Distribution and Abundance of Seabirds in the Northeastern Chukchi Sea, August–September 2014

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Prepared for
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Anchorage, Alaska

and

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Cover: Black-legged Kittiwakes (*Rissa tridactyla*), flying over the northern Chukchi Sea at sunset, 2014 © Olgoonik/Fairweather.
EXECUTIVE SUMMARY

• In 2014, we collected data on the distribution and abundance of seabirds in and near 3 oil and gas lease areas in the northeastern Chukchi Sea. We surveyed an area encompassing ~51,150 km² that extended between Barrow and Point Lay along the Alaska coast and northwest to ~200 km offshore.

• The objectives of this study were to describe: (1) temporal and spatial changes in species-composition along the nearshore–offshore oceanographic gradient; and (2) temporal and spatial distribution and abundance of seabirds.

• We conducted seabird surveys during August (20 Aug–4 Sep) and September (9–23 Sep) 2014. The seas and weather were poor overall, especially during the September cruise, when 25% of all transects were sampled during Beaufort 6 conditions.

• We divided the overall study area into the Nearshore and Offshore strata along the 40-m isobath to account for oceanographic differences between those two areas.

• Species-composition varied between months and along a gradient from nearshore to offshore. Planktivores were numerically dominant in both August and September, with Short-tailed Shearwaters and Crested Auklets being the most numerous species overall. Densities of both Short-tailed Shearwater and Crested Auklet declined from August to September; this decline was larger nearshore than offshore.

• Piscivores composed a part of the community at nearly all distances in both August and September, but represented a greater proportion of the community in September than August. Their numerical dominance in September was a result of both a reduction in densities of planktivores and an increase in densities of piscivores. Murres were more abundant in August than September, whereas all other piscivores were more abundant after their breeding seasons ended in September than in August.

• Omnivores were nearly absent from the Chukchi Sea in August, when most breeding adults are incubating or tending to young on nests inland or along the coast, but densities increased in September.

• Benthic-feeders were distributed more evenly and farther offshore in September than in August, when they were aggregated within 25 km of the coast. Spectacled Eiders were found primarily within the Ledyard Bay Critical Habitat Unit in both months.

• The gradients in seabird abundance and species composition from nearshore to offshore are influenced strongly by the physical and biological oceanography of the northeastern Chukchi shelf. Planktivorous seabirds were distributed throughout the study area, whereas piscivorous and omnivorous seabirds concentrated in nearshore areas characterized by ACW.

• The highest densities of total seabirds occurred near the head of Barrow Canyon and within 100 km westward of Icy Cape, suggesting that the best foraging conditions were in areas where BSW flowed eastward and northward, interacting with ACW on its way to Barrow Canyon.
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ACKNOWLEDGMENTS

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### ACRONYMS AND ABBREVIATIONS

<table>
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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ACC</td>
<td>Alaska Coastal Current</td>
</tr>
<tr>
<td>ACW</td>
<td>Alaskan Coastal Water</td>
</tr>
<tr>
<td>AIC</td>
<td>Akaike’s Information Criterion</td>
</tr>
<tr>
<td>AKMAP</td>
<td>Alaska Monitoring and Assessment Program</td>
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<tr>
<td>BSW</td>
<td>Bering Sea Water</td>
</tr>
<tr>
<td>°C</td>
<td>degrees Celsius</td>
</tr>
<tr>
<td>CSESP</td>
<td>Chukchi Sea Environmental Studies Program</td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
</tr>
<tr>
<td>GPS</td>
<td>global positioning system</td>
</tr>
<tr>
<td>GIS</td>
<td>geographic information system</td>
</tr>
<tr>
<td>km</td>
<td>kilometer</td>
</tr>
<tr>
<td>MW</td>
<td>Meltwater</td>
</tr>
<tr>
<td>NEPA</td>
<td>National Environmental Policy Act</td>
</tr>
<tr>
<td>NM</td>
<td>nautical mile</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
</tr>
<tr>
<td>OCSEAP</td>
<td>Outer Continental Shelf Environmental Assessment Program</td>
</tr>
<tr>
<td>SST</td>
<td>sea surface temperature</td>
</tr>
<tr>
<td>WW</td>
<td>Winter Water</td>
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INTRODUCTION

Seabird distribution across a seascape can reflect oceanographic conditions at lower trophic levels, serving as important visible indicators of an otherwise cryptic marine ecosystem (Cairns 1987, Furness and Camphuysen 1997, Piatt and Sydeman 2007). The northeastern Chukchi Sea is being affected by fundamental changes in the regional climate that are creating an environment that is warmer, fresher, and more ice-free than in the previous 3 decades (Wood et al. 2015). These changes are affecting processes that influence the distribution, life history, and interactions of biological communities (e.g., Overland and Wang 2010, Grebmeier 2012, Day et al. 2013a, 2013b; Gall et al. in review). Declining seasonal ice cover also is increasing access to the Chukchi Sea, providing opportunities for human activities such as recreational boating, commercial shipping, and oil and gas exploration. The seabird community offers benchmarks to evaluate both the short-term effects of anthropogenic activity and the long-term responses to climate change.

The eastern Chukchi shelf sustains a diverse seabird community during the July–October open-water season (Divoky 1987, Gall et al. 2013, Kuletz et al. 2015). A few species of piscivorous seabirds nest in large colonies (~500,000 birds) at Cape Thompson and Cape Lisburne to take advantage of the fish available in nearshore waters (Springer et al. 1989, Piatt et al. 1991, Hatch et al. 2000). Other species nest on the tundra and commute to the nearby ocean to feed their chicks (e.g., Rizzolo et al. 2015). In addition to breeding seabirds, non-breeding and post-breeding seabirds move into the northern Chukchi Sea as the ice recedes to feed on both fish and zooplankton (Divoky 1987, Gall et al. 2013, Kuletz et al. 2015). This community of 60 species of seabirds depends on the variety of habitats created when warm water masses moving northward from the Bering Sea (Coachman et al. 1975) interact with cold water masses present on the northern shelf that have been modified by ice formation in the winter (Kawaguchi et al. 2011, Weingartner et al. 2005). The prey communities associated with these water masses also differ substantially, which helps structure the gradient in species-composition of the seabird communities. Prey species associated with ACW include small neritic copepods and a variety of forage fishes such as salmonids (Salmonidae), rainbow smelt (Osmerus mordax), Pacific sandlance (Ammodytes hexapterus), and Arctic cod (Boreogadus saida; Norcross et al. 2010, Logerwell et al. 2015). Salmonids are found almost exclusively in the surface waters of the shelf (Fechhelm et al. 1984, Logerwell et al. 2015), whereas other forage fish are found throughout the water column. The low temperatures of two-layered MW/WW near Hanna Shoal preclude the development of a diverse fish community (Bluhm et al. 2009, Day et al. 2013b). Instead, the pelagic community is characterized primarily by cold-tolerant Arctic cod and the seasonal development of a zooplankton community that includes the large arctic copepod Calanus glacialis (Hopcroft et al. 2014). BSW is intermediate in temperature and salinity between

(Gall et al. 2014). The Alaska Coastal Current (ACC) lies east near the Alaska coastline and flows northward, carrying Alaskan Coastal Water (ACW), a warm (>2 °C), low-salinity (<32.2) water-mass that originates in the southeastern Bering Sea (Figure 1). The currents farther offshore move Bering Sea Water (BSW; Coachman et al. 1975), a warm (>2 °C), high-salinity (>32.4) water-mass, northward through the Central Channel and Herald Valley (Figure 1; Weingartner et al. 2005). This BSW is a mixture of Anadyr Water and Bering Shelf Water from south of Bering Strait; it has a higher nutrient content and transports more oceanic zooplankton, especially larger zooplankton, than does ACW (Walsh et al. 1989, Springer and McRoy 1993). Water masses are modified on the Chukchi shelf in the winter when ice formation produces cold (<2 °C), high-salinity (>33) Winter Water (WW) and in the spring when ice melts and leaves cold, low-salinity (<32.2) Meltwater (MW) at the surface. These 4 water masses provide habitat for a seasonally diverse assemblage of seabirds, with dynamic fronts that occur at the boundaries between water masses helping to concentrate plankton and increasing foraging opportunities for surface-feeding and near-surface-feeding seabirds.

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Figure 1. Sampling lines and major ocean currents in the northeastern Chukchi Sea, Alaska, in 2014.
WW and ACW and transports Pacific zooplankton prey, including *Neocalanus* copepods and euphausiids, into the study area (Questel et al. 2013).

In addition to its rich marine resources, the Chukchi Sea is of great interest for offshore oil development. Exploration for offshore oil began in arctic Alaska in the 1970s and led to the exploratory drilling of 5 wells in the northeastern Chukchi Sea in 1989–1990. Two of these wells, known as Klondike and Burger, are located ~100–130 km (~60–80 mi) west of the village of Wainwright. Drilling in these areas was not pursued beyond exploration at that time, and there was no further activity until February 2008, when nearly 3 million acres in the Chukchi Sea were leased for oil exploration (Lease Sale 193, 79 FR 66401). The companies that purchased the leases recognized the need for improved information about the marine environment to develop environmentally responsible drilling plans and apply for permits.

A few studies of marine ecology were conducted in the late 1970s and early 1980s as part of the National Oceanic and Atmospheric Administration’s Outer Continental Shelf Environmental Assessment Program (OCSEAP; Hopcroft and Day 2013). Since then, there has been a resurgence in oceanographic and ecological research, especially during the past decade, primarily because of imminent oil exploration. The Chukchi Sea Environmental Studies Program (CSESP) was initiated in 2008 to inform government agencies and industry about the oceanography and ecology of the northeastern Chukchi Sea, including the species composition, distribution, abundance, and timing of occurrence of seabirds. During 2008–2013, CSESP focused on the offshore areas of the northeastern Chukchi Sea, but little effort was spent on nearshore areas or the transition zone between nearshore and offshore areas. As part of the Alaska Monitoring and Assessment Program, seabird surveys were conducted in the nearshore area (<100 km from shore) between Point Hope and Barrow in 2011–2012 in conjunction with studies of the chemical, physical, and biological environment (Morgan et al. 2012). In 2014, CSESP redesigned its sampling to describe the broad-scale ecological patterns from the nearshore to offshore waters during August and September.

In 2014, we studied the distribution, abundance, and community composition of seabirds in the Chukchi Sea from Alaska’s northwestern coast to 220 km offshore. The objectives of this study were to describe: (1) temporal and spatial changes in seabird species-composition along the nearshore–offshore oceanographic gradient; and (2) the temporal and spatial distribution and abundance of seabirds. Synthesis reports (e.g., Gall et al. 2014) provide detailed information on spatial, seasonal, and interannual variation in the ecology of seabirds in the Greater Hanna Shoal study area in 2008–2013, and publications (Day et al. 2013a, 2013b; Gall et al. 2013) summarize some of this information. This study provides baseline information on the distribution and abundance of seabirds during 2014 near the lease areas, including the transition from nearshore to offshore waters. It also provides a broader spatial and ecological context for the distribution and abundance of seabirds in the Chukchi Sea. This information will be used for analyses of the potential impacts of offshore exploration and development activities; will be included in National Environmental Policy Act (NEPA) documents required for exploration; and will be used as needed for planning mitigation of exploration activities.

**METHODS**

**STUDY AREA**

This study was conducted in the northeastern Chukchi Sea between approximately Barrow and Point Lay, with data collection focused in an area extending from Alaska’s northwestern coastline to ~220 km northwest of the village of Wainwright (Figure 1). The study area is bounded to the west by the Central Channel flow over the central portion of the shelf and to the east by the Alaskan Coastal Current and the coast of Alaska (Weingartner et al. 2005, 2013). We divided the overall study area into 2 geographical/ecological strata: the area between shore and the 40-m isobath (Nearshore stratum) and the area offshore of the 40-m isobath (Offshore stratum). Although the exact location of the front between ACW and the
offshore water-masses (BSW, MW, WW) may change within and among years (Weingartner et al. 2013), the 40-m isobath approximates the composite location of this front over time. We sampled along 4 lines that generally ran orthogonal to the shoreline, crossing the nearshore–offshore dividing line and along 2 lines that generally ran parallel to the shoreline (Figure 1), with the inner line sampling the Nearshore stratum and the offshore line sampling the Offshore stratum. Alternative sampling lines were established 5.5 km on either side of and parallel to the primary sampling lines and were used if conditions did not permit access to primary lines (e.g., the presence of ice, transit between areas after completing a line) or if the nearby primary line already had been sampled. Because seabird communities are considered spatially independent at scales of ≥3 km (Elphick and Hunt 1993, O’Driscoll 1998, Oppel et al. 2012), these alternative lines were considered statistically independent of primary lines. In addition to established survey lines, we also sampled opportunistically when traveling within the study area (Figure 2).

DATA COLLECTION

We conducted seabird surveys during August (20 Aug–4 Sep) and September (9–23 Sep) 2014 as continuous sampling when the ship was moving along a straight-line course at a minimal velocity of 9.3 km/h (5 kt; Tasker et al. 1984, Gould and Forsell 1989). These straight lines subsequently were split into 3-km sampling units (transects) for analysis using GIS. We collected data 9–12 h/day during daylight hours, weather and ice conditions permitting. Surveys generally were stopped when sea state was Beaufort 6 (seas ~2–3 m [~6–10 ft]) or higher, although we occasionally continued to sample if the visibility still was good (e.g., if seas were at the lower end of Beaufort 6 and we were traveling downwind). One observer stationed on the bridge of the ship recorded all birds seen within a radius of 300 m in a 90° arc from the bow to the beam on the port side of the ship (the count zone) and located and identified seabirds with 10 × binoculars. For each bird or group of birds, we recorded:

- species (or identity to lowest possible taxon);
- total number of individuals;
- distance from the observer when sighted (in categories; 0–50 m [0–164 ft], 51–100 m [165–328 ft], 101–150 m [329–492 ft], 151–200 m [493–656 ft], 201–300 m [657–984 ft]);
Methods

- radial angle of the bird(s) from the bow of the ship (to the nearest 1°);
- number in each age-class (juvenile, subadult, adult, unknown age), if possible;
- habitat (air, water, flotsam/jetsam, ice); and
- behavior (flying, sitting, swimming, feeding, comfort behavior, courtship behavior, other).

We counted all birds on the water within the count zone, taking care to avoid recounting the same individuals. For flying birds, however, we conducted scans ~1 time/min (the exact frequency varied with ship’s speed) and recorded an instantaneous count (“snapshot”) of all birds flying within the count zone. This snapshot method reduces the bias of overestimating the abundance of flying birds (Tasker et al. 1984, Gould and Forsell 1989). We counted only those flying birds that entered the count zone from the sides or front and did not count those that entered from behind the ship (i.e., an area that already had been surveyed), to avoid the possibility of counting ship-following birds.

We entered observations of all birds directly into a computer connected to a global positioning system (GPS) with TigerObserver software (TigerSoft, Las Vegas, NV). This program time-stamped and georeferenced every observation entered in real time and provided a trackline of our sampling effort.

DATA ANALYSIS

The sea state and weather conditions were poor overall in 2014, especially during the September cruise, when 25% of all transects were sampled during Beaufort 6 conditions. For community analyses, we selected only those transects that were surveyed under conditions Beaufort ≤5 (Figure 2). We restricted analyses of distribution and abundance to lines that were sampled in both months. We saved all other data as incidental observations.

COMMUNITY ANALYSES

We used descriptive statistics to explore changes in the structure of the seabird community between months and between the nearshore and offshore strata. We divided the study area into 7 distance bins, with the midpoint of each distance bin corresponding to the distance of concurrently sampled oceanographic stations from the coastline, and used all observations recorded within each bin to calculate community composition. The distance bins were: 5–10 km, 10.1–25 km, 25.1–50 km, 50.1–100 km, 100.1–150 km, 150.1–200 km, 200.1–250 km, and 250.1–300 km from shore. We included all observations of birds that were identified at least to family to determine the numerically dominant species-assemblages composing each sample (Magurran 2004). We aggregated species into 4 ecological groups that represented foraging guilds (Table 1): benthic-feeders (predominantly seaducks), omnivores (e.g., jaegers, fulmars, large gulls), piscivores (e.g., loons, murrets, guillemots, puffins, small gulls), and planktivores (e.g., shearwaters, phalaropes, murrelets, auklets) and calculated the percentage of the community each of these guilds composed. (Scientific names of birds species mentioned in this report are listed in Table 1.)

ABUNDANCE CALCULATIONS AND ANALYSES

We selected 14 focal taxa for statistical analyses, including the 13 most abundant taxa and 1 species of conservation concern (Spectacled Eider; Table 1). Because Red-necked and Red phalaropes often occur in mixed-species flocks and are difficult to distinguish at a distance, especially during the molt, we combined observations of these 2 species with those of unidentified phalaropes and analyzed them collectively as “phalaropes.” These 14 focal taxa represented a variety of foraging methods (Table 1), thereby providing an overview of functional ecological groups of the seabird community in both the nearshore and offshore strata.

We estimated detection-corrected densities (hereafter; densities; birds/km²) along each transect by using line-transect sampling analyses and following analytical methods described by Buckland et al. (2001, 2004). This approach accounts for the decreasing probability of detecting
Table 1. Density (birds/km²) of seabirds recorded on transects during surveys of the northeastern Chukchi Sea, August and September 2014.

<table>
<thead>
<tr>
<th>Taxon/species</th>
<th>Common name</th>
<th>Scientific name</th>
<th>Foraging guild</th>
<th>August Density</th>
<th>95% CI</th>
<th>September Density</th>
<th>95% CI</th>
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<td>Ducks</td>
<td>Spectacled Eider</td>
<td>Somateria fischeri</td>
<td>Benthic</td>
<td>0.06</td>
<td>0.02–0.23</td>
<td>0.03</td>
<td>0.01–0.13</td>
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<td></td>
<td>King Eider</td>
<td>S. spectabilis</td>
<td>Benthic</td>
<td>0</td>
<td>–</td>
<td>0.07</td>
<td>0.02–0.26</td>
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<td></td>
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<td>S. mollissima</td>
<td>Benthic</td>
<td>0</td>
<td>–</td>
<td>0.12</td>
<td>0.05–0.32</td>
</tr>
<tr>
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<td>Unidentified eider</td>
<td>Polysticta stelleri or Somateria spp.</td>
<td>Benthic</td>
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<td>0.04–1.14</td>
<td>0.12</td>
<td>0.03–0.43</td>
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<td>Long-tailed Duck</td>
<td>Clangula hyemalis</td>
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<td>–</td>
<td>0.20</td>
<td>0.06–0.74</td>
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<td>Gavia stellata</td>
<td>Piscivore</td>
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<td>–</td>
<td>0.02</td>
<td>0.01–0.04</td>
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<td>Piscivore</td>
<td>0.03</td>
<td>0.01–0.10</td>
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<td>0.27–0.71</td>
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<td>–</td>
<td>0.06</td>
<td>0.02–0.15</td>
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<td>Fulmarus glacialis</td>
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<td>0.13–0.36</td>
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<td>Planktivore</td>
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<td>0.01–0.04</td>
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<td>Uria aalge</td>
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<td>0.01–0.07</td>
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<td>–</td>
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<td>Cepphus columba</td>
<td>Piscivore</td>
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<td>0.00–0.04</td>
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<tr>
<td>Taxon/species</td>
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<td>Scientific name</td>
<td>Foraging guild</td>
<td>August</td>
<td>September</td>
<td></td>
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<td></td>
<td></td>
<td>Density</td>
<td>Density</td>
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<td></td>
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<td></td>
<td></td>
<td>95% CI</td>
<td>95% CI</td>
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</tr>
<tr>
<td>Alcids (continued)</td>
<td>Kittlitz's Murrelet</td>
<td><em>Brachyramphus brevirostris</em></td>
<td>Planktivore</td>
<td>0.05</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.02–0.14</td>
<td>0.01–0.06</td>
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<tr>
<td></td>
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<td><em>Synthliboramphus antiquus</em></td>
<td>Planktivore</td>
<td>0</td>
<td>0.79</td>
<td></td>
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<td></td>
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<td>0.54–1.14</td>
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<tr>
<td></td>
<td>Parakeet Auklet</td>
<td><em>Aethia psittacula</em></td>
<td>Planktivore</td>
<td>0</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>–</td>
<td>0.01–0.06</td>
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</tr>
<tr>
<td></td>
<td>Least Auklet</td>
<td><em>A. pusilla</em></td>
<td>Planktivore</td>
<td>0.23</td>
<td>0.28</td>
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<td>0.1–0.51</td>
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<tr>
<td></td>
<td>Crested Auklet</td>
<td><em>A. cristatella</em></td>
<td>Planktivore</td>
<td>9.84</td>
<td>1.23</td>
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<td></td>
<td>Unidentified auklet</td>
<td><em>Aethia spp.</em></td>
<td>Planktivore</td>
<td>0.01</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
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<td>0.00–0.05</td>
<td>–</td>
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<td></td>
<td>Horned Puffin</td>
<td><em>Fratercula corniculata</em></td>
<td>Piscivore</td>
<td>0.02</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>0.01–0.07</td>
<td>–</td>
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<tr>
<td></td>
<td>Tufted Puffin</td>
<td><em>F. cirrhata</em></td>
<td>Omnivore</td>
<td>0.02</td>
<td>0</td>
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<td></td>
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<td>0.01–0.05</td>
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<tr>
<td></td>
<td>Unidentified small alcid</td>
<td><em>murrelets and auklets</em></td>
<td>Omnivore</td>
<td>0</td>
<td>0.04</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
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<td>Unidentified alcid</td>
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<td>Omnivore</td>
<td>0.03</td>
<td>0.08</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.01–0.16</td>
<td>0.03–0.20</td>
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<tr>
<td>Gulls and terns</td>
<td>Black-legged Kittiwake</td>
<td><em>Rissa tridactyla</em></td>
<td>Piscivore</td>
<td>0.08</td>
<td>0.32</td>
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<td></td>
<td></td>
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<td>0.21–0.50</td>
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<tr>
<td></td>
<td>Glaucous Gull</td>
<td><em>Larus hyperboreus</em></td>
<td>Omnivore</td>
<td>0.03</td>
<td>0.17</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.01–0.08</td>
<td>0.12–0.24</td>
<td></td>
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<tr>
<td></td>
<td>Arctic Tern</td>
<td><em>Sterna paradisaea</em></td>
<td>Piscivore</td>
<td>0.03</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.01–0.13</td>
<td>–</td>
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</tr>
</tbody>
</table>
Results

In 2014, we recorded 7,274 seabirds on 3,276 km of transects conducted at sea states Beaufort ≤5 (Figure 2). We identified 32 species of seabirds, of which 25 were recorded on transect and used in analysis of species composition and density estimates (Table 1). Two species seen off-transect were not recorded during the CSESP in previous study years: Black Scoter (*Melanitta americana*) and Rock Sandpiper (*Calidris ptilocnemis*). Four species have been recorded within the study area previously but were recorded only off-transect during this study: Sabine’s Gull (*Xema sabini*), Herring Gull (*Larus argentatus*), Long-tailed Jaeger (*Stercorarius longicaudus*), and Black Guillemot (*Cepphus grille*).

\[
\hat{D} = \frac{n \cdot \hat{E}(s)}{L \cdot \hat{P}_o}
\]

where \( \hat{D} \) is the corrected density estimate, \( n \) is the total number of observations on transects, \( \hat{E}(s) \) is the mean flock size, \( L \) is the total length of transects sampled, and \( \hat{P}_o \) is the probability of detection estimated by the model (Buckland et al. 2001). The distance analyses were conducted with the statistical package mrds (Laake et al. 2013) for R. We used R v. 3.0.1 (http://www.r-project.org) for all analyses.

We compared densities among 4 stratum-months (August nearshore, September nearshore, August offshore, and September offshore) to assess seasonal and spatial patterns in seabird distribution and abundance. Our count data were typical of seabird survey data in that they were zero-inflated and had a non-normal distribution, precluding the use of parametric statistics. Instead, we used a 2-factor bootstrap analysis that calculated mean densities and 95% confidence intervals for each stratum-month based on 5,000 samples drawn with replacement within each of the 4 categories. We also explored the distribution of focal species throughout the study area by mapping the density by transect of the 14 focal taxa for August and September. These maps provide an overview of both the spatial and temporal distribution of each species.

**RESULTS**
Results

Species-composition varied between August and September along a nearshore–offshore gradient (Figure 3). Planktivores were numerically dominant in both months, with abundance highest in August and increasing with distance from shore. In September, after Short-tailed Shearwaters had mostly left the Chukchi Sea, planktivores were recorded exclusively >10 km from shore. Piscivores composed a part of the community at nearly all distances in both August and September, but they were more dominant numerically in September than August. Their numerical dominance in September was a result of both a reduction in absolute densities of planktivores and an increase in absolute densities of piscivores. Omnivores were nearly absent from the Chukchi Sea in August, when most breeding adults are incubating or tending to young on nests. In September, however, most nesting birds leave their breeding sites; as a consequence, omnivores numerically dominated the 5–10-km distance bin at that time and composed a larger proportion of the community in all distances in September than they did in August. Benthic-feeders demonstrated the greatest seasonal shift in distribution. In August, they were recorded exclusively within 25 km of the coast, whereas, in September, they were absent from the 5–10-km distance bin and instead represented 2–35% of the seabird community in each of the bins >10 km from the coast. The difference in community structure between August and September was driven largely by a substantial reduction in planktivore densities from August to September.

Table 2. Detection-function models used to calculate corrected abundances of 14 focal taxa of seabirds. Models are based on all data from 2008 through 2014. Blank lines separate groups of species for which the same model (shape of detection function, covariates, probability of detecting a flock, and CV of the probability of detection) was applied.

<table>
<thead>
<tr>
<th>Species/taxon</th>
<th>Shape of detection function</th>
<th>Covariates</th>
<th>Average probability detecting a flock</th>
<th>CV</th>
<th>Mean flock size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crested Auklet</td>
<td>half-normal</td>
<td>observer + vessel + sea state</td>
<td>0.63</td>
<td>0.9</td>
<td>3.4</td>
</tr>
<tr>
<td>Ancient Murrelet</td>
<td></td>
<td></td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Least Auklet</td>
<td>hazard-rate</td>
<td>observer + sea state</td>
<td>0.67</td>
<td>1.6</td>
<td>3.0</td>
</tr>
<tr>
<td>Black-legged Kittiwake</td>
<td>half-normal</td>
<td>observer</td>
<td>0.57</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Glaucous Gull</td>
<td></td>
<td></td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern Fulmar</td>
<td></td>
<td></td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectacled Eider</td>
<td></td>
<td></td>
<td>3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>King Eider</td>
<td></td>
<td></td>
<td>3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Eider</td>
<td></td>
<td></td>
<td>6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phalaropes</td>
<td>half-normal</td>
<td>observer + vessel + sea state</td>
<td>0.48</td>
<td>3.5</td>
<td>4.4</td>
</tr>
<tr>
<td>Short-tailed Shearwater</td>
<td>hazard-rate</td>
<td>observer + sea state</td>
<td>0.72</td>
<td>2.2</td>
<td>16.9</td>
</tr>
<tr>
<td>Pacific Loon</td>
<td></td>
<td></td>
<td>1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thick-billed Murre</td>
<td>hazard-rate</td>
<td>observer + sea state</td>
<td>0.75</td>
<td>1.9</td>
<td>2.6</td>
</tr>
<tr>
<td>Common Murre</td>
<td></td>
<td></td>
<td>1.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PATTERNS OF DISTRIBUTION AND ABUNDANCE

For total birds (i.e., all seabirds combined), overall abundance was lower in September than August, with little apparent spatial pattern in distribution and abundance (Figure 4). Most densities on individual transects were ≤100 birds/km². In August, transects with the highest densities mainly were located inshore of the 40-m isobath, especially in the southern portion of the study area. In September there were no transects with densities higher than 100 birds/km².

PLANKTIVORES

We recorded 7 taxa that were classified as planktivorous species. Planktivores were the most abundant species-group in both months (Figure 3), with Short-tailed Shearwaters and Crested Auklets being the most numerous species overall (Figure 5). Densities of both Short-tailed Shearwaters and

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**Figure 3.** Percent totals of feeding guilds that compose the seabird community in the northeastern Chukchi Sea in 2014, by month and distance from shore. Asterisks indicate no data.
Crested Auklets declined from August to September, with the decline being larger in the Nearshore stratum than the Offshore stratum (Figure 5). Short-tailed Shearwaters were more abundant Nearshore than Offshore in August but were nearly absent from both strata in September (Figure 6). Crested Auklets were distributed throughout the study area in August and were more abundant in the Offshore stratum than the Nearshore stratum in September (Figure 6), albeit at lower densities than in August. Ancient Murrelets were not recorded in August but were recorded in both strata in September (Figure 5); similar to the pattern for Least Auklets, the largest aggregations occurred offshore of Icy Cape (Figure 7). Least Auklets were more abundant in the Nearshore than the Offshore stratum in August, whereas abundance was similar between strata in September (Figure 6). The largest aggregations were located at the head of Barrow Canyon in August but shifted south to waters offshore of Icy Cape in September (Figure 7). Phalaropes had similar abundance in both strata and in both months (Figure 5), although their distribution was more focused near the head of Barrow Canyon in September than in August (Figure 8). The other planktivores included Kittlitz’s Murrelets and Parakeet Auklets, neither of which were abundant enough to model densities. Kittlitz’s Murrelets were recorded primarily in the Nearshore stratum in both months, whereas Parakeet Auklets were recorded only in September and in both distance strata.

**PISCIVORES**

Piscivores are a species-rich group that included terns, some gulls, and some alcids. Of the 8 species of piscivores recorded on transect, only Pacific Loons, Black-legged Kittiwakes and Thick-billed and Common murres were abundant enough to examine patterns of distribution and abundance (Figure 9).

Black-legged Kittiwakes and Pacific Loons had similar patterns of abundance (Figure 9). Both species were more abundant in September than in August and were more abundant in the Nearshore stratum than the

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**Figure 4.** Distribution of all seabirds combined on transects in the northeastern Chukchi Sea in August and September 2014.
Results

Figure 5. Mean density (birds/km²) of planktivorous seabirds on transects in the northeastern Chukchi Sea in August and September 2014, by stratum and month. Error bars represent 95% confidence intervals obtained from bootstrap analysis of 5,000 samples drawn with replacement within each of the 4 stratum-months.
Figure 6. Distribution of Crested Auklets and Short-tailed Shearwaters on transects in the northeastern Chukchi Sea in August and September 2014.
Figure 7. Distribution of Ancient Murrelets and Least Auklets on transects in the northeastern Chukchi Sea in August and September 2014.
Offshore stratum (Figures 9 and 10). Both murre species were more abundant in August than in September, although Thick-billed Murres were more abundant in the Nearshore stratum and Common Murres were more abundant in the Offshore stratum (Figure 9). Similar to the pattern seen for planktivores, the largest groups of murres were located at the head of Barrow Canyon in August, whereas the few remaining murres were located within 50 km of Icy Cape in September (Figure 11).

The other 4 species of piscivores included Red-throated Loons, Arctic Terns, Pigeon Guillemots, and Horned Puffins. These species were rare throughout the seven years of the CSESP study, including 2014. Red-throated Loons were seen only in September and primarily in the Nearshore stratum. Arctic Terns were recorded only in August in the Nearshore stratum (<15 km from shore) and between Point Lay and Icy Cape. Two Pigeon Guillemots were seen in August in the Offshore stratum. Horned Puffins were recorded in both strata, but in very low numbers and only in August.

OMNIVORES

We recorded 5 species of omnivores, only 2 of which were recorded frequently enough to compare densities between strata and months. Northern Fulmars and Glaucous Gulls had similar maximal densities but opposite patterns of seasonal abundance (Figure 9). Northern Fulmars were more abundant in both distance strata in August than in September, whereas Glaucous Gulls were more abundant in both strata in September than in August. Both species were widely distributed (Figure 12). The highest densities of Northern Fulmars were located along the boundary between the Nearshore and Offshore strata in August, whereas the highest density of Glaucous Gulls was located over the Central Channel in September. The other omnivores included Pomarine Jaegers, Parasitic Jaegers, and Tufted Puffins. All 3 of these species were recorded exclusively in August. Parasitic Jaegers were recorded only in the Nearshore stratum, but the other 2 were recorded in both distance strata.

BENTHIC-FEEDERS

Benthic-feeders comprised 4 species of seaducks, with Common Eiders being the most abundant. Both King and Common eiders were more abundant Nearshore in September than in August (Figures 13 and 14), whereas Spectacled...
Results

Figure 9. Mean density (birds/km²) of piscivorous and omnivorous seabirds on transects in the northeastern Chukchi Sea in August and September 2014, by stratum and month. Error bars represent 95% confidence intervals obtained from bootstrap analysis of 5,000 samples drawn with replacement within each of the 4 stratum-months.
Figure 10. Distribution of Black-legged Kittiwakes and Pacific Loons on transects in the northeastern Chukchi Sea in August and September 2014.
Figure 11. Distribution of Thick-billed and Common murres on transects in the northeastern Chukchi Sea in August and September 2014.
Figure 12. Distribution of Northern Fulmars and Glaucous Gulls on transects in the northeastern Chukchi Sea in August and September 2014.
Discussion

Eiders were more abundant in August than September. Eiders were uncommon in the Offshore stratum. The only other benthic-feeding seabird we recorded within the study area was Long-tailed Duck, which was not recorded frequently enough to compare densities between months or strata. Long-tailed Ducks were recorded on-transect only during September, but in both strata.

SPECIES OF CONSERVATION CONCERN

Spectacled Eider was the only federally listed species of conservation concern recorded on transect in 2014. They were recorded in both August and September (Figure 13) and mostly in the Nearshore stratum; we recorded a single group of 2 individuals in the Offshore stratum (Figure 14). Altogether, 24 (89%) of the 27 individuals were recorded inside of the Ledyard Bay Critical Habitat Area. These birds were seen primarily in ~12–13 m of water and ~3–4 NM (~5.5–7.5 km) offshore. Of the 3 individuals recorded outside of Ledyard Bay, 2 were the flock described above and 1 was recorded off-transect, >300 m from the vessel, north of Icy Cape, and in approximately 30 m of water. The group of 2 seen in the offshore stratum were in flight, whereas the single individual seen near the coast was on the water.

DISCUSSION

The seabird community we recorded in the Offshore stratum during this study was similar to what has been observed in the Chukchi Sea in recent years (Gall et al. 2014, Kuletz et al. 2015). It was dominated numerically by planktivorous
seabirds, primarily Short-tailed Shearwaters and Crested Auklets. Recent surveys determined that Short-tailed Shearwaters are among the most abundant birds in the Chukchi Sea and that they are most abundant within 40 km of the coast, where they forage primarily in ACW (Gall et al. 2013, Wong et al. 2014, Kuletz et al. 2015). In 2014, densities of Short-tailed Shearwater were lower than those recorded in 2007–2013 (Morgan et al. 2012, Gall et al. 2014) and were higher nearshore than offshore. In contrast to previous years, Ancient Murrelets occurred in fairly high densities in September. They regularly occur in the Chukchi Sea but generally occur in low numbers in most years (Day et al. 2013a, Gall et al. 2014). They have been recorded most frequently in warm (SST >5 °C) years with little ice present during the open-water season (Gall et al. 2014).

The gradients in seabird abundance and species-composition from nearshore to offshore are influenced strongly by the physical and biological oceanography of the northeastern Chukchi shelf. The Nearshore stratum is characterized by ACW that is warmer, less saline, and less strongly stratified than the waters offshore (Norcross et al. 2010). It also is shallower than the Offshore stratum, making the demersal community of fish more accessible to diving birds. Piscivores occurred there in higher proportions of the community and often were present in higher densities than they were Offshore. The front between ACW and offshore water masses is variable in location, but the long-term average location appears to be along the 40-m isobath (Johnson 1989, Weingartner 1997). The waters west of this front tend to be colder and more strongly stratified than ACW because ice formation in fall/winter supports the maintenance of a pool of cold, saline water in the lower layer. Circulation patterns suggest that most of the BSW moves northward through the Central Channel, which is located 100–200 km offshore (Winsor and Chapman 2004, Weingartner et al. 2013). In many years, a branch of this water mass also intrudes over the southern flank of Hanna Shoal and flows eastward from the Central Channel in a small depression to join ACW flowing into the head of

![Figure 14. Distribution of all eiders combined on transects in the northeastern Chukchi Sea in August and September 2014.](image-url)
Discussion

Barrow Canyon (Weingartner et al. 2013). Planktivorous species occurred offshore as a high proportion of the total seabird community and, in some cases, were more abundant offshore than they were nearshore.

Bathymetry and landforms encountered by ACW as it flows north can create smaller areas of fronts as well (Genin 2004), concentrating prey for both planktivores and piscivores in the Nearshore stratum. ACW flowing into the deep Barrow Canyon can produce fronts near the head of the canyon as well as along its flanks (Stafford et al. 2013). Similarly, as ACW flows rapidly north around Cape Lisburne, fronts occur where it meets with slower moving water near shore and creates an anticyclonic gyre (Coachman et al. 1975). Small fishes and piscivores seabirds concentrate just north of Cape Lisburne, where the gyre is strongest (Fadely et al. 1989). In the Nearshore stratum, planktivores occurred in highest densities west of Icy Cape and near the 40-m isobath in both August and September. Least Auklets were unusual among planktivores in that they were concentrated in areas similar to those used by piscivores, with concentrations occurring near the head of Barrow Canyon as well as west of Icy Cape.

Some prey are specific to particular habitats, whereas others are more flexible in their distribution, affecting the distribution of avian predators. For example, forage fishes (e.g., Pacific sandlance, Pacific herring [Clupea harengus], capelin [Mallotus villosus], rainbow smelt) prefer habitats close to shore such as lagoons, beaches, and nearshore waters (Fechhelm et al. 1984, Logerwell et al. 2015). Other taxa such as sculpins (Cottidae) and arctic and saffron (Eleginus gracilis) cod are found in a variety of habitats, with juveniles found nearshore and older fish found offshore (Logerwell et al. 2015). Other taxa such as sculpins (Cottidae) and arctic and saffron (Eleginus gracilis) cod are found in a variety of habitats, with juveniles found nearshore and older fish found offshore (Logerwell et al. 2015). The higher abundance of fish in the ACW and the small size-classes in particular make the ACW ideal foraging habitat for piscivorous seabirds because they are limited in the size of prey they can capture. Small zooplankton taxa (i.e., those captured in 150-μm-mesh nets) generally are more abundant nearshore than offshore (Eisner et al. 2013), although they occur in all water masses of the northeastern Chukchi Sea (Questel et al. 2013). Large zooplankton (i.e., those captured in 505-μm-mesh nets), including euphausiids and oceanic copepods, are concentrated offshore in BSW (Eisner et al. 2013, Questel et al. 2013). Planktivorous seabirds typically consume prey of the large size-classes because small zooplankton are too energetically expensive to acquire.

Because Crested Auklets, Short-tailed Shearwaters, and Ancient Murrelets all commonly feed on euphausiids (Bédard 1969, Hunt et al. 2002, Jahncke et al. 2005, Gall et al. 2006, Gaston and Shoji 2010), the differences among species in distribution that we saw may be related to interspecific differences in feeding niches, which reflect feeding technique, behavior, and prey preference. Individuals with the flexibility to choose optimal foraging areas may demonstrate segregation based on inter- and intraspecific competition and on energetics (Ballance et al. 1997, Davoren et al. 2003, Hashmi and Causey 2008). Although Short-tailed Shearwaters can dive for food, Ancient Murrelets and Crested Auklets are more efficient divers than Short-tailed Shearwaters are. When the water column primarily is mixed or the sea-state is high, small divers may have an advantage over larger species such as shearwaters, which are highly suited to skimming the surface for euphausiids and other prey. In 2014, sea-surface temperatures (SST) were warm (Timmermans and Proshutinsky 2014), and the sea-state was high, with wave heights >2 m recorded during 31% of our sampling transects. These conditions may be poorer for shearwaters foraging on the wing than for auklets and murrelets diving from the surface. In contrast to the highly mobile shearwaters, Crested Auklets are semi-flightless during their September molt, making the energetic cost of mobility high and unfeasible for some individuals. During August, when Crested Auklet abundance was highest, there was no difference in density between the Nearshore and Offshore strata. The Nearshore densities we recorded in 2014 were 30 times the densities recorded during the AKMAP studies in 2010–2011 (Morgan et al. 2012), suggesting that foraging conditions in the Nearshore stratum were at least as good as conditions offshore in 2014.

Although Ancient Murrelets and Crested Auklets both are efficient divers that consume euphausiids, Ancient Murrelets also consume small fish, including capelin, sandlance, and rainbow smelt (Gaston and Shoji 2010). These
Conclusions

prey species all are found in ACW but are rare farther offshore (Logerwell et al. 2015). In contrast, Crested Auklets in northern Alaska feed almost exclusively on large zooplankton and take small larval fish only occasionally (Bédard 1969, Gall et al. 2006, Guy et al. 2009). Their heavy reliance on zooplankton may explain why auklets were distributed farther offshore than Ancient Murrelets were in September.

In addition to proximal factors such as physical oceanography and prey availability, seasonal changes in the composition of seabirds in the Arctic also are dictated by breeding phenology and success and by the timing of migration. Foraging areas used by breeding seabirds are influenced by proximity to colonies and by avoidance of competition by conspecifics (Hatch et al. 2000, Masello et al. 2010). Seabird distribution in the northeastern Chukchi Sea, however, provides an ecosystem-level perspective because most seabirds there are not restricted by central-place foraging associated with breeding colonies (Ainley et al. 2012). In this study, we found that seasonal and spatial changes in community composition probably were influenced by both species-specific phenology and oceanographic conditions.

Changes in the distribution and abundance of all foraging guilds occurred concurrently with the end of the breeding season. During the open-water season, Crested Auklets, Short-tailed Shearwaters, and Ancient Murrelets move into the Chukchi Sea from summer ranges farther south (Divoky 1987, Gall et al. 2014); their numbers peak after the breeding season has ended. In contrast, Glaucous Gulls, jaegers, phalaropes, and loons nest on the Chukchi coast and the Arctic Coastal Plain. The abundance of these tundra-nesters increased in September, presumably reflecting an influx of both adults and juveniles post-breeding. Thick-billed Murres, Common Murres, and Black-legged Kittiwakes nest in large numbers on cliffs along the eastern Chukchi coast as far north as Cape Lisburne (Dragoo et al. 2013). Murres that we recorded in August probably were non-breeders because most of our study area lies beyond the typical foraging distance observed for murres nesting at Cape Lisburne (Hatch et al. 2000). Some of the murres that we saw in September appeared to be parent–offspring pairs, an observation that is consistent with the hypothesis that fledgling chicks drift north with their parents after fledging while following both currents and prey (Hatch et al. 2000). Murres fledge at about two-thirds of adult size and finish growing at sea, reaching an asymptote of 90–95% of adult weight 45–60 days after leaving the colony (Smith and Gaston 2012). Although chicks are flightless when they fledge, their parents guide them to areas of persistent prey to fuel their final stage of growth. In 2014, it appears that waters near Icy Cape supplied prey for both planktivorous and piscivorous birds.

Although benthic-feeding eiders nest on the tundra, males return to sea long before the breeding season ends. They are joined there in late August and September by post-breeding females from the Arctic Coastal Plain (Johnson and Herter 1989), when large flocks of both sexes migrate through the Chukchi Sea (Oppel et al. 2008, 2009) and congregate in staging areas. Eiders typically feed in shallow water and commonly use Ledyard Bay, where we observed most flocks of Spectacled Eiders in waters ≤20 m deep. We recorded both King and Common eiders in the Offshore stratum in September; these probably were birds that were en route to wintering areas in the Bering Sea and Gulf of Alaska.

CONCLUSIONS

The Chukchi Sea supports a diverse seabird community of more than 40 species; in some months, maximal densities of >60 birds km² can occur. The extensive seasonal and spatial variation in the abundance of seabirds is attributable almost entirely to planktivorous species. Despite general seasonal trends, much of the spatial variation in species-specific distribution is related to the strength, timing, and movements of BSW and ACW from south of Bering Strait. The nearshore and offshore waters of the Chukchi Sea vary in bathymetry, oceanography, and prey communities. Although many seabird species can function in a gradient of conditions, some are tied more closely to the nearshore environment than to the offshore environment because of foraging strategy, prey type, and/or life history. Benthic-feeding species such as eiders demonstrate little flexibility in distribution and occur primarily in ACW, whereas planktivorous Crested Auklets and Short-tailed Shearwaters use both ACW and BSW. The
dynamics of prey availability also appear to differ seasonally, affecting the distribution of both planktivorous and piscivorous seabirds. In 2014, seabird distributions shifted seasonally from the head of Barrow Canyon in August to waters near Icy Cape in September. Resource developers and managers need to take into consideration these types of seasonal variability in the distribution and abundance of seabirds when planning for infrastructure and other industrial activities.

LITERATURE CITED


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