DISTRIBUTION AND ABUNDANCE OF SEABIRDS IN THE NORTHEASTERN CHUKCHI SEA, 2008–2010

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PREPARED FOR

CONOCOPHILLIPS ALASKA, INC.
ANCHORAGE, ALASKA

SHELL EXPLORATION & PRODUCTION COMPANY
ANCHORAGE, ALASKA

STATOIL USA E & P, INC.
ANCHORAGE, ALASKA

PREPARED BY

ABR, INC.–ENVIRONMENTAL RESEARCH & SERVICES
FAIRBANKS, ALASKA

Inset: Selection of seabirds, by column, left to right:

Sabine’s Gull
Dovekie
Tufted Puffin

Pomarine Jaeger
Common Murre
Crested Auklet
Black-legged Kittiwake
Short-tailed Shearwater

Thick-billed Murre
Northern Fulmar
Glaucous Gull

Arctic Tern
Least Auklet

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Executive Summary

- In 2008–2010, we collected data on the distribution and abundance of seabirds in the northeastern Chukchi Sea in the vicinity of several oil and gas lease areas. The 3 study areas were ~110–180 km (~60–100 NM) northwest of the village of Wainwright and known as Klondike, Burger, and Statoil.
- The objectives of this study were to: (1) describe seasonal, spatial, and interannual variation in the distribution and abundance of seabirds; (2) describe seasonal and interannual changes in species-richness and species-composition; (3) compare our results with historical data available in the North Pacific Pelagic Seabird Database (NPPSD); and (4) explore relationships between seabirds and the physical and biological oceanography of the region.
- We conducted seabird surveys during 3 seasons that covered the entire open-water period of the northeastern Chukchi Sea: late summer (Jul/Aug), early fall (Aug/Sep), and late fall (Sep/Oct).
- The analyses of densities, species-richness, and species-composition used data collected only within the boundaries of the 3 study-area boxes, whereas data collected opportunistically within ~92 km (50 NM) of each study-area box were used when making comparisons with historical data.
- In 2008, sampling effort was greater in Klondike than in Burger, especially during the Jul/Aug cruise, because it generally had less ice cover. In 2009, we did not encounter any ice in the study areas during the sampling period, and sampling effort was similar between Klondike and Burger. In 2010, we sampled all 3 study areas in Jul/Aug and Aug/Sep but sampled only Burger in Sep/Oct.
- Seabirds were more abundant in the study areas in 2009 than in 2008 or 2010, although we recorded fewer species in 2009. In 2008, we recorded 4,646 individuals of 31 species on transect within the 2 study areas combined; in 2009, we recorded 31,579 individuals of 24 species on transect within the 2 study areas combined. In 2010, we added the Statoil study area and recorded 10,827 individuals of 29 species on transect within the 3 study areas combined.
- We had sufficient detections to generate reliable estimates of density for 8 focal species. Densities of each of the 8 focal species differed significantly among seasons, and these seasonal patterns differed among years. In 2008, seabirds were more abundant in the second half of the open-water period. In 2009, however, seabirds were more abundant in the first half of the open-water period. In 2010, densities appeared intermediate between 2008 and 2009, and seasonal patterns appeared more similar to 2009 than to 2008.
- The total density of seabirds was considerably higher in 2009 than it was in 2008 or 2010 and generally was higher in Klondike than in Burger in 2008 and 2009. There were no significant difference in densities among Klondike, Burger, and Statoil in 2010.
- Alcids were the most abundant species group in 2008 and 2010, and were the second-most abundant species group recorded in 2009. In 2008, densities of alcids were significantly higher in Klondike than in Burger during all three seasons, whereas, in 2009, densities were higher in Burger than in Klondike during Jul/Aug and Aug/Sep but were higher in Klondike than in Burger in Sep/Oct. In 2010, densities of alcids were similar among all 3 study areas and seasons.
- Tubenoses were the second-most-abundant species-group in 2008 and 2010 and were the most abundant species-group recorded in 2009, primarily because of large flocks of Short-tailed Shearwaters moving through Klondike in Aug/Sep. The maximal density of Short-tailed Shearwaters in 2009 was nearly 16 times the maximal density in 2008 or 2010.
- Multivariate analyses of the seabird community composition indicated that species-composition varied among seasons and among study areas and that the dominant pattern differed among years. The numerical

dominance of alcids in all study areas combined increased from 2008 to 2010. Klondike was numerically dominated by alcids and tubenoses in all years. Burger was numerically dominated by larids and tubenoses in 2008, and by alcids in 2009 and 2010. Statoil also was numerically dominated by alcids in 2010.

- We recorded 11 species on transect in the study areas that are classified as being of conservation concern. One (Spectacled Eider) is listed as a threatened species under the U.S. Endangered Species Act of 1973, as amended (ESA), 2 (Kittlitz's Murrelet and Yellow-billed Loon) are classified as candidate species under the ESA, and 2 (Red-throated Loon and Arctic Tern) are classified as species of conservation concern by the U.S. Fish and Wildlife Service.
- Spatial overlap between the NPPSD historical data set and the 2008–2010 data set was greatest in Jul/Aug and, to some extent, Aug/Sep, but no historical transects were conducted within ~9 km of any study area in Sep/Oct. Consequently, comparisons between the 2 data sets have been made with several caveats.
- Densities from the historical data collected within the study areas suggest that total densities of seabirds in Klondike, Burger, and Statoil were similar between the historical data and densities in 2010, whereas densities in 2008 were lower and densities in 2009 were more than 6 times any historical values.
- Seasonal and spatial patterns of species-composition suggest that alcids and tubenoses are more abundant in the northeastern Chukchi Sea now than they were historically.
- We propose here that the structure of the seabird community differs substantially between the Klondike and Burger study areas and that these differences reflect what we believe are oceanographic differences between the 2 study areas, with Statoil straddling these two oceanographic systems.
- The Klondike study area appears to be a more pelagically-dominated system with a higher biomass of copepods than seen in Burger. The Burger study area appears to be a benthically-dominated system with higher abundance, biomass, and number of benthic taxa than Klondike. Diving alcids and Short-tailed Shearwaters that forage on large oceanic copepods and euphausiids are more abundant in Klondike, whereas surface-feeding or near-surface-feeding larids that feed on zooplankton and fishes are more abundant in Burger. Statoil appears to represent elements of both of the other study areas.
- The distribution of seabirds, particularly the planktivorous species, may be strongly influenced by advective processes that transport oceanic species of zooplankton from the Bering Sea to the Chukchi Sea. This transport apparently differed among years and resulted in a broader northeastward intrusion of Bering Sea Water, higher abundance of large oceanic copepods and euphausiids, and greater abundance of planktivorous seabirds in both study areas, in 2009 than in 2008 or 2010.

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Acknowledgments

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Acronyms and Abbreviations

ADFG	Alaska Department of Fish and Game
ANOVA	analysis of variance
Aug	August
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
° C	degrees centigrade
CSESP	Chukchi Sea Environmental Studies Program
CTD	Conductivity, temperature, depth sensor
ESA	U.S. Endangered Species Act of 1973
GIS	geographic information system
GPS	global positioning system
IDW	inverse distance weighting
Jul	July
km	kilometer
MMS	Minerals Management Service
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NM	Nautical mile
nMDS	Non-metric multidimensional scaling
NPPSD	North Pacific Pelagic Seabird Database
m	meter
OCSEAP	Outer Continental Shelf Environmental Assessment Program
Oct	October
psu	practical salinity units
Sep	September
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Introduction

The Chukchi Sea has one of the highest rates of primary productivity in the world's oceans (Grebmeier et al. 2006). This extraordinary productivity supports rich benthic and planktonic communities that, in turn, support large communities of apex predators such as seabirds, seals, and whales. Although the region is ice-covered for much of the year, the ice-free waters and the ice edges become important habitat for non-breeding, staging, and migratory seabirds from mid-July to mid-October. Of the colonial seabirds, Thick-billed Murres (*Uria lomvia*), Common Murres (*U. aalge*), and Black-legged Kittiwakes (*Rissa tridactyla*) in particular, nest in large numbers on cliffs along the Chukchi coast and are common offshore during July/August and August/September (Divoky 1987, Divoky and Springer 1988). Species that nest on the tundra, such as phalaropes and jaegers, move out to sea in August/September and join millions of migratory Short-tailed Shearwaters (*Puffinus tenuirostris*) foraging in the area (Divoky 1987, Divoky and Springer 1988). Finally, ice-associated gulls such as Ross's Gulls (*Rhodostethia rosea*) and Ivory Gulls (*Pagophila eburnea*) migrate from high-arctic breeding areas in Russia and Canada into the Chukchi Sea as the ice advances southward in the late fall. As many as 5 million seabirds of at least 22 species were believed to use the American waters of the Chukchi Sea during the ice-free season in the 1980s (Divoky 1987).

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 exploratory drilling of 5 wells in 1989 and 1990. Two of these wells, known as Klondike and Burger, are located west of the village of Wainwright. These areas were 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. 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), and there has been resurgence in oceanographic research during the past decade. This study was conducted to inform managers and industry about the recent distribution, abundance, and timing of seabirds using the northeastern Chukchi Sea. It forms one component of the Chukchi Sea Environmental Studies Program (CSESP), a multidisciplinary study of the marine ecology of this area.

History of Previous Research

Data on seabirds in the northeastern Chukchi Sea during the open-water season are limited, primarily because of the area's historic inaccessibility. Much of the interest in seabirds in this area has concentrated on mainland seabird colonies and on seabirds at sea in the vicinity of the Hope Basin, which lies immediately north of Bering Strait, in the southeastern Chukchi Sea. The focus of seabird colony research has been Cape Lisburne, which is part of the Alaska Maritime National Wildlife Refuge; data also have been collected at irregular intervals at Cape Thompson, ~50 miles south of Cape Lisburne. These colonies have been studied periodically since 1976 by David Roseneau and others at the U.S. Fish and Wildlife Service (USFWS) who built on earlier work begun on nesting seabirds by Swartz (1966) during the Cape Thompson environmental studies of the U.S. Atomic Energy Commission in the 1950s.

Another area of research has focused on use of the coastal-lagoon systems of the northeastern Chukchi Sea by birds. The early work by Johnson (1993) and Johnson et al. (1993) described baseline use of the Chukchi lagoon systems, whereas recent work has focused on monitoring population trends of birds in all lagoon systems in northern and northwestern Alaska annually (e.g., Dau and Larned 2004 and related annual reports). There also have been extensive studies of eider migration at Barrow, which has perhaps the highest concentration of migrating waterfowl on this continent (Thompson and Person 1963; Woodby and Divoky 1982; Suydam et al. 1997, 2000a, 2000b; Day et al. 2004), and studies of migrating Ross's Gulls, which concentrate at Barrow in the fall (Divoky et al. 1988). Aerial surveys for and satellite telemetry of migrating and staging Spectacled (*Somateria fischeri*) and Steller's eiders (*Polysticta stelleri*), both of which are protected under the Endangered Species Act (ESA) of 1973, as amended (PL 93-205; 16 USC §1531), in the Chukchi Sea have indicated that shallow, nearshore waters of Ledyard Bay and Peard Bay form important stopover areas for migrating Spectacled and King (*Somateria spectabilis*) eiders in both the summer and fall (Balogh 1997, Oppel et al. 2009). In fact, the USFWS designated the nearshore waters of Ledyard Bay as critical habitat for Spectacled Eiders in 2001 (Federal Register 2001).

In comparison to the well-known coastal seabird community, few historical data on the at-sea distribution and abundance of seabirds are available for the offshore region of the northeastern Chukchi Sea. The earliest research was conducted by Jacques (1930), who surveyed birds in the Bering Sea and western Chukchi Sea in July–August 1928. Later, Swartz (1967) examined the at-sea distribution of seabirds in the southern and central Chukchi during the environmental studies at Cape Thompson. The interest in oil development in arctic Alaska in the 1970s prompted a decade of research on seabirds and other marine organisms in this region. The main seabird studies in areas important for oil development were conducted by (1) Watson and Divoky (1972), who studied seabirds in the eastern Chukchi Sea from a U.S. Coast Guard icebreaker; (2) Divoky (1979), who described some aspects of the Chukchi Sea open-water and ice-edge avifauna; and (3) Divoky (1987), who studied seabirds throughout the Chukchi Sea in the early 1980s as part of OCSEAP. The latter report was never released by OCSEAP as part of its "Environmental Assessment of the Alaskan Continental Shelf" publication series, so it is not widely available or widely known. Another source of information on seabirds near this area is Divoky and Springer (1988), who provided an overview of the data available on seabirds in the southern Chukchi Sea for a Minerals Management Service (now Bureau of Ocean Energy Management, Regulation, and Enforcement [BOEMRE]) synthesis report.

Studies conducted during the past 5 years are filling in some gaps in knowledge about the at-sea ecology of seabirds the northeastern Chukchi Sea. Recently, there has been ship-of-opportunity sampling of seabirds in the Chukchi Sea conducted primarily by the USFWS and BOEMRE. These data have not been published yet, but they have been contributed to the North Pacific Pelagic Seabird Database (NPPSD), a publicly available information resource maintained by the U.S. Geological Survey, that is updated periodically. The current version of that database includes data from USFWS surveys as recent as October 2009. Other ongoing studies that provide detail on the use of nearshore and offshore waters by birds include satellite telemetry studies of Spectacled Eiders (Sexson 2010); Long-tailed Ducks (*Clangula hyemalis*) and King Eiders (Dickson and Bowman 2008); and Red-throated (*Gavia stellata*) and Yellow-billed loons (*G. adamsii*; Rizzolo and Schmutz 2009). The present study, which was conducted in 2008–2010, provides information on the recent distribution and abundance of marine birds in the northeastern Chukchi Sea.

Study Objectives

In this study, we explored the distribution and abundance of seabirds in the northeastern Chukchi Sea in 3 areas where ConocoPhillips Company, Shell Exploration & Production Company, and Statoil USA E & P have several lease-blocks for offshore oil and gas exploration and development. The objectives of this study were to: (1) describe seasonal, spatial, and interannual variation in the distribution and abundance of seabirds; (2) describe seasonal and interannual changes in species-richness and species-composition; (3) compare our results with historical data that are publicly available in the NPPSD; and (4) explore relationships between seabirds and the physical and biological oceanography of the region. This study both provides baseline information on the recent distribution and abundance of seabirds in the lease areas and summarizes information on the historical distribution and abundance of seabirds in the northeastern Chukchi Sea in the vicinity of those lease areas. This information will be used for an analysis of potential impacts resulting from offshore exploration and development activities and will be included within a National Environmental Policy Act (NEPA) document required for exploration.

Methods

Study Area

This study was conducted in the northeastern Chukchi Sea, in an area extending ~110–180 km (~60–100 NM) west of the village of Wainwright, which is located on the northwestern coast of Alaska. The overall survey area is bounded by 2 currents flowing from the Chukchi Sea to the Arctic Ocean: the Central Channel Current, to the west, and the Alaska Coastal Current, to the east (Weingartner et al. 2005, 2008). The survey area included 3 study areas called "Klondike," "Burger," and "Statoil" (Figure 1). The Klondike study area was located on the eastern side of the Central Channel and near the inflow of Bering Shelf water, whereas the Burger study area was located to the northeast of Klondike and on the southern slope of Hanna Shoal. The Statoil study area was located to the north of both Klondike and Burger, with its western edge close to the Central Channel and the eastern half on Hanna Shoal. The Alaska Coastal Current flows east of all 3 study areas, exiting the area via Barrow Canyon.

The Klondike and Burger study areas consisted of a core area of greatest interest for exploration that was ~18 km (~10 NM) on a side within a larger study-area box that was ~55 km (30 NM) on a side (Figure 1). The larger study-area box included a buffer zone around the proposed exploration area that provided spatial context for all of the scientific disciplines. The Statoil box was configured to encompass several Statoil lease blocks and had the same total area as Klondike and Burger. These ~3,087-km² (900-NM²) study-area boxes were the primary focus of all sampling. We surveyed along a series of parallel survey lines that ran north–south through these study-area boxes. The primary sampling grid included lines on the eastern and western boundaries of each study area and lines spaced ~3.7 km (2 NM) apart within each study area, creating a set of 16 parallel survey lines in Klondike and Burger that each were ~55.6 km (30 NM) long. Because the Statoil box was not square, it had 19 parallel survey lines of variable length. In all study-area boxes, a sampling grid of secondary lines was offset from the primary lines by ~1.8 km (1 NM) and was sampled as time allowed, when the primary lines were obstructed by ice, or if nearby primary lines had been sampled under poor observation conditions. In addition to transects within the study areas, we also sampled opportunistically near both study areas (primarily when ice prevented us from sampling within the study areas themselves) and when transiting between Wainwright and the study areas. Some of these additional data are included in the comparison with the historical data set.

OCEANOGRAPHIC STRUCTURE

The Chukchi Sea is a shallow (~50-m-deep) shelf sea north of Bering Strait and south of the basin of the Arctic Ocean. The primary inflow of nutrient-rich water comes from the south through Bering Strait and has 3 main outflows to the Arctic Ocean (Weingartner et al. 2005, Woodgate et al. 2005, Grebmeier et al. 2006). The physical structure of the study areas in 2008–2010 may be seen in a series of vertical sections of CTD data collected during each of the 3 research cruises (Figures 2–5). These vertical sections show temperature (°C) and salinity (psu [practical salinity units]) along a series of stations extending from the southwestern corner (far left side of plots) to the northeastern corner (at ~80 km along the X-axis) of the Klondike study area, then from the southwestern corner (at ~100 km along the X-axis) to the northeastern corner (far right side of plots) of the Burger study area, except for September/October 2010, which displays data from Burger only because there was no sampling in Klondike or Statoil during that cruise. The physical oceanography of the 3 study areas is described in greater detail by Weingartner et al. (2011).

In all 3 years, the water structure in the region was influenced by the influx of warm, saline water from the Bering Sea. The transport of this water mass varied among years, however, in both timing and magnitude (Weingartner et al. 2011). In 2008, overall water temperatures were cold, reflecting the presence of ice that lasted into August and a persistent deep pool of cold, high-salinity water that remained in Klondike until September and in Burger until October (Figure 2). The surface layers had a more complex temperature and salinity structure in August/September than in July/August (Figure 2, middle panel). Warm water was

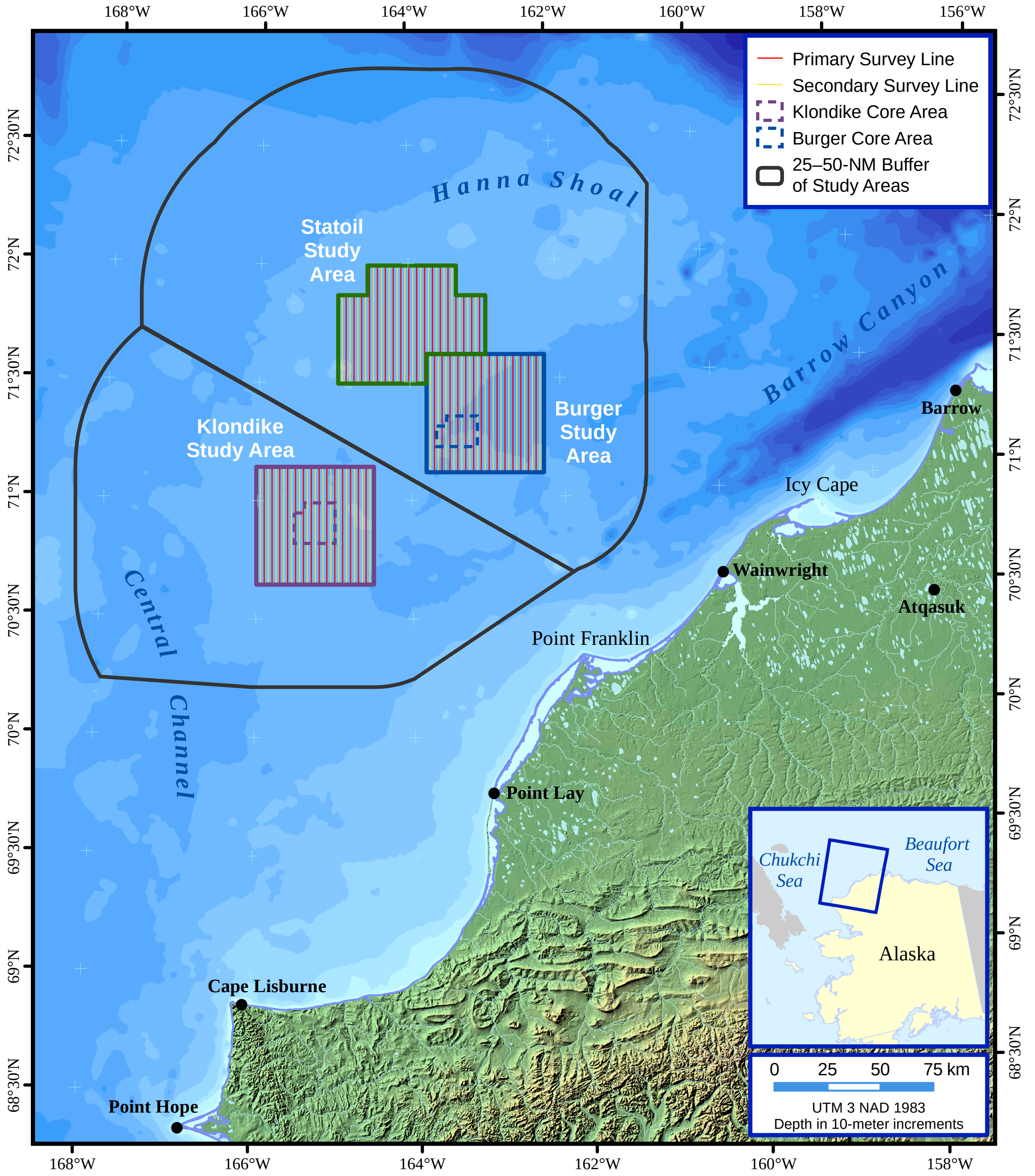

Figure 1. Locations of the Klondike, Burger, and Statoil study areas in the northeastern Chukchi Sea. Also shown are the locations of the survey lines and the buffer zones used for examining the historical data.

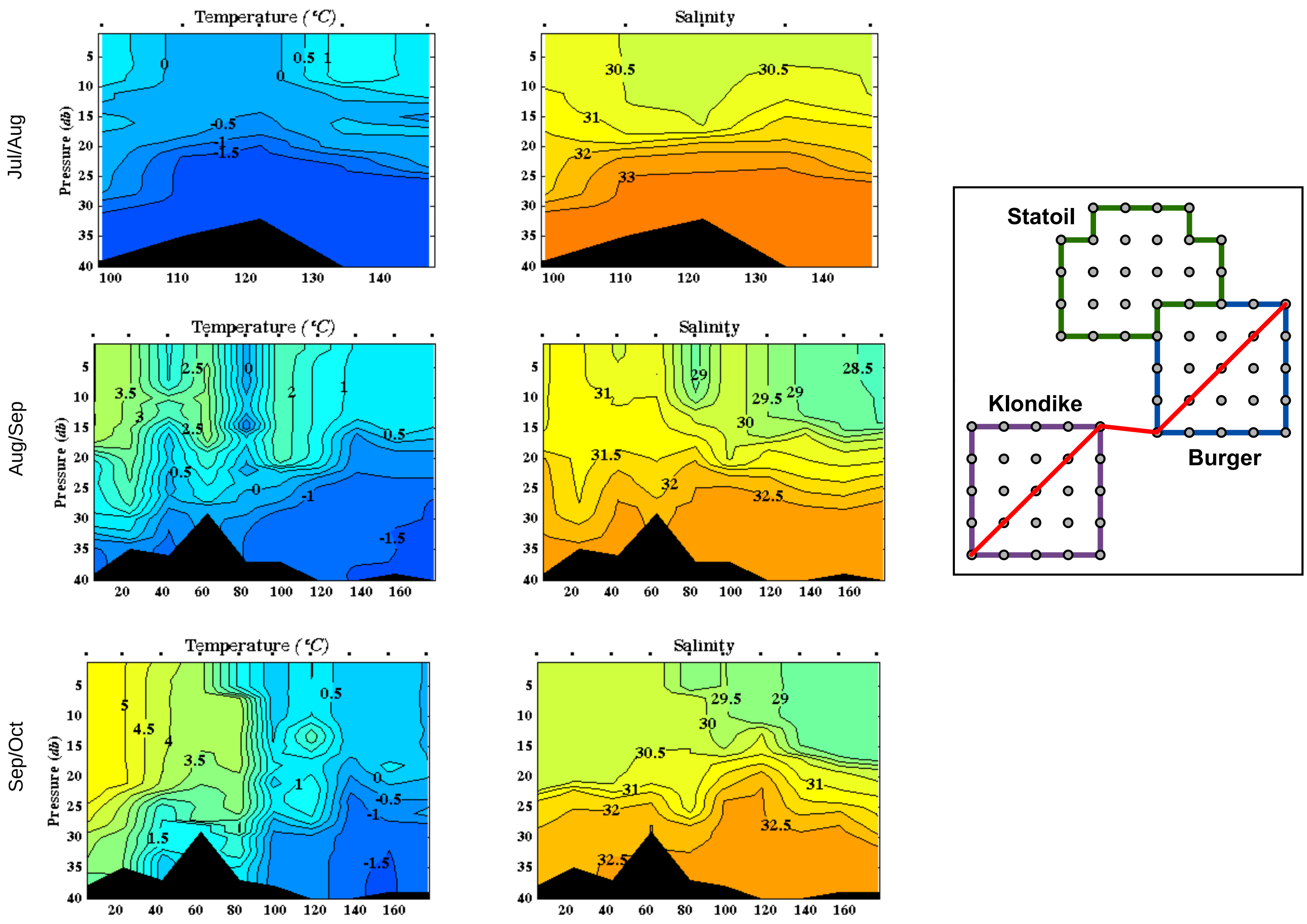

Figure 2. Vertical sections of temperature (°C), and salinity (psu) in the Klondike and Burger study areas, 2008 (Weingartner et al. 2011).

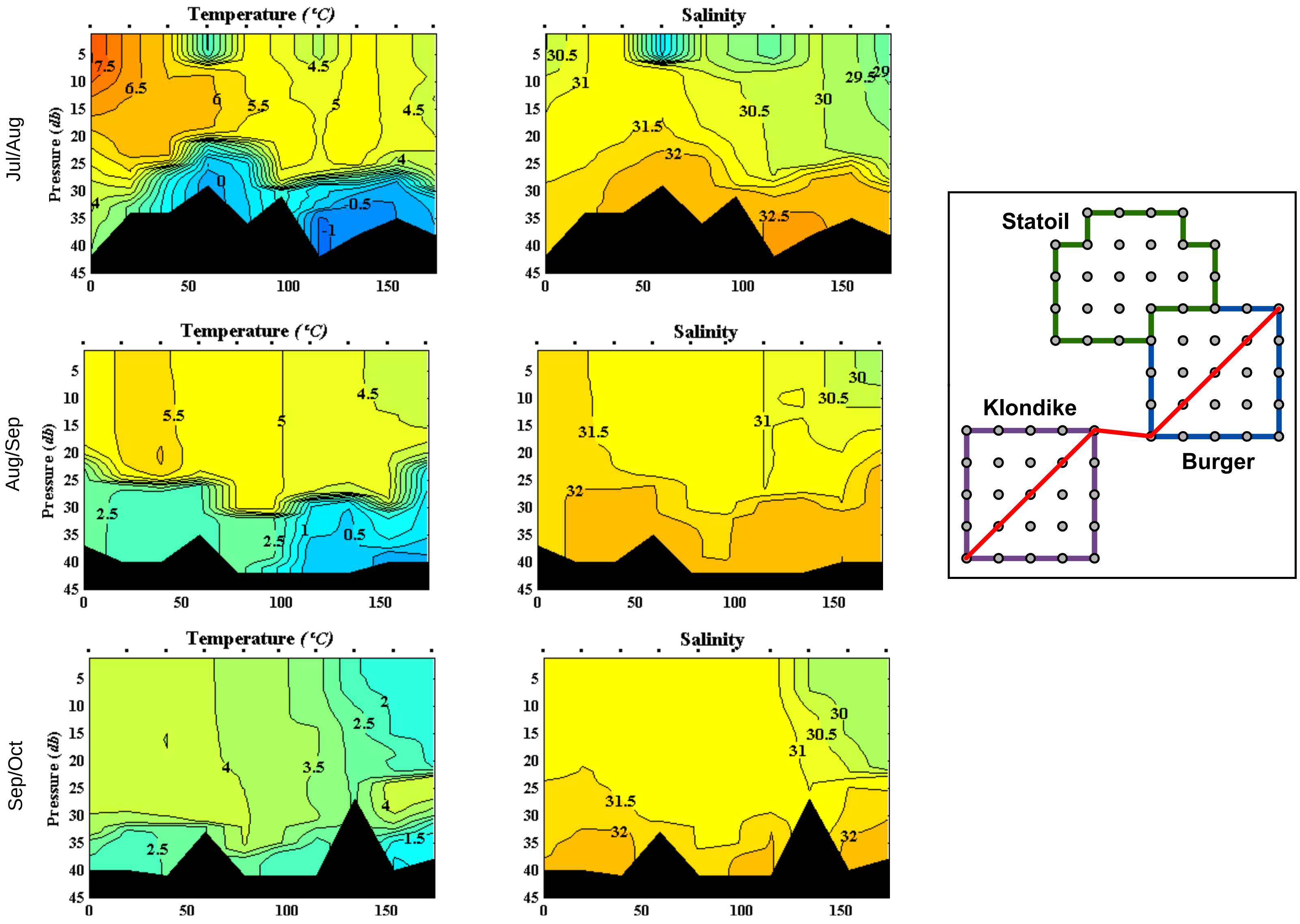

Figure 3. Vertical sections of temperature (°C) and salinity (psu) in the Klondike and Burger study areas, 2009 (Weingartner et al. 2011).

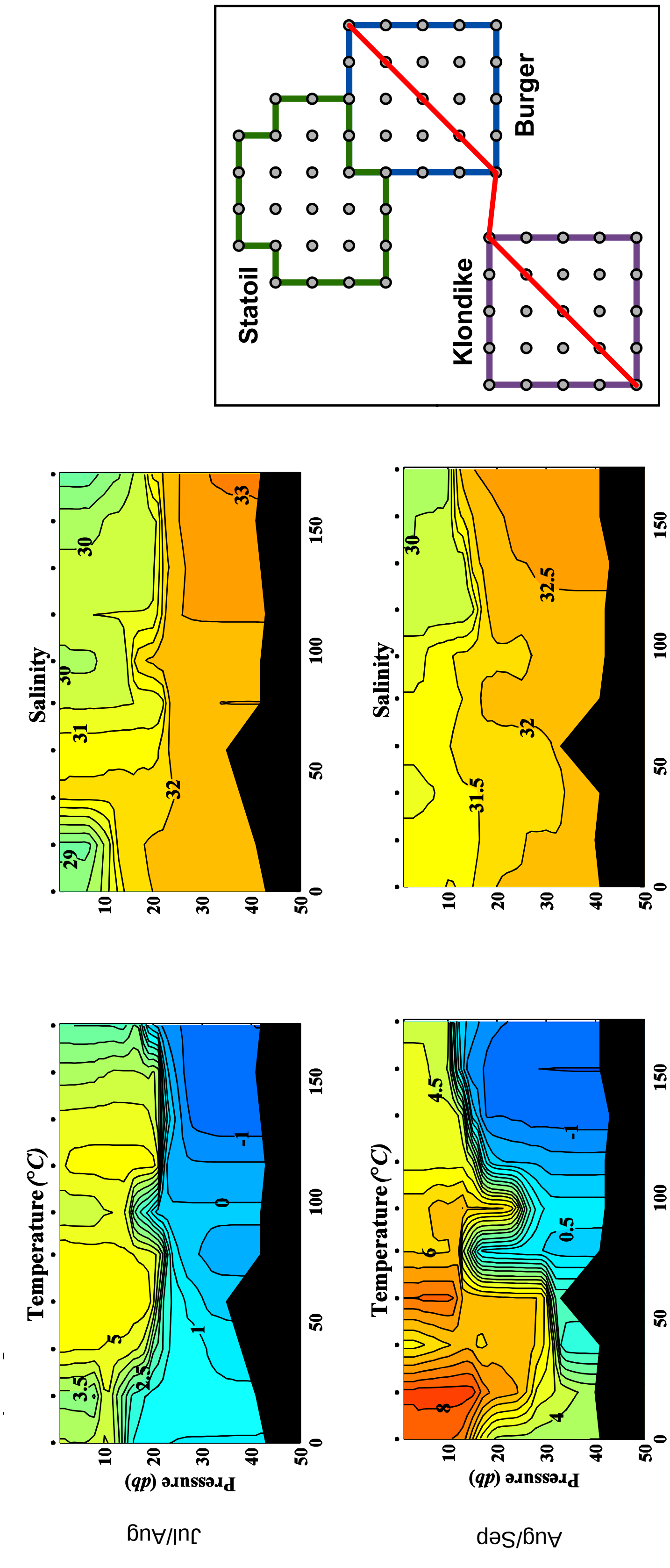

Figure 4. Vertical sections of temperature (°C) and salinity (psu) in the Klondike and Burger study areas, 2010 (Weingartner et al. 2011).

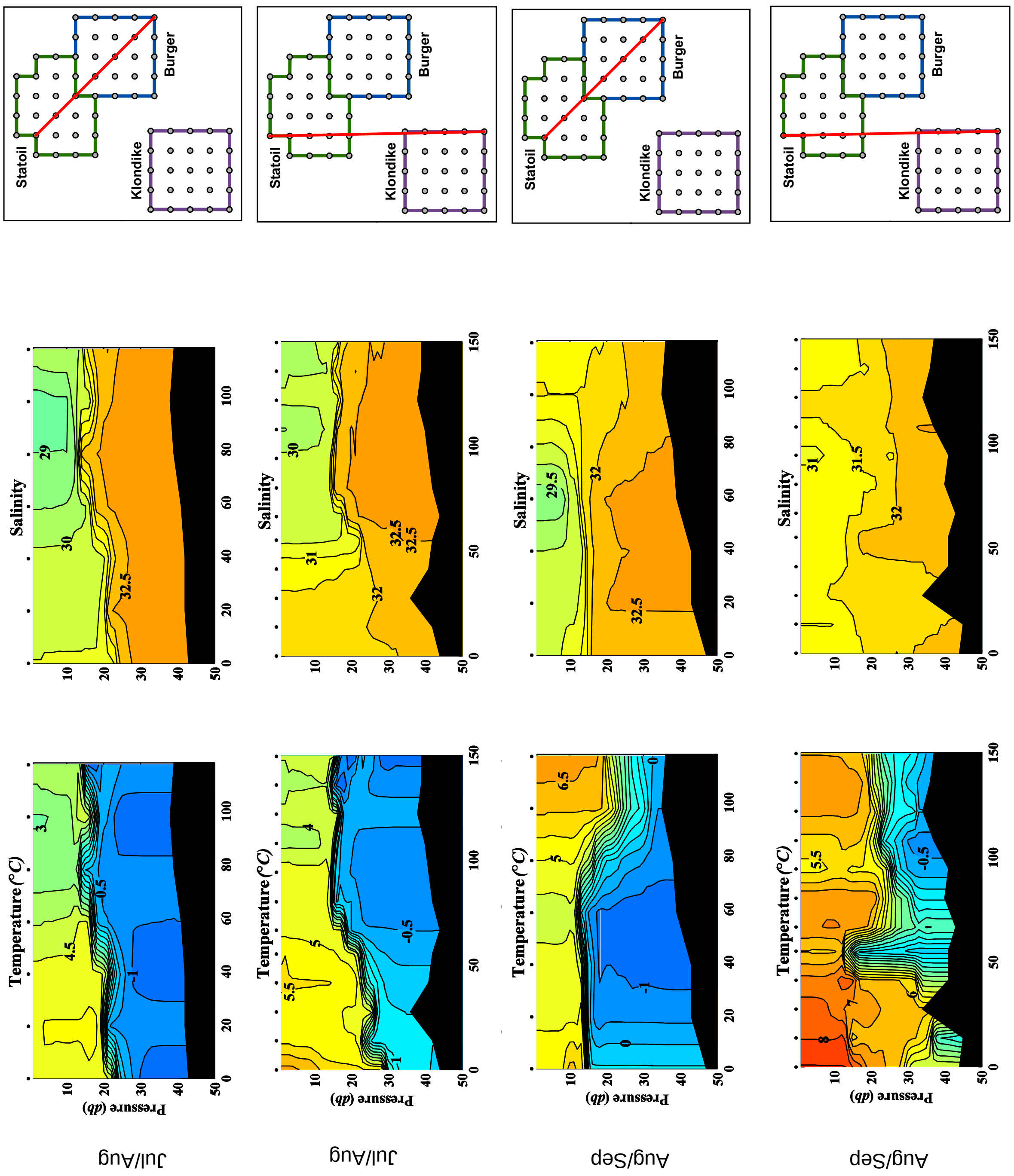

Figure 5. Vertical sections of temperature (°C) and salinity (psu) in the Klondike, Burger, and Statoil study areas, 2010 (Weingartner et al. 2011).

intruding from the western edge of the Klondike study area (0 to ~30 km along the X-axis), whereas the surface layer over the northeastern corner of Klondike and most of Burger (~50 km to ~180 km along the X-axis) remained cold, low-salinity meltwater, with the 2 areas separated by warmer and saltier filaments. In September/October, the front between the 2 water masses became very distinct and centered near the zone between the 2 study-area boxes (Figure 2, bottom panel).

In contrast, the study area in 2009 was ice-free at the beginning of sampling in August, and the water structure was nearly homogenous throughout both study areas during the entire study period. In July/August, water in the western part of the Klondike study area (0 to ~25 km along the X-axis) was warmer and more saline than water in the eastern half of Klondike and in Burger (Figure 3, top panel), although both study areas showed stratification and water temperatures that were similar and 4–7° C warmer than in 2008. In August/September, stratification was consistent across both study areas, with both the thermocline and halocline located 20–30 m below the surface (Figure 3, middle panel), and, by September/October, the hydrography was homogenous throughout both study areas and showed little stratification. The water-mass that covered all of Klondike and most of Burger was essentially uniform in temperature and salinity (Figure 3, bottom panel). A filament of cold, low-salinity meltwater remained at the surface in the northeastern corner of Burger (~150 km to 200 km along the X-axis), probably indicating the edge of a larger pool of meltwater over Hanna Shoal.

In 2010, the timing and strength of intrusion of Bering Sea water appeared intermediate between the patterns seen in 2008 and 2009. The water structure over Klondike became warmer, less saline, and less stratified in August/September than in July/August, whereas the water over Burger and Statoil was stratified during the entire study period. In July/August, water in the western part of the Klondike study area (0 to ~25 km along the X-axis) was warmer and more saline than water in the eastern half of Klondike and in Burger (Figure 4, top panel). Water in Statoil was colder than in Klondike or Burger (Figure 5, top 2 panels), although all 3 study areas showed similar stratification. A salty pool of winter water lay across the bottom of much of Klondike and was colder and saltier in Burger and Statoil. In August/September, there was little stratification in the western half of Klondike. Stratification developed abruptly at a front on the eastern edge of Klondike (~60 km on the X-axis) and this strong stratification was consistent across Burger, with both the thermocline and halocline located ~20 m below the surface (Figure 4, middle panel). Statoil showed a structure intermediate between the other 2 study areas, with stratification that was strongest on the eastern edge and weakest on the western edge (Figure 5, bottom 2 panels). By this time, the pool of cold, salty winter water at the bottom was present only in Burger and the eastern half of Statoil. In September/October, water remained stratified over Burger, with tongues of warm water intruding along the thermocline on both the western and eastern edges of the study area (Figure 4, bottom panel). There was no oceanographic sampling over Klondike or Statoil during September/October 2010.

Data Collection

We conducted seabird surveys during 3 seasons covering the entire open-water period of the northeastern Chukchi Sea (Figure 6): late summer (hereafter "Jul/Aug"), early fall (hereafter "Aug/Sep"), and late fall (hereafter "Sep/Oct"). These surveys were designed to quantify the distribution, abundance, and species composition of the seabird community within the 3 study areas.

The surveys were conducted as consecutive 10-min counting periods (hereafter, transects) 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). We collected data 9–12 h/day during daylight hours, weather and ice conditions permitting. Surveys generally were stopped when sea height was Beaufort 6 (seas ~2–3 m [~6–10 ft]) or higher, although we occasionally continued to sample if observation conditions still were good (e.g., if seas were at the lower end of Beaufort 6 and we were traveling with the wind). One observer stationed on the bridge of the vessel recorded all birds seen within a radius of 300 m in a 90° arc from the bow to the beam on one side of the ship (the count zone) and located and identified seabirds with 10′

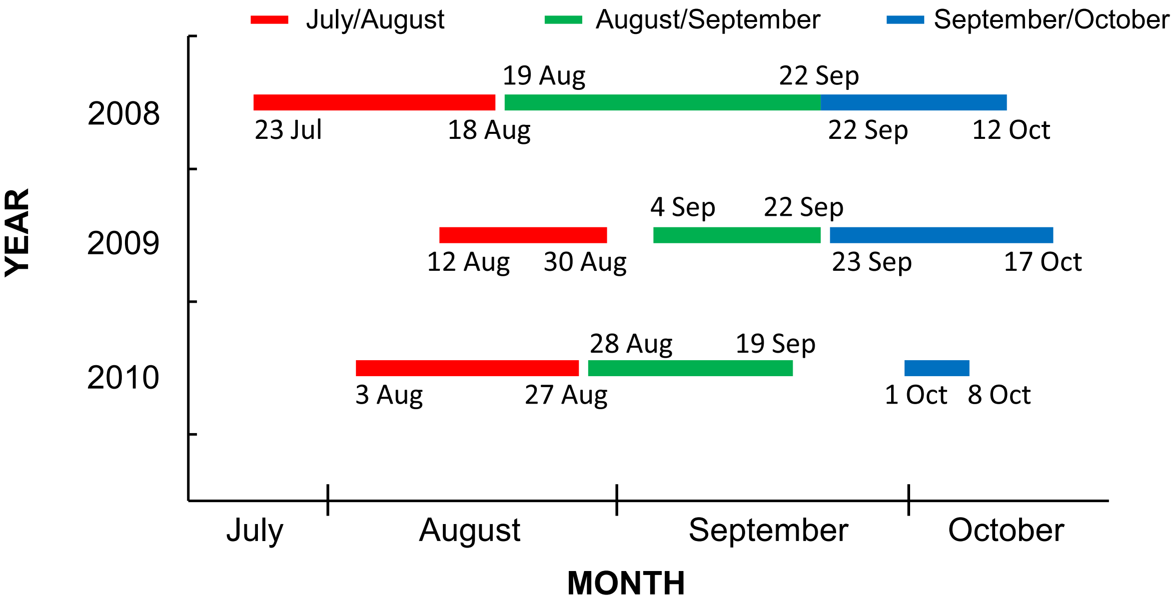

Figure 6. Timing of boat-based surveys for marine birds in the Klondike, Burger, and Statoil study areas, 2008, 2009, and 2010.

binoculars. For each bird or group of birds, we recorded:

- species (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]);
- radial angle of the observation 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).

All birds on the water and in the count zone were counted, taking care to avoid recounting the same individuals. For flying birds, however, observers conducted scans for them ~1 time/min (the exact frequency varied with ship's speed) and recorded an instantaneous count (or "snapshot") of all birds flying within the count zone. This "snapshot" method reduces the bias of overestimating the density of flying birds (Tasker et al. 1984, Gould and Forsell 1989). Only those flying birds that entered the count zone from the sides or front were counted; flying birds that entered from behind the ship (i.e., an area that already had been surveyed) were not counted to avoid the possibility of counting ship-following birds.

Observations of all birds were entered directly into a computer connected to a global positioning system (GPS) with DLog software (R. G. Ford Consulting, Portland, OR) in 2008 and TigerObserver software (TigerSoft, Las Vegas, NV) in 2009 and 2010; these programs time-stamped and geo-referenced every observation entered in real time. In 2008, the primary GPS connected to the data-collection computer lost communication with satellites on 3 occasions (a total of 74 min during 2 d), resulting in missing locations for observations and transect cutoff points. To fill these GPS data gaps, we used the position track from the ship's meteorological station, which used a different GPS, by linking the time stamps of the records. In 2009 and 2010, we patched a few similar gaps in the location record (a total of 42 min during 2 d) by interpolating the ship's location from the last known waypoint using the ship's speed and the time of the observation.

Data Analysis

The analyses of densities, species-richness, and species-composition used data collected only within the boundaries of the 3 study-area boxes (Figure 1). Because the historical data set covered a much larger area, we included data collected opportunistically within ~90 km (50 NM) of each study area to increase our sampling area when making comparisons with the historical data (Figure 1). Data collected when traveling outside of the study-area boxes were recorded following the same sampling protocol as data collected when sampling within the study area.

DENSITY CALCULATIONS AND ANALYSES

We calculated densities (birds/km^2) of birds within each study area from the combined counts of birds sitting on the water and "snapshot" counts of flying birds. The area for each transect was determined from the strip width (usually 300 m, unless limited by fog to 200 m) and the transect length (calculated from the start and stop coordinates recorded by the GPS). We aggregated transects with a minimal length of 2 km and a minimal area of 0.4 km^2 to calculate the average density for each survey line. Survey lines were 9–55 km (5–30 NM) long and were considered long enough to be robust to autocorrelation in seabird distribution (Haney 1991, Yen et al. 2004). We used the line densities to calculate means and variances in density in each study area in each season and year. This approach provides an index to bird abundance that can be used for inference about spatial and temporal trends and is comparable to the historical data from this area. We calculated log-normal, *z*-based, 2-sided 95% confidence intervals for the estimates of density with equations 3.71–3.74 in Buckland et al. (2001: 77).

Eight focal species were selected for statistical analyses from among the 10 most-abundant species in every year. These 8 focal species represented a variety of foraging methods, thereby providing an overview of functional ecological groups of the seabird community. We used repeated-measures ANOVAs in SPSS (2009) to examine differences between the Klondike and Burger study areas, among seasons, and among years for each species. The models included the additive effects of STUDY AREA and YEAR and the interactions between these main effects. We specified SEASON as the repeated measure. Repeated-measures ANOVAs in SPSS allow for unbalanced designs (SPSS 2009), as we had in this study because we did not sample in Klondike in Sep/Oct 2010. We examined the seasonal trend in Statoil in 2010 but did not include Statoil in the repeated-measures analysis because it was surveyed only twice and only in 2010. In all statistical tests, the level of significance (α) was 0.05.

We also used the geo-located observations to generate maps of distribution and abundance for all birds combined and for individual species of interest. First, we assigned the density value of each transect to its respective transect centroid coordinate. We then used the inverse-distance-weighted (IDW) interpolation technique of the Spatial Analyst extension of ArcMap GIS software (Environmental Systems Research Institute, Inc., Redlands, CA) to generate contours of similar density, based on the mean density for each grid-cell centroid. To conduct the IDW analysis, we first overlaid a 1,000 × 1,000-m grid over the study area. The IDW interpolation technique calculated the distance-weighted mean density of up to 9 centroids within 7,000 m of each 1,000-m pixel in the study area. This analysis produced contoured portrayals of bird densities on maps for each of the 8 focal species within each of the 3 study areas.

COMMUNITY ANALYSES

We summarized seabird species-richness and species-composition by study area, season, and year (Magurran 2004). We aggregated individual species into 6 taxonomic species-groups prior to analysis: waterfowl (family Anatidae, including geese, swans, and ducks), loons (family Gaviidae), tubenoses (family Procellariidae, including fulmars and shearwaters), phalaropes (unusual shorebirds of the family Scolopacidae that spend most of their lives in water), larids (families Laridae and Stercorariidae, including gulls, terns, and jaegers), and alcids (family Alcidae, including murres, guillemots, murrelets, auklets, and puffins).

We used multivariate analyses and descriptive statistics to explore the changes in structure of the seabird community among seasons, study areas, and years. Data were grouped into sample units by study area, season, and year. The overall similarity in the species-composition of samples is determined by their closeness in the cluster dendrogram or ordination. This approach is useful for detecting patterns in overall community structure and similarities among species assemblages (Blanchard et al. 2010). We used cluster analysis and ordination (where new "axes" that summarize community structure are derived and can be plotted) for analysis of the 2008–2010 seabird data from all study areas. These procedures consisted of 4 steps:

1. We calculated the Bray–Curtis measure of similarity among Study Area*Season*Years (hereafter, "samples") to be classified.
2. We sorted the matrix of Bray-Curtis similarity coefficients to arrange the samples in a dendrogram (cluster analysis) and in a 2-dimensional plot (ordination).
3. We determined groups of samples within the dendrogram or ordination based on the agreement of the 2 multivariate procedures.
4. We determined the dominant species assemblages composing each sample.

Data reduction prior to calculation of similarity coefficients consisted of eliminating observations that could not be identified to at least species-group level. The Bray–Curtis coefficient (Bray and Curtis 1957) was used to calculate similarity matrices for cluster analysis and ordination and is defined as:

$$S_{ij} = \left(1 - \frac{\sum_{j=1}^{n} |y_{ij} - y_{kj}|}{\sum_{j=1}^{n} (y_{ij} + y_{kj})}\right) 100$$

where y_{ij} = the jth species of sample i and y_{kj} = the jth species of sample k. The Bray–Curtis coefficient is widely used in marine benthic studies (A. Blanchard, pers comm.), and we have adapted it for use in this seabird study. For the present study, the Bray–Curtis coefficient was used to calculate similarity matrices for natural logarithm-transformed density data [*ln*(bird km^{-2} + 1)]. Cluster analysis is useful to summarize data by sorting samples into "natural groupings" based on their attributes, and the results are summarized in a dendrogram (Johnson and Wichern 1992). Similarity among sample groups is inferred from a dendrogram by interpreting the joining of branches in the plot. We constructed a dendrogram using a group-average agglomerative hierarchical cluster analysis (Clifford and Stephenson 1975) on STUDY AREA*SEASON*YEAR samples as entities to be classified and species-group density as their attributes. The grouping of samples into patterns reflecting species-composition similarities were interpreted as ecologically meaningful groupings.

Non-metric multidimensional scaling (nMDS; Kruskal and Wish 1978, Clarke and Green 1988) is used extensively to detect ecological patterns in species-composition data from the marine environment (e.g., Gray et al. 1988, Agard et al. 1993, Clarke 1993). As described by Gray et al. (1988) ". . . nMDS attempts to construct a 'map' of the sites in which the more similar . . . samples, . . . in terms of species abundances, are nearer to each other on the 'map'." The extent to which the relationships can be adequately represented in a 2-dimensional map (rather than 3 dimensions or higher) is summarized by a "stress" coefficient that should be ≤0.15 for a good fit (Clarke and Ainsworth 1993). Agreement in the groupings of samples in the cluster and nMDS ordination provides evidence that the sample groupings represent a reasonable summary of the multi-dimensional relationships of the data. Cluster analysis and nMDS analyses were conducted with the package 'vegan' (Oksanen et al. 2011) in R.

Comparison with Historical Data

We compared our data with historical data from the same area collected in 1975–1981. The historical data were collected from a variety of ships by numerous observers and are stored in the

NPPSD (USGS 2010). Across all years, most transects were 10–15 min in duration (~3–4.5 km [1.6–2.4 NM] in length), and other important attributes of the sampling methods (e.g., transect width, exclusion of ship-following birds) were similar to methods used in this study. To increase sample sizes for comparison with data from this study, we used all historical transects that occurred within a ~50–100-km (30–50-NM) buffer around each study box (Figure 1). We compared historical species-richness, species-composition, and total density in each study area with the 2008–2010 data.

Results

Within the 3 study areas, we sampled a total of 6,040 km (3,260 NM) of transects in 2008; 5,144 km (2,772 NM) in 2009; and 5,531 km (2,987 NM) in 2010. In 2008, sampling effort was greater in Klondike (846–1,329 km/cruise [457–717 NM/cruise]) than in Burger (716–1,071 km/cruise [387–578 NM/cruise]), especially during the Jul/Aug cruise, because Klondike generally had less ice cover than Burger did. In 2009, we did not encounter any ice in the study areas during the sampling period and sampling effort was similar in both study areas, with 833–855 km (450–460 NM) surveyed within each study area/cruise. In 2010, we added the Statoil study area and encountered a prolonged period of rough seas during the Jul/Aug cruise that limited sampling to 653–773 km (353–396 NM) within each of the 3 study areas. Sampling effort for the remainder of 2010 was similar to previous years, with 800–870 km (432–470 NM) surveyed within each study area/cruise.

Patterns of Abundance and Distribution

Seabirds were more abundant in the study areas in 2009 than they were in 2008 or 2010, although we recorded the fewest species in 2009. In 2008, we recorded 4,650 individuals of 31 species during surveys within the 2 study areas combined; we also recorded 2 other species only off-transect (Table 1). In 2009, we recorded 31,579 individuals of 24 species on transect within the 2 study areas combined; we saw no other species only off-transect. In 2010, we added the Statoil study area and recorded a total of 10,827 individuals of 29 species on transect within the 3 study areas combined; we also recorded 4 other species only off-transect (Table 2).

ALCIDS

Alcids were the most abundant species-group in 2008 and 2010, and were the second-most-abundant group in 2009. Densities of alcids in 2008 were significantly higher in Klondike than in Burger during all 3 seasons, whereas densities in 2009 were higher in Klondike than in Burger in Sep/Oct but higher in Burger than in Klondike in Jul/Aug and Aug/Sep (Figure 7, Tables 3–5). In 2010, densities of alcids as a group were similar among study areas, but individual species' densities did differ among study areas. Of the 11 species of alcids recorded on transect within the study areas over the 3 years, Crested Auklets, Least Auklets, and Thick-billed Murres were abundant enough to model trends in distribution and abundance.

Crested Auklets were the most abundant species recorded in all 3 years of the study (Figure 7, Tables 3–5). The maximal density in 2009 was nearly 7 times the maximal density in 2008 and 3 times that in 2010. Densities differed significantly among seasons and between study areas in all 3 years ($P < 0.001$ for STUDY AREA*SEASON*YEAR): Crested Auklets were more abundant in Klondike than in Burger in 2008, more abundant in Burger than in Klondike in 2009, and not significantly different among study areas in 2010. In 2008, densities were low in both study areas in Jul/Aug and Aug/Sep and highest in Sep/Oct, especially in Klondike. In 2009, the seasonal pattern of abundance differed significantly between the 2 study areas. Densities in Klondike were low in Jul/Aug and highest in Aug/Sep and Sep/Oct, whereas densities in Burger were highest in Jul/Aug and Aug/Sep and declined in Sep/Oct. In 2010, there was no strong seasonal trend in abundance, and densities were similar among study areas in Jul/Aug and Aug/Sep.

The only consistent spatial pattern for the distribution of Crested Auklets in both 2008 and 2009 was the abundance of Crested Auklets in Klondike and their near-absence from Burger in Sep/Oct (Figure 8). Patterns in 2009 indicated that

Table 1. Species of seabirds identified during boat-based surveys in the northeastern Chukchi Sea, by study area and season. Species identified on-transect within the study area are designated as “X8”, “X9” and/or “X10”, for 2008, 2009, and 2010, respectively. Species identified only off-transect in a given year are designated as “OT8”, “OT9”, and, “OT10” for 2008, 2009, and 2010 respectively. Species seen only on-transect and only within the 30-NM buffer zone (used in the historical comparisons) are designated as “B8”, “B9”, “B10”, for 2008, 2009, and 2010 respectively. Species identified in the historical dataset within the study area or buffer zone, available from the North Pacific Pelagic Seabird Database, are designated as “H.”

	Study area/season					
	Klondike			Burger		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
WATERFOWL						
Spectacled Eider	–	X9	–	–	OT9	OT10
King Eider	X8	–	X8	–	X8, OT10	X8, X10
Common Eider	–	–	–	–	X8	X10
White-winged Scoter	–	–	OT8	–	–	X8, OT10
Long-tailed Duck	X8	X9, H	X8, X9, B10	B9, H	X8, X9, X10, H	X8, B9, X10, H
LOONS						
Red-throated Loon	–	–	–	–	X8	–
Pacific Loon	–	X8, X9, X10	X8, X9	–	X8, X9, X10	X8, X9, OT10
Arctic Loon	H	–	H	–	H	–
Common Loon	–	H	–	–	–	–
Yellow-billed Loon	–	X8, X9	X8, X9	–	X8, X9, OT10	OT9
TUBENOSES						
Northern Fulmar	X8, X9, X10	X8, X9, X10, H	X8, X9	X8, X9, X10	X8, X9, X10	X8, X9, X10
Short-tailed Shearwater	X8, X9, X10	X8, X9, X10, H	X8, X9, B10, H	X9, X10	X8, X9, X10, H	X8, X9, X10
PHALAROPES						
Red-necked Phalarope	X9, X10	X8, X9, X10	X8, X9	X9, X10	X8, X9, X10	X9
Red Phalarope	X8, X9, X10, H	X8, X10, H	X8, X9	X9, OT10, H	X8, X9, X10, H	X9, X10
LARIDS						
Black-legged Kittiwake	X8, X9, X10, H	X8, X9, X10, H	X8, X9, B10, H	X8, X9, X10, H	X8, X9, X10, H	X8, X9, OT10, H
Ivory Gull	H	–	–	H	H	X8, H
Sabine's Gull	X8, OT9, X10, H	X8, X9, X10, H	X8, X9	X8, OT9, X10, H	OT8, X10	X9

Table 1. Continued.

	Study area/season					
	Klondike			Burger		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
LARIDS (cont'd.)						
Ross's Gull	–	–	–	H	OT9, H	X8, X9, X10, H
Herring Gull	X8, H	X9, H	X8	X9, H	X9, X10	X8
Glaucous-winged Gull	OT8	–	–	–	–	–
Glaucous Gull	X8, X10, H	X8, X9, X10, H	X8, X9, B10	X8, X9, X10, H	X8, X9, X10, H	X8, X9, X10, H
Arctic Tern	B8, H	X8, X10	–	X9, X10, B8	OT8, X9	–
Pomarine Jaeger	X8, X9, X10, H	X8, X9, X10, H	X8, X9	X8, X9, X10, H	X8, X9, X10	–
Long-tailed Jaeger	X9, X10, H	OT8, OT10, H	–	X9, H	OT8, X10	–
Parasitic Jaeger	X8, H	X8, OT10, H	–	X8, H	X10, B8, H	–
ALCIDS						
Dovekie	X8	–	X8	–	H	X8, X10
Common Murre	X8, B10, H	X9, X10, H	X8, X9	B10, H	X9, X10	X9
Thick-billed Murre	X8, X9, X10, H	X8, X9, X10, H	X8, X9, H	X8, X9, X10, H	X9, X10, B8	X8, X9, X10
Black Guillemot	X8, X10, H	–	–	X8, X10, H	B8, H	X8, OT10
Pigeon Guillemot	X8	–	–	X8	–	–
Kittlitz's Murrelet	X10, H	X9, X10, H	X8, B9	–	X10, B9	X9
Ancient Murrelet	–	X10	OT10	–	X10	X10
Parakeet Auklet	X10, H	X8, X9, X10, H	–	–	X10, H	X8, X10
Least Auklet	X8, X9, X10	X8, X9, X10, H	X8, X9, B10, H	X9, X10, H	X8, X9, X10	X8, X9, X10
Crested Auklet	X8, X9, X10	X8, X9, X10, H	X8, X9, B10, H	X9, X10	X8, X9, X10, H	X8, X9, X10
Horned Puffin	X8, X9, X10, H	X9	–	X8, X10, OT9	X10	–
Tufted Puffin	X8, X9, X10, H	OT9	X8	–	X10	–

Table 2. Species of seabirds identified during boat-based surveys in the northeastern Chukchi Sea, in the Statoil study area by season. Species identified on-transect within the study area are designated as "X10", for 2010. Species identified only off-transect are designated as "OT10" for 2010. Species identified in the historical dataset within the study area or buffer zone, available from the North Pacific Pelagic Seabird Database, are designated as "H."

	Study area/season		
	Statoil		
Species-group/species	Late summer	Early fall	Late fall
WATERFOWL			
Spectacled Eider	–	–	–
King Eider	–	–	–
Common Eider	–	OT10	–
White-winged Scoter	–	–	–
Long-tailed Duck	X10, H	X10, H	H
LOONS			
Red-throated Loon	–	X10	–
Pacific Loon	–	X10	–
Arctic Loon	–	H	–
Common Loon	–	–	–
Yellow-billed Loon			
TUBENOSES			
Northern Fulmar	X10	X10	–
Short-tailed Shearwater	X10	X10, H	–
PHALAROPES			
Red-necked Phalarope	X10	X10	–
Red Phalarope	OT, H	X10	–
LARIDS			
Black-legged Kittiwake	X10, H	X10, H	–
Ivory Gull	–	H	–
Sabine's Gull	X10	–	–
Ross's Gull	H	H	OT10, H
Herring Gull	H	X10	–
Glaucous-winged Gull	–	–	–
Glaucous Gull	X10, H	X10, H	H
Arctic Tern	–	–	–
Pomarine Jaeger	X10, H	X10	–
Long-tailed Jaeger	H	–	–
Parasitic Jaeger	H	H	–

Table 2. Continued.

	Study area/season		
	Statoil		
Species-group/species	Late summer	Early fall	Late fall
ALCIDS			
Dovekie	–	X10, H	–
Common Murre	H	X10	–
Thick-billed Murre	X10, H	X10	–
Black Guillemot	X10, H	H	–
Pigeon Guillemot	–	–	–
Kittlitz's Murrelet	X10	–	–
Ancient Murrelet	–	X10	–
Parakeet Auklet	X10	X10	–
Least Auklet	X10, H	X10	OT10
Crested Auklet	X10	X10, H	–
Horned Puffin	X10	X10	–
Tufted Puffin	X10	–	–

Crested Auklets were concentrated primarily in eastern Klondike in Jul/Aug, throughout Klondike in Aug/Sep, and in western Klondike in Sep/Oct, whereas they were concentrated in western Burger in all 3 seasons. In 2010, Crested Auklets were distributed throughout all 3 study areas in Jul/Aug and Aug/Sep, with densities following a similar pattern of spatially even distribution in Burger in Sep/Oct (Figure 8).

Least Auklet densities differed significantly among seasons and among study areas in all 3 years ($P < 0.001$ for STUDY AREA* SEASON*YEAR). Densities of Least Auklets were higher in Klondike than in Burger in all 3 seasons of 2008 and in Sep/Oct 2009, higher in Burger than in Klondike in Jul/Aug 2009, and similar between study areas in Jul/Aug 2010 and Aug/Sep 2009 (Figure 7, Tables 3–5). In 2010, densities were higher in Statoil than in both Burger and Klondike in Jul/Aug but higher in Burger than in both Klondike and Statoil in Aug/Sep 2010. In all 3 years, the seasonal pattern of abundance differed substantially among study areas. In 2008, densities of Least Auklets in Klondike were lowest in Jul/Aug, highest in Aug/Sep, and intermediate in Sep/Oct, whereas densities in Burger were zero in Jul/Aug and nearly zero in both Aug/Sep and Sep/Oct. In 2009, densities of Least Auklets in Klondike increased from Jul/Aug to Sep/Oct, whereas densities in Burger decreased from Jul/Aug to Sep/Oct. In 2010, densities increased sharply in Burger, increased moderately in Klondike, and remained similar in Statoil between Jul/Aug and Aug/Sep.

The patterns of distribution of Least Auklets were strongest in 2008, with birds concentrating in the northeastern half of Klondike in Jul/Aug and Aug/Sep but in the southwestern half in Sep/Oct (Figure 9). In 2009, there was a shift in overall distribution from Burger in Jul/Aug to Klondike in Sep/Oct, whereas there was no apparent spatial pattern of distribution within either study area in Aug/Sep. In 2010, there was a shift southward in concentration from Statoil in Jul/Aug to Burger in Aug/Sep. We have no data to evaluate the spatial pattern in Sep/Oct 2010.

Thick-billed Murre densities were consistently higher in Klondike than in Burger or Statoil and were lowest in Sep/Oct in all years ($P < 0.001$ for STUDY AREA and SEASON; Figure 7, Tables 3–5). In 2008, densities in Klondike were highest in Jul/Aug and low in Aug/Sep and Sep/Oct, whereas densities in Burger were extremely low in all 3 seasons. In 2009, densities of Thick-billed Murres in Klondike were low in Sep/Oct, high in Aug/Sep, and intermediate in Jul/Aug, whereas densities in Burger again were extremely low in all 3 seasons. In 2010, densities

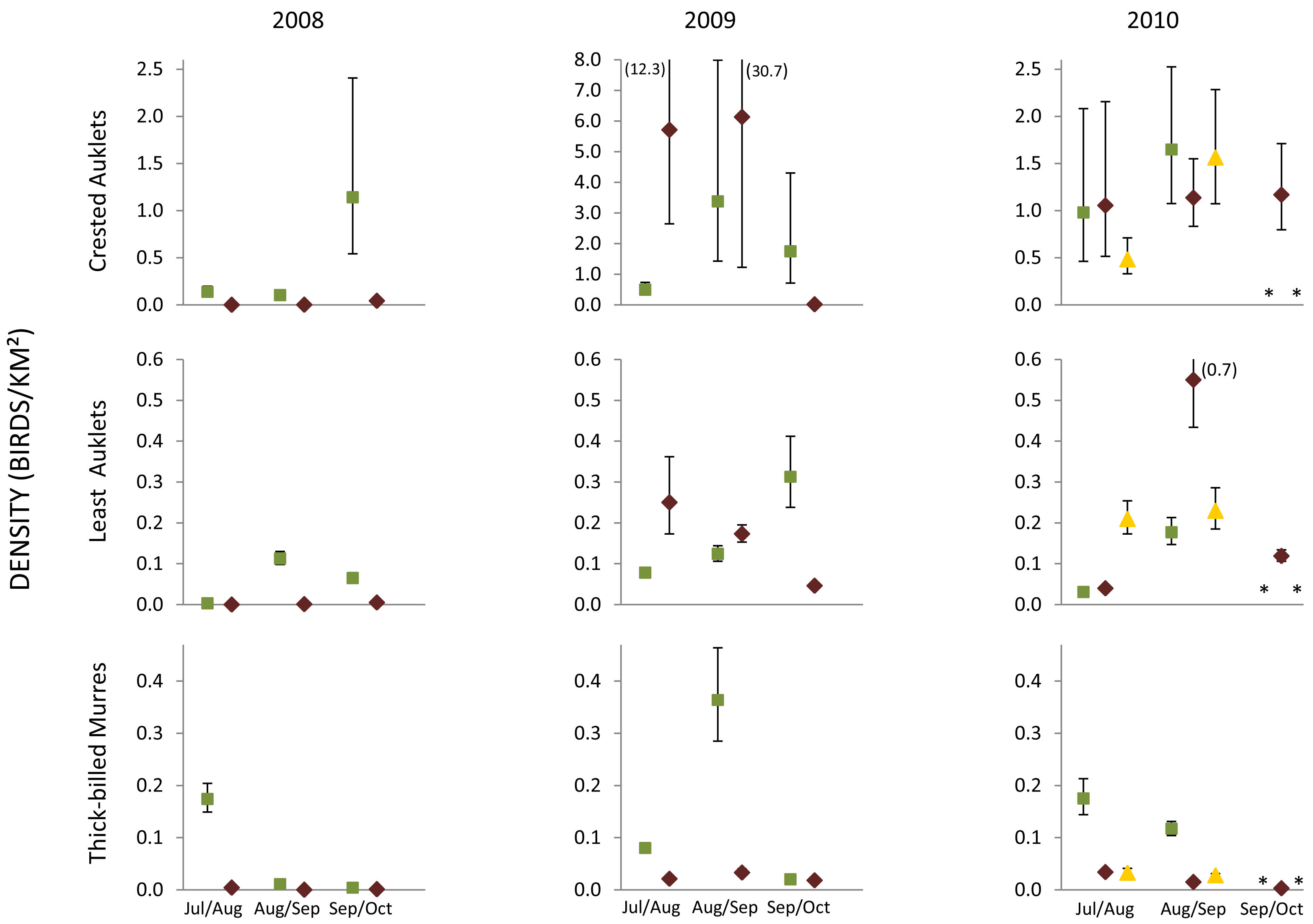

Figure 7. Mean density (birds/km^2) of Crested Auklets, Least Auklets, and Thick-billed Murres on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by study area and season. Error bars represent 95% confidence intervals. Asterisks indicate no data.

Table 3. Estimated densities (birds/km^2) of the 8 focal species of seabirds counted during boat-based marine surveys in the central Chukchi Sea, by study area and season, 2008. Values in parentheses are 95% confidence intervals.

	Study area/season					
Species-group/	Klondike			Burger		
species	July/August	August/September	September/October	July/August	August/September	September/October
PHALAROPES	0.004	0.08	0.095	0.0	0.14	0.0
	(0.003–0.004)	(0.06–0.107)	(0.075–0.121)	(0)	(0.115–0.17)	(0)
TUBENOSES						
Northern Fulmar	0.049	0.114	0.044	0.009	0.008	0.01
	(0.045–0.054)	(0.102–0.128)	(0.037–0.052)	(0.008–0.009)	(0.007–0.008)	(0.009–0.011)
Short–tailed Shearwater	0.003	0.232	0.323	0.0	0.192	0.067
	(0.003–0.003)	(0.17–0.315)	(0.212–0.492)	(0)	(0.121–0.303)	(0.055–0.08)
LARIDS						
Black–legged Kittiwake	0.074	0.038	0.139	0.020	0.123	0.021
	(0.066–0.083)	(0.034–0.042)	(0.118–0.165)	(0.018–0.022)	(0.104–0.146)	(0.019–0.023)
Glaucous Gull	0.009	0.011	0.082	0.009	0.032	0.023
	(0.008–0.009)	(0.01–0.011)	(0.076–0.089)	(0.008–0.009)	(0.029–0.034)	(0.02–0.027)
ALCIDS						
Thick–billed Murre	0.174	0.011	0.004	0.004	0.0	0.001
	(0.149–0.203)	(0.01 –0.012)	(0.003–0.004)	(0.004–0.004)	(0)	(0.001–0.001)
Least Auklet	0.003	0.113	0.065	0.0	0.001	0.005
	(0.003–0.003)	(0.098–0.13)	(0.055–0.078)	(0)	(0.001–0.001)	(0.005–0.005)
Crested Auklet	0.138	0.104	1.142	0.0	0.001	0.042
	(0.096–0.197)	(0.088–0.122)	(0.542–2.407)	(0)	(0.001–0.001)	(0.035–0.05)

Table 4. Estimated densities (birds/km^2) of the 8 focal species of seabirds counted during boat-based marine surveys in the central Chukchi Sea, by study area and season, 2009. Values in parentheses are 95% confidence intervals.

	Study area/season					
	Klondike			Burger		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
PHALAROPES	0.12	0.011	0.016	0.362	0.228	0.011
	(0.092–0.157)	(0.01–0.011)	(0.013–0.019)	(0.252–0.519)	(0.166–0.315)	(0.01–0.012)
TUBENOSES						
Northern Fulmar	0.142	0.056	0.007	0.173	0.041	0.026
	(0.121–0.166)	(0.049–0.064)	(0.006–0.007)	(0.14–0.215)	(0.038–0.044)	(0.022–0.031)
Short–tailed Shearwater	0.028	12.843	0.374	0.316	0.4	0.078
	(0.025–0.031)	(1.673–98.604)	(0.193–0.724)	(0.122–0.822)	(0.277–0.576)	(0.064–0.096)
LARIDS						
Black–legged Kittiwake	0.011	0.318	0.123	0.02	0.319	0.026
	(0.01–0.013)	(0.238–0.424)	(0.103–0.148)	(0.018–0.022)	(0.259–0.392)	(0.22–0.031)
Glaucous Gull	0.0	0.025	0.06	0.009	0.077	0.064
	(0)	(0.021–0.03)	(0.05–0.072)	(0.008–0.01)	(0.07–0.085)	(0.056–0.072)
ALCIDS						
Thick–billed Murre	0.08	0.364	0.02	0.021	0.033	0.018
	(0.071–0.09)	(0.285–0.464)	(0.017–0.022)	(0.02–0.023)	(0.027–0.04)	(0.015–0.021)
Least Auklet	0.078	0.124	0.313	0.25	0.173	0.046
	(0.067–0.092)	(0.106–0.144)	(0.237–0.412)	(0.172–0.362)	(0.153–0.195)	(0.041–0.051)
Crested Auklet	0.496	3.378	1.751	5.715	6.135	0.019
	(0.336–0.734)	(1.428–7.988)	(0.712–4.305)	(2.646–12.343)	(1.227–30.692)	(0.017–0.022)

Table 5. Estimated densities (birds/km^2) of the 8 focal species of seabirds counted during boat-based marine surveys in the central Chukchi Sea, by study area and season, 2010. Values in parentheses are 95% confidence intervals.

	Study area/season								
	Klondike			Burger			Statoil		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
PHALAROPES	0.083 (0.06–0.115)	0.319 (0.24–0.423)	–	0.007 (0.006–0.008)	0.108 (0.091–0.129)	0.006 (0.005–0.006)	0.028 (0.023–0.034)	0.221 (0.172–0.285)	–
TUBENOSES									
Northern Fulmar	0.024 (0.022–0.027)	0.034 (0.031–0.037)	–	0.039 (0.034–0.045)	0.012 (0. 0.013)	0.001 (0.001–0.001)	0.013 (0.012–0.014)	0.028 (0.025–0.031)	–
Short–tailed Shearwater	0.013 (0.011–0.015)	0.473 (0.314–0.713)	–	0.01 (0.009–0.011)	011–0.497 (0.284-0.87)	0.006 (0.005–0.006)	0.194 (0.128–0.295)	0.387 (0.286–0.523)	–
LARIDS									
Black–legged Kittiwake	0.028 (0.023–0.033)	0.163 (0.142–0.187)	–	0.018 (0.016–0.1)	0.065 (0.1–0.02)	0.0 (0)	0.016 (0.014–0.018)	0.096 (0.083–0.111)	–
Glaucous Gull	0.003 (0.003–0.003)	0.013 (0.012–0.015)	–	0.006 (0.005–0.006)	0.014 (0.013–0.015)	0.017 (0.016–0.019)	0.004 (0.004–0.004)	0.014 (0.013–0.015)	–
ALCIDS									
Thick–billed Murre	0.175 (0.144–0.213)	0.117 (0.105–0.131)	–	0.034 (0.031–0.036)	0.015 (0.014–0.017)	0.003 (0.003–0.004)	0.033 (0.027–0.041)	0.028 (0.025–0.031)	–
Least Auklet	0.031 (0.026–0.036)	0.177 (0.147–0.214)	–	0.04 (0.036–0.045)	0.55 (0.435–0.697)	0.119 (0.106–0.134)	0.21 (0.174–0.255)	0.23 (0.185–0.286)	–
Crested Auklet	0.981 (0.462–2.082)	1.648 (1.076–2.526)	–	1.054 (0.515–2.156)	1.136 (0.833–1.55)	1.168 (0.797–1.711)	0.484 (0.329–0.711)	1.565 (1.072–1.283)	–

of Thick-billed Murres in Klondike were high in Jul/Aug and low in Aug/Sep, and densities in Burger and Statoil were lower than densities in Klondike but followed a similar trend. Densities in Burger were near zero in Sept/Oct. The spatial pattern of distribution suggested higher densities in the southern half of Klondike in Jul/Aug 2008, Aug/Sep 2009 and 2010, and Sep/Oct 2008 and 2009, whereas there was no apparent spatial pattern of distribution within either Burger or Statoil (Figure 10).

Of the other 9 species of alcids recorded, Ancient Murrelets were the most abundant, despite occurring only in 2010 and only on the Aug/Sep and Sep/Oct cruises (Appendices B–D). They were present in all 3 study areas in Aug/Sep and were most abundant in Statoil. Parakeet Auklets were seen in Klondike in Aug/Sep of all 3 years; in Burger in Sep/Oct 2008 and 2010 and in Aug/Sep 2010; and in Statoil in Aug/Sep and Sep/Oct 2010. Common Murres occurred primarily in Klondike in Jul/Aug and Sep/Oct in 2008, in both Klondike and Burger in Aug/Sep and Sep/Oct in 2009, and in all 3 study areas in Aug/Sep 2010. In all 3 years, Tufted Puffins and Horned Puffins were seen primarily in Klondike in Jul/Aug. Kittlitz's Murrelets were rare in all 3 years and may have occurred in Klondike in Sep/Oct 2008 (we believe that the 5 unidentified murrelets were of this species), Aug/Sep 2009, and Jul/Aug and Aug/Sep 2010; and in Burger in Sep/Oct 2009 and Sep/Oct 2010. Black Guillemots and Dovekies also were seen in both Klondike and Burger, but only in low numbers and only in 2008 and 2010. Pigeon Guillemots were seen in both study areas and only in Jul/Aug 2008.

TUBENOSES

Tubenoses were the second-most-abundant species-group in 2008 and 2010 and the most abundant species-group in 2009, primarily because of large flocks of Short-tailed Shearwaters moving through Klondike in Aug/Sep (Figure 11). This species-group includes both non-breeding seasonal migrants and Northern Hemisphere residents. For example, Short-tailed Shearwaters migrate to the Bering and Chukchi seas from the Southern Hemisphere to feed during their non-breeding season, whereas Northern Fulmars are Northern Hemisphere breeders that nest in the Chukchi Sea and visit the study area during the open-water season.

Short-tailed Shearwaters were the second-most-abundant species in all 3 years of the study. The maximal density in 2009 was 30 times the maximal density in 2008 and 16 times the maximal density in 2010 (Figure 11, Tables 3–5). Short-tailed Shearwaters occurred in both study areas in Aug/Sep and Sep/Oct in 2008, in both study areas and in all 3 seasons in 2009, and in all 3 study areas in Jul/Aug and Aug/Sep in 2010. They generally were more abundant in Klondike than in Burger in 2008 and 2009 and occurred in similar, but lower, densities in Jul/Aug and Aug/Sep 2010. The highest densities were recorded in Statoil in Jul/Aug, and there was no significant difference in densities among the 3 study areas in Aug/Sep. In 2008, densities were lowest in Jul/Aug and high in Aug/Sep and Sep/Oct, when they are preparing to move from summer feeding areas back to breeding areas in the Southern Hemisphere. In 2009, densities were low at all times except for a large pulse of birds in Klondike in Aug/Sep. In 2010, densities were higher in Aug/Sep than in Jul/Aug, and we have no data to evaluate the trend in Sep/Oct.

The distribution of Short-tailed Shearwaters tended to be clumped in 2008 and 2009, whereas it was more uniform across all 3 study areas in Aug/Sep 2010 (Figure 12). In 2008, they tended to occur in the northeastern half of Klondike and the southwestern half of Burger when they were present. In 2009, they concentrated in the western halves of both Klondike and Burger in Jul/Aug, were most abundant in the western half of Klondike in Aug/Sep, and concentrated in the western half of Klondike but the eastern half of Burger in Sep/Oct (Figure 12). In 2010, they concentrated in the western half of Statoil in Jul/Aug and were scattered across all 3 study areas in Aug/Sep, whereas they occurred in Burger in very low densities in Sep/Oct.

Northern Fulmars were widespread, occurring in all study areas and in all 3 seasons during all years; their seasonal patterns of density did not differ significantly among the 3 study areas (P = 0.115 for STUDY AREA*SEASON). Northern Fulmars were significantly more abundant in Klondike than in Burger in 2008 (Figure 11), whereas densities did not differ significantly

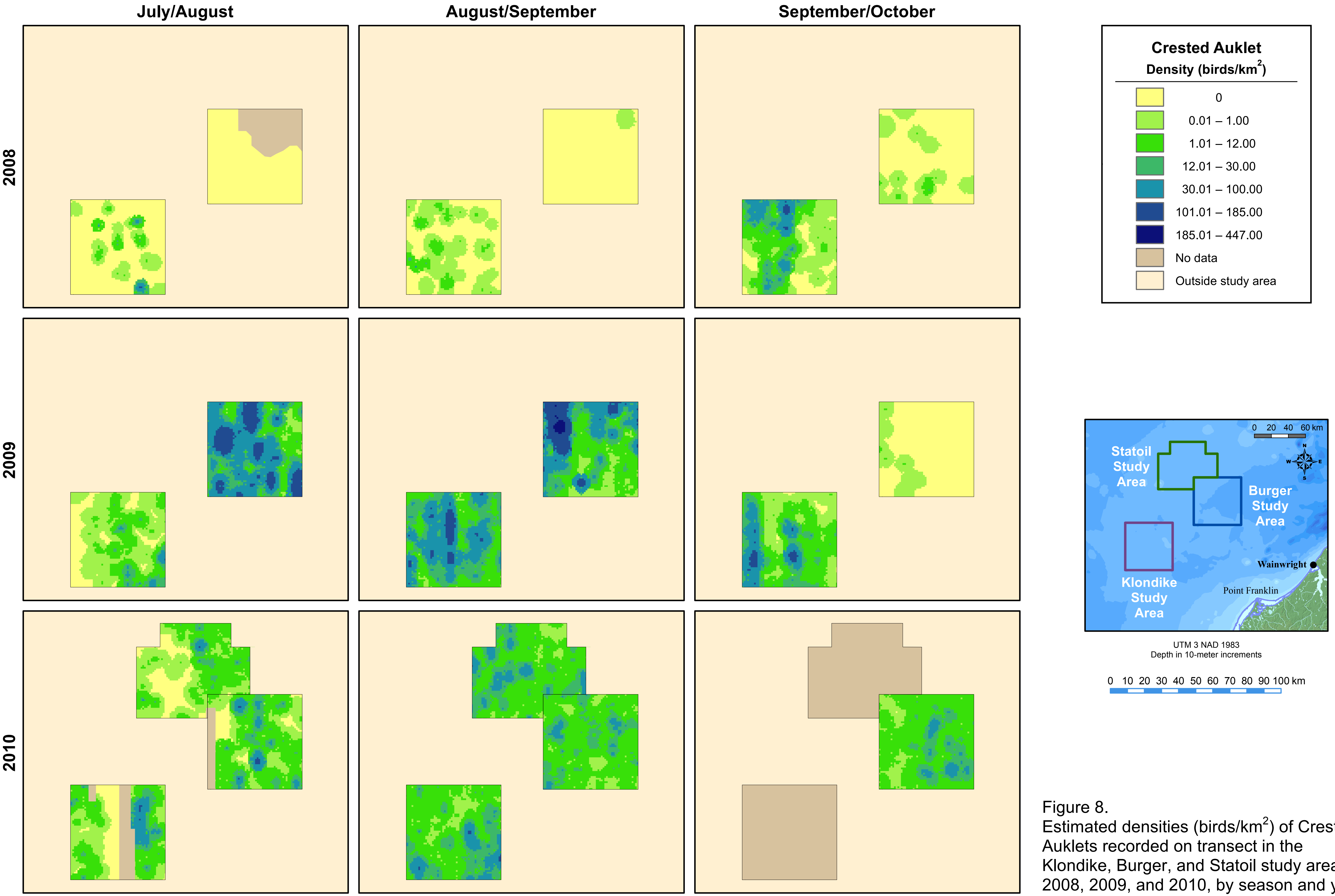

Figure 8.
Estimated densities (birds/km^2) of Crested Auklets recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by season and year.

Figure 9.
Estimated densities (birds/km^2) of Least Auklets recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by season and year.

Figure 10.
Estimated densities (birds/km^2) of Thick-billed Murres recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by season and year.

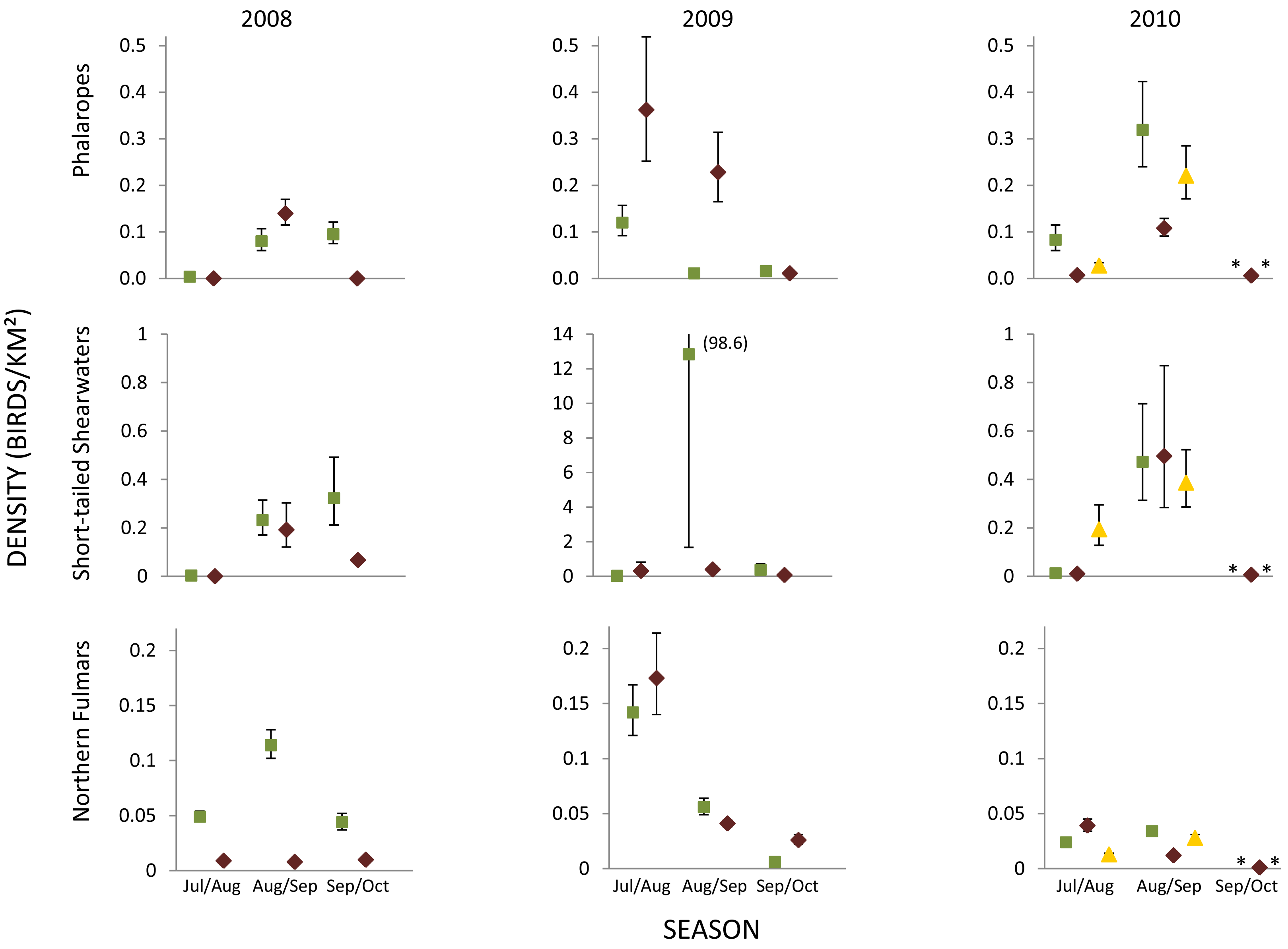

Figure 11. Mean density (birds/km^2) of phalaropes, Short-tailed Shearwaters, and Northern Fulmars on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by study area and season. Error bars represent 95% confidence intervals. Asterisks indicate no data.

between the 2 study areas in 2009 or 2010 (Figure 11; Tables 3–5).The seasonal abundance of Northern Fulmars differed among years, in that they were most abundant in Aug/Sep in 2008 and in Jul/Aug in 2009 but were low in all 3 study areas in Jul/Aug and Aug/Sep in 2010. Northern Fulmars were distributed across the entire Klondike study area in all 3 years (Figure 13) and across the entire Burger study area in 2009 and most of 2010, whereas they occurred primarily in the western half of Burger in 2008 and in Sep/Oct in 2010.

LARIDS

Larids were the third-most-abundant species group recorded during surveys. This group included gulls, terns, and jaegers. Of the 11 species of larids recorded on transect, Black-legged Kittiwakes and Glaucous Gulls were abundant enough in every year to examine patterns in distribution and abundance.

Black-legged Kittiwakes were widespread, occurring in both study areas and in all 3 seasons during 2008 and 2009 (Figure 14, Tables 3–5). In 2010, Black-legged Kittiwakes occurred in all 3 study areas and in Jul/Aug and Aug/ Sep but were absent from Burger in Sep/Oct. Densities of Black-legged Kittiwakes differed significantly among seasons and between study areas in both years ($P < 0.001$ for STUDY AREA*SEASON). Seasonal patterns differed more strongly between study areas in 2008, when densities were higher in Klondike in Jul/Aug and Sep/Oct but higher in Burger in Aug/Sep. In contrast, densities in 2009 were low and similar between study areas in Jul/Aug, highest and similar in Aug/Sep, and intermediate but higher in Klondike than in Burger in Sep/Oct. In 2010, seasonal patterns were similar to 2009, with low densities in Jul/Aug and high densities and no significant differences in density among the 3 study areas in Aug/Sep. There was little evidence of a spatial pattern in the distribution of Black-legged Kittiwakes within the study areas in any season or year (Figure 15).

Glaucous Gulls also were widespread, occurring in all study areas and in all seasons surveyed except for Klondike in Jul/Aug 2009 (Figure 14, Tables 3–5). Densities of Glaucous Gulls differed significantly among seasons and between study areas in 2008 and 2009 ($P \leq 0.01$ for STUDY AREA*SEASON*YEAR), and the seasonal pattern was similar among years. In all 3 years, densities of Glaucous Gulls in Klondike, Burger, and Statoil (in 2010) increased from Jul/Aug to Aug/Sep. Densities continued to increase from Aug/Sep to Sep/Oct in Klondike in 2008 and 2009 and in Burger in 2009 and 2010, whereas they declined in Burger during that period in 2008. There were no strong spatial patterns in the distribution of Glaucous Gulls within the study areas in any season or year (Figure 16).

Of the other 9 species of larids, Sabine's Gulls, Arctic Terns, Pomarine Jaegers, and Parasitic Jaegers were most common in Aug/Sep, Ross's Gulls were recorded only in Burger and only in Sep/Oct, and Herring Gulls occurred primarily in early and Sep/Oct (Appendices B–D). Sabine's Gulls and jaegers occurred primarily in Klondike, whereas Arctic Terns occurred in Klondike in 2008, in Burger in 2009, and in both study areas in 2010. Long-tailed Jaegers were seen off-transect on both study areas in Aug/Sep 2008 and on transect in both study areas in 2009 and 2010. Ivory Gulls occurred only in Burger, similar to the pattern seen for Ross's Gulls, and only in Sep/Oct 2008. A single Glaucous-winged Gull was seen only off-transect in Klondike and only in Jul/Aug 2008, after a storm with strong southerly winds.

PHALAROPES

Phalaropes were seen in patchy feeding flocks, primarily in Aug/Sep and Sep/Oct in 2008, in Jul/Aug and Aug/Sep in 2009, and in Aug/Sep in 2010 (Figure 11). Both Red and Red-necked phalaropes were seen feeding in mixed-species flocks, and numbers were pooled for estimates of density. In 2008, they were most abundant in Klondike in Sep/Oct and in Burger in Aug/Sep but, in both areas, the high counts occurred during transects surveyed in September and we saw few phalaropes in August and none in October. In 2009, phalaropes were most abundant in Burger and in both Jul/Aug and Aug/Sep, whereas numbers declined substantially in Sep/Oct. In 2010, phalaropes were more abundant in Aug/Sep than in Jul/Aug.

The spatial pattern of distribution indicates that phalaropes occurred in clumps in the southern half of Burger in Aug/Sep in 2008 and the southern

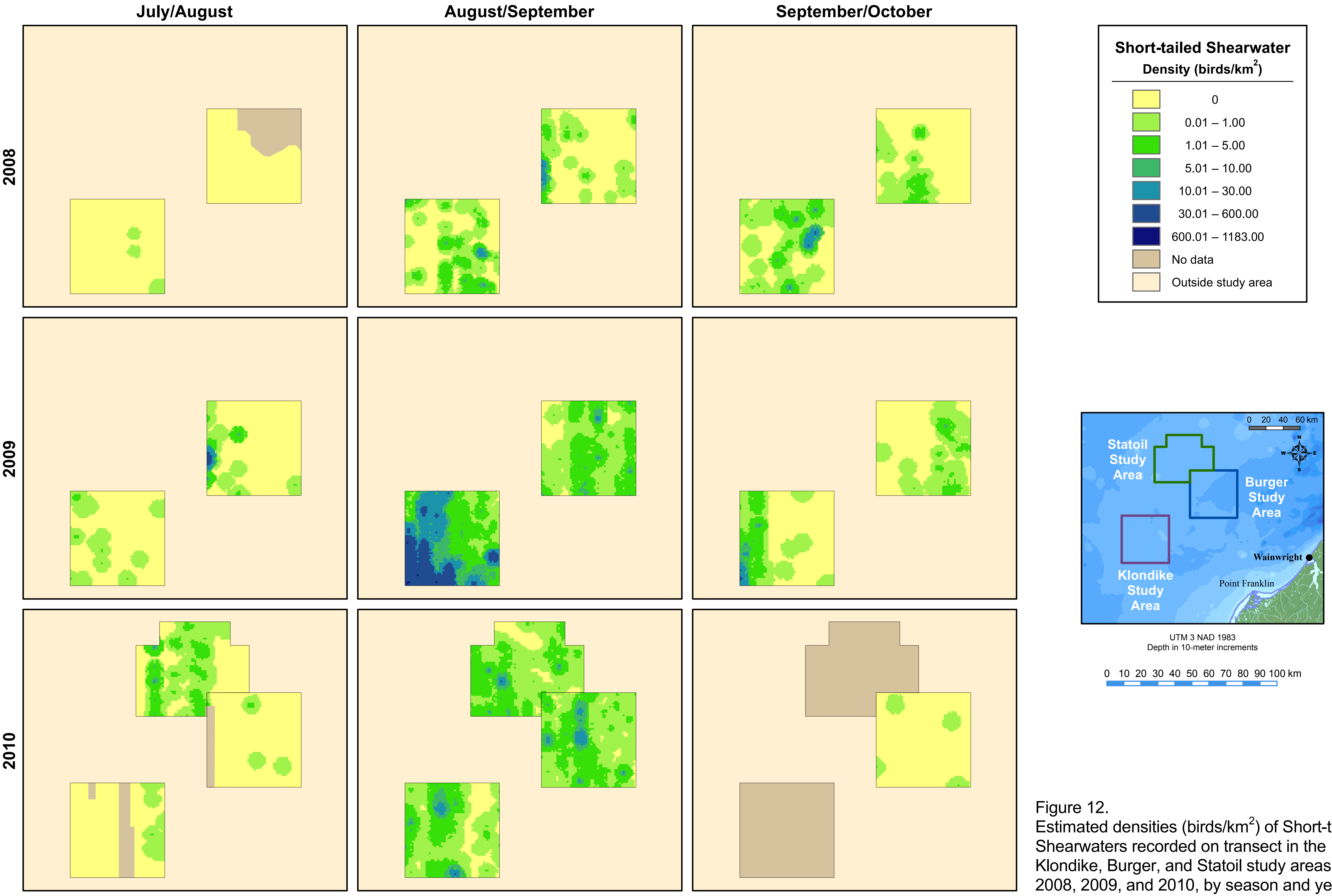

Figure 12.
Estimated densities (birds/km^2) of Short-tailed Shearwaters recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by season and year.

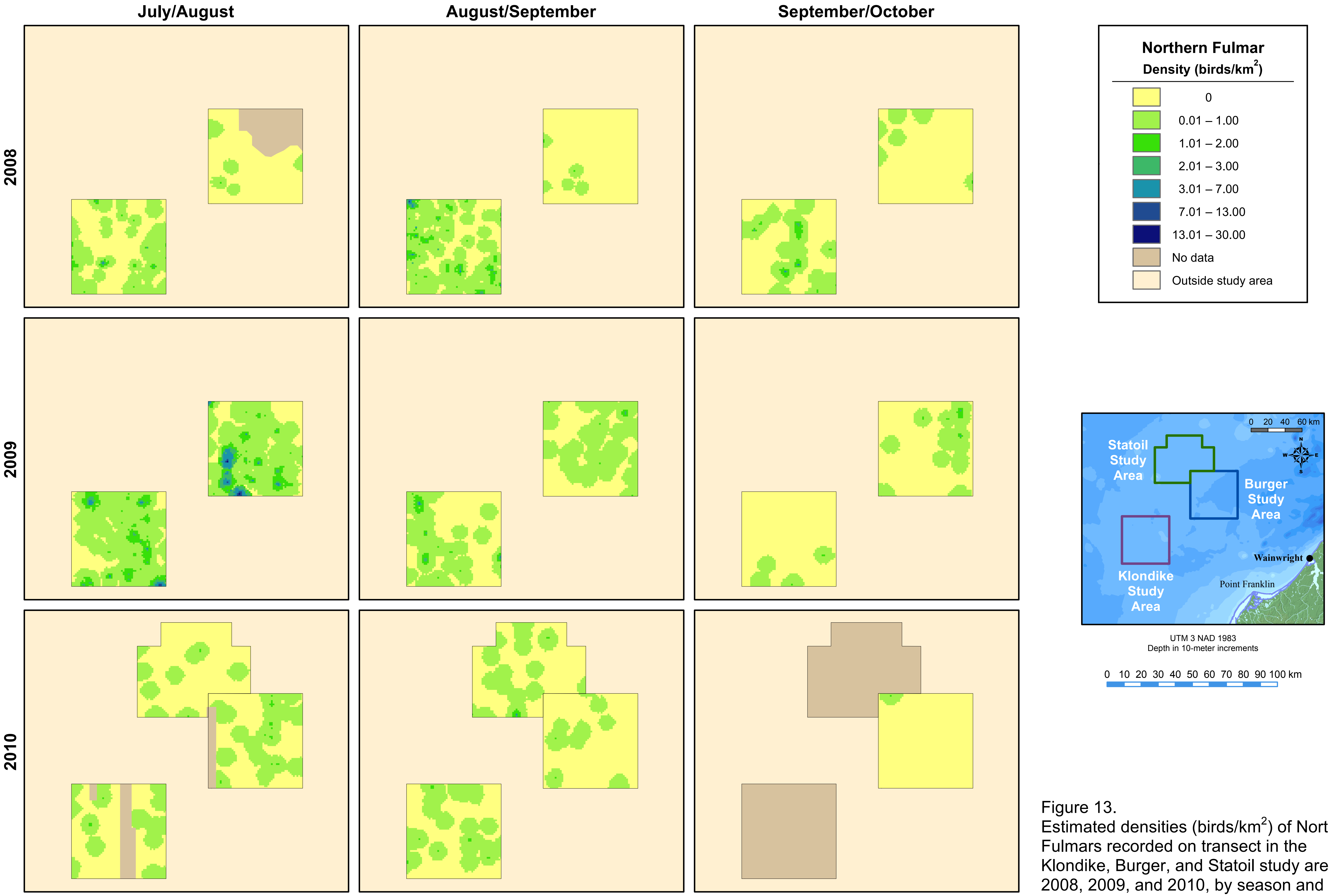

Figure 13.
Estimated densities (birds/km^2) of Northern Fulmars recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by season and year.

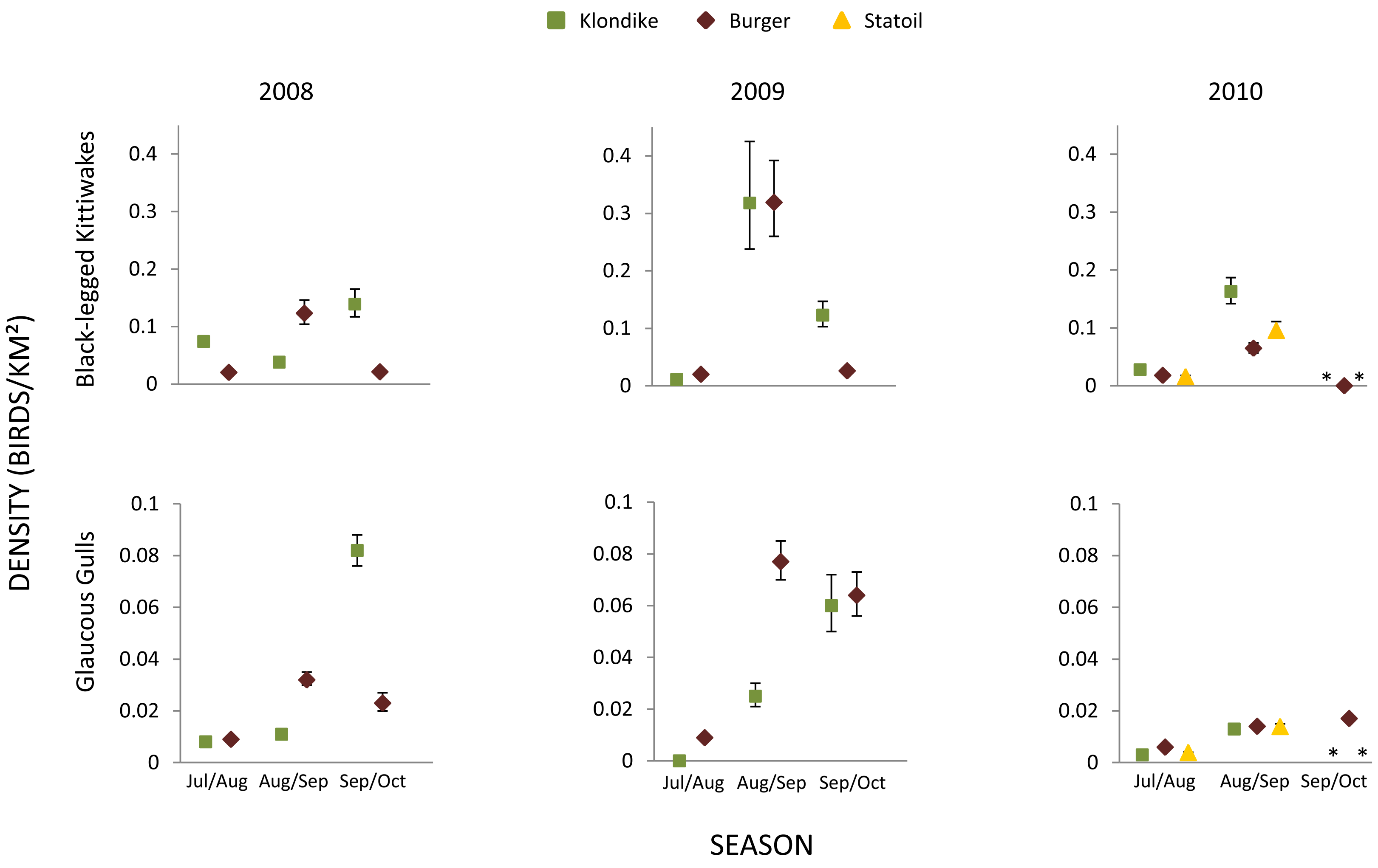

Figure 14. Mean density (birds/km^2) of Black-legged Kittiwakes and Glaucous Gulls on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by study area and season. Error bars represent 95% confidence intervals. Asterisks indicate no data.

half of Klondike in Sep/Oct (Figure 17). In 2009, phalaropes were concentrated on the western half of Burger in Jul/Aug and the eastern half of Burger in Aug/Sep. In 2010, there was no apparent spatial pattern in the distribution of phalaropes.

LOONS

In all 3 years, loons were recorded in both Aug/Sep and Sep/Oct and were completely absent from both study areas in Jul/Aug (Appendices B–D). Pacific Loons occurred in all 3 study areas but only in Aug/Sep and Sep/Oct. In 2008 and 2009, Pacific Loons were more abundant in Burger than Klondike in Aug/Sep but were more abundant in Klondike than Burger in Sep/Oct, suggesting a southward shift in distribution later in the fall. In 2010, the abundance of Pacific Loons was low in all 3 study areas, and they occurred only in Aug/Sep.

Of the other 2 species of loons, Yellow-billed Loons occurred in 2008 and 2009, whereas Red-throated Loons occurred in 2008 and 2010. Yellow-billed Loons were rare in 2008 but were more common in 2009 (Appendices B–D). In 2008, we saw a group of 3 Yellow-billed Loons in Klondike and 2 groups totaling 3 birds in Burger in Aug/Sep; we also saw a single bird in Klondike in Sep/Oct. In 2009, we saw 23 groups totaling 48 Yellow-billed Loons, and they were seen primarily in Aug/Sep and primarily in Burger and the eastern half of Klondike. Red-throated Loons were rare during these surveys: we saw one in Burger in Aug/Sep 2008, none in 2009, and one in Statoil in Aug/Sep 2010.

WATERFOWL

Waterfowl were seen in low densities in all seasons and in all 3 study areas and generally were more common in 2008 than in 2009 or 2010 (Table 1, Appendices B–D). Of the 5 species of waterfowl recorded, none was abundant enough to provide reliable estimates of density. In all years, Long-tailed Ducks were the most abundant waterfowl species, and they were seen in both study areas and in all seasons in 2008 and primarily in Aug/Sep in 2009 and 2010. Waterfowl species seen only in 2008 and 2010 included King Eiders, which were seen flying singly or in pairs on all 3 cruises, and single flocks of Common Eiders and White-winged Scoters recorded in Burger in Sep/Oct. We recorded a single flock of White-winged Scoters in Burger in Sep/Oct 2008, a single Spectacled Eider in Klondike on 8 September 2009, and a single Spectacled Eider off transect in Burger on 16 September 2009.

Total Density Estimates

The total density of marine birds differed among study areas in each season and year (Table 6). The total density of marine birds was significantly higher in 2009 than it was in 2008 or 2010. In spite of the much higher overall densities in 2009, relative densities were higher in Klondike than in Burger in both Aug/Sep and Sep/Oct. In contrast, the pattern differed among years in Jul/Aug, with densities higher in Klondike than in Burger in 2008, higher in Burger than in Klondike in 2009, and no significant difference among the 3 study areas in 2010 (Figure 18).

Community Structure

The total species list of birds seen on transect within study areas was similar between Klondike and Burger during all 3 years (Table 1), although overall species richness was higher in 2008 and 2010 than in 2009 (Figure 19). Of the 31 species recorded on transect in 2008, we recorded 26 in Klondike and 27 in Burger. Of the 24 species recorded on transect in 2009, we recorded 23 in Klondike and 20 in Burger. Of the 29 species recorded on transect in 2010, we recorded 21 in Klondike, 28 in Burger, and 23 in Statoil. Species that we saw only in 2008 included Pigeon Guillemot and the ice-associated Ivory Gull. The species that we saw only in 2010 was Ancient Murrelet. Species that we saw in 2008 and 2010, but not in 2009, included King Eider, Common Eider, Red-throated Loon, Parasitic Jaeger, Black Guillemot, and Dovekie, whereas all species seen in 2009 also were recorded in the other 2 years of the study. The species-richness of birds seen on transect was higher in Klondike than in Burger in all seasons and years except for Jul/Aug 2009 and Aug/Sep 2010. Species-richness in Statoil was equal to Klondike in Jul/Aug 2010 and was higher than Klondike but less than Burger in Aug/Sep 2010.

Figure 15.
Estimated densities (birds/km^2) of Black-legged Kittiwakes recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by season and year.

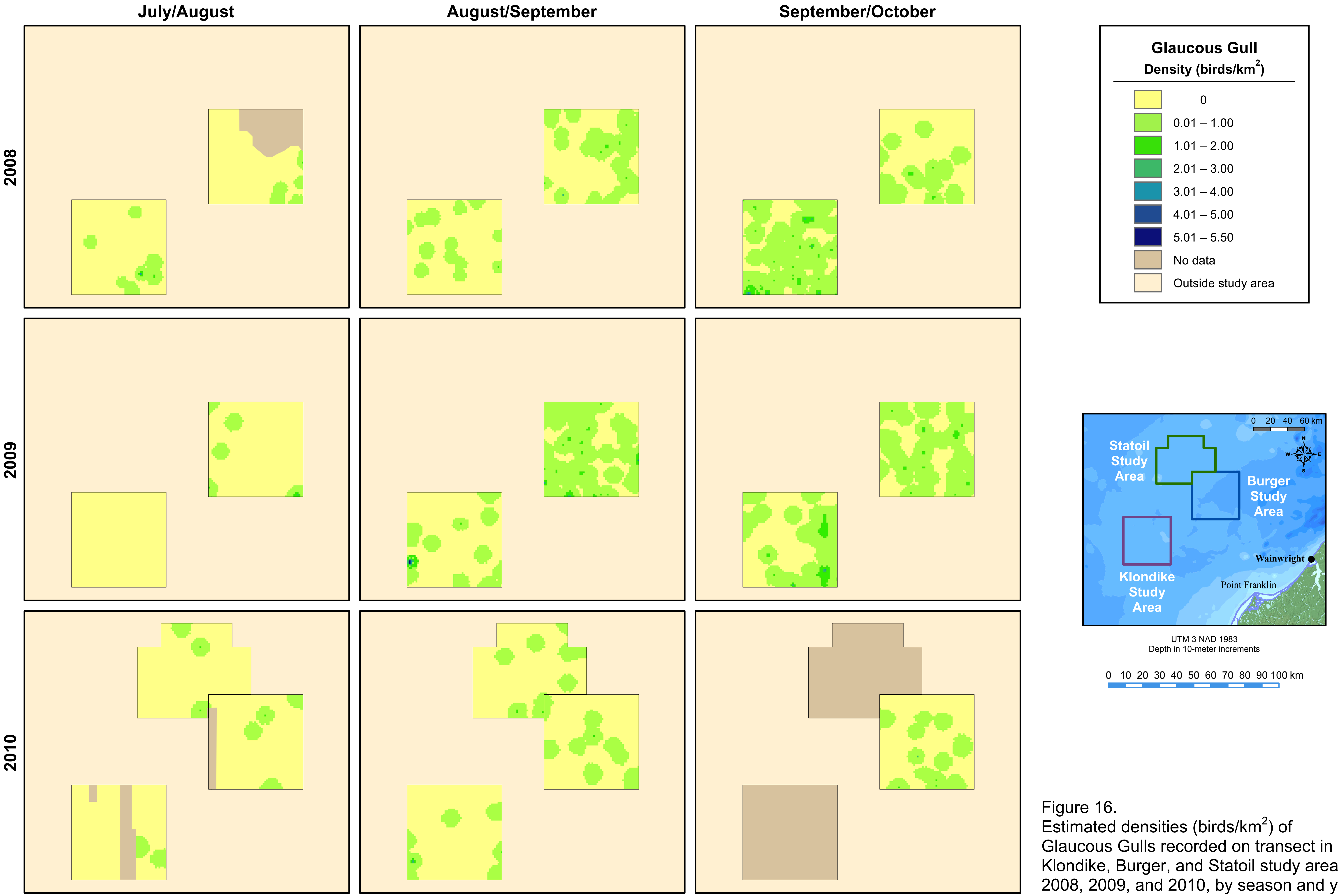

Figure 16.
Estimated densities (birds/km^2) of Glaucous Gulls recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by season and year.

Figure 17.
Estimated densities (birds/km^2) of phalaropes recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by season and year.

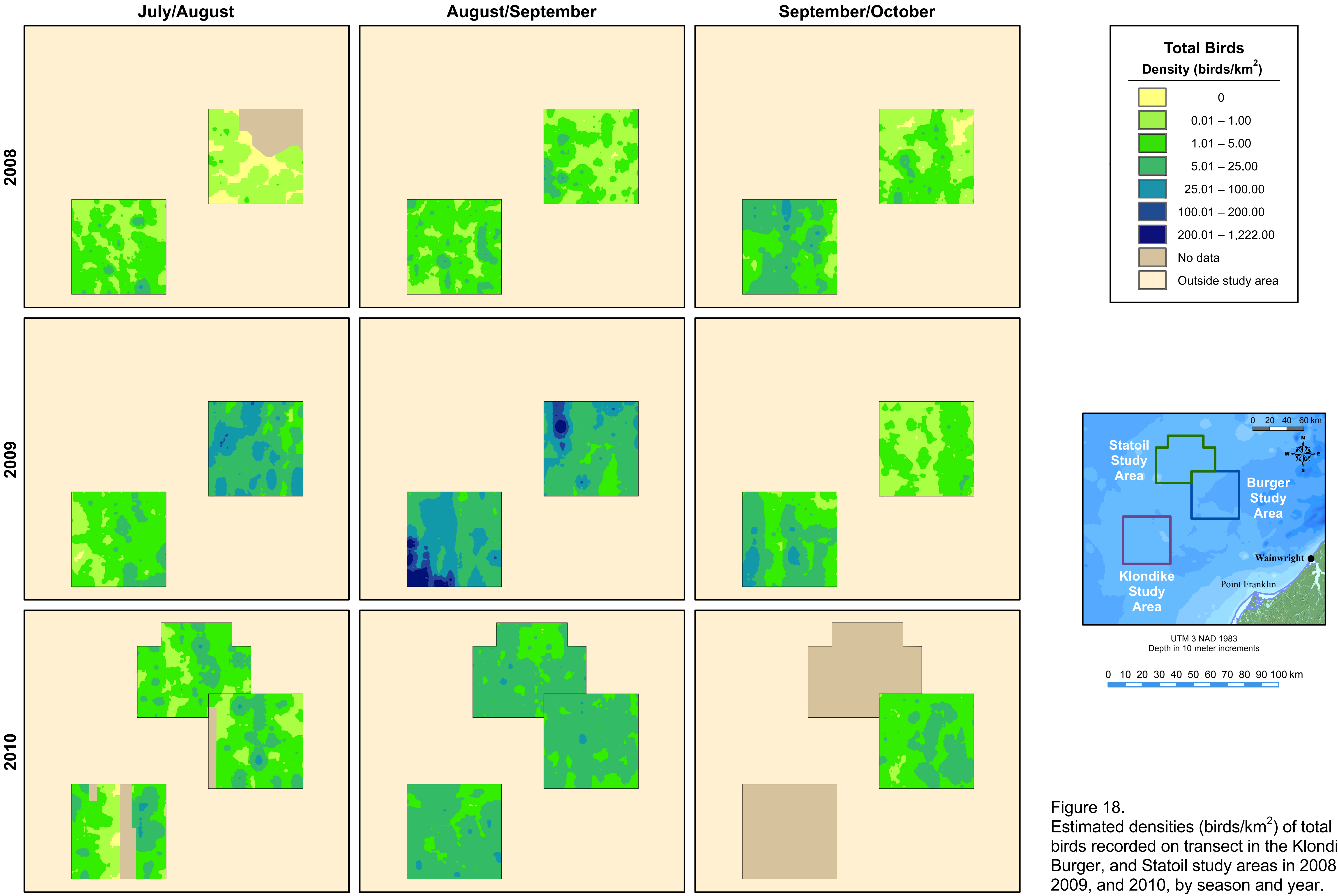

Figure 18.
Estimated densities (birds/km^2) of total birds recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010, by season and year.

Table 6. Estimated total densities (birds/km^2) of seabirds counted during boat-based marine surveys in the northern Chukchi Sea, by study area, season, and year. Values in parentheses are 95% confidence intervals.

	Study area		
Year/season	Klondike	Burger	Statoil
2008			
Jul/Aug	0.55 (0.44–0.67)	0.06 (0.05–0.06)	—
Aug/Sep	0.84 (0.64–1.08)	0.62 (0.47–0.83)	—
Sep/Oct	2.14 (1.13–4.05)	0.43 (0.35–0.53)	—
2009			
Jul/Aug	0.94 (0.67–1.33)	6.58 (3.07–14.13)	—
Aug/Sep	17.23 (2.52–117.91)	7.75 (1.80–33.42)	—
Sep/Oct	2.72 (1.23–6.00)	0.40 (0.32–0.51)	—
2010			
Jul/Aug	1.35 (0.69–2.61)	1.23 (0.64–2.35)	1.00 (0.70–1.43)
Aug/Sep	3.08 (2.28–4.16)	2.50 (1.68–3.74)	2.65 (1.93–3.63)
Sep/Oct	—	1.43 (1.03–1.99)	—

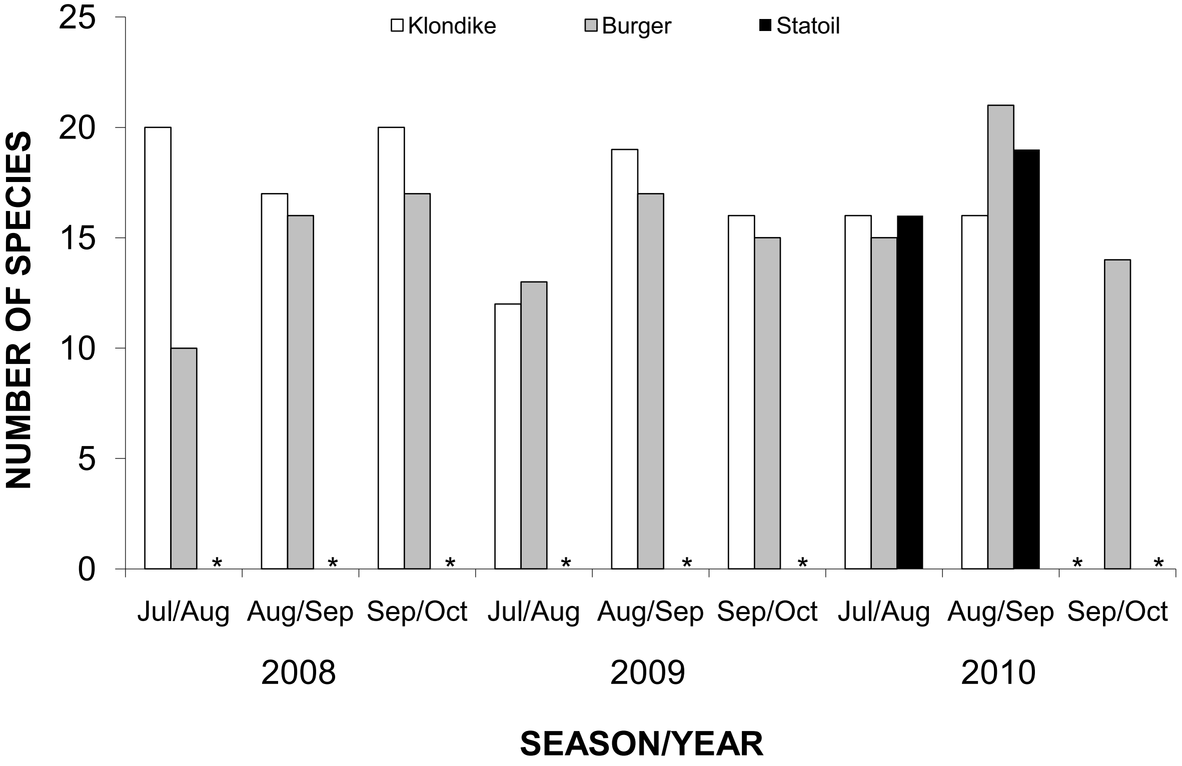

Figure 19. Species-richness of the seabird community recorded on transect in the Klondike, Burger, and Statoil study areas in 2008, 2009, and 2010 by study area and season. Asterisks indicate no data.

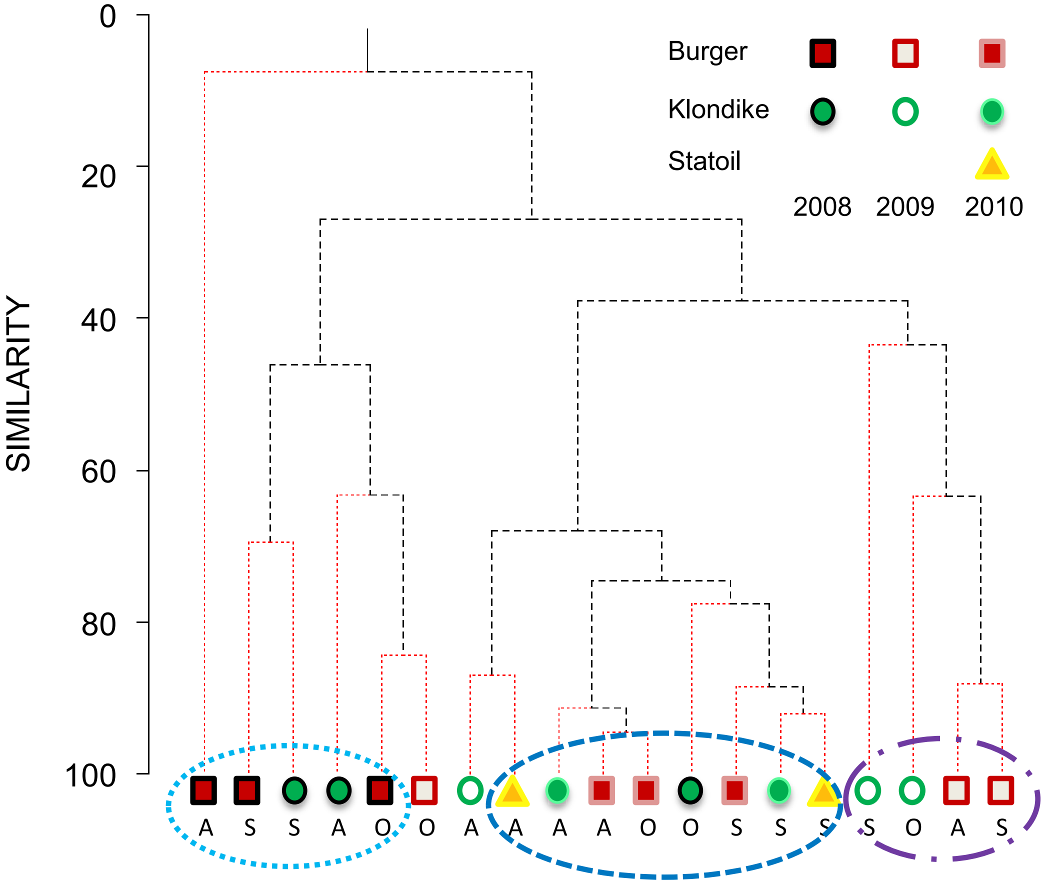

Figure 20. Cluster analysis of Bray-Curtis similarities based on *ln*(x+1)-transformed density of seabirds recorded in the northern Chukchi Sea during 2008, 2009, and 2010.

Multivariate analyses of the seabird community composition indicated that species-composition varied among seasons and among study areas, but the dominant pattern differed among years. The cluster analysis and nMDS ordination separated into 3 groups, with some overlap (misclassification) of areas by season and year (Figures 20 and 21). The variability among seasons and study areas was reflected in the low similarities of STUDY AREA*SEASON*YEAR samples within years. In the cluster analysis, 2008 samples were clustered at 44% similarity, 2009 samples were clustered at 45% similarity, and 2010 samples were clustered at 62% similarity (Figure 20). Overlap in community composition among years was demonstrated in the cluster analysis by 3 samples (Burger in Sep/Oct 2009, Klondike in Jul/Aug 2009, and Klondike in Sep/Oct 2008) that were classified as belonging to other years and 1 sample (Burger in Jul/Aug 2008) that did not join a multivariate group.

In the nMDS ordination, 2008 and 2010 represented distinct groups with little overlap (Figure 21, top panel). In contrast, 2009 overlapped both of the other years in Jul/Aug and Sep/Oct but showed a distinct community structure in Aug/Sep. When the points in the nMDS ordination were grouped by season, there was a strong shift in community composition from Jul/Aug to Aug/Sep, then community structure tended to shift back towards the Jul/Aug structure in Sep/Oct (Figure 21, bottom panel).

The patterns in species composition identified in the multivariate analyses could be identified in changes in the relative abundance of each of the 6 species-groups among seasons, study areas, and years (Figure 22). For example, the numerical dominance of alcids in all study areas combined

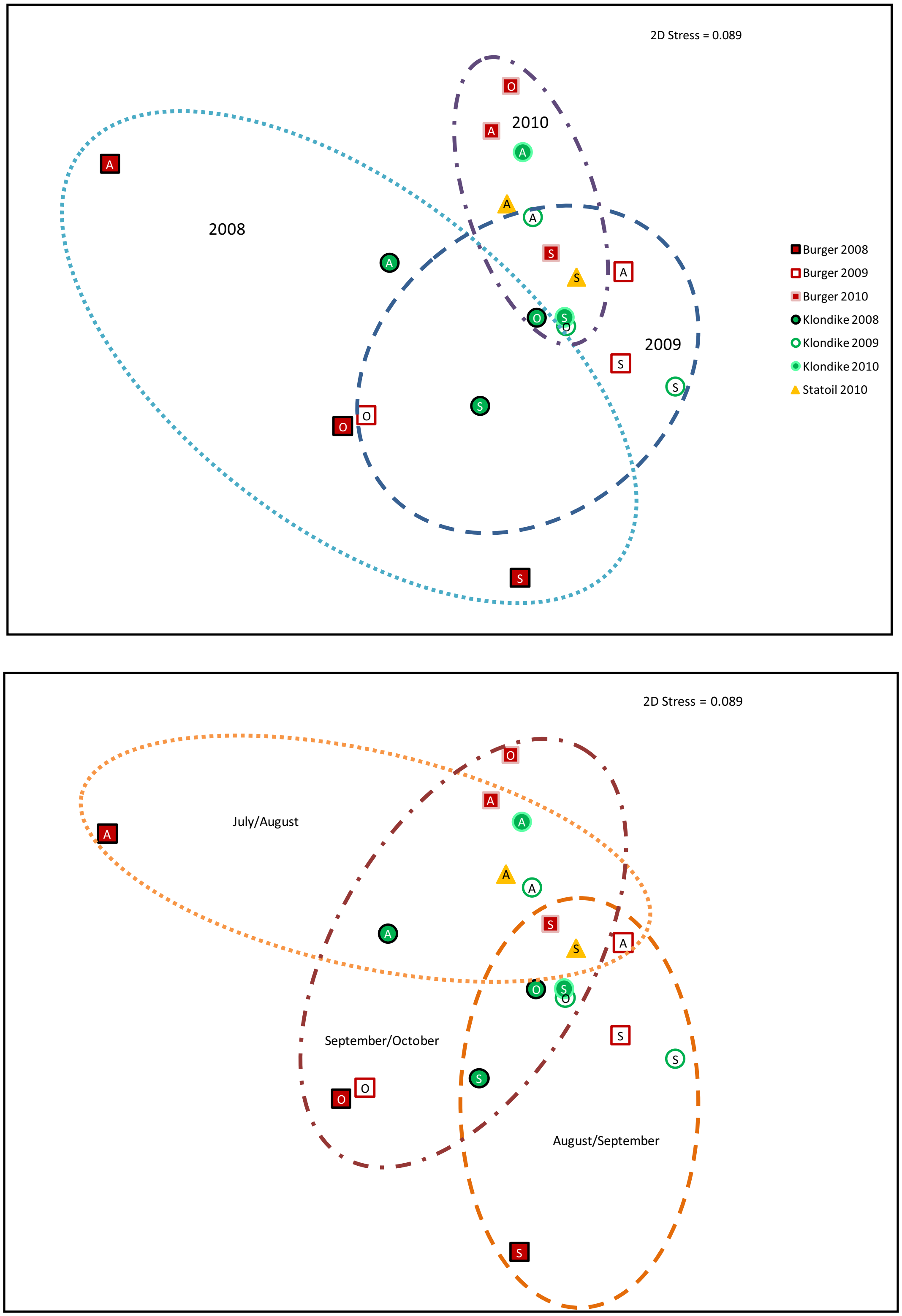

Figure 21. Nonmetric multidimensional scaling ordination plot of Bray-Curtis similarities for *ln*(x+1)-transformed density of seabirds recorded in the northern Chukchi Sea during 2008, 2009, and 2010.

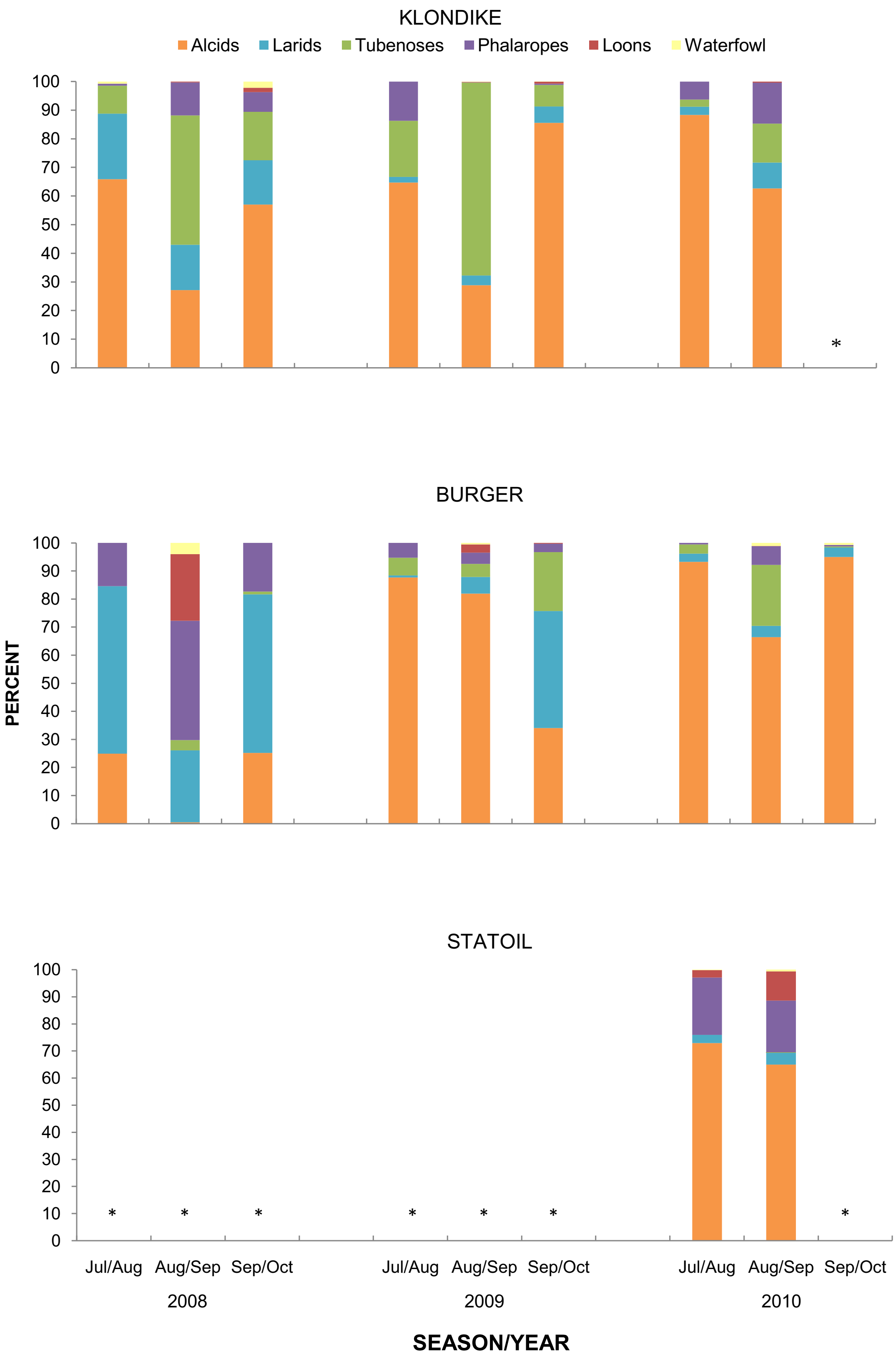

Figure 22. Species-composition of the seabird community on transect in the Klondike, Burger, and Statoil study areas, by season and year. Asterisks indicate no data.

increased from 2008 to 2010. Klondike was numerically dominated by alcids and tubenoses in all years. In 2008, alcids were the most abundant species-group and composed 53% of all birds, followed in decreasing order by tubenoses (24%) and larids (17%); in 2009, however, tubenoses were the most abundant species-group, composing 65% of all birds. Alcids remained important, but larids were present in trace numbers. Burger was numerically dominated by larids and tubenoses in 2008, but alcids were most abundant in 2009, composing 82% of all birds recorded there. In 2010, alcids were the most abundant species-group in all 3 study areas and in all seasons.

In Jul/Aug, alcids were the most abundant species-group in Klondike in all 3 years (Figure 22). In Jul/Aug 2008, alcids composed 62% of the seabird community in Klondike. In Jul/Aug 2009, alcids (primarily Crested Auklets) again were the most abundant species-group in Klondike, composing 68% of all birds; phalaropes and tubenoses collectively composed 30% of all birds, whereas larids composed only 2%. In contrast to the pattern seen in Klondike, the species-composition in Burger in Jul/Aug changed substantially among years. In 2008, larids (primarily Black-legged Kittiwakes) were the most abundant species-group in Jul/Aug, composing 65% of all birds, followed in decreasing abundance by alcids (20%) and tubenoses (15%); the other three species-groups were not recorded. In 2009, however, alcids (primarily Crested Auklets) were the most abundant species-group in Burger, composing 87% of all birds and followed in decreasing abundance by tubenoses (7%) and phalaropes (5%); larids accounted for <1% of all birds in Burger at that time. In Jul/Aug 2010, alcids were the most abundant species-group in all 3 study areas, composing 88% of the seabird community in Klondike, 92% of the seabird community in Burger, and 64% of the seabird community in Statoil.

In Aug/Sep, tubenoses were the most abundant species-group in Klondike and Burger in 2008 and in Klondike in 2009, whereas alcids were the most abundant species-group in Burger in 2009 and in all 3 study areas in 2010 (Figure 22). In 2008, tubenoses (especially Short-tailed Shearwaters) composed 46% of all birds recorded in Klondike, followed in decreasing order by alcids (30%) and larids (20%); loons and phalaropes occurred in minor percentages. In 2009, tubenoses again were the most abundant species-group in Klondike (74% of all birds), followed by alcids (23%), and trace percentages of other taxa. The species-composition in Burger in Aug/Sep changed substantially among years. In 2008, tubenoses (38% of all birds) and larids (30%) were the most abundant groups, followed in decreasing abundance by small percentages of waterfowl (primarily Long-tailed Ducks), phalaropes, and loons (primarily Pacific Loons). In 2009, however, alcids composed 82% of all birds, with tubenoses, larids, and loons in low and similar percentages; waterfowl and phalaropes were rare. In 2010, alcids numerically dominated all 3 study areas, composing 63% of all birds in Klondike, 66% of all birds in Burger, and 65% of all birds in Statoil.

In Sep/Oct, the pattern of species-composition in Klondike and Burger was similar between 2008 and 2009 (Figure 22). Alcids (primarily Crested Auklets) were the most abundant species-group in Klondike, and larids were the most abundant species-group in Burger, with tubenoses (primarily Short-tailed Shearwaters) second in abundance in Klondike and third in abundance in Burger. The most abundant larid species in Burger in 2008 was Ross's Gull, whereas the most abundant species in 2009 were Glaucous Gulls and Ross's Gulls. Loons, phalaropes, and waterfowl were rare in both study areas and in both years in Sep/Oct. In 2010, alcids were the most abundant species-group in Burger, composing 95% of all birds; we have no data on species abundance or composition in Klondike or Statoil in Sep/Oct 2010.

Conservation Status

During the surveys of 2008, 2009, and 2010, we recorded 11 species on transect in the study areas that are classified as being of conservation concern (Table 7). All of these species occurred on at least 2 of the 5 lists. Of these 11 species, 1 (Spectacled Eider) is listed as threatened under the ESA, 2 (Kittlitz's Murrelet and Yellow-billed Loon) are classified as candidate species under the ESA, and 2 (Red-throated Loon and Arctic Tern) are classified as species of conservation concern by the USFWS. The Bureau of Land Management considers all 4 species listed by the USFWS, plus 2

Table 7. Bird species in the northeastern Chukchi Sea that are of conservation concern.

	Listing organization				
Species[a]	USFWS[b]	BLM[c]	ADFG[d]	Audubon Alaska[e]	Alaska Natural Heritage Program[f]
Spectacled Eider	threatened species under the ESA	threatened species under the ESA	species of special concern	nationwide species of conservation concern	species of conservation concern
King Eider	–	sensitive species	featured species	state species of conservation concern	species of conservation concern
Common Eider	–	–	featured species	state species of conservation concern	–
White-winged Scoter	–	–	featured species	–	–
Long-tailed Duck	–	sensitive species	featured species	–	–
Red-throated Loon	species of conservation concern	sensitive species	featured species	state species of conservation concern	–
Yellow-billed Loon	candidate species under the ESA	sensitive species	featured species	nationwide species of conservation concern	species of conservation concern
Arctic Tern	species of conservation concern	–	featured species	–	–
Dovekie	–	sensitive species	–	–	species of conservation concern
Black Guillemot	–	sensitive species	–	–	species of conservation concern
Kittlitz's Murrelet	candidate species under the ESA	sensitive species	featured species	nationwide species of conservation concern	species of conservation concern

a. Only species with low population levels or similar concerns (e.g., rapidly declining populations; highly restricted breeding, staging, and/or wintering areas) are listed.

b. U.S. Fish and Wildlife Service, List of endangered, threatened, proposed, candidate, and delisted species in Alaska (USFWS 2009), and birds of conservation concern (USFWS 2008).

c. Bureau of Land Management, Special status species list for Alaska 2005 (http://www.blm.gov/pgdata/etc/medialib/blm/ak/aktest/ims.Par.13157.File.dat/im_ak_2006_003.pdf)

d. Alaska Department of Fish and Game, Division of Wildlife Conservation, Endangered Species in Alaska (http://www.adfg.state.ak.us/special/esa/esa_home.php), Alaska Species of Special Concern (http://www.adfg.state.ak.us/special/esa/species_concern.php), and State of Alaska's Comprehensive Wildlife Conservation Strategy (http://www.sf.adfg.state.ak.us/statewide/ngplan/).

e. The Audubon Alaska Watchlist 2010 (Kirchoff and Padula 2010).

f. Alaska Natural Heritage Program, Environmental and Natural Resources Institute, University of Alaska, Anchorage, AK; AKNHP Vertebrate Species Tracking List, November 2008 (http://aknhp.uaa.alaska.edu/zoology/Zoology_Birds_track08.htm). Species of conservation concern are categorized by status (critically imperiled, imperiled, vulnerable), geographic scale (global, national, sub-national), and breeding status in the region of concern (breeding, non-breeding, migrant).

others, to be sensitive species. Surprisingly, the Alaska Department of Fish and Game (ADFG) does not list any of the USFWS-listed species as species of special concern; instead, that state agency classifies eight species as featured for management in the State of Alaska's Comprehensive Wildlife Conservation Strategy. The non-governmental organization Audubon Alaska classifies 7 of the 11 species as being of conservation concern. Finally, the quasi-governmental organization Alaska Natural Heritage Program classifies 6 of the 11 species as being of conservation concern.

Of the 11 species of conservation concern, 4 (King Eider, Spectacled Eider, Yellow-billed Loon, and Kittlitz's Murrelet) occurred on all 5 lists, and Red-throated Loon occurred on 4 of the 5 lists, indicating that there is a high level of concern about the long-term fate of these 5 species in a wide variety of organizations. Only Arctic Tern occurred on 3 of the 5 lists, including both the USFWS and ADFG, so there is a substantial concern about them. The other 5 species occurred on 2 of the 5 lists, indicating concern but not widespread alarm about population trends of those species.

Yellow-billed Loons were rare in 2008, with a total of 4 seen in Klondike and 3 seen in Burger (Figure 23); in 2009, however, they were widely distributed throughout Burger, occurred in the eastern half of Klondike in Aug/Sep, and occurred in both study areas in low numbers in Sep/Oct (Figure 24). In 2010, we saw 2 Yellow-billed Loons in Burger in Sep/Oct (Figure 25).

Of the 5 species of waterfowl that are of conservation concern, only the Long-tailed Duck was recorded and widely distributed in all 3 years (Figures 26–28). In 2008, that species occurred only in Klondike in Jul/Aug, only in Burger in Aug/Sep, and essentially only in Klondike in Sep/Oct. In 2009, however, Long-tailed Ducks occurred in both study areas, primarily in Sep/Oct; in 2010, they were recorded in Statoil and Burger, primarily in Aug/Sep, whereas none were recorded in Klondike. Waterfowl species recorded in 2008 and 2010 but not in 2009 included King Eiders in both study areas, Common Eiders only in Burger, and White-winged Scoters only in Klondike in 2008 and in Burger in 2010. Spectacled Eiders were seen in Sep/Oct 2009 (1 in Klondike and 1 in Burger) and in Sep/Oct 2010 (1 in Statoil).

Arctic Terns occurred primarily in Klondike in Aug/Sep 2008 and Aug/Sep 2010, whereas the two observations in 2009 both occurred in Burger (Figures 23–25). The other 4 species of conservation concern were rare, with ≤21 observations/species in all seasons and years combined (Figures 23–25). A single Red-throated Loon was seen in Burger in Aug/Sep 2008 and 2 were seen in Statoil in Aug/Sep 2010. Dovekies were all seen as single birds and occurred in Klondike in Jul/Aug and Sep/Oct 2008, in Burger in Sep/Oct 2008, and in Statoil in Sep/Oct 2010. Black Guillemots were recorded in both study areas throughout 2008, but they primarily were associated with sea ice; as a result, none were seen in 2009, and we saw only 1 in each of the 3 study areas in Jul/Aug 2010. Finally, Kittlitz's Murrelets were rare: a total of 4 in Klondike in Sep/Oct 2008; 1 in Klondike in Aug/Sep and a group of 6 in Burger in Sep/Oct 2009; and 1 in Statoil and 2 in Klondike in Jul/Aug and 1 each in Klondike and Burger in Sep/Oct 2010.

Comparison with Historical Data

We compared seabird densities in this part of the Chukchi Sea between historical data contained in the NPPSD and those from our 2008–2010 surveys; however, the differences in sampling intensity between the 2 data sets preclude direct statistical comparisons. Spatial overlap between the 2 data sets was greatest in Jul/Aug and, to some extent, Aug/Sep, but no historical transects were conducted within ~9 km of any study area in October. Consequently, we are unable to derive any strong inferences from a qualitative comparison between the 2 data sets during that season.

In general, average uncorrected densities (birds/km^2) in the historical data set were higher on transects outside of the study-area boxes than on transects within the boxes (Figure 29). The highest densities in the vicinity of Klondike occurred west of the study area in Aug/Sep, whereas the highest densities in the vicinity of Burger and Statoil occurred north and northeast of the study area, over Hanna Shoal, also in Aug/Sep. Mean uncorrected densities recorded on historical transects within the study-area boxes were 4.3 ± 2.2 birds/km^2 in

Jul/Aug and 11.8 ± 4.8 birds/km² Aug/Sep. For data from this study, the lowest uncorrected densities were recorded in 2008 and were 1.3 ± 0.3 birds/km² in Jul/Aug and 2.6 ± 0.2 birds/km² in Aug/Sep (Figure 18). The highest mean uncorrected densities were recorded in Jul/Aug (12.6 ± 1.0 birds/km²) and Aug/Sep (43.1 ± 10.0 birds/km²) 2009 (Figure 18). Total densities were intermediate in 2010, with 3.9 ± 0.3 birds/km² in Jul/Aug and 9.0 ± 0.3 birds/km² in Aug/Sep. Although historical data were sparse in our study areas, these results indicate that the densities in Jul/Aug 2009 were 2 times higher than historical densities and that densities in Aug/Sep 2009 were 2.7 times higher than densities in the historical dataset, whereas densities in 2008 were lower and densities in 2010 were similar to historical densities.

The species-richness of birds in and near the 3 study areas was lower in the historical surveys (Figure 30) than it was in the CSESP surveys, especially in Sep/Oct (Figure 19). Although 8 of the 10 most abundant species were shared between the 2 data sets, another 8 species (King Eider, Common Eider, White-winged Scoter, Red-throated Loon, Yellow-billed Loon, Red-necked Phalarope, Ancient Murrelet, and Pigeon Guillemot) recorded on the 2008–2010 surveys were not recorded on the historical surveys. In contrast, only one species (Arctic Loon; *Gavia arctica*) was recorded on the historical surveys that was not recorded on the 2008–2010 surveys, and we suspect that that record represented an uncorrected data point (Pacific Loon was separated taxonomically from Arctic Loon in the 1980s). To a great extent, however, the higher richness in the CSESP surveys, when sampling effort was much greater than that in the historical data set, was to be expected because species-richness is sensitive to sampling effort (Magurran 2004).

Seasonal and spatial patterns in species-composition suggest that alcids and tubenoses are more abundant in the northern Chukchi Sea now than they were historically (Figures 22 and 31). In Klondike, the historical data indicate that larids were the most abundant species-group in Jul/Aug, and tubenoses were the most abundant species-group in Aug/Sep and Sep/Oct. Loons also were numerically important in Klondike in Sep/Oct, composing 20% of all birds. In Burger/Statoil, however, the historical data indicate that larids were the most abundant species group in Jul/Aug and Aug/Sep, whereas larids and waterfowl were equally abundant in Sep/Oct. There were no historical records of tubenoses in or near Burger in any season. In contrast, data from our study indicated that alcids were most abundant in Klondike in Jul/Aug and Sep/Oct, alcids were the most abundant species group in Burger in all 3 seasons, and tubenoses were recorded in Burger in all 3 season of every year.

Discussion

Oceanographic Relationships

We propose here that the structure of the seabird community in the northeastern Chukchi Sea differs spatially and temporally and that these differences reflect oceanographic differences among the 3 study areas, seasons, and years. The oceanography of this area is well documented in recent literature (Coachman et al. 1975, Weingartner et al. 2005, Woodgate et al. 2005, Grebmeier et al. 2006, Hopcroft et al. 2008). In the Chukchi Sea, the net flow of water is northward through Bering Strait and toward the Arctic Ocean. The flow is contained within 2 main water-masses, with (1) the Alaska Coastal Current flowing northward in Alaska Coastal Water, a warm, low-salinity water-mass that lies near the Alaska coastline; and (2) a current farther offshore that moves Bering Shelf Water (a combination of shelf water from the Bering Sea and oceanic Anadyr Water that has flowed northward across the Bering Sea shelf) northward through Bering Strait. This movement of water influences the patterns of productivity throughout the Chukchi Sea (Grebmeier et al. 2006). *In-situ* primary productivity in the northern Chukchi Sea generally is not very high (on the order of ~80 g C/m²/yr), whereas productivity in the Bering Shelf Water that is transported from farther south may be on the order of ~470 g C/m²/yr near Bering Strait (also see Sambrotto et al. 1984 and Hansell et al. 1989). This Bering Shelf Water also advects large oceanic zooplankton into the area from the Bering Sea basin (Grebmeier et al. 2006), and these large

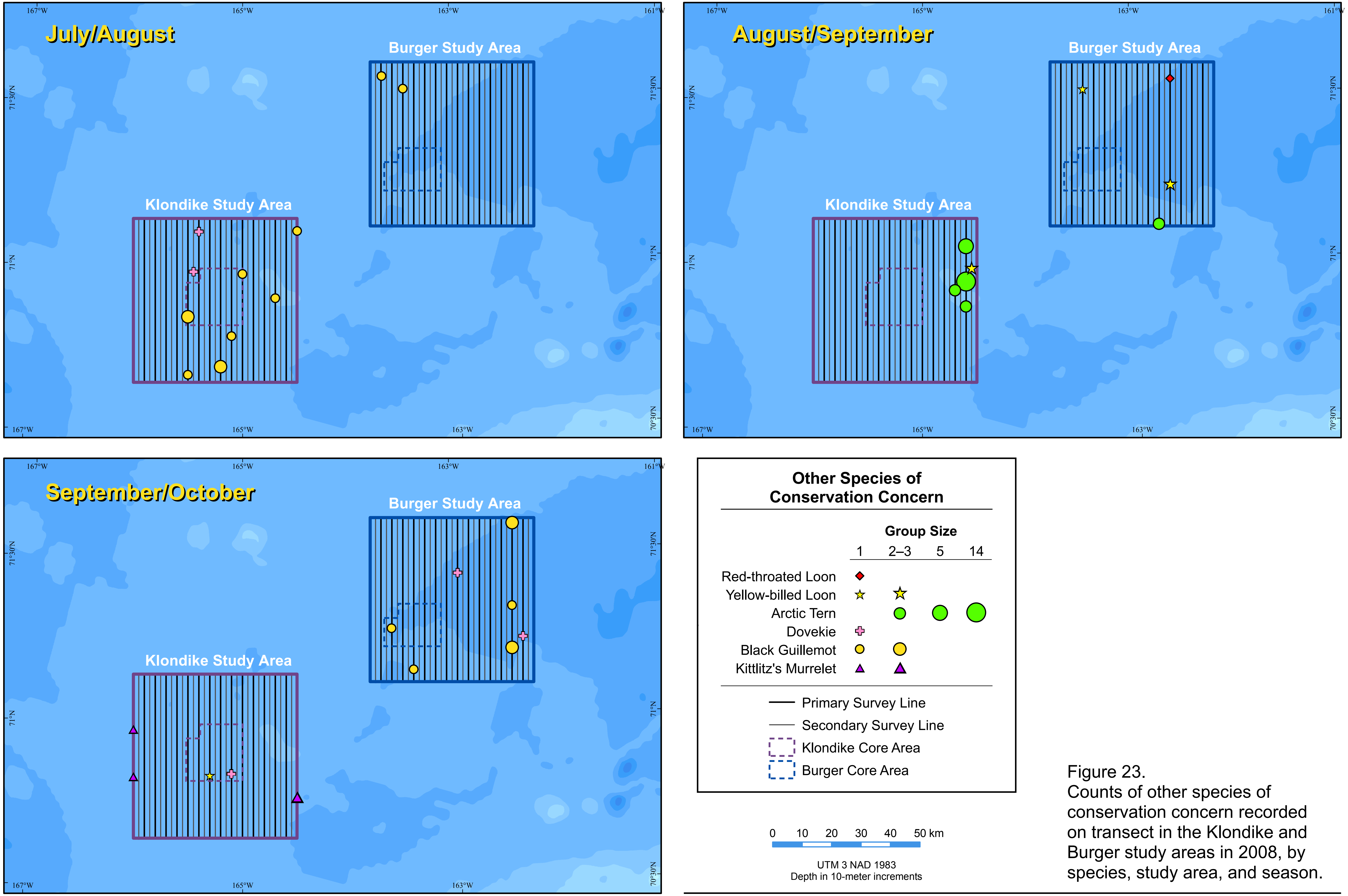

Figure 23.
Counts of other species of conservation concern recorded on transect in the Klondike and Burger study areas in 2008, by species, study area, and season.

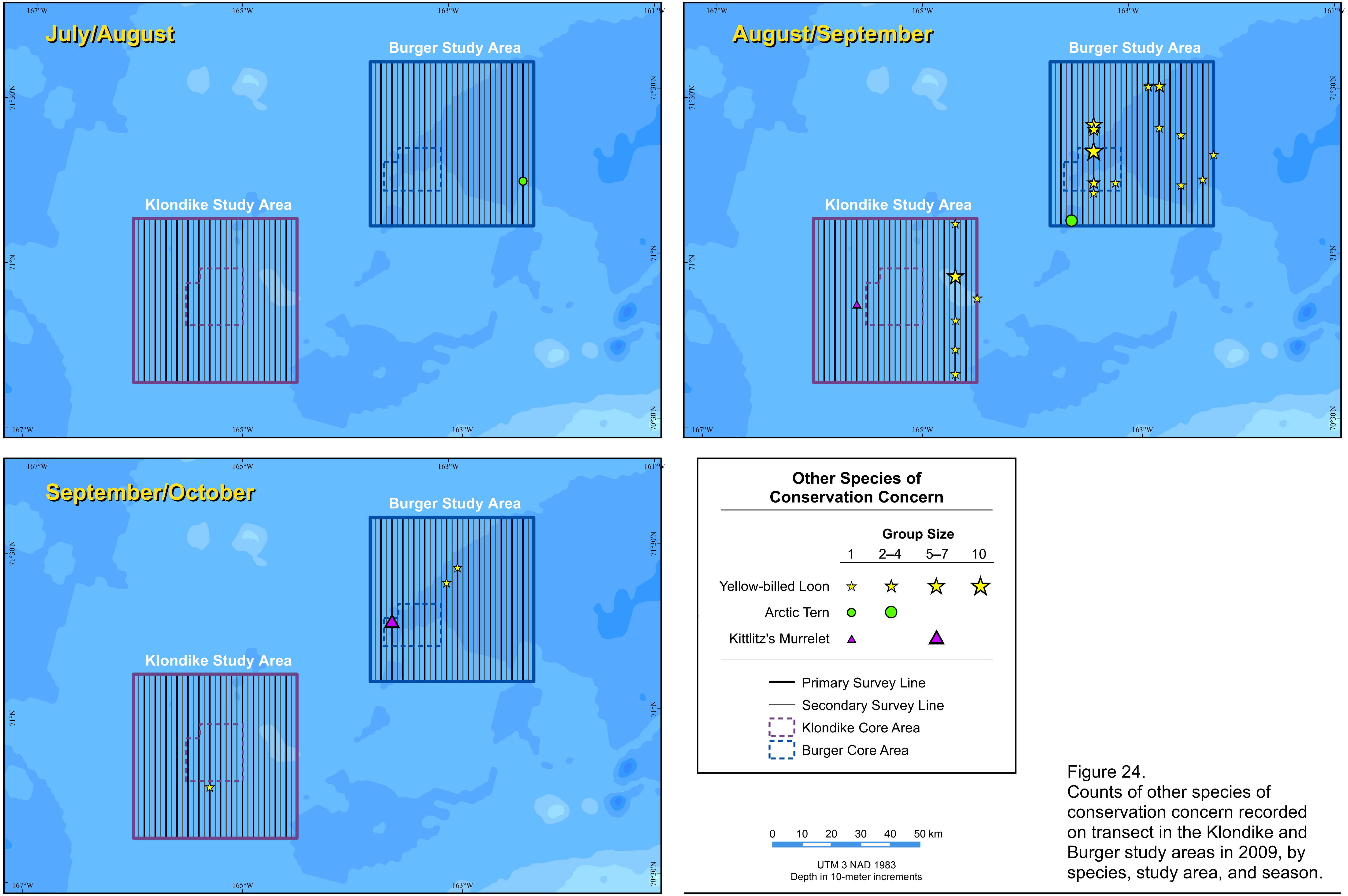

Figure 24.
Counts of other species of conservation concern recorded on transect in the Klondike and Burger study areas in 2009, by species, study area, and season.

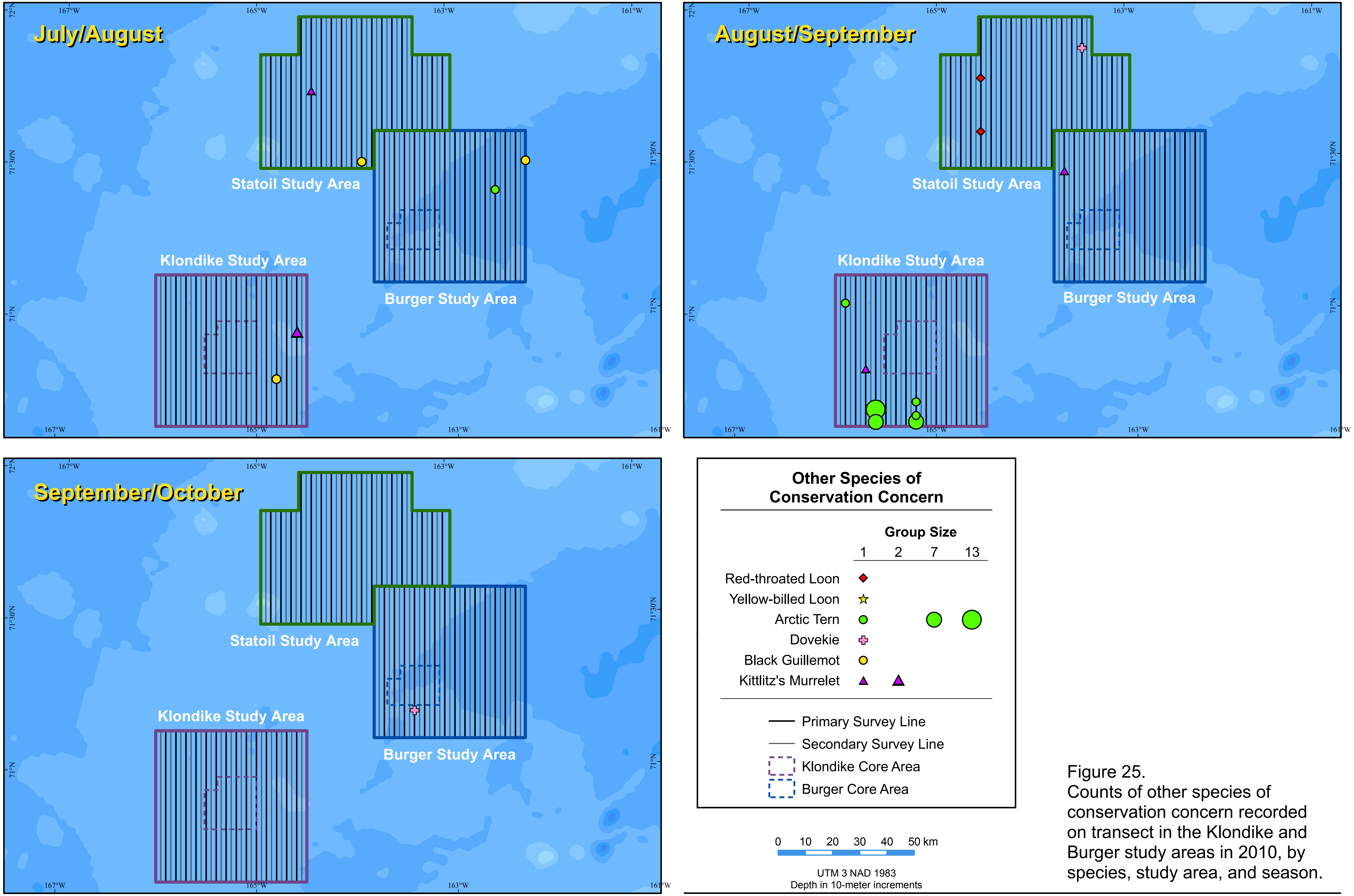

Figure 25.
Counts of other species of conservation concern recorded on transect in the Klondike and Burger study areas in 2010, by species, study area, and season.

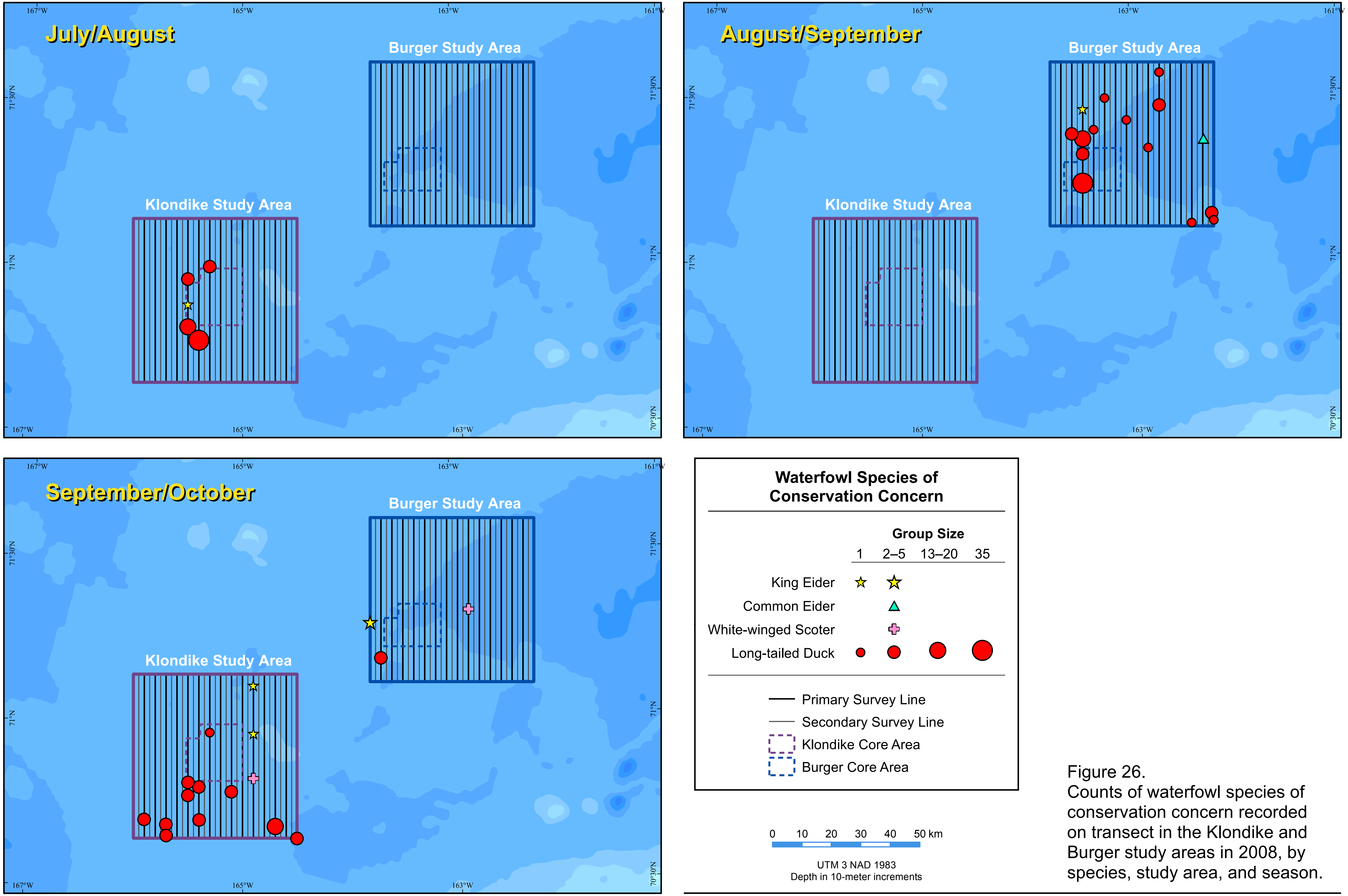

Figure 26.
Counts of waterfowl species of conservation concern recorded on transect in the Klondike and Burger study areas in 2008, by species, study area, and season.

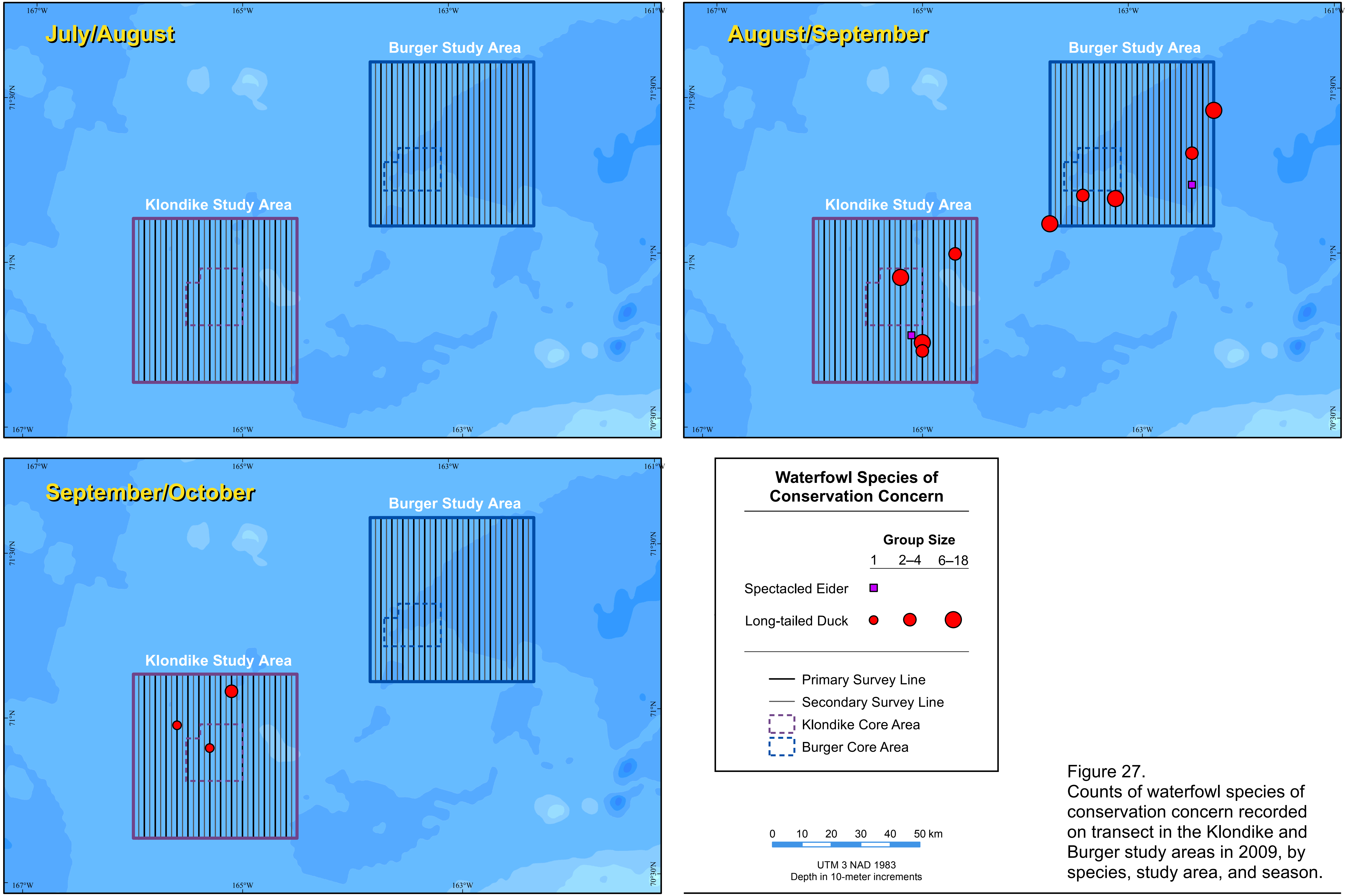

Figure 27.
Counts of waterfowl species of conservation concern recorded on transect in the Klondike and Burger study areas in 2009, by species, study area, and season.

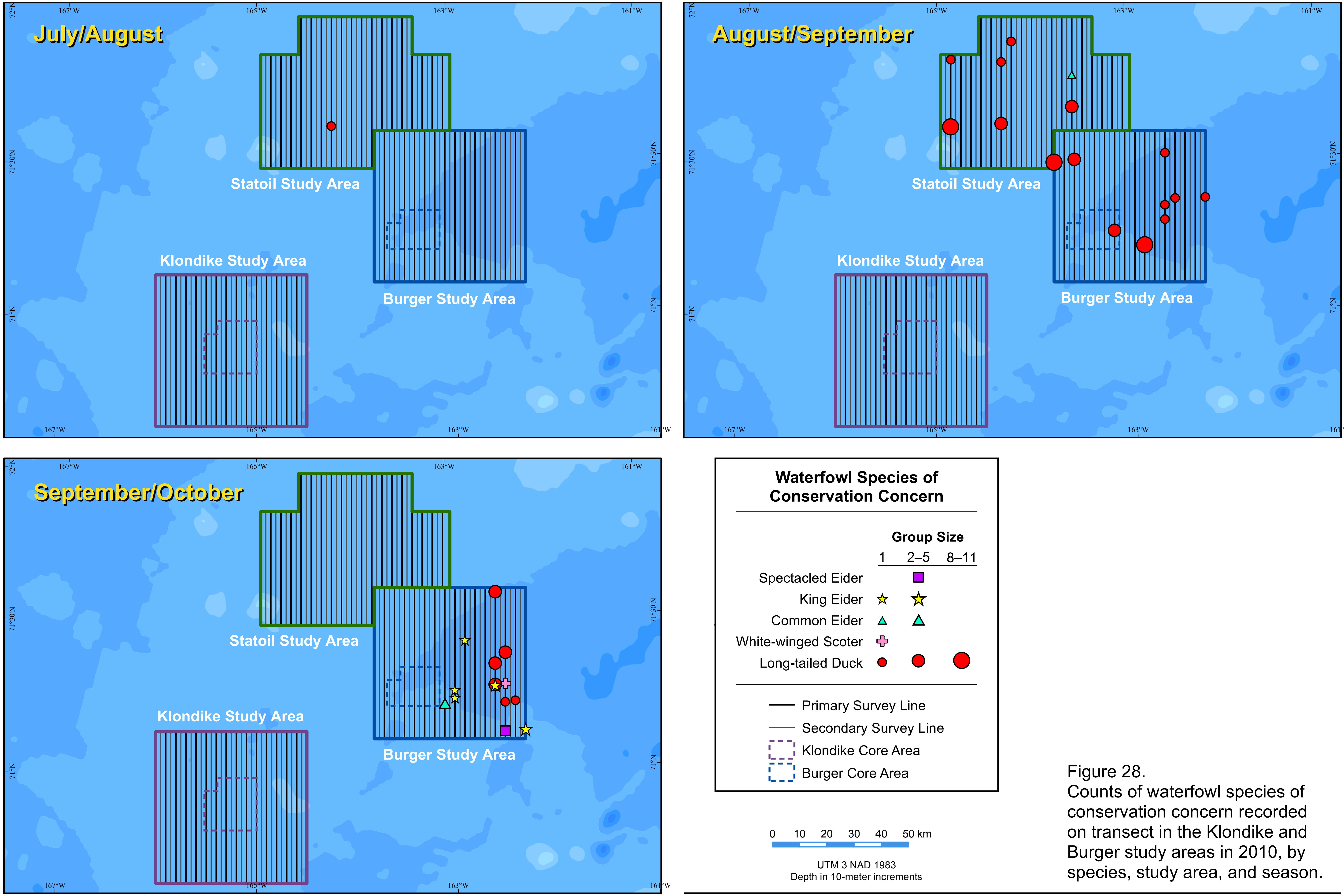

Figure 28.
Counts of waterfowl species of conservation concern recorded on transect in the Klondike and Burger study areas in 2010, by species, study area, and season.

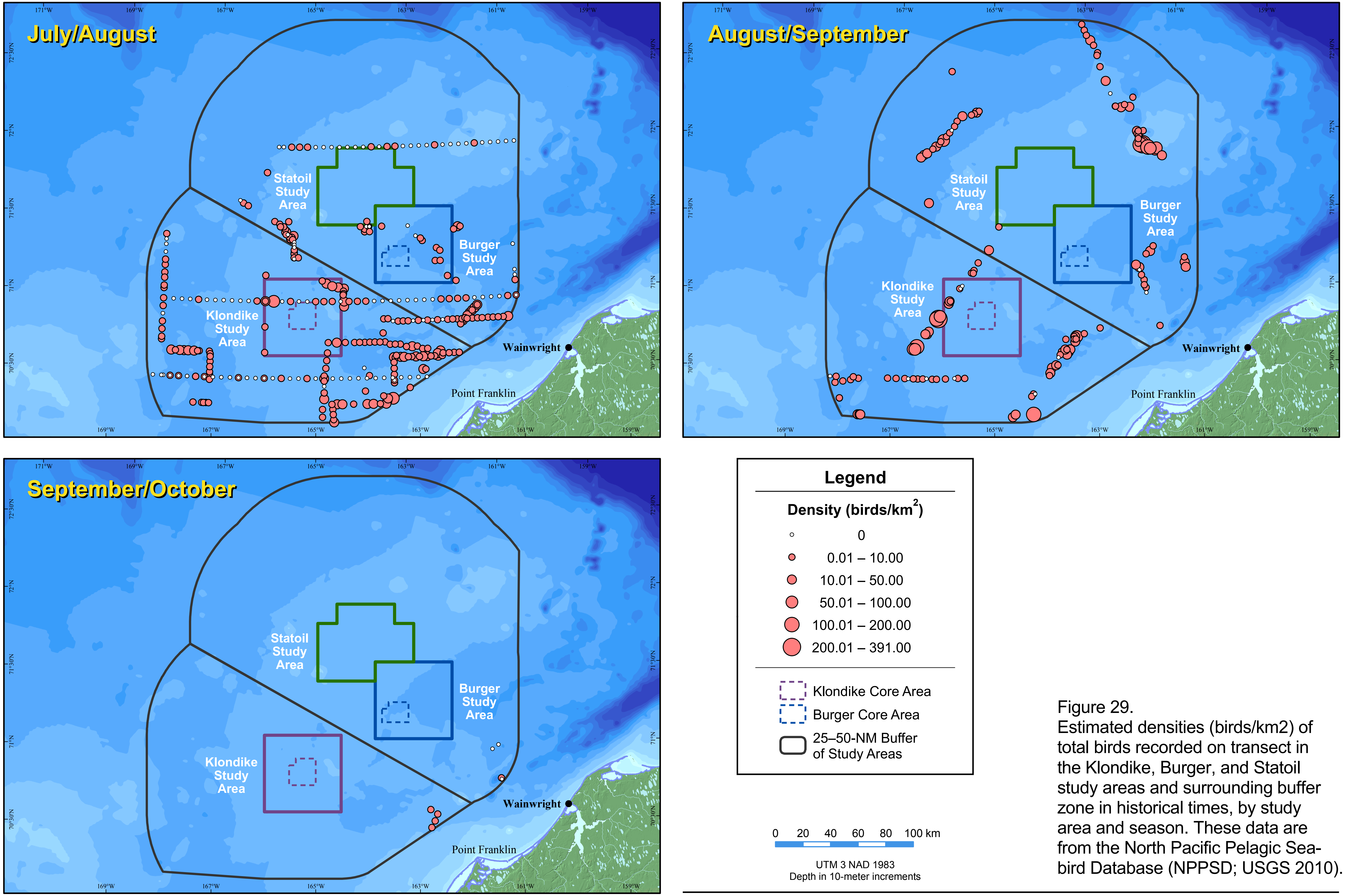

Figure 29.
Estimated densities (birds/km2) of total birds recorded on transect in the Klondike, Burger, and Statoil study areas and surrounding buffer zone in historical times, by study area and season. These data are from the North Pacific Pelagic Seabird Database (NPPSD; USGS 2010).

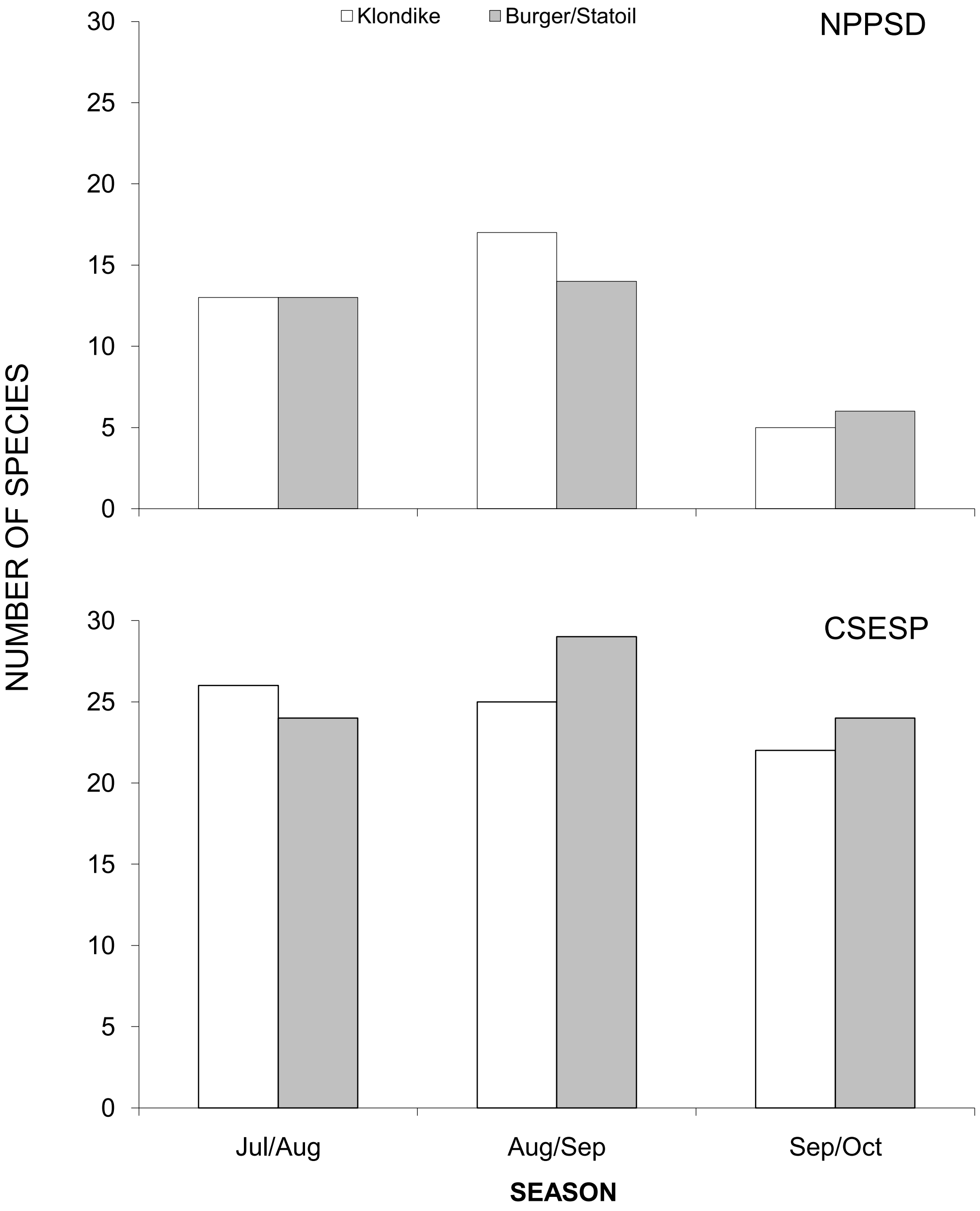

Figure 30. Species-richness of the seabird community on transect in the Klondike and Burger study areas and surrounding buffer zones in historical times, by study area and season. These data are from the North Pacific Pelagic Seabird Database (NPPSD; USGS 2010).

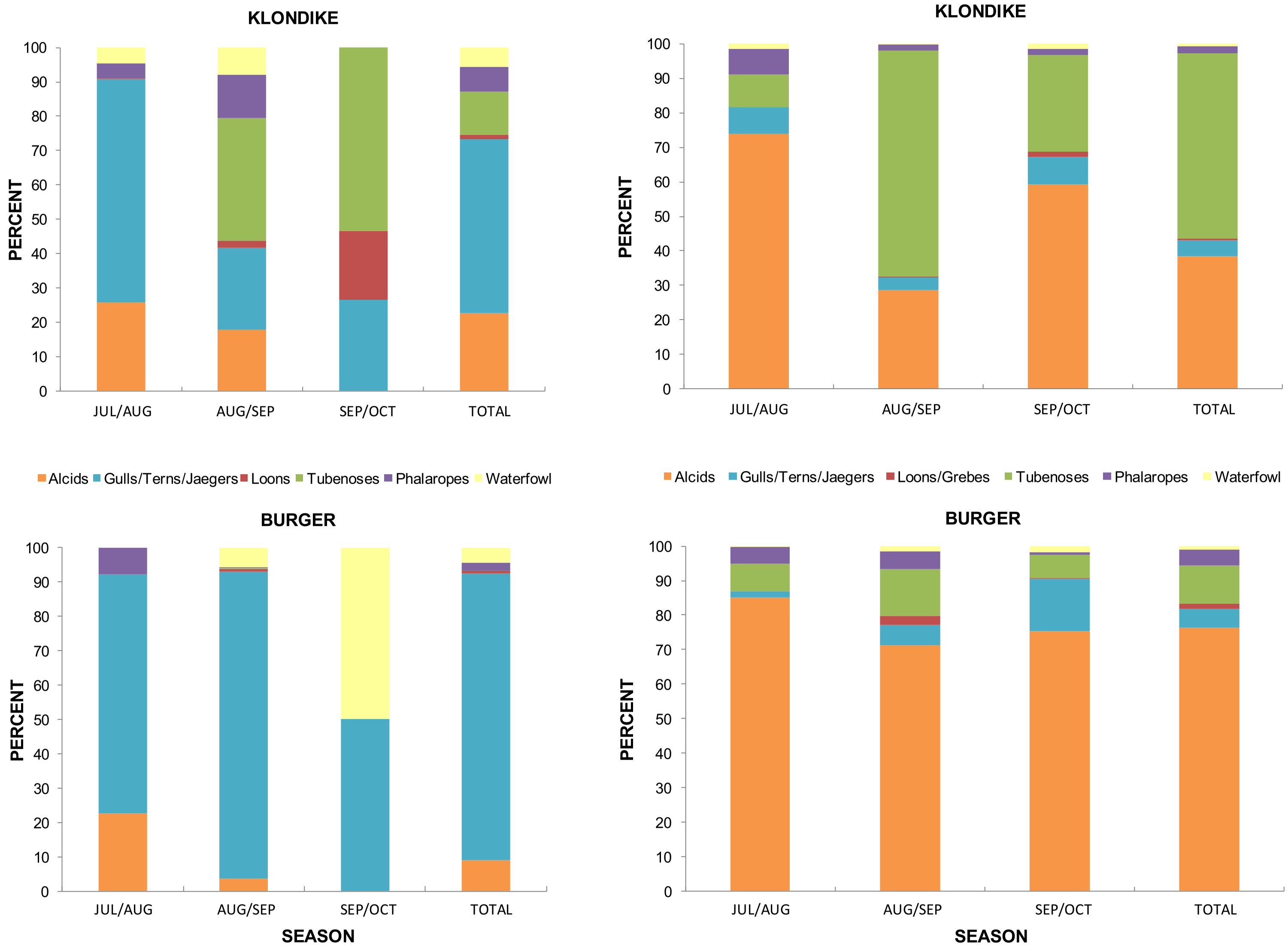

Figure 31. Species-composition of the seabird community in the Klondike, Burger, and Statoil study areas and surrounding buffer zones. Historical data are from the North Pacific Pelagic Seabird Database (NPPSD; USGS 2010). Data from 2008, 2009, and 2010 (CSESP) are pooled across years by study area and season.

zooplankton can graze much of the phytoplankton when they are present. In contrast, shelf zooplankton associated with coastal waters are too small during most of the summer to graze much of the primary production, which falls to the bottom and nourishes a large and diverse benthic community (Feder et al. 1994a, 1994b; Grebmeier et al. 2006).

Although the exact placement of these 3 study areas was not intended to compare ecological systems, the Klondike study area appears to be more of a pelagically-dominated system and the Burger study area appears to be more of a benthically-dominated system, with the transition zone (often an oceanographic front) between the 2 systems appearing to fall somewhere between the 2 study areas. Some of this transition zone is captured in the Statoil study area, which was added in 2010. As seen on the vertical sections of temperature and salinity, the edge of the current flowing north in the Central Channel (the Central Channel Current) was visible along the western edge of the Klondike study area throughout the open-water season of 2008, and much of that study area was dominated by the edge of that current and its associated water mass (Bering Shelf Water). In contrast, the surface of Burger had no strong currents and was dominated by water indicative of remnants of the pack ice that were melting in place (i.e., it functioned more as shelf or coastal water than as oceanic water). This oceanographic boundary between the 2 study areas shifted in 2010, a warmer year when the pack ice retreated almost entirely before the start of our sampling. In that year, the water-column structure indicated that oceanic water dominated Klondike in Jul/Aug and expanded toward the northeast, into Burger and Statoil, in Aug/Sep. These oceanographic distinctions between the Klondike and Burger study areas were less apparent in 2009, the warmest year of the study, when the water-column was essentially oceanic water across most of both study areas (there was a small remnant of meltwater over the northeastern corner of Burger).

Species Distribution and Abundance

Total seabird abundance was highest in 2009, lowest in 2008, and intermediate in 2010; and this variation was associated with interannual changes in the physical oceanography of the region. The year of lowest total seabird abundance (2008) was associated with the coldest overall water temperatures and weak stratification and inflow of Bering Sea Water that did not develop until Sep/Oct, whereas the year of highest total seabird abundance (2009) was associated with the strongest and earliest intrusion of warm Bering Sea Water into the study region. These warm waters established vertical stratification of the water column in Jul/Aug that persisted until Sep/Oct. Both planktivorous and piscivorous seabird species prefer to forage in areas where the water column is stratified, concentrating prey (Piatt and Springer 2003); thus, foraging conditions in 2009 were ideal for these marine predators. The year of intermediate seabird abundance (2010) was associated with intrusion of warm Bering Sea Water and the establishment of stratification during Aug/Sep. Based on the limited sampling conducted in Burger in Sep/Oct, it appears that the stratification weakened, but persisted, in Burger, and this persistent stratification was reflected in the persistence of seabirds in the study area.

The distribution of seabirds, particularly the planktivorous species, may be influenced by the advective processes that transport oceanic species of zooplankton from the Bering Sea to the Chukchi Sea, and this transport apparently differed between years. Planktivorous seabirds thrive where their prey is concentrated within 20 m of the surface (Haney 1991, Piatt and Springer 2003), so they therefore are responsive to changes in oceanographic conditions that affect the availability of their prey.

PLANKTIVOROUS SEABIRDS

The distribution and abundance of individual species of planktivorous seabirds demonstrates the relationship between foraging strategy and foraging habitat as defined by physical oceanography. For example, Crested Auklets are diving seabirds that mostly consume euphausiids (e.g., *Thysanoessa raschii*) and large copepods (e.g., *Neocalanus cristatus*) characteristic of oceanic water (Bédard 1969, Kitaysky and Golubova 2000, Gall et al. 2006). Areas of high Crested Auklet density tended to coincide with upper layer water temperatures of 4–5°C and stratified water with pycnoclines 20–25 m from the surface, regardless of season or study area. These conditions may have been ideal for the presence and availability of their preferred prey. In contrast, Least Auklets consume both oceanic and shelf copepods (e.g., *Calanus marshallae*), and do not dive as deeply as Crested Auklets because of their smaller body size (Hunt et al. 1998); therefore, they should concentrate in areas with shallow pycnoclines. Like Crested Auklets, areas of high Least Auklet density coincided with Bering Sea Water, but they also tended to occur where and when pycnoclines were strongest and only 10–20 m from the surface.

The distribution and abundance of planktivorous species that feed at the surface also reflected their respective foraging strategies. Phalaropes have the most restricted foraging habitat of the planktivorous species we studied in detail because they are small shorebirds that forage only on the surface and typically are associated with localized upwelling and convergence fronts that concentrate prey within ~0.2 m of the surface (Brown and Gaskin 1988). Like Least Auklets, areas of high phalarope density tended to occur over strong, shallow pycnoclines. Additionally, their distribution was highly clumped, and they were particularly abundant when and where there were filaments of cold water near or at the surface (e.g., Klondike in Aug/Sep 2008). In contrast, the distribution of Short-tailed Shearwaters did not appear tightly coupled with particular features of the water column. Short-tailed Shearwaters are fairly large seabirds that consume a wide variety of zooplankton, in addition to fish and squid (Jahnke et al. 2005). The interannual variation in abundance of Short-tailed Shearwaters during this study was similar to that of other planktivorous seabirds, but their pattern in seasonal abundance was consistent among years, suggesting that Short-tailed Shearwaters are responding to oceanographic structure at a broader spatial scale than are phalaropes and alcids.

Omnivorous Seabirds

The distribution and abundance of omnivorous species, as characterized by Northern Fulmars and Glaucous Gulls, reflected their flexibility in foraging behavior. Both species were present in low densities in all 3 years—densities considerably lower than the large and variable densities of planktivorous species—and both were most abundant in 2009, least abundant in 2010, and intermediate in abundance in 2008. Northern Fulmars had consistent seasonal patterns among years, but their abundance declined from Jul/Aug to Sep/Oct, perhaps indicating their greater reliance on zooplankton than the generalist Glaucous Gulls. Glaucous Gulls were the least abundant of the 8 focal species in our study and showed a consistent seasonal pattern of increasing abundance from Jul/Aug to Sep/Aug in all years.

Piscivorous Seabirds

The distribution and abundance of piscivorous species, as indicated by Thick-billed Murres and Black-legged Kittiwakes, reflected the difference in foraging strategies between these two species. Despite being classified as piscivorous (Piatt and Springer 2003), Thick-billed Murres are diving alcids that will consume “most kinds of marine invertebrates and fish” (Gaston and Hipfner 2000), and Black-legged Kittiwakes are surface-feeding gulls that will consume both fishes and zooplankton such as euphausiids and amphipods (Hatch et al. 2009). Thick-billed Murres occurred almost exclusively in Klondike in all years and disappeared by Sep/Oct of each year, suggesting that they had very restricted foraging habitat that was oriented to oceanic Bering Sea Water. Black-legged Kittiwakes had a consistent seasonal pattern of abundance in Burger in all years, but densities in Klondike tended to be highest when water temperatures were warm and the water-column was stratified, suggesting that Black-legged Kittiwakes there also were foraging on prey species associated with Bering Shelf Water but may be less restricted in their foraging requirements than Thick-billed Murres.

Rare Species

The presence and absence of species among years also demonstrates the influence of physical oceanography on seabird community structure. In 2008, when water temperatures remained cold until late in the open-water season, we saw ice-associated species such as Ivory Gulls and Black Guillemots. In 2009, when water temperatures were warm for most of the open-water season, we did not see the ice-associated species, migrating waterfowl and waterbirds such as King Eiders, Common Eiders, and Red-throated Loons, or species that would be considered outside of their range (e.g., Dovekies, Pigeon Guillemots); these species were spotted only in 2008 and/or 2010.

Perhaps the most curious presence of a rare species was the appearance of Ancient Murrelets in all 3 study areas in Aug/Sep 2010 and lingering in Klondike and Burger into Sep/Oct 2010. This small alcid breeds as far north as the Aleutian Islands, and its winter range is largely unknown (Gaston and Shoji 2010). There was no record of Ancient Murrelets in the historical dataset from the NPPSD and few records of these birds moving north of Bering Strait in the fall (Kessel 1989). Surveys conducted by the USFWS recorded 68 Ancient Murrelets in the Chukchi Sea in Sep/Oct 2007 (NPPSD 2010), suggesting that this species is an occasional visitor to the region and is abundant in the years when it is present.

The final rare species of note was a single record of a Northern Gannet (*Morus bassanus*) on 16 Aug 2010. It was seen closely, but we were unable to obtain photographic evidence of it. What presumably was this same bird was seen ~2 days later by ornithologists near Barrow (LGL Alaska Ecological Research Associates, Anchorage, AK, in litt.). This species occurs exclusively in the North Atlantic (Mawbray 2002) making this the first record of this species in the Pacific Ocean. It is possible that this species came through the Northwest Passage, which was open in 2010.

We hypothesize that differences in oceanographic structure among the 3 study areas and among years explains many of the ecological differences in the seabird community and in other trophic levels as well. For example, as mentioned above, large oceanic zooplankton were more common in the Klondike study area, whereas smaller shelf zooplankton were more common in the Burger study area (Hopcroft et al. 2010). Similarly, analysis of benthic samples so far in Klondike and Burger suggests that the infaunal benthic community differs between the 2 study areas, with Klondike having lower biomass and species-diversity than Burger (Blanchard et al. 2010). The scientists conducting baseline chemical sampling in 2008 also found large numbers of epibenthic amphipods, most of which are detritivores, in Burger but few in Klondike (Neff et al. 2010), suggesting that much of the primary productivity is falling to the bottom in Burger but not in Klondike. Finally, benthic-feeding marine mammals such as Pacific walruses (*Odobenus* rosmarus) and bearded seals (*Erignathus barbatus*) were more common in Burger than in Klondike, whereas pelagic-feeding seals were more common in Klondike (Brueggeman 2009). All of this information suggests that these 2 study areas may be different ecologically and that the differences in the seabird community reflect the influence of oceanography on trophic structure in the northeastern Chukchi Sea. We suspect that Statoil has characteristics of both of the other study areas, with the western half similar to Klondike and the eastern half similar to Burger.

Comparison with Historical Data

We must begin our discussion about the comparisons of the CSESP data and historical NPPSD data with several caveats. First, the historical data set was collected during 1975–1981, with incomplete spatial and/or seasonal coverage in any given year, whereas the data in this study were collected systematically during most of the open-water season in all 3 years. Although our data provide strong evidence of seasonal and interannual differences in densities, there are not enough historical data for a quantitative comparison with historical data among seasons or years. Second, the historical data do not have good spatial overlap with our study-area boxes. As a result, we had to increase our comparison area by adding ~56–92-km (30–50-NM) buffer zones around the study areas to provide enough data for a comparison. Third, survey design differed between the 2 data sets: some of the historical data were collected opportunistically during other oceanographic sampling, so few transects were replicated, whereas data from the CSESP surveys were collected during dedicated seabird surveys and along transects that were replicated among seasons. Finally, the sample size (number of transects) in the historical data set that met the spatial criteria for comparison was small ($n = 539$ transects across all years), whereas sample sizes in the CSESP data sets were large ($n = 2{,}690$ transects in 2008, $n = 2{,}506$ transects in 2009, and $n = 2{,}976$ transects in 2010).

Given these caveats, it nevertheless appears that, although the patterns in the seasonal occurrence of many species and the general distribution of many species are similar to those seen in both the NPPSD data and data presented in Divoky (1987), planktivorous seabirds are considerably more common now than they were historically. The latter report summarized several years of shipboard surveys in the Chukchi Sea by species or species-group and geographic area (our study areas were located in what he then called the central Chukchi Sea), and those seasonal periods matched ours almost exactly. In the Klondike buffer area, alcids composed ≤ 25% of all birds historically, and in the Burger/Statoil buffer area, alcids were rare and tubenoses were absent in the historical data, whereas both species-groups now are abundant in all 3 study areas. Conversely, the historical data set was dominated numerically by larids.

Historically, the areas of highest bird densities were located outside of the boundaries of the Klondike and Burger study areas (Divoky 1987, USGS 2010), near oceanographic features that may provide good foraging habitat (Piatt and Springer 2003). For example, the highest densities in the vicinity of Klondike were recorded west of the study area and close to the main flow of the Central Channel Current. In contrast, the highest densities in the vicinity of Burger were recorded north of the study area, along the edge of the remnant pack ice over Hanna Shoal, in Aug/Sep. Historical densities on transects conducted within the boundaries of the Klondike and Burger study areas were lower than those conducted outside of the boundaries. This spatial difference in historical densities is consistent with the hypothesis that oceanographic structure influences the distribution and abundance of seabirds in the northern Chukchi Sea.

After accounting for spatial and temporal overlap, it appears that densities recorded historically (Divoky 1987, USGS 2010) were similar to those recorded in 2010, lower than those recorded in 2009, and higher than those recorded in 2008. Uncorrected densities within Klondike, Burger, and Statoil during Jul/Aug and Aug/Sep were 4.3–11.8 birds/km^2 in the historical data, 1.3–2.6 birds/km^2 in 2008, and 12.6–43.1 birds/km^2 in 2009. We caution that comparisons between the historical data and the recent data are imperfect, but they suggest that densities were higher in 2009 than in previous years.

Species of Conservation Concern

During these surveys, we recorded 11 species of seabirds that are of conservation concern: 5 species of waterfowl (all seaducks), 2 species of loon, 1 species of tern, and 3 species of alcids. With the exception of Yellow-billed Loons in 2009 and Long-tailed Ducks in 2008 and 2009, however, none of the species occurred within the 2 study areas in substantial numbers. The highest-profile species are the Spectacled Eider, which is listed as threatened under the ESA, and the Yellow-billed Loon and the Kittlitz's Murrelet, both of which are candidate species for listing under the ESA.

Conclusions

The 3 study areas in the northeastern Chukchi Sea collectively have a diverse seabird community of more than 30 species and, at times, maximal densities of over 17 birds/km^2 within a study area. Eleven species of seabirds of conservation concern occur in this area, including 1 (Spectacled Eider) listed as threatened and 2 listed as candidate species under the ESA. There is extensive seasonal and interannual variation in the abundance of the seabirds in this area, attributable primarily to planktivorous species. The greatest number of birds generally occurs in Aug/Sep (approximately 20 August to approximately 20 September), presumably reflecting a variety of factors that may include the timing of melt of sea ice, seasonal changes in the oceanography of the area, bird migration, nesting phenology and success of birds in the Arctic, the strength and timing of inflow of Bering Sea Water from south of Bering Strait, and overall oceanographic characteristics. Although focusing sampling during this season of highest abundance will improve estimates of the maximal density of seabirds in the study areas, it is precisely the high variation in populations during Jul/Aug and Sep/Oct that require continued data collection. When variation is high, more samples are required to obtain accurate and precise predictions of seabird abundance and distribution, information that is critical to assessing the impacts of change to the system.

There also is extensive spatial variation in the distribution and abundance of the seabirds in this area, with numbers of most (but not all) species generally higher in Klondike than in Burger or Statoil. The structure of the seabird community differed among the 3 study areas and among years. We hypothesize that these differences reflect oceanographic differences between Klondike and Burger, with Statoil representing elements of the other 2 study areas. We propose that the Klondike study area is characterized as more of a pelagically-dominated ecosystem and the Burger study area is characterized as more of a benthically-dominated ecosystem; Statoil tends to be pelagically dominated in its western half (that part nearest the Central Channel) and benthically dominated in its eastern half (similar to Burger). Several other components of this multidisciplinary study also suggest a similar structuring of the ecosystem (Blanchard et al. 2010, Hopcroft et al. 2010) and sampling being conducted over a more extensive study area in 2011 will provide a context to better understand the relationship between seabirds and their habitat in the northeastern Chukchi Sea.

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Appendix A. List of all species recorded during boat-based marine surveys in the northeastern Chukchi Sea, 2008 – 2010. Iñupiaq names are provided when known.

Species-group/species	Scientific name	Iñupiaq name
WATERFOWL		
Spectacled Eider	*Somateria fischeri*	qavaasuk
King Eider	*S. spectabilis*	qiŋalik
Common Eider	*S. mollissima*	amauligruaq
White-winged Scoter	*Melanitta fusca*	killalik
Long-tailed Duck	*Clangula hyemalis*	aahaaliq
LOONS		
Red-throated Loon	*Gavia stellata*	qaksrauq
Pacific Loon	*G. pacifica*	malġi
Yellow-billed Loon	*G. adamsii*	tuutlik
TUBENOSES		
Northern Fulmar	*Fulmarus glacialis*	
Short-tailed Shearwater	*Puffinus tenuirostris*	
SHOREBIRDS		
Pectoral Sandpiper	*Calidris melanotos*	puviaqtuuq
Long-billed Dowitcher	*Limnodromus scolopaceus*	siiyukpalik
Red-necked Phalarope	*Phalaropus lobatus*	qayyiuġun
Red Phalarope	*P. fulicarius*	auksruaq
LARIDS		
Black-legged Kittiwake	*Rissa tridactyla*	
Ivory Gull	*Pagophila eburnea*	
Sabine's Gull	*Xema sabini*	aqargigiaq
Ross's Gull	*Rhodostethia rosea*	
Herring Gull	*Larus argentatus*	nauyatchiaq
Glaucous Gull	*L. hyperboreus*	nauyavasrugruk
Arctic Tern	*Sterna paradisaea*	mitqutailḷaq
Pomarine Jaeger	*Stercorarius pomarinus*	isuŋŋaġluk
Parasitic Jaeger	*S. parasiticus*	miġiaqsaayuk
Long-tailed Jaeger	*S. longicaudus*	isuŋŋaq
ALCIDS		
Dovekie	*Alle alle*	
Common Murre	*Uria aalge*	aqpaq

Appendix A. Continued.

Species-group/species	Scientific name	Iñupiaq name
Thick-billed Murre	*U. lomvia*	
Black Guillemot	*Cepphus grylle*	iŋaġiq
Pigeon Guillemot	*C. columba*	
Kittlitz's Murrelet	*Brachyramphus brevirostris*	
Ancient Murrelet	*Synthliboramphus antiquus*	
Parakeet Auklet	*Aethia psittacula*	
Least Auklet	*A. pusilla*	
Crested Auklet	*A. cristatella*	
Horned Puffin	*Fratercula corniculata*	
Tufted Puffin	*F. cirrhata*	Qiḷaŋaq
OWLS		
Short-eared Owl	*Asio flammeus*	nipaiḷuktaq
PASSERINES		
American Pipit	*Anthus rubescens*	
Snow Bunting	*Plectrophenax nivalis*	amaułigaaluk

Appendix B. Counts of all birds recorded on transects during boat-based marine surveys in the central Chukchi Sea, by study area and season, 2008.

	Study area/season					
	Klondike			Burger		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
WATERFOWL						
Spectacled Eider	0	0	0	0	0	0
King Eider	1	0	2	0	1	2
Common Eider	0	0	0	0	5	0
Unidentified eider	0	10	5	0	9	0
White-winged Scoter	0	0	0	0	0	3
Long-tailed Duck	44	0	37	0	68	2
Unidentified diver	0	0	1	0	0	0
LOONS						
Red-throated Loon	0	0	0	0	1	0
Pacific Loon	0	1	27	0	33	3
Yellow-billed Loon	0	3	1	0	2	0
Unidentified loon	0	0	1	0	22	0
TUBENOSES						
Northern Fulmar	65	141	38	6	8	8
Short-tailed Shearwater	4	286	271	0	199	54
Unidentified procellarid	0	0	25	0	0	1
SHOREBIRDS						
Unid. (*Pluvialis*) plover	0	2	0	0	0	0
Pectoral Sandpiper	0	0	0	0	0	0
Long-billed Dowitcher	0	0	0	0	0	0
Red-necked Phalarope	0	20	69	0	59	0
Red Phalarope	5	5	1	0	1	0
Unidentified phalarope	0	74	10	0	85	0
Unid. shorebird - small	0	0	0	0	0	0

Appendix B. Continued.

	Study area/season					
	Klondike			Burger		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
SHOREBIRDS (cont'd.)						
Unid. shorebird - medium	0	0	0	0	0	0
LARIDS						
Black-legged Kittiwake	99	47	117	14	129	17
Ivory Gull	0	0	0	0	0	2
Sabine's Gull	9	92	5	2	0	0
Ross's Gull	0	0	0	0	0	127
Herring Gull	1	0	18	0	0	1
Glaucous Gull	11	13	70	6	33	19
Unidentified gull - small	0	0	0	0	0	0
Unidentified gull - large	0	0	0	0	1	0
Unidentified gull	0	0	0	0	0	0
Arctic Tern	0	24	0	0	0	0
Pomarine Jaeger	32	12	1	3	3	0
Parasitic Jaeger	4	2	0	1	0	0
Long-tailed Jaeger	0	0	0	0	0	0
Unidentified jaeger	0	0	0	0	0	0
ALCIDS						
Dovekie	2	0	1	0	0	2
Common Murre	13	0	11	0	0	0
Thick-billed Murre	228	14	3	3	0	1
Unidentified murre	1	9	4	0	2	14
Black Guillemot	9	0	0	2	0	6
Pigeon Guillemot	4	0	0	1	0	0
Unidentified guillemot	0	0	0	0	0	1
Kittlitz's Murrelet	0	0	0	0	0	0

Appendix B. Continued.

	Study area/season					
	Klondike			Burger		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
ALCIDS (cont'd.)						
Unidentified murrelet	0	0	5	0	0	0
Parakeet Auklet	0	7	0	0	0	44
Least Auklet	4	139	55	0	1	4
Crested Auklet	179	128	959	0	1	34
Unidentified auklet	1	22	66	0	0	1
Horned Puffin	2	0	0	2	0	0
Tufted Puffin	8	0	1	0	0	0
Unidentified alcid - small	0	0	1	0	0	6
Unidentified alcid	0	2	8	0	6	1
OWLS						
Short-eared Owl	0	0	0	0	0	0
PASSERINES						
American Pipit	0	0	0	0	1	0
Snow Bunting	0	0	0	0	1	0

Appendix C. Counts of all birds recorded on transects during boat-based marine surveys in the central Chukchi Sea, by study area and season, 2009.

	Study area/season					
	Klondike			Burger		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
WATERFOWL						
Spectacled Eider	0	1	0	0	0	0
King Eider	0	0	0	0	0	0
Common Eider	0	0	0	0	0	0
Unidentified eider	0	15	1	0	2	5
White-winged Scoter	0	0	0	0	0	0
Long-tailed Duck	0	19	3	0	41	0
Unidentified diver	0	2	0	0	0	0
LOONS						
Red-throated Loon	0	0	0	0	0	0
Pacific Loon	0	24	22	0	181	1
Yellow-billed Loon	0	9	1	0	24	0
Unidentified loon	0	6	5	0	30	0
TUBENOSES						
Northern Fulmar	115	52	5	141	34	22
Short-tailed Shearwater	22	11,946	313	252	331	66
Unidentified procellarid	0	0	0	0	0	0
SHOREBIRDS						
Unid. (*Pluvialis*) plover	0	0	0	0	0	0
Pectoral Sandpiper	0	3	0	3	5	0
Long-billed Dowitcher	0	0	0	1	0	0
Red-necked Phalarope	37	10	2	201	106	4
Red Phalarope	3	0	2	15	32	1
Unidentified phalarope	55	0	9	72	51	4
Unid. shorebird - small	1	2	0	0	17	0

Appendix C. Continued.

	Study area/season					
	Klondike			Burger		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
SHOREBIRDS (cont'd.)						
Unid. shorebird - medium	0	1	0	0	10	0
LARIDS						
Black-legged Kittiwake	9	296	101	16	266	22
Ivory Gull	0	0	0	0	0	0
Sabine's Gull	0	1	2	0	0	2
Ross's Gull	0	0	0	0	0	48
Herring Gull	0	10	0	4	2	0
Glaucous Gull	0	23	49	7	65	54
Unidentified gull - small	0	0	3	0	0	0
Unidentified gull - large	0	0	0	0	0	0
Unidentified gull	2	0	3		1	11
Arctic Tern	0	0	0	1	2	0
Pomarine Jaeger	6	23	0	10	1	0
Parasitic Jaeger	0	0	0	0	0	0
Long-tailed Jaeger	1	0	0	2	0	0
Unidentified jaeger	0	1	0	0	1	0
ALCIDS						
Dovekie	0	0	0	0	0	0
Common Murre	0	8	3	0	3	14
Thick-billed Murre	64	338	16	17	27	15
Unidentified murre	0	35	7	0	8	1
Black Guillemot	0	0	0	0	0	0
Pigeon Guillemot	0	0	0	0	0	0
Unidentified guillemot	0	0	0	0	0	0
Kittlitz's Murrelet	0	1	0	0	0	6

Appendix C. Continued.

	Study area/season					
	Klondike			Burger		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
ALCIDS (cont'd.)						
Unidentified murrelet	0	0	0	0	0	0
Parakeet Auklet	0	21	0	0	0	0
Least Auklet	63	115	257	201	143	39
Crested Auklet	394	3,139	1,455	4,566	5,082	16
Unidentified auklet	8	52	11	11	26	0
Horned Puffin	4	2	0	0	0	0
Tufted Puffin	1	0	0	0	0	0
Unidentified alcid - small	0	0	10	0	0	14
Unidentified alcid	0	18	0	0	11	0
OWLS						
Short-eared Owl	0	0	0	1	0	0
PASSERINES						
American Pipit	0	0	0	0	2	0
Snow Bunting	0	0	0	0	0	0

Appendix D. Counts of all birds recorded on transect during boat-based marine surveys in the central Chukchi Sea, by study area and season, 2010.

	Study area/season								
	Klondike			Burger			Statoil		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
WATERFOWL									
Spectacled Eider	0	0	–	0	0	0	0	0	–
King Eider	0	0	–	0	0	2	0	0	–
Common Eider	0	0	–	0	0	3	0	0	–
Unidentified eider	0	0	–	7	0	7	0	0	–
White-winged Scoter	0	0	–	0	0	0	0	0	–
Long-tailed Duck	0	0	–	0	16	7	1	12	–
Unidentified diver	0	0	–	0	0	0	0	0	–
LOONS									
Red-throated Loon	0	0	–	0	0	0	0	1	–
Pacific Loon	0	11	–	0	6	0	0	2	–
Yellow-billed Loon	0	0	–	0	0	0	0	0	–
Unidentified loon	0	0	–	0	0	0	0	4	–
TUBENOSES									
Northern Fulmar	17	28	–	29	10	1	10	22	–
Short-tailed Shearwater	8	393	–	8	426	5	150	341	–
Unidentified procellarid	0	0	–	0	0	0	0	0	–
			–						–
SHOREBIRDS			–						–
Unid. (*Pluvialis*) plover	0	0	–	0	0	0	0	0	–
Pectoral Sandpiper	4	0	–	0	0	0	0	0	–
Long-billed Dowitcher	0	0	–	0	0	0	0	0	–

Appendix D. Continued.

	Study area/season								
	Klondike			Burger			Statoil		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
SHOREBIRDS (cont.)									
Red-necked Phalarope	1	90	–	4	31	0	12	91	–
Red Phalarope	21	5	–	0	32	5	0	42	–
Unidentified phalarope	30	169	–	1	30	0	10	42	–
Unid. shorebird - small	6	1	–	0	0	0	3	0	–
Unid. shorebird - medium	0	0	–	0	0	0			
LARIDS									
Black-legged Kittiwake	17	135	–	13	56	0	13	76	–
Ivory Gull	0	0	–	0	0	0	0	0	–
Sabine's Gull	1	21	–	1	1	0	5	0	–
Ross's Gull	0	0	–	0	0	28	0	0	–
Herring Gull	0	0	–	0	1	0	0	1	–
Glaucous Gull	2	11	–	4	12	15	3	11	–
Unidentified gull - small	0	0	–	0	0	0	0	0	–
Unidentified gull - large	0	0	–	0	0	0	0	0	–
Unidentified gull	0	0	–	0	0	0	0	0	–
Arctic Tern	0	29	–	1	0	0	0	0	–
Pomarine Jaeger	1	14	–	5	1	0	2	3	–
Parasitic Jaeger	0	0	–	0	1	0	0	0	–
Long-tailed Jaeger	2	0	–	0	1	0	0	0	–
Unidentified jaeger	0	0	–	0	0	0	0	0	–
ALCIDS									
Dovekie	0	0	–	0	0	1	0	1	–
Common Murre	0	7	–	0	2	0	0	1	–

Appendix D. Continued.

	Study area/season								
	Klondike			Burger			Statoil		
Species-group/species	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall	Late summer	Early fall	Late fall
ALCIDS (cont.)									
Thick-billed Murre	115	97	–	24	16	3	25	22	–
Unidentified murre	0	3	–	0	3	0	1	1	–
Black Guillemot	0	0	–	1	0	0	1	0	–
Pigeon Guillemot	0	0	–	0	0	0	0	0	–
Unidentified guillemot	0	0	–	0	0	0	0	0	–
Kittlitz's Murrelet	2	1	–	0	1	0	1	0	–
Ancient Murrelet	0	18	–	0	16	28	0	41	–
Unidentified murrelet	4	3	–	0	0	0	0	0	–
Parakeet Auklet	1	8	–	0	15	17	10	2	–
Least Auklet	29	148	–	29	474	103	163	184	–
Crested Auklet	639	1380	–	806	976	1011	383	1243	–
Unidentified auklet	8	18	–	1	40	1	3	2	–
Horned Puffin	4	0	–	3	1	0	1	1	–
Tufted Puffin	1	0	–	0	1	0	2	0	–
Unidentified puffin				1	0	0	0	0	–
Unidentified alcid - small	0	0	–	0	0	11	0	0	–
Unidentified alcid	19	7	–	0	3	0	1	2	–
OWLS									
Short-eared Owl	0	0	–	0	0	0	0	0	–
PASSERINES									
American Pipit	0	0	–	0	0	0	0	0	–
Snow Bunting	0	0	–	0	0	0	0	1	–