

Distribution and Community Characteristics of Staging Shorebirds on the Northern Coast of Alaska

AUDREY R. TAYLOR,¹ RICHARD B. LANCTOT,² ABBY N. POWELL,³ FALK HUETTMANN,⁴
DEBORA A. NIGRO⁵ and STEVEN J. KENDALL⁶

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ABSTRACT. Avian studies conducted in the 1970s on Alaska's Arctic Coastal Plain (ACP) indicated that coastal littoral habitats are important to Arctic-breeding shorebirds for staging prior to fall migration. However, relatively little recent, broad-scale, or quantitative information exists on shorebird use of staging areas in this region. To locate possible shorebird concentration areas in the littoral zone of the ACP, we conducted aerial surveys from the southwest end of Kasegaluk Lagoon on the Chukchi Sea to Demarcation Point on the Beaufort Sea during the summers of 2005–07. These surveys identified persistent within- and between-year concentrations of staging shorebirds at Peard Bay, Point Barrow/Elson Lagoon, Cape Simpson, and Smith Bay to Cape Halkett. Among river deltas in the Beaufort Sea, the Sagavanirktok and Kongakut deltas had large concentrations of staging shorebirds. We also collected data on shorebird community characteristics, staging phenology, and habitat use in 2005 and 2006 by conducting land-based surveys at six camps: Kasegaluk Lagoon, Peard Bay, Point Barrow/Elson Lagoon, Colville Delta, Sagavanirktok Delta, and Okpilak Delta. The shorebird community was more even and diverse (evenness E and Shannon Weiner H') along the Beaufort Sea compared to the Chukchi Sea and in 2005 versus 2006. Staging phenology varied by species and location and differed for several species from that reported in previous studies. Our results suggest the existence of three foraging habitat guilds among the shorebird species observed in this study: gravel beach, mudflat, and salt marsh/pond edge. A comparison to data collected in the mid-1970s suggests that these foraging associations are conserved through time. Results from this research will be useful to land managers for monitoring the effects of changing environmental conditions and human activity on shorebirds and their habitats in Arctic Alaska.

Key words: shorebird, postbreeding, staging, distribution, community composition, phenology, habitat selection, aerial survey, climate change, industrial development, Arctic Coastal Plain, Alaska

RÉSUMÉ. Des études aviaires réalisées dans les années 1970 sur la plaine côtière de l'Arctique en Alaska ont permis de constater que les habitats du littoral côtier revêtent de l'importance pour les oiseaux de rivage nicheurs de l'Arctique en halte migratoire avant la migration d'automne. Cependant, relativement peu d'information récente, à grande échelle ou quantitative existe à propos de l'utilisation que font les oiseaux de rivage des haltes migratoires de cette région. Afin de localiser des zones de concentration possibles d'oiseaux de rivage dans la région littorale de la plaine côtière de l'Arctique, nous avons effectué des levés aériens du sud-ouest de la lagune Kasegaluk dans la mer des Tchouktches jusqu'à Demarcation Point dans la mer de Beaufort au cours des étés allant de 2005 à 2007. Ces levés ont permis de repérer des concentrations durables d'oiseaux de rivage en halte migratoire au cours d'une même année ainsi que d'une année à l'autre à la baie Peard, à pointe Barrow et à la lagune Elson, au cap Simpson de même que de la baie Smith jusqu'au cap Halkett. Parmi les deltas de rivières de la mer de Beaufort, les deltas Sagavanirktok et Kongakut comptaient de fortes concentrations d'oiseaux de rivage en halte migratoire. Nous avons également recueilli des données sur les caractéristiques des populations d'oiseaux de rivage, sur la phénologie des haltes migratoires de même que sur l'utilisation des habitats en 2005 et en 2006 au moyen de levés terrestres effectués à six camps, soit celui de la lagune Kasegaluk, de la baie Peard, de la pointe Barrow et de la lagune Elson, du delta Colville, du delta Sagavanirktok et du delta Okpilak. La population d'oiseaux de rivage était plus homogène et diverse (homogénéité E et Shannon Weiner H') le long de la mer de Beaufort comparativement à la mer des Tchouktches, ainsi qu'en 2005 par rapport à 2006. La phénologie en halte migratoire variait selon les espèces et les emplacements, et différait pour plusieurs espèces

¹ Corresponding author: Department of Biology and Wildlife, 211 Irving I, University of Alaska Fairbanks, Fairbanks, Alaska 99775, USA; present address: U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Cascadia Field Station, Box 352100, School of Forest Resources, University of Washington, Seattle, Washington 98195, USA; ataylor@usgs.gov

² U.S. Fish and Wildlife Service, Migratory Bird Management, 1011 E. Tudor Road, MS 201, Anchorage, Alaska 99503, USA

³ U.S. Geological Survey, Alaska Cooperative Fish and Wildlife Research Unit and Institute of Arctic Biology, 209 Irving I, University of Alaska Fairbanks, Fairbanks, Alaska 99775, USA

⁴ EWHALE Lab, Institute of Arctic Biology, Department of Biology and Wildlife, University of Alaska Fairbanks, Fairbanks, Alaska 99775, USA

⁵ Bureau of Land Management, Arctic Field Office, 1150 University Avenue, Fairbanks, Alaska 99709, USA

⁶ U.S. Fish and Wildlife Service, Arctic National Wildlife Refuge, 101 12th Avenue, Room 236, Fairbanks, Alaska 99701, USA

de celles signalées dans le cadre d'études ultérieures. Nos résultats laissent croire à l'existence de trois guildes d'habitats de fourrage chez les espèces d'oiseaux de rivage observées dans cette étude : plage de gravier, vasière et marais salant ou bordure d'étang. La comparaison des données recueillies au milieu des années 1970 laisse entendre que ces associations de fourrage se sont conservées au fil du temps. Les résultats découlant de cette recherche seront utiles aux gestionnaires de terres dans le cadre de la surveillance des effets des conditions environnementales changeantes et de l'activité humaine sur les oiseaux de rivage et leurs habitats de l'Arctique alaskien.

Mots clés : oiseau de rivage, post-reproduction, halte migratoire, répartition, composition de la population, phénologie, sélection de l'habitat, levé aérien, changement climatique, développement industriel, plaine côtière de l'Arctique, Alaska

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INTRODUCTION

At least 20 species of shorebirds stage in littoral habitats on the northern coast of Alaska (the Arctic Coastal Plain, or ACP), where they acquire the fat reserves necessary for long-distance flights prior to fall migration (Connors, 1984). Although there is a considerable body of literature on the stopover ecology of shorebirds during migration (e.g., Holmgren et al., 1993; Skagen and Knopf, 1994; Lyons and Haig, 1995), less research has been conducted on their staging prior to migration. Numerous studies have addressed shorebird use of ACP littoral habitats, but many of these are relatively dated, somewhat anecdotal in nature, or focused on a single or a few study areas, and the data are not readily available in the published literature (e.g., Johnson, 1978; Spindler, 1979; Lehnhausen and Quinlan, 1981; Gill et al., 1985; Andres, 1989; Johnson et al., 1993). In addition, few studies have been designed specifically to examine the distribution of small shorebird species: most were ancillary to studies of larger, more obvious species (such as waterfowl). Much of what is known regarding shorebird populations staging on the coast of the ACP resulted from research done during the Outer Continental Shelf Environmental Assessment Program (OCSEAP) in the mid-1970s (Connors et al., 1979, 1981; Connors, 1984). These studies found that shorebirds moved from tundra breeding sites to coastal littoral staging areas as the summer progressed. Birds tended to aggregate in littoral areas at that time and were found in greater densities than during the breeding season, underscoring the importance of coastal zones in the life cycles of migratory shorebirds in northern Alaska.

Various studies have identified shorebirds as an avian group highly susceptible to human-induced disturbance (Burger, 1981; Smit and Visser, 1993; Burger et al., 2007). Global populations of shorebirds are in decline (Brown et al., 2001; International Wader Study Group, 2003), including 11 species that regularly breed and stage on the ACP. Nine of these have been classed as "highly imperiled" or "of high concern" at the global or North American level (U.S. Shorebird Conservation Plan, 2004). The International Wader Study Group (2003:10) concluded that "reduced suitability of staging sites [has] major implications for the survival and reproduction of [long-distance] migrants," and that "virtual habitat loss" can occur...as a consequence of poor management such as that which arises from

unsustainable exploitation of natural resources, disturbance, and other local perturbations." Industrial development is increasing in scope and intensity across the Arctic (Gilders and Cronin, 2000; National Research Council, 2003), creating the potential for disturbance, habitat modification, and contaminant spills to affect a large segment of a species' population, especially when species become aggregated in coastal areas after the breeding season. In addition, increases in surface air temperature leading to rapid ecological change are believed to be amplified at higher latitudes (Serreze et al., 2000; IPCC, 2001; Holland and Bitz, 2003). Accelerated ecological change in a warming Arctic may add to the potential effects of industrial development through processes such as sea level rise, coastal erosion and inundation, and altered sediment transport and deposition patterns (ACIA, 2005). These processes may modify the spatial or temporal availability of littoral habitats suitable for staging shorebirds. Changes in the timing of insect emergence patterns could also alter the phenology of the staging period for postbreeding shorebirds (Tulp and Schekermann, 2008; Van der Jeugd et al., 2009).

Information on current distribution, relative abundance, phenology, and habitat preferences is critical for predicting the effects of changing Arctic conditions on the location and persistence of staging shorebird aggregations on the northern Alaska coast (Serreze et al., 2000; McCarty, 2001; Hinzman et al., 2005; Maclean et al., 2008). Also, comparing current shorebird diversity and abundance with previous shorebird community data could aid in setting conservation targets and priorities if maintenance of historic species composition and diversity patterns is a goal (Stein and Davis, 2000). Documenting habitat use and selection by postbreeding shorebirds is important for understanding large-scale patterns of distribution and abundance, and for predicting effects of ecological change that may vary by habitat type. Our overall objective was to document two sets of data for the postbreeding staging period on the ACP coast: (1) geographic distribution of shorebirds on a large scale, including temporal variation, and (2) community characteristics, species composition, phenology, and habitat selection for the staging shorebird communities at six specific sites on the northern Alaska coast. We also compared our data to previous work conducted between 1975 and 1993 to determine what changes may have already occurred in postbreeding shorebird ecology on the northern Alaska coast.

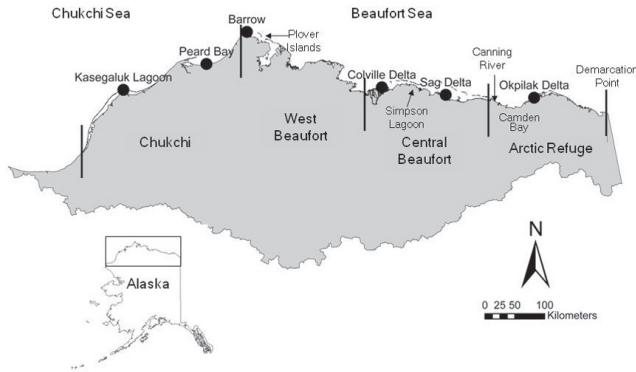


FIG. 1. Aerial survey regions and ground camp locations, 2005–07. Dark vertical lines indicate boundaries of regions. The outermost lines show the western (SW end of Kasegaluk Lagoon) and eastern boundaries (Demarcation Point) of the study area. Barrow = Point Barrow/Elson Lagoon; Sag = Sagavanirktok.

STUDY AREA

Our study area was the coastline and major river deltas of the Chukchi and Beaufort seas between the southwest end of Kasegaluk Lagoon and the Alaska-Canada border at Demarcation Point (Fig. 1). Littoral habitats along this portion of the ACP include brackish water mudflats and marsh; low-lying saline tundra; mud and gravel shores of sloughs, river deltas, and lagoons; and gravel mainland and barrier island beaches. Tidal influence in the absence of storms is less than 30 cm vertical fluctuation, but wind-driven tidal intrusion is common during the ice-free period (July–September), resulting in brackish habitats well above normal high tide lines (Connors et al., 1979).

We flew aerial surveys across the study area to collect information on geographic distribution of staging shorebirds. We also established six ground camps (Fig. 1), located at Kasegaluk Lagoon (70.301° N, 161.888° W; operated 2006 only), Peard Bay (70.812° N, 158.323° W), Point Barrow/Elson Lagoon (71.290° N, 156.788° W), Colville Delta (70.473° N, 150.564° W), Sagavanirktok Delta (70.291° N, 148.202° W in 2005; moved to 70.246° N, 147.832° W in 2006), and Okpilak Delta (70.080° N, 144.011° W). The ground camp locations were selected opportunistically for (1) the presence of either a large lagoon system (Kasegaluk, Peard Bay, Point Barrow/Elson Lagoon) or a large river delta (Colville, Sagavanirktok, Okpilak), both of which might support large numbers of staging shorebirds, (2) the potential for logistical support from other project collaborators for conducting work at the site, and (3) the ability to access the sites with fixed-wing aircraft or boats for deployment of personnel and equipment.

METHODS

Geographic Distribution from Aerial Surveys

To obtain a broad-scale perspective on staging shorebird distribution through time, we conducted aerial surveys

of the ACP coast from 2005 to 2007. Surveys comprised counts of birds within a fixed-width transect along the land/sea interface of the coastline. This survey band included the vast majority of the ACP littoral zone, defined as the region from the lowest tide level to the highest storm-driven water line (Connors et al., 1981). The area covered during each survey varied for logistical reasons and because weather often limited the number and extent of flights (Table 1). From 7 to 16 August 2005, we conducted a single survey of the ACP coastline between the southwest end of Kasegaluk Lagoon and Demarcation Point with a Robinson R-44 helicopter, flying at an altitude of approximately 15 m and a cruising speed of 95–115 km/hr (depending on wind speed). The biologist seated at front left identified and counted birds within 150 m to the left of the centerline of the aircraft (looking from the edge of the water inland), while the biologist at rear left recorded the data. We documented all shorebirds within belt transect sections designated by GPS locations recorded every two minutes. The use of two-minute intervals enabled calculation of bird densities on a per-time period, per-transect, or per-habitat basis (Johnson et al., 1993). Between 22 July and 27 August 2006, we conducted four surveys of the ACP coast in a Bellanca Scout fixed-wing aircraft, flying at an altitude of approximately 15 m and a cruising speed of 130–170 km/hr. Shorebird observations were recorded by a single observer from the rear seat of the plane, looking on one side of the aircraft from the land/sea interface to 150 m inland. We used the GPSVOX voice-recorder interface program developed by John Hodges (U.S. Fish and Wildlife Service, Juneau, AK), which records a GPS location and an audio file for each observation. These locations were later transcribed into geo-referenced data points. In addition to the coastlines, we surveyed all major river deltas in 2006 by recording birds along transects spaced 1 km apart that ran perpendicular to the coastline from the coast to the inland extent of salt marsh or mudflat habitat. In 2007, we used the same fixed-wing aircraft survey techniques as in 2006, but we limited our surveys to an area infrequently surveyed in the previous year: the Arctic National Wildlife Refuge coast from the Canning River to Demarcation Point.

We divided the ACP coast into four main regions to analyze the aerial survey data: 1) Chukchi, from the southwest end of Kasegaluk Lagoon to the Chukchi Sea side of Point Barrow, 2) Western Beaufort, from the Elson Lagoon side of Point Barrow to the west side of the Colville River delta, 3) Central Beaufort, from the Colville River delta to the West Canning River delta, and 4) Arctic Refuge, from the West Canning River delta to Demarcation Point (Fig. 1). We then created subregions delineated by boundaries between habitat types within each of the four larger regions. We chose to divide the analysis this way because we believed that comparing shorebird abundance across the entire ACP coast would potentially disvalue concentration areas that may have been locally important to birds moving along the coastline during the staging period. The four regions we delineated represent significantly different habitats: the

TABLE 1. Dates and area surveyed for each of six aerial surveys conducted in 2005–07 along the ACP littoral zone. See Figure 1 for location of endpoints.

Survey	Aircraft	Dates	Endpoints (W to E)
Survey 1-2005	Helicopter	7–16 August	SW end Kasegaluk Lagoon to Demarcation Point
Survey 1-2006	Fixed-wing	22–26 July	Peard Bay to Demarcation Point
Survey 2-2006	Fixed-wing	3–7 August	Kasegaluk Lagoon camp to Demarcation Point
Survey 3-2006	Fixed-wing	9–17 August	SW end Kasegaluk Lagoon to Camden Bay
Survey 4-2006	Fixed-wing	23–27 August	SW end Kasegaluk Lagoon to Canning River Delta
Survey 1-2007	Fixed-wing	7–8 August	Canning River Delta to Demarcation Point

Chukchi coast is mostly gravel beach and exposed shorelines, the Western Beaufort consists of many coastal lakes, the Central Beaufort contains the oil fields and is mostly high bluff habitat, and the Arctic Refuge region consists of many small (and some larger) river deltas. If all these regions were available to choose from at the same time, birds might prefer some over others, but the fact that a bird must fly from one point to another in a linear pattern likely constrains its choice of staging areas at any given time. Additionally, development decisions on the ACP are likely to be made on a relatively local level (e.g., an oil platform may be put at this delta or the next one over), so it is valuable to examine where shorebirds choose to stage in relation to other nearby areas.

To show shorebird distributions for the 2005 helicopter survey, we imported the coordinates of the endpoints of all the two-minute flight intervals (each representing ca. 3.5 km on the ground) and the total number of birds within each interval into ArcMap 9.1 (ESRI Inc., 2005). Because the exact number of birds counted within each interval was not available (these detailed data were lost), we report the data for each flight interval in categories of less than 50, 50–99, 100–499, 500–999, and 1000 or more birds. Then, we overlaid the 2006–07 fixed-wing data on top of the 2005 intervals to obtain the number of birds within each two-minute interval for each of the five survey periods, four in 2006 and one in 2007 (Table 1). We averaged these per-interval counts for each subregion in each survey period. For the purpose of delineating important staging areas, we defined a “shorebird concentration area” as a subregion with mean per-interval counts of birds at least 50% higher than those in other subregions of the same region during the same time period. We then compared results from the single 2005 helicopter survey to the results from the third 2006 fixed-wing survey to assess basic similarities across years in abundance and distribution. These two surveys were conducted during approximately parallel time periods, August 7–16 in 2005 and August 9–17 in 2006 (Table 1). We did not correct for the differences in aircraft used in the two years because we felt that the faster speed of the fixed-wing aircraft was balanced by the greater disturbance potential of the helicopter (Ward et al., 1999), resulting in similar detectability from both aircraft.

We considered river deltas along the Beaufort Sea coast separately. These areas comprise a distinct habitat demarcated by the location of the active floodplain of the river, and their potential staging habitat is much wider than along

a non-deltaic coastline. Surveying deltas required us to fly linear transects perpendicular to the coast, rather than flying a single linear survey that paralleled the coastline as we did in non-delta areas. Since we did not collect categorical data for the deltas in 2005 and thus did not delineate two-minute flight intervals, we determined the total number of shorebirds observed on each river delta in each 2006 and 2007 survey rather than using per-interval counts. We considered a delta to be a “shorebird concentration area” if its total shorebird count was at least 50% higher than those of other deltas during the second 2006 survey, when all deltas were surveyed within five days. This definition of importance is less rigorous than the one for coastal subregions (see above) because we had less comparative data for the deltas.

All aerial survey data are reported as raw count data, uncorrected for detectability. We attempted to use distance sampling analysis methods (implemented in Program DISTANCE; Thomas et al., 2006) to estimate detection rates for shorebirds from aerial surveys but found that our own methods violated key assumptions of such analysis, in that (1) shorebirds exhibited evasive movement in response to the aircraft and thus were not detected at their initial location, and (2) birds that flew under the aircraft were not observed, so detection on the transect line was far from 100% (Buckland et al., 2001). We stress that our emphasis is on large-scale distribution of staging shorebirds rather than on exact density or abundance in any one location. Since we were unable to identify individual species reliably from the air, we report distribution and abundance patterns for all shorebirds combined.

Shorebird Community Characteristics from Ground Camps

During 2005 and 2006, we conducted a series of surveys at each of the ground camps to assess species composition, staging phenology, and habitat use of staging shorebirds. We established nine 1 km transects within a 10 km diameter study area at each ground camp. Transects were not located randomly, but rather at places where birds had been seen (or were believed to be) foraging, and, if possible, where we could sample each of four habitat types: gravel beach, mudflat (silt barren), pond edge, and salt marsh. The proportions of these habitats varied with location; thus, habitats were not sampled equally across all camps. Gravel beach was typically found on exposed shorelines along the Chukchi Sea and along barrier islands in the Beaufort Sea.

Mudflat consisted of open riverine silt deposits or dried pond or lake basins. Pond edge comprised shallow water, mud, and sand found along the border of small ponds, lakes, or lagoons. Salt marsh was characterized by low-growing, saline-tolerant vegetation and periodically inundated substrate. Transects at each camp were surveyed by a single observer on foot once every three days throughout the field season (24 July–30 August 2005, 15 July–4 September 2006), although exact survey dates varied slightly by camp. We recorded species, group size, age composition (number of adult and juvenile birds), distance from transect, and habitat type occupied for all shorebirds observed on either side of each transect, out to 300 m. To characterize available habitat for later assessment of habitat selection, we also recorded the proportion of each of the four habitat types along each transect by measuring the length of the transect that ran through each habitat type.

Species Richness, Evenness, and Diversity: We quantified shorebird communities by calculating (1) species richness (s), the total number of species observed; (2) evenness (E), the abundance of each species relative to others in the community; and (3) the proportion of the total community belonging to each species (H' ; Shannon-Wiener diversity index) at each ground camp in each year (Pielou, 1974). To obtain measures of precision for evenness and diversity, we performed a series of 100 bootstrap simulations of the observed count data for each species and used their standard errors for subsequent comparisons of geographic variation (Kowalewski et al., 2006). We tested variability of species evenness and diversity by camp with one-way ANOVA (Proc GLM, SAS 9.1, SAS Institute, Inc., 2003) and by coast (Chukchi vs. Beaufort) with t-tests (Proc TTEST, SAS 9.1, SAS Institute, Inc., 2003), using Satterthwaite's approximation for degrees of freedom because sample sizes were not equal across camps (Snedecor and Cochran, 1980:97).

Species Composition and Phenology: To assess species composition (relative abundance of shorebird species at each site) and phenological patterns in the ground transect data, we calculated the number of individuals of each species recorded during each transect survey, after assigning all data to 16 survey periods that were consistent across camps: (1) 17–19 July, (2) 20–22 July, (3) 23–25 July, (4) 26–28 July, (5) 29–31 July, (6) 1–3 August, (7) 4–6 August, (8) 7–9 August, (9) 10–12 August, (10) 13–15 August, (11) 16–18 August, (12) 19–21 August, (13) 22–24 August, (14) 25–27 August, (15) 28–30 August, and (16) 31 August–2 September. Survey periods were the same in 2005 as 2006, except that surveys were not conducted during the first two periods or the last period in 2005. We do not present shorebird densities because some habitats were best estimated as a linear density and others as an areal density, making such comparisons impractical and misleading. Reporting actual counts rather than densities also facilitated comparisons with previous studies, although detectability is unknown in both those studies and our own study.

To place the phenology data in context, we used snow depth data from NOAA's National Weather Service Barrow

Post Rogers Airport station (NCDC, 2010). For the snowmelt date of a given year, we used the date that snow depth at Barrow was first reported to be a "trace" instead of a number of inches. We chose this measurement because the amount of snow covering tundra nesting habitat appears to have a greater impact than ambient temperature on the breeding behavior of shorebirds (ACIA, 2005; Meltofte et al., 2008).

Habitat Selection: Habitat use is said to be selective if habitats are used disproportionately to their availability (Allredge and Griswold, 2006). We used the ground transect data to create resource selection functions (RSF; Manly et al., 2002) in TreeNet (Salford Systems, 2003) to assess habitat selection for 12 relatively common shorebird species: American golden-plover (*Pluvialis dominica*), black-bellied plover (*P. squatarola*), dunlin (*Calidris alpina*), long-billed dowitcher (*Limnodromus scolopaceus*), pectoral sandpiper (*C. melanotos*), red phalarope (*Phalaropus fulicarius*), red-necked phalarope (*P. lobatus*), ruddy turnstone (*Arenaria interpres*), sanderling (*C. alba*), semipalmated sandpiper (*C. pusilla*), stilt sandpiper (*C. himantopus*), and western sandpiper (*C. mauri*). TreeNet is a non-parametric data mining and modeling program that constructs additive regression trees by sequentially fitting a simple parameterized tree function at each iteration (Friedman, 2001; Craig et al., 2009). All species datasets entered into TreeNet were randomly split into 90% training data and 10% testing data for model accuracy assessment. For increased accuracy, a subset of the training data was randomly selected without replacement and used in place of the full training set to compute the model update at each step (stochastic gradient boosting; Friedman, 2001). For each species, we examined the relative importance of habitat type, ground camp, year, and season (early: 15–31 July, mid: 1–15 August, or late: 16 August to end of field season) in determining the ratio of used vs. available habitat. We considered the number of birds (by species) counted in each habitat type/camp/season/year combination as a metric of habitat used, and the proportion of habitats across each of the nine transects within a camp as habitat availability. The results of the TreeNet analysis are partial dependence values, which indicate the effect of an individual predictor variable (habitat category) on the modeled response (in this case, the resource selection ratio) after accounting for the average effect of all other multivariate predictors (in this case, ground camp, season, and year; Friedman, 2001; Hochachka et al., 2007). The greater the absolute partial dependence values for a given predictor, the more dependent the response is on variation within that predictor. For a given species, positive partial dependence values for a habitat category indicate selective use of that habitat, while negative values indicate selection against that habitat. Because ground camps and transects were not randomly located, we recognize that our results cannot be extended beyond the area directly sampled by our transects without further evaluation data.

All shorebird survey activities for this project were conducted under a University of Alaska Fairbanks Institutional Animal Care and Use Committee protocol (#04-31).

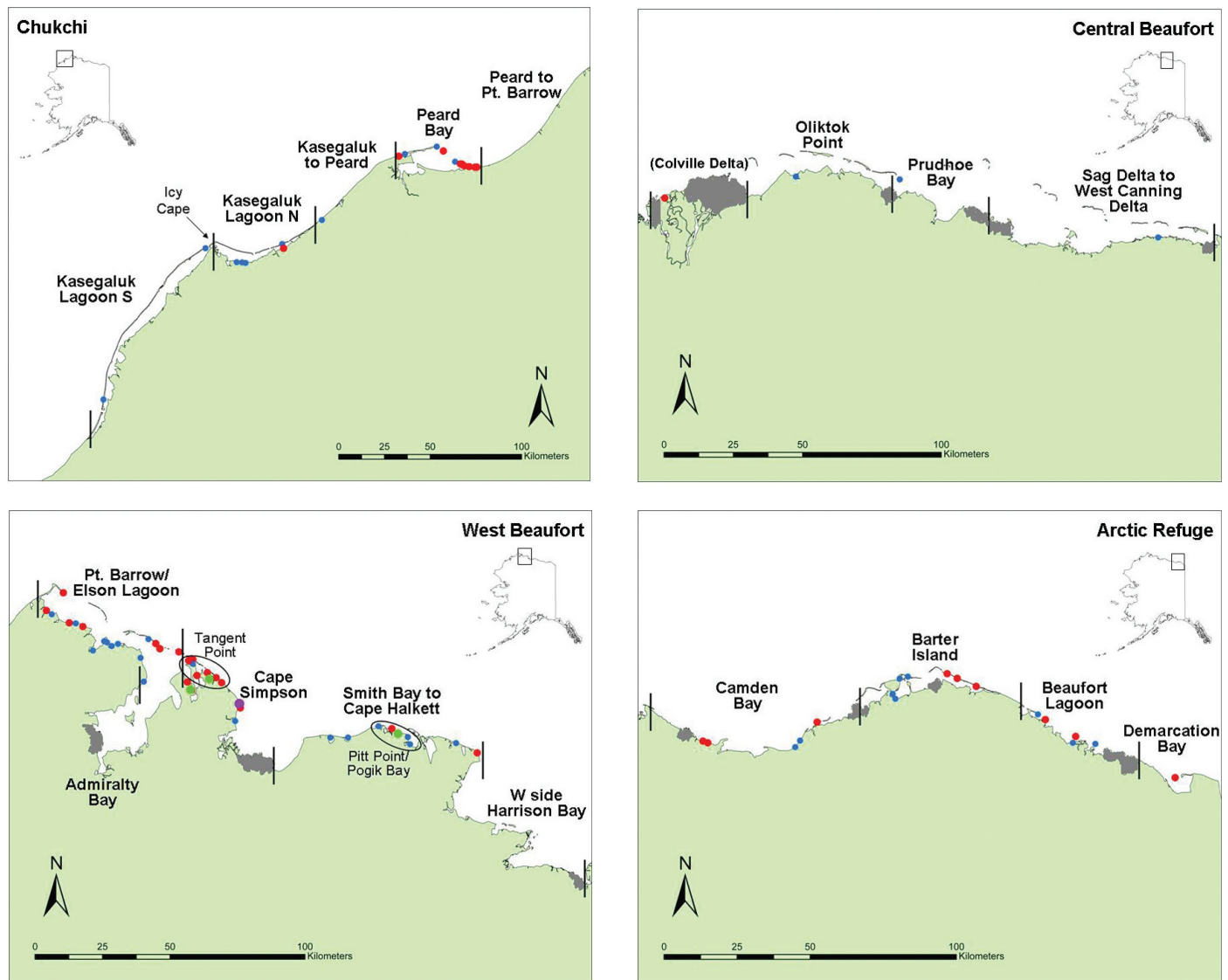


FIG. 2. Aerial survey subregion endpoints (vertical black lines) in the four major survey regions along the northern coast of Alaska: Chukchi, West Beaufort, Central Beaufort, and Arctic Refuge. Colored dots indicate shorebird abundance per two-minute survey interval during the 2005 helicopter survey: blue = 50–99 birds, red = 100–499 birds, green = 500–999 birds, and purple = 1000 or more birds per interval. (No dot indicates that fewer than 50 birds were counted in that two-minute interval.) Gray shaded areas represent river delta transects for which no 2005 data exist. Sag = Sagavanirktok.

RESULTS

Geographic Distribution from Aerial Surveys

Within Years: In 2005, we found shorebird concentration areas (each defined as a subregion with mean per-interval bird counts at least 50% higher than those of other subregions within that region during the same time period) at Kasegaluk Lagoon N and Peard Bay in the Chukchi region; Point Barrow/Elson Lagoon, Cape Simpson, and Smith Bay to Cape Halkett in the Western Beaufort region; and at numerous lagoons within the Central Beaufort and Arctic Refuge regions (Fig. 2).

In 2006, relative shorebird abundance varied by subregion and across surveys, although overall distribution patterns were similar to those observed in 2005. Peard Bay had higher per-interval counts than all other subregions in the

Chukchi region during the first three surveys. In contrast, the subregions to either side of Peard Bay had high counts of birds during the fourth survey. The Western Beaufort region as a whole had higher per-interval counts than any other region in the 2006 surveys, with Point Barrow/Elson Lagoon, followed by Cape Simpson, having more birds than any other subregion across the ACP coast. Within the Western Beaufort region, however, Admiralty Bay and the west side of Harrison Bay had lower counts of birds. Overall, the Central Beaufort region had the lowest per-interval counts of shorebirds of any region for all 2006 surveys, particularly for the fourth survey, when almost no shorebirds were observed. Within-season patterns were more difficult to discern for the Arctic Refuge region, since poor weather conditions in 2006 permitted completion of only the first two surveys. Per-interval shorebird counts during the second survey were generally higher than those recorded during

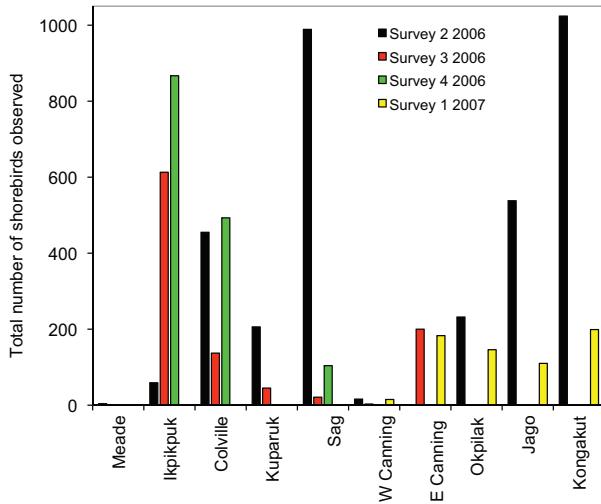


FIG. 3. Distribution results for river deltas from aerial surveys along the Beaufort Sea in northern Alaska, 2006–07. Graph shows total number of birds observed per survey for each delta. A lack of bars on the graph for a given survey indicates that no aerial surveys were conducted at that delta in that period. Deltas are listed from west to east along the Beaufort coast and correspond to the gray shaded areas in Figure 2. Sag = Sagavanirktok.

the first survey, especially for the Beaufort Lagoon subregion, in which they were much higher.

Between Years: A comparison of the 2005 survey results with those from the third 2006 survey indicates that Peard Bay had consistently higher per-interval counts of staging shorebirds than other subregions of the Chukchi region in both years. In the Western Beaufort region, Point Barrow/Elson Lagoon and the Cape Simpson area had the highest counts of staging birds in both years, while Smith Bay to Cape Halkett had moderate counts of staging birds in both years. We observed few concentrations of staging shorebirds in the Central Beaufort region in either year. We were unable to survey the Arctic Refuge region in 2006 on the same dates when we flew the helicopter survey in 2005. However, we can compare the second fixed-wing survey of 2006 and our single survey of 2007 conducted in the Arctic Refuge region (August 6–7 in 2006 and August 7–8 in 2007; Table 1). Camden Bay had higher counts of staging shorebirds than other subregions of the Arctic Refuge coast (excluding river deltas) in 2007, while the Beaufort Lagoon had at least twice as many shorebirds during the second survey in 2006 than any other lagoon in either year. However, neither area showed consistently high shorebird numbers across years. Demarcation Bay had low counts of shorebirds in both 2006 and 2007.

River Deltas: In terms of total number of birds observed, the Sagavanirktok and Kongakut deltas had particularly high counts during the second survey in 2006 (Fig. 3), which qualified them as shorebird concentration areas under our definition. We were able to examine only between-year data for the Arctic Refuge deltas. Between years, total numbers for the Jago and Kongakut deltas during the second survey in 2006 were substantially higher than those recorded on the same deltas during the 2007

survey, even though these surveys took place over the same time period in both years.

Shorebird Community Characteristics from Ground Camps

Species Richness, Evenness, and Diversity: Generally, species richness, evenness, and diversity were higher in 2005 than in 2006 (Table 2). In both years, species richness was lowest at the Peard Bay and Sagavanirktok camps and highest at the Point Barrow/Elson Lagoon, Colville Delta, and Okpilak Delta camps. Richness at Kasegaluk Lagoon was also low in 2006 (the only year for that camp). Species evenness (2005 E: $F = 49588.6$, $df = 4$, $p < 0.001$; 2006 E: $F = 2094510$, $df = 5$, $p < 0.001$) and diversity (2005 H': $F = 72725.9$, $df = 4$, $p < 0.0001$; 2006 H': $F = 1674642$, $df = 5$, $p < 0.0001$) across ground camps varied significantly within each year, although there was not a consistent pattern across space or time (Table 2). Therefore, we grouped camps located along each coast (Chukchi vs. Beaufort Sea) and analyzed these regions for richness, evenness, and diversity. We included Point Barrow/Elson Lagoon in the Chukchi coast region because the habitat is mainly gravel beach, making the camp more similar to the Chukchi camps than to the Beaufort camps located at river deltas. Species richness did not differ between the Beaufort and Chukchi coasts in either year (2005: $t = 0.52$, $p = 0.32$; 2006: $t = 0.16$, $p = 0.44$). The Beaufort coast had greater evenness and diversity than the Chukchi coast in both 2005 and 2006, although the difference in evenness in 2006 was only marginally significant (Table 2; significance of difference between 2005 and 2006 evenness and diversity indicated by overlap of bootstrapped 95% confidence intervals).

Species Composition: Overall, the postbreeding shorebird community was composed of three species (semipalmated sandpiper, dunlin, and red-necked phalarope) common to all locations, and two species (western sandpiper and red phalarope) that were common on the Chukchi coast but declined in relative abundance going east along the Beaufort coast (Table 3). Red phalaropes and dunlins were found in large numbers (> 3000 and > 1000 individuals, respectively) in several different survey periods, whereas semipalmated sandpipers and red-necked phalaropes were found in intermediate numbers (~ 300 individuals). Western sandpipers were the least common species comparatively. For all of these common species except dunlin, juveniles (hatch-year; HY) far outnumbered adults (after hatch-year; AHY) on our transects; for dunlin, the reverse was true (Table 3). Ten other species—American golden-plover, Baird's sandpiper (*Calidris bairdii*), black-bellied plover, buff-breasted sandpiper (*Tryngites subruficollis*), long-billed dowitcher, pectoral sandpiper, ruddy turnstone, sanderling, semipalmated plover (*Charadrius semipalmatus*), and stilt sandpiper—were present at some or all camps in each year, but not more than ~ 300 individuals of all these species combined were observed at any one camp in a given year (Table 4). Long-billed dowitchers were more common on the Chukchi than the Beaufort coast, whereas black-bellied

TABLE 2. Species richness, evenness (E), and Shannon-Weiner diversity index (H') values derived from shorebird transect surveys at each of six ground camps on the ACP. Results are presented by camp; bolded lines are camps averaged by coast, with the relevant camps listed from west to east above each coast. 95% confidence intervals were derived via bootstrap simulations. See Figure 1 for camp and coast locations. Point Barrow = Point Barrow/Elson Lagoon camp. We considered evenness and diversity measures significantly different if the 95% confidence intervals did not overlap.

Year	Coast	Camp	Richness	Evenness (E)	95% CI (E)	Diversity (H')	95% CI (H')
2005	Chukchi	Peard Bay	11	0.4117	0.4111, 0.4123	0.9873	0.9857, 0.9887
		Point Barrow	12	0.5283	0.5277, 0.5289	1.3128	1.3114, 1.3142
		Average for Coast	11.5	0.4700	0.4420, 0.4980	1.1500	1.0719, 1.2282
	Beaufort	Colville	14	0.5732	0.5726, 0.5738	1.5128	1.5114, 1.5142
		Sagavanirktok	10	0.5762	0.5756, 0.5768	1.3267	1.3253, 1.3282
		Okpilak	13	0.5051	0.5045, 0.5057	1.2955	1.2941, 1.2969
		Average for Coast	12.3	0.5515	0.5390, 0.5640	1.3783	1.3419, 1.4148
2006	Chukchi	Kasegaluk	8	0.6175	0.6172, 0.6177	1.2840	1.2834, 1.2846
		Peard Bay	10	0.3698	0.3695, 0.3700	0.8514	0.8508, 0.8520
		Point Barrow	14	0.1407	0.1404, 0.1409	0.3713	0.3707, 0.3719
		Average for Coast	10.7	0.3760	0.3020, 0.4499	0.8356	0.6940, 0.9771
	Beaufort	Colville	12	0.3256	0.3253, 0.3259	0.8091	0.8085, 0.8097
		Sagavanirktok	8	0.5927	0.5924, 0.5929	1.2325	1.2319, 1.2330
		Okpilak	11	0.5567	0.5564, 0.5570	1.3349	1.3344, 1.3355
		Average for Coast	10.3	0.4917	0.4467, 0.5366	1.1255	1.0391, 1.2119

plovers, American golden-plovers, and stilt sandpipers were more common on the Beaufort than the Chukchi coast. Pectoral sandpipers were present at all camps in both years. Sanderlings and ruddy turnstones were more abundant at some camps than at others, with no particular geographic pattern. Baird's sandpipers, buff-breasted sandpipers, and semipalmated plovers were relatively rare at all camps. For all less common species, juveniles outnumbered adults on our transects.

Phenology: Semipalmated sandpipers were present at all camps only early in the staging period. Peak abundance of juveniles occurred during 29 July–3 August on the Chukchi coast and during 4–9 August on the Beaufort coast; juveniles were mostly absent after 7–9 August on the Chukchi coast and 10–12 August on the Beaufort coast. Peak numbers of adults preceded those of juveniles by approximately six days at most camps; adults were mostly absent from our transects after 29–31 July.

Dunlin tended to be present over a longer portion of the staging period than other species. Peak abundance was earliest at Kasegaluk Lagoon (26–28 July) and latest at the Okpilak Delta (31 August–2 September), although there was not a clear temporal trend between these sites. Peak numbers of adult dunlins were observed earlier than those of juvenile dunlins at most camps, but both age groups were present until the end of the field season. Within each camp, the periods of peak abundance were similar for both age groups.

For red-necked phalaropes, the period of peak abundance was relatively short at the Kasegaluk Lagoon, Peard Bay, and Okpilak camps, and longer at the Point Barrow/Elson Lagoon, Colville Delta, and Sagavanirktok Delta camps. Peak abundance of juveniles occurred between 26 and 28 July at the Kasegaluk Lagoon camp and between 13 and 15 August at Point Barrow/Elson Lagoon. There was no clear trend in date of peak abundance from east to west. Adults peaked in abundance up to 12 days in advance of juveniles and were absent from the transects before juveniles at most camps.

Red phalaropes were relatively abundant throughout most of the staging period, especially at the Peard Bay and Point Barrow/Elson Lagoon camps. Peak numbers of juveniles occurred between 1 and 6 August at all four camps where they were recorded; thus, there was no clear trend in date of peak abundance from east to west. Adults and juveniles of this species peaked in abundance at approximately the same time at most camps, although adults were absent from the transects before the juveniles left.

For western sandpipers, the peak of abundance was 13–15 August at all camps, again showing no trend in date of peak abundance from west to east. This species was present at Chukchi Sea staging areas after the beginning of August for a relatively long period of time (especially in Barrow) compared to semipalmated sandpipers, a similar species. Very few adult western sandpipers were observed except at Kasegaluk Lagoon, where adults peaked in abundance up to three weeks in advance of juveniles and were also absent from the transects prior to juveniles.

Black-bellied plovers, American golden-plovers, pectoral sandpipers, and ruddy turnstones were present sporadically throughout the staging period at most camps. Baird's sandpipers, buff-breasted sandpipers, and semipalmated plovers were observed primarily during the first half of the staging period, while stilt sandpipers were mostly observed during the middle of the staging period. Sanderlings were recorded mostly during the second half of the staging period, except for a small pulse of individuals early in the staging period at Peard Bay. Long-billed dowitchers exhibited a distinct short pulse of abundance late in the staging period that was particularly evident at the Kasegaluk Lagoon and Peard Bay camps.

The snowmelt dates for the study years were 28 May in 2005 and 7 June in 2006. The ten-year average for 2000–09 was 28 May, while the five-year averages were 24 May for 2000–04 and 1 June for 2005–09.

TABLE 3. Raw counts for the five most common shorebird species (semipalmated sandpipers, dunlins, red-necked phalaropes, red phalaropes, and western sandpipers) observed on survey transects at each ground camp on the ACP 2005–06. Observations from all survey periods in each year are lumped. Camps are listed from west to east across the ACP. For each camp, the top line for each species shows the count for that species and the second line, the percent of total (in parentheses), which refers to the proportion of the total observations summed across all five species that each species represents. The third and fourth lines show the counts for adult (AHY) and juvenile (HY) individuals for each species.

Species	Chukchi Sea					Beaufort Sea					
	Kasegaluk Lagoon	Peard Bay		Point Barrow/Elson Lagoon		Colville Delta		Sagavanirktok Delta		Okpilak	
	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Semipalmated sandpiper	262 (2.2)	119 (6.0)	110 (4.5)	377 (7.8)	161 (1.3)	480 (53.7)	787 (17.5)	29 (26.9)	766 (56.9)	118 (14.0)	537 (49.9)
AHY	18	5	4	7	36	19	25	8	11	0	18
HY	244	114	106	370	125	461	762	21	755	118	519
Dunlin	1038 (53.9)	118 (6.0)	142 (5.8)	499 (10.3)	159 (1.3)	277 (31.0)	3565 (79.3)	12 (11.1)	528 (39.2)	91 (10.8)	84 (7.8)
AHY	848	4	17	387	39	162	3242	1	406	45	14
HY	190	114	125	112	120	115	323	11	122	46	70
Red-necked phalarope	20 (1.0)	91 (4.6)	62 (2.5)	873 (18.1)	565 (4.7)	89 (10.0)	113 (2.5)	67 (62.0)	52 (3.9)	632 (75.1)	456 (42.3)
AHY	18	37	10	18	132	5	2	29	4	295	41
HY	2	54	52	855	433	84	111	38	48	337	415
Red phalarope	35 (1.8)	1580 (79.8)	2058 (84.0)	2827 (58.5)	11175 (92.4)	48 (5.4)	29 (0.6)	0	0	0	0
AHY	21	35	269	114	502	1	2	0	0	0	0
HY	14	1545	1789	2713	10673	47	27	0	0	0	0
Western sandpiper	791 (41.1)	73 (3.7)	79 (3.2)	257 (5.3)	34 (0.3)	0	0	0	0	0	0
AHY	125	1	0	1	0	0	0	0	0	0	0
HY	666	72	79	256	34	0	0	0	0	0	0
Total	2146	1981	2451	4833	12094	894	4494	108	1346	841	1077

Habitat Selection: We detected three distinct patterns in species-habitat associations (which we termed “foraging guilds”) at our six ground camps. Black-bellied plovers, red phalaropes, ruddy turnstones, and sanderlings selected for gravel beaches, whereas dunlins and semipalmated sandpipers selected strongly for mudflats. American golden-plovers, long-billed dowitchers, pectoral sandpipers, and western sandpipers selected for salt marshes, although three of these species (long-billed dowitchers, pectoral sandpipers, and western sandpipers) also selected for pond edge, which was often interspersed with salt marsh across our study site. Stilt sandpipers, while not widely distributed or numerous across our study area, also selected for pond edge where they were locally present, mostly east of the Colville delta. Red-necked phalaropes were the only species that did not fit clearly into a foraging guild: they showed approximately equal selection for gravel beach and pond edge.

DISCUSSION

Geographic Distribution from Aerial Surveys

On the basis of research done in the late 1970s as part of the Outer Continental Shelf Environmental Assessment Program (OCSEAP; Connors et al., 1981), we expected that staging shorebird distribution across the ACP coast would be non-uniform. Our findings during aerial surveys were

consistent with this expectation: in some areas (at Peard Bay, Point Barrow/Elson Lagoon, and Cape Simpson, and between Smith Bay and Cape Halkett) we found shorebird concentrations each year, whereas along other areas of the coastline we observed few or no shorebirds. In addition, we found concentrations of shorebirds at the Sagavanirktok and Kongakut river deltas during the second survey in 2006, when we were able to survey all deltas in just five days. Below, we compare our aerial survey results to those reported by previous investigators for areas that we or others found to be shorebird concentration areas. We present this information in geographic order from west to east across the ACP (see Fig. 1). To facilitate comparisons, we converted our per-interval count data to linear densities (birds/km) by dividing by 3.5 km (the approximate length of a two-minute flight in an R-44 helicopter).

Kasegaluk Lagoon: Although we did not find Kasegaluk Lagoon to be a shorebird concentration area across years, Johnson et al. (1993) reported large numbers of shorebirds across the entire lagoon during aerial surveys from 1989 to 1991, with densities of unidentified small shorebirds averaging between 4.4 (1989) and 45.5 (1991) birds/km. Peak counts of small shorebirds in each year were 4000 in 1989, 8000 in 1990, and 29 000 in 1991. Our peak counts of shorebirds during the 2006 surveys ranged from 39 to 1561 individuals per survey, and linear densities (averaged across all surveys) were approximately 2.0 birds/km in the south part of the lagoon and 0.9 birds/km in the north part. Given the

TABLE 4. Raw counts for less common shorebird species observed on survey transects at each ground camp on the ACP 2005–06. Observations from all survey periods are lumped within each year, as are adults and juveniles. Camps are listed from west to east across the ACP.

Species	Chukchi Sea					Beaufort Sea						
	Kasegaluk Lagoon		Peard Bay		Point Barrow/Elson Lagoon		Colville Delta		Sagavanirktok Delta		Okpilak	
	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	
American golden-plover	4	3	1	0	2	42	15	0	18	27	30	
Baird's sandpiper	0	0	1	3	27	2	0	2	0	1	0	
Black-bellied plover	0	0	0	1	10	55	16	0	53	52	70	
Buff-breasted sandpiper	0	0	0	0	1	15	2	0	0	5	0	
Long-billed dowitcher	17	20	46	9	3	9	11	6	0	6	0	
Pectoral sandpiper	59	12	5	29	25	66	65	221	39	30	56	
Ruddy turnstone	0	10	0	50	40	22	15	10	0	20	33	
Sanderling	0	20	29	16	2	1	0	0	0	102	47	
Semipalmated plover	0	1	0	1	13	0	0	1	0	0	1	
Stilt sandpiper	0	0	0	0	0	117	61	3	338	11	9	
Total	80	66	82	109	123	329	185	243	448	254	246	

historically high numbers of birds in this subregion, Kasegaluk Lagoon may merit further investigation as a concentration area for shorebird staging/migration.

Peard Bay: Connors et al. (1981) listed Peard Bay as a sensitive concentration area for staging shorebirds because its extensive gravel spit/beach habitat is favored by phalaropes. Gill et al. (1985), who conducted aerial shoreline surveys at Peard Bay from July to September 1983, recorded a linear density of 0.8 shorebirds/km (mostly red phalaropes) on 10 August 1983. We observed approximately 2.5 shorebirds/km (mostly phalaropes) during our aerial survey on 9 August 2006. Connors and Risebrough (1978) and Gill et al. (1985) found that densities of shorebirds at Peard Bay were lower than densities at Icy Cape (in Kasegaluk Lagoon). In contrast, we found that densities of shorebirds at Peard Bay were higher than those at Kasegaluk Lagoon in all of our surveys. Gill et al. (1985) considered Peard Bay to represent a transition zone between estuarine systems typical of the Arctic coast and those typical of sub-Arctic areas to the south. If this transitional habitat is related to food availability, Peard Bay may attract birds migrating south from the Beaufort coast as the first sub-Arctic staging area on the Chukchi Sea. Birds staging at Peard Bay may then bypass Kasegaluk Lagoon, located only 80 miles southwest of Peard Bay along the Chukchi coast. A warming trend in the Arctic may increase the possibility for Peard Bay to serve as a sub-Arctic staging site, resulting in more individuals' skipping Kasegaluk Lagoon.

Point Barrow/Elson Lagoon: We recorded the highest density (38.4 birds/km) of all surveyed regions (excluding deltas) at Point Barrow/Elson Lagoon during the third fixed-wing survey in 2006. Counts of birds in this subregion were comparatively high in 2005 and during the other 2006 surveys as well. Connors et al. (1981) considered both Point Barrow and the Plover Islands (extending southeast from Point Barrow; Fig. 1) to be concentration areas for staging shorebirds during the OCSEAP study, and they surmised that the extensive gravel spits and barrier islands of this area were attractive to staging shorebirds, particularly phalaropes.

Cape Simpson: The Cape Simpson subregion had a peak density of 36.9 birds/km during the third survey in 2006, which was the second-highest density we observed during our aerial surveys. However, there are no other comparative data on staging shorebird abundance in this subregion. The Cape Simpson area (particularly at Tangent Point, circled on Fig. 2) is characterized by numerous small- to medium-sized lakes near the coastline, many of which show evidence of being breached by salt water during high water events. This type of habitat is denoted as “tapped basins” by Jorgenson and Brown (2005) in their characterization of Beaufort Sea coastlines, and is found only near Tangent Point and at Pitt Point/Pogik Bay (see below). Given that we observed large concentrations of staging shorebirds at both Tangent Point and Pitt Point/Pogik Bay, further investigation of the importance of this habitat for staging shorebirds may be warranted.

Smith Bay to Cape Halkett: The Smith Bay to Cape Halkett subregion had a peak density during the fourth survey in 2006 of 14.9 birds/km. Although they did not systematically survey the area, Connors et al. (1981) hypothesized that Pitt Point in this subregion might attract large concentrations of postbreeding shorebirds because of its extensive littoral flats and lagoon/slough edge habitat (also circled in Fig. 2). We recorded large per-interval counts both in 2005 and during the latter two surveys in 2006 at Pitt Point and nearby Pogik Bay, where the habitat is also classified as “tapped basins” by Jorgenson and Brown (2005; see above).

Colville Delta: We did not find the Colville delta to be a shorebird concentration area as defined in this study, although Andres (1989) indicated this area was important to postbreeding dunlins and estimated that approximately 41 000 shorebirds of multiple species may pass through during fall staging. The visually homogenous delta substrate (the area provides the most extensive salt marsh and mudflat habitat along the central Beaufort coast; Andres 1989) is a good match for the plumage of a shorebird, which may have made it more difficult to locate birds during aerial surveys. It is the contrast between flying birds and the background

vegetation and water that enables their detection from the air. Relatively high numbers of semipalmated sandpipers and dunlins were recorded during the ground transect surveys at the Colville Delta camp in 2006, lending support to the idea that our aerial surveys may have failed to detect birds that were really present. Alternatively, if shorebirds move through the Colville delta in distinct pulses, our aerial surveys may have missed large groups of birds staging in the area. Andres (1994) reported a sudden pulse of dunlins and sanderlings on shoreline silt barrens of the Colville delta in mid-August 1988 after high water receded.

Simpson Lagoon: This extensive lagoon system (in the Oliktok Point subregion) did not contain large numbers of shorebirds during our aerial surveys in either year, and linear densities were 0–2 birds/km in 2006. In contrast, Johnson and Richardson (1981) observed 30–130 birds/km (mostly juvenile phalaropes, which numbered in the thousands) during the period 16–24 August in 1977 and 1978. We may have missed a similar pulse of phalaropes in Simpson Lagoon in 2005 or 2006, since we conducted no aerial surveys from 16 to 22 August; however, Johnson and Richardson (1981) were still observing relatively high densities in the final week of August, the time of our last fixed-wing survey in 2006.

River Deltas: Our data are equivocal with respect to describing the relative importance of river deltas for staging shorebirds. Because Survey 2 in 2006 was the only one that covered all the Beaufort Coast deltas at once, we used high overall counts during that survey as the criterion for labeling a delta as a concentration area. Therefore only the Sagavanirktok and Kongakut deltas, on which we observed 989 and 1024 birds, respectively, during that survey, were named as concentration areas. Spindler (1979) recorded higher densities of shorebirds in the eastern lagoons of the Arctic Refuge than in the western lagoons, which is similar to our results from 2006. However, when we used 3.5 km sections of delta transect routes to calculate density on all deltas for comparison with non-delta areas, the eastern portion of the Canning delta did support a relatively high linear density of shorebirds in both 2006 and 2007. Martin and Moiteret (1981) reported peak linear densities of approximately 20 phalaropes/km during ground-based shoreline transects conducted on the Canning delta in 1980; we estimated 25.0 shorebirds/km (of all species) on the delta during Survey 3 in 2006. Similarly, the Ikpikpuk delta had high total numbers of birds during the third and fourth surveys in 2006. Thus, the importance of a given delta to staging shorebirds may vary within and across years, so that repeat surveys within a year and over long time periods are needed for a full assessment of concentration areas.

Deltas Versus Coastlines: Spindler (1979) observed clusters of high bird-density (mostly phalaropes, pectoral sandpipers, loons, and diving ducks) on the Canning, Okpilak-Hulahula, Jago, and Aichilik deltas during aerial surveys conducted 0.5 km inland of the Arctic Refuge coast in 1978 and 1979, indicating that at times, delta habitats may attract more birds than surrounding coastal areas. Andres

(1989) found the Colville delta to be important to many species of postbreeding shorebirds, particularly the dunlin. However, our data did not suggest that staging shorebirds used deltas to the exclusion of coastal areas. Shorebirds may move through staging areas in waves, using different littoral habitats within a region concurrently rather than aiming for specific coastal landforms. Use of coastal vs. delta areas likely varies by species because of differences in the habitat present, and it may also vary with wind and weather conditions, which create spatial and temporal differences in thermal cover and food availability (Connors and Risebrough, 1978; Martin and Moiteret, 1981).

Variability and Reliability of Aerial Surveys for Staging Shorebirds: We observed a high level of spatial and temporal variability in the number and location of shorebirds staging on the ACP coast in 2005 and 2006, as noted in other aerial surveys conducted across the ACP (Spindler, 1979; Gill et al., 1985; Johnson et al., 1993). Such variability is likely a result of two factors. The first is sampling error (i.e., failure to count birds that were actually present), which could occur for a variety of reasons: birds flying under the aircraft, birds not flushing in response to the aircraft, or errors in counting flock size. The second is inherent variability in shorebird numbers caused by underlying processes creating distribution and abundance patterns. Process variation includes changes in shorebird numbers between our survey dates that are due to migration timing, shoreline exposure, and food availability. High water events on Alaska's Arctic coast are primarily driven by wind patterns (which create storm surges), rather than by lunar tides. Thus water levels, and resulting shoreline/mudflat exposure and food availability, are temporally unpredictable. Skagen and Knopf (1993) concluded that variability in the exposure of ephemeral wetland complexes in the prairie pothole region of the Northern Great Plains significantly affected the distribution of migrating small shorebirds. In northern Alaska, Connors and Risebrough (1978) reported a correlation in some years between wind direction and phalarope use of the leeward vs. windward shores of barrier islands. Martin and Moiteret (1981) hypothesized that strong (and unpredictable) west wind events on the Canning delta left deposits on barrier island shores of benthic prey items, which then attracted large numbers of phalaropes for short periods of time. These results suggest that while aerial surveys may work well to discern large-scale patterns of shorebird distribution, population estimates based on such surveys could be biased if shorebird abundance changes rapidly in response to short-term variability in weather conditions, shoreline exposure, and food availability.

It is not appropriate to compare our aerial and ground surveys quantitatively because the ground transects were not located randomly within the study area. However, as a qualitative example of aerial survey validity, we compared linear densities estimated from the aerial and ground surveys at Point Barrow/Elson Lagoon in 2006. To obtain an overall linear density for the ground surveys, we totaled the number of individuals of all species seen in each of the

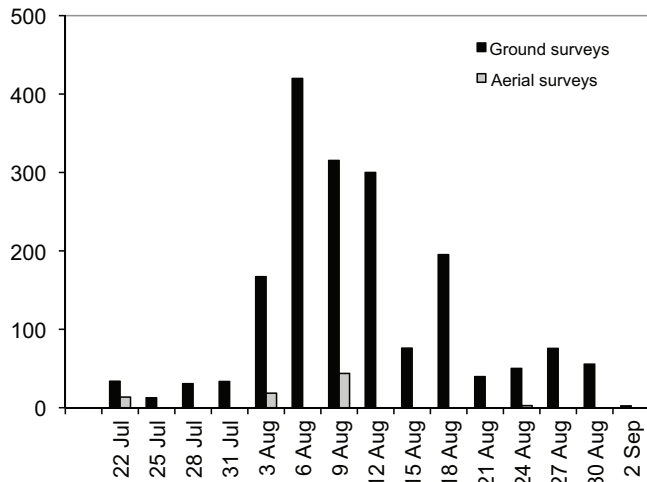


FIG. 4. Qualitative comparison of linear densities (birds/km) from ground surveys (black bars) and aerial surveys (grey bars) for Point Barrow/Elson Lagoon in 2006. Dates on the x-axis are the last day of each ground transect survey period; one complete survey (nine 1 km transects) was conducted in each period. Aerial surveys were conducted on 22 July, 3 August, 9 August, and 23 August 2006.

16 survey periods (see Methods) and divided by the total length of transects surveyed (9 km in each survey period). We compared these values to the linear densities for the four 2006 aerial surveys of the Point Barrow/Elson Lagoon subregion (calculated by dividing the per-interval shorebird counts by 3.5 km as mentioned above). The aerial surveys recorded much lower densities than the ground surveys (Fig. 4), probably because the ground transects were located in known shorebird foraging areas, where higher densities would be expected, rather than at random coastal locations. While the highest density recorded from the aerial surveys did coincide with higher densities observed on the ground transects, it is clear that the peak of staging shorebird abundance in the Barrow vicinity occurred between two of our aerial surveys and thus was not captured by this survey method.

We acknowledge these and other limitations of aerial surveys to detect true staging shorebird abundance and distribution, but we lack other adequate methods for monitoring a large number of small, mobile birds that cannot be detected remotely via satellite or GPS tracking devices. Development of such methods should be a priority, particularly for management of wildlife resources across large, remote areas like Alaska's northern coast. In the future, more frequent aerial surveys may help to avoid missing the occasions when shorebirds peak at a given site. Repeating aerial surveys over many years using the same methods would also provide more information on the degree of variability in shorebird numbers over time, which is necessary to detect trends in staging site use resulting from natural or anthropogenic causes. Unfortunately, we suspect that in many cases, financial costs and logistical problems (e.g., weather) may inhibit repetition of survey effort over many years.

Shorebird Community Characteristics from Ground Camps

Species Richness, Evenness, and Diversity: We found that diversity (a combination of species richness and evenness) was lower on the Chukchi coast than on the Beaufort coast. This difference was likely due to species evenness on the Chukchi coast being lowered by the predominance of phalaropes, which comprised 84% of shorebird sightings at the Peard Bay camp and 77% at the Point Barrow/Elson Lagoon camp in 2005, and 87% and 97% at those camps in 2006. At the three Beaufort Sea camps, by comparison, phalaropes on average comprised only 23% of all sightings in both 2005 and 2006. Species richness did not differ substantially between coasts in either year, although we expected it to be higher on the Chukchi coast if staging shorebird distribution reflects breeding distribution patterns (see Species Composition below; Johnson et al., 2007). This pattern of diversity is the reverse of that found when all staging birds (loons, waterfowl, shorebirds, and larids) were considered: in that case, species diversity was lower on the Beaufort coast because the bird community was dominated by long-tailed ducks (*Clangula hyemalis*; Johnson et al., 1993).

Species Composition: We expected the patterns of species composition at our ground camps to reflect the way these same species are distributed during the breeding season (Connors, 1984). However, the patterns of distribution revealed in our study differed somewhat from that expectation, particularly later in the staging period. Two mechanisms—fall migration routes and habitat preference—may be responsible for this difference, and it is likely that they act in concert. Johnson et al. (2007) surmised that species-specific differences in breeding distribution of shorebirds were related to their spring migration routes. Distribution of postbreeding shorebirds, particularly later in the staging period, may likewise be related to fall migration routes. For example, dunlins are more common as breeders in the central portion of the ACP (Johnson et al., 2007), yet we also observed them in large numbers at Kasegaluk Lagoon on the Chukchi coast. The northern Alaska subspecies of dunlin (*arcticola*) migrates to Asia for the winter (Warnock and Gill, 1996), so individuals likely leave breeding territories in the central ACP and migrate westward and southward along the Beaufort and Chukchi coasts, respectively, toward western Alaska and Asia. Less certain, yet possibly still related to fall migration routes, is the postbreeding distribution of red and red-necked phalaropes. Both species breed across the Arctic Coastal Plain, although red phalaropes are more common in the west, while red-necked phalaropes seem to favor inland wet-tundra breeding sites over coastal areas (Johnson and Herter, 1989; Johnson et al., 2007). We rarely observed red phalaropes on the coast at our two easternmost ground camps (Sagavanirktok and Okpilak), which may indicate a movement of this species toward the western Beaufort and Chukchi coasts, from which they migrate pelagically south through the Bering Sea. However, Johnson and Richardson (1981) recorded an average of 4:1 red

to red-necked phalaropes in Simpson Lagoon to the east of the Colville River delta. We found red-necked phalaropes in much larger numbers at our eastern ground camps, despite their ACP-wide breeding distribution. It is unknown which direction Alaska-breeding red-necked phalaropes take on fall migration, but one speculation is that they may fly eastward to join northern Canada-breeding populations that stage in the Bay of Fundy in early fall (Rubega et al., 2000). The eastern-trending distribution of red-necked phalaropes along the ACP coast during the staging period may lend support to this idea.

The postbreeding distribution patterns we observed may also be related to preferred staging habitat. Johnson et al. (2007) reported pectoral sandpipers, long-billed dowitchers, and American golden-plovers as common breeding species across the entire ACP. However, none of these species were abundant at coastal staging areas, probably because they tend to stage in non-littoral tundra habitats (Connors et al., 1981; A. Taylor, pers. obs.).

Our ground-based surveys also provided an opportunity to compare our data on relative abundance of various shorebird species with that collected by previous researchers. We found notable differences in the relative abundance of dunlins and western sandpipers between this study and previous work done on the northern Alaska coast. Lehnhausen and Quinlan (1981) reported seeing flocks of over 1000 dunlins using Kasegaluk Lagoon during mid-August 1980. Although we did not survey the entirety of Kasegaluk Lagoon in 2006, the largest flocks observed by our ground crew had only 100–200 individuals. Connors et al. (1981) observed 2110 dunlins over four years at Barrow during transect surveys that totaled approximately 200 km, while we recorded a total of only 647 dunlins at Barrow over two years during transect surveys that totaled 252 km. We did record large numbers of staging dunlins at the Colville delta, a result similar to Andres' (1989) results. These apparent declines in dunlin numbers at several staging sites mirror a 50% decline in breeding density at Prudhoe Bay documented between 1981 and 1992 (Troy Ecological Research Associates, 1993). It is still unclear, however, whether the differences in staging site numbers are caused by large interannual variability in shorebird population sizes, which may result from differential use of staging sites across years or from variable breeding productivity in a given year (Gill et al., 1985).

When comparing species composition at ACP staging areas, Andres (1989) found that western sandpipers were relatively more abundant at the Colville delta than at Point Barrow, comprising 4% (his data) and 2% (Connors, 1984) of all shorebird observations, respectively. In contrast, we found that western sandpipers were more numerous at all Chukchi coast camps (Kasegaluk Lagoon, Peard Bay, and Point Barrow/Elson Lagoon) than at the Colville Delta camp in 2005 and 2006. This species has long been assumed to be a rare breeder on the ACP, occurring mostly on the Yukon-Kuskokwim delta more than 500 km to the south (Johnson and Herter, 1989; Wilson, 1994). However,

recent studies have shown that western sandpipers may have a larger breeding range on the ACP than previously thought, nesting in low densities across the entire western half of the region (Cotter and Andres, 2000; Johnson et al., 2007). It is unknown whether this larger range is a recent change caused by a warming Arctic climate, or whether the difference reflects the more limited scope and length of earlier studies of breeding shorebirds on the ACP. It is possible that some of the postbreeding western sandpipers observed on the Chukchi coast may be from a population that breeds on the Chukotski Peninsula in Russia (Kozlova, 1962). Additional research using genetic data or individuals marked on the breeding grounds in the United States and Russia, or both, could help answer this question.

Seasonal Phenology: Accelerated rates of warming in the Arctic (Serreze and Francis, 2006) may have a large impact on the phenology of shorebird staging on the northern Alaska coast. Advancement of spring life events is a highly apparent result of global warming thus far (Durant et al., 2007); the average snowmelt date in northern Alaska has advanced ~8 days since the 1960s (Stone et al., 2002). If accelerated snowmelt in the Arctic results in earlier shorebird breeding, fledging of chicks and movement of shorebirds to coastal areas may begin earlier. On the other hand, there is some evidence to suggest that Arctic-breeding shorebirds are capable of replacing clutches lost early in incubation (Naves et al., 2008). If a warming Arctic climate results in a longer period of favorable weather (Callaghan et al., 2005), movements of birds to coastal staging areas could be delayed if more individuals replace lost clutches (or attempt second clutches) and chicks fledge later in the breeding season (Jenni and Kéry, 2003). These two effects may also act in concert, in which case the timing of peak staging should remain the same. However, the overall length of the staging period should then increase as a result of less synchrony in chick fledging and the subsequent arrival of adults and juveniles at staging areas.

Several observed differences between data collected at our ground camps and previous research on the phenology of staging on the northern Alaska coast suggest that shorebirds may be staging earlier now than in previous decades. Lehnhausen and Quinlan (1981) reported a peak in dunlin use of beach transects at Kasegaluk Lagoon in mid-August 1980, whereas in our study the peak was approximately two weeks earlier. Similarly, Gill et al. (1985) reported that red phalarope abundance at Peard Bay peaked in mid-August in 1983, whereas our data show a peak in early August. Johnson (1978) and Johnson and Richardson (1981) recorded the highest densities of staging phalaropes at Simpson Lagoon between 10–20 August 1977 and 19–24 August 1978, whereas we observed the highest counts of phalaropes between 1 and 9 August at the Sagavanirktok camp (close to Simpson Lagoon) in 2005 and 2006. However, we cannot be sure whether these differences reflect annual variation in how and when shorebirds use the coast or true changes in seasonal phenology over time.

While the onset of dunlin and phalarope staging may be advancing, western sandpiper staging may be delayed relative to that previously reported. Johnson et al. (1993) reported that in 1990 and 1991, western sandpipers were the most common small shorebird along Kasegaluk Lagoon shorelines in late July and early August, after which their numbers declined. In our study, western sandpipers in 2006 did not become more numerous than dunlins or semipalmated sandpipers at Kasegaluk Lagoon until mid-August, possibly indicating a delay in the movement of western sandpiper juveniles from tundra breeding areas to coastal staging areas, or from other breeding populations to northern Alaska (see above). This pattern is similar to one described by Jenni and Kéry (2003), in which peak fall passage times for short-distance migrant songbirds in Switzerland have been delayed 3.4 days over four decades. Of all common species staging on the northern Alaska coast, western sandpipers have the shortest total migration length (Wilson, 1994), so they may be more likely to delay staging and migration than other species with longer migration distances. Alternatively, this pattern may reflect the fact that 2006 was a relatively late year for spring phenology (six days later than the five-year average for snowmelt date measured at Barrow), which may have resulted in delayed onset of shorebird breeding and subsequent staging behavior.

Habitat Selection: Habitat selection by postbreeding shorebirds in this study was similar to the patterns of habitat use reported by Connors et al. (1981) from their studies at Point Barrow in 1975–79. Like us, they found evidence for several distinct foraging guilds (gravel beach, mudflat, and salt marsh/pond edge), and species composition of these guilds was comparable to ours. We interpret this similarity to mean that species-habitat associations for shorebirds staging along the northern Alaska coastline are relatively invariant through time. Anecdotal observations indicate that localized habitat availability and therefore selection by postbreeding shorebirds were likely affected by wind or weather patterns. Data that inform predictions of how wind speed/direction and rainfall affect water levels at coastal staging sites on the ACP would be particularly useful in understanding the mechanisms underlying variation in shorebird distribution and habitat selection, and in predicting how climate-related changes in weather patterns may affect habitat availability for staging shorebirds. For example, there were fewer dunlins and semipalmated sandpipers at Pea Island (North Carolina) and Merritt Island (Florida) National Wildlife Refuges as water depth increased, but dunlins preferred deeper water than semipalmated sandpipers at local scales (Collazo et al., 2002). In addition to knowledge of the amount of terrestrial habitat exposed, predictions of water levels along shorelines and in coastal ponds and lagoons are important because shorebird species staging on the ACP coast differ generally in size, and particularly in tarsus and bill length (both morphological characteristics that determine the depth of water in which the species is able to feed). Thus, variation in water levels may

affect habitat selection and species composition at a particular location.

Conservation Implications

Our data indicate that some littoral areas on the ACP attracted large numbers of shorebirds during our study (concentration areas) while other seemingly suitable areas were not as heavily used. Disturbance from industrial or anthropogenic development would have a larger impact on shorebirds at heavily used sites than at sites of lesser importance, although synergistic effects of disturbance and climate change are difficult to predict. Additionally, given existing infrastructure and the probable development of new oil and gas fields along the northern Alaska coast (Bird et al., 2008), the potential exists for a significant oil spill to occur somewhere in the ACP littoral zone during the ice-free season, when shorebirds are present. Such an event could affect a substantial segment of a shorebird species or population if it occurs near a postbreeding concentration area and results in oiling of birds' plumage or food supply. Juvenile shorebirds may be particularly susceptible to oiling: juvenile red and red-necked phalaropes did not at first differentiate between oiled and non-oiled surface water during trials conducted at Point Barrow (Connors et al., 1981). Habitat suitability could also be reduced through oiling of coastlines, which may reduce forage quality and availability. The impact of an oil spill could be extensive: because river and ocean currents and wind-driven waves move the oil along the coast, staging areas many kilometers from development sites may be affected.

Increasing industrial activity is also likely to increase the human footprint in the Arctic, which could affect patterns of species prevalence, distribution, and habitat use in unpredictable ways if artificial habitats, such as roads, pipelines, gravel pads, or treatment ponds, become more common. For example, over the course of the staging period in 2006, we counted 5512 phalaropes (almost half of the total observed on ground transects during 2006) in the Barrow sewage treatment lagoon. These individuals were not included in our analyses because they were not located on our survey transects, and there was no comparable habitat type at the other staging sites we studied. Should artificial habitats become common enough, some species may stage there preferentially, leading to changes in abundance of staging shorebirds in natural coastal habitats. This type of change would be important to consider when examining trends in postbreeding shorebird distribution and abundance through time.

Lastly, climate change may have obvious effects on Arctic bird populations via changes in timing of life history events (Walther et al., 2002). Our data indicate that dunlins and red phalaropes may have advanced the onset of staging in recent decades as a result of changing environmental conditions. Conversely, western sandpipers may be delaying the onset of their staging period. These data provide a baseline for developing testable hypotheses about

the effects of climate change on the length and timing of the staging period on the ACP coast. An understanding of how the initiation and termination of breeding and staging periods may change in response to changing climatic conditions is essential to developing monitoring protocols that account for variation in when individuals are most visible or available for observation. Repeating studies such as ours to document phenological changes resulting from changing environmental conditions will be important for long-term monitoring.

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