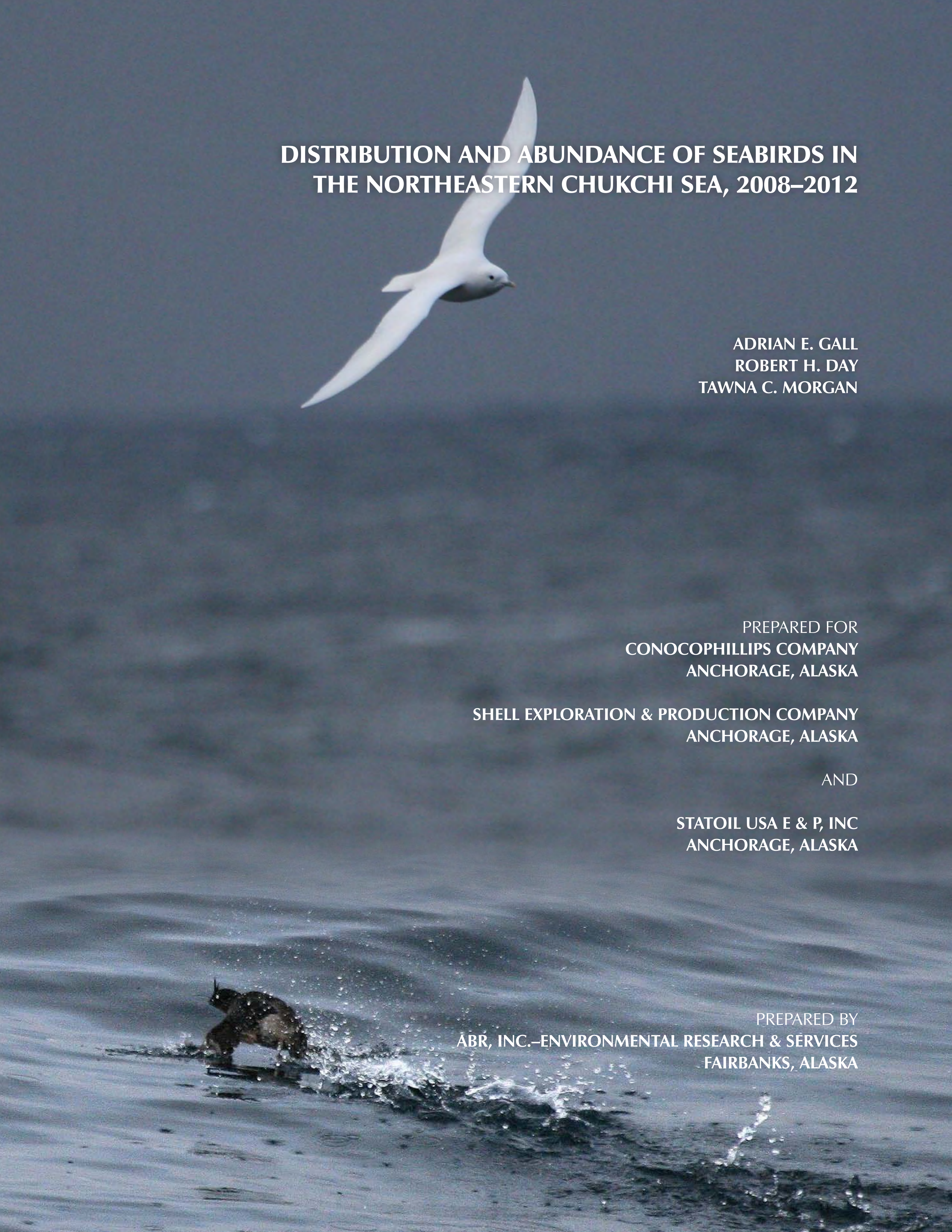

DISTRIBUTION AND ABUNDANCE OF SEABIRDS IN THE NORTHEASTERN CHUKCHI SEA, 2008–2012

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FINAL REPORT

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October 2013

Printed on recycled paper.

EXECUTIVE SUMMARY

- In 2008–2012, we collected data on the distribution and abundance of seabirds in the northeastern Chukchi Sea in and near 3 oil and gas lease areas. The Greater Hanna Shoal (GHS) study area, which was sampled only in 2011–2012, was located ~110–180 km (~60–100 NM) northwest of the village of Wainwright and included study-area boxes known as Klondike and Burger (sampled in 2008–2012) and Statoil (sampled in 2010–2012).
- 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 -composition; (3) relate the patterns of distribution and abundance within the 3 study-area boxes to the regional pattern seen in the Greater Hanna Shoal (GHS) study area as a whole; and (4) assess changes in the relative abundance, distribution, and species composition of seabird communities throughout the U.S. sector of the Chukchi Sea during 1975–2012.
- We also used the data set to evaluate the relationship between survey effort and the precision of abundance estimates. This investigation of the effects of sample size on the precision of population estimates and on statistical power will inform the development of monitoring efforts in the future.
- We conducted seabird surveys during 3 periods that covered the entire open-water season of the northeastern Chukchi Sea: late summer (Aug), early fall (Sep), and late fall (Sep/Oct; 2008–2010 only). In 2011 and 2012, we conducted an extended fall cruise that combined the early and late fall cruises from earlier years.
- In 2008 and 2009, we sampled Klondike and Burger in Aug, Sep, and Sep/Oct. In 2010, we added Statoil and sampled all 3 study areas in Aug and Sep but sampled only Burger in Sep/Oct. In 2011 and 2012, we added sampling in the GHS and did not sample the study-area boxes in Sep/Oct.
- Seabirds were least abundant overall in 2008, most abundant in 2009, and intermediate in abundance in 2010–2012.
- Planktivores were the most abundant feeding guild in all years and in most seasons. In general, they were more abundant in the southwestern half of the GHS study area in 2011–2012. Crested Auklets were the most abundant planktivores.
- Omnivores were present in low densities in all 5 years—densities considerably lower than the large and variable densities of planktivorous species—and were least abundant in 2010, most abundant in 2009, and intermediate in abundance in the other 3 years.
- Piscivores were variable in their patterns of distribution and abundance within the GHS study area. Black-legged Kittiwakes were distributed widely in all seasons and years and occupied all of the GHS study area, whereas Thick-billed Murres typically were concentrated in the southern third of the GHS study area.
- When compared with conditions 30 years ago, sea ice now forms later in fall, melts earlier in summer, and melts completely in all strata of the eastern Chukchi Sea by late summer. These changes in ice cover are associated with large declines in the abundance of surface-feeding piscivorous and planktivorous species of seabirds and modest increases in the abundance of diving planktivorous species.
- Multivariate analyses of the seabird community indicated that community composition in the northeastern Chukchi Sea was similar among study-area boxes and in most years, with the exception of 2008. In that year, piscivores and omnivores composed a higher proportion of the birds in Klondike and Burger than in subsequent years because of the low abundance of auklets and shearwaters.
- Although planktivorous seabirds did not numerically dominate the seabird community in the 1970s and 1980s, they have become the dominant feeding guild of the 2000s and 2010s, especially diving species such as Crested Auklets and Short-tailed Shearwaters.

- We recorded 11 species on transects 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), and 1 (Yellow-billed Loon) is classified as a candidate species under the ESA. Listing decision for the loon is expected in September 2014. Another candidate species, the Kittlitz's Murrelet, was evaluated by the U.S. Fish and Wildlife Service (USFWS) in September 2013 for possible listing, but that petition was denied. The Red-throated Loon and the Arctic Tern are classified as species of conservation concern by the USFWS.
- For 7 of the 8 focal seabird taxa, annual survey effort of 1,000 km is adequate to generate reliable detection functions and abundance estimates with target precision close to 30%. For phalaropes that are patchily distributed and can occur in groups of up to 150 birds, sampling effort needs to be at least 1,800 km in one survey to estimate abundance with a target precision of 30%.
- Comparisons among the study-area boxes suggest that the structure and variability of the seabird community respond to the flow of Bering Sea Water (BSW) northward in the Central Channel. Data collected from the GHS study area in 2011–2012 provide further evidence to support this hypothesis. The scale of effect is approximately 2 times the size of the 3 study-area boxes combined.
- The southwestern half of the GHS study area, including Klondike and the western half of Statoil, is a more pelagically-dominated system with a greater abundance of diving alcids and Short-tailed Shearwaters and a higher biomass of copepods than is present in the northeastern half of the study area. The northeastern half of the GHS study area, including Burger and the eastern half of Statoil, is a benthically-dominated system with a greater abundance of surface-feeding larids and a higher abundance, biomass, and number of benthic taxa than is seen in the southwestern half.
- The distribution of seabirds, particularly the planktivores, may be strongly influenced by advective processes that transport oceanic zooplankton from the Bering Sea to the Chukchi Sea. This transport varied among years and resulted in a broader northeastward intrusion of BSW in 2009 and 2011 than in other years. Planktivorous seabirds concentrated in areas characterized by BSW, especially along thermohaline fronts, whereas piscivorous and omnivorous seabirds concentrated in areas characterized by cold Meltwater and Winter Water.

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ACKNOWLEDGMENTS

ConocoPhillips Company (COP), Shell Exploration & Production Company (Shell), and Statoil USA E &P, Inc. (Statoil), funded this research; in addition, COP provided project management and oversight during 2008–2009. We thank Caryn Rea, James Darnall, and Mike Faust of COP; Michael Macrander of Shell; and Karin Berentsen and Steinar Eldøy of Statoil for support and advice during all phases of this study. We also thank John Burns, Jeff Hastings, Waverly Thorsen, and Sheyna Wisdom of Fairweather Science; Bob Shears, Tom Mahoney, and Blair Paktokak of Olgoonik Oilfield Services; and David Aldrich, Abby Antonelis, and Sarah Norberg of Aldrich Offshore Services for logistical and operational support in the field. We thank the Captains and crews of the M/V *Bluefin*, M/V *Norseman II*, and M/V *Westward Wind* for keeping us safe at sea. In addition, we thank the other Principal Investigators and other scientists involved with this project; special thanks go to Thomas Weingartner of the Institute of Marine Sciences (IMS), University of Alaska, Fairbanks, for insights into the physical oceanography of the Chukchi Sea and to Arny Blanchard of IMS for statistical guidance. At ABR, we thank Lauren Attanas, Jennifer Boisvert, Corey Grinnell, Tawna Morgan, Steve Murphy, Tim Obritschkewitsch, Jon Plissner, John Rose, and Peter Sanzenbacher for help with the seabird sampling; Rebecca Baird, Matt Macander, Allison Zusi-Cobb, and Dorte Dissing for help with GIS work; Chris Swingley for help with data management; Alex Prichard for statistical advice; Pam Odom for report production; and Thomas DeLong for project support. We thank Caryn Rea of COP, Michael Macrander of Shell, and Steinar Eldøy of Statoil for review of this report.

ACRONYMS AND ABBREVIATIONS

ACW	Alaska Coastal Water
ADFG	Alaska Department of Fish and Game
AIC	Akaike's Information Criterion
AKMAP	Alaska Monitoring and Assessment Program
Aug	August
BSW	Bering Sea Water
°C	degrees Celsius
CSESP	Chukchi Sea Environmental Studies Program
CTD	conductivity, temperature, depth sensor
ESA	U.S. Endangered Species Act of 1973 (as amended)
GHS	Greater Hanna Shoal
GLM	generalized linear model
GPS	global positioning system
Jul	July
km	kilometer
MMS	Minerals Management Service
MW	Meltwater
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
Sep	September
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
U.S.S.R.	Union of Soviet Socialist Republics
WW	Winter Water

INTRODUCTION

The seasonally ice-covered Chukchi Sea shelf is one of the largest continental shelves in the world. It is highly productive, although much of the primary production and zooplankton biomass can be attributed to the northward flow of nutrient-rich oceanic water that originates far to the south, in the basin of the Bering Sea (Springer and McRoy 1993, Grebmeier et al. 2006). This influx of oceanic nutrients and plankton sustains a seabird community that otherwise would have little prey available (Springer et al. 1989). Despite an understanding of the importance of advection to the food web of the Chukchi Sea, questions remain about the spatial and temporal scales of processes that link the Bering and Chukchi ecosystems (Springer et al. 1996). Seasonal, annual, and decadal changes in ice cover and advection may have profound effects on the distribution and abundance of non-breeding, staging, and migratory seabirds that rely on these resources during the open-water season (June to mid-October).

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 60–80 mi 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. Scattered 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 a resurgence in oceanographic research during the past decade. This study was initiated in 2008 to inform managers and industry about the recent distribution, abundance, and timing of occurrence of seabirds in 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.

STUDY OBJECTIVES

We explored the distribution, abundance, and community composition of seabirds in the northeastern Chukchi Sea in and around 3 study areas where ConocoPhillips Company, Shell Exploration & Production Company, and Statoil USA E & P have lease-blocks for offshore oil and gas exploration and development. We compared these patterns to changes in the seabird community of the eastern Chukchi Sea over the past 40 years. 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-composition; (3) relate the patterns in distribution and abundance within the 3 study-area boxes to the regional pattern on and near Hanna Shoal (i.e., the greater Hanna Shoal [GHS] study area); and (4) assess changes in the relative abundance, distribution, and species composition of seabird communities throughout the U.S. sector of the Chukchi Sea during 1975–2012. In addition to the ecological objectives, we also used the data set to evaluate the relationship between survey effort and the accuracy of abundance estimates. This investigation of the effects of sample size will inform the development of monitoring efforts in the future.

A synthesis report (Gall and Day 2012) provides detailed information on spatial, seasonal, and interannual variation in the ecology of seabirds in the GHS study area in 2008–2011, and publications (Gall et al. 2012, Day et al. 2013) summarize some of this information. This study provides baseline information on the recent distribution and abundance of seabirds in the lease areas and provides spatial and ecological context for the distribution and abundance of seabirds in the northeastern Chukchi Sea in the vicinity of those lease areas. This information will be used for analyses of potential impacts of offshore exploration and development activities, will be included within a National Environmental Policy Act (NEPA) document required for exploration, and will be useful for other needs such as planning mitigation of exploratory activities.

METHODS

STUDY AREA

This study was conducted in the eastern Chukchi Sea, with data collection focused in an area extending ~180 km west of the village of Wainwright (Figure 1). The overall survey area is bounded by 2 currents flowing from the Chukchi Sea to the Arctic Ocean: the Central Channel flow, to the west, and the Alaskan Coastal Current, to the east (Weingartner et al. 2005, 2008, 2013). During 2008–2010, surveys focused on 3 study-area boxes located ~110–180 km offshore called Klondike, Burger, and Statoil that were sampled during 2–3 research cruises/yr. The Klondike study-area box is located on the eastern side of the Central Channel and near the inflow of Bering Shelf Water. The Burger study-area box is located to the northeast of Klondike and is located on the southern slope of Hanna Shoal. The Statoil study-area box was added in 2010 and lies north of Klondike and northwest of Burger. Its western boundary is adjacent to the Central Channel and its eastern half is on the southern slope of Hanna Shoal. The study area was expanded in 2011 and 2012 to include an extensive area north and west of the 3 study-area boxes. This larger area, including the 3 boxes, is ~39,000 km^2 in area and is referred to as the Greater Hanna Shoal (GHS) study area. The Alaskan Coastal Current flows east of the GHS, exiting the region via Barrow Canyon.

Each study-area box was a polygon ~3,000 km^2 in area. Observers surveyed seabirds along a series of parallel survey lines spaced 2 NM (3.7 km) apart that ran north–south through the 3 study-area boxes. A subsample of lines was included in the survey design for data collection during 2011–2012, that consisted of broad-scale survey lines in the GHS study area spaced 7.5 NM (13.75 km) apart and lines within the study-area boxes that were spaced 2, 3, or 4 NM (3.7, 5.6, or 7.4 km) apart (Figure 1). In addition to established survey lines, we also sampled opportunistically when transiting to, from, and within the GHS study area.

For the comparison with historical data, we included data collected throughout the U.S. sector of the Chukchi Sea. We divided the Chukchi into 4 strata (Figure 1) to account for the effects that latitude, water-masses, and currents can have on determining oceanic habitat (Piatt and Springer 2003). The Southern stratum has an area of 56,835 km^2 and is bounded by Bering Strait (66.00 °N) to the south, the latitude of Cape Lisburne (68.75 °N) to the north, inner Kotzebue Sound to the east, and the International Date Line to the west. This stratum is influenced by strong flows through Bering Strait of Bering Shelf Water and Anadyr Water to the west and of Alaskan Coastal Water (ACW) to the east. The Nearshore stratum has an area of 35,682 km^2 and is bound by the latitude of Cape Lisburne (68.75 °N) to the south, the Chukchi shelf-break (72.00 °N) to the north, the Chukchi/Beaufort boundary (155.00 °W) to the east, and the 40-m isobath (including Barrow Canyon) to the west. This stratum is influenced by coastal flows that carry predominantly ACW, although there is some suggestion of reversal of flows in the northern half of this stratum with intrusions of arctic water up Barrow Canyon (Weingartner et al. 2005). The Offshore stratum has an area of 130,354 km^2 and is bounded by the latitude of Cape Lisburne (68.75 °N) to the south, the Chukchi shelf-break (72.00 °N) to the north, the International Date Line to the west, and the 40-m isobath (excluding Barrow Canyon) to the east. This stratum is influenced by both the Central Channel flow that entrains Bering Sea Water along the western edge and resident waters over Hanna Shoal that are characterized by a two-layer water column with Meltwater (MW) on top and Winter Water (WW) on the bottom. The Northern stratum is bounded between 72.00 °N to the south, 73.00 °N to the north, 155° W to the east, and the International Date Line to the west. This stratum includes the continental slope that drops into the Arctic Basin and is influenced by waters that flow north from the Chukchi and upwelling along the continental shelf-break from the Arctic Ocean.

It is important to note that the International Date Line and the U.S.-Russia maritime boundary line are not the same. The International Date Line was treated as the boundary during many of the research cruises conducted in the 1970s and 1980s. In 1990, the U.S.A. and the U.S.S.R. signed an agreement to abide by the maritime boundary as established in Article 1 of the Convention Ceding Alaska, signed 30 March 1867 (U.S. Department

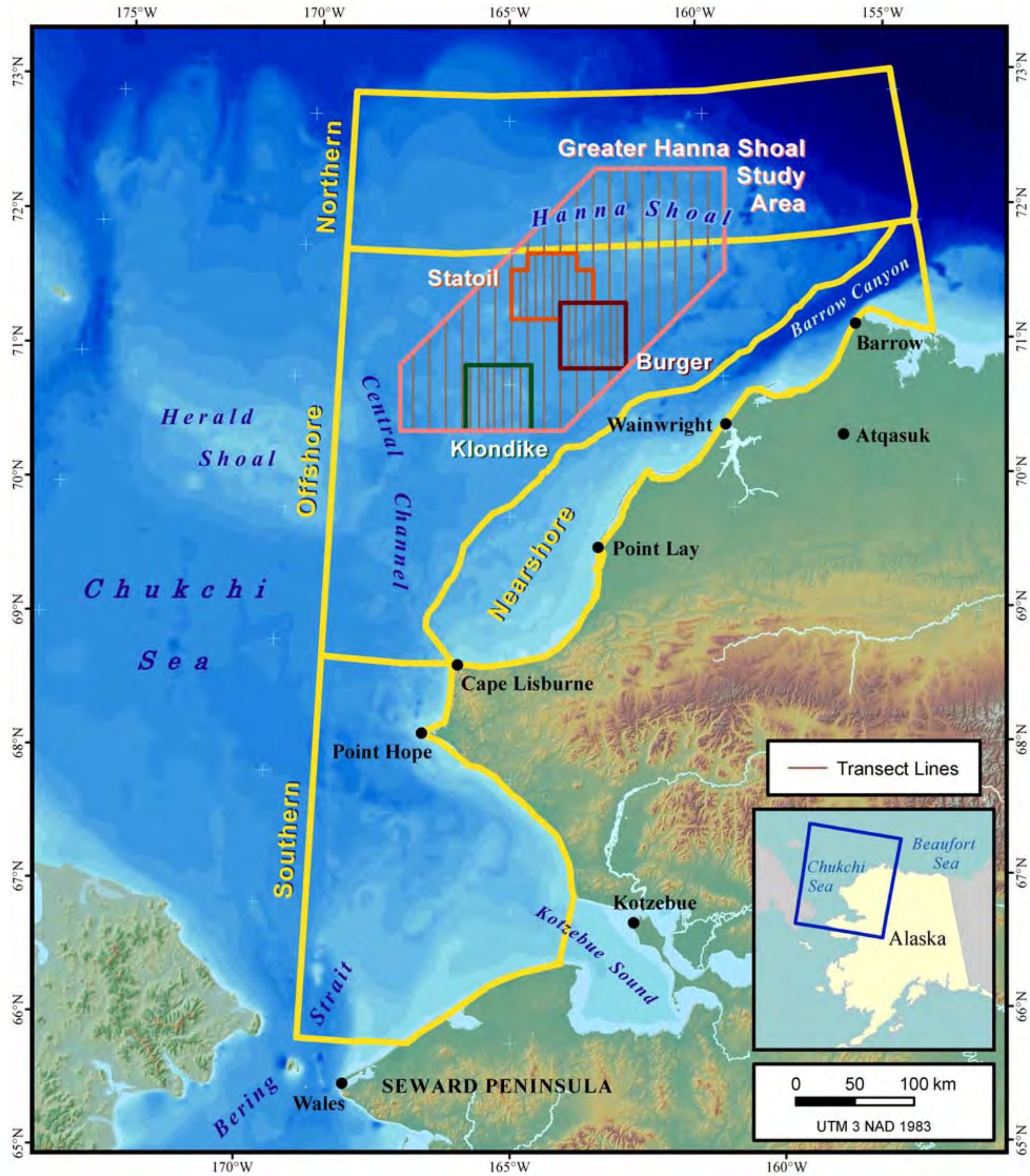

Figure 1. Locations of the Klondike, Burger, Statoil, and Greater Hanna Shoal study areas. Also shown are the regional strata used to compare recent data to historical data (1975–1981) and locations of the seabird survey lines.

of State 1990). This agreement specified that the maritime boundary in the Chukchi Sea extends north from its initial point, 65°30’ N, 168°58’ 37” W along that same meridian through the Bering Strait and Chukchi Sea into the Arctic Ocean as far as permitted under international law. This is why we have included historical data from the Russian side of what is now the U.S. sector of the Chukchi Sea, but our sampling for CSESP and other projects conducted 2008–2012 was limited to the area defined by the agreement signed in 1990.

DATA COLLECTION

We conducted seabird surveys during the open-water season in the northeastern Chukchi Sea (Figure 2). In 2008–2010, we surveyed only the 3 study-area boxes during each of 3 time periods: July/August (hereafter, Aug), August/September (hereafter, Sep), and late September/early October (hereafter Sep/Oct). In 2011–2012, we surveyed the study-area boxes during Aug and part of the GHS (including the boxes) during Sep, and then completed surveys of the GHS during Sep/Oct.

We conducted the surveys as consecutive 10-min counting periods (hereafter, transect segments) 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 downwind). One observer stationed on the bridge of the ship recorded all birds seen within a radius of 300 m in a 90° arc from the bow to the beam on one side of the ship (the count zone) and located and identified seabirds with 10 X binoculars. For each bird or group of birds, we recorded:

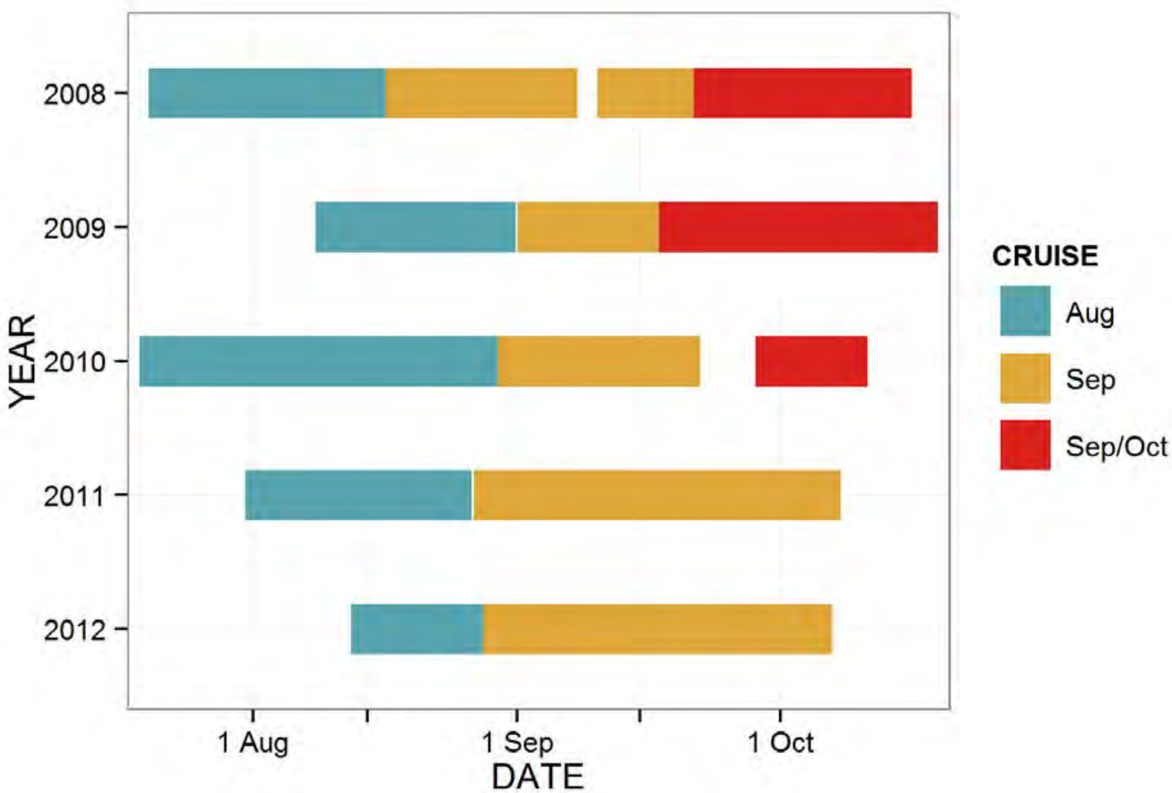

Figure 2. Timing of ship-based surveys of seabirds in the Greater Hanna Shoal study area, 2008–2012.

- species (or identity to lowest possible taxon);
- total number of individuals;
- distance from the observer when sighted (in categories; 0–50 m [0–164 ft], 51–100 m [165–328 ft], 101–150 m [329–492 ft], 151–200 m [493–656 ft], 201–300 m [657–984 ft]);
- radial angle of the observation from the bow of the ship (to the nearest 1°);
- number in each age-class (juvenile, sub-adult, adult, unknown age), if possible;
- habitat (air, water, flotsam/jetsam, ice); and
- behavior (flying, sitting, swimming, feeding, comfort behavior, courtship behavior, other).

We counted all birds on the water that were in the count zone, taking care to avoid recounting the same individuals. For flying birds, however, we 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). We counted only those flying birds that entered the count zone from the sides or front and did not count flying birds that entered from behind the ship (i.e., an area that already had been surveyed), to avoid the possibility of counting ship-following birds.

We entered observations of all birds directly into a computer connected to a global positioning system (GPS) with DLog software (R. G. Ford Consulting, Portland, OR) in 2008 and TigerObserver software (TigerSoft, Las Vegas, NV) in 2009–2011; these programs time-stamped and geo-referenced every observation entered in real time. The primary GPS connected to the data-collection computer occasionally lost communication with satellites, resulting in missing locations for observations and transect cutoff points. To fill these GPS data gaps (a total of 5.5 h across the 5 yr), we interpolated the ship's location between known waypoints by using its speed and the time of the observation.

For the historical comparison, we used data collected from ships of opportunity during 1975–1981 by researchers following protocols developed by the U.S. Fish and Wildlife Service (USFWS; Tasker et al. 1984, Gould and Forsell 1989). These protocols are comparable to ours. These data were archived in the North Pacific Pelagic Seabird Database, which is maintained by the U.S. Geological Survey (Anchorage, AK). We combined data sets from 3 recent studies that ABR, Inc.—Environmental Research & Services conducted in the region to obtain coverage in all strata (Figure 3): the Chukchi Sea Environmental Studies Program (CSESP; 2008–2011; Day et al. 2013), the Alaska Monitoring and Assessment Program (AKMAP; 2010–2011; Morgan et al. 2012), and surveys conducted for the U.S. Fish and Wildlife Service near Barrow (2009–2010; Gall and Day 2009, Morgan et al. 2010). Data from all of these studies are publicly available from USGS.

DATA ANALYSIS

DENSITY CALCULATIONS AND ANALYSES

We estimated detection-corrected (hereafter, corrected) densities (birds/km²) of birds within each study area during 2008–2012 by using line-transect sampling analyses and followed analytical methods described by Buckland et al. (2001, 2004). This approach accounts for the decrease in probability of detecting a bird with increased distance from the survey line. The analysis consisted of 3 steps. First, we fitted a detection function for each species (or group of species) to the observed distances of sightings from a line directly ahead of the ship to estimate the probability of detection for each species. Next, we used the observed flock sizes to estimate the mean flock size for each species. Finally, we estimated the corrected density of birds for each transect and study area during each season (cruise) by incorporating the probability of detection, the area surveyed, and the mean flock size.

We selected 8 focal taxa for statistical analyses from among the 10 most-abundant species in all years: Crested Auklet, Least Auklet, phalaropes, Short-tailed Shearwater, Black-legged Kittiwake, Thick-billed Murre, Glaucous Gull, and Northern Fulmar. Red-necked and Red phalaropes often occur in mixed-species flocks and are

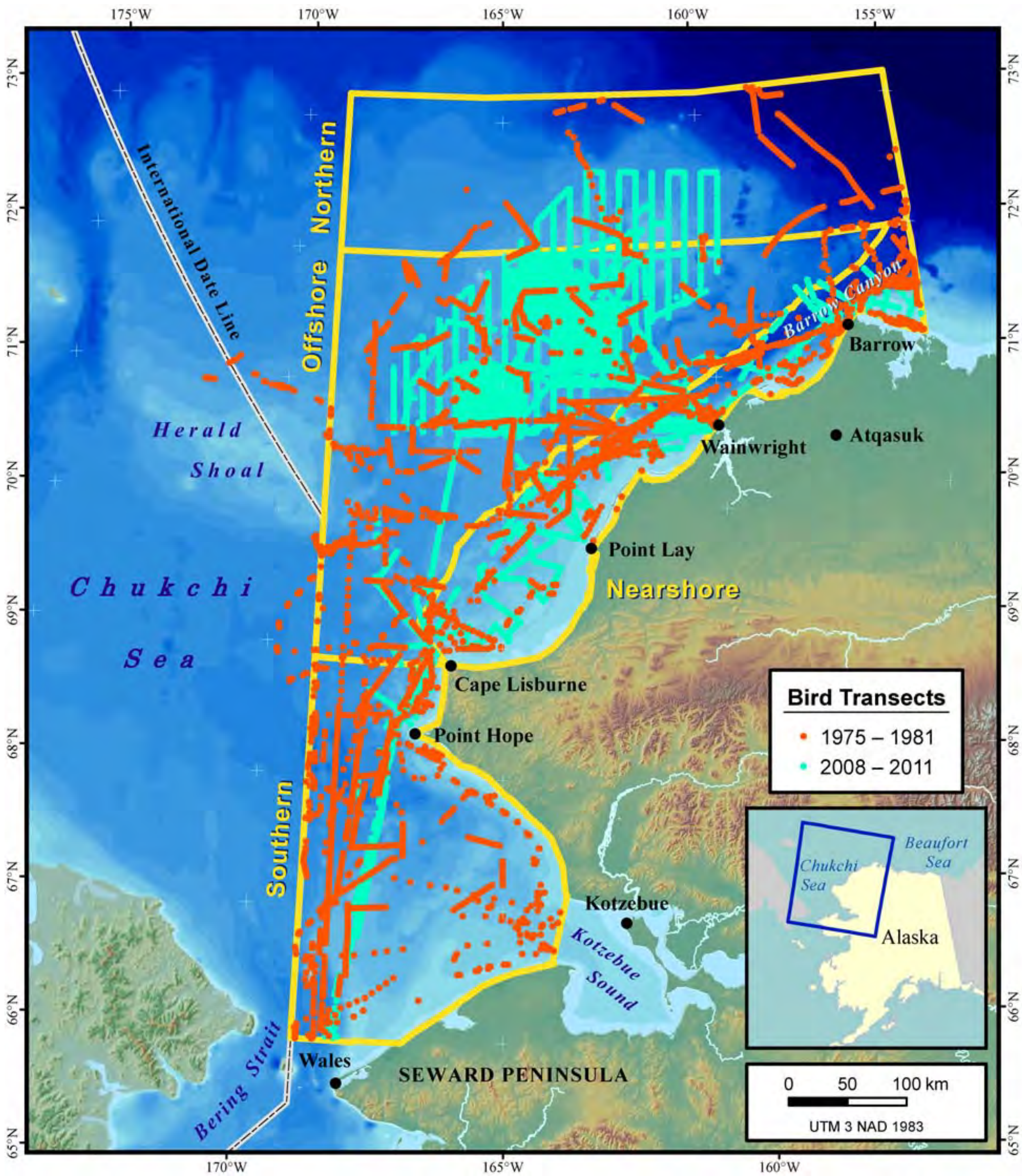

Figure 3. Transect locations of historical (1975–1981) and recent (2008–2012) seabird surveys in the eastern Chukchi Sea.

difficult to distinguish during molt. We therefore combined observations of these 2 species with those of unidentified phalaropes and treated them collectively as phalaropes. These 8 focal taxa represented a variety of foraging methods, thereby providing an overview of functional ecological groups of the seabird community. Scientific names and guild assignments of all bird species discussed in this report are presented in Appendix A.

We assigned all species to one of 6 detection groups based on their similarity in size, color, behavior, and/or perpendicular distance histograms. For each detection group, we fitted models that used 1 of 2 possible key functions (half-normal or hazard-rate) to the distribution of observation distances to find the model that best estimated the probability of detection (Table 1). We included covariates in the model sets to account for possible differences in detection among observation platforms (i.e., ship), observers, and sea-surface conditions (measured on the Beaufort scale). The fit of each model was assessed with Akaike's Information Criterion (AIC), diagnostic plots, and a Kolmogorov–Smirnov goodness-of-fit test (following Buckland et al. 2004). The one exception was for phalaropes, in which the detections were concentrated in the first distance interval. Consequently, we fitted only the half-normal model to prevent overfitting the skewed distance distribution (S. T. Buckland, University of St. Andrews, St. Andrews, Scotland, in litt.). Once a model was selected for a detection group, we calculated species-specific corrected density estimates within that group by running a separate analysis that filtered for each species and then applied the detection model to generate the estimates and associated 95% confidence intervals. These corrected density estimates were calculated with the formula:

$$\hat{D} = \frac{n \cdot \hat{E}(s)}{L \cdot \hat{P}_a}$$

where $\hat{D}$ is the corrected density estimate, n is the total number of observations on transects, $\hat{E}(s)$ is the mean flock size, L is the total length of transects sampled, and $\hat{P}_a$ is the probability of detection estimated by the model (Buckland et al. 2001). The distance analysis was conducted with the statistical package mrds (Laake et al. 2012) for R. We used R v. 2.15 (http://www.r-project.org) for all analyses.

We calculated mean corrected densities of each species by study area, season, and year. We calculated variances with the delta method and calculated log-normal, *z*-based, two-sided 95% confidence intervals for the estimates of density with equations 3.71–3.74 in Buckland et al. (2001: 77). We used generalized linear models (package MASS; Venables and Ripley 2002) to examine differences among the Klondike, Burger, and Statoil study areas; among seasons; and among years for each species (Tables 2 and 3). The models included the additive effects of the factors STUDY AREA, SEASON, and YEAR and the 2-way interactions between STUDY AREA and the temporal variables. We specified SEASON as nested within YEAR as repeated measurements for each study area but found no support for including random effects in the model (P = 0.99 for likelihood-ratio tests). We ran 2 separate analyses because we did not sample in Klondike or Statoil in Oct 2010 and did not sample any of the study-area boxes in Oct 2011 or Oct 2012. In the first analysis, we compared densities between Burger and Klondike in Aug and Sep during 2008–2012. In the second analysis, we compared densities in all three study areas between Aug and Sep 2010–2012. Models of data sets with many zeros can fail to converge, as was the case for Glaucous Gulls and Short-tailed Shearwaters. We used confidence intervals to support inferences in those cases. In all statistical tests, the level of significance (α) was 0.05.

We also used the geolocated observations to generate maps of distribution and abundance for individual species of interest integrated over the GHS study area. First, we standardized transect segments to 2.5 km and estimated the corrected abundance on each segment following the distance sampling method described above. We then overlaid a 3.0 × 3.0-km grid over the GHS study area and used generalized additive models (package mcgv; Wood 2004) to predict the density surface by using the estimated abundance for each survey transect as a response and the interaction of latitude and longitude as explanatory variables. This analysis produced color maps showing

Table 1. Detection function models used to calculate corrected densities of 8 most abundant taxa of seabirds.

Species/taxon	Function shape	Covariates	Average probability of detecting a flock	CV[a] (%)	Mean flock size
Crested Auklet	half-normal	observer + vessel + Beaufort	0.63	0.9	3.9
Least Auklet	half-normal	observer + Beaufort	0.59	2.0	1.9
Black-legged Kittiwake	half-normal	observer	0.57	1.5	1.8
Glaucous Gull					1.2
Northern Fulmar					1.2
Phalaropes	half-normal	observer + vessel + Beaufort	0.46	3.4	4.3
Short-tailed Shearwater	hazard-rate	observer	0.72	2.4	6.5
Thick-billed Murre	hazard-rate	observer + Beaufort	0.77	2.2	1.7

[a] Coefficient of variation of the probability of detection

surface models of the density of each of the 8 focal taxa within the GHS to create contoured portrayals of the data.

HISTORICAL ABUNDANCE

We compared the abundance of birds during 1975–1981 (hereafter, historical period) with abundance during 2008–2012 (hereafter, recent period) in each of 3 strata in the U.S. sector of the Chukchi Sea (hereafter, Chukchi Sea) to explore long-term changes in the seabird community (Figure 3). For abundance analysis, we pooled data from the Offshore and Northern strata because the trends were similar and the sample size was limited in the Northern stratum. Because distance data were not available for the historical observations, we did not correct for detection probability in this portion of the analysis. We pooled years within the 2 time periods and evaluated changes in abundance with generalized linear models that included time period, region, and the interaction between these factors as explanatory variables. We modeled the error terms with a negative binomial distribution to account for overdispersion in count data and used the area (km^2) of each transect as an offset to account for survey effort.

We also assessed the influence of changing sea-ice conditions on the abundance of seabirds by modeling the influence of date of ice retreat and days of ice-free water on abundance of 6 species of seabirds that had sufficient sample size in both historical and recent years. We used Special Sensor Microwave Imagery (SSM/I; i.e., sensor data from a passive microwave satellite) from the National Snow and Ice Data Center (NSIDC; www.nsidc.org) to quantify the annual timing of ice advance, ice retreat, and changes in percent sea-ice cover in each stratum during 1979–2012. These data are available from the fall and winter of 1978–1979 to the present (e.g. Cavalieri et al. 2004). We used the gridded daily data product with standard 25-km resolution for consistent data resolution throughout the analysis period.

We built generalized linear models for each stratum and focal species that included the onset and duration of ice-free waters as continuous variables. We used zero-altered negative-binomial models (package pscl; Zeileis et al. 2008) to account for overdispersion in the distribution of the data. These models have 2 portions that address bird distribution across the seascape, with the zero portion modeling the probability of presence

Table 2. Species of seabirds identified during ship-based surveys in the northeastern Chukchi Sea, in the Klondike and Burger study areas by season. Species identified on-transect within the study area are designated as “X8”, “X9”, “X10”, “X11”, and/or “X12” for 2008–2012, respectively. Species identified only off-transect in a given year are designated as “OT8”, “OT9”, “OT10”, “OT11”, and/or “OT12” for 2008–2012 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	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct
WATERFOWL						
Spectacled Eider	–	X9	–	–	OT9	OT10
King Eider	X8	X12	X8	–	X8, OT10, OT12	X8, X10
Common Eider	–	X12	–	X12	X8	X10
White-winged Scoter	–	–	OT8	–	–	X8, OT10
Long-tailed Duck	X8	X9, H, X12	X8, X9, B10	B9, H	X8, X9, X10, X12, H	X8, B9, X10, H
LOONS						
Red-throated Loon	–	–	–	–	X8, X11	–
Pacific Loon	–	X8, X9, X10, OT12	X8, X9	–	X8, X9, X10, X11, X12	X8, X9, OT10
Arctic Loon	H	–	H	–	H	–
Common Loon	–	H	–	–	–	–
Yellow-billed Loon	–	X8, X9	X8, X9	–	X8, X9, X11, OT10	OT9
TUBENOSES						
Northern Fulmar	X8, X9, X10, X11, X12	X8, X9, X10, X11, X12, H	X8, X9	X8, X9, X10, X11, X12	X8, X9, X10, X12	X8, X9, X10
Short-tailed Shearwater	X8, X9, X10, X11, X12	X8, X9, X10, X11, X12, H	X8, X9, B10, H	X9, X10, X11, X12	X8, X9, X10, X11, X12, H	X8, X9, X10
PHALAROPES						
Red-necked Phalarope	X9, X10, X12	X8, X9, X10, X11	X8, X9	X9, X10, X11, X12	X8, X9, X10, X11	X9
Red Phalarope	X8, X9, X10, X12, H	X8, X10, X12, H	X8, X9	X9, X11, X12, OT10, H	X8, X9, X10, X12, H	X9, X10
LARIDS						
Black-legged Kittiwake	X8, X9, X10, X11, X12, H	X8, X9, X10, X11, X12, H	X8, X9, B10, H	X8, X9, X10, X11, X12, H	X8, X9, X10, X11, X12, H	X8, X9, OT10, H
Ivory Gull	H	–	–	H	OT12, H	X8, H
Sabine's Gull	X8, OT9, X10, X12, H	X8, X9, X10, OT12, H	X8, X9	X8, OT9, X10, X11, X12, H	OT8, X10, OT12	X9

Table 2. Continued.

Species-group/species	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct
Ross's Gull	–	OT12	–	H	OT9, X11, H	X8, X9, X10, H
LARIDS (continued)						
Herring Gull	X8, H	X9, H	X8	X9, H	X9, X10	X8
Glaucous-winged Gull	OT8	–	–	–	–	–
Glaucous Gull	X8, X10, H	X8, X9, X10, X11, X12, H	X8, X9, B10	X8, X9, X10, X11, H	X8, X9, X10, X11, X12, H	X8, X9, X10, H
Arctic Tern	B8, H	X8, X10	–	X9, X10, X12, B8	OT8, X9	–
Pomarine Jaeger	X8, X9, X10, H	X8, X9, X10, X11, H	X8, X9	X8, X9, X10, X11, H	X8, X9, X10, X11, OT12	–
Long-tailed Jaeger	X9, X10, X12, H	OT8, OT10, H	–	X9, H	OT8, X10	–
Parasitic Jaeger	X8, X12, H	X8, X11, OT10, OT12, H	–	X8, X12, H	X10, B8, H	–
ALCIDS						
Dovekie	X8, X12	–	X8	–	H	X8, X10
Common Murre	X8, X11, X12, B10, H	X9, X10, X11, X12, H	X8, X9	X11, X12, B10, H	X9, X10, X11, X12	X9
Thick-billed Murre	X8, X9, X10, X11, X12, H	X8, X9, X10, X11, X12, H	X8, X9, H	X8, X9, X10, X11, X12, H	X9, X10, X11, X12, B8	X8, X9, X10
Black Guillemot	X8, X10, H	X12	–	X8, X10, X11, H	X12, B8, H	X8, OT10
Pigeon Guillemot	X8	–	–	X8	–	–
Kittlitz's Murrelet	X10, X11, X12, H	X9, X10, X11, H	X8, B9	–	X10, X11, X12, B9	X9
Ancient Murrelet	–	X10, X12	OT10	–	X10, X11, OT12	X10
Parakeet Auklet	X10, X12, H	X8, X9, X10, X11, X12, H	–	–	X10, X12, H	X8, X10
Least Auklet	X8, X9, X10, X11, X12	X8, X9, X10, X11, X12, H	X8, X9, B10, H	X9, X10, X11, X12, H	X8, X9, X10, X11, X12	X8, X9, X10
Crested Auklet	X8, X9, X10, X11, X12	X8, X9, X10, X11, X12, H	X8, X9, B10, H	X9, X10, X11, X12	X8, X9, X10, X11, X12, H	X8, X9, X10
Horned Puffin	X8, X9, X10, X11, X12, H	X9	–	X8, X10, OT9, OT12	X10	–
Tufted Puffin	X8, X9, X10, X12, H	OT9	X8	X12	X10	–

Table 3. Species of seabirds identified during ship-based surveys in the northeastern Chukchi Sea, in the Statoil and Greater Hanna Shoal (outside of the three study-area boxes) study areas by season. Species identified on-transect within the study area are designated as “X10”, “X11”, and/or “X12” for 2010–2012, respectively. Species identified only off-transect are designated as “OT10”, “OT11”, and/or “OT12”. Species identified in the historical dataset within the study area, available from the North Pacific Pelagic Seabird Database, are designated as “H.”

	Study area/season			
	Statoil			Greater Hanna Shoal
Species-group/species	Aug	Sep	Sep/Oct	Aug–Oct
WATERFOWL				
Spectacled Eider	–	–	–	–
King Eider	–	–	–	X11, X12
Common Eider	–	OT10, X11	–	X11, OT12
White-winged Scoter	–	–	–	–
Long-tailed Duck	X10, H	X10, X12, H	H	X12
LOONS				
Red-throated Loon	–	X10	–	X11
Pacific Loon	–	X10, X11, X12	–	X11, X12
Arctic Loon	–	H	–	–
Common Loon	–	–	–	–
Yellow-billed Loon	–	–	–	X11, X12
TUBENOSES				
Northern Fulmar	X10, X11, X12	X10, X11, X12	–	X11, X12
Short-tailed Shearwater	X10, X11, X12	X10, X11, X12, H	–	X11, X12
PHALAROPES				
Red-necked Phalarope	X10, X11, X12	X10, X11, X12	–	X11, X12
Red Phalarope	X12, OT11, H	X10, X12	–	X11, X12
LARIDS				
Black-legged Kittiwake	X10, X11, X12, H	X10, X11, X12, H	–	X11, X12
Ivory Gull	–	H	–	X11, X12
Sabine's Gull	X10, X12	–	–	X11, X12
Ross's Gull	H	H	OT10, H	X11, X12
Herring Gull	H	X10	–	X11
Glaucous-winged Gull	–	–	–	–
Glaucous Gull	X10, X11, X12, H	X10, X11, OT12, H	H	X11, X12
Arctic Tern	OT12	–	–	X11
Pomarine Jaeger	X10, OT12, H	X10, X11	–	X11, OT12
Long-tailed Jaeger	X12, H	–	–	–
Parasitic Jaeger	X11, X12, H	H	–	X11, OT12
ALCIDS				
Dovekie	–	X10, H	–	X11
Common Murre	X11, H	X10, X11	–	X11, X12
Thick-billed Murre	X10, X11, X12, H	X10, X11	–	X11, X12
Black Guillemot	X10, H	H	–	X11, X12
Pigeon Guillemot	–	–	–	–

Table 3. Continued.

Species-group/species	Statoil Aug	Statoil Sep	Statoil Sep/Oct	Greater Hanna Shoal Aug–Oct
Kittlitz's Murrelet	X10	X11	–	X11, X12
Ancient Murrelet	–	X10, X11, OT12	–	X11, X12
Parakeet Auklet	X10	X10, X11, X12	–	X11, X12
Least Auklet	X10, X11, X12, H	X10, X11, X12	OT10	X11, X12
Crested Auklet	X10, X11, X12	X10, X11, X12, H	–	X11, X12
Horned Puffin	X10, X11, X12	X10, X11	–	X11, X12
Tufted Puffin	X10, X11, X12	–	–	–

versus absence given a set of parameters and the count portion modeling factors that influence abundance in areas where birds occur. We started with full models, including both terms (ICE RETREAT DATE and DAYS ICE-FREE) in both the zero and count portion of the models and used backwards stepwise removal of non-significant terms from each portion of the model. Because transect length varied from 500 m to 10 km, we included sampling area as an offset based on each transect's width and length. We evaluated strength of the models with AIC and drew inference from the model that best fit the data.

COMMUNITY ANALYSES

We used multivariate analyses and descriptive statistics to explore the changes in structure of the seabird community among seasons, study areas, and years. For the multivariate analyses, we grouped the data into sample units by study area, season, and year for the CSESP analysis and by stratum and year for the historical comparison. We included all bird observations that were identified to species. The overall similarity in the species-composition of samples is determined by their closeness in the two-dimensional ordination. This approach is useful for detecting patterns in overall community structure and similarities among species assemblages (Blanchard et al. 2010). We used the species information to calculate a Bray–Curtis similarity matrix (Bray and Curtis 1957) to which we applied non-metric multidimensional scaling (nMDS; Clarke and Green 1988). The stress coefficient of the ordinations was 0.17 for the CSESP data and 0.14 for the historical comparison, indicating adequate fit to the data (Clarke and Ainsworth 1993). The nMDS analysis was conducted in R with the package vegan (Oksanen et al. 2011).

For descriptive summaries of historical (1975–1981) and recent (2008–2012) data, we included all bird observations that were identified at least to family to determine the numerically dominant species assemblages composing each sample (Magurran 2004). We aggregated species into 5 ecological groups that represented foraging guilds (Appendix A) to test the hypothesis of a shift in community structure: benthic-feeders (predominantly eiders *Somateria* spp. and *Polysticta stelleri*), omnivores (e.g., jaegers, fulmars, and large gulls), fish-feeders (e.g., murres, guillemots, puffins, loons, and small gulls), plankton-feeders (e.g., Dovekie, auklets, murrelets, and phalaropes), and Short-tailed Shearwaters, which primarily are planktivorous but also are extremely flexible in their prey consumption and foraging strategy (Hunt et al. 2002, Weimerskirch and Cherel 1998).

SAMPLING EFFORT

Sampling effort must yield sample sizes large enough to estimate reliable detection functions and to estimate abundance accurately. Because detection probabilities vary among detection groups, we calculated sampling effort separately for each of the 6 detection groups (small alcids, medium alcids, large alcids, gulls, shearwaters, and phalaropes).We used the encounter rates (numbers of observations/km of transect line surveyed) within each study-area box by season and year to calculate the range of total survey-length values (*L*) required to obtain 60 detections, which is the minimal number required to estimate the detection probability function with confidence. We compared this range of values for each of the 6 detection-groups with the survey effort in each year to evaluate how well our current protocols are meeting the sample requirements for estimating reliable detection functions and for informing future study designs.

We used our survey data to calculate the coefficient of variation (*CV*) of abundance estimates from surveying 55-km survey lines (*L*) within a study-area box with the equation:

$$\{CV(\hat{D})\}^2 = \frac{1}{L} \cdot \frac{L_0}{n_0} \cdot \left[b + \left\{ \frac{\widehat{sd}(s)}{\bar{s}} \right\}^2 \right]$$

with $b = n_0 \cdot [CV(\hat{D}_s)]^2$ where n_0 is the number of flocks (i.e., observations) detected during a survey covering a total length L_0, $\widehat{sd}(s)$ is the empirically estimated standard deviation of flock size *(s)*, $\bar{s}$ is the mean flock size, and $CV(\hat{D}_s)$ is the empirically estimated coefficient of variation of flock size (Buckland et al. 2001, eq. 7.11). We calculated CV values for 1–16 survey lines; replicates (L_o) consisted of empirically derived values from a single study-area box/season/year. We identified the stabilization point for abundance estimates of 6 detection groups as that sample size at which there is a reduction of <10% of the CV with the addition of another survey line. At that point, an increase in survey effort does not produce a biologically relevant change in the precision of the estimate. We also calculated the survey effort required to estimate abundance with CVs of 0.20, 0.30, and 0.40.

We also conducted a power analysis to determine the probability of detecting increasing or decreasing linear trends in seabird abundance within the study-area boxes. Factors that influence the power function are: (1) the probability of a Type I error (i.e., concluding that there is a trend when in fact there is not; α); (2) the probability of a Type II error (i.e., concluding that there is not a trend when in fact there is one; β); (3) the number of years surveyed (*n*); (4) sample variability (*cv*); and (5) the rate of change to be detected (*r*; Gerrodette 1987). They are related with the equation:

$$r^2 n(n-1)(n+1) \geq 12cv^2 (z_{\frac{\alpha}{2}} + z_\beta)^2 \cdot \left\{1 + r(n-1)\left[1 + \frac{r}{6}(2n-1)\right]\right\}$$

For this exercise, we set α = 0.1 and assumed that the coefficient of variation does not depend on abundance (Eberhardt 1967). We solved for the probability to detect a trend (1 – β) given sampling at regular intervals (i.e., annually). Functions were calculated with the package fishmethods (Nelson 2013).

RESULTS

OCEANOGRAPHIC STRUCTURE

We present here a summary of the oceanographic conditions in the sampling region to provide context for interpreting the seabird data. For detail on the sampling and analysis of the physical oceanography data, see Weingartner et al. (2012). The physical structure of the GHS study area in 2008–2012 may be seen in a series of vertical sections (Figures 4–6) and plan views (Figures 7 and 8) of CTD data collected during each of the research cruises. The first 2 vertical section figures (Figures 4 and 5) show temperature (°C) and salinity (psu) 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 Klondike, then from the southwestern corner (at ~100 km along the X-axis) to the northeastern corner (far right side of plots) of Burger. This sampling pattern is consistent for all cruises except Sep/Oct 2010, when data were available only for Burger during that cruise. The third vertical-section figure (Figure 6) shows a transect extending from the southeastern corner of Burger to the northwestern corner of Statoil. The plan views show the distribution of temperature and salinity in the upper 10 m of the water column over the study-area boxes in 2008–2010 and throughout the GHS study area in 2011 and 2012. The physical oceanography of the region is

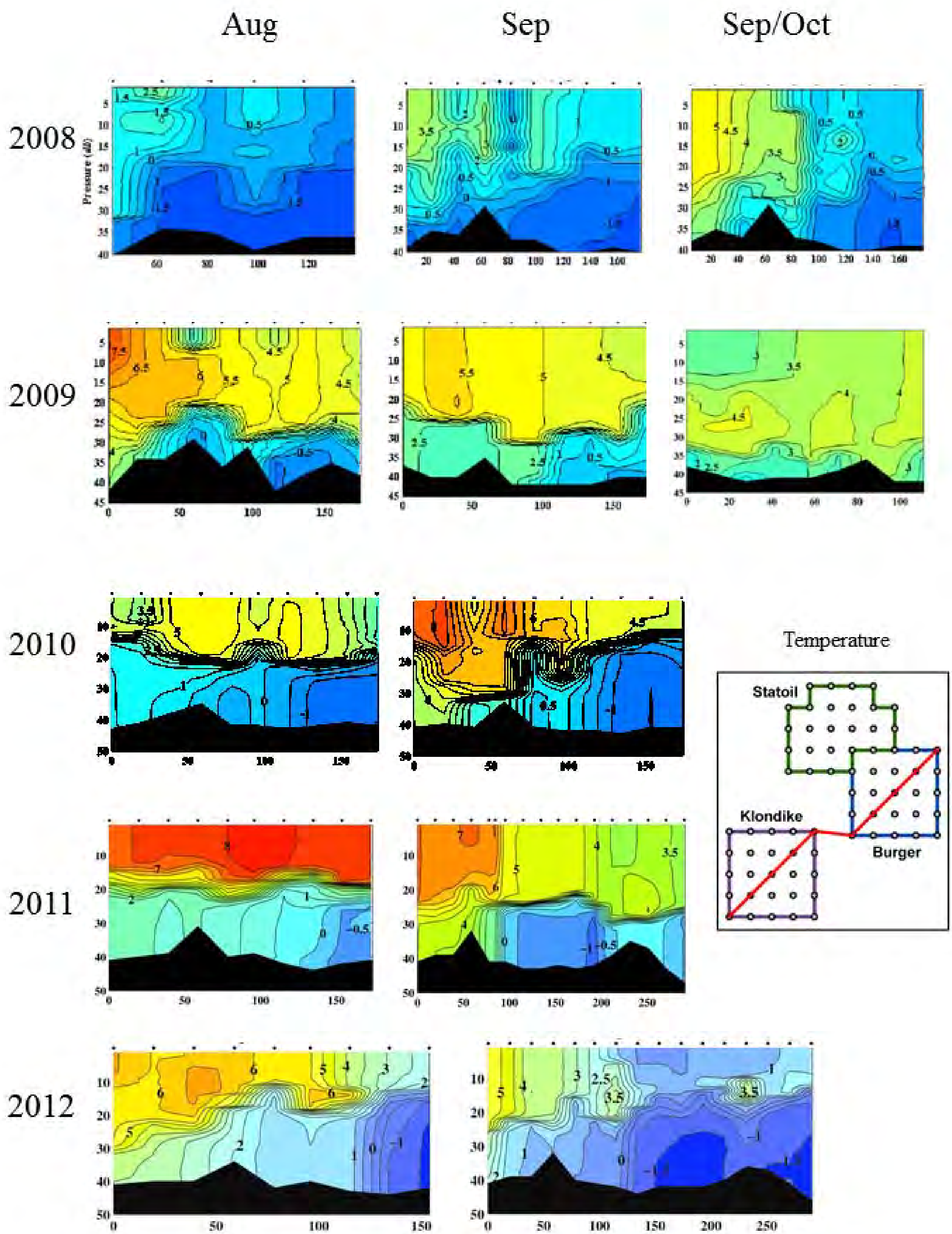

Figure 4. Vertical sections of temperature (°C) in the Klondike and Burger study-area boxes, 2008–2012 (Weingartner et al. 2011, 2012, 2013).

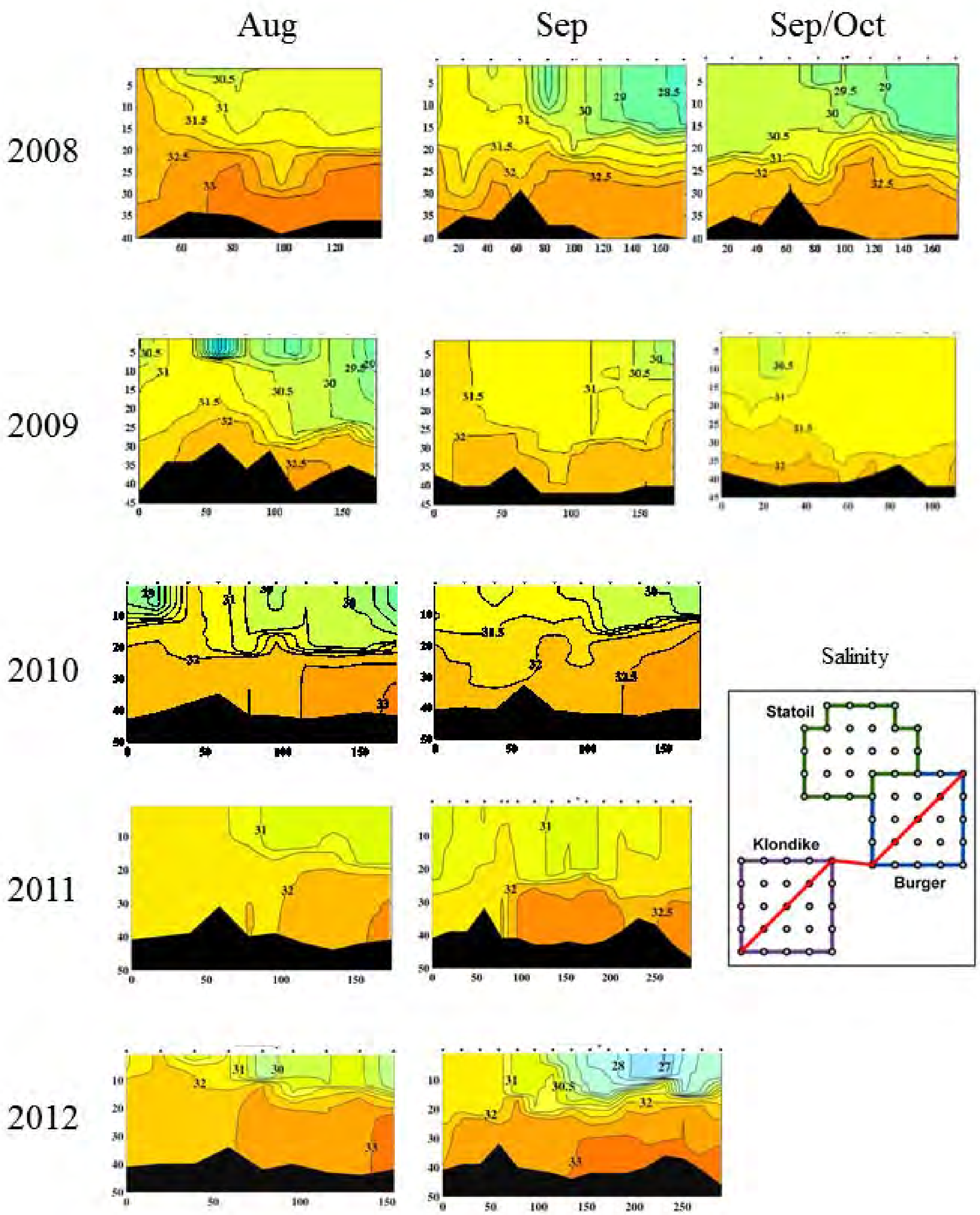

Figure 5. Vertical sections of salinity (psu) in the Klondike and Burger study-area boxes, 2008–2012 (Weingartner et al. 2011, 2012, 2013).

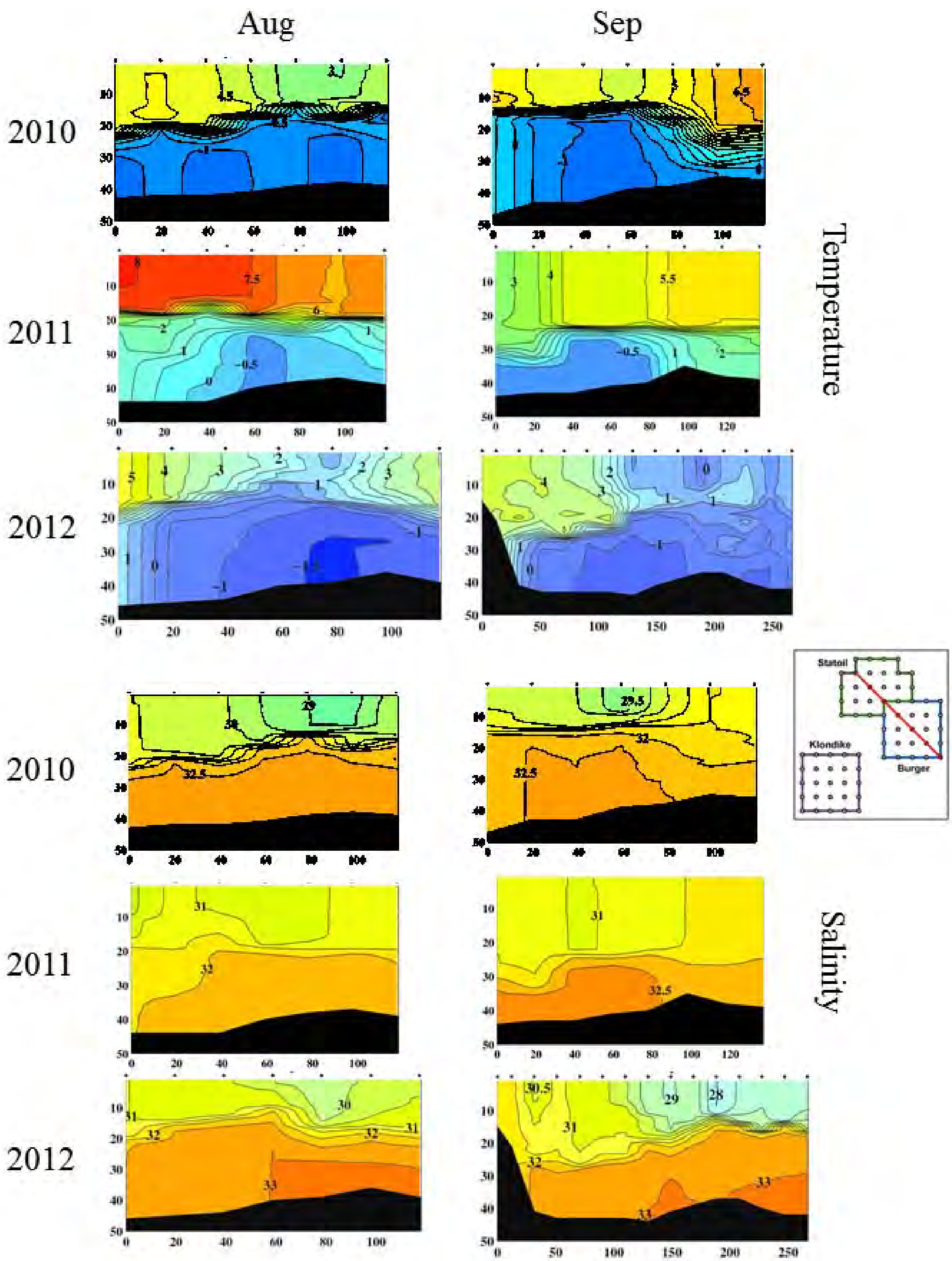

Figure 6. Vertical sections of temperature (°C) and salinity (psu) in the Burger and Statoil study-area boxes, 2010–2012 (Weingartner et al. 2012, 2013).

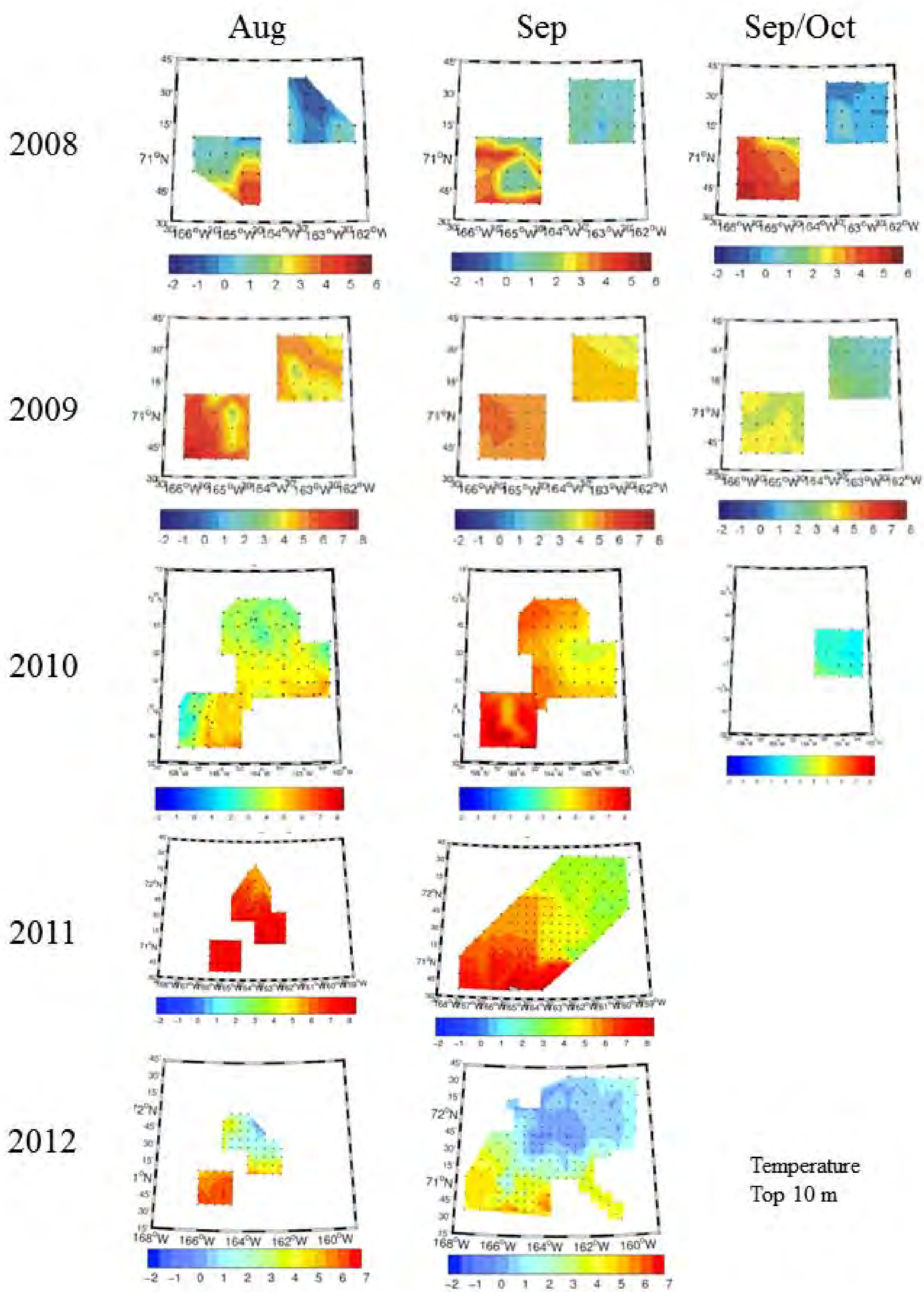

Figure 7. Plan views of temperature (°C) in the Greater Hanna Shoal study area, 2008–2012 (Weingartner et al. 2012, 2013).

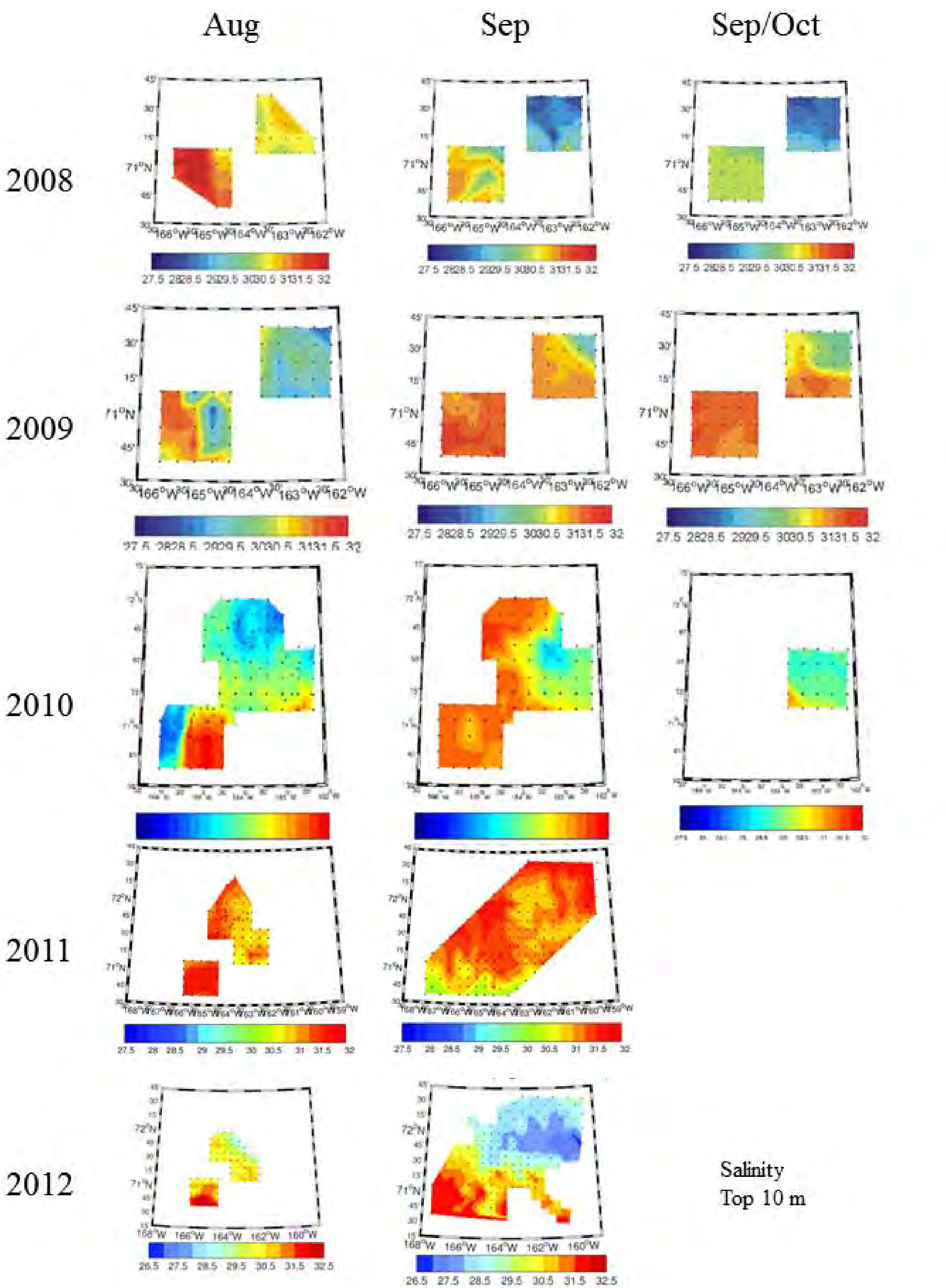

Figure 8. Plan views of salinity (psu) in the Greater Hanna Shoal study area, 2008–2012 (Weingartner et al. 2012, 2013).

described in greater detail by Weingartner et al. (2011, 2012), and this section of the report is derived from their work.

In all years, warm (3–8 °C), moderately saline (30–32 psu) Bering Sea Water (BSW) flowed northward into the vicinity of the study-area boxes, gradually replacing the cold (–1.5 to +1 °C), saline (31–33 psu) Winter Water (WW) formed during the previous winter and sharing the surface layer with cold, fresh (28–30 psu) Meltwater (MW; Figures 4–6). WW was representative of the entire water-column during the winter and was modified in the upper layer during the spring and summer by ice melt and advection. In all years, the temperature and salinity were higher over Klondike than over Burger, indicating that some BSW always was present. In contrast, MW was present over Burger in all years, although its spatial extent varied widely among years: extensive in 2008, restricted to the northeastern corner in 2009 and 2011, and restricted to the northeastern half in 2010 and 2012. In both 2010 and 2011, BSW occurred over the northwestern and western parts of Statoil, whereas MW occurred over the eastern part of Statoil (Figures 7–8); in 2012, MW was pushed toward the southwest to cover most of Statoil in Sep.

Although the intrusion of BSW occurred every year, the extent of the intrusion, the temperature of the water mass, and the persistence of WW below the pycnocline varied seasonally among years. In 2008, water temperatures in all study areas were <4 °C until Sep/Oct, and BSW was not identified in Burger. In 2009 and 2011, BSW extended over most of the region in Aug, with temperatures 4–7.5 °C in 2009 and as high as 9 °C in 2011. The mixed layer cooled in Sep and Sep/Oct, and remnants of WW were present in the bottom 5–10 m of the water column. In 2010, BSW extended over much of the study region in Aug; the mixed layer warmed and shoaled over Burger from Aug to Sep, with WW persisting below the thermocline. In Aug 2012, there was BSW over Klondike, the southern half of Burger, and the western edge of Statoil that cooled in Sep. Much of this cooling was related to pack ice that persisted over Burger into Sep. In addition, a strong front developed in Sep that extended from the southeastern corner of Burger to the southwestern corner of Statoil.

PATTERNS OF ABUNDANCE AND DISTRIBUTION

Total abundance of seabirds within individual study areas varied by more than 2 orders of magnitude during the 5 years of the study (range: 800–249,200 birds; Table 4). Seabirds were most abundant overall in 2009 and least abundant overall in 2008 (Figure 9). In 2011 and 2012, total abundance was similar within the study-area boxes but was lower than in 2009 and higher than in 2008 and 2010. There was no consistent pattern to seasonal changes in abundance (Figure 9).

PLANKTIVORES

Planktivores were the most abundant species-group in all years and in most seasons (Figure 10). Of the 10 taxa classified as planktivores and recorded on transects within the study areas during 2008–2012, only Crested Auklets, Least Auklets, and phalaropes were numerous enough to model trends in distribution and abundance. Short-tailed Shearwaters also are included here.

Crested Auklets were the most abundant species recorded in all 5 years of the study (Tables 5–9). Abundance differed significantly among study areas, seasons, and years, although the patterns were not consistent ($P < 0.001$ for STUDY AREA*SEASON*YEAR; Figure 11). They were least abundant in 2008 (mean abundance: 0.0–5.2 birds/km^2), and most abundant in 2009 (mean abundance: 0.1–30.2 birds/km^2), with abundances in 2011 and 2012 overlapping confidence intervals with all previous years. Seasonal patterns in abundance differed among years; abundance increased seasonally in 2008 and 2011, whereas it decreased in 2009 and 2012 and there was no apparent seasonal trend in 2010. Patterns of abundance among study areas also differed among years. Abundances were highest in Klondike in 2008, in Burger in 2009 and 2012, and in Statoil in 2011, whereas they were similar in all study areas in 2010. Crested Auklets occurred throughout the GHS study area in 2011 and 2012 (Figure 12). In 2011, the highest abundance was in the northeastern part of Statoil, near an area where sea-surface temperatures dropped quickly (Figures 6 and 7), and other locations south (in Burger) and west of Statoil. In 2012, the highest abundance was in southwestern Burger, near a frontal area of

Table 4. Estimated total abundance of seabirds counted during ship-based surveys in the northeastern Chukchi Sea, by study area, season, and year. Values in parentheses are 95% confidence intervals.

	Study area		
Year/season	Klondike	Burger	Statoil
2008			
Aug	8,800	800	--
	(6,300–12,500)	(600–1,100)	(--)
Sep	16,900	11,500	--
	(13,000–22,100)	(7,900–16,900)	(--)
Sep/Oct	32,300	7,000	--
	(24,100–42,600)	(4,700–10,400)	(--)
2009			
Aug	19,700	116,800	--
	(14,900–26,100)	(91,000–150,000)	(--)
Sep	249,200	106,600	--
	(187,600–330,900)	(79,200–143,500)	(--)
Sep/Oct	46,900	7,400	--
	(33,900–64,800)	(5,700–9,700)	(--)
2010			
Aug	21,400	17,300	18,900
	(13,700–33,300)	(9,800–30,600)	(13,900–25,600)
Sep	36,200	26,800	37,400
	(30,200–43,300)	(21,200–33,900)	(31,200–44,700)
Sep/Oct	--	19,400	--
	(--)	(14,100–26,700)	(--)
2011			
Aug	13,300	14,000	40,900
	(9,900–17,900)	(6,900–28,400)	(21,300–77,400)
Sep	72,500	45,000	88,800
	(52,900–99,300)	(25,300–79,900)	(58,900–133,900)
Sep/Oct	--	--	--
	(--)	(--)	(--)
2012			
Aug	54,400	98,900	36,700
	(40,100–73,900)	(62,700–156,000)	(22,900–58,800)
Sep	27,000	24,400	37,000
	(21,000–34,800)	(20,200–29,300)	(27,500–49,700)
Sep/Oct	--	--	--
	(--)	(--)	(--)

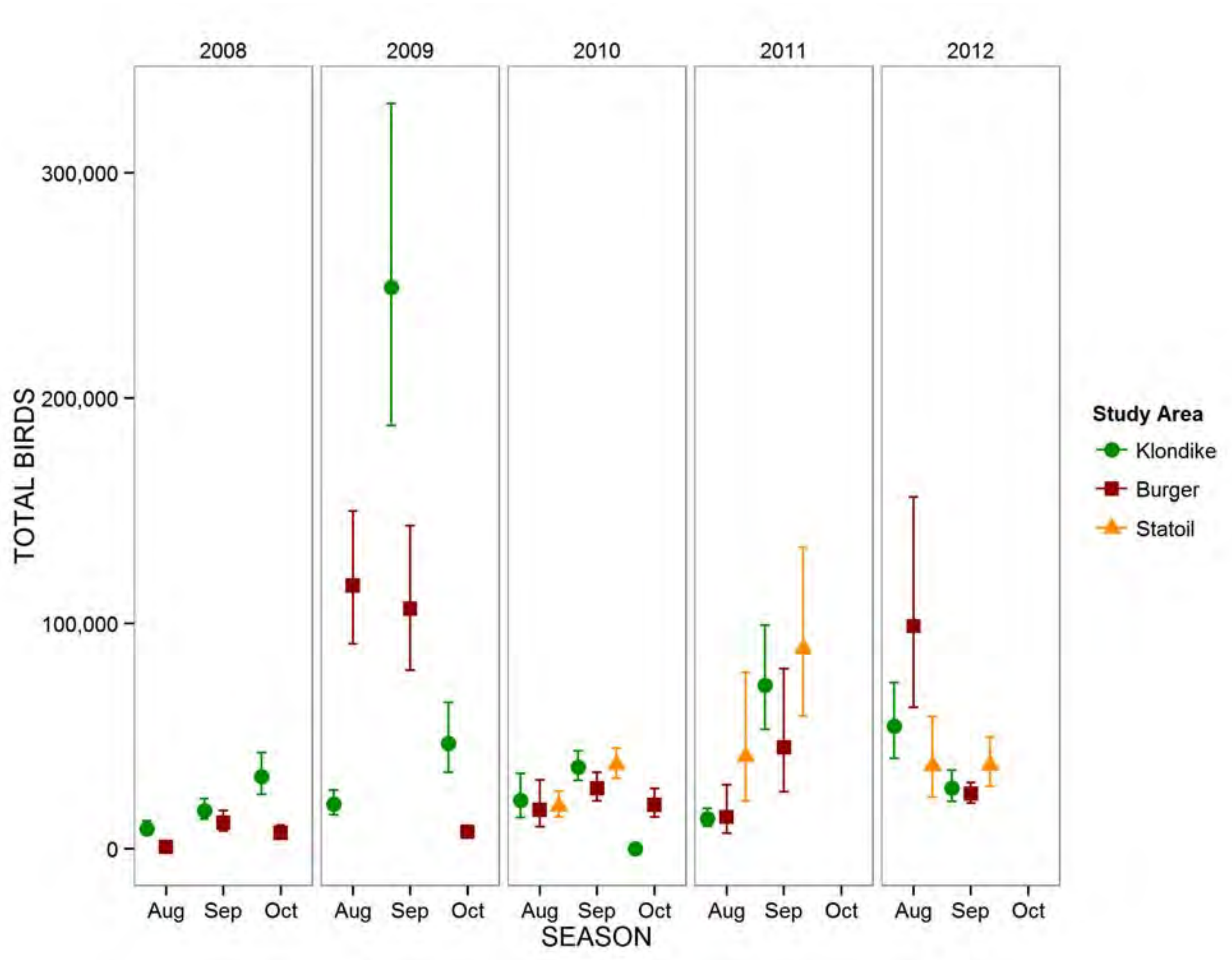

Figure 9. Total abundance of birds on transect in the Klondike, Burger, and Statoil study areas in 2008–2012, by study-area box and month. Error bars represent 95% confidence intervals.

converging water masses (Figure 6). In both years, abundance was lowest over northern Hanna Shoal and northeast of Burger.

Abundance of Least Auklets differed significantly among study areas, seasons, and years, although the patterns were not consistent ($P < 0.001$ for STUDY AREA*SEASON*YEAR). Least Auklets were more abundant in 2012 than in any of the previous 4 years (Figure 11; Tables 5–9). There was no consistent trend in abundance among seasons or study areas (Figure 11). In 2011, Least Auklets were concentrated in Klondike (Figure 12) and appeared to be associated with an area of salinity fronts. In 2012, abundance was double that seen in 2011 and was concentrated in 2 areas: southern Klondike and a band running southeast to northwest through Burger and Statoil, near a front with surface convergence. As was seen for Crested Auklets, abundance was lowest over northern Hanna Shoal and northeast of Burger in 2011 and 2012.

Phalaropes were seen in patchily distributed feeding flocks, primarily in Aug and Sep of all years. Their abundance differed significantly among study areas, seasons, and years, although the patterns were not consistent ($P < 0.001$ for STUDY AREA*SEASON*YEAR). There was no consistent trend among seasons or study areas (Figure 11). Phalaropes were rare during the Sep cruise in 2011, with small flocks located at the northwestern corner of the GHS, in an area that did not appear to have distinct oceanographic structures, and in Burger (Figure 12). In 2012, they were most abundant in eastern Statoil. In both

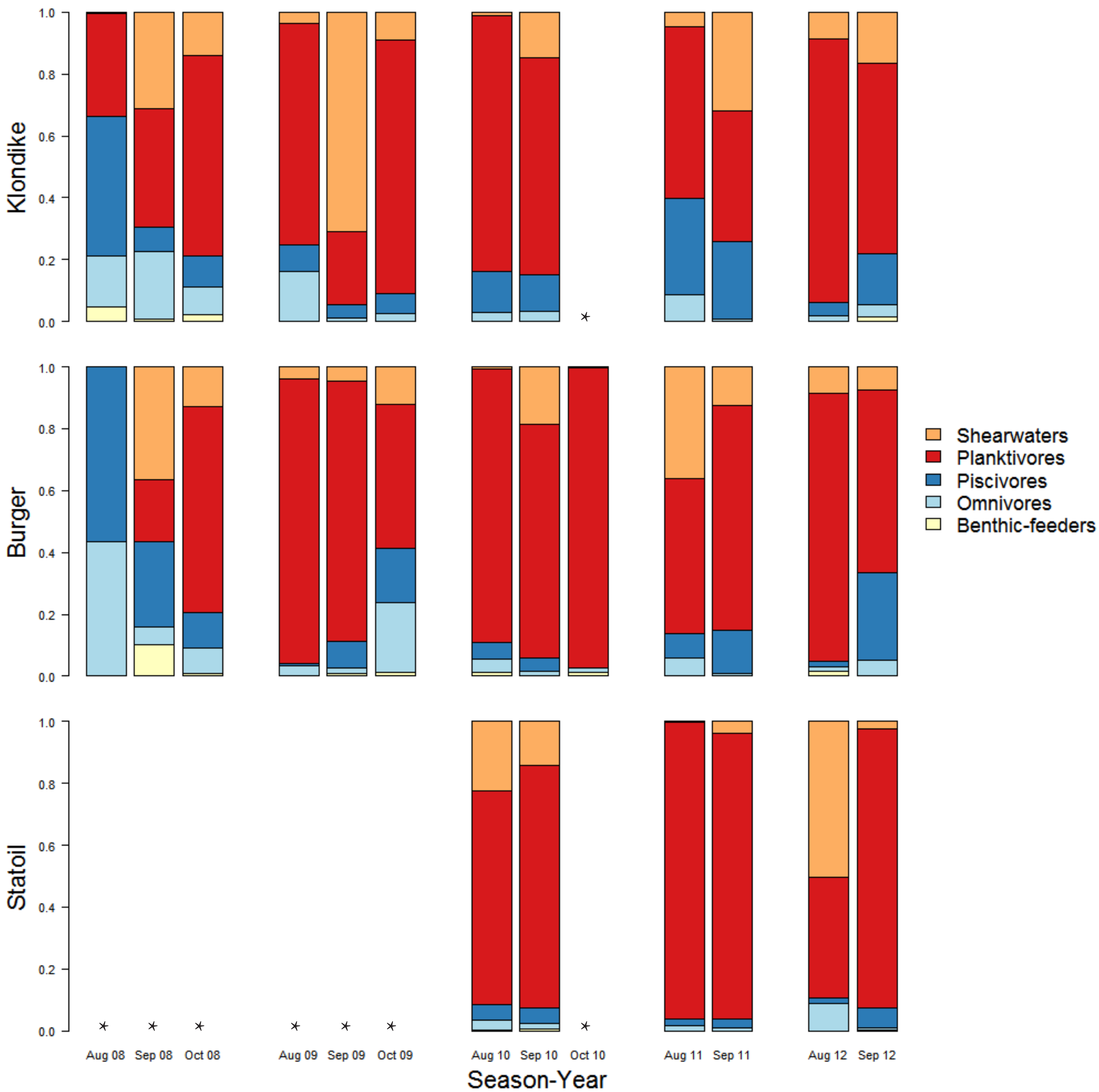

Figure 10. Feeding guilds that comprise the seabird community on transect in the Klondike, Burger, and Statoil study areas, by month and year. Asterisks indicate no data.

Table 5. Estimated densities (birds/km^2) of the 8 focal species of seabirds counted during ship-based surveys in the northeastern Chukchi Sea, by study area and season, 2008. Values in parentheses are 95% confidence intervals.

Species-group/species	Study area/season					
	Klondike			Burger		
	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct
PLANKTIVORES						
Least Auklet	0.03	0.89	0.35	0	0.01	0.03
	(0.01–0.1)	(0.55–1.44)	(0.17–0.75)	(0–0)	(0–0.04)	(0.01–0.12)
Crested Auklet	0.89	0.56	5.20	0	0.01	0.17
	(0.31–2.53)	(0.31–1)	(2.99–9.04)	(0–0)	(0–0.03)	(0.07–0.44)
Phalaropes	0.02	0.54	0.69	0	0.71	0
	(0–0.1)	(0.12–1.56)	(0.29–1.67)	(0–0)	(0.33–1.52)	(0–0)
SHEARWATERS	0.01	1.70	1.34	0	1.36	0.29
	(0–0.05)	(0.81–3.56)	(0.66–2.73)	(0–0)	(0.51–3.65)	(0.15–0.58)
OMNIVORES						
Northern Fulmar	0.26	0.64	0.26	0.04	0.04	0.06
	(0.16–0.43)	(0.45–0.91)	(0.11–0.62)	(0.02–0.09)	(0.01–0.1)	(0.02–0.15)
Glaucous Gull	0.04	0.06	0.50	0.04	0.16	0.12
	(0.02–0.11)	(0.03–0.12)	(0.37–0.67)	(0.02–0.1)	(0.1–0.26)	(0.05–0.29)
PISCIVORES						
Black–legged Kittiwake	0.39	0.21	0.81	0.09	0.63	0.10
	(0.26–0.59)	(0.12–0.38)	(0.53–1.25)	(0.05–0.18)	(0.38–1.05)	(0.04–0.23)
Thick-billed Murre	0.78	0.05	0.02	0.02	0	0.01
	(0.51–1.19)	(0.02–0.12)	(0.01–0.05)	(0.01–0.04)	(0–0)	(0–0.04)

Table 6. Estimated densities (birds/km^2) of the 8 focal species of seabirds counted during ship-based surveys in the northeastern Chukchi Sea, by study area and season, 2009. Values in parentheses are 95% confidence intervals.

Species-group/species	Study area/season					
	Klondike			Burger		
	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct
PLANKTIVORES						
Least Auklet	0.58	0.75	2.17	1.66	0.83	0.34
	(0.34–1)	(0.46–1.21)	(1.38–3.4)	(0.93–2.97)	(0.59–1.17)	(0.21–0.54)
Crested Auklet	2.87	17.70	9.96	30.16	26.57	0.13
	(1.61–5.13)	(12.23–25.61)	(6.02–16.48)	(21.76–41.8)	(17.72–39.85)	(0.05–0.35)
Phalaropes	1.05	0.07	0.13	3.01	1.44	0.10
	(0.50–2.18)	(0.04–0.12)	(0.03–0.70)	(1.80–5.04)	(0.82–2.53)	(0.04–0.28)
SHEARWATERS	0.23	57.32	1.38	1.45	1.63	0.29
	(0.11–0.47)	(37.59–87.41)	(0.53–3.54)	(0.34–6.26)	(0.91–2.94)	(0.14–0.63)
OMNIVORES						
Northern Fulmar	0.96	0.32	0.03	1.04	0.20	0.15
	(0.55–1.66)	(0.17–0.6)	(0.01–0.09)	(0.59–1.84)	(0.13–0.32)	(0.05–0.47)
Glaucous Gull	0	0.14	0.33	0.06	0.39	0.37
	(0–0)	(0.05–0.43)	(0.16–0.69)	(0.02–0.19)	(0.27–0.57)	(0.22–0.63)
PISCIVORES						
Black–legged	0.08	1.73	0.69	0.13	1.66	0.15
Kittiwake	(0.03–0.22)	(1.15–2.61)	(0.44–1.07)	(0.05–0.3)	(1.17–2.35)	(0.05–0.43)
Thick-billed Murre	0.42	1.41	0.09	0.12	0.11	0.09
	(0.26–0.7)	(0.98–2.01)	(0.04–0.18)	(0.06–0.21)	(0.03–0.34)	(0.03–0.29)

Table 7. Estimated densities (birds/km^2) of the 8 focal species of seabirds counted during ship-based surveys in the northeastern Chukchi Sea, by study area and season, 2010. Values in parentheses are 95% confidence intervals.

Species-group/species	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct	Statoil Aug	Statoil Sep	Statoil Sep/Oct
PLANKTIVORES									
Least Auklet	0.19 (0.07–0.48)	0.73 (0.44–1.2)	–	0.24 (0.12–0.5)	1.88 (1.2–2.95)	0.50 (0.33–0.77)	1.47 (0.95–2.26)	0.99 (0.7–1.41)	–
Crested Auklet	4.73 (2.49–8.99)	5.78 (4.41–7.58)	–	4.66 (2.23–9.72)	3.74 (2.57–5.45)	5.16 (3.48–7.66)	2.45 (1.35–4.43)	6.46 (4.93–8.45)	–
Phalaropes	0.60 (0.18–1.94)	1.45 (0.83–2.55)	–	0.05 (0.01–0.22)	0.66 (0.30–1.45)	0.03 (0.02–0.08)	0.23 (0.08–0.67)	1.75 (0.95–3.20)	–
SHEARWATERS	0.08 (0.02–0.27)	1.74 (0.93–3.25)	–	0.03 (0.01–0.15)	1.63 (0.81–3.26)	0.02 (0.01–0.05)	1.37 (0.66–2.84)	1.74 (1.08–2.81)	–
OMNIVORES									
Northern Fulmar	0.13 (0.06–0.28)	0.17 (0.1–0.28)	–	0.16 (0.08–0.32)	0.05 (0.02–0.11)	0.01 (0–0.03)	0.08 (0.05–0.14)	0.13 (0.07–0.25)	–
Glaucous Gull	0.02 (0.01–0.07)	0.06 (0.02–0.16)	–	0.04 (0.01–0.1)	0.06 (0.03–0.11)	0.07 (0.04–0.14)	0.03 (0.01–0.1)	0.07 (0.03–0.15)	–
PISCIVORES									
Black-legged Kittiwake	0.17 (0.08–0.4)	0.74 (0.48–1.14)	–	0.1 (0.05–0.24)	0.27 (0.15–0.48)	0 (0–0)	0.12 (0.04–0.35)	0.48 (0.33–0.72)	–
Thick-billed Murre	0.69 (0.42–1.15)	0.40 (0.28–0.56)	–	0.15 (0.08–0.27)	0.05 (0.02–0.11)	0.01 (0–0.03)	0.18 (0.06–0.49)	0.10 (0.05–0.17)	–

Table 8. Estimated densities (birds/km^2) of the 8 focal species of seabirds counted during ship-based surveys in the northeastern Chukchi Sea, by study area and season, 2011. Values in parentheses are 95% confidence intervals.

	Study area/season					
	Klondike		Burger		Statoil	
Species-group/species	Aug	Sep	Aug	Sep	Aug	Sep
PLANKTIVORES						
Least Auklet	0.08 (0.02-0.25)	1.09 (0.52-2.25)	0 (0-0)	0.13 (0.05-0.35)	0.03 (0.01-0.14)	0.22 (0.09-0.55)
Crested Auklet	2.12 (1.18-3.8)	8.29 (5.1-13.47)	1.73 (1.01-2.95)	9.48 (3.52-25.54)	11.63 (5.35-25.26)	26.01 (15.62-43.31)
Phalaropes	0.12 (0.02–0.66)	0.19 (0.07–0.55)	0.54 (0.21–1.39)	0.29 (0.09–0.89)	1.05 (0.14–7.89)	0.09 (0.03–0.32)
SHEARWATERS	0.2 (0.07-0.55)	7.51 (2.84-19.9)	1.64 (0.28-9.66)	1.82 (0.86-3.83)	0.02 (0-0.08)	1.08 (0.57-2.05)
OMNIVORES						
Northern Fulmar	0.38 (0.21-0.69)	0.11 (0.05-0.27)	0.21 (0.12-0.37)	0 (0-0)	0.17 (0.08-0.35)	0.08 (0.03-0.22)
Glaucous Gull	0 (0-0)	0.06 (0.02-0.18)	0.01 (0-0.07)	0.1 (0.04-0.26)	0.03 (0-0.16)	0.14 (0.07-0.27)
PISCIVORES						
Black–legged Kittiwake	0.06 (0.02-0.22)	0.21 (0.1-0.43)	0.05 (0.02-0.14)	1.15 (0.62-2.11)	0.05 (0.01-0.21)	0.34 (0.21-0.53)
Thick-billed Murre	0.89 (0.61-1.3)	5 (3.26-7.66)	0.3 (0.18-0.5)	0.21 (0.07-0.61)	0.18 (0.12-0.29)	0.32 (0.18-0.56)

Table 9. Estimated densities (birds/km^2) of the 8 focal species of seabirds counted during ship-based surveys in the northeastern Chukchi Sea, by study area and season, 2012. Values in parentheses are 95% confidence intervals.

	Study area/season					
	Klondike		Burger		Statoil	
Species-group/species	Aug	Sep	Aug	Sep	Aug	Sep
PLANKTIVORES						
Least Auklet	5.00 (3.03–8.27)	1.99 (1.13–3.51)	2.05 (1.32–3.2)	1.01 (0.56–1.79)	1.58 (1.1–2.26)	3.56 (2.54–5)
Crested Auklet	9.78 (5.38–17.77)	2.97 (1.69–5.24)	24.83 (13–47.43)	3.46 (2.67–4.47)	1.97 (0.85–4.57)	6.87 (4.14–11.39)
Phalaropes	0.06 (0.01–0.25)	0.03 (0.01–0.10)	0.83 (0.25–2.72)	0.03 (0.01–0.10)	1.07 (0.47–2.45)	0.31 (0.10–0.98)
SHEARWATERS	1.50 (0.46–4.82)	1.45 (0.75–2.8)	2.73 (0.98–7.59)	0.60 (0.18–2.03)	5.99 (2.4–14.91)	0.28 (0.17–0.44)
OMNIVORES						
Northern Fulmar	0.25 (0.12–0.52)	0.18 (0.05–0.6)	0.47 (0.31–0.7)	0.05 (0.02–0.13)	0.59 (0.21–1.67)	0.10 (0.04–0.23)
Glaucous Gull	0 (0–0)	0.18 (0.1–0.35)	0 (0–0)	0.33 (0.2–0.55)	0.11 (0.04–0.35)	0.01 (0–0.08)
PISCIVORES						
Black-legged Kittiwake	0.10 (0.03–0.38)	0.61 (0.36–1.04)	0.09 (0.03–0.29)	0.52 (0.29–0.94)	0.11 (0.04–0.31)	0.74 (0.39–1.38)
Thick-billed Murre	0.59 (0.39–0.88)	0.72 (0.38–1.37)	0.39 (0.25–0.61)	1.36 (0.85–2.16)	0.04 (0.02–0.12)	0.01 (0–0.05)

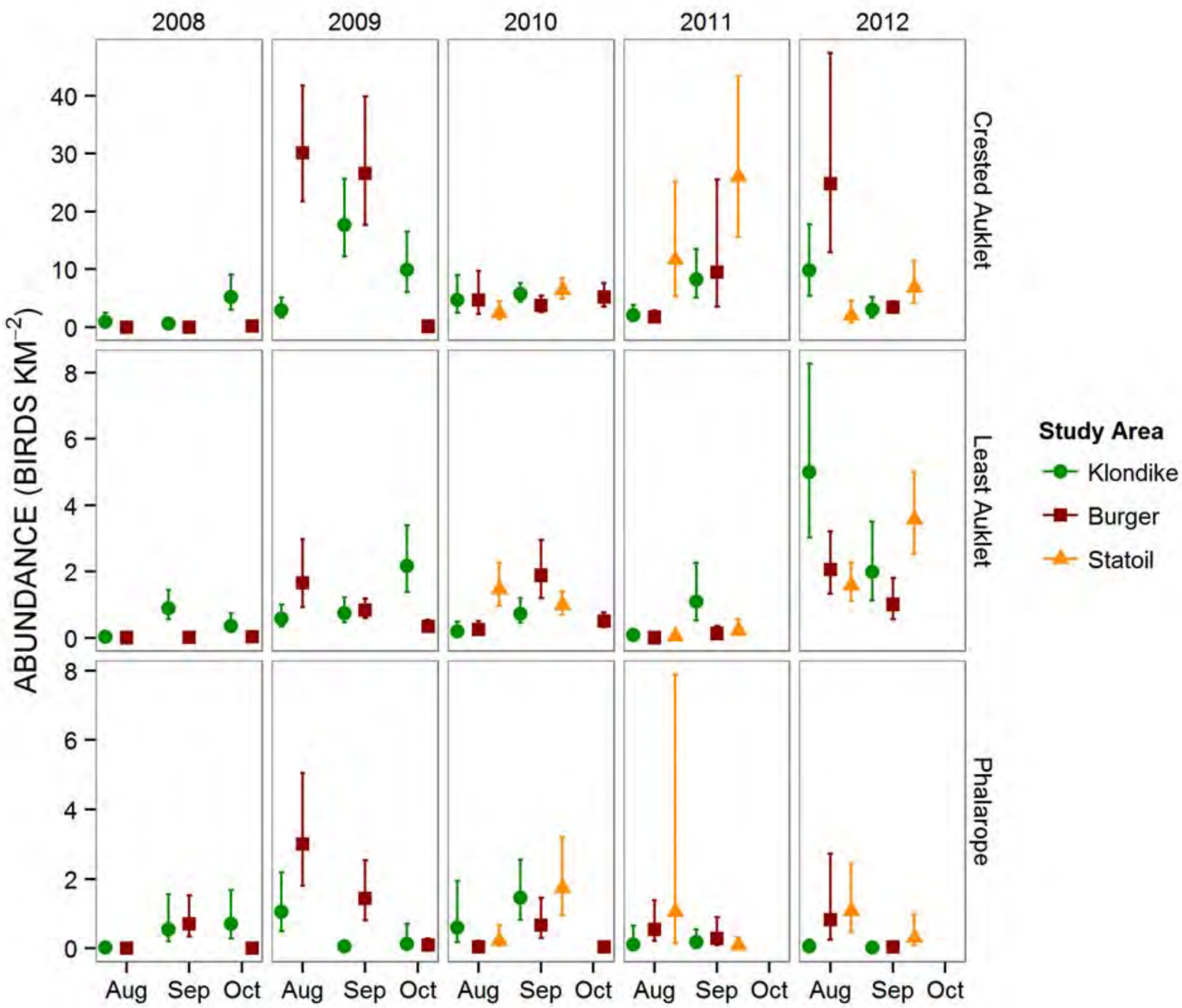

Figure 11. Mean abundance (birds/km^2) of Crested Auklets, Least Auklets, and phalaropes on transect in the Klondike, Burger, and Statoil study areas in 2008–2012, by study area and month. Error bars represent 95% confidence intervals.

2011 and 2012, phalarope abundance was low in Klondike, northern Hanna Shoal, and northeast of Burger.

Short-tailed Shearwaters were the second-most-abundant species in all 5 years of the study, primarily because of large flocks moving through in Sep (Figure 13). Their abundance differed significantly among study areas, seasons, and years (Figure 13). Abundance was higher in Klondike than in the other study area(s) in 2009 and 2011 but was not significantly different among study areas in the other years (Figure 13, Tables 5–9). Seasonal patterns in abundance also differed among years. In 2008–2011, Short-tailed Shearwaters were most abundant in Sep (Aug–Oct in 2011), but in 2012, they were more abundant in Aug than in Sep. Similar to the other planktivorous seabirds, Short-tailed Shearwaters were concentrated in the southern half of the GHS study area in both 2011 and 2012 (Figure 14). In 2011, they were most abundant in Klondike and the eastern edge of Burger; in 2012, they were abundant in Klondike and along a line that ran from southeastern Burger to northwestern Statoil, near the convergent front

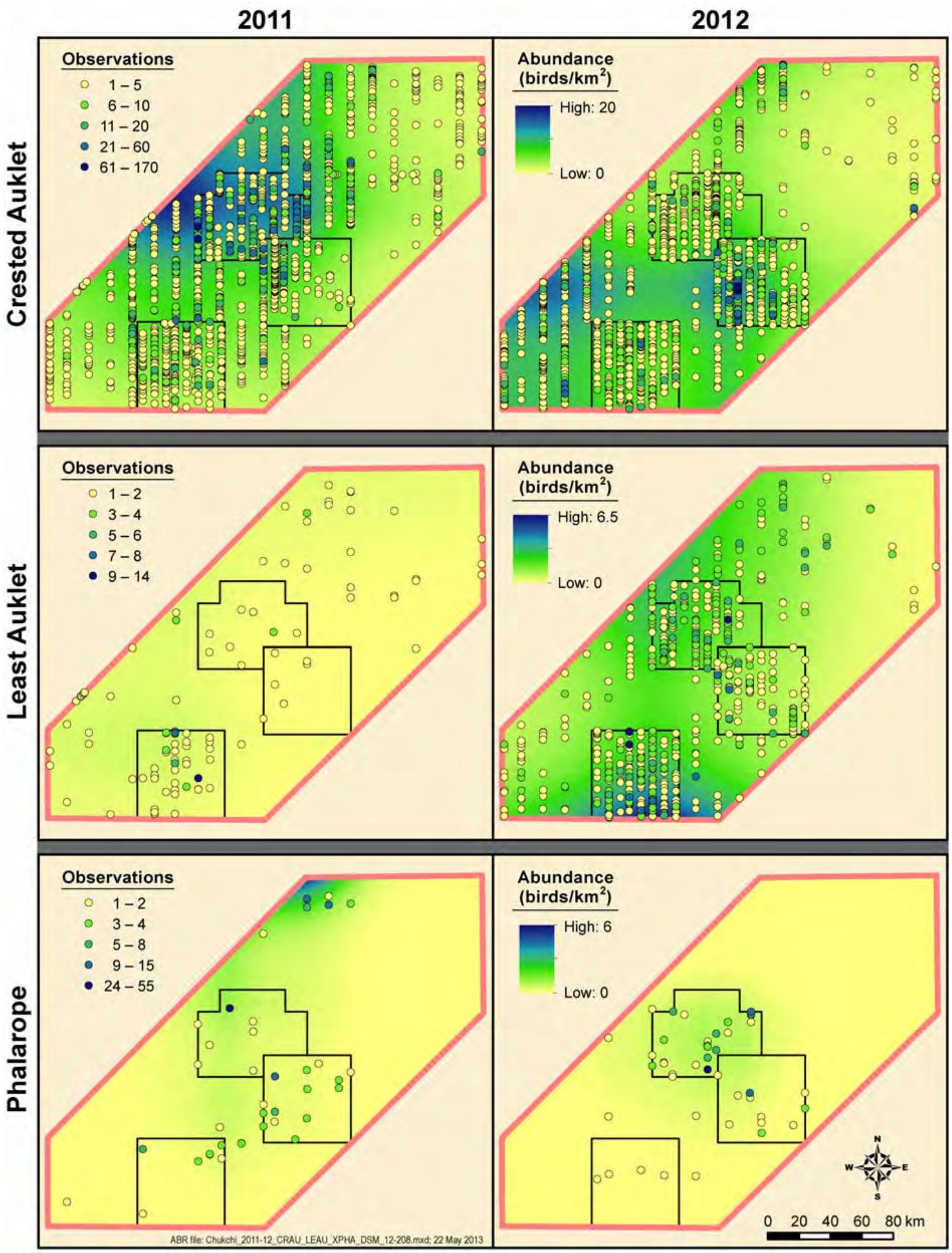

Figure 12. Distribution and abundance (birds/km^2) of Crested Auklets, Least Auklets, and phalaropes recorded on transect in the Greater Hanna Shoal study area in Sep, 2011 and 2012.

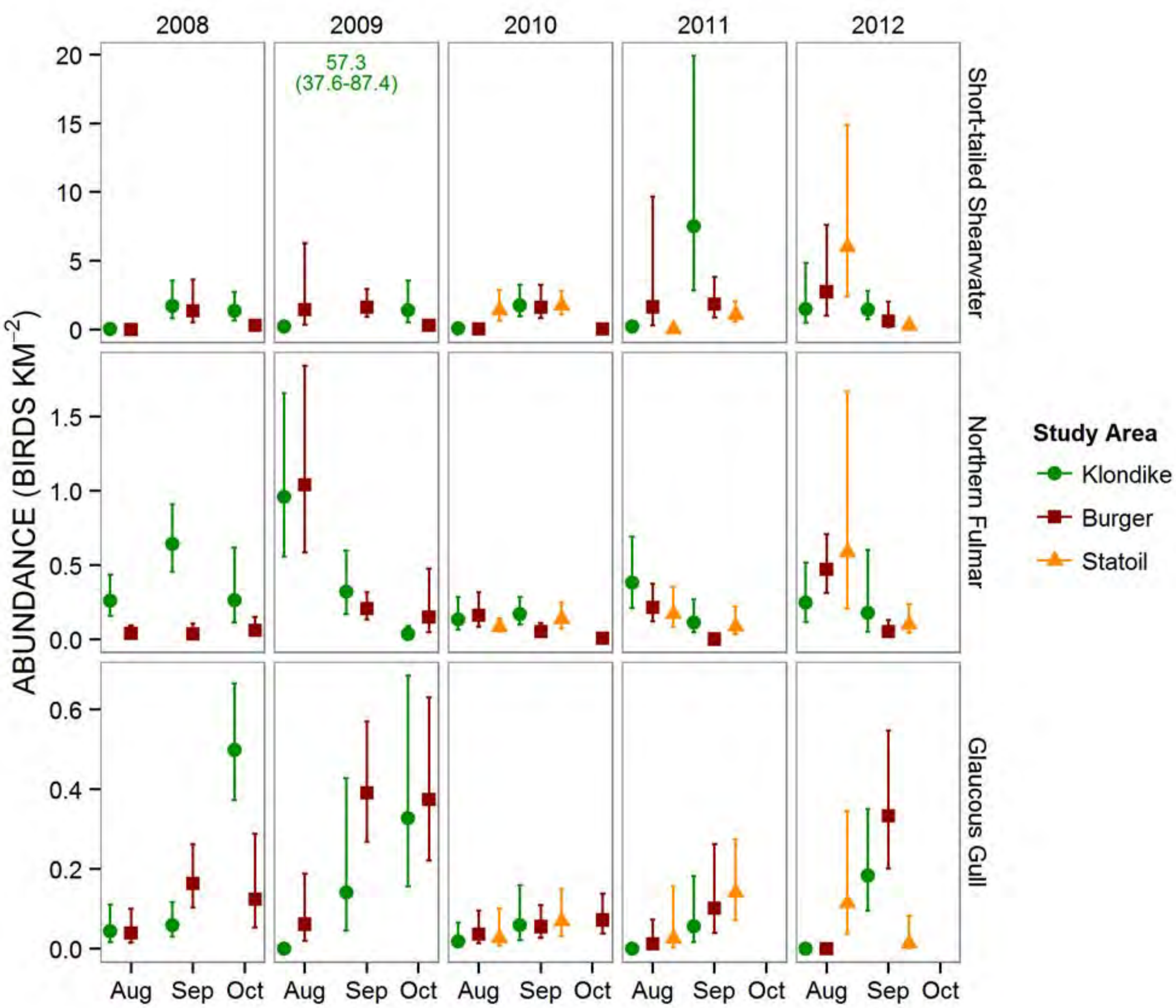

Figure 13. Mean abundance (birds/km^2) of Short-tailed Shearwaters, Northern Fulmars, and Glaucous Gulls on transect in the Klondike, Burger, and Statoil study areas in 2008–2012, by study area and month. Error bars represent 95% confidence intervals.

described above. Few Short-tailed Shearwaters were recorded in the northwestern half of the GHS or northern Hanna Shoal in either year.

Of the other 5 planktivores recorded (Appendix A), Ancient Murrelets were most abundant in 2010 and 2012 (Appendix B) and Ross's Gulls were most abundant in 2008 and 2009. Ancient Murrelets were present in all 3 study areas in Sep 2010–2012, whereas Ross's Gulls were recorded only in Burger and only in Sep/Oct. Parakeet Auklets were seen in low numbers every year and in all study areas. Kittlitz's Murrelets were most abundant in 2011, when they were recorded in Klondike in Aug and in all 3 study-area boxes and the northern part of GHS in Sep. Dovekies were seen in all 3 study-area boxes and in the northern section of the GHS in all years except 2009, but only in low numbers.

OMNIVORES

The abundance of Northern Fulmars differed significantly among seasons in all years. The seasonal pattern of abundance was consistent among study areas ($P < 0.001$ for

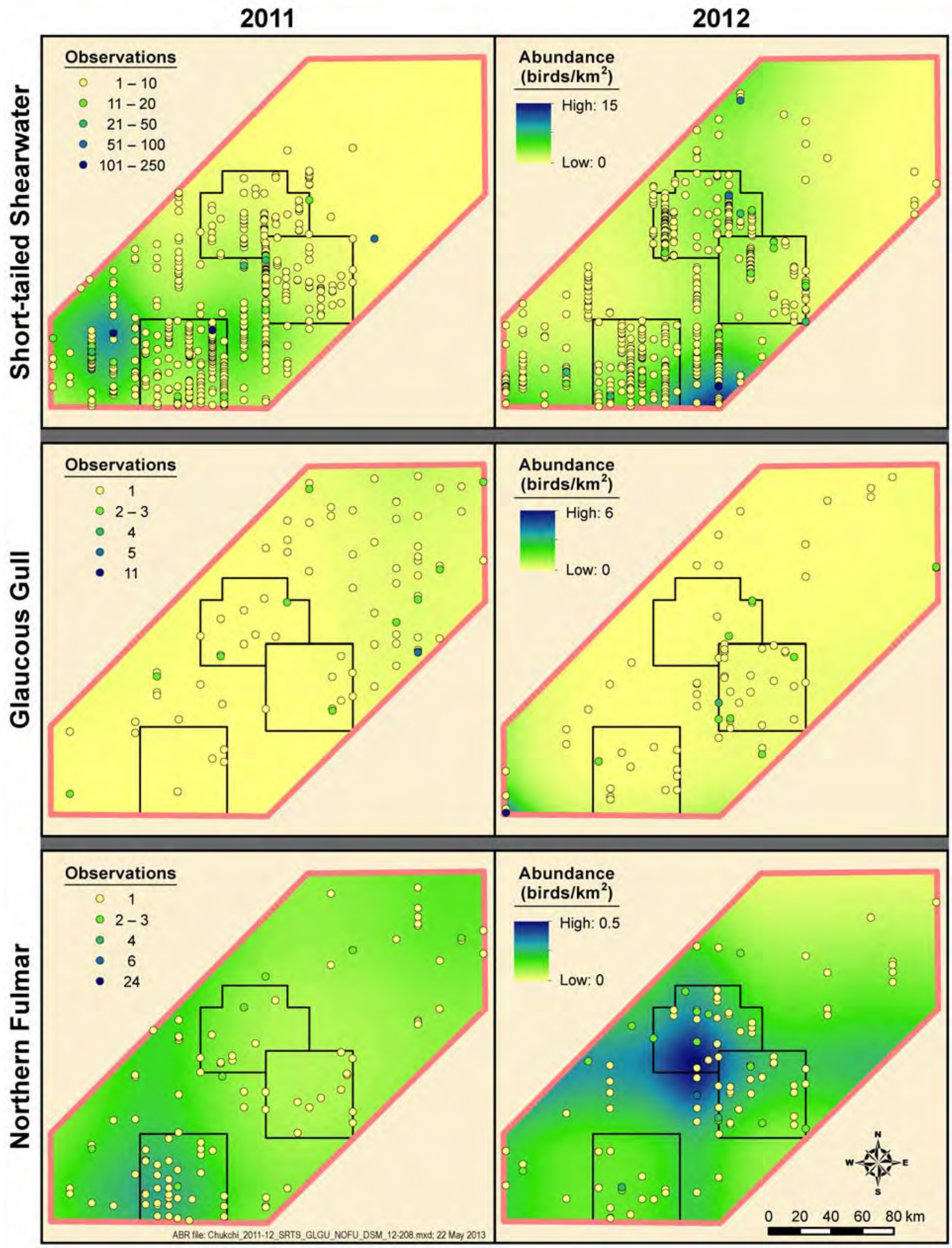

Figure 14. Distribution and abundance (birds/km^2) of Short-tailed Shearwaters, Northern Fulmars, and Glaucous Gulls recorded on transect in the Greater Hanna Shoal study area in 2011 and 2012.

SEASON*YEAR). They were most abundant in Aug 2009 and least abundant in Sep/Oct of all years. Their seasonal abundance declined from Aug to Sep/Oct, with the exception of Klondike in 2008, when they were most abundant in Sep (Figure 13, Tables 5–9). There was no consistent pattern in abundance among study areas (Figure 13). In 2011 and 2012, Northern Fulmars occurred in low abundance throughout the GHS study area (Figure 14). They were most abundant in Klondike in 2011and in in Statoil and northern Burger in 2012.

The abundance of Glaucous Gulls differed significantly among seasons and years, and the seasonal pattern of abundance was consistent among study areas. In all 5 years, abundance in Klondike and Burger increased from Aug to Sep (Figure 13). Abundance remained high or continued to increase from Sep to Sep/Oct in 2008–2010. Abundance in Statoil was similar to that in Klondike and Burger in 2010–2011, but displayed an opposite pattern in 2012, being high in Aug and low in Sep. Glaucous Gulls were not recorded in Klondike in Aug 2009, 2011, and 2012 or in Oct 2010. In 2011 and 2012, they occurred in low densities throughout the GHS study area (Figure 14).

Of the other 7 species of omnivores, Sabine's Gulls, Pomarine Jaegers, and Parasitic Jaegers were recorded most commonly in Sep, and Herring Gulls occurred primarily in Sep and Sep/Oct (Appendix B). Sabine's Gulls and jaegers occurred primarily in Klondike, whereas Long-tailed Jaegers were seen off-transect in Klondike and Burger in Sep 2008 and on-transect in Klondike and Burger in 2009 and 2010. Tufted Puffins were seen in all study areas in low numbers, primarily in Aug. A single Glaucous-winged Gull was seen off-transect in Klondike in Aug 2008, after a storm with strong southerly winds.

PISCIVORES

Piscivores were a species-rich group that included terns, some gulls, and some alcids. Of the 11 species of piscivores recorded on transect, only Black-legged Kittiwakes and Thick-billed Murres were abundant enough in every year to examine patterns in distribution and abundance.

The abundance of Black-legged Kittiwakes increased from Aug to Sep in all years, although the magnitude of change differed among years and study areas ($P < 0.001$ for STUDY AREA*SEASON*YEAR). They were distributed widely, occurring in all study areas and in all seasons during the 5 years of the study (Figure 15, Tables 5–9). Abundance differed among study areas only in Sep/Oct 2008 and Sep 2011. As suggested by data from the study-area boxes, Black-legged Kittiwakes occurred in low densities throughout the GHS study area in 2011 and 2012 (Figure 16). In 2011, there were concentrations occurring over the shallowest part of Hanna Shoal and in southern Burger, an area with what appeared to be a salinity front. In 2012, Black-legged Kittiwakes were most abundant in the southwestern corner of the GHS and along the convergent front extending from the southwestern corner of Burger to the northeastern corner of Statoil.

The abundance of Thick-billed Murres was higher in Klondike than in Burger or Statoil in all years except 2012 ($P < 0.001$ for STUDY AREA*SEASON). In 2012, however, they were more abundant in Burger than in Klondike or Statoil during Sep. The highest mean density in any season or year was recorded in Klondike in Sep 2011 (Figure 15, Tables 5–9). In 2011, they were concentrated along the southern edge of the GHS study area, in an area where warm, low-salinity water appeared to be intruding (Figure 16), with mostly small groups recorded throughout the northwestern half of the GHS; mean densities approached zero over most of Hanna Shoal. In 2012, Thick-billed Murres were concentrated in Klondike and Burger, and the southwestern corner of the GHS study area; they also were recorded over Hanna Shoal and into the northeastern corner of the GHS study area.

The other 9 species of piscivores were rare throughout the study areas in all years (≤ 0.9 birds/km^2 for any single species). Arctic Terns were recorded in all years but only in Aug and Sep (Tables 2 and 3, Appendix B). Ivory Gulls occurred only during Sep/Oct, in Burger in 2008 and over northern Hanna Shoal in 2011 and 2012. Black Guillemots were recorded in all 3 study-area boxes in all years except 2009 and in the northern section of the GHS in 2011–2012. Pigeon Guillemots were seen in Klondike and Burger only in Aug 2008. In all 5 years, loons were recorded in

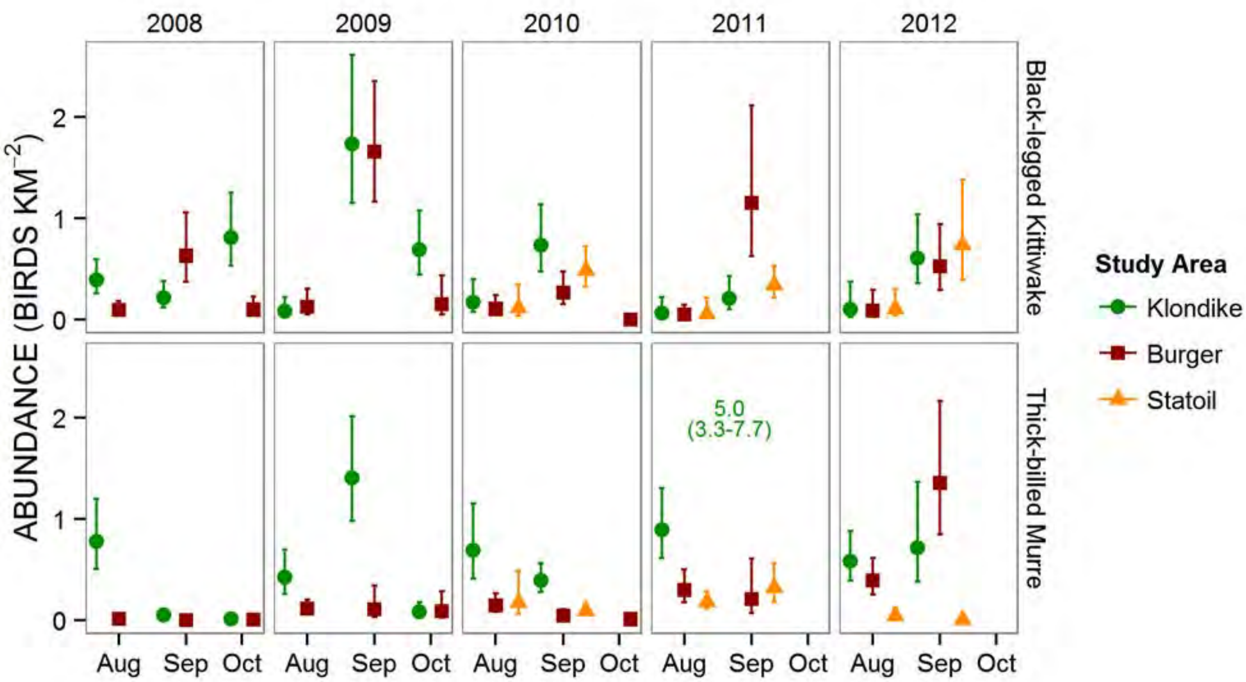

Figure 15. Mean abundance (birds/km^2) of Black-legged Kittiwakes and Thick-billed Murres on transect in the Klondike, Burger, and Statoil study areas in 2008–2012, by study area and month. Error bars represent 95% confidence intervals.

Sep and Sep/Oct (Tables 2 and 3), when they were migrating through the Chukchi Sea on their way to wintering areas. Pacific Loons occurred in all years, Yellow-billed Loons occurred in all years except 2010, and Red-throated Loons occurred in all years except 2009. Yellow-billed Loons were rare in 2008 and 2011 and were most common in 2009 (Appendix B). Red-throated Loons were rare during these surveys and were seen only in Sep: we saw 1 in Burger in 2008, 1 in Statoil in 2010, and 4 in and near Burger in 2011.

BENTHIC-FEEDERS

Benthic-feeders comprised 5 species of seaducks, but none was abundant enough to provide reliable estimates of abundance. They were recorded in low numbers in all seasons and in all 3 study-area boxes and generally were more common in 2008 than in subsequent years (Tables 2 and 3, Appendix B). In all years except 2011, Long-tailed Ducks were the most abundant benthic-feeding species; they were seen in both study areas and in all seasons in 2008 and primarily in Aug/Sep in 2009 and 2010. Benthic-feeding 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 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. We saw only 1 species of waterfowl, a Common Eider, in 2011.

HISTORICAL COMPARISON

The total abundance of seabirds has declined significantly in all strata of the Chukchi Sea over the past 37 years ($P < 0.001$ for PERIOD*STRATUM), with the largest declines occurring in the Nearshore stratum (Figure 17; Appendix C). These declines were driven primarily by declines in piscivorous and omnivorous species. Planktivorous Crested and Least auklets were significantly more abundant in recent years than they were in historical years, with the largest increases in the Offshore stratum for both species (Figure 18). In contrast, phalaropes were less

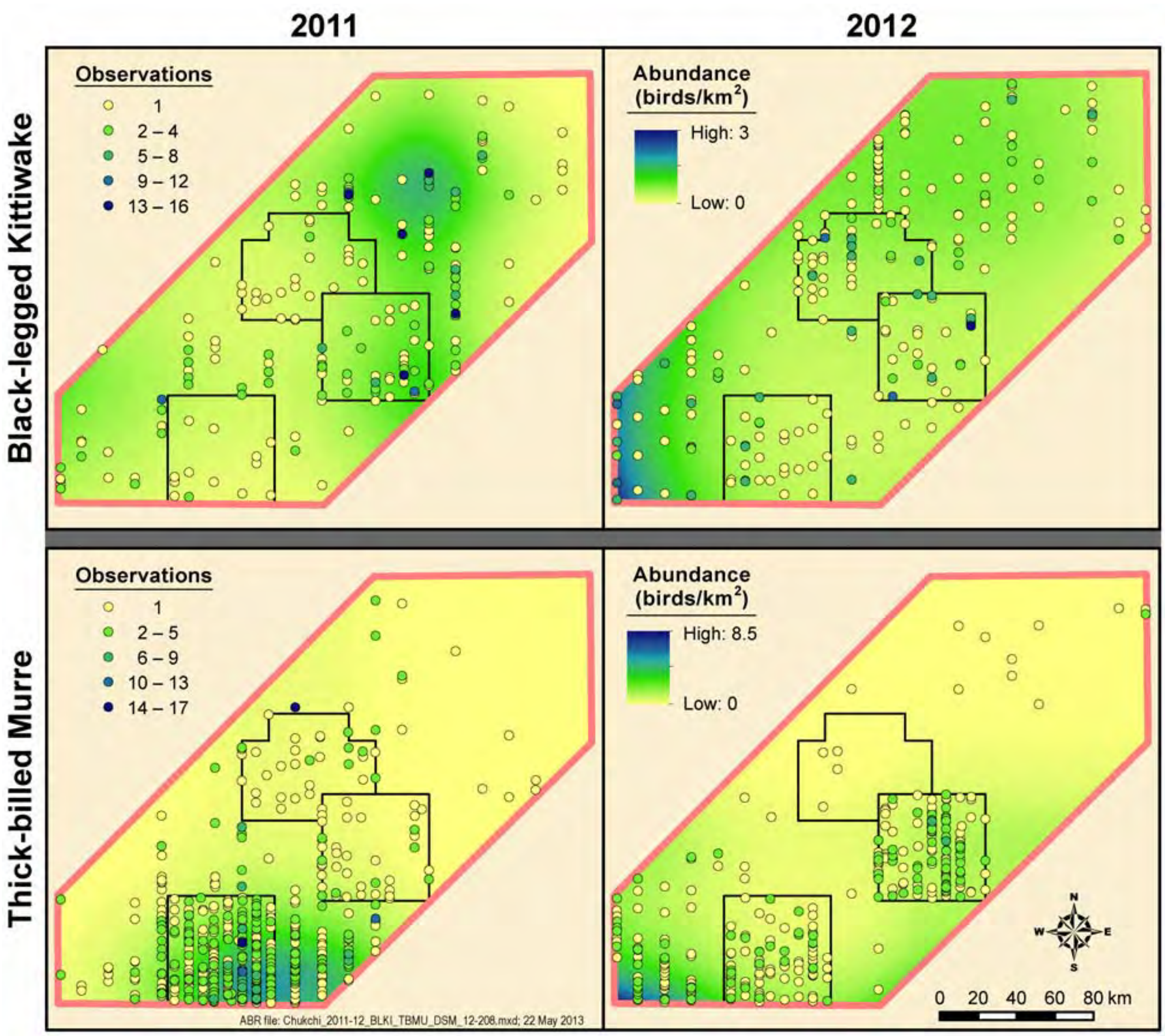

Figure 16. Distribution and abundance (birds/km^2) of Black-legged Kittiwakes and Thick-billed Murres recorded on transect in the Greater Hanna Shoal study area in 2011 and 2012.

abundant in recent years than they were in historical years (Figure 18), with the biggest decline occurring in the Southern stratum. Abundance of Short-tailed Shearwaters increased in the Nearshore stratum, declined in the Offshore stratum, and showed no significant change in the Southern stratum, suggesting a spatial shift in distribution rather than an overall change in abundance (Figure 18).

Piscivorous Black-legged Kittiwakes and Thick-billed Murres and omnivorous Glaucous Gulls were less abundant in all strata in recent than historical time periods (Figure 19). Declines were greatest in the Nearshore stratum, with mean decreases of 14.2 birds/km^2 for Black-legged Kittiwakes and 13.8 birds/km^2 for Glaucous Gulls. Northern Fulmars were present in low abundance (<0.5 birds/km^2) both historically and recently; as with Short-tailed Shearwaters, their abundance increased in the Nearshore stratum, decreased in the Offshore stratum, and showed no significant change in the Southern stratum (Figure 19).

The duration of open water (defined as 25-km^2 grid points with <10 % ice cover) in the Northern, Offshore, and Nearshore strata of the eastern Chukchi Sea has increased by 50 days over

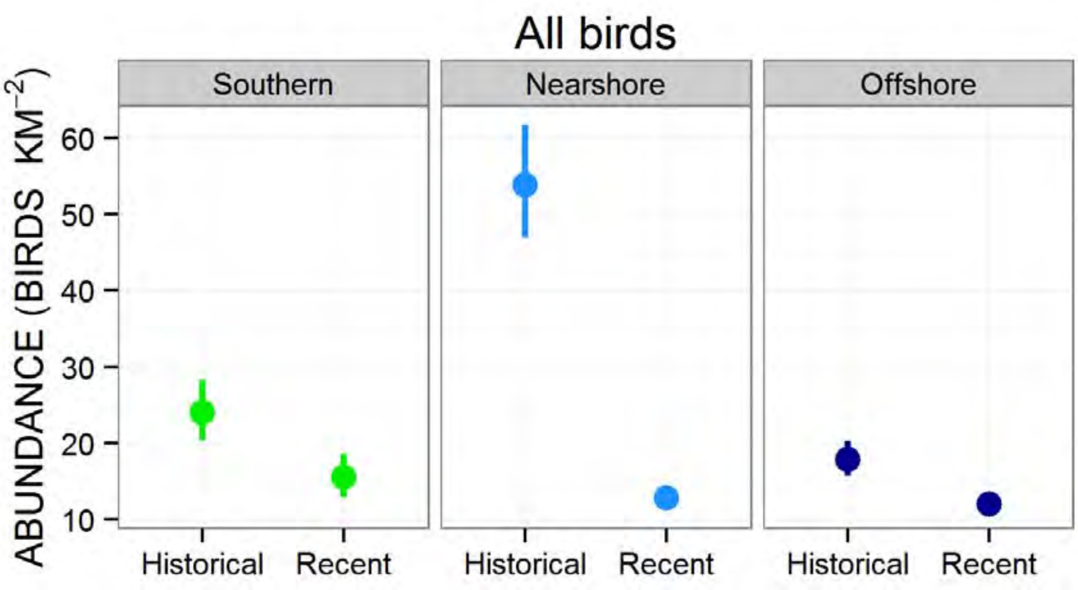

Figure 17. Abundance of all seabirds in the U.S. sector of the Chukchi Sea during historical (1975–1981) and recent (2008–2011) surveys. Values are predicted from generalized linear models that account for geographic stratum, time period, and the negative binomial distribution of the data. Error bars represent 95% confidence intervals.

the past 3 decades (Figure 20). When compared with conditions 30 years ago, sea ice now forms later, melts earlier, and melts completely in all strata of the eastern Chukchi Sea (Figure 20).

These changes in ice cover are associated with overall increases in the abundance of diving planktivores and in declines in the abundance of piscivores, primarily in the Nearshore stratum (Figure 21). Crested Auklets were significantly more abundant in years of early ice retreat in the Nearshore stratum and in years with more ice-free days in the Offshore and Southern strata (Table 10).

Phalaropes were significantly more abundant in years with more ice-free days in the Offshore and Southern strata (Table 10). In the Nearshore stratum, they had a significantly higher probability of occurrence in years with earlier ice retreat, although this parameter was not a significant predictor of abundance there.

Short-tailed Shearwaters were significantly more abundant in years with more ice-free days in the Offshore stratum (Table 10). They had a higher probability of occurrence in years with more ice-free days in the Nearshore and Southern strata, although this parameter was not a significant predictor of abundance there.

Black-legged Kittiwakes were significantly more abundant in years with more ice-free days in the Offshore and Southern strata (Figure 21). In the Nearshore stratum, they had a significantly higher probability of occurrence in years with late ice retreat but also with more ice-free days (Table 10).

Thick-billed Murres were significantly more abundant in years with more ice-free days and late ice retreat both in the Nearshore and Offshore strata (Figure 21; Table 10). In the Southern stratum, they had a significantly higher probability of occurrence in years with more ice-free days.

Glaucous Gulls were significantly more abundant in years with fewer ice-free days in the Nearshore stratum and in years with later ice retreat in the Offshore stratum (Figure 21; Table 10). In the Southern stratum, they had a significantly higher probability of occurrence in years with more ice-free days.

COMMUNITY STRUCTURE

CSESP 2008–2012

Multivariate analyses of the seabird community indicated that species-composition varied primarily among seasons, with no consistent group separation by year or study area (Figure 22).

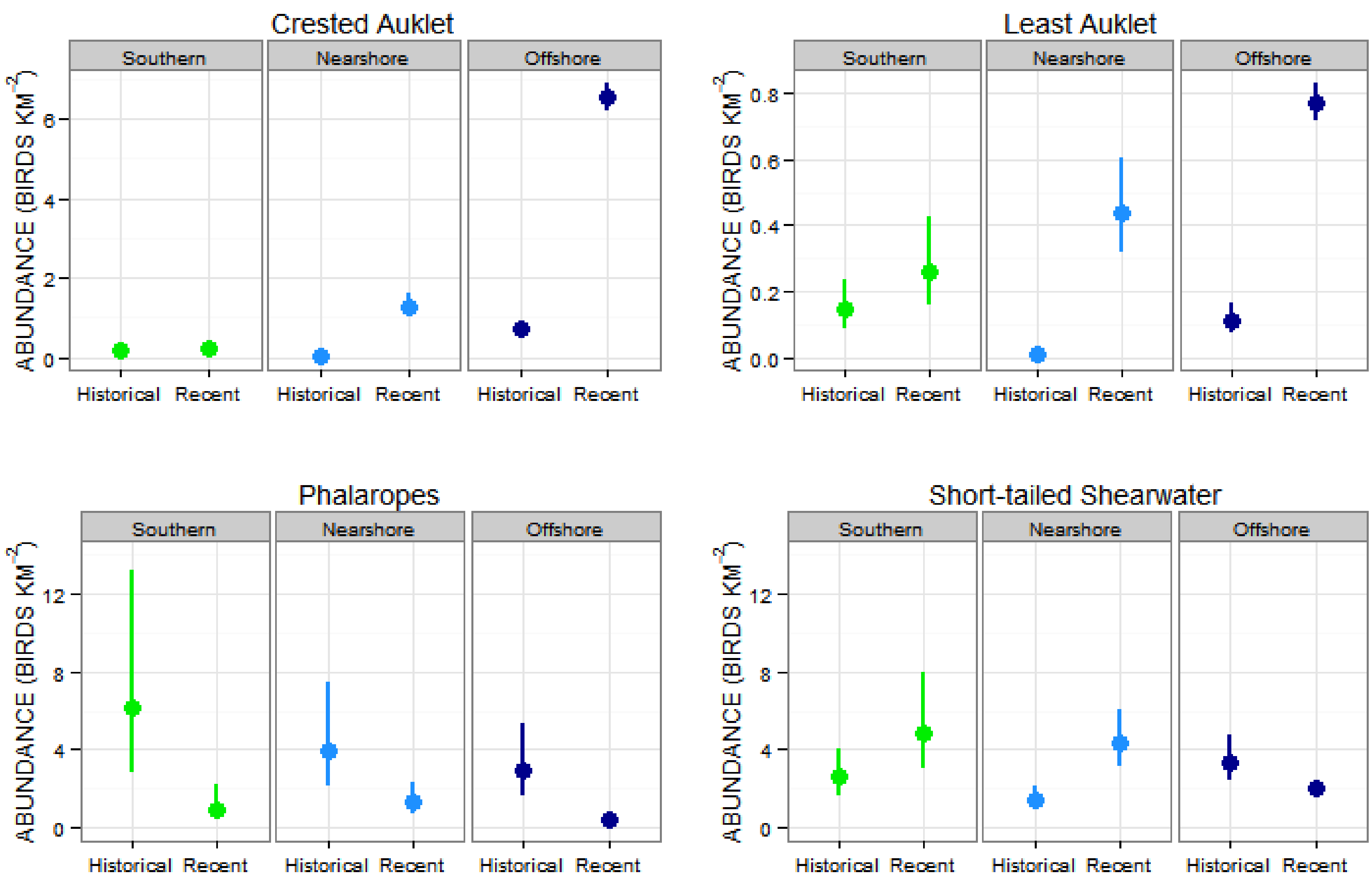

Figure 18. Abundance of 4 species of planktivorous seabirds in the U.S. sector of the Chukchi Sea during historical (1975–1981) and recent (2008–2011) surveys. Values are predicted from generalized linear models that account for geographic stratum, time period, and the negative binomial distribution of the data. Error bars represent 95% confidence intervals.

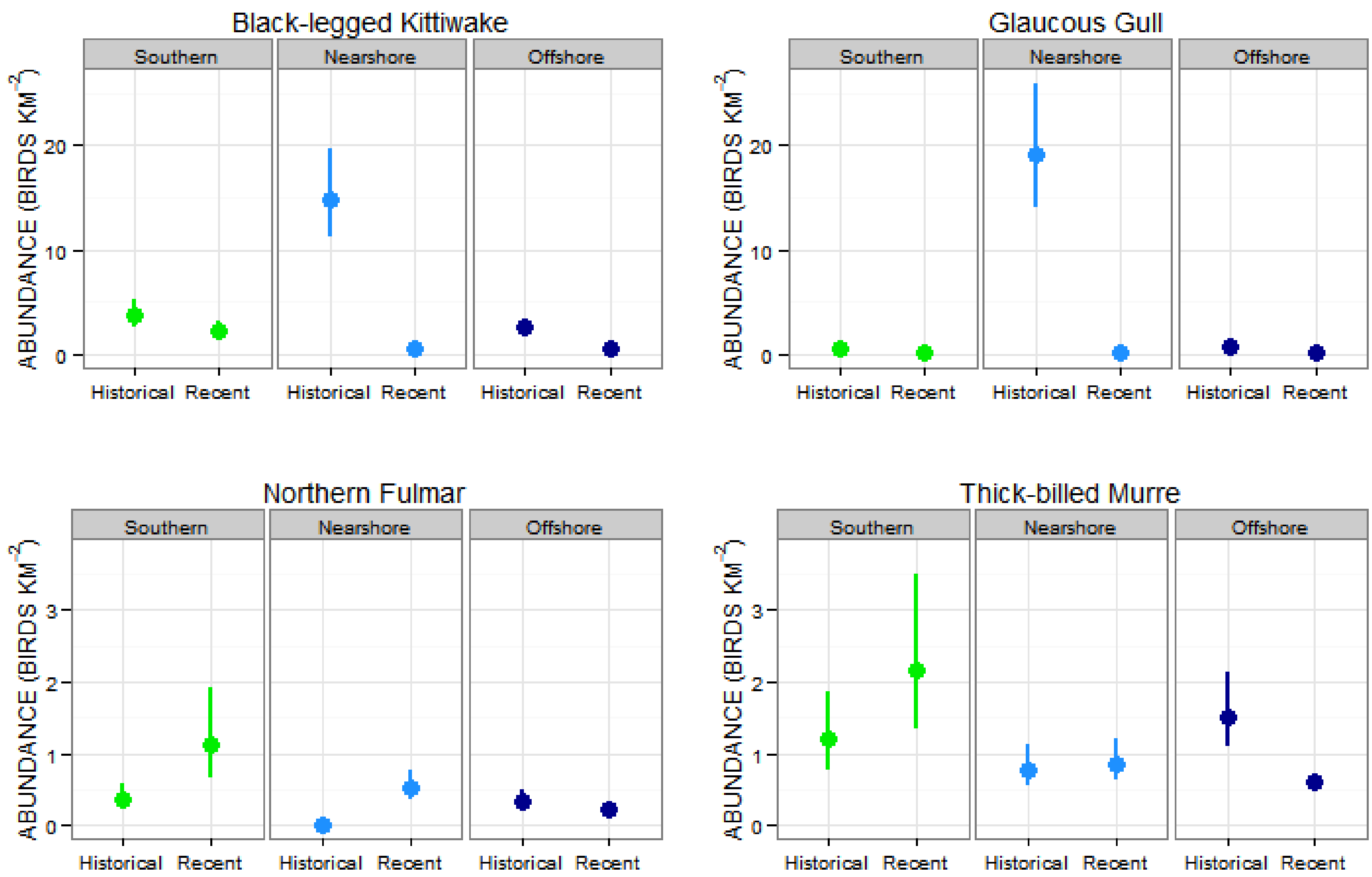

Figure 19. Abundance of 4 species including piscivorous and omnivorous seabirds in the U.S. sector of the Chukchi Sea during historical (1975–1981) and recent (2008–2011) surveys. Values are predicted from generalized linear models that account for geographic stratum, time period, and the negative binomial distribution of the data. Error bars represent 95% confidence intervals.

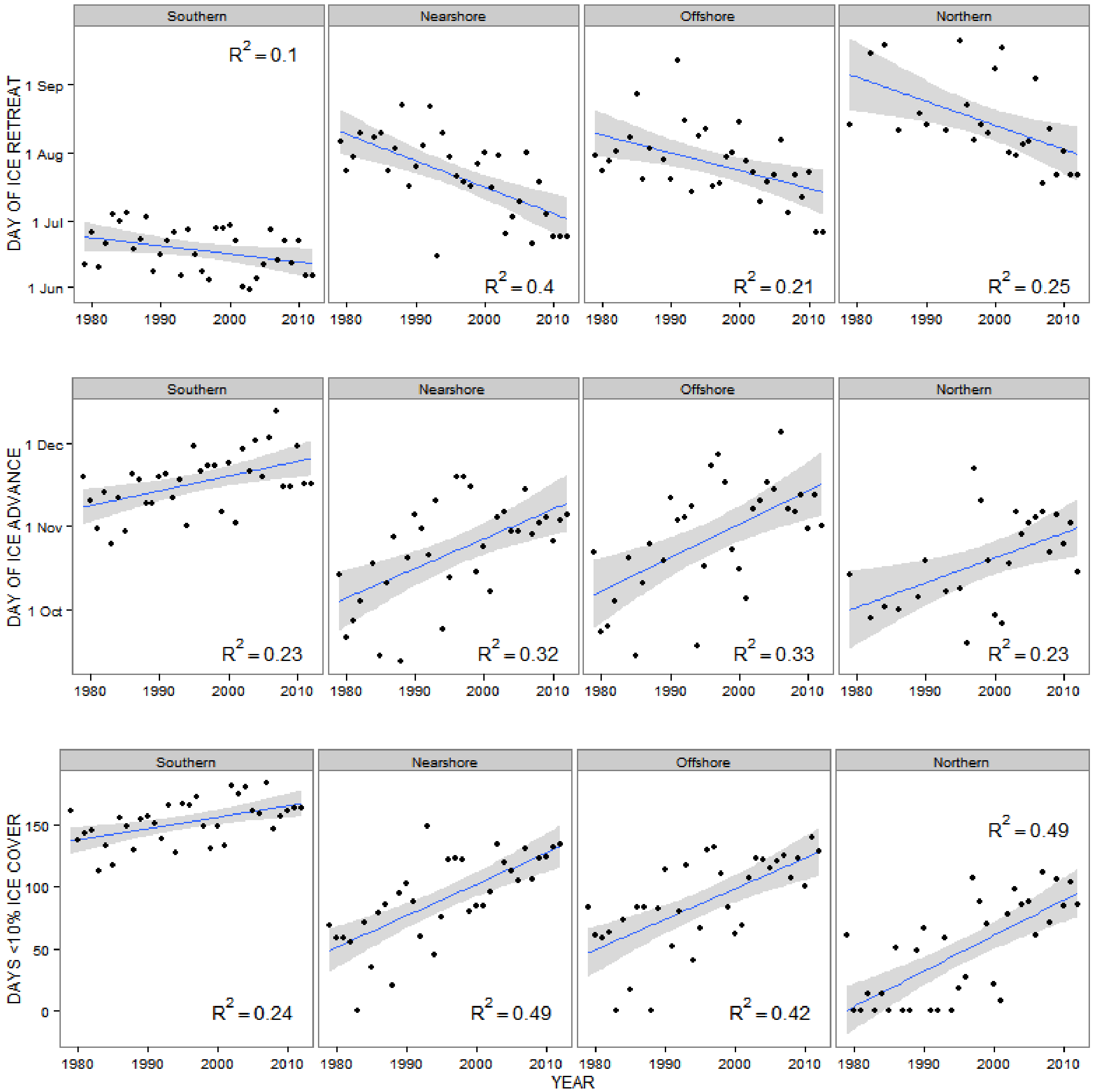

Figure 20. Linear trends in date of ice retreat (top), date of ice advance (middle), and number of days with ≤10% ice cover (bottom) in the Chukchi Sea, by geographic stratum, 1979–2010. Blue lines are the least-squares linear fit and the gray shading is the 95% confidence interval around the fit of the line.

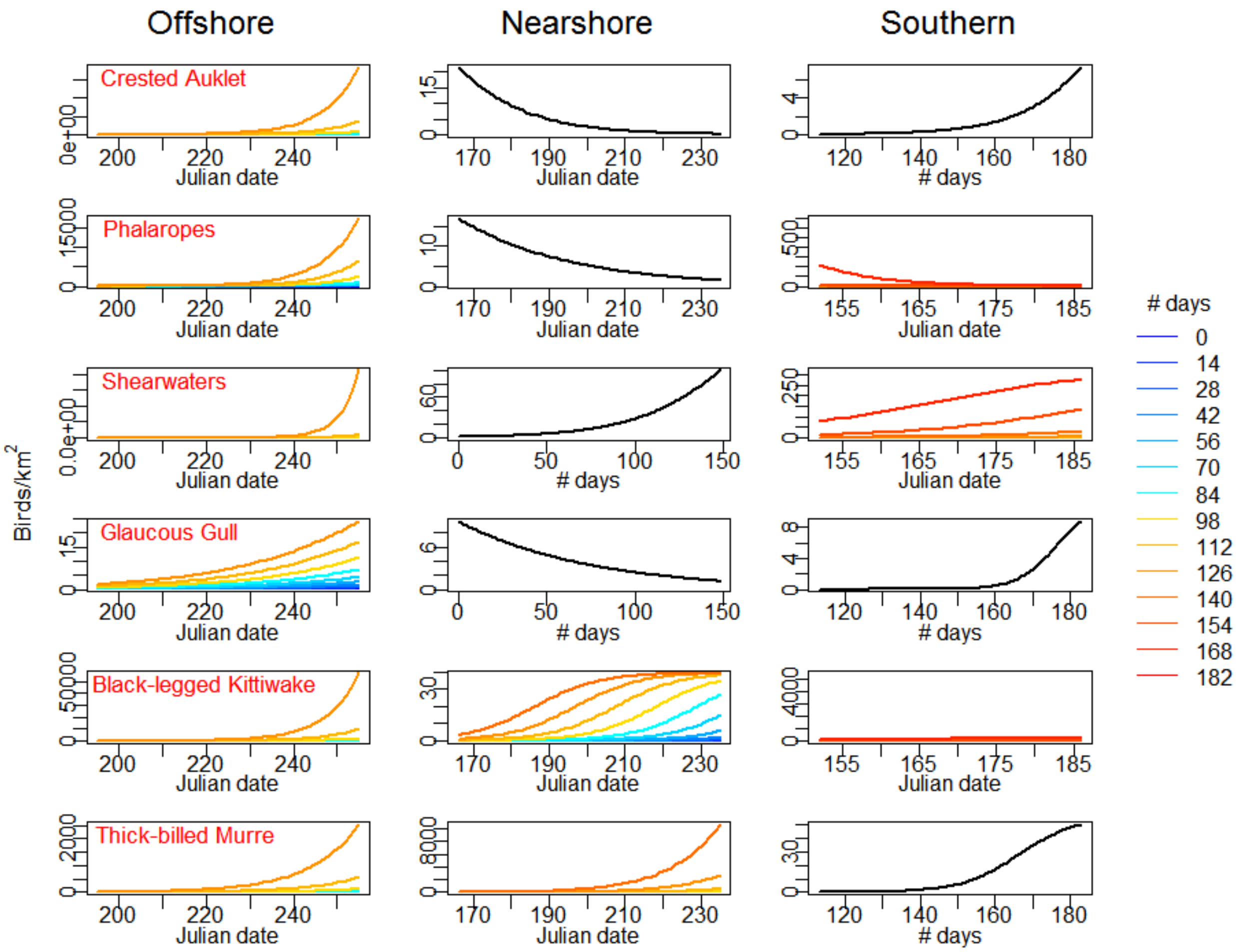

Figure 21. Relationship between ice chronology and abundance of 6 species of seabirds in the eastern Chukchi Sea. Values of date of ice retreat and number of ice-free days on seabird probability of occurrence and abundance are predicted from zero-adjusted negative-binomial models of the effects.

When points in the MDS ordination were visualized by season, they clustered more tightly in Sep than in Aug or Oct, indicating less variability in species-composition among study areas and years in that month (Figure 22). Samples from 2008 were more widely dispersed in MDS space than those of 2009–2012, indicating that species-composition in 2008 differed from composition in subsequent years. With the exception of 2008, samples do not separate into distinct groups, suggesting that, in most years, seabird community composition in the northeastern Chukchi Sea is similar among study areas.

Patterns in species-composition identified in the multivariate analyses were reflected by changes in the relative abundance of each of the 5 feeding guilds among study areas, seasons, and years (Figure 10). Most notably, planktivorous seabirds dominated numerically in all study areas combined in Sep/Oct 2008 and in all seasons of 2009–2012. Klondike and Burger were dominated numerically by planktivores (primarily Crested Auklets) and Short-tailed Shearwaters in all seasons and years except for Aug 2008, when the community was composed primarily of piscivores and omnivores. In Statoil, planktivores were the most abundant species-group in 2010–2012, except for Aug 2012, when Short-tailed Shearwaters dominated numerically. Species-composition was nearly identical in the GHS study area in 2011 and 2012

Table 10. Parameter estimates of the effects of date of sea-ice retreat and number of ice-free days (days with ≤ 10% ice cover) on seabird occurrence and abundance in the eastern Chukchi Sea from zero-adjusted negative binomial models. Errors are 95% confidence intervals and NS indicates that the parameter was not supported by the data.

		Probability of occurrence				Abundance			
		Date of retreat		Ice-free days		Date of retreat		Ice-free days	
Species	Stratum	Estimate	*P*	Estimate	*P*	Estimate	*P*	Estimate	*P*
Crested Auklet	Southern	NS		0.08 ± 0.07	0.02	NS		NS	
	Nearshore	–0.07 ± 0.02	<0.001	NS		NS		NS	
	Offshore	–0.01 ± 0.006	<0.001	0.007 ± 0.005	<0.001	0.14 ± 0.01	<0.001	0.11 ± 0.008	<0.001
Phalarope	Southern	–0.14 ± 0.11	0.010	NS		NS		0.27 ± 0.23	0.04
	Nearshore	–0.04 ± 0.03	0.041	NS		NS		NS	
	Offshore	0.05 ± 0.02	<0.001	0.02 ± 0.01	0.013	0.09 ± 0.03	<0.001	0.06 ± 0.02	<0.001
Shearwater	Southern	0.08 ± 0.04	<0.001	0.14 ± 0.04	<0.001	NS		NS	
	Nearshore	NS		0.03 ± 0.01	<0.001	NS		NS	
	Offshore	0.012 ± 0.01	0.014	0.022 ± 0.008	<0.001	0.24 ± 0.02	<0.001	0.21 ± 0.02	<0.001
Black-legged Kittiwake	Southern	0.08 ± 0.04	<0.001	0.16 ± 0.05	<0.001	NS		0.26 ± 0.16	0.002
	Nearshore	0.12 ± 0.05	<0.001	0.09 ± 0.04	<0.001	NS		NS	
	Offshore	0.03 ± 0.01	<0.001	0.03 ± 0.01	<0.001	0.12 ± 0.02	<0.001	0.10 ± 0.01	<0.001
Thick-billed Murre	Southern	NS		0.13 ± 0.04	<0.001	NS		NS	
	Nearshore	0.06 ± 0.05	0.026	0.09 ± 0.05	<0.001	0.07 ± 0.06	0.022	0.09 ± 0.06	0.006
	Offshore	–0.021 ± 0.001	<0.001	0.014 ± 0.008	0.003	0.11 ± 0.02	<0.001	0.09 ± 0.01	<0.001
Glaucous Gull	Southern	NS		0.20 ± 0.18	0.019	NS		NS	
	Nearshore	NS		0.024 ± 0.022	0.033	NS		–0.04 ± 0.03	0.012
	Offshore	0.04 ± 0.02	<0.001	0.04 ± 0.02	<0.001	0.01 ± 0.007	<0.001	NS	

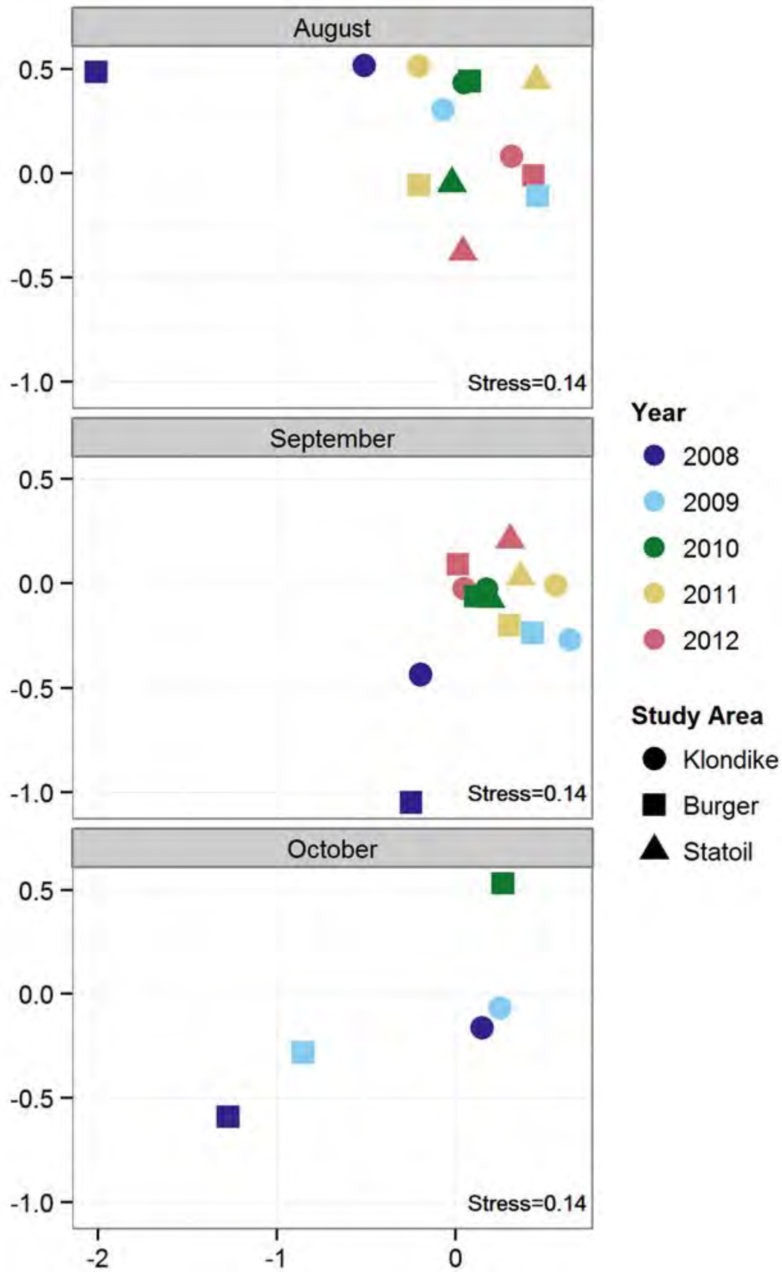

Figure 22. Non-metric multidimensional scaling ordination plot of Bray–Curtis similarities for *ln*(x+1)-transformed abundance of seabirds recorded in the northeastern Chukchi Sea during 2008–2012. Samples are grouped by month.

(Figure 23), even though abundance in 2011 was twice that in 2012. Benthic-feeders were the least common species-group in all years and study areas and consisted primarily of flocks of Long-tailed Ducks and Pacific Loons.

HISTORICAL COMPARISON

Over the past 37 years, the seabird community has included a total of 49 species. Of those, 33 species were recorded in both historical and recent time periods, 11 were recorded only during 1975–1981, and 5 were recorded only during 2008–2012. Multivariate analyses indicated that species-composition varied primarily between the two time periods (Figure 24A), shifting from a community dominated by piscivores to one dominated by planktivores; this shift was evident in all strata (Figure 24B). The MDS ordination separated into 2 temporal groups, with no misclassification between the historical and recent data points (Figure 24A). Historical samples from the Southern stratum were similar to samples from recent years. The Northern stratum showed the biggest shift in community structure over time (Figure 24B), converging in composition with the other regions in the recent years in which it was sampled.

Patterns in species-composition identified in the multivariate analyses were reflected in changes in the relative abundance of each of the 5 feeding guilds among strata and years (Figure 25). Most notably, the relative abundance of piscivores in all regions decreased from the historical period to the recent period. The Northern stratum was dominated numerically by planktivores in 1976 and 2011–2012, but they were absent from there in 1977, suggesting high variability in species-composition. The Offshore stratum had an increase in proportions of planktivores and shearwaters from the 1970s to 1980, with planktivores dominating numerically in 2008–2012. The Nearshore stratum also had an increase in shearwaters and planktivores over time, with shearwaters dominating numerically in 2008–2011. In contrast, the Southern stratum did not show a consistent temporal trend in species-composition. Shearwaters, planktivores, and piscivores dominated numerically in different years. Benthic-feeding birds (primarily eiders) composed 2–85% of all birds, depending on the stratum and year, because they sometimes occurred in large groups (up to 1,500 birds).

NEW SPECIES

Observers on CSESP cruises added 2 new seabird species not previously recorded in the eastern Chukchi Sea: Short-tailed Albatross (*Phoebastria albatrus*) at 71.3°N 163.22°W on 6 August 2012, and Northern Gannet (*Morus bassanus*) at 71.85°N 161.80°W on 16 August 2010. In addition, we documented a range expansion of Ancient Murrelets (*Synthliboramphus antiquus*) into the eastern Chukchi since 2006. We recorded Ancient Murrelets between Bering Strait and the northeastern Chukchi in 2010 (253 birds on 70 transect segments; range 1–12; seen 31 August–8 October), 2011 (31 birds on 11 transect segments; range 1–6; seen 8 September–10 October), and 2012 (152 birds on 48 transect segments; range 1–9; seen 1 September–11 October). We also recorded the first observations of this species in the western Beaufort Sea: 2 Ancient Murrelets at 71.15°N 152.59°W and a group of 3 at 71.12°N 152.28°W on 21 September 2010.

SPECIES OF CONSERVATION CONCERN

During the surveys of 2008–2012, we recorded 11 species classified as being of conservation concern on transects in the study areas (Table 11). All occurred on at least 2 of the 5 lists. Of these 11 species, 1 (Spectacled Eider) is listed as threatened under the ESA, 1 (Yellow-billed Loon) is 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 4 others, to be sensitive species. The Alaska Department of Fish and Game (ADFG) does not list any of the USFWS-listed species as being species of special concern. Instead, the State of Alaska's Comprehensive Wildlife Conservation Strategy classifies 8 of the 11 species as featured for management. The non-governmental organization Audubon Alaska classifies 7 of the 11 species as being of conservation concern. Finally, the quasi-governmental organization Alaska Natural

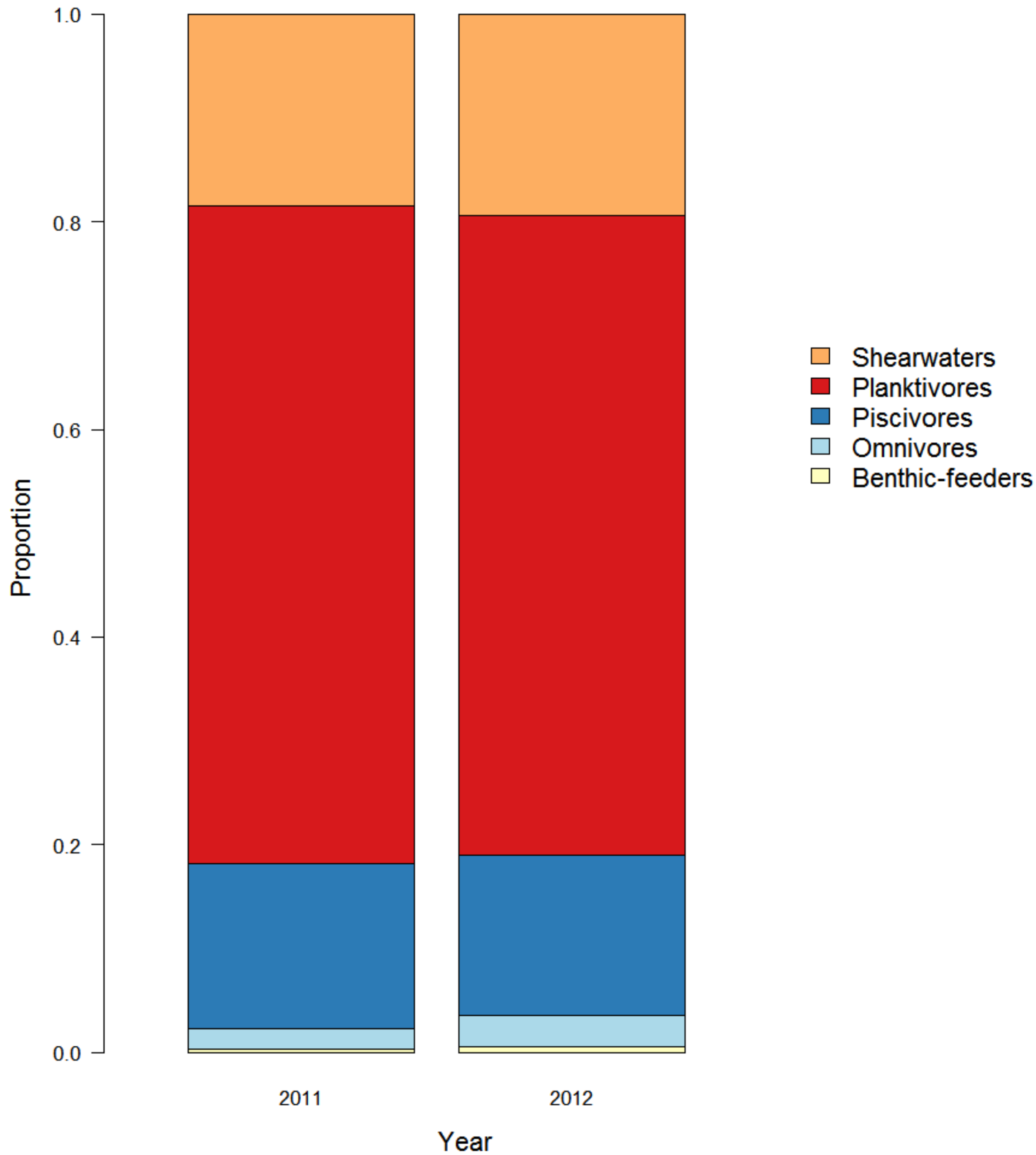

Figure 23. Feeding guilds that compose the seabird community on transect in the greater Hanna Shoal study area, 2011 and 2012.

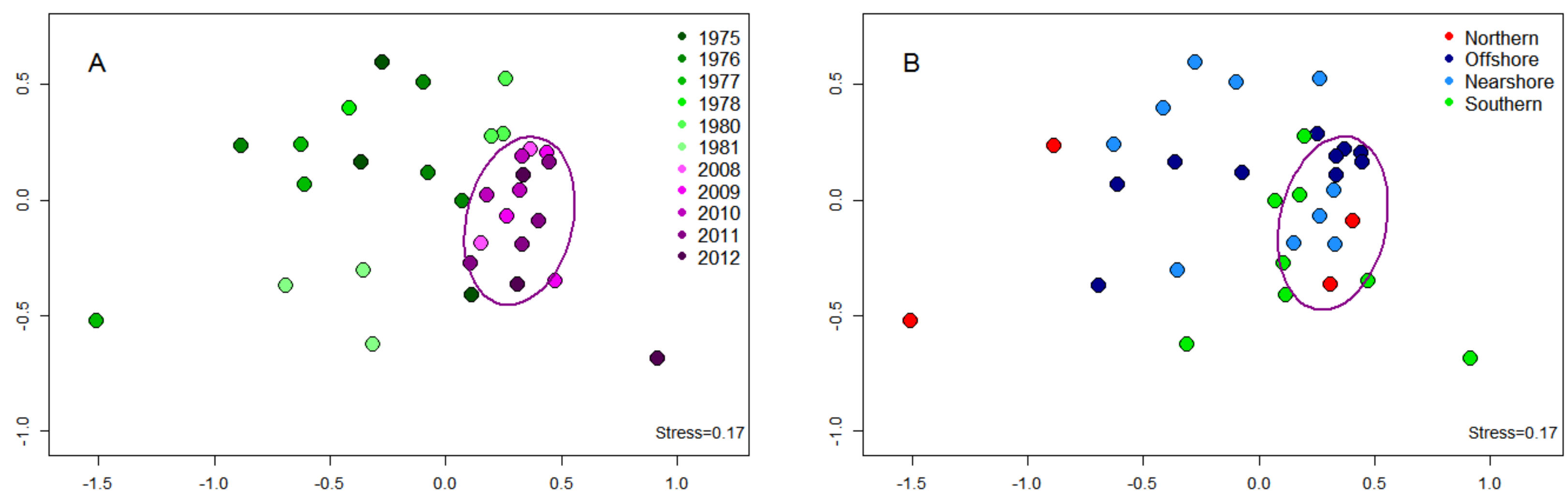

Figure 24. Non-metric multidimensional scaling (nMDS) ordination plot of Bray–Curtis similarities for seabirds recorded in the Chukchi Sea during 1975–2011. Distance between samples represents similarity in composition. Samples are grouped by year (A) and by stratum (B) with samples from the recent time period circled.

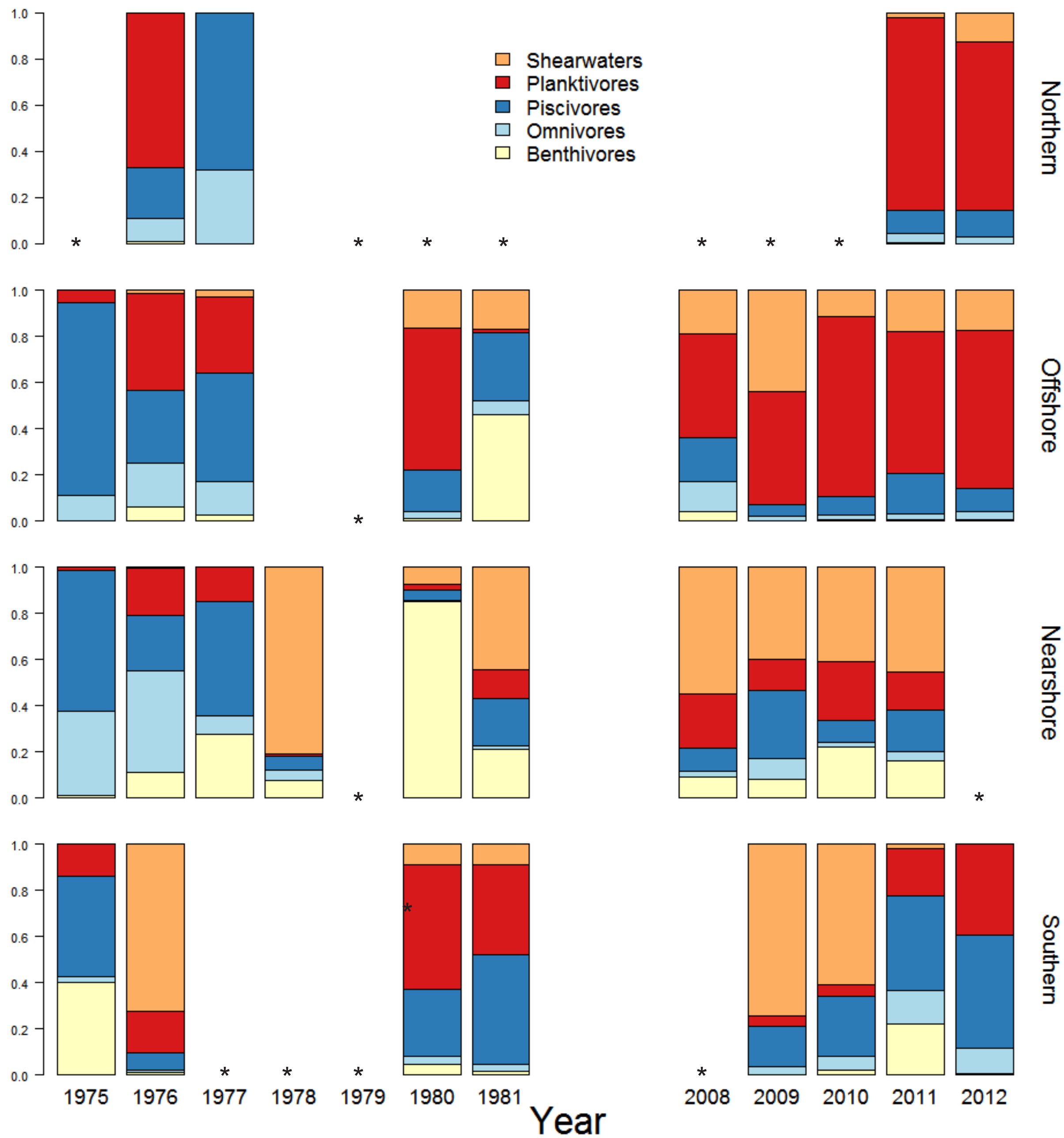

Figure 25. Feeding guilds that compose the seabird community in the Northern, Offshore, Nearshore, and Southern strata of the eastern Chukchi Sea, 1975–2011. Asterisks indicate no data.

Table 11. 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	–	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).

Heritage Program classifies 6 of the 11 species as being of conservation concern.

Of the 11 species of conservation concern, 3 (King Eider, Spectacled Eider, and Yellow-billed Loon) occurred on all 5 lists, and 2 (Red-throated Loon and Kittlitz's Murrelet) occurred on 4 of the 5 lists. These listings indicate that there is a high level of concern in many organizations about the long-term fate of these 5 species. Only Arctic Tern occurred on 3 of the 5 lists, including those of 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 their population trends.

Of the 5 waterfowl species that are of conservation concern, only the Long-tailed Duck was recorded in all years and was widely distributed in 2008–2010; however, it was rare in 2011 and 2012. We recorded 3–19 King Eiders in each year except 2009, when we recorded none. They occurred in all study areas except Statoil. Common Eiders also were recorded in every year except 2009 and were recorded in all study areas. Spectacled Eiders were seen in Sep/Oct 2009 (1 in Klondike and 1 in Burger) and in Sep/Oct 2010 (1 in Statoil). White-winged Scoters were not recorded during any of the multi-disciplinary science cruises, although they were recorded during mooring-retrieval efforts in Oct 2011.

We saw a total of 7 Yellow-billed Loons in 2008, 48 in 2009, 8 in 2011, and 3 in 2012. Of all observations, 52 (71%) were seen in Burger, 15 (21%) were seen in Klondike, 6 (8%) were seen in the GHS, and none (0%) were seen in Statoil. Arctic Terns occurred primarily in Klondike in Aug/Sep 2008 and Aug/Sep 2010, whereas the 2 observations in 2009 and 2 observations in 2012 occurred in Burger, and the single observation in 2011 occurred near Statoil.

The other 4 species of conservation concern were rare, with ≤21 observations/species in all seasons/years combined. Red-throated Loons were most common in 2011, with 7 observations of single birds in Burger and GHS. In addition, a single Red-throated Loon was seen in Burger in Sep 2008, and 2 were seen in Statoil in Sep 2010. We recorded 9 Dovekies during 2008–2012 with an annual maximum of 5 in 2008 and none in 2009; all observations were of single birds. Black Guillemots were recorded in Klondike and Burger throughout 2008, but they primarily were associated with sea ice. None were seen in 2009, presumably because no sea ice was present. We saw 1 in each of the 3 study areas in Aug 2010. We saw a total of 8 Black Guillemots in Burger, Klondike, and the GHS combined in 2012. Finally, Kittlitz's Murrelets were rare, with the highest abundance recorded in 2011.

SAMPLING EFFORT

We exceeded the minimum of 60 detections for 5 of the 6 detection-groups in all 5 years (Table 12), providing enough data in each year of sampling to model detection functions adequately. For phalaropes, we recorded <60 detections in 2011 and 2012, but the total sample size for all years combined was adequate for detection-function models. In some study-area boxes/seasons/years, the encounter rates were low (<0.2 observations/km), leading to predicted sampling requirements of >3,000 km to obtain 60 detections (Figure 26). By pooling data among study-area boxes and cruises, we met or exceeded the sample sizes required for most detection groups in all years.

For all detection-groups, the coefficient of variation (CV) around the abundance estimate stabilized after surveying 11 lines (605 km; Figure 27). Gulls had the lowest mean CV, which approached 0.20 after sampling 16 lines, and phalaropes had the highest CV, which declined to 0.48 after sampling 16 lines. Survey effort of ~2,000 km/year would be required to achieve a target CV of ≤30% for these 6 detection-groups (Figure 28).

There is a higher probability of detecting a linear trend (i.e., power) if that trend is declining than if it is increasing (Figures 29 and 30). The power increases with the number of years sampled (Figure 29) and/or by increasing the precision of estimates (Figure 30). If we assume a CV of 30% (obtained by sampling ≥2,000 km/year), we would have to sample for at least 10 years to have a probability of 0.64 to detect a 50% decline in the population and a probability of 0.34 to detect a 50% increase in the population (Figure 29). If we assume a 10-year sampling program and increase

Table 12. Number of detections by year and detection group for seabirds recorded within the 3 study-area boxes (Klondike, Burger, and Statoil) during at-sea surveys in the northeastern Chukchi Sea, 2008–2012. Numbers in bold indicate samples that were smaller than the 60 detections required for modeling detection functions adequately.

	Year				
Detection group	2008	2009	2010	2011	2012
Small alcids	107	437	687	77	612
Medium alcids	392	2,455	2,306	1,225	1,516
Large alcids	207	264	224	484	312
Shearwaters	351	1,646	709	441	502
Gulls	701	818	401	171	264
Phalaropes	61	133	156	**31**	**45**

the sampling effort to 2,500 km/year, the reduction in CV to 20% would increase the probability of detecting a 50% decline to 0.91 and the probability of detecting a 50% increase to 0.57 (Figure 30).

DISCUSSION

INFLUENCE OF PHYSICAL OCEANOGRAPHY ON THE REGION

Oceanographic conditions and features differ throughout the GHS study area seasonally and interannually (Weingartner et al. 2011, 2012, 2013). We propose that these differences create spatial and temporal differences in the abundance and distribution of the seabird community in the northeastern Chukchi Sea. The movement of oceanic water northward from the Gulf of Anadyr through the Bering Strait influences patterns of productivity throughout the Chukchi Sea (Grebmeier et al. 2006). In the southern Chukchi Sea, an oceanographic front between Bering Sea Water (BSW) and Alaskan Coastal Water (ACW) is the defining feature that separates distinct benthic communities (Grebmeier et al 2006, Bluhm et al. 2009), with higher biomass and bivalve abundance under BSW and lower biomass under ACW. In our study areas, biological communities also are structured to some extent by processes associated with fronts, although the water masses involved are modified from those present farther south. Despite its shallow overall bathymetry, the GHS study area straddles a region that oceanographically resembles an interface at a shelf-break. There is a transition from a stream of oceanic water entrained in the Central Channel to a 2-layered water-column trapped over Hanna Shoal that has little transport (Weingartner et al. 2005, Spall 2007, Day et al. 2013).

In terms of the fate of primary production, the southwestern half of the GHS appears to be more of a pelagic-dominated system and the northeastern half appears to be more of a benthic-dominated system, with a transition between the 2 systems occurring between Klondike and Burger (Day et al. 2013). This transition zone is seen in Statoil, which spans the longitudes between Klondike and Burger. The boundary between these two main water-masses is seen in surface temperatures and in bottom temperatures and salinities in the plan-view maps.

Observations from 2008–2010 focused on 3 study-area boxes that offered only a fragmented look at the fronts that develop each summer between BSW that is intruding from the south and MW and WW that are formed on the northeastern Chukchi shelf during winter and spring. Comparisons among the study-area boxes suggested that the structure and variability of the seabird community reflects the flow of BSW northward in the Central Channel. Data collected in 2011–2012 from the GHS study area provide further evidence to support this hypothesis and suggest that the spatial scale defining these communities is roughly twice that of the study-area boxes. Species associated with BSW in the study-area boxes such as Least Auklets, Short-tailed Shearwaters, Thick-billed Murres, and Northern Fulmars were concentrated in the

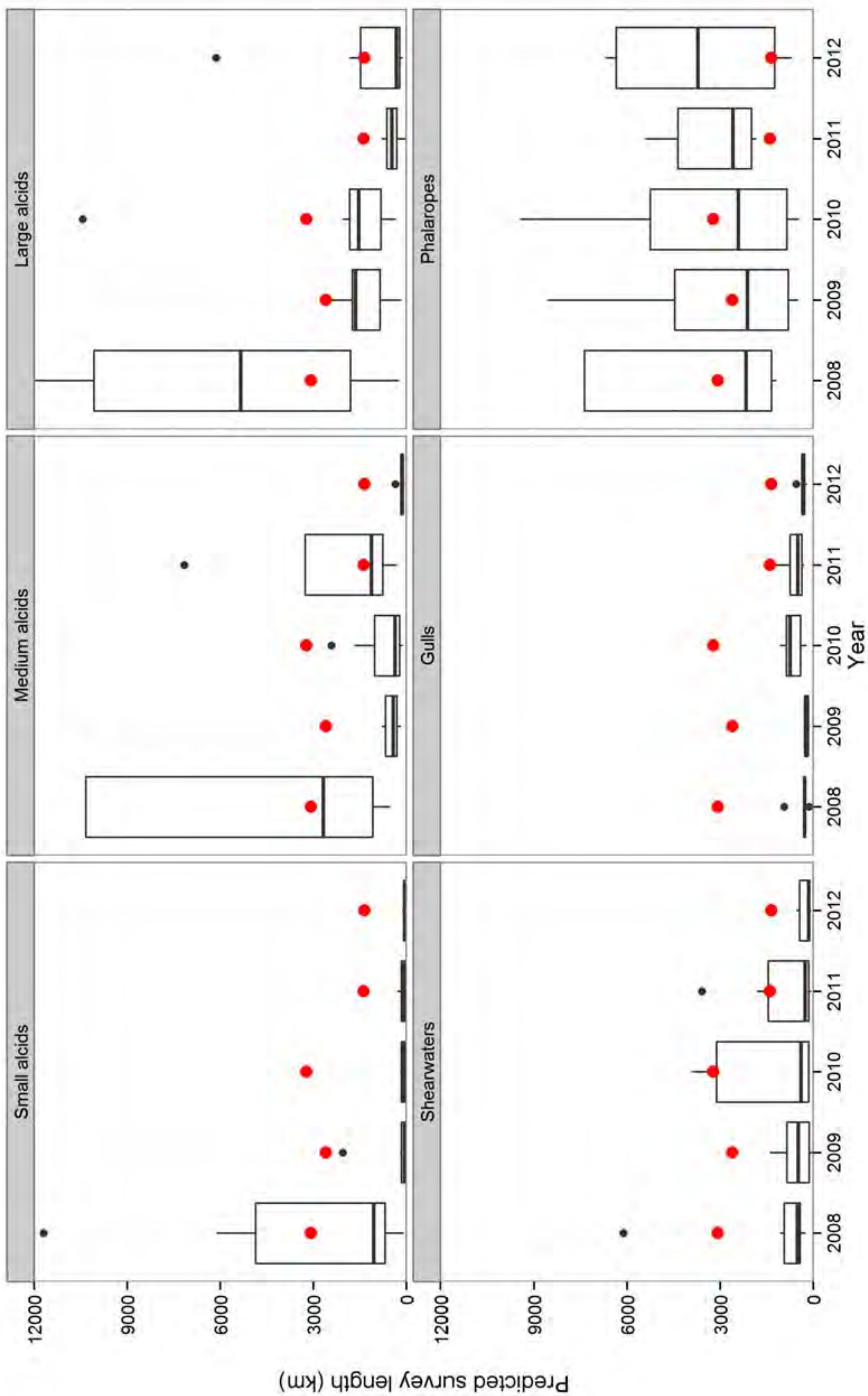

Figure 26. Survey effort (km) required to obtain 60 detections of seabirds at-sea, by detection group. Values summarized in boxplots are predicted from encounter rates measured during surveys in the northeastern Chukchi Sea, 2008–2012. Red dots represent actual survey effort in each year.

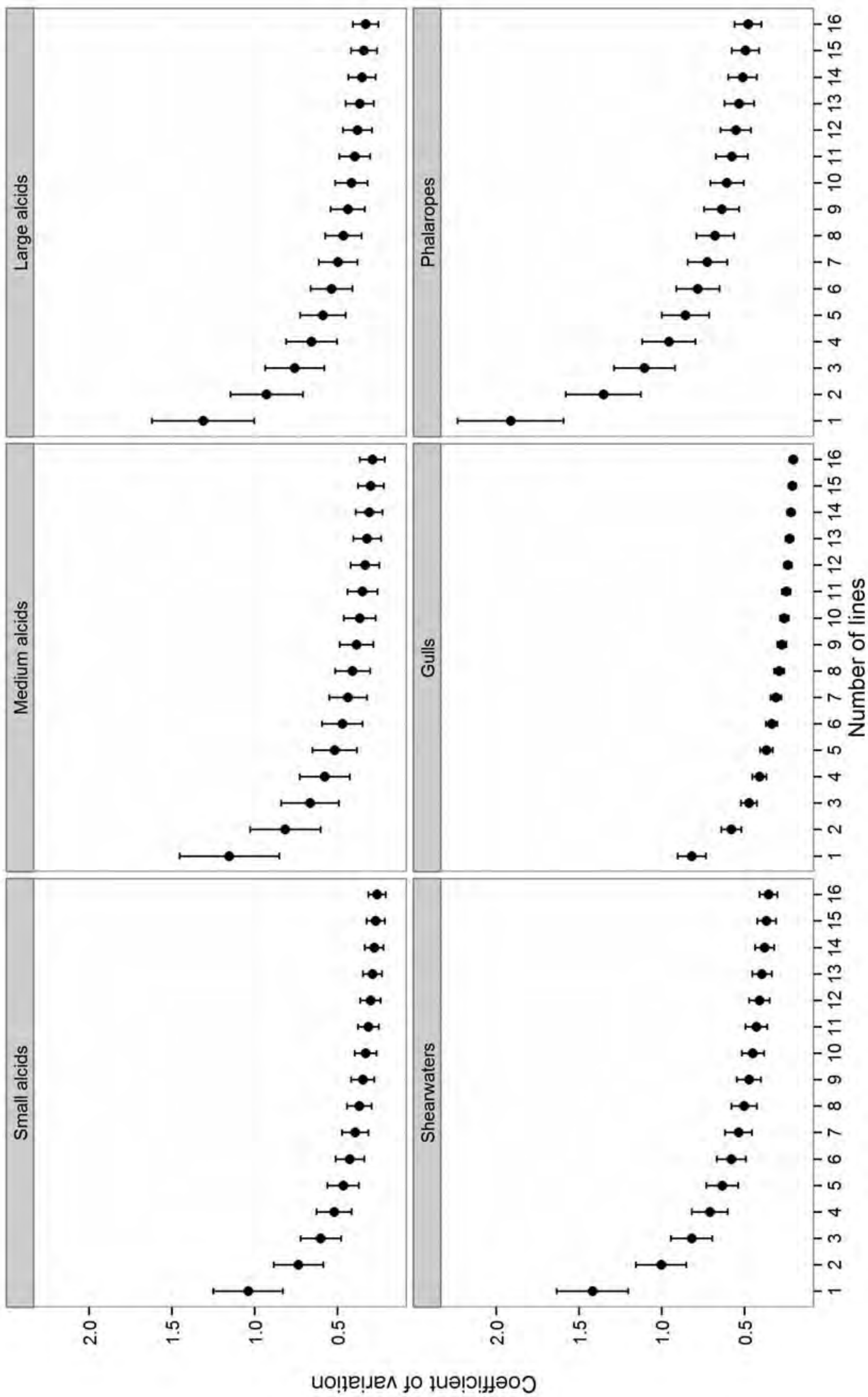

Figure 27. Relationship between coefficient of variation (CV) of abundance estimates and sampling effort for seabirds at-sea in the northeastern Chukchi Sea, by detection group. Each sampling line is 55 km long.

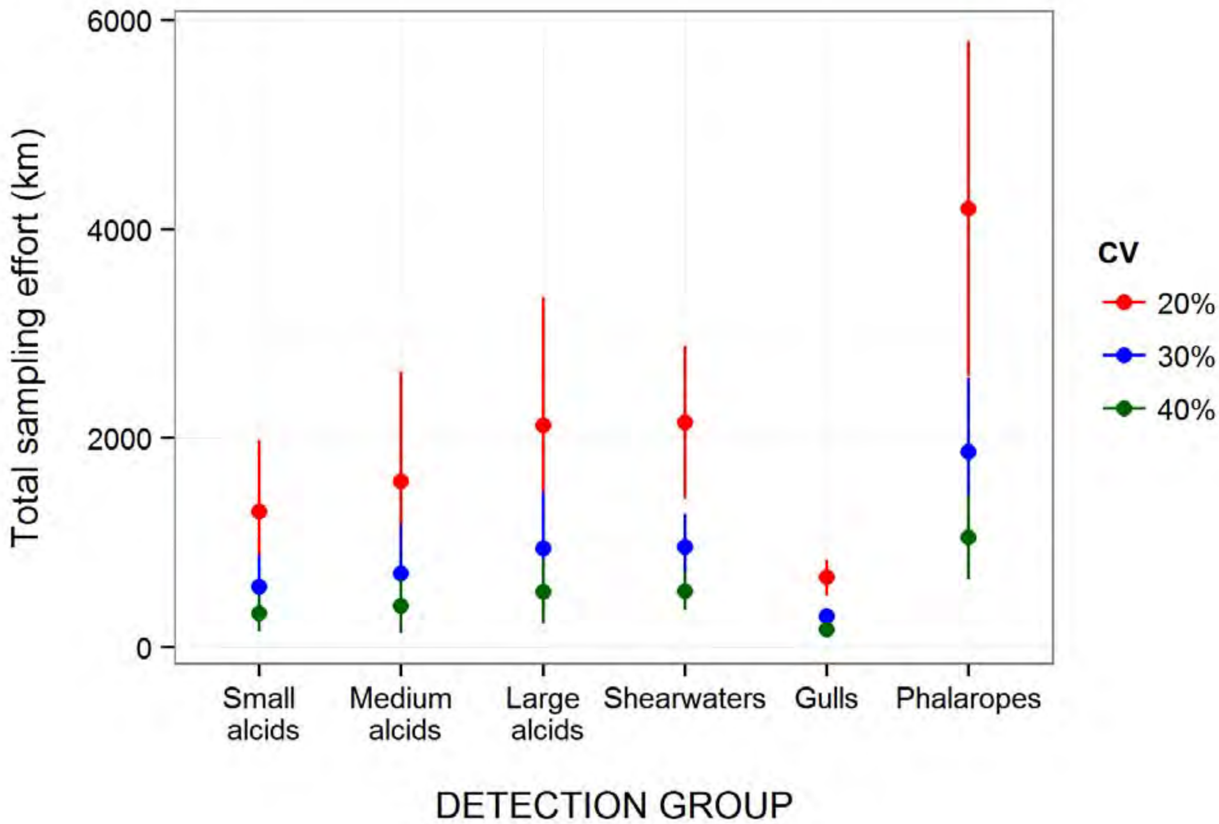

Figure 28. Sampling effort (km) required to achieve target values of sampling precision for abundance estimates of seabirds in the northeastern Chukchi Sea, by detection group.

southwestern half of the GHS. These patterns closely resembled the distribution of warm, salty water in the upper 10 m of the water column (i.e., BSW). Crested Auklets were present throughout the GHS study area. They were abundant near the Central Channel and concentrated near the front between the water-masses. In 2012, all of these BSW-associated species appeared to concentrate along a thermohaline front that extended from the southeastern corner of Burger to the northwestern corner of Statoil.

For species that occurred in low abundance, such as Glaucous Gulls and Black-legged Kittiwakes, the larger GHS study area surveyed in 2011 and 2012 helped clarify the patterns of distribution. These two species were more abundant in the northeastern half of the GHS, an area avoided by birds associated with BSW and avoided by planktivores in general. The northeastern GHS was characterized by a 2-layer system consisting of MW at the surface and WW on the bottom. Ross's Gulls were rare in the study-area boxes and in 2011 and 2012, this ice-associated species occurred almost exclusively northeast of the boxes, instead migrating across the cooler area in northern Hanna Shoal that was covered by MW.

The presence or absence of some of the rarer species among years 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, Dovekies, and Black Guillemots in the study-area boxes. In 2009 and 2011, 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 at the edges of

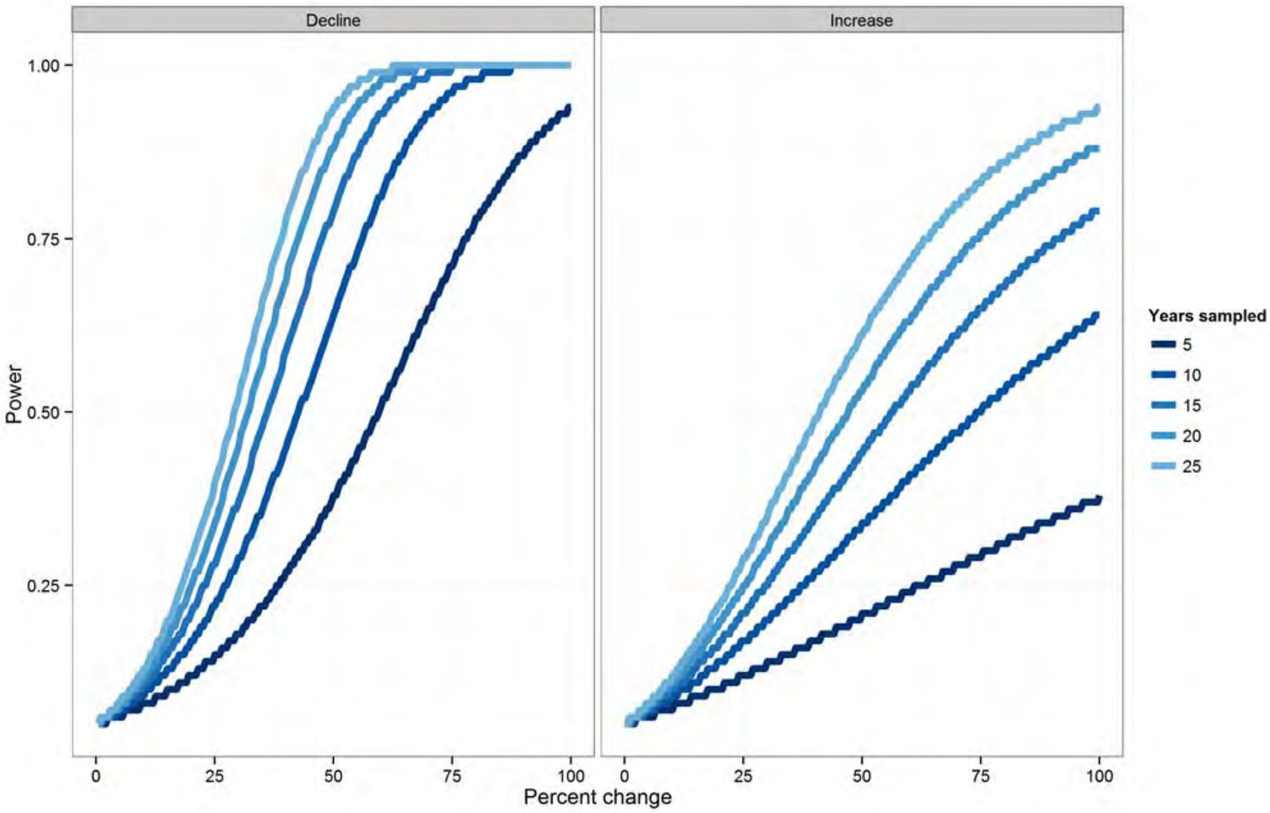

Figure 29. Power to detect a linear change in abundance as a function of rate of change (r) and number of years sampled. Curves assume CV = 0.3 and α = 0.1.

their range (e.g., Pigeon Guillemots); these species were recorded only in 2008 and/or 2010.

BASELINE DISTRIBUTION AND ABUNDANCE OF SEABIRD SPECIES

The distribution of seabirds, particularly the planktivores, is influenced in the northeastern Chukchi Sea by advective processes that transport oceanic species of zooplankton from the Bering Sea. Because planktivorous seabirds are most abundant in areas where their prey are concentrated within 20 m of the ocean's surface (Haney 1991, Piatt and Springer 2003), they are responsive to conditions that make their prey both abundant and accessible. Total seabird abundance was lowest in 2008, highest in 2009, and intermediate in 2010–2012. This interannual variation reflected changes in the location and strength of the boundary between BSW and MW, although the effects on zooplankton populations appeared less clear (Questel et al. 2012). The year of lowest total seabird abundance (2008) was associated with a combination of the coldest overall water temperatures, weak stratification, late inflow of BSW that did not develop until Sep/Oct, and the lowest biomass of large zooplankton recorded in the 5 years of the CSESP study.

The year of highest total seabird abundance (2009) was associated with extensive and early intrusion of warm BSW into the study region that cooled slowly. It was accompanied by only an intermediate biomass of large zooplankton. The warm BSW established vertical stratification of the water-column at a depth of 25–35 m in Aug that persisted until Sep/Oct.

The years of intermediate seabird abundance (2010–2012) were associated with greater variability in water mass characteristics throughout the open-water season than occurred in 2008 or 2009. In all 3 of these intermediate years, BSW

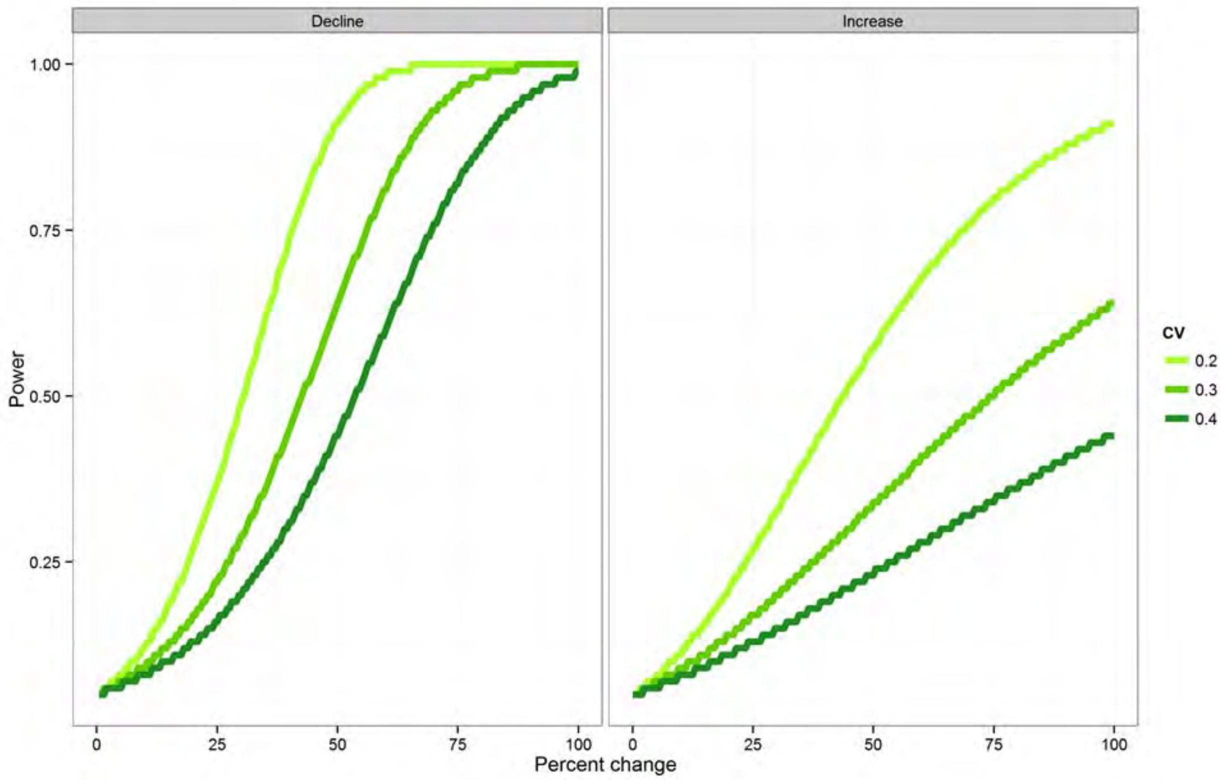

Figure 30. Power to detect a linear change in abundance as a function of rate of change (*r*) and coefficient of variation (CV). Curves assume 10 years of sampling and α = 0.1.

occupied the upper mixed layer of Klondike by Aug and extended over parts of Burger and Statoil in 2010 and 2011. These early intrusions of BSW were associated with high bird abundance similar to that recorded in Aug 2009. In contrast, the presence of both ice and MW over Burger in Sep 2012 was associated with lower seabird abundance. In 2010, BSW over Klondike warmed in Sep, and seabird abundance was similar to that measured in Aug 2010.

At this time, we do not fully understand the mechanisms that concentrate prey and create efficient foraging conditions for seabirds. Clearly the interactions among BSW, MW and WW affect the strength, location, depth, and persistence of fronts and pycnoclines. In addition, the thermal conditions and nutrients advected from the Bering Sea affect the biomass of zooplankton available. In years that are consistently cold (e.g., 2008), low overall seabird abundance can be expected, but, for years in which there is variation throughout the open-water season, the expected magnitude of seabird abundance or even seasonal trends in abundance still are challenging to predict.

Seasonal changes in community composition are dictated partially by the development of open water. As sea ice retreats and foraging habitat becomes available, species move in from foraging areas to the south and from terrestrial breeding areas. Of the colonial seabirds, Thick-billed Murres, Common Murres, and Black-legged Kittiwakes nest in large numbers on cliffs along the eastern Chukchi coast as far north as Cape Lisburne and are common offshore during Aug and Sep (Divoky 1987). Species that nest on the tundra, such as phalaropes and jaegers, move out to sea in Aug and Sep and join millions of Short-tailed Shearwaters that migrate from their breeding grounds in Australia to forage in the Northern Hemisphere during the austral winter (Divoky 1987). Finally, ice-associated gulls such as Ross's Gulls and Ivory Gulls migrate from high-arctic breeding areas in Russia and Canada into the Chukchi and Beaufort seas to forage before the ice-edge moves southward again in late Oct (Divoky et al. 1988).

Species-composition was similar from year to year and was dominated numerically by a mix of auklets, shearwaters, and phalaropes, all of which are primarily zooplankton-feeders. The most remarkable difference in species-composition among years occurred in the cold water year of 2008 (and especially in Burger), primarily because of the low abundance of auklets in that year and the numerical importance of larids in Burger. Abundance of diving species such as Crested Auklets and Short-tailed Shearwaters fluctuated by 4 orders of magnitude among years, whereas the variation in the abundance of surface-feeding larids among years was only 1 order of magnitude. This fairly consistent annual contribution of larids indicates that most of the variation in the seabird community can be attributed to planktivorous seabirds.

PLANKTIVOROUS SEABIRDS

Distribution and abundance of individual species of planktivores demonstrates the relationship between foraging strategy and foraging habitat, as defined by physical oceanography. For example, Crested Auklets are diving seabirds that consume primarily euphausiids (e.g., *Thysanoessa* spp.) and large copepods (e.g., *Neocalanus cristatus*, *N. plumchrus*) characteristic of oceanic water from the North Pacific and Bering seas (Bédard 1969, Kitaysky and Golubova 2000, Gall et al. 2006). Areas of high Crested Auklet abundance during this study tended to coincide with upper-layer water temperatures of 4–5 °C and salinities >30, regardless of stratification conditions, month, 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 (e.g., *N. plumchrus*) and shelf copepods (e.g., *Calanus marshallae*) and, because of their smaller body size, do not dive as deeply as Crested Auklets do (Hunt et al. 1998); therefore, they should concentrate in areas with shallow pycnoclines. Like Crested Auklets, areas of high Least Auklet abundance coincided with BSW, but they also tended to occur where and when pycnoclines were strongly established and only 10–20 m from the surface or when the water-column was well-mixed, a characteristic that increases the availability of prey near the surface. Both of these conditions were present along the frontal boundary in Burger and Statoil in 2012.

The distribution and abundance of planktivores that feed at the surface also reflected their respective foraging strategies. Phalaropes have the most restricted foraging habitat of the planktivores we studied in detail. They are small shorebirds that forage only on the surface and typically are associated with microscale 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 either strong, shallow pycnoclines or well-mixed water. Their distribution was highly clumped, and they were particularly abundant when and where there were filaments of cold water at or near the surface embedded within warmer waters (e.g., Klondike in Sep 2008, Statoil in Sep 2012), indicating microscale divergences.

The distribution of Short-tailed Shearwaters did not appear to be tightly coupled with particular features of the water-column, although concentrations always were highest in the southern half of the GHS study area (i.e., in BSW). They are fairly large seabirds that consume a variety of large zooplankton, in addition to fish and squid (Hunt et al. 2002; Jahncke et al., 2005) and can forage as deeply as 70 m (Weimerskirch and Cherel 1998). The magnitude and pattern of interannual variation in the abundance of Short-tailed Shearwaters during this study was similar to that of primarily planktivorous Crested Auklets, whereas their seasonal pattern of abundance was consistent among years (i.e., typically highest in Sep). This suggests that they are responding to oceanographic structure at a broader spatial scale than the areas sampled in this study. These insights were possible only with the broader sampling across the entire GHS study area conducted in 2011–2012.

OMNIVOROUS SEABIRDS

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 all

5 years and at densities considerably lower than the large and variable densities of planktivores. Both were least abundant in 2010, most abundant in 2009, and intermediate in abundance in the other 3 years. Northern Fulmars had a consistent seasonal pattern among years: their abundance declined from Aug to Sep/Oct, perhaps indicating their greater reliance on prey associated with BSW 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 Aug to Sep/Oct in all years.

PISCIVOROUS SEABIRDS

Variation in the distribution and abundance of piscivorous species, as indicated by Black-legged Kittiwakes and Thick-billed Murres, probably is related to differences in foraging strategies of these two species. Despite being classified as piscivores (Piatt and Springer 2003), Black-legged Kittiwakes are surface-feeding gulls that will consume both fishes and larger zooplankton (Hobson 1993, Jodice et al. 2006, Iverson et al. 2007). Thick-billed Murres are diving alcids that eat primarily fishes but also will consume larger invertebrates (Woo et al. 2008). Thick-billed Murres occurred almost exclusively in Klondike in all years except 2012 and disappeared by Sep/Oct of each year, suggesting that they had very restricted foraging habitat that was located primarily in BSW. Black-legged Kittiwakes had a consistent seasonal pattern of abundance in Burger in all years. In Klondike, however, abundance tended to be highest when BSW occupied more of Klondike than it did in Burger, suggesting that Black-legged Kittiwakes were foraging primarily on prey species associated with BSW but may be less restricted in their foraging requirements than are Thick-billed Murres. These results are consistent with patterns observed in the southeastern Bering Sea, where Black-legged Kittiwakes were found to be widespread foragers and Thick-billed Murres foraged close to their breeding colonies (Sigler et al. 2012).

IMPLICATIONS FOR A CHANGING ENVIRONMENT

Most of the research on seabirds at-sea in the Chukchi Sea prior to 2007 was conducted in the 1970s and 1980s. A large data set from those decades is available for exploring changes in the ecology of the Chukchi Sea over the past 40 yr. Based on these historical data, phalaropes were thought to replace auklets as the dominant planktivorous birds north of Bering Strait (Piatt and Springer 2003). Planktivorous seabirds in general were assumed to be insignificant consumers in the Chukchi Sea as a whole (Piatt and Springer 2003, Hunt et al. 2013). Our data, together with results of other recent studies, indicate that although planktivores did not numerically dominate the seabird community in the 1970s and 1980s, they have become the dominant feeding guild of the 2000s and 2010s. This change is particularly true for diving species such as Crested Auklets and Short-tailed Shearwaters (Gall et al. 2012; Kathy Kuletz, U.S. Fish and Wildlife Service, Anchorage, 2013, pers. comm.). Studies of ecosystem dynamics that rely only on data collected >30 yr ago do not reflect the way that species-composition and the distribution and abundance of seabirds has changed in response to climate change.

When compared with conditions 30 yr ago, sea ice now forms later, melts earlier, and is completely gone from all parts of the Chukchi Sea by late summer. Earlier ice retreat and a longer ice-free season may contribute to an environment that is more amenable to the production and growth of euphausiids. In a shallow Chukchi Sea with less ice cover than there used to be, increased easterly winds could intensify shelf-break upwelling (Carmack and Chapman 2003, Mathis et al. 2012), enhance nutrient supply, and support larger communities of phytoplankton and zooplankton (Lane et al. 2008) for longer periods in the summer. There also is evidence that the northward flow of water through Bering Strait is increasing (Woodgate et al. 2012) and with it, the advection of phytoplankton and zooplankton into the Chukchi Sea (Springer et al. 1989). These Pacific zooplankters are being advected into a region where warming summer waters can sustain higher growth rates and develop greater biomass of zooplankton (Questel et al. 2012). Although the historical zooplankton community is not as well documented as is the seabird community, there are indications of higher zooplankton abundance and biomass along the Chukchi shelf-break in the

2000s than historically (Lane et al. 2008) and of increased abundance of meroplankton over the northeastern Chukchi shelf between 1991–1992 and 2007–2008 (Matsuno et al. 2011). We propose here that the changes in the abundance and species-composition of the seabird community in the eastern Chukchi Sea reflect an increase in the abundance of large zooplankton prey in the region.

New seabird species also have been added to the community or have become common in the Chukchi Sea in the past 7 years (Day et al., in press). The Northern Gannet is an Atlantic species that was recorded in the Chukchi Sea for the first time; it presumably traversed the Northwest Passage during a period of open water, the second seabird species from the North Atlantic recorded in the Pacific in recent years (Kharitonov 2009). The Short-tailed Albatross, Ancient Murrelet, and Rhinoceros Auklet all are Pacific and Bering Sea species that have been able to extend their ranges northward, presumably in response to ameliorating ice, oceanic, and climatic conditions in the Chukchi Sea (Day et al., in press).

Perhaps the most curious indicator of change was the widespread occurrence of Ancient Murrelets in all 3 study-area boxes in Aug/Sep 2010 and 2011 and their lingering presence in Burger into Sep/Oct 2010. The winter range of this small, nocturnal alcid is largely unknown (Gaston and Shoji 2010). The closest known breeding populations are in the Aleutian Islands, ~1,600 km south of the Chukchi Sea. There are no records of Ancient Murrelets in the northern Chukchi Sea in the North Pacific Pelagic Seabird Database (USGS 2010) in the ~35 years prior to 2007, and there are few records of these birds north of Bering Strait, in the southern Chukchi (Kessel 1989; Day et al., in press). In contrast, they have been recorded in the Chukchi Sea in 5 of the 7 years from 2006 to 2012 (Day et al, in press), and sometimes in substantial numbers, which suggests a true range expansion sometime during the intervening period. In addition, recent records from the Beaufort Sea (Day et al., in press) imply that further northward/eastward expansion of the range is occurring.

SPECIES OF CONSERVATION CONCERN

During these surveys, we recorded 11 species of seabirds that are of conservation concern: 5 are waterfowl (all seaducks), 2 are of loon, 1 is a tern, and 3 are alcids. With the exception of Yellow-billed Loons in 2009 and Long-tailed Ducks in 2008 and 2009, none of the species occurred in substantial numbers. The highest-profile species are Spectacled Eider, which is listed as threatened under the ESA, and Yellow-billed Loon, which is a candidate species for listing under the ESA. The status of the Kittlitz's Murrelet was evaluated in 2013, and the draft decision made public on 1 October 2013 stated that listing this species is not warranted at this time (Federal Register 78 [192]: 61,764–61,01). A listing evaluation for the Yellow-billed Loon will occur by the end of September 2014.

SAMPLING EFFORT AND IMPLICATIONS FOR POPULATION MONITORING

A key assumption of line-transect sampling is that the minimal sample required for obtaining accurate abundance estimates is determined by encounter rates and clustering behavior, rather than scaling to a proportion of the population (Buckland et al. 2001). If the survey effort is too small, it will provide little precise information about abundance or detection probabilities. As survey effort increases, the precision of the abundance estimate increases asymptotically, meaning that, at some point, expending extra effort yields only a modest increase in precision and is not an efficient use of resources (Legault et al. 2012). A good starting point for sample sizes is 60–80 detections for each detection-group, although this number may have to be higher for populations that are clustered and/or whose cluster sizes are highly variable (Buckland et al. 2001). For example, our survey effort in each of the 5 years was sufficient to obtain 60 detections for most detection groups. A preferred precision (CV) of abundance estimates of ±20%, which is desirable for accurate detection of changes in abundance (Buckland et al. 2001), may require prohibitively high survey effort for all but the most evenly distributed species (e.g., gulls). The studies that we have conducted represent some of the most spatially intensive at-sea sampling ever conducted in the Chukchi Sea, yet our mean estimate of precision for a detection-group within a study-area box/season/year was 0.35 (95% CI: 0.32–0.38).

For species that occur in small groups and are distributed throughout the study area (i.e., the 3 study-area boxes), annual survey effort of ~1,000 km is adequate to generate reliable detection functions and abundance estimates with target precision approaching 30%. Phalaropes, however, are patchily distributed and can occur in groups of up to 150 birds. For that detection-group, sampling effort needs to be at least 1,800 km in one survey to estimate abundance with a target precision of 30% and to detect population trends accurately.

The high interannual variability of seabird populations at high latitudes makes it challenging to detect long-term trends in abundance. Power curves based on a precision of 30% indicate that a 5-year study such as the one we report on here would have only a 38% probability of detecting a 50% decline in the population and only a 21% probability of detecting a 50% increase over those 5 years. Comparisons with the historical studies, however, highlight the value of long-term monitoring. If surveys are conducted annually for 25 years, the probability of detecting a 50% decline over 25 years increases to 94%, and the probability of detecting a 50% increase over 25 years increases to 61%. Projects that compile data from multiple government and industry sources (e.g., Distributed Biological Observatory, repositories managed by the Alaska Ocean Observing System) can boost sample sizes to increase estimates of precision and the power to detect trends in seabird populations.

CONCLUSIONS

The GHS study area in the northeastern Chukchi Sea supports a diverse seabird community of more than 30 species and, during some months, a maximal abundance of >60 birds km² within a single study-area box. There is extensive seasonal and interannual variation in the abundance of seabirds that is almost entirely attributable to planktivorous species. The greatest number of birds generally occurs in Sep (~25 August to ~ 20 September), presumably reflecting a variety of factors that may include the timing of melt of sea ice, seasonal changes in the oceanography and of prey in the region, bird migration, nesting phenology, and breeding success of birds in the Arctic. Despite this general seasonal trend, the interannual variation in timing of species-specific maximal abundance is related to the strength and timing of inflow of BSW from south of Bering Strait. Planktivorous seabirds generally are more abundant close to the Central Channel (southwestern half of the GHS study area) and in BSW. Piscivorous species generally are more abundant in the northeastern half of the GHS study area and in two-layered MW/WW.

The scientific community is moving beyond describing this system to quantifying the spatial and temporal scales of ecological processes in this region. We demonstrate that differences in the seabird community reflect the shifting dynamics of BSW throughout the GHS study area. Several other components of this multidisciplinary study also suggest a similar structuring of the ecosystem (Questel et al. 2012; Blanchard et al., in press). Our growing understanding of factors that influence interannual variability is informing the development of long-term plans to monitor the seabird community and predict the effects of changing environmental conditions in this region of interest for oil and gas exploration.

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Appendix A. List of all bird species recorded during ship-based surveys in the northeastern Chukchi Sea, 2008–2012. Iñupiaq names are provided when known by us. Ecological guild classifications are provided only for seabirds included in the analyses.

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

Appendix A. Continued.

Species-group/species	Scientific name	Iñupiaq name	Ecological guild
ALCIDS			
Dovekie	*Alle alle*		Planktivore
Common Murre	*Uria aalge*	aqpaq	Piscivore
Thick-billed Murre	*U. lomvia*		Piscivore
Black Guillemot	*Cepphus grylle*	iŋaġiq	Piscivore
Pigeon Guillemot	*C. columba*		Piscivore
Kittlitz's Murrelet	*Brachyramphus brevirostris*		Planktivore
Ancient Murrelet	*Synthliboramphus antiquus*		Planktivore
Parakeet Auklet	*Aethia psittacula*		Planktivore
Least Auklet	*A. pusilla*		Planktivore
Crested Auklet	*A. cristatella*		Planktivore
Horned Puffin	*Fratercula corniculata*		Piscivore
Tufted Puffin	*F. cirrhata*	Qiḷaŋaq	Omnivore
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 transect during ship-based surveys in the central Chukchi Sea, by study area and month, 2008–2012.

Species-group/ species	Period/ year	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct	Statoil Aug	Statoil Sep	Statoil Sep/Oct	Hanna Shoal Sep
WATERFOWL											
Spectacled Eider	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	1	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
King Eider	2008	1	0	2	0	1	2	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	2	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	8
	2012	0	1	–	0	0	–	0	0	–	18
Common Eider	2008	0	0	0	0	5	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	3	0	0	–	–
	2011	0	0	–	0	0	–	0	1	–	3
	2012	0	9	–	42	0	–	0	0	–	0
Unidentified eider	2008	0	10	5	0	9	0	–	–	–	–
	2009	0	15	1	0	2	5	–	–	–	–
	2010	0	0	–	7	0	7	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	7
	2012	0	0	–	0	0	–	0	0	–	0
White-winged Scoter	2008	0	0	0	0	0	3	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–

Appendix B. Continued.

		Study area/season									
		Klondike			Burger			Statoil			Hanna Shoal
Species-group/ species	Period/ year	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Sep
White-winged Scoter (cont.)	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
Long-tailed Duck	2008	44	0	37	0	68	2	–	–	–	–
	2009	0	19	3	0	41	0	–	–	–	–
	2010	0	0	–	0	16	7	1	12	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	1	–	0	5	–	0	1	–	4
Unidentified diving duck	2008	0	0	1	0	0	0	–	–	–	–
	2009	0	2	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
LOONS											
Red-throated Loon	2008	0	0	0	0	1	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	1	–	–
	2011	0	0	–	0	2	–	0	0	–	4
	2012	0	0	–	0	0	–	0	0	–	0
Pacific Loon	2008	0	1	27	0	33	3	–	–	–	–
	2009	0	24	22	0	181	1	–	–	–	–
	2010	0	11	–	0	6	0	0	2	–	–

Appendix B. Continued.

		Study area/season									
		Klondike			Burger			Statoil			Hanna Shoal
Species-group/ species	Period/ year	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Sep
Pacific Loon (cont.)	2011	0	0	–	0	24	–	0	1	–	30
	2012	0	0	–	0	32	–	0	1	–	12
Yellow-billed Loon	2008	0	3	1	0	2	0	–	–	–	–
	2009	0	9	1	0	24	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	8	–	0	0	–	8
	2012	0	0	–	0	0	0	0	0	–	2
Unidentified loon	2008	0	0	1	0	22	0	–	–	–	–
	2009	0	6	5	0	30	0	–	–	–	–
	2010	0	0	–	0	0	0	0	4	–	–
	2011	0	0	–	0	17	–	0	0	–	19
	2012	0	0	–	0	0	0	0	0	–	0
TUBENOSES											
Northern Fulmar	2008	65	141	38	6	8	8	–	–	–	–
	2009	115	52	5	141	34	22	–	–	–	–
	2010	17	28	–	29	10	1	10	22	–	–
	2011	30	8	–	14	0	–	9	6	–	15
	2012	17	15	–	43	6	–	48	7	–	64
Short-tailed Shearwater	2008	4	286	271	0	199	54	–	–	–	–
	2009	22	11,946	313	252	331	66	–	–	–	–
	2010	8	393	–	8	426	5	150	341	–	–
	2011	13	704	–	132	164	–	2	155	–	1,817
	2012	121	164	–	268	94	–	539	28	–	1,225

Appendix B. Continued.

		Study area/season									
		Klondike			Burger			Statoil			Hanna Shoal
Species-group/ species	Period/ year	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Sep
Unidentified procellariid	2008	0	0	25	0	0	1	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
SHOREBIRDS											
Unidentified (*Pluvialis*) plover	2008	0	2	0	0	0	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
Pectoral Sandpiper	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	3	0	3	5	0	–	–	–	–
	2010	4	0	–	0	0	0	0	0	–	–
	2011	0	1	–	4	0	–	9	0	–	1
	2012	0	0	–	2	1	–	19	0	–	0
Long-billed Dowitcher	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	0	0	1	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0

Appendix B. Continued.

Species-group/ species	Period/ year	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct	Statoil Aug	Statoil Sep	Statoil Sep/Oct	Hanna Shoal Sep
Red-necked Phalarope	2008	0	20	69	0	59	0	–	–	–	–
	2009	37	10	2	201	106	4	–	–	–	–
	2010	1	90	–	4	31	0	12	91	–	–
	2011	0	12	–	16	9	–	57	4	–	47
	2012	4	0	–	13	2	–	12	1	–	4
Red Phalarope	2008	5	5	1	0	1	0	–	–	–	–
	2009	3	0	2	15	32	1	–	–	–	–
	2010	21	5	–	0	32	5	0	42	–	–
	2011	0	0	–	9	0	–	0	0	–	1
	2012	2	1	–	2	1	–	32	9	–	15
Unidentified phalarope	2008	0	74	10	0	85	0	–	–	–	–
	2009	55	0	9	72	51	4	–	–	–	–
	2010	30	169	–	1	30	0	10	42	–	–
	2011	5	0	–	3	9	–	0	1	–	25
	2012	0	1	–	53	2	–	47	5	–	1
Unidentified shorebird—small	2008	0	0	0	0	0	0	–	–	–	–
	2009	1	2	0	0	17	0	–	–	–	–
	2010	6	1	–	0	0	0	3	0	–	–
	2011	3	6	–	2	0	–	5	3	–	18
	2012	0	0	–	0	0	–	0	0	–	1
Unid. shorebird—medium	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	1	0	0	10	0	–	–	–	–

Appendix B. Continued.

Species-group/ species	Period/ year	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct	Statoil Aug	Statoil Sep	Statoil Sep/Oct	Hanna Shoal Sep
Unid. shorebird—medium (cont.)	2010	0	0	–	0	0	0	0	0	0	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
LARIDS & JAEGERS											
Black-legged Kittiwake	2008	99	47	117	14	129	17	–	–	–	–
	2009	9	296	101	16	266	22	–	–	–	–
	2010	17	135	–	13	56	0	13	76	–	–
	2011	1	15	–	3	90	–	3	30	–	384
	2012	7	48	–	8	63	–	9	54	–	304
Ivory Gull	2008	0	0	0	0	0	2	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	1
	2012	0	0	–	0	0	–	0	0	–	2
Sabine's Gull	2008	9	92	5	2	0	0	–	–	–	–
	2009	0	1	2	0	0	2	–	–	–	–
	2010	1	21	–	1	1	0	5	0	–	–
	2011	0	0	–	1	0	–	0	0	–	1
	2012	3	0	–	2	0	–	27	0	–	3
Ross's Gull	2008	0	0	0	0	0	127	–	–	–	–
	2009	0	0	0	0	0	48	–	–	–	–
	2010	0	0	–	0	0	28	0	0	–	–

Appendix B. Continued.

Species-group/ species	Period/ year	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct	Statoil Aug	Statoil Sep	Statoil Sep/Oct	Hanna Shoal Sep
Ross's Gull (cont.)	2011	0	0	–	0	20	–	0	0	–	135
	2012	0	0	–	0	1	–	0	0	–	60
Herring Gull	2008	1	0	18	0	0	1	–	–	–	–
	2009	0	10	0	4	2	0	–	–	–	–
	2010	0	0	–	0	1	0	0	1	–	–
	2011	0	0	–	0	0	–	0	0	–	5
Herring Gull (cont.)	2012	0	0	–	0	0	–	0	0	–	0
Glaucous Gull	2008	11	13	70	6	33	19	–	–	–	–
	2009	0	23	49	7	65	54	–	–	–	–
	2010	2	11	–	4	12	15	3	11	–	–
	2011	0	4	–	1	8	–	2	13	–	86
	2012	0	15	–	0	44	–	9	1	–	82
Unidentified gull—small	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	0	3	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
Unidentified gull—large	2008	0	0	0	0	1	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0

Appendix B. Continued.

Species-group/ species	Period/ year	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct	Statoil Aug	Statoil Sep	Statoil Sep/Oct	Hanna Shoal Sep
Unidentified gull	2008	0	0	0	0	0	0	–	–	–	–
	2009	2	0	3	0	1	11	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
Arctic Tern	2008	0	24	0	0	0	0	–	–	–	–
	2009	0	0	0	1	2	0	–	–	–	–
	2010	0	29	–	1	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	1
Arctic Tern (cont.)	2012	0	0	–	14	0	–	0	0	–	0
Pomarine Jaeger	2008	32	12	1	3	3	0	–	–	–	–
	2009	6	23	0	10	1	0	–	–	–	–
	2010	1	14	–	5	1	0	2	3	–	–
	2011	0	1	–	1	2	–	0	1	–	7
	2012	0	0	–	0	0	–	0	0	–	0
Parasitic Jaeger	2008	4	2	0	1	0	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	1	0	0	0	–	–
	2011	0	1	–	0	0	–	2	0	–	1
	2012	1	0	–	0	0	–	1	0	–	–
Long-tailed Jaeger	2008	0	0	0	0	0	0	–	–	–	–
	2009	1	0	0	2	0	0	–	–	–	–
	2010	2	0	–	0	1	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	1	0	–	0	0	–	1	0	–	0

Appendix B. Continued.

Species-group/ species	Period/ year	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct	Statoil Aug	Statoil Sep	Statoil Sep/Oct	Hanna Shoal Sep
Unidentified jaeger	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	1	0	0	1	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
ALCIDS											
Dovekie	2008	2	0	1	0	0	2	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
Dovekie (cont.)	2010	0	0	–	0	0	1	0	1	–	–
	2011	0	0	–	0	0	–	0	0	–	1
	2012	1	0	–	0	0	–	0	0	–	0
Common Murre	2008	13	0	11	0	0	0	–	–	–	–
	2009	0	8	3	0	3	14	–	–	–	–
	2010	0	7	–	0	2	0	0	1	–	–
	2011	8	44	–	1	11	–	1	8	–	79
	2012	5	2	–	1	27	–	0	1	–	17
Thick-billed Murre	2008	228	14	3	3	0	1	–	–	–	–
	2009	64	338	16	17	27	15	–	–	–	–
	2010	115	97	–	24	16	3	25	22	–	–
	2011	87	538	–	30	22	–	16	31	–	839
	2012	55	75	–	46	257	–	5	1	–	252
Unidentified murre	2008	1	9	4	0	2	14	–	–	–	–
	2009	0	35	7	0	8	1	–	–	–	–

Appendix B. Continued.

Species-group/ species	Period/ year	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct	Statoil Aug	Statoil Sep	Statoil Sep/Oct	Hanna Shoal Sep
Unidentified murre (cont.)	2010	0	3	–	0	3	0	1	1	–	–
	2011	19	29	–	1	7	–	1	6	–	61
	2012	0	4	–	2	4	–	2	0	–	32
Black Guillemot	2008	9	0	0	2	0	6	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	1	0	0	1	0	–	–
	2011	0	0	–	1	0	–	0	0	–	4
	2012	0	2	–	0	1	–	0	0	–	4
Pigeon Guillemot	2008	4	0	0	1	0	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
Pigeon Guillemot (cont.)	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
Unidentified guillemot	2008	0	0	0	0	0	1	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2011	0	0	–	0	0	–	0	0	–	0
Kittlitz's Murrelet	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	1	0	0	0	6	–	–	–	–
	2010	2	1	–	0	1	0	1	0	–	–
	2011	1	5	–	0	14	–	0	5	–	35
	2012	1	0	–	0	2	–	0	0	–	9

Appendix B. Continued.

		Study area/season									
		Klondike			Burger			Statoil			Hanna Shoal
Species-group/ species	Period/ year	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Sep
Ancient Murrelet	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	18	–	0	16	28	0	41	–	–
	2011	0	0	–	0	4	–	0	4	–	12
	2012	0	29	–	0	12	–	0	1	–	73
Unidentified murrelet	2008	0	0	5	0	0	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	4	3	–	0	0	0	0	0	–	–
	2011	0	0	–	0	10	–	0	0	–	21
	2012	0	0	–	0	0	–	0	0	–	0
Parakeet Auklet	2008	0	7	0	0	0	44	–	–	–	–
Parakeet Auklet (cont.)	2009	0	21	0	0	0	0	–	–	–	–
	2010	1	8	–	0	15	17	10	2	–	–
	2011	0	8	–	0	0	–	0	8	–	5
	2012	5	3	–	2	13	–	0	1	–	23
Least Auklet	2008	4	139	55	0	1	4	–	–	–	–
	2009	63	115	257	201	143	39	–	–	–	–
	2010	29	148	–	29	474	103	163	184	–	–
	2011	4	76	–	1	8	–	3	12	–	158
	2012	437	178	–	211	150	–	147	272	–	486
Crested Auklet	2008	179	128	959	0	1	34	–	–	–	–
	2009	394	3,139	1,455	4,566	5,082	16	–	–	–	–
	2010	639	1,380	–	806	976	1,011	383	1,243	–	–

Appendix B. Continued.

Species-group/ species	Period/ year	Klondike Aug	Klondike Sep	Klondike Sep/Oct	Burger Aug	Burger Sep	Burger Sep/Oct	Statoil Aug	Statoil Sep	Statoil Sep/Oct	Hanna Shoal Sep
Crested Auklet (cont.)	2011	182	595	–	145	729	–	1,062	1,786	–	4,865
	2012	892	276	–	2,298	562	–	184	591	–	1,983
Unidentified auklet	2008	1	22	66	0	0	1	–	–	–	–
	2009	8	52	11	11	26	0	–	–	–	–
	2010	8	18	–	1	40	1	3	2	–	–
	2011	5	10	–	0	3	–	0	3	–	42
	2012	9	0	–	0	0	–	1	3	–	5
Horned Puffin	2008	2	0	0	2	0	0	–	–	–	–
	2009	4	2	0	0	0	0	–	–	–	–
	2010	4	0	–	3	1	0	1	1	–	–
	2011	4	0	–	0	0	–	2	1	–	4
	2012	2	0	–	1	0	–	2	0	–	1
Tufted Puffin	2008	8	0	1	0	0	0	–	–	–	–
	2009	1	0	0	0	0	0	–	–	–	–
	2010	1	0	–	0	1	0	2	0	–	–
	2011	0	0	–	0	0	–	1	0	–	0
	2012	1	0	–	1	0	–	1	0	–	0
Unidentified puffin	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	1	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0

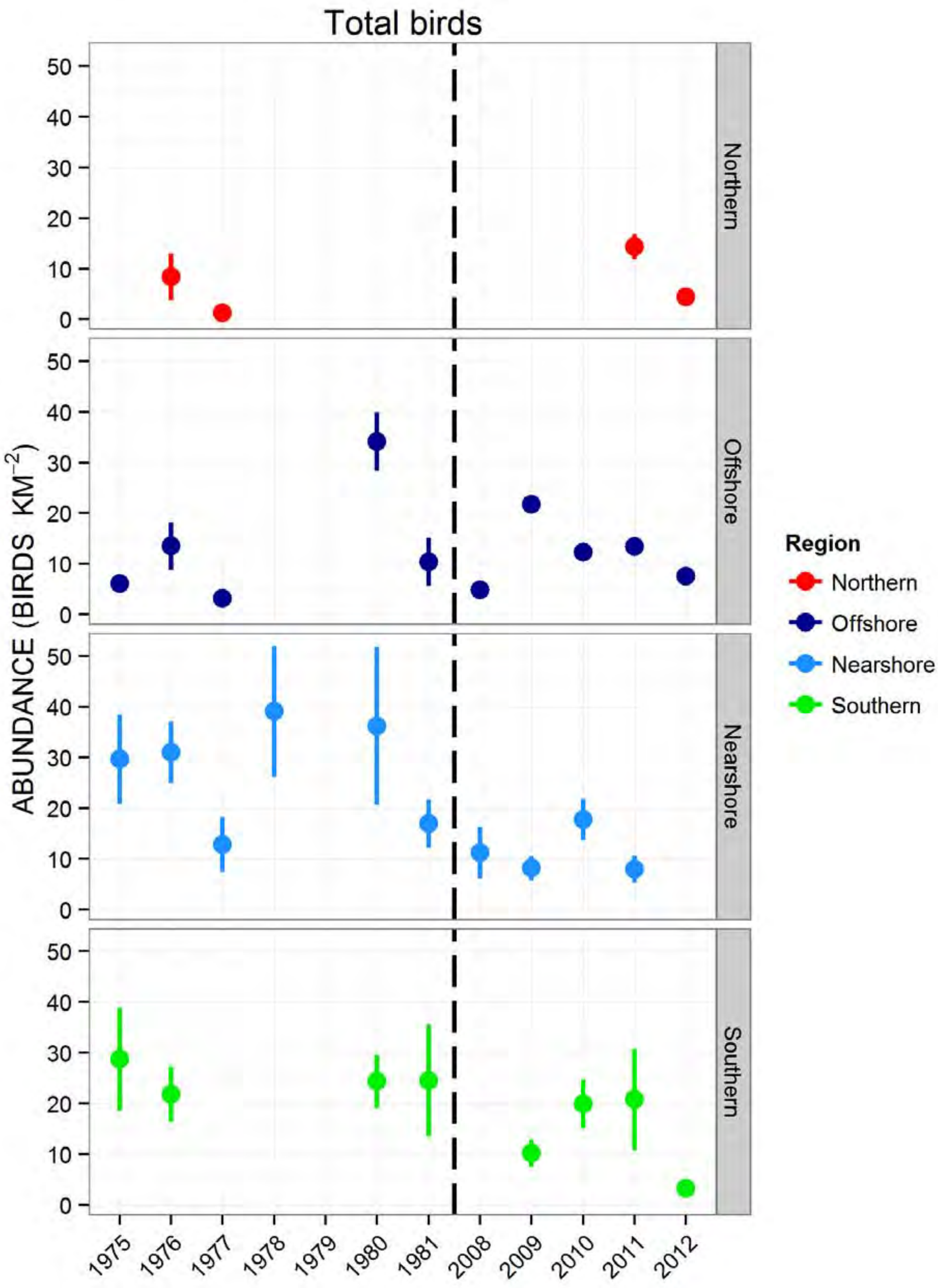
Appendix B. Continued.

Species-group/ species	Period/ year	Study area/season									
		Klondike			Burger			Statoil			Hanna Shoal
		Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Sep
Unidentified alcid – small	2008	0	0	1	0	0	6	–	–	–	–
	2009	0	0	10	0	0	14	–	–	–	–
	2010	0	0	–	0	0	11	0	0	–	–
	2011	0	0	–	0	4	–	0	2	–	8
	2012	0	0	–	0	0	–	0	1	–	15
Unidentified alcid	2008	0	2	8	0	6	1	–	–	–	–
	2009	0	18	0	0	11	0	–	–	–	–
	2010	19	7	–	0	3	0	1	2	–	–
	2011	0	1	–	0	1	–	0	0	–	5
	2012	1	0	–	0	2	–	0	0	–	0
OWLS											
Short-eared Owl	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	0	0	1	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
Short-eared Owl (cont.)	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0
PASSERINES											
American Pipit	2008	0	0	0	0	1	0	–	–	–	–
	2009	0	0	0	0	2	0	–	–	–	–
	2010	0	0	–	0	0	0	0	0	–	–
	2011	0	0	–	0	0	–	0	0	–	0
	2012	0	0	–	0	0	–	0	0	–	0

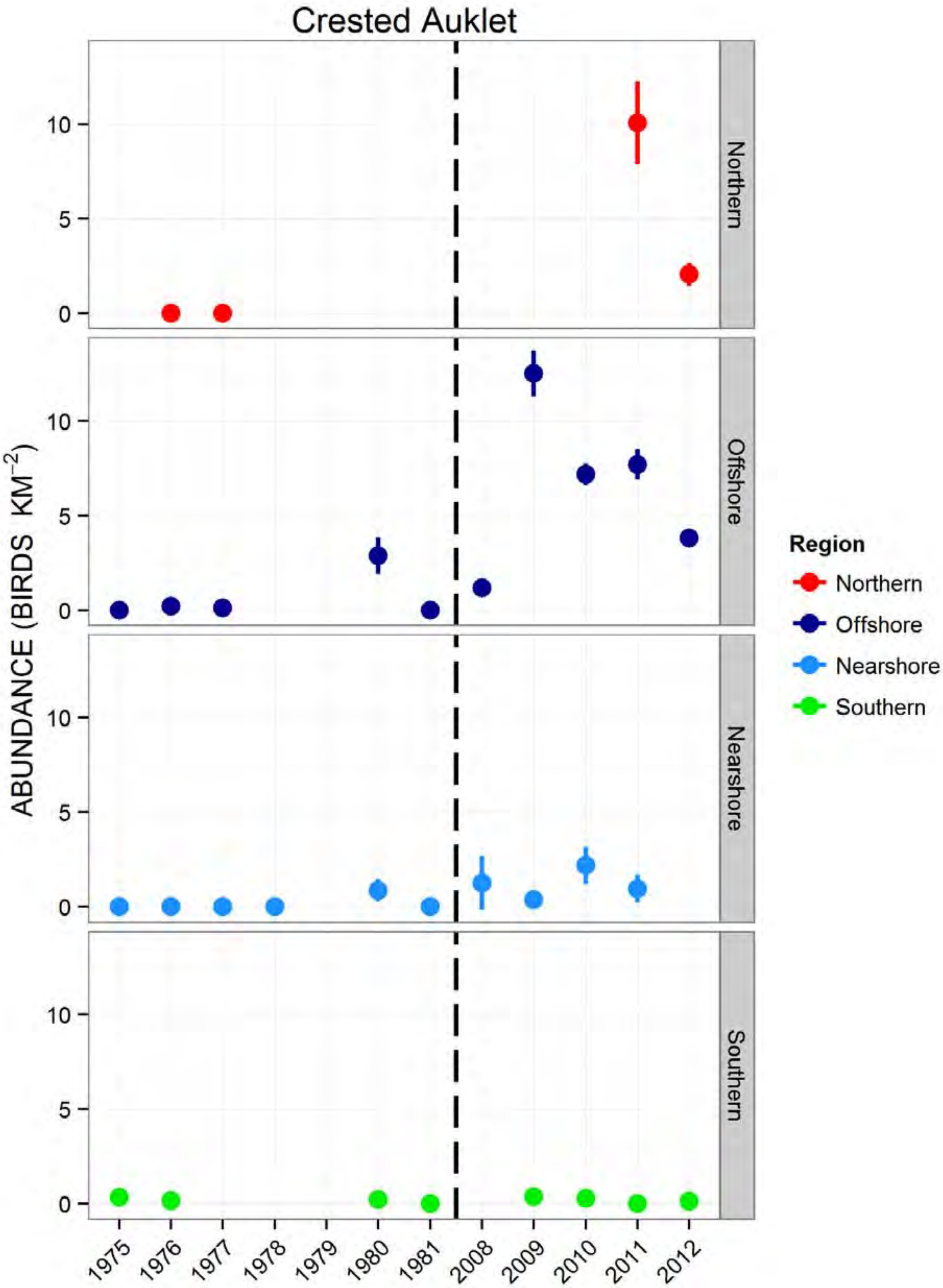
Appendix B. Continued.

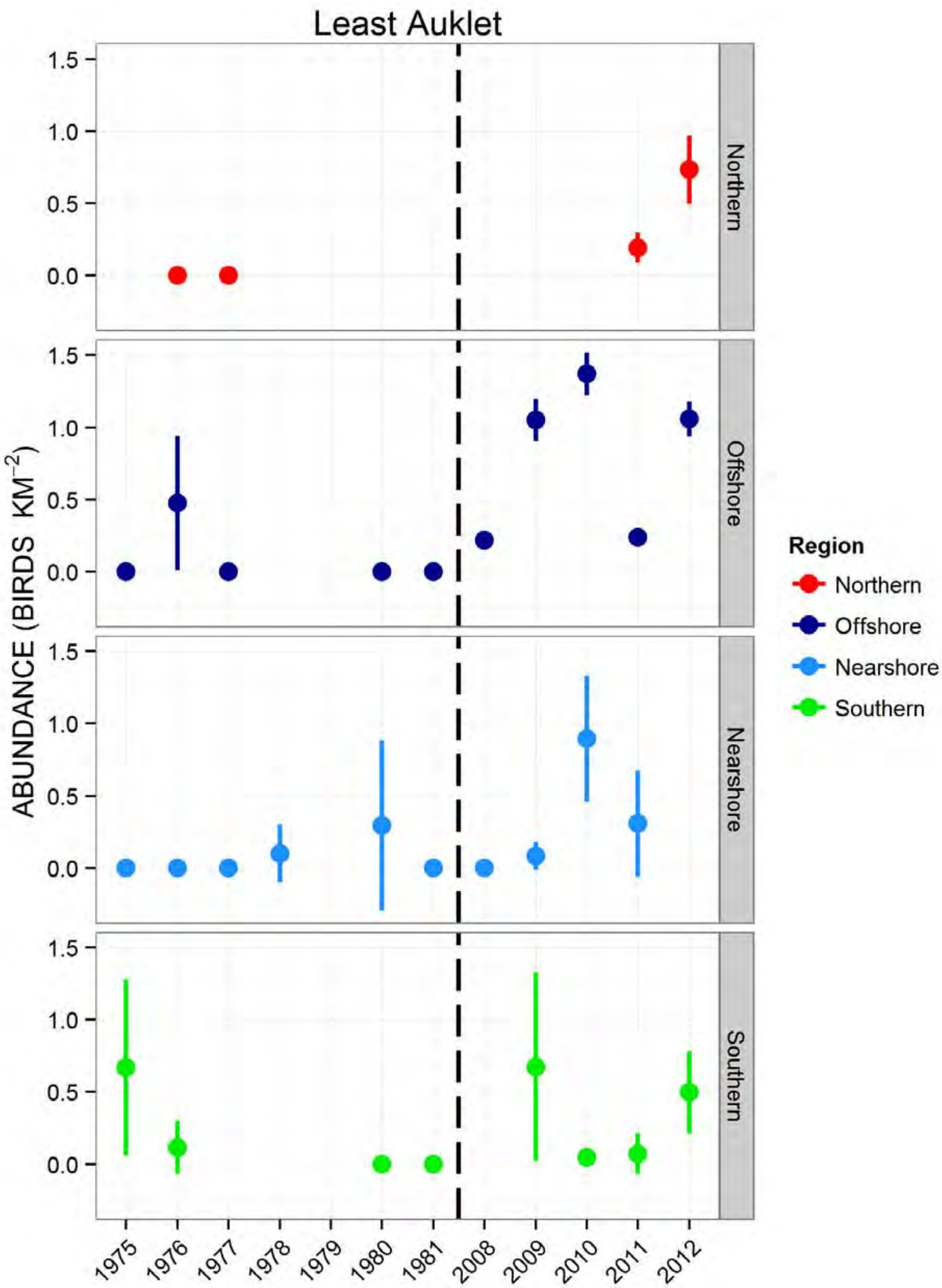
Species-group/ species	Period/ year	Study area/season									
		Klondike			Burger			Statoil			Hanna Shoal
		Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Aug	Sep	Sep/Oct	Sep
Snow Bunting	2008	0	0	0	0	0	0	–	–	–	–
	2009	0	0	0	0	0	0	–	–	–	–
	2010	0	0	–	0	0	0	0	1	–	–
	2011	0	0	–	0	0	–	0	0	–	4
	2012	0	0	–	0	0	–	0	0	–	0

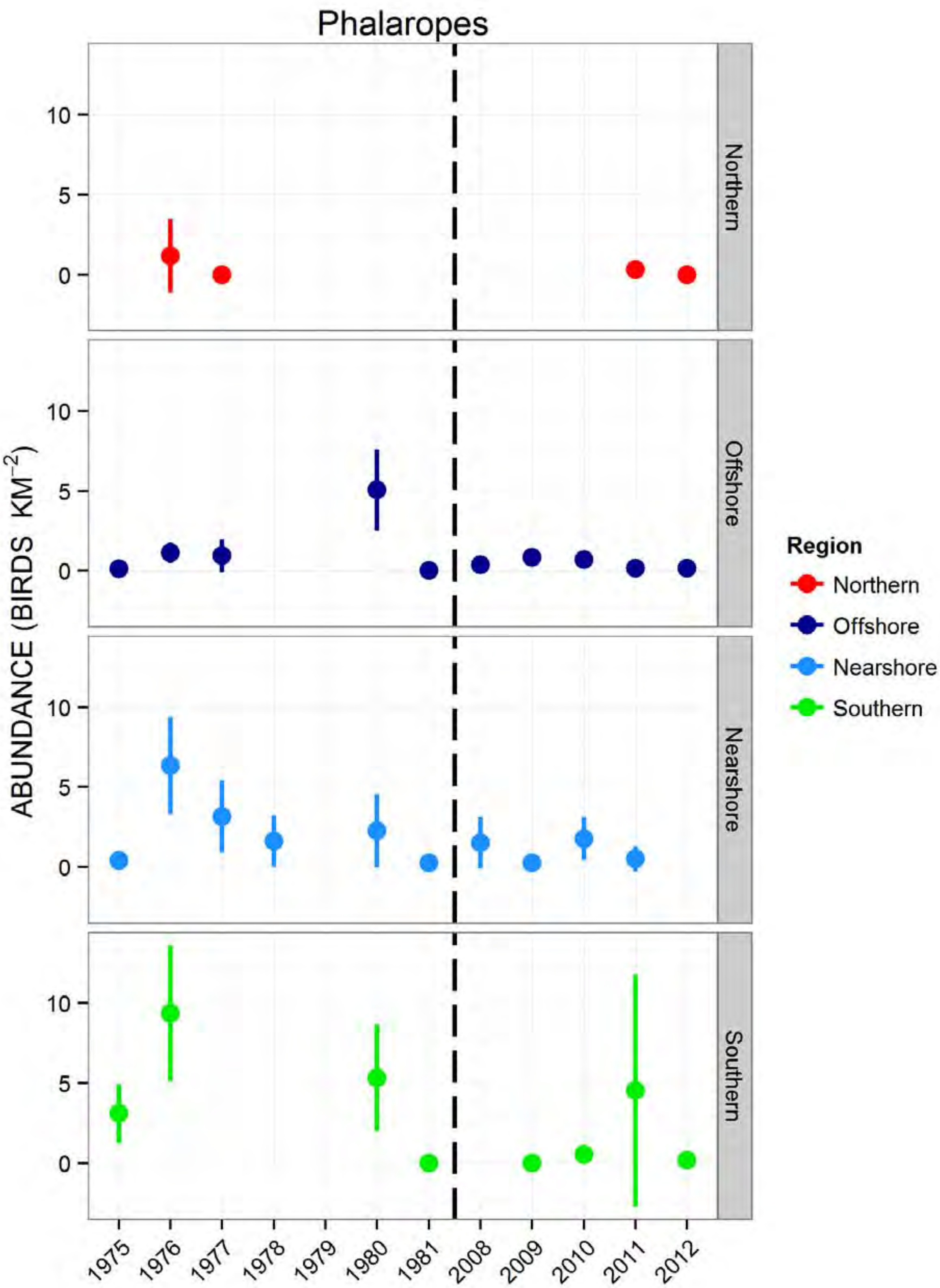
Appendix C. Mean abundance (birds/km^2) of total seabirds and 8 species of seabirds in 4 strata of the eastern Chukchi Sea, 1975–2011. Error bars represent 95% confidence intervals.



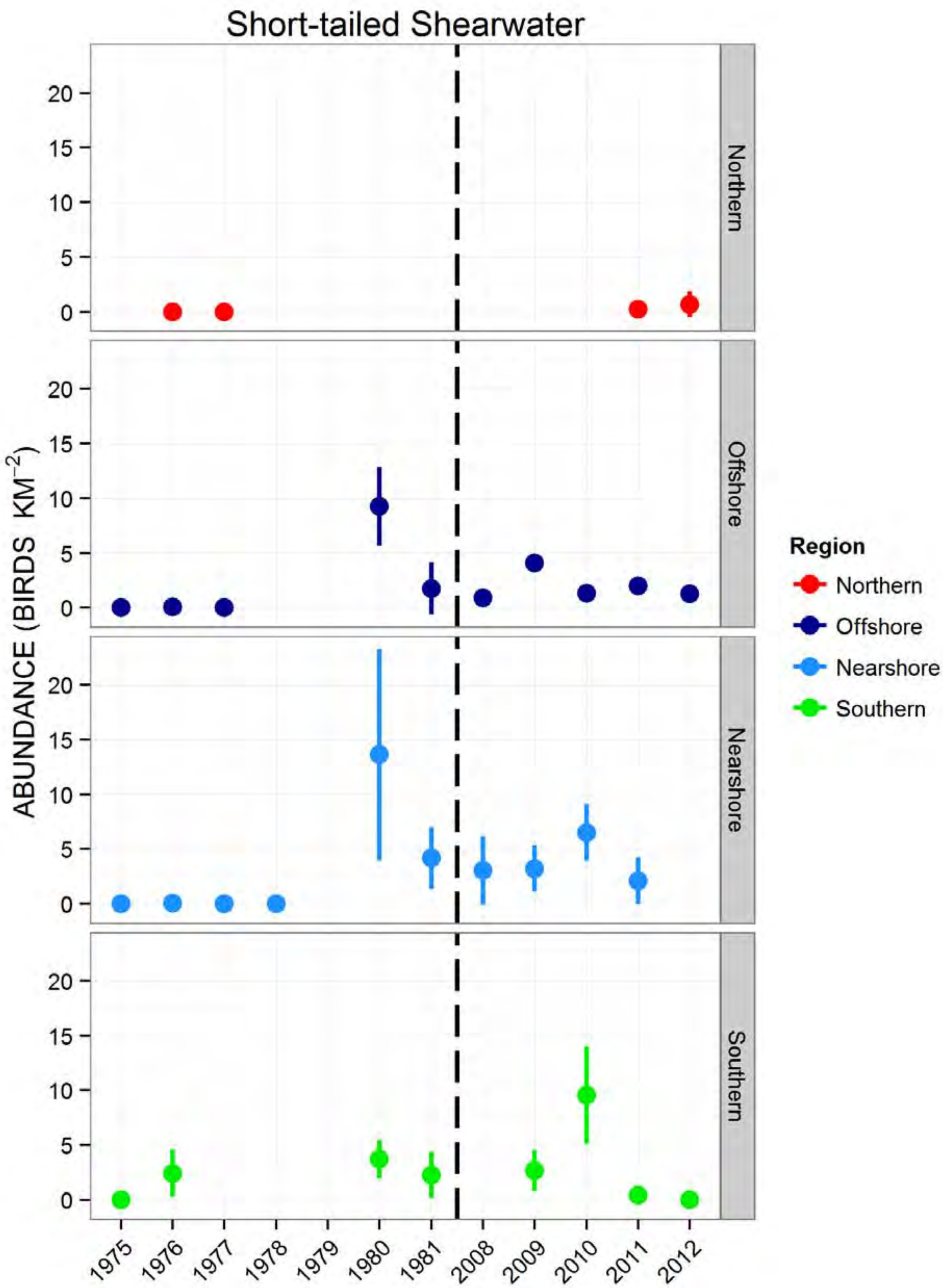
Total birds
ABUNDANCE (BIRDS KM^{-2})
Northern
Offshore
Nearshore
Southern
0
10
20
30
40
50
1975
1976
1977
1978
1979
1980
1981
2008
2009
2010
2011
2012
Region
Northern
Offshore
Nearshore
Southern


Crested Auklet
ABUNDANCE (BIRDS KM^-2)
Northern
Offshore
Nearshore
Southern
Region
Northern
Offshore
Nearshore
Southern
0
5
10
1975
1976
1977
1978
1979
1980
1981
2008
2009
2010
2011
2012

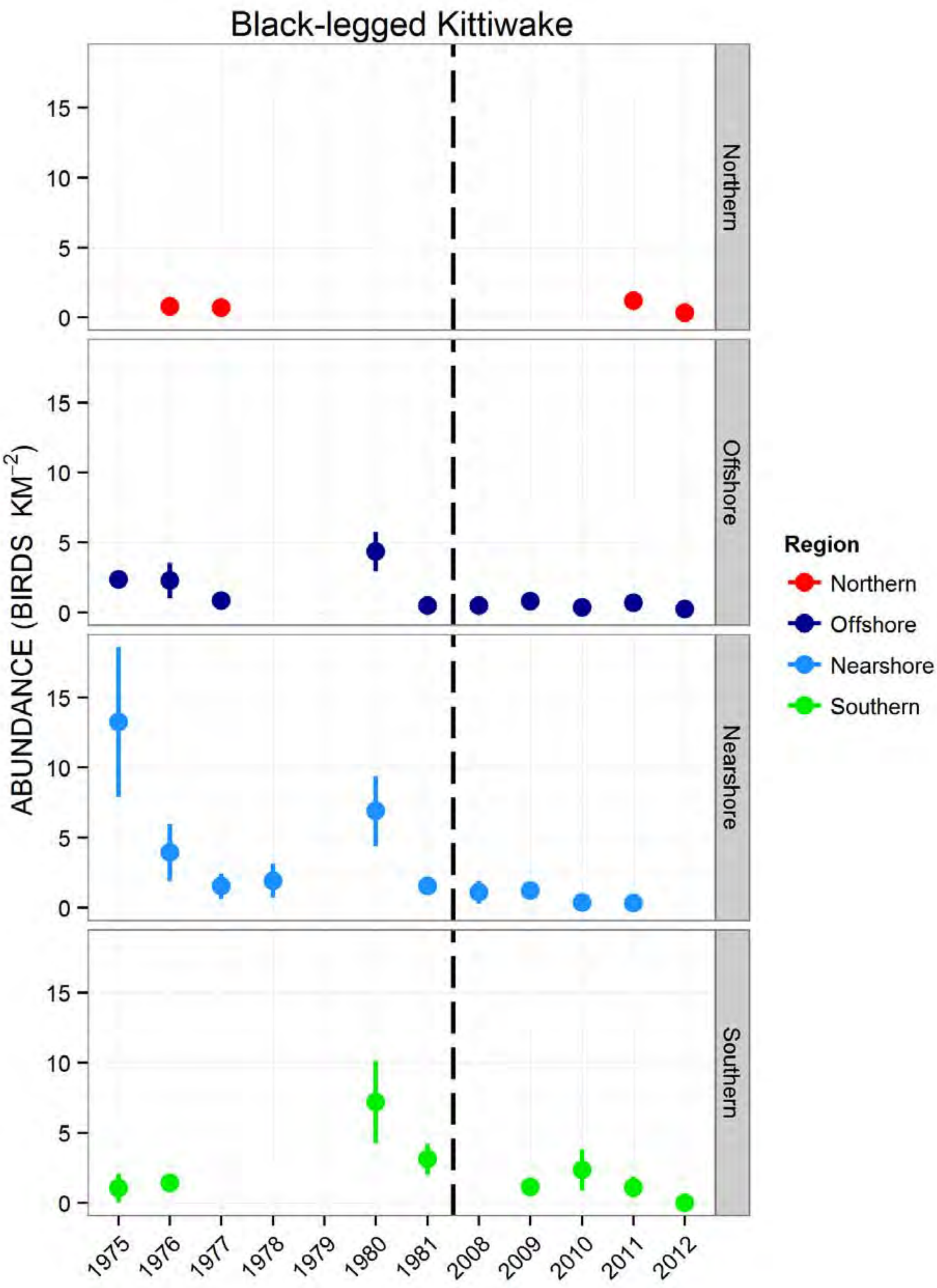

Least Auklet
ABUNDANCE (BIRDS KM^{-2})
1.5
1.0
0.5
0.0
Northern
Offshore
Nearshore
Southern
Region
Northern
Offshore
Nearshore
Southern
1975
1976
1977
1978
1979
1980
1981
2008
2009
2010
2011
2012

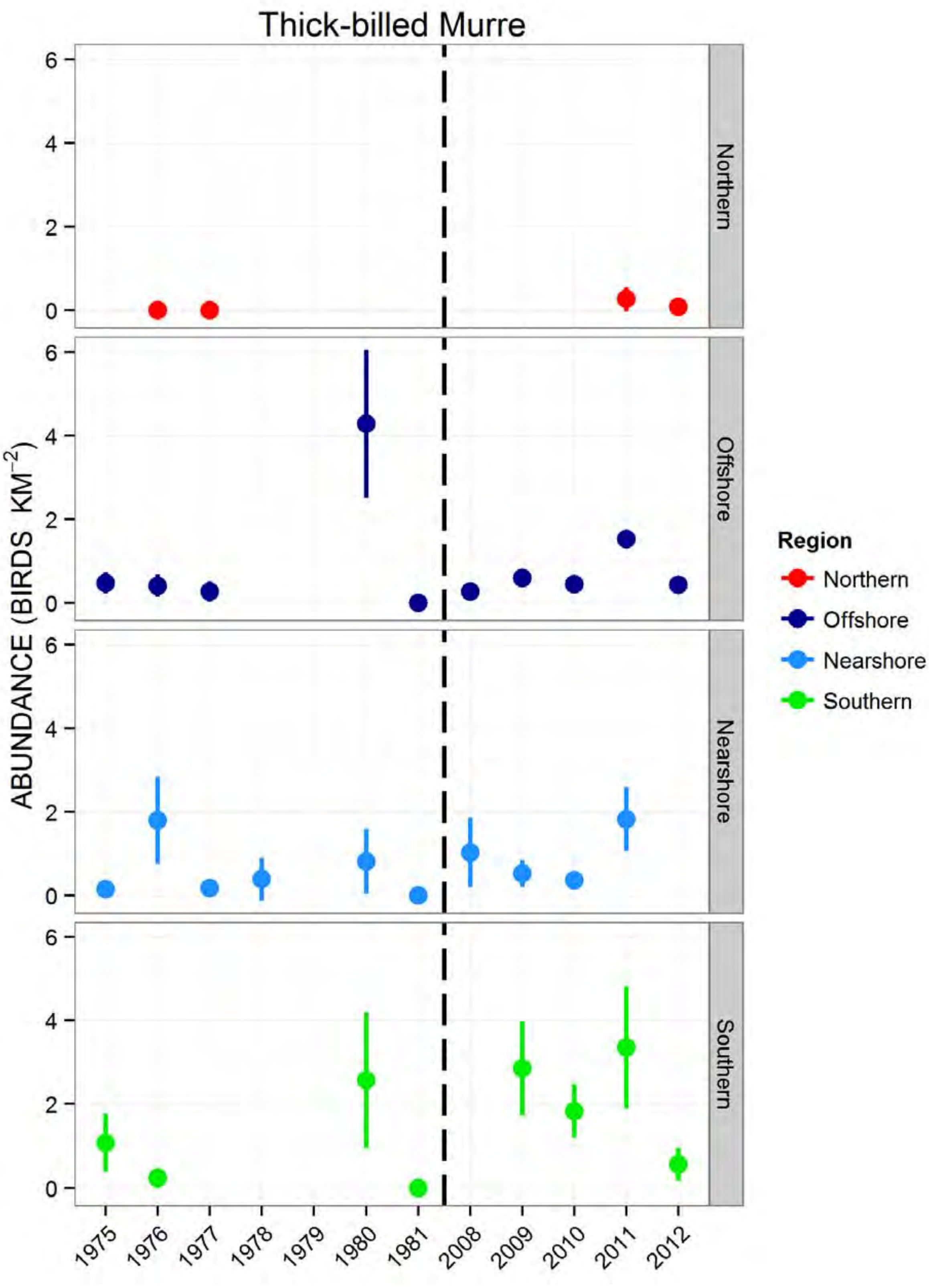


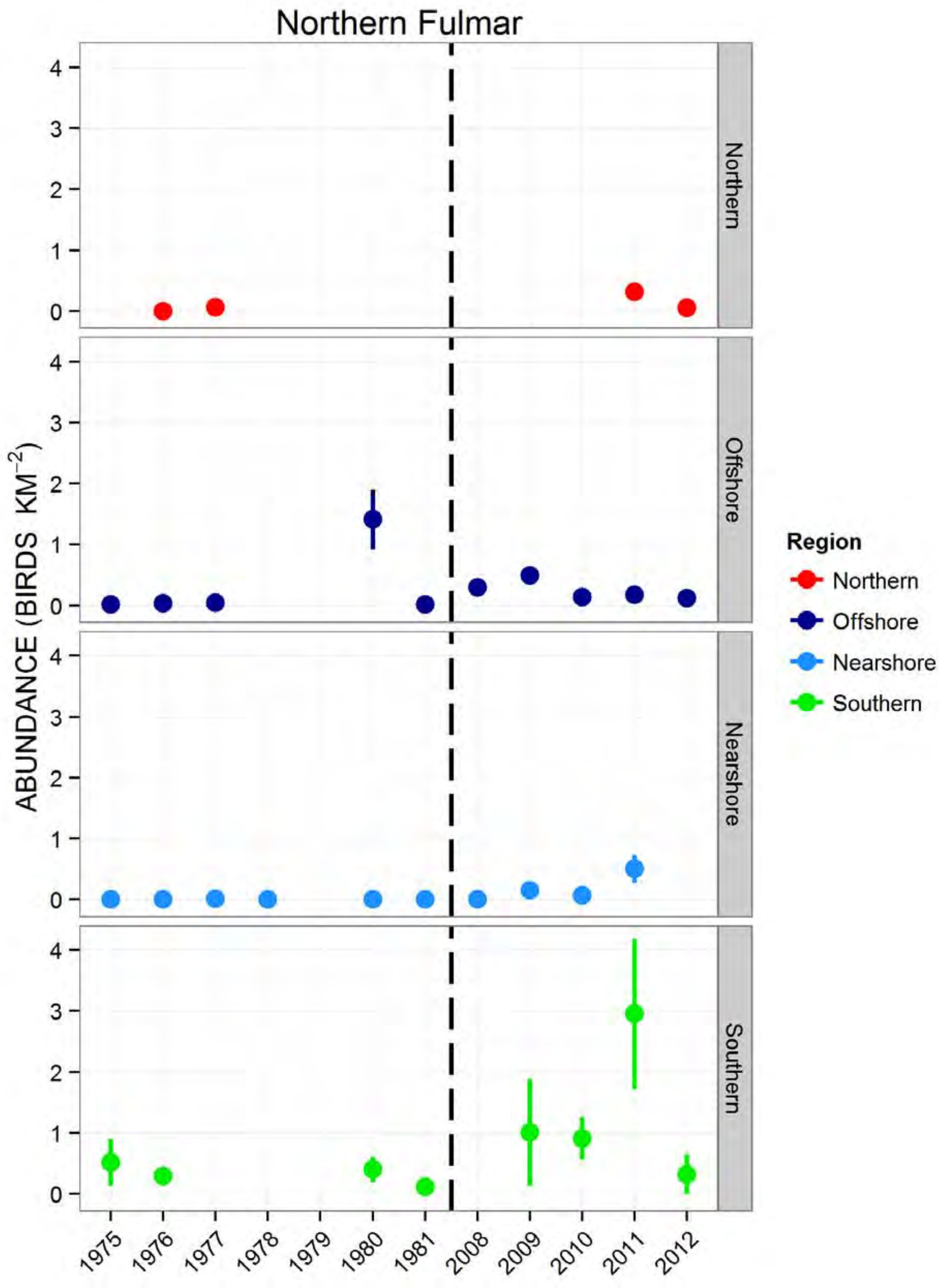
Phalaropes
ABUNDANCE (BIRDS KM^-2)
10
5
0
Northern
Offshore
Nearshore
Southern
1975
1976
1977
1978
1979
1980
1981
2008
2009
2010
2011
2012
Region
Northern
Offshore
Nearshore
Southern



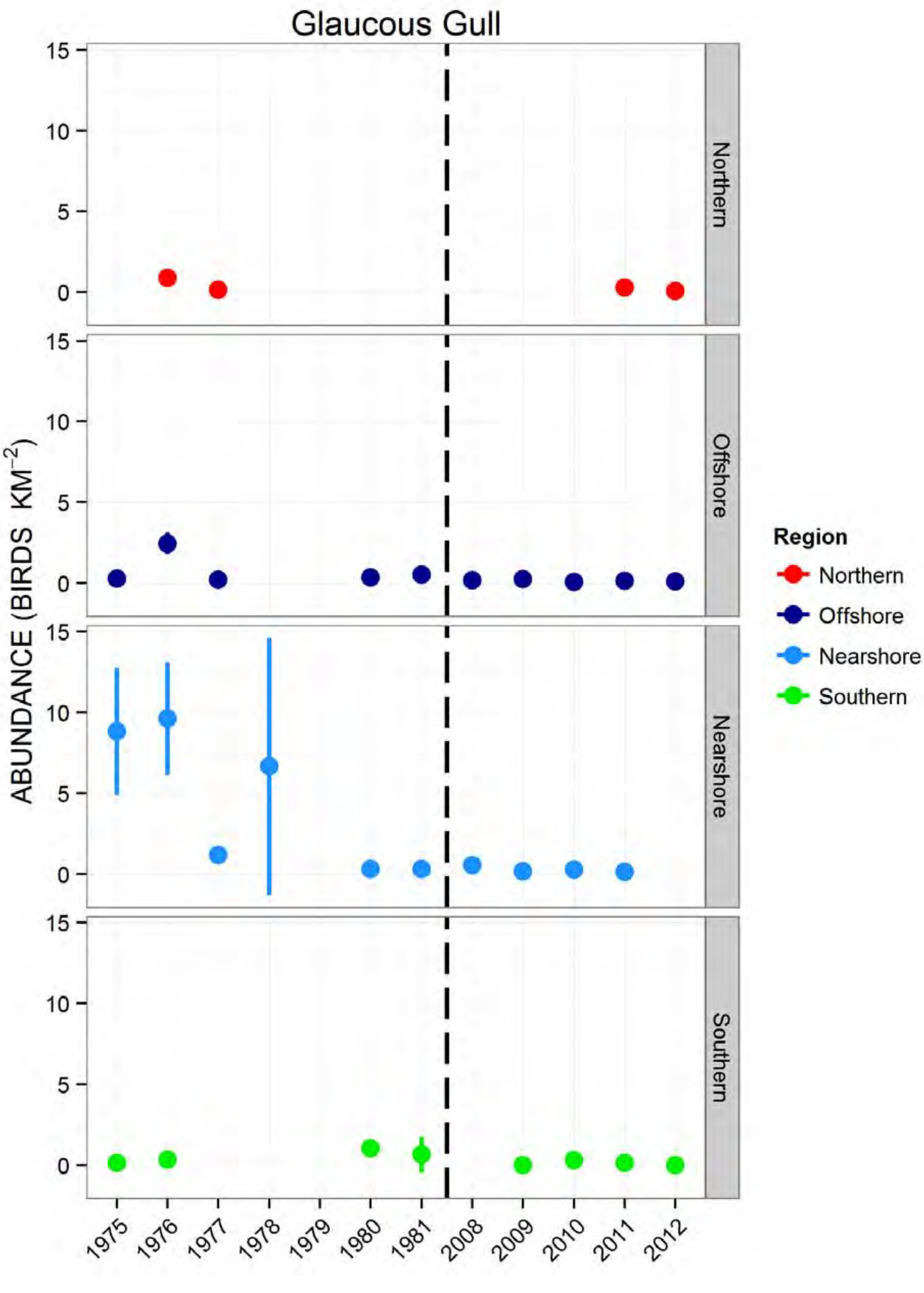
Short-tailed Shearwater
ABUNDANCE (BIRDS KM^{-2})
20
15
10
5
0
Northern
Offshore
Nearshore
Southern
1975
1976
1977
1978
1979
1980
1981
2008
2009
2010
2011
2012
Region
Northern
Offshore
Nearshore
Southern


Black-legged Kittiwake
ABUNDANCE (BIRDS KM^{-2})
Northern
Offshore
Nearshore
Southern
Region
Northern
Offshore
Nearshore
Southern
0
5
10
15
1975
1976
1977
1978
1979
1980
1981
2008
2009
2010
2011
2012


Thick-billed Murre
ABUNDANCE (BIRDS KM^{-2})
Northern
Offshore
Nearshore
Southern
Region
Northern
Offshore
Nearshore
Southern
1975
1976
1977
1978
1979
1980
1981
2008
2009
2010
2011
2012



Northern Fulmar
ABUNDANCE (BIRDS KM^{-2})
Northern
Offshore
Nearshore
Southern
Region
Northern
Offshore
Nearshore
Southern
0
1
2
3
4
1975
1976
1977
1978
1979
1980
1981
2008
2009
2010
2011
2012


Glaucous Gull
ABUNDANCE (BIRDS KM^{-2})
15
10
5
0
Northern
Offshore
Nearshore
Southern
Region
Northern
Offshore
Nearshore
Southern
1975
1976
1977
1978
1979
1980
1981
2008
2009
2010
2011
2012