in Lower Cook Inlet.

Table 2. Densities of all seabird species combined (means +/- SE) in eastern and western part of Lower Cook Inlet and the ratio between those two densities by season (2012–2016).

Season	mean	west	east	ratio
Winter	19.4+/-6.5	7.9+/-5	31+/-8.1	3.9
Spring	18+/-6.2	18.1+/-9.1	17.8+/-3.4	1
Summer	20.6+/-5.6	11.8+/-2.4	29.3+/-8.8	2.5
Fall	9.9+/-2.1	9.1+/-1.7	10.7+/-2.5	1.2

Table 3. Comparison of Shannon's diversity index for marine bird communities among seasons and regions in Lower Cook Inlet, based on 2007-2016 KBRR-USFWS surveys.

Season	west	east	mean
Winter	1.25	1.2	1.23
Spring	1.32	2.08	1.7
Summer	1.98	1.84	1.91
Fall	1.93	2.3	2.12
Mean	1.62	1.86	1.74

4.2 Seasonality of seabird community composition

Seabird species composition changed considerably, nevertheless average densities of all marine bird species combined remained fairly high throughout the year (Table 2, Table 4). The most common species were white-winged scoter (*Melanitta fusca*), common murre (year round), black-legged kittiwake, (summer), red-necked phalarope (*Phalaropus lobatus*; spring), and sooty shearwater (*Ardenna grisea*; summer and fall) (Table 4). White-winged scoters were particularly common along the shores of outer Kachemak Bay. High concentrations were also found in Kamishak Bay, north of Augustine Island (Figure 10). Sooty shearwaters were the most abundant seabird during summer that does not breed within Alaska. The similar short-tailed shearwater (*A. tenuirostris*) was also observed, but in smaller numbers (Table 4). Highest densities of sooty shearwaters were found on the east side of LCI (Figure 11). Red-necked phalaropes were found to have an even more restrictive distribution, being concentrated on the south side of Kachemak Bay, off Seldovia (Figure 12). Black-legged kittiwakes (Figure 13) and common murres (Figure 14), the two most abundant cliff nesting seabird species in the area, were both widely distributed, but more common on the eastern side of LCI. There appears to be a north-south difference between these two primarily fish-eating species (Figure 13, Figure 14), which should be further investigated for oceanographic or prey relationships driving their respective distributions.

Table 4. Average densities +/- SE [birds km^{-2}] of marine birds in LCI by seasons.

	winter	spring	summer	fall	year
White-winged Scoter	12.08+/-0.02	3.06+/-0.24	0+/-1.24	0.16+/-0.92	3.83+/-0.6
Common Murre	1.5+/-0.02	3.4+/-0.08	1.58+/-0	1.74+/-0	2.05+/-0.03
Black-legged Kittiwake	0.03+/-0.02	1.29+/-0	4.25+/-0.01	2.11+/-0	1.92+/-0.01
Red-necked Phalarope	0+/-0.07	5.24+/-0	0+/-0	0.28+/-0	1.38+/-0.02
Sooty Shearwater	0+/-0.03	0.01+/-0.06	3.72+/-0.04	1.23+/-0	1.24+/-0.03
Unidentified Shearwater	0+/-0.29	0.73+/-1.73	2.63+/-0.39	1.58+/-0.38	1.24+/-0.7
Northern Fulmar	0.38+/-0	0.07+/-0.01	2.08+/-0	1.31+/-0	0.96+/-0
Glaucous-winged Gull	1.43+/-0	1.32+/-0.1	0.29+/-0.25	0.19+/-0.12	0.81+/-0.12
Horned Puffin	0.01+/-0	0.02+/-0	1.83+/-0.01	0.17+/-0	0.51+/-0
Pigeon Guillemot	1+/-0.29	0.48+/-0.28	0.39+/-0.1	0+/-0.1	0.47+/-0.19
Tufted Puffin	0+/-0.1	0.19+/-0.03	0.31+/-0	0.78+/-0	0.32+/-0.03
Fork-tailed Storm-Petrel	0+/-0.03	0.18+/-0.01	0.63+/-0.01	0.22+/-0.03	0.26+/-0.02
Pelagic Cormorant	0.19+/-0.01	0.36+/-0.02	0+/-0.66	0.02+/-0.07	0.14+/-0.19
Marbled Murrelet	0.05+/-0	0.28+/-0.01	0.11+/-0.02	0.04+/-0	0.12+/-0.01
Northern Pintail	0+/-0.05	0.33+/-0	0+/-0	0+/-0	0.08+/-0.01
Short-tailed Shearwater	0+/-0.04	0.01+/-0.14	0.1+/-0.06	0.22+/-0.04	0.08+/-0.07
Mew Gull	0.16+/-0.11	0.04+/-0.05	0.03+/-0.62	0+/-0.38	0.06+/-0.29
Brachyramphus murrelet	0.04+/-0	0.16+/-0.28	0+/-0	0+/-0	0.05+/-0.07
Pacific Loon	0+/-0	0.13+/-0	0+/-0	0.07+/-0.09	0.05+/-0.02
Parakeet Auklet	0+/-0	0+/-0.06	0+/-0	0.16+/-0.05	0.04+/-0.03
Common Loon	0.03+/-0.06	0.09+/-0.29	0.04+/-0	0+/-0.02	0.04+/-0.09
Harlequin Duck	0.11+/-0.36	0.03+/-0.13	0+/-0.15	0+/-0	0.03+/-0.16
Herring Gull	0.04+/-0	0.01+/-0	0.01+/-0.02	0.06+/-0.03	0.03+/-0.01
Common Eider	0.09+/-0	0+/-0.03	0+/-0	0+/-0	0.02+/-0.01
Long-tailed Duck	0.09+/-0	0+/-0	0+/-0	0+/-0.02	0.02+/-0.01
Pomarine Jaeger	0+/-0	0+/-0.01	0.02+/-1.48	0.04+/-0.66	0.02+/-0.54
Parasitic Jaeger	0+/-0	0.01+/-0.01	0.04+/-0.05	0.01+/-0.15	0.01+/-0.05
Ancient Murrelet	0+/-0.01	0+/-0.04	0.06+/-0	0+/-0	0.01+/-0.01
Surf Scoter	0.01+/-0	0.04+/-0.07	0+/-0.08	0+/-0.2	0.01+/-0.09
Red-breasted Merganser	0+/-0	0.05+/-0.01	0+/-0	0+/-0	0.01+/-0
Kittlitz's Murrelet	0+/-0.02	0.01+/-0.02	0.02+/-0.01	0+/-0.03	0.01+/-0.02
Cassin's Auklet	0.02+/-0	0+/-0	0.01+/-0	0+/-0.01	0.01+/-0
Rhinoceros Auklet	0+/-0.02	0+/-0	0+/-0	0.02+/-0.03	0.01+/-0.01
Red-faced Cormorant	0.01+/-0.06	0.01+/-0	0+/-0	0+/-0.02	0+/-0.02
Double-crested Cormorant	0+/-0	0.01+/-0	0+/-0.04	0+/-0	0+/-0.01
Hybrid Gull	0+/-0	0+/-0.01	0.01+/-0	0+/-0.02	0+/-0.01
Thick-billed Murre	0.01+/-4.39	0+/-1.68	0+/-0	0+/-0.16	0+/-1.56

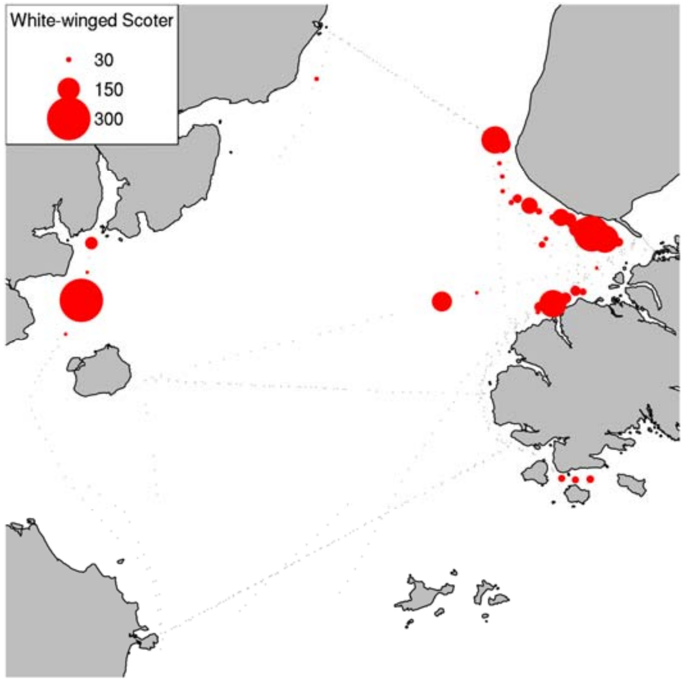

Figure 10. Spatial distribution of white-winged scoter, the most abundant marine bird recorded during KBRR-USFWS surveys, occurring mostly during the winter months, 2012–2016.

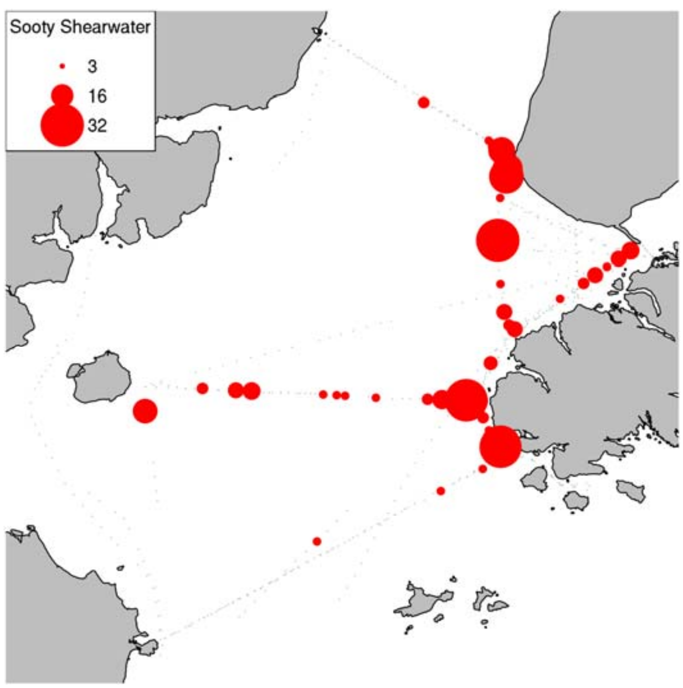

Figure 11. Spatial distribution of Sooty Shearwater in LCI, 2012–2016.

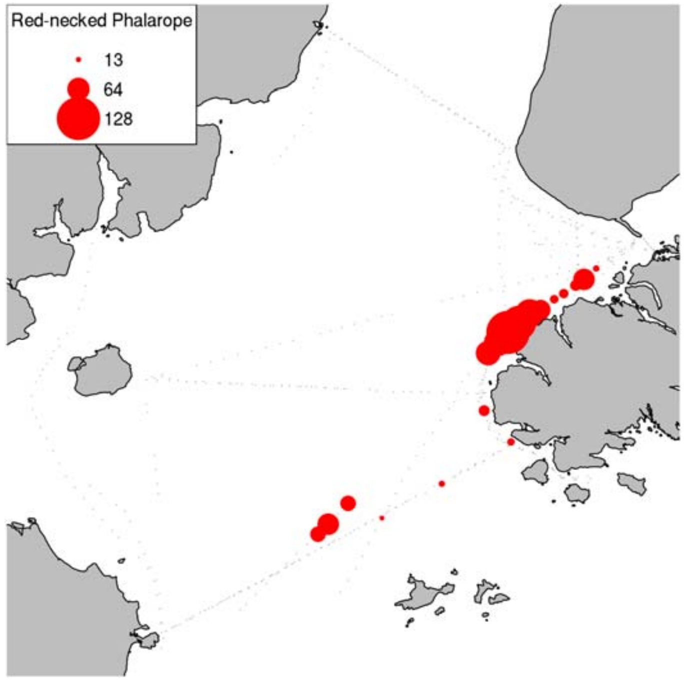

Figure 12 Spatial distribution of red-necked phalarope, occurring mostly during spring migration, 2012–2016.

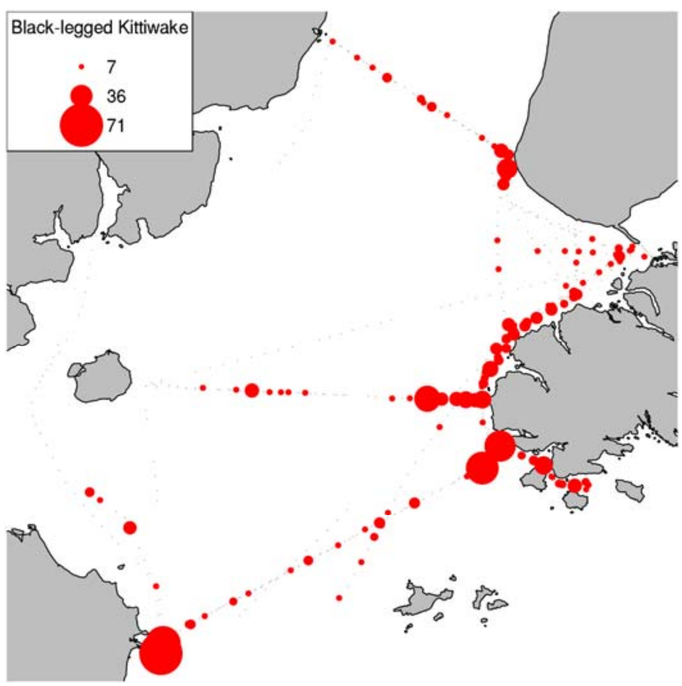

Figure 13. Spatial distribution of black-legged kittiwakes in LCI (see Figure 4 for locations of breeding colonies), 2012–2016.

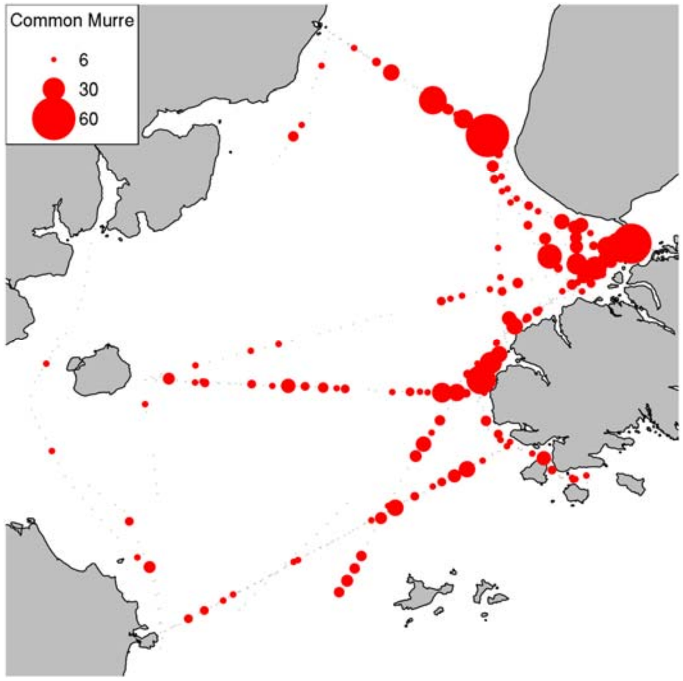

Figure 14. Spatial distribution of common murre in LCI (see Figure 4 for colony locations), 2012–2016.

4.3 Comparing closely related species

Within LCI, two species of *Brachyramphus* murrelets and two *Fratercula* puffin species are common. The marbled murrelet was over ten times more abundant than Kittlitz's murrelet (Table 2). Both species were more abundant on the eastern than the western part of LCI. During the LCI surveys (which did not include inner Kachemak Bay), Kittlitz's murrelet were concentrated in the central and northern parts of outer Kachemak Bay, whereas marbled murrelets were more widespread, including the Anchor Point area, and abundant along the south-coast of Kachemak Bay (Figure 15).

Comparing the distributions of the two *Fratercula*, horned and tufted puffin, the former had a more limited distribution, being primarily encountered along transect 3 in the northwestern most part of the study area (Figure 16). The tufted puffin in contrast was more widely distributed and were found in higher densities in the southeastern sector of the study area, north of the Barren Islands and west of Port Graham, despite being less abundant overall (Table 4).

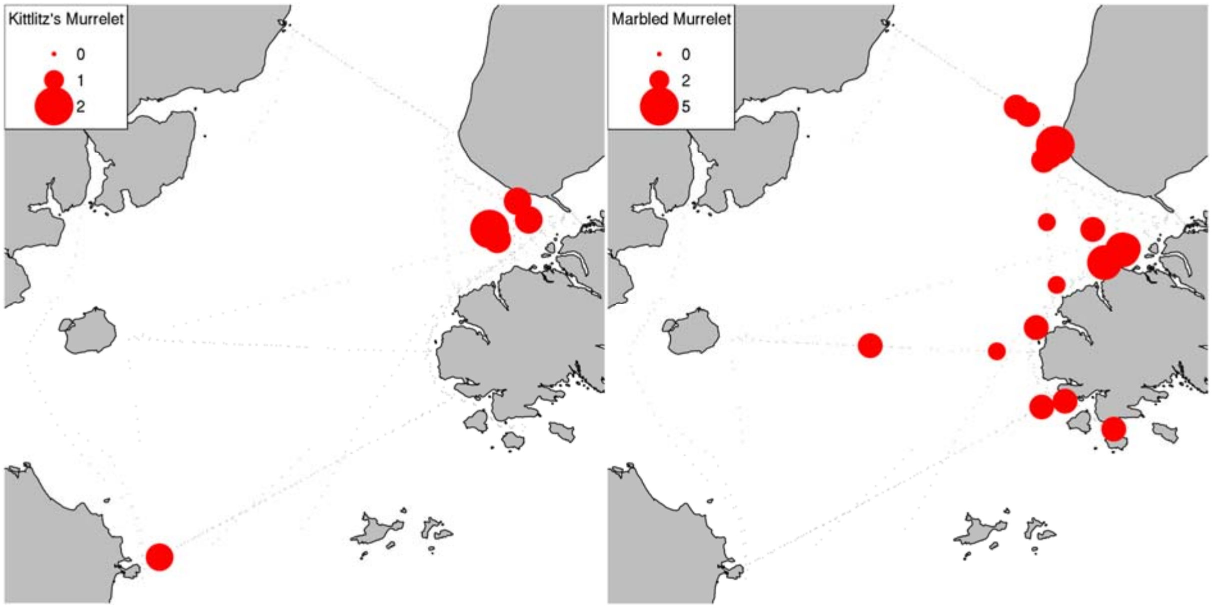

Figure 15**.** Comparison of the spatial distribution of the two *Brachyramphus* murrelets breeding within LCI, Kittlitz's murrelet (left) and marbled murrelet (right), 2012–2016.

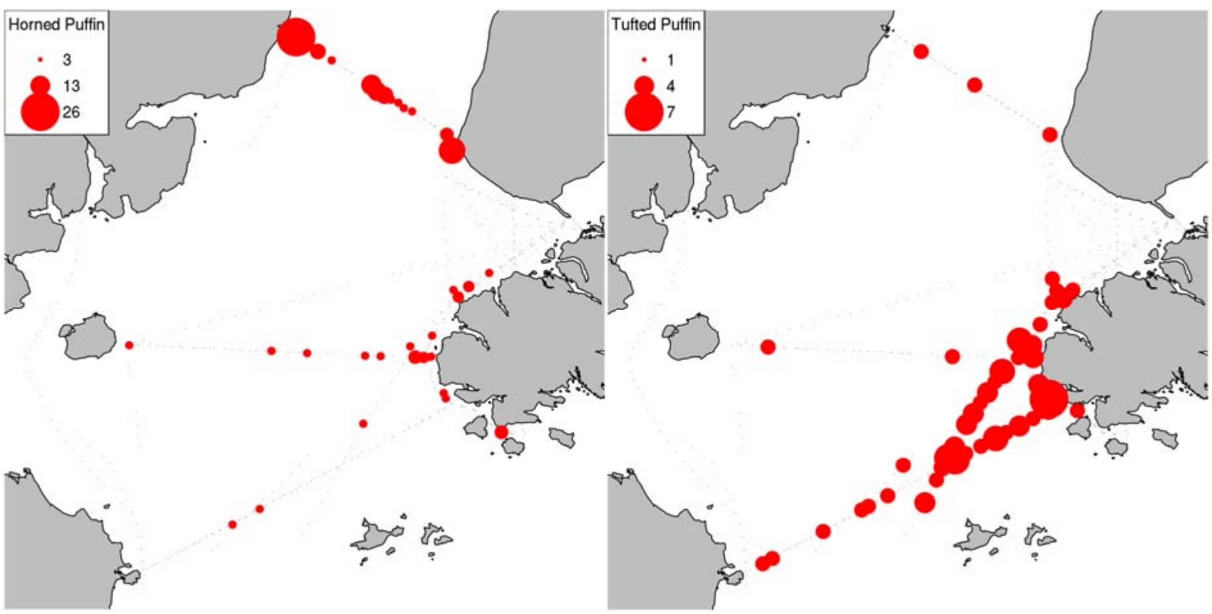

Figure 16**.** Comparison of the spatial distribution of the two *Fratercula* puffin species breeding within LCI, horned puffin (left) and tufted puffin (right), 2012–2016.

4.4 Marine Mammals

Sea otters were the most abundant and widespread marine mammal recorded during the 2007-2016 USFWS surveys. By far the highest densities occurred in the northern part of outer Kachemak Bay, but were also widespread off Anchor Point and Kamishak Bay (Figure 17).

Harbor seals (*Phoca vitulina)*, and harbor porpoise, and Dall's porpoise (*Phocoenoides dalli*), were also recorded in most years (Table 5). A total of six cetacean species were recorded during this study. The Fin whale (*Balaenoptera physalus*), and minke whale (*Balaenoptera acutorostrata*) were only encountered opportunistically, beyond the 300 m transect window.

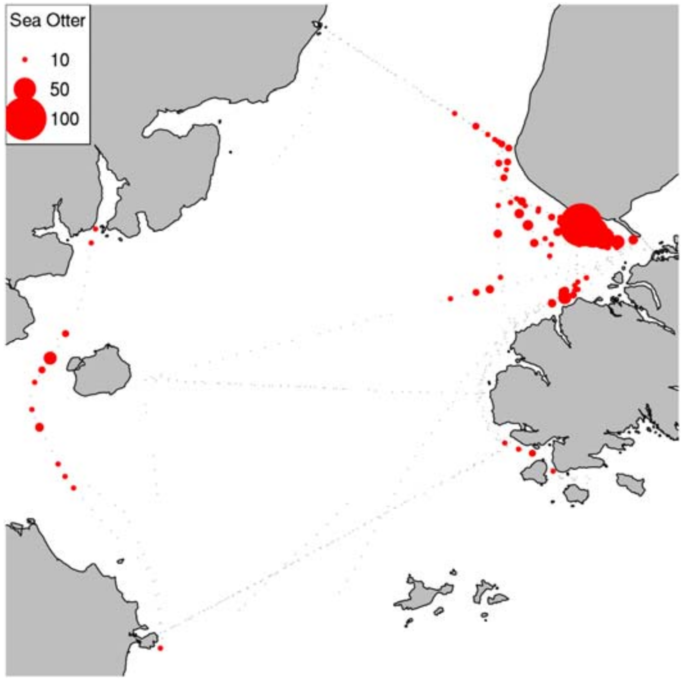

Figure 17. Spatial distribution of sea otters in LCI, 2012–2016.

Table 5. Marine mammal counts on LCI at-sea surveys conducted by KBRR-USFWS, by seasons. On transect counts were within the 300 m survey strip, and off transect counts were outside the 300 m survey strip. Note that effort was not consistent across seasons, 2012-2016.

Species	Spring	Summer	Fall	Winter	Total
On Transect					
Sea Otter	225	53	56	163	497
Harbor Seal	0	10	0	4	14
Dall's Porpoise	0	3	7	0	10
Harbor Porpoise	0	1	0	4	5
Humpback Whale	0	2	0	0	2
Killer Whale	0	1	6	0	7
Unid. Whale	2	0	0	0	2
Off Transect					
Sea Otter	64	16	34	180	294
Dall's Porpoise	0	2	9	0	11
Unid. Whale	1	8	0	0	9
Humpback Whale	1	1	0	0	2
Minke Whale	0	2	0	0	2
Harbor Seal	0	0	0	1	1
Harbor Porpoise	0	0	0	1	1
Fin Whale	0	1	0	0	1
Unid. Seal	0	0	1	0	1

4.5 Kachemak Bay survey

During the three days of surveys of Kachemak Bay, 3446 marine birds of 19 species were recorded, plus bald eagles (*Haliaeetus leucocephalus*), and 521 marine mammals from 6 species on transect. In July 2016, common murres were the most abundant marine bird species. The next most common species was black-legged kittiwake, which were observed in both the in inner and outer Kachemak Bay (Table 6). For the entire bay (excluding 400 m around the two seabird colonies, Gull Islands and 60 Foot Rock), we estimated an uncorrected density for total marine birds of 18.6 birds km^{-2}. Sea otters were the most abundant marine mammal recorded during this survey, followed by harbor seal, Dall's porpoise, and harbor porpoise.

Table 6. Average densities [birds km^{-2}] of marine birds in Kachemak Bay, 27-29 July 2016. Observations within 400 m of the large colony at Gull Island were excluded from this summary. No correction was applied to flying birds, which were counted continuously.

Species	N	density
Common Murre	1899	10.265
Black-legged Kittiwake	442	2.389
Marbled Murrelet	322	1.741
Kittlitz's Murrelet	194	1.049
Glaucous-winged Gull	170	0.919
Pelagic Cormorant	115	0.622
Red-necked Phalarope	76	0.411
Surf Scoter	62	0.335
Harlequin Duck	47	0.254
Pigeon Guillemot	32	0.173
Brachyramphus murrelet	28	0.151
Sooty Shearwater	24	0.130
Herring Gull	10	0.054
White-winged Scoter	5	0.027
Bald Eagle	4	0.022
Common Loon	3	0.016
Unidentified loon	3	0.016
Mew Gull	2	0.011
Parasitic Jaeger	2	0.011
Unidentified cormorant	2	0.011
Pacific Loon	1	0.005
Red-throated Loon	1	0.005
Tufted Puffin	1	0.005
Unidentified shearwater	1	0.005
Sum of all species	3446	18.627

5 Discussion

High densities of marine birds were found throughout the year, despite considerable turnover in community composition. Of the five most common species (red-necked phalarope, sooty shearwater, common murre, black-legged kittiwake, white-winged scoter), only murres and kittiwakes commonly breed within the study area. White-winged scoters breed on inland lakes in Alaska and Canada and are winter visitors to Cook Inlet (Brown and Fredrickson, 1997). Red-necked phalaropes breed in small numbers on freshwater marshes around Cook Inlet, but are seasonally abundant migrants, most likely from the North Slope of Alaska (pers. obs., Rubega et al., 2000). Sooty shearwaters breed in New Zealand and spend their southern-hemisphere winter in the North Pacific.

Within Kachemak Bay a few Kittliz's murrelets were observed in the north outer bay (Figure Figure 15) during the KBRR-USFWS surveys, but the intensive Kachemak Bay surveys showed that most of the Kittlitz's murrelets were in the south inner bay, primarily near Grewingk Glacier runoff, as was found in previous Kachemak Bay surveys (Kuletz et al., 2011).

High densities of seabirds on the east side of LCI (Figure 1) coincide with inflowing oceanic water from the northern GOA (Figure 9). This pattern has been observed previously, in seabirds as well as in forage fish and oceanographic parameters (Speckman et al. 2005), but seasonal aspects have not yet been published. The study design in Speckman et al. (2005), which surveyed primarily in the northwest and southeast (Figure 4) resulted in limited ability to distinguish north-south from east-west gradients. The addition of surveys in the southwest quadrant of the study area enabled us to address this weakness in Speckman et al. 2005 and confirm that the predominant gradient in LCI is east-west rather than north-south.

It was unfortunate that the summer and fall surveys of 2015 were missed, because it was an unusual year oceanographically. Ocean conditions were unusually warm that year and a large die off of marine birds (primarily common murres) occurred in northern GOA. The warm water anomaly continued throughout 2016 with the highest mortality for common murres apparently occurring in January 2016. Several GOA murre colonies monitored by the AMNWR exhibited breeding failure (including no nesting attempts at all) in 2016, as did black-legged kittiwake colonies in Prince William Sound; the latter had not failed in over 30 years of monitoring (D. Irons, pers. comm). The high densities of murres throughout Kachemak Bay during the July 2016 intensive survey of the bay may have been influenced by lack of breeding attempts at colonies.

Our study emphasizes the importance of Kachemak Bay for marine birds and marine mammals during all seasons. This area has previously been identified as a nursery for juvenile marbled murrelets (Kuletz and Piatt, 1999), a stop-over site for satellite tagged murrelets from southeast Alaska (Madison and Piatt, pers. com), and as an important wintering area for seaducks (Sanger, 1987). Analyses exploring the fine-scale correlations between physical and biological variables would help identify mechanisms driving the high productivity, and thus marine bird abundance in and around Kachemak Bay. The data collected during this study expands our knowledge of seasonal aspects of marine bird distribution, which can inform managers of the potential effects of human activities (e.g., shipping, fishing, oil and gas exploration, extraction, and transport).

5.1 Management Implications and Recommendations

The collaboration with the KBRR provided a rare opportunity for a cost-effective monitoring program for seabirds at-sea, across seasons, and integrated within a larger program investigating oceanography and zooplankton. Surveys during winter months are still scarce and therefore particularly important. At the same time, continuing the strong time series of summer data should produce insights into long-term trends and sensitivities of various species to changes in climate or human activity.

Because of its location, seabird populations, and accessibility, LCI holds potential for integrating a long-term monitoring program of at-sea surveys with colony-based investigations into demographic parameters as well as diet and telemetry-based foraging studies. The area is of human and commercial interest, biologically rich throughout the year, and supports several species of conservation concern (e.g. Aleutian terns, Kittlitz's murrelet, Steller's Eider). The collaboration between KBRR and USFWS was cost effective by the sharing of ship time. Additionally, it can ultimately facilitate an interdisciplinary approach, integrating data on physical oceanography and lower trophic levels with data on upper trophic level species.

5.2 Recommendations:

- A comprehensive long-term monitoring scheme that is sustainable will be required to examine changes in populations.
- Future studies will require use of consistent protocols, ideally linked to prey and/or oceanographic data collection, but should also incorporate the ability to compare with historic data (i.e., seabird abundance and distribution data in the NPPSD).
- The eastern side of LCI requires more survey effort given its importance to avifauna of LCI as well as to humans.
- Winter and summer surveys might be emphasized, given higher overall densities of birds during those seasons.
- There is a lack of current data on seabird colonies. Major colonies should be recensused and a dedicated search effort should be undertaken to look for small colonies of priority species like Aleutian and Arctic Terns.
- At-sea surveys for juveniles of some species (i.e., Kittlitz's murrelet, marbled murrelet, pigeon guillemot) would be useful and informative in late summer in Kachemak Bay.
- Continuation of the Gulf Watch Alaska shared work space (via Alaska Ocean Observing System) and accessible data (including mapping, spatial modeling, and outreach products) would leverage historic and on-going data integration.

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7 Appendices

7.1 Appendix A. Latin names of marine bird species

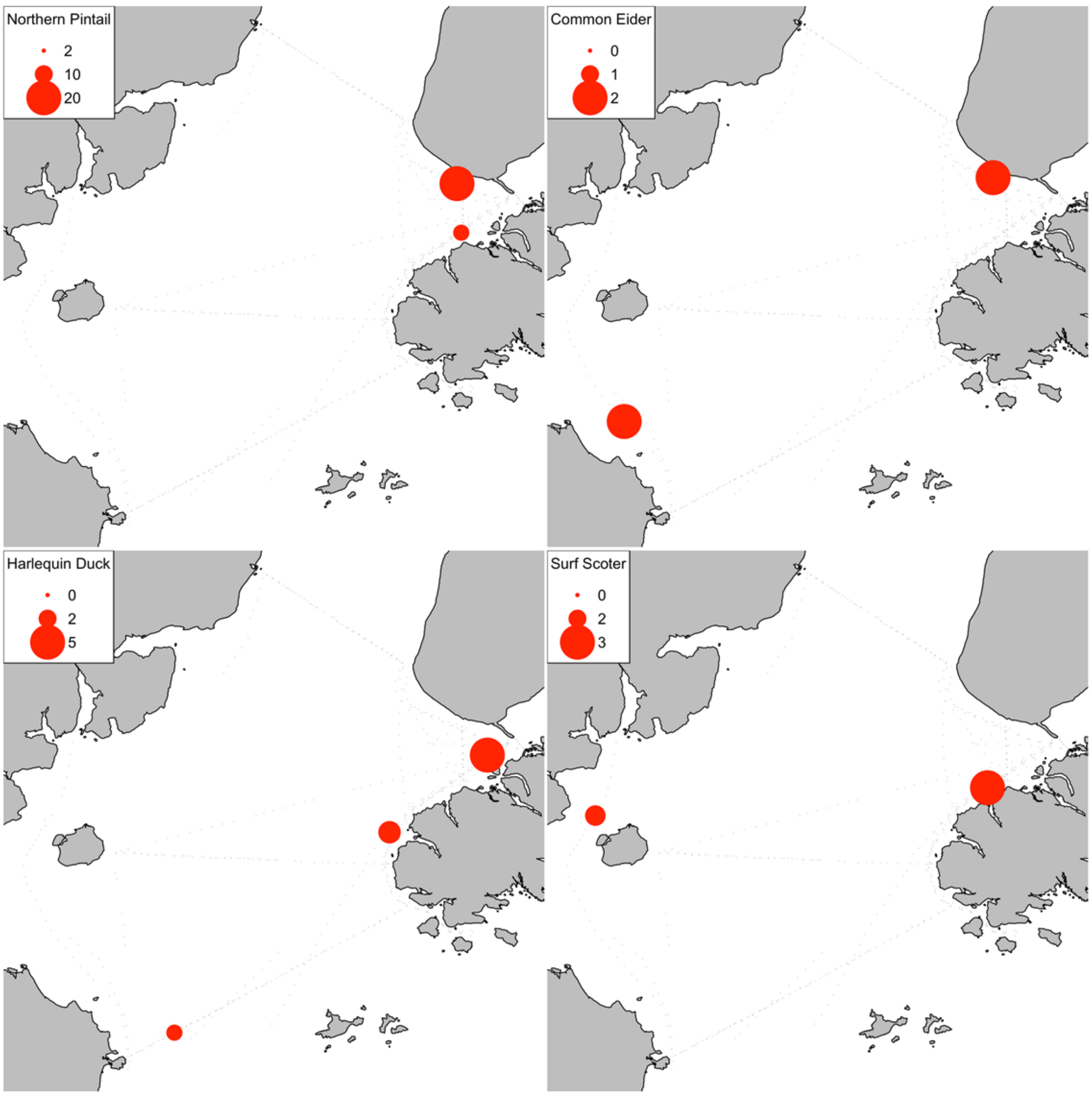
Common	Latin
Black-legged Kittiwake	*Rissa tridactyla*
Black Turnstone	*Arenaria melanocephala*
Common Eider	*Somateria mollissima*
Common Loon	*Gavia immer*
Common Murre	*Uria aalge*
Fork-tailed Storm-Petrel	*Oceanodroma furcata*
Glaucous-winged Gull	*Larus glaucescens*
Harlequin Duck	*Histrionicus histrionicus*
Herring Gull	*Larus argentatus*
Horned Puffin	*Fratercula corniculata*
Kittlitz's Murrelet	*Brachyramphus brevirostris*
Long-tailed Duck	*Clangula hyemalis*
Marbled Murrelet	*Brachyramphus marmoratus*
Mew Gull	*Larus canus*
Northern Fulmar	*Fulmarus glacialis*
Northern Pintail	*Anas acuta*
Parakeet Auklet	*Aethia psittacula*
Parasitic Jaeger	*Stercorarius parasiticus*
Pacific Loon	*Gavia pacifica*
Pelagic Cormorant	*Phalacrocorax pelagicus*
Pigeon Guillemot	*Cepphus columba*
Pomarine Jaeger	*Stercorarius pomarinus*
Red-breasted Merganser	*Mergus serrator*
Red-necked Phalarope	*Phalaropus lobatus*
Sooty Shearwater	*Ardenna grisea*
Short-tailed Shearwater	*Ardenna tenuirostris*
Surf Scoter	*Melanitta perspicillata*
Tufted Puffin	*Fratercula cirrhata*
White-winged Scoter	*Melanitta fusca*

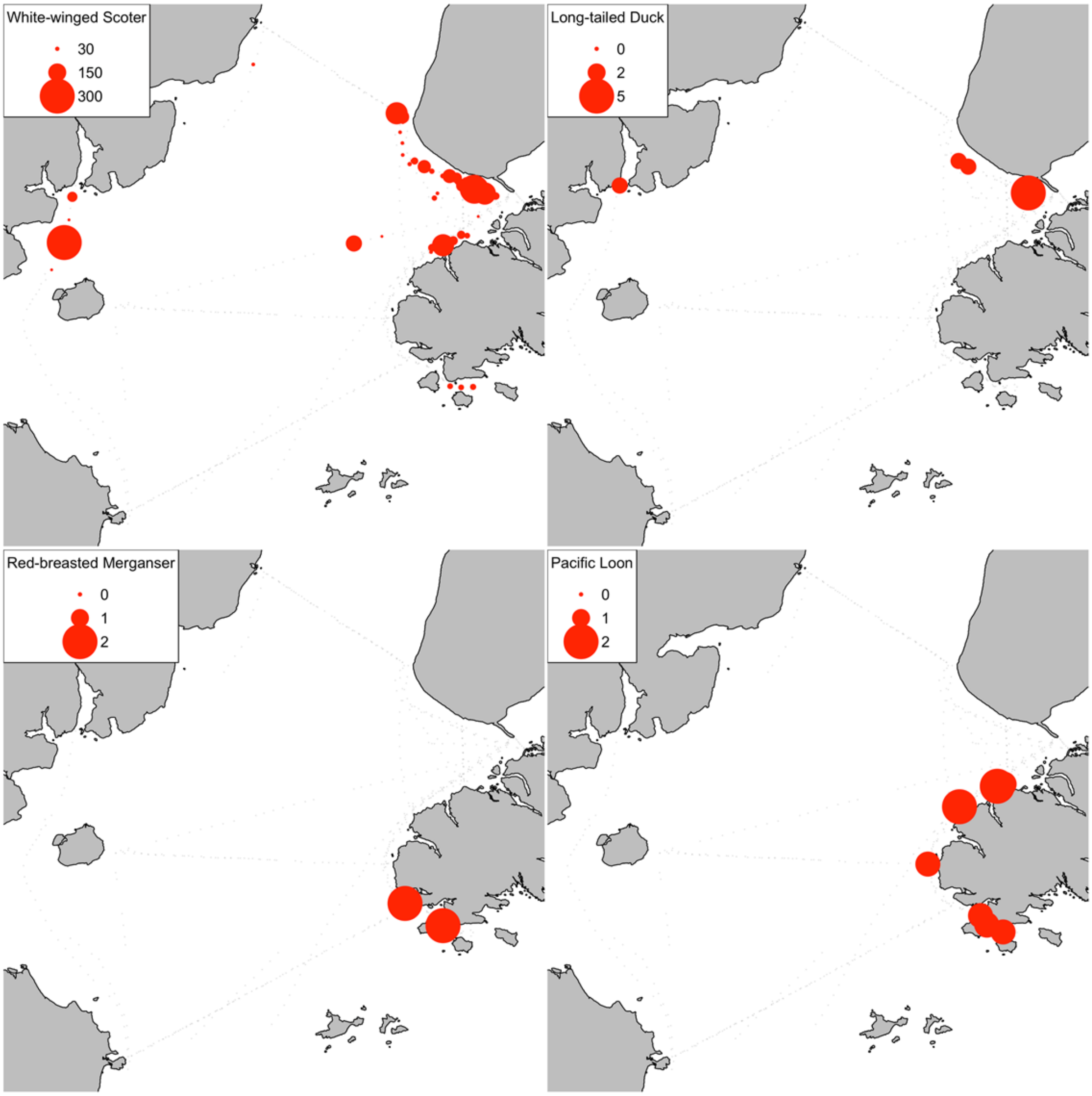
7.2 Appendix B. Latin names of marine mammal species

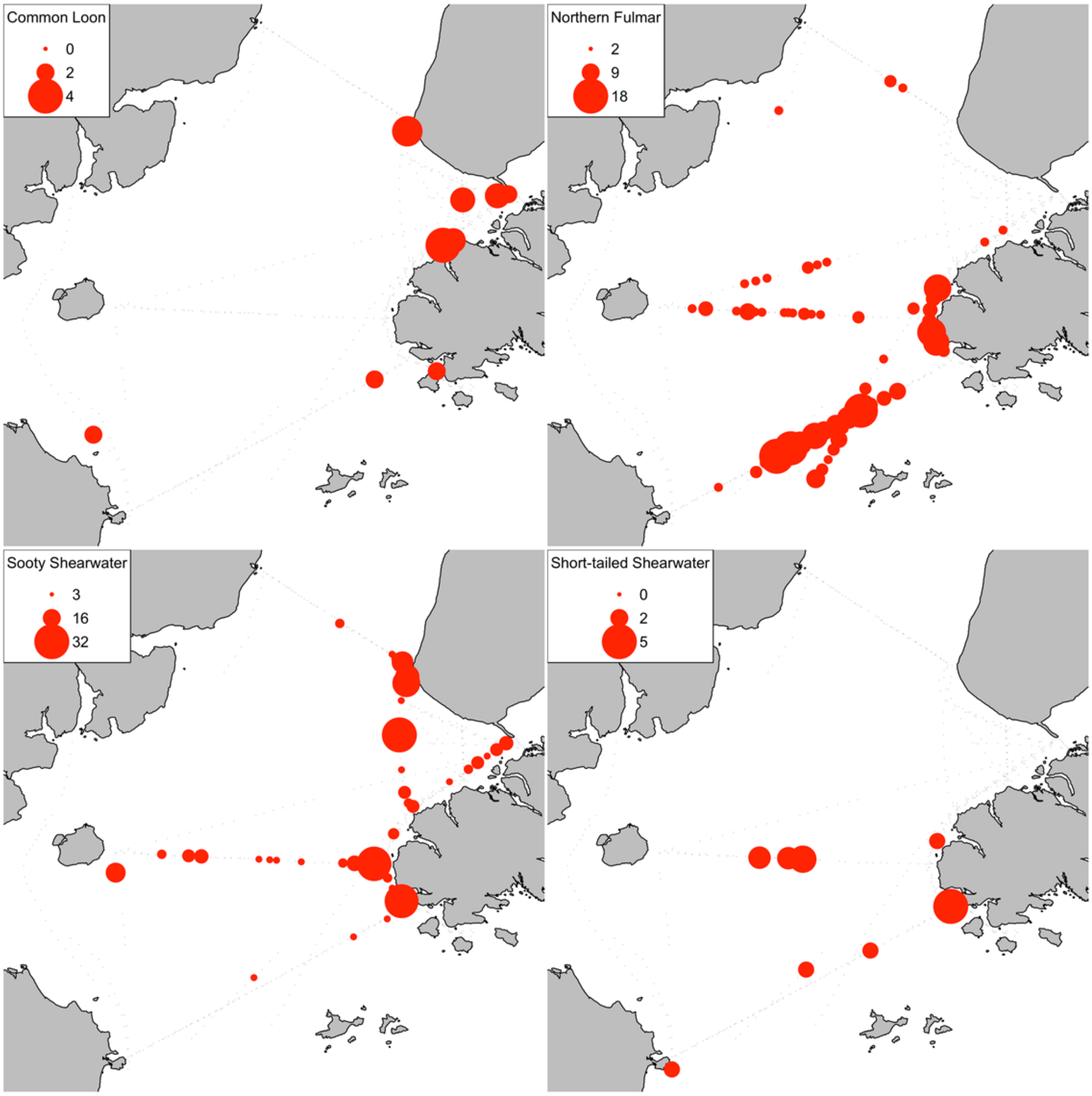
Common	Latin
Dall’s porpoise	Phocoenoides dalli
Fin whale	Balaenoptera physalus
Harbor porpoise	Phocoena phocoena
Harbor seal	Phoca vitulina
Humpback whale	Megaptera novaeangliae
Killer whale	Orcinus orca
Minke whale	Balaenoptera acutorostrata
Sea otter	Enhydra lutris

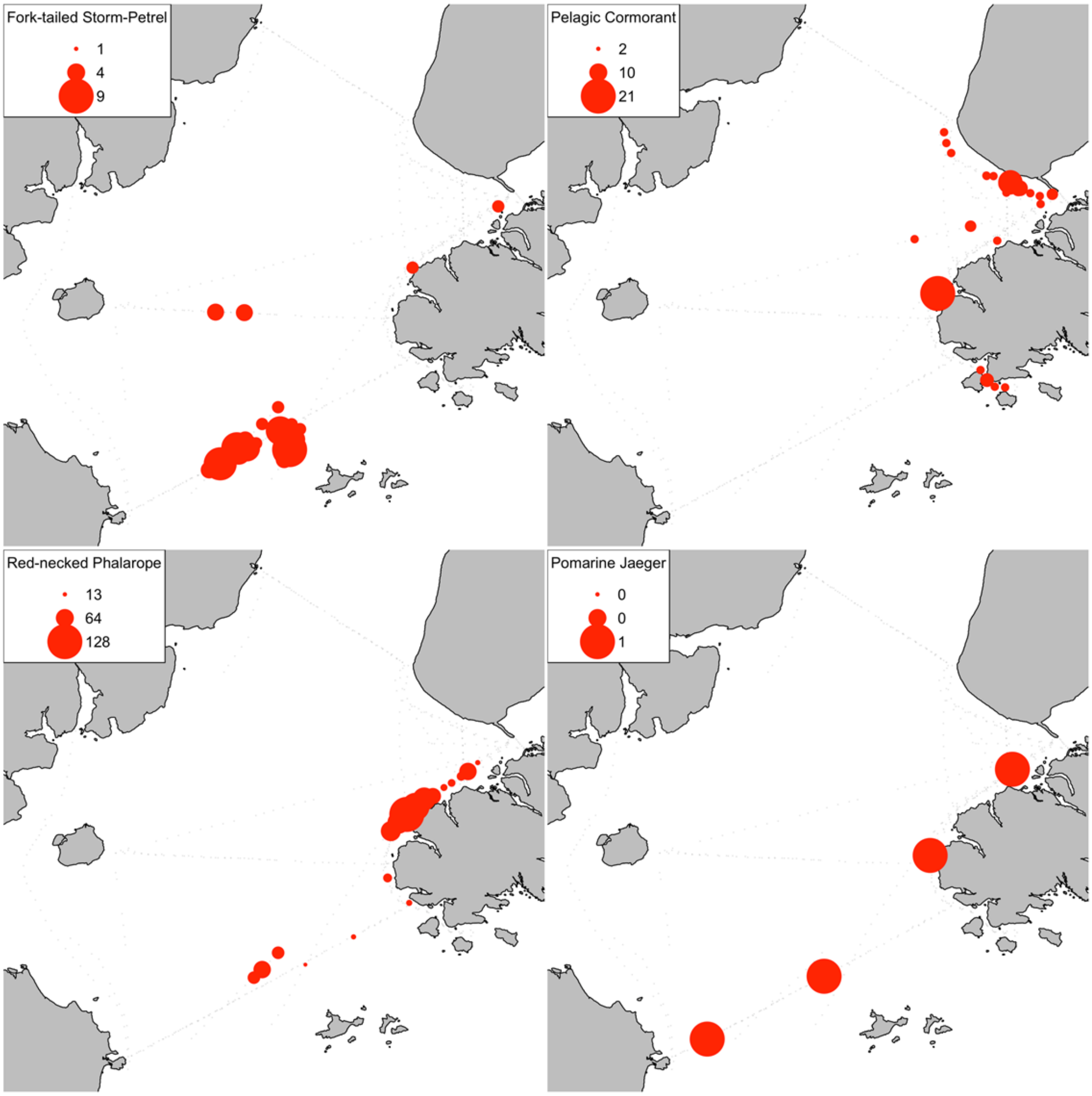
7.3 Appendix C Maps marine bird distribution in LCI

Spatial distribution maps of all seabird species in systematic order based on KBRR-USFWS surveys, 2012–2016.

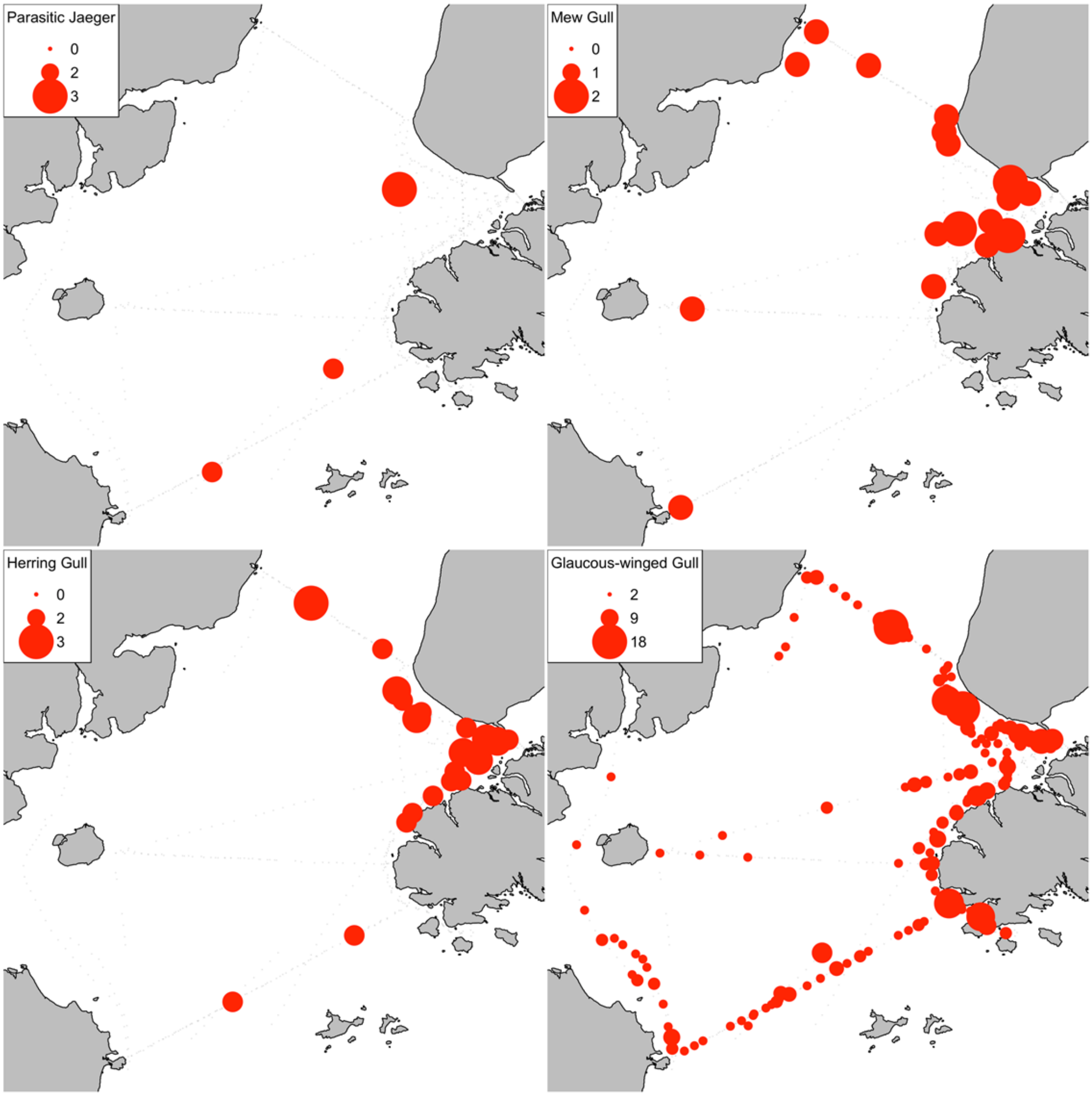


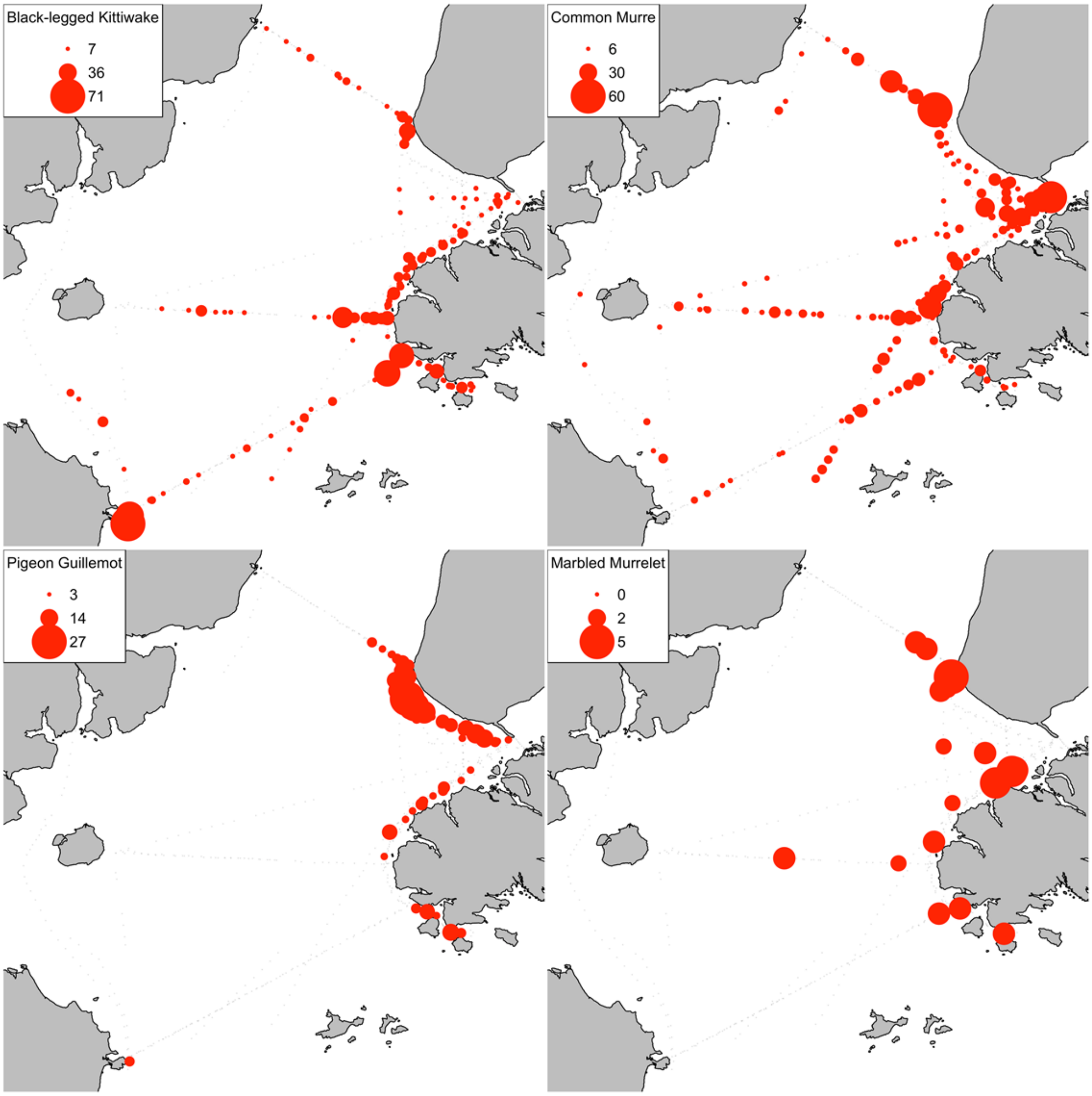

White-winged Scoter
30
150
300
Long-tailed Duck
0
2
5
Red-breasted Merganser
0
1
2
Pacific Loon
0
1
2


Common Loon
0
2
4
Northern Fulmar
2
9
18
Sooty Shearwater
3
16
32
Short-tailed Shearwater
0
2
5



Fork-tailed Storm-Petrel
1
4
9
Pelagic Cormorant
2
10
21
Red-necked Phalarope
13
64
128
Pomarine Jaeger
0
0
1


Parasitic Jaeger
0
2
3
Mew Gull
0
1
2
Herring Gull
0
2
3
Glaucous-winged Gull
2
9
18


Black-legged Kittiwake
7
36
71
Common Murre
6
30
60
Pigeon Guillemot
3
14
27
Marbled Murrelet
0
2
5


Kittlitz's Murrelet
0
1
2
Parakeet Auklet
1
3
6
Horned Puffin
3
13
26
Tufted Puffin
1
4
7

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.

The BOEM Environmental Studies Program

The mission of the Environmental Studies Program (ESP) is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.