

Distribution of Breeding Shorebirds on the Arctic Coastal Plain of Alaska

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ABSTRACT. Available information on the distribution of breeding shorebirds across the Arctic Coastal Plain of Alaska is dated, fragmented, and limited in scope. Herein, we describe the distribution of 19 shorebird species from data gathered at 407 study plots between 1998 and 2004. This information was collected using a single-visit rapid area search technique during territory establishment and early incubation periods, a time when social displays and vocalizations make the birds highly detectable. We describe the presence or absence of each species, as well as overall numbers of species, providing a regional perspective on shorebird distribution. We compare and contrast our shorebird distribution maps to those of prior studies and describe prominent patterns of shorebird distribution. Our examination of how shorebird distribution and numbers of species varied both latitudinally and longitudinally across the Arctic Coastal Plain of Alaska indicated that most shorebird species occur more frequently in the Beaufort Coastal Plain ecoregion (i.e., closer to the coast) than in the Brooks Foothills ecoregion (i.e., farther inland). Furthermore, the occurrence of several species indicated substantial longitudinal directionality. Species richness at surveyed sites was highest in the western portion of the Beaufort Coastal Plain ecoregion. The broad-scale distribution information we present here is valuable for evaluating potential effects of human development and climate change on Arctic-breeding shorebird populations.

Key words: Alaska, Arctic, birds, breeding shorebirds, coastal plain, distribution, North Slope

Реферат. Имеющаяся информация о распространении гнездящихся куликов на Арктической прибрежной равнине Аляски устарела, имеет фрагментарный характер и ограниченный охват территории. В настоящей публикации мы описываем распределение 19 видов куликов на основании данных, собранных на 407 учетных площадках в период с 1998 по 2004 год. При сборе информации использовался метод быстрых одноразовых посещений в период установления гнездовых территорий и начала инкубации, когда демонстрационное поведение и вокализации куликов делают их наиболее заметными. Мы отмечали наличие каждого вида, а также указывали их общее число, получая таким образом общую картину регионального размещения видов куликов. Сравнивая и противопоставляя полученные нами карты распространения куликов с картами предыдущих исследований, мы смогли описать выраженные варианты размещения видов. Анализ изменения размещения и численности куликов в широтном и меридиональном направлениях в пределах Арктической прибрежной равнины Аляски показал, что большинство видов куликов чаще встречалось в экорегионе Прибрежной равнины моря Бофорта (то есть ближе к побережью), чем в экорегионе Подножья хребта Брукс (т.е. дальше вглубь суши). Более того, встречаемость некоторых видов свидетельствует о выраженной меридианальной направленности. Из всех обследованных участков богатство видового разнообразия было наибольшим в западной части экорегиона Прибрежной равнины моря Бофорта. Представленная здесь информация о широкомасштабном размещении куликов имеет особую ценность при оценке воздействия хозяйственного освоения и глобального изменения климата на популяции куликов, гнездящихся в Арктике.

Ключевые слова: Аляска, Арктика, птицы, гнездящиеся кулики, прибрежная равнина, распределение, Северный склон

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RÉSUMÉ. Les renseignements qui existent en matière de répartition des oiseaux de rivage en reproduction sur la plaine côtière de l'Arctique en Alaska sont anciens, fragmentés et restreints. Ici, nous décrivons la répartition de 19 espèces d'oiseaux de rivage à partir de données recueillies à 407 lieux de recherche entre 1998 et 2004. Cette information a été recueillie grâce à une technique de recherche consistant en une seule visite rapide durant les périodes d'établissement du territoire et de début d'incubation, périodes pendant lesquelles les comportements sociaux et les vocalisations permettent de bien repérer les oiseaux. Nous décrivons la présence ou l'absence de chaque espèce, de même que le nombre général d'espèces, ce qui procure une perspective régionale de la répartition des oiseaux de rivage. Nous comparons et contrastons nos cartes de répartition des oiseaux de rivage à celles d'études antérieures, en plus de décrire les tendances les plus marquées en matière de répartition des oiseaux de rivage. Notre examen de la variation latitudinale et longitudinale en matière de répartition et de nombre d'espèces d'oiseaux de rivage à l'échelle de la plaine côtière arctique de l'Alaska nous a permis de constater que la plupart des espèces d'oiseaux de rivage se manifestaient plus souvent dans la région écologique de la plaine côtière de Beaufort (c'est-à-dire plus proche de la côte) que dans la région écologique des contreforts de Brooks (c'est-à-dire plus à l'intérieur des terres). Par ailleurs, l'occurrence de plusieurs espèces indiquait une directionalité longitudinale substantielle. La richesse des espèces aux sites à l'étude était à son meilleur dans la partie ouest de la région écologique de la plaine côtière de Beaufort. Les renseignements sur la répartition à grande échelle que nous présentons ici jouent un rôle dans l'évaluation des effets éventuels des travaux de mise en valeur par l'être humain et du changement climatique sur les populations d'oiseaux de rivage en reproduction de l'Arctique.

Mots clés : Alaska, Arctique, oiseaux, oiseaux de rivage en reproduction, plaine côtière, répartition, versant nord

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INTRODUCTION

During June–September, the Arctic Coastal Plain of Alaska (hereafter Coastal Plain) provides important habitat for millions of shorebirds that breed in and migrate through the area (Johnson and Herter, 1989). At least 29 species breed on the Coastal Plain, and as many as six million birds are estimated to occur in the National Petroleum Reserve-Alaska (NPR-A) alone (King, 1979). These shorebirds and many other bird species migrate to nonbreeding areas in the southern parts of the Western Hemisphere, Southeast Asia, Oceania, Australia, and New Zealand (Hayman et al., 1986).

The worldwide populations of many shorebird species, including species that breed on the Coastal Plain, have recently declined (Brown et al., 2001; International Wader Study Group, 2003). Declines are suspected or have been documented for 11 shorebird species that regularly breed on the Coastal Plain (U.S. Shorebird Conservation Plan, 2004), and nine of these species have been classified as species of high concern or as highly imperiled at a hemispheric or global level (U.S. Shorebird Conservation Plan, 2004). Furthermore, the majority of the U.S. breeding populations of seven species occurs on the Coastal Plain (Alaska Shorebird Working Group, 2000).

Human alteration of land on the Coastal Plain may have negative consequences for shorebirds. New and expanding native villages, along with a recently legalized spring and summer subsistence harvest of shorebirds (Alaska Migratory Bird Co-Management Council, 2003), may negatively affect shorebirds through habitat alteration, hunting mortality, and subsequent population reduction. Oil production in the central portion of the Coastal Plain began in 1977 (Gilders and Cronin, 2000), and oil development has expanded in all directions over the past 30 years (National

Research Council, 2003). Besides the initial Prudhoe Bay Oil Field, at least nine additional fields have begun production (Gilders and Cronin, 2000). Recently, areas within the NPR-A previously closed to oil and gas exploration and development have been leased (U.S. Bureau of Land Management, 2006). Legislation has also been proposed to authorize oil exploration and development in a designated section (1002 Area) of the coastal plain of the Arctic National Wildlife Refuge (Arctic Refuge). Potential effects of oil and gas development on wildlife include the loss of habitat through the building of roads, pads, pipelines, dumps, gravel pits, and other infrastructure. Roads and pads also increase levels of dust, alter hydrology, thaw permafrost, and increase roadside snow accumulation (Auerbach et al., 1997; National Research Council, 2003). These impacts may decrease habitat quantity and quality for nesting shorebirds (Meehan, 1986; Troy Ecological Research Associates, 1993a; Auerbach et al., 1997). Furthermore, oil field infrastructure may enhance predator numbers by providing denning and nesting habitat and supplemental food (through human garbage) during winter months. An increase in predators may result in lower adult shorebird and nest survival (Eberhardt et al., 1983; Day, 1998; National Research Council, 2003). Lower adult survival and nesting success may create population sinks in the vicinity of human developments (National Research Council, 2003), especially for species with high site fidelity. Therefore, expanding oil development could have cumulative negative effects on breeding shorebirds of the Coastal Plain.

Climate change may also affect shorebird habitats and populations on the Coastal Plain by altering coastal and inland tundra habitats (Arctic Climate Impact Assessment, 2004). A rise in sea level is expected to change rates of sedimentation, permafrost aggradation and degradation,

storm frequency, and subsidence; all of these factors are likely to influence coastal geomorphology and perhaps invertebrate communities (Jorgenson and Ely, 2001; Rehfish and Crick, 2003). These changes may negatively affect shorebirds breeding in low-lying areas or staging in littoral areas prior to fall migration. Other habitat-altering effects are also likely. For example, climate models predict longer growing seasons and warmer temperatures, which are already thought to be responsible for northward advancement of shrubs (Sturm et al., 2001; Arctic Climate Impact Assessment, 2004). In addition, accelerated ice wedge degradation and accompanying thermokarst pond development have increased the proportion of land covered with surface water (Shur et al., 2003). These habitat changes may have both positive and negative effects on a particular shorebird species, and assemblage-wide effects are difficult to predict. Beyond direct effects on habitat conditions, earlier snowmelt may decouple the apparent synchrony between shorebird breeding chronology and food availability (MacLean, 1980). The timing and availability of surface-active insects is critical to shorebirds for egg production (Klaassen et al., 2001), chick growth (Schekkerman et al., 2003), and pre-migratory fattening (Connors et al., 1979, 1981; Connors, 1984; Andres, 1994). Decoupling of these events could negatively affect shorebird productivity and survival.

An important step in evaluating the potential impacts of human activities and climate change on shorebirds in the Coastal Plain is to document the current distribution of species. The earliest avifaunal accounts of coastal northern Alaska came from naturalists participating in Arctic expeditions (Nelson, 1883; Stone, 1900; Bishop, 1944), followed by museum collectors (Bailey, 1948) and taxonomists (Bee, 1958; Gabrielson and Lincoln, 1959; Kessel and Gibson, 1978; Gibson and Kessel, 1997). These accounts included natural history observations and a limited number of locations where species were collected or observed breeding. Quantitative ornithological studies on the Coastal Plain began with the International Biological Programme and the Coastal Tundra Biome Studies at Barrow in the 1970s (Brown et al., 1980). These programs focused on studies of breeding and postbreeding shorebirds (Pitelka, 1974; Myers and Pitelka, 1980). In anticipation of oil development, the U.S. government also initiated the Outer Continental Shelf Environmental Assessment Program (OCSEAP), which documented the nearshore marine resources along the Beaufort Sea coast (Engelmann, 1976; Connors et al., 1979; Barnes et al., 1984). Extensive aerial and ground-based surveys were also conducted in and outside of the Prudhoe Bay region (Gavin, 1975; Haddock and Evans, 1975; Norton et al., 1975; Bergman et al., 1977; Derksen et al., 1981). The potential for future oil development led to two additional large-scale ground studies on tundra areas in north-central Alaska (Field, 1993) and the Arctic Refuge (Garner and Reynolds, 1986). Additional pre-development and, more rarely, post-development studies of avifauna at oil exploration sites have been conducted

(e.g., Martin and Moitoret, 1981; Andres, 1989; Troy and Carpenter, 1990; Moitoret et al., 1996; Anderson et al., 2000; Cotter and Andres, 2000; Johnson et al., 2003). Notable contributions include a long-term study of birds at Point McIntyre (Troy Ecological Research Associates, 1993b) and extensive reviews of regional avifauna and their relationship to oilfield infrastructure and activities (Johnson and Herter, 1989; Truett and Johnson, 2000).

Despite more than 100 years of study, specific information on the breeding distribution of birds on the Coastal Plain remains limited and fragmented. This is particularly true for species like shorebirds that cannot be easily counted from aircraft. Unlike most waterfowl species, whose distributions are fairly well known (e.g., Mallek et al., 2004; Larned et al., 2005), shorebirds are described by references based primarily on checklists of birds detected near major villages, at oil field sites, along inland rivers, and at a limited number of remote inland sites (e.g., Bailey, 1948; Gabrielson and Lincoln, 1959; Kessel and Gibson, 1978; Johnson and Herter, 1989). Species distribution maps from the Birds of North America series (Poole and Gill, 2005) and field guides (e.g., Sibley, 2000; National Geographic Society, 2002) are very general, and may not accurately depict the regional distribution of shorebirds on the Coastal Plain.

As a first step towards a better description of shorebird distribution throughout the Coastal Plain, we conducted ground surveys at 625 sites. We report here the distribution of 19 species of breeding shorebirds and compare these results with previous descriptions of species distributions. We also evaluate patterns of species occurrences and species richness along latitudinal and longitudinal gradients defined by natural physiographic features.

STUDY AREA

Our study area in northern Alaska included land lower than 350 m in elevation north of the Brooks Range between Icy Cape in western Alaska and the Aichilik River near the Canadian border (Fig. 1). We chose 350 m as the elevation limit because the majority of shorebirds breed below this elevation (Johnson and Herter, 1989). The 107 000 km² study area is approximately 850 km from east to west and 25–220 km from north to south. Sampling was conducted in the Colville River delta and the eastern portion of the NPR-A in 1998–2000, throughout the NPR-A (from Icy Cape to the Colville River) in 2001, between the Colville River and the Aichilik River in 2002, and between the Canning and Aichilik rivers within the Arctic Refuge in 2004.

Continuous permafrost underlies most of the Coastal Plain, and shallow soils remain frozen between mid-September and mid-May (Black and Barksdale, 1949; Carson and Hussey, 1962). Coastal areas are typically snow-covered until early to mid-June, and ice often remains on deeper lakes until mid-July. Annual precipitation on the Coastal Plain is low, ranging from 10 to 30 cm

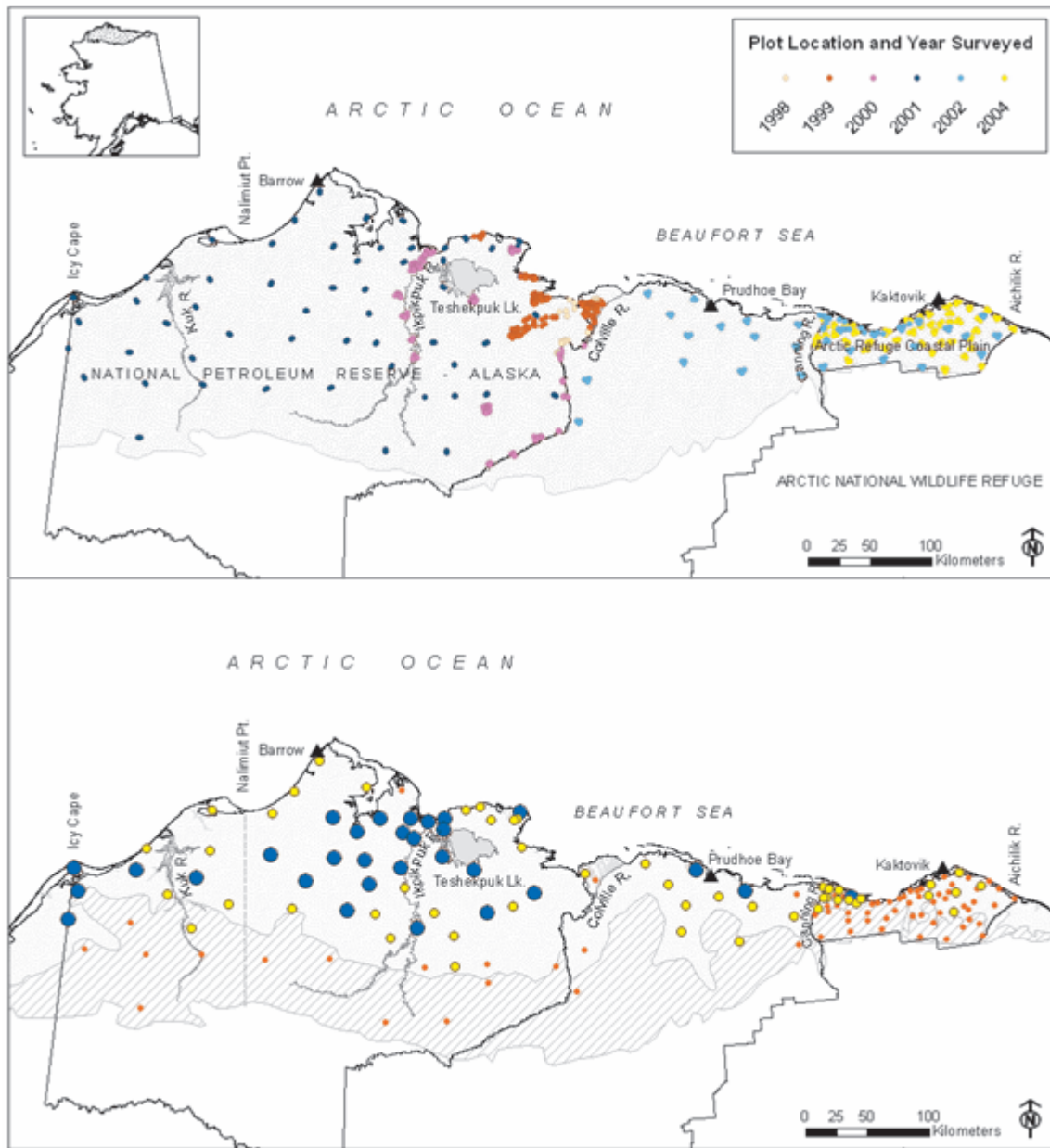


FIG. 1. (top) Location of the Arctic Coastal Plain of Alaska, major administrative boundaries, major riverine areas, and plots surveyed between 1998 and 2004. The study area is shaded. (bottom) Mean number of shorebird species at clusters sampled between 1998 and 2004 on the Arctic Coastal Plain of Alaska. Blue (large) circles define plots with 5.46–9.0 species, yellow (medium) circles have 2.71–5.45 species, and orange (small) circles have 0–2.70 species. The Beaufort Coastal Plain ecoregion is shaded and the Brooks Foothills ecoregion is striped.

(Gallant et al., 1995), but the combination of shallow permafrost, flat to rolling topography, and peaty soils allows much of the land surface to remain moist throughout the summer. The cool growing season is about six weeks long and has continuous daylight. The Coastal Plain is treeless (Gallant et al., 1995); low-lying areas are characterized by flooded, moist patterned (e.g., high- and low-centered polygons) and nonpatterned (e.g., meadows) wetlands, whereas well-drained and upland sites consist primarily of drier tundra (e.g., tussocks; see Walker and Acevedo, 1987; Markon and Derksen, 1994; Jorgenson et al., 1994). The most northern portion of the Coastal Plain is the wettest, with higher elevations and drier landscapes

in the south, west, and east. Several major rivers transect the study area from south to north. River corridors are characterized by extensive alluvial bars, and the dominant vegetation is dwarf (< 15 cm) to medium (< 2 m) shrubs (e.g., *Salix*, *Betula*, *Alnus* spp.).

METHODS

Estimates of animal distribution are affected by the spatial and temporal characteristics of the survey effort. We chose to describe the distribution of shorebirds on the Coastal Plain by using only the data collected during our

six-year study. We did this, despite the many other available sources of information, for three reasons. First, our survey method was relatively standardized across the entire Coastal Plain. Other studies varied tremendously in intensity of survey effort (days to months) and in enumeration methods (checklists to intensive studies of marked birds). Second, we were concerned that data from older studies might not accurately reflect current species ranges, since changes in habitat conditions through time are known to affect shorebird distributions (Jehl and Lin, 2001). Finally, the boundaries of our 1998–2004 study encompassed all the locations where previous studies had been conducted. Thus, our exclusion of these other data sets did not compromise our goal of describing shorebird distribution for the entire Coastal Plain. Importantly, we compare our results to those of other studies, which would not be possible if we had included their results.

Survey Approach

We conducted our surveys on the Coastal Plain using methods outlined in the Program for Regional and International Shorebird Monitoring (PRISM; Harrington et al., 2002; Skagen et al., 2003; Bart et al., 2005). The PRISM approach relies on double sampling to estimate bird abundance. Double sampling involves a primary sample of rapid surveys on a large number of plots and a secondary subsample of intensive surveys of these same plots to adjust counts for estimates of actual density (Bart and Earnst, 2002). For this study, we used only presence/absence data from the rapidly surveyed plots and did not adjust the count data by estimates of detectability obtained from intensive surveys.

General Plot Selection

Over our six-year study period, funding levels and specific protocols for Arctic PRISM varied, and there were minor variations in the methods used to select plots. In 1998–2000, we used fixed-winged aircraft or boats to access our survey sites, which limited the areas we could visit to within 10 km of rivers, airstrips, and other accessible locations. In these years, many plot boundaries followed natural borders between wetlands and uplands, and as a result, the size and shape of plots varied. In 2001, 2002, and 2004, we used a helicopter to visit a wider selection of sites. To maximize the number of plots that we could visit in a given day, we surveyed plots in clusters of two in 2001 and clusters of three in 2002 and 2004. We also standardized the size and shape of plots in 2002 and 2004, allowing observers to complete surveys in a similar amount of time.

Specific Plot Selection

Methods varied somewhat during the course of the study because PRISM protocols were under development,

and because studies in particular years had other goals in addition to documenting shorebird distribution.

In 1998–2000 (Fig. 1), we randomly selected plots from accessible areas that had previously been stratified into wet and dry classes using a land-cover classification derived from Landsat imagery (U.S. Dept. of the Interior, 2002). Areas classified as wetlands were 2–342 ha in size. For upland areas, we randomly selected a sample of 9 ha square plots; we excluded portions of the plots containing unsuitable habitats, such as open water or other habitats (e.g., mudflats) that were not used for nesting.

In 2001 (Fig. 1), we classified the study area into wetlands, uplands, and unsuitable habitats using the previously described land-cover map (U.S. Dept. of the Interior, 2002). We then selected random points to define the locations of two-plot clusters. We first determined the habitat in which the random point fell and then expanded away from this point by moving outward in all directions, without crossing a habitat border, until a plot size of 12–21 ha was obtained. If the point fell in unsuitable habitat, we selected another point. We then selected the second plot of the cluster within suitable habitat 1–3 km from the initial plot. The plot was then delineated by expanding outwards from the point as described above. If possible, we selected plots to include one wetland and one upland plot in each cluster. In early years, plots conformed to natural features; in later years, all plots were square.

In 2002 (Fig. 1), we randomly selected most plot locations without regard for habitat type. We used the procedure outlined for 2001 to select initial starting points and subsequent plot sites, but standardized plots to be 400 × 400 m (16 ha). A large portion of these randomly placed plots occurred in upland habitat types, where shorebird abundance and species richness (i.e., number of species) was low. As a result, we non-randomly selected additional plots near the coast.

We modified our placement of plots in 2004 (Fig. 1) to ensure that we surveyed sites located in other, rarer habitat types with potentially higher numbers of birds. We did this by first defining four composite habitat classes (riparian, flooded, very wet, and upland) from the 16 original land-cover classes developed for the Arctic Refuge coastal plain by Jorgenson et al. (1994). Second, we created a grid of 400 × 400 m (16 ha) cells over the Arctic Refuge coastal plain and calculated the cover of the composite classes within each. Third, we systematically located general areas stratified by latitude and longitude throughout the Arctic Refuge coastal plain as starting points to place plots. This procedure ensured plots were surveyed throughout the entire Arctic Refuge coastal plain, allowing us also to examine bird-habitat associations throughout this region (Brown et al., 2007). Finally, we randomly selected a grid cell as our starting plot within each of these general areas, and randomly chose two more plots within 3–5 km. We further modified the selection of plots by allocating more samples to classes with higher expected density based on Garner and Reynolds (1986).

Plot Survey Methods

We surveyed shorebirds between 8 June and 1 July, using a single-visit, rapid area search technique. Surveyors systematically traversed each plot and recorded the presence of all shorebirds seen or heard within the plot boundary. To locate plot boundaries, surveyors used natural changes in habitat type, land-cover maps, and handheld GPS units. On plot maps we recorded nests, probable nests, pairs, males, females, birds of unknown sex, and groups. For our presence/absence analyses, we included a small number of birds observed either on or just outside the plot boundaries, but only if their location and behavior indicated that a portion of their territory was within the plot. The time spent on plots was greater during the early years, when we covered about 7 ha in an hour, but we standardized coverage to 10 ha/h in 2001–04. Because of earlier snowmelt, and thus earlier initiation of breeding activities at inland sites, we typically surveyed inland plots before coastal plots, although sampling dates were on average only two days earlier for inland regions. Scheduling surveys in this manner ensured that we visited areas at the time when birds were most detectable.

Because of the short display period of Arctic-nesting shorebirds, we conducted surveys in most weather conditions except for periods of high winds, fog, and heavy precipitation. All surveyors practiced identification skills for several days before collecting data. Most surveyors had previously worked with shorebirds, and many participated in this study for two or more field seasons.

Data Analysis

We suspected that the probability of a species' occurrence would be influenced by varying plot size. Therefore, we restricted our analysis to plots that were 12–21 ha (the range of plot sizes sampled in 2001 and close to the 16 ha plot size used in 2002 and 2004). We combined small, adjacent plots if their combined area fell within our threshold size range. To help avoid potential influences of year-to-year temporal and phenological variation in species occurrence, we also restricted the analysis to plots surveyed during 8–23 June, the period when the majority of shorebirds are establishing territories and initiating nests. These dates also encompass the incubation period; however, they do not include the last week of incubation, when detection rates may decline substantially. These restrictions reduced the number of plots available for analysis from an initial sample of 625 to 407 plots. Most of the omitted data were from 1998–2000, the years when plot selection varied the most during the six-year study.

We subdivided the study area into ecoregional and longitudinal strata to test for spatial variation of species occurrences and species richness. We assigned plots to either a coastal or an inland ecoregion (e.g., Beaufort Coastal Plain or Brooks Foothills, Fig. 1; Nowacki et al., 2001), because certain species were more likely to occur in

the predominately wetter coastal or drier inland sites (Myers and Pitelka, 1980; Troy, 2000). We then divided plots on the Beaufort Coastal Plain into five areas demarcated by geographical features and major rivers: 1) Icy Cape to Nalimiut Point, 2) Nalimiut Point to the Ikpikpuk River, 3) the Ikpikpuk River to the Colville River, 4) the Colville River to the Canning River, and 5) the Canning River to the Aichilik River (Fig. 1). Because sampling intensity was lower in the Brooks Foothills, we grouped plots there into two longitudinal strata separated by the Colville River. We measured the area within each of the seven strata using ARCGIS® 9.0 (ESRI Inc., 2005).

Because plots were not chosen independently, especially in 1998–2000, we assigned groups of adjacent plots to clusters ($n = 144$), which we used as our sample units for analysis. We estimated a) the percentage of occurrence (and calculated the standard error) for each species and b) mean species richness (i.e., average number of species detected on plots in a cluster) across clusters within strata, using a stratified random estimator (Cochran, 1977: 89–110). We tested whether changes in species occurrence were concordant with changes in longitude across the Beaufort Coastal Plain strata, using Kendall's test for concordance (Hollander and Wolfe, 1973:185–199). Next, we determined whether species occurrences differed between ecoregions, using *t*-tests. We also tested whether mean species richness varied with ecoregion and longitudinal strata, with a series of *t*-tests. Because variances and sample sizes were not equal, we calculated the degrees of freedom for all *t*-tests using Satterthwaite's approximation (Snedecor and Cochran, 1980:97). We mapped the occurrence of each species and mean species richness using estimates from clusters of plots. However, for mapping purposes, we did subdivide clusters that spanned more than 20 km. This resulted in 149 mapping units. All means are reported \pm SE. Significance levels were set at $p = 0.05$, unless otherwise noted. Scientific names are provided in the section *Distribution of Individual Species*.

RESULTS AND DISCUSSION

Comparisons of Species Occurrence by Longitude and Ecoregion

We recorded 19 species of breeding shorebirds on 144 clusters (407 plots; Table 1). Only seven species occurred in more than 25% of the clusters across the entire study area (American golden-plover, semipalmated sandpiper, pectoral sandpiper, dunlin, long-billed dowitcher, red-necked phalarope, and red phalarope). The remaining species ($n = 12$) we detected were relatively rare and occurred on no more than 15% of surveyed clusters. Of these 12 rare species, eight occurred on 5% or less of clusters (Table 1).

There was strong longitudinal directionality ($p < 0.05$) for six of the 11 species tested. Bar-tailed godwits,

TABLE 1. Percent (\pm SE) of species occurrence in clusters within longitudinal strata and ecoregions of the Arctic Coastal Plain of Alaska. Species with a majority of their Alaskan breeding population occurring on the Coastal Plain (Alaska Shorebird Working Group, 2000) are highlighted in bold.

Species	Entire Study Area					Beaufort Coastal Plain					Brooks Foothills								
	Icy-Nal ¹	Nal-Ikp	Ikp-Col	Col-Can	Can-Aic	K ² N = 5	p-value	Icy-Col	Col-Aic	r ³	df	p-value	Icy-Nal ¹	Nal-Ikp	Ikp-Col	Col-Can	Can-Aic	K ² N = 5	p-value
Black-bellied plover	15.4 \pm 5.1	44.5 \pm 11.1	22.6 \pm 8.4	22.2 \pm 6.3	15.4 \pm 1.0	4	0.242	0.1 \pm 0.10	2.7 \pm 2.7	-0.962	24	0.346	20.0 \pm 8.2	44.5 \pm 11.1	22.6 \pm 8.4	22.2 \pm 6.3	15.4 \pm 1.0	4	0.242
American golden-plover	25.4 \pm 8.1	21.8 \pm 7.7	28.1 \pm 9.6	36.1 \pm 9.6	34.8 \pm 4.6	8	0.042	18.2 \pm 10.2	42.7 \pm 5.6	-2.106	17	0.050	5.0 \pm 5.0	21.8 \pm 7.7	28.1 \pm 9.6	36.1 \pm 9.6	34.8 \pm 4.6	8	0.042
Semipalmated plover	1.8 \pm 0.8	—	—	—	4.4 \pm 2.0	—	—	—	9.3 \pm 4.1	-2.268	24	0.033	—	—	—	—	4.4 \pm 2.0	—	—
Whimbrel	3.7 \pm 2.2	—	—	—	1.5 \pm 1.5	—	—	9.2 \pm 6.2	6.7 \pm 2.7	0.370	15	0.717	—	—	—	—	1.5 \pm 1.5	—	—
Bar-tailed godwit	12.4 \pm 6.4	14.9 \pm 8.3	8.7 \pm 5.0	8.3 \pm 6.0	4.4 \pm 1.7	10	0.008	18.2 \pm 7.7	1.3 \pm 1.3	2.164	11	0.053	25.0 \pm 13.4	14.9 \pm 8.3	8.7 \pm 5.0	8.3 \pm 6.0	4.4 \pm 1.7	10	0.008
Ruddy turnstone	1.9 \pm 1.4	3.3 \pm 2.8	6.0 \pm 4.2	—	0.7 \pm 0.7	—	—	—	1.3 \pm 1.3	-1.000	24	0.327	—	—	—	—	0.7 \pm 0.7	—	—
Sanderling	> 0.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Semipalmated sandpiper	42.6 \pm 7.0	80.8 \pm 8.1	69.7 \pm 9.0	66.7 \pm 10.1	47.4 \pm 4.8	8	0.042	4.6 \pm 4.6	12.0 \pm 4.3	-1.175	28	0.250	70.0 \pm 11.1	80.8 \pm 8.1	69.7 \pm 9.0	66.7 \pm 10.1	47.4 \pm 4.8	8	0.042
Western sandpiper	15.3 \pm 5.9	16.8 \pm 7.2	—	—	0.7 \pm 0.7	—	—	22.5 \pm 12.3	—	1.892	11	0.085	60.0 \pm 12.5	16.8 \pm 7.2	—	—	0.7 \pm 0.7	—	—
White-rumped sandpiper	2.8 \pm 1.7	2.4 \pm 2.4	14.2 \pm 6.8	—	0.7 \pm 0.7	—	—	—	—	—	—	—	—	—	—	—	0.7 \pm 0.7	—	—
Baird's sandpiper	2.9 \pm 1.8	7.2 \pm 3.9	2.8 \pm 2.8	5.6 \pm 3.8	2.2 \pm 1.3	—	—	—	—	—	—	—	—	—	—	—	2.2 \pm 1.3	—	—
Pectoral sandpiper	50.3 \pm 5.8	83.6 \pm 7.0	82.4 \pm 6.4	80.6 \pm 5.0	52.6 \pm 5.0	10	0.008	4.8 \pm 4.7	21.3 \pm 5.7	-2.233	33	0.032	90.0 \pm 6.7	83.6 \pm 7.0	82.4 \pm 6.4	80.6 \pm 5.0	52.6 \pm 5.0	10	0.008
Dunlin	30.1 \pm 5.9	73.1 \pm 10.5	60.7 \pm 10.6	33.3 \pm 9.2	14.1 \pm 4.0	6	0.117	—	—	—	—	—	50.0 \pm 14.9	73.1 \pm 10.5	60.7 \pm 10.6	33.3 \pm 9.2	14.1 \pm 4.0	6	0.117
Stilt sandpiper	10.0 \pm 3.6	23.2 \pm 9.3	13.0 \pm 5.8	27.8 \pm 6.9	15.6 \pm 3.1	4	0.242	0.2 \pm 0.1	5.3 \pm 2.5	-2.038	24	0.053	—	—	—	—	—	—	—
Buff-breasted sandpiper	4.9 \pm 3.0	11.9 \pm 8.9	5.7 \pm 3.9	19.4 \pm 8.7	8.1 \pm 2.6	4	0.242	—	—	—	—	—	—	—	—	—	8.1 \pm 2.6	4	0.242
Long-billed dowitcher	37.0 \pm 9.0	59.2 \pm 11.0	48.4 \pm 9.1	52.8 \pm 9.6	12.6 \pm 3.4	8	0.042	22.7 \pm 10.4	5.3 \pm 3.2	1.600	13	0.134	70.0 \pm 13.3	59.2 \pm 11.0	48.4 \pm 9.1	52.8 \pm 9.6	12.6 \pm 3.4	8	0.042
Wilson's snipe	2.1 \pm 1.9	—	0.4 \pm 0.4	2.8 \pm 2.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Red-necked phalarope	28.5 \pm 8.3	46.2 \pm 8.4	23.9 \pm 8.7	33.3 \pm 9.2	40.7 \pm 4.2	4	0.242	4.7 \pm 4.6	2.7 \pm 1.9	0.402	14	0.694	55.0 \pm 11.7	46.2 \pm 8.4	23.9 \pm 8.7	33.3 \pm 9.2	40.7 \pm 4.2	4	0.242
Red phalarope	32.4 \pm 6.6	67.3 \pm 7.5	53.2 \pm 10.3	38.9 \pm 10.7	20.0 \pm 4.7	10	0.008	4.5 \pm 4.5	1.3 \pm 1.3	0.683	12	0.508	70.0 \pm 11.1	67.3 \pm 7.5	53.2 \pm 10.3	38.9 \pm 10.7	20.0 \pm 4.7	10	0.008
Total Area (km ²)	107 474	17 666	16 217	9930	4446			29 433	18 402				11 380	17 666	16 217	9930	4446		
# of clusters	144	21	19	12	45			12	25				10	21	19	12	45		
# of plots	407	50	59	36	135			32	75				20	50	59	36	135		

¹ Icy-Nal = region between Icy Cape and Nalimut Point, Nal-Ikp = region between Nalimut Point and Ikpikpuk River, Ikp-Col = region between the Ikpikpuk and Colville rivers, Col-Can = region between the Colville and Canning rivers, Can-Aic = region between the Canning and Aichilik rivers.

² Kendall's Coefficient of Concordance was used to test whether changes in occurrence were concordant with changes in longitude across Beaufort Coastal Plain strata.

³ *t*-tests were used to test for differences between Brooks Foothills strata.

semipalmated sandpipers, pectoral sandpipers, long-billed dowitchers, and red phalaropes occurred most frequently in the clusters in the west and decreased to the east. Conversely, the occurrence of American golden-plovers was highest in the east and decreased to the west (Table 1). There was no significant directional trend in the occurrences of western sandpipers and dunlins across the five longitudinal strata (Table 1). However, when we separated the Beaufort Coastal Plain into two strata—Icy Cape to Colville River and Colville River to Aichilik River—a high degree of directionality was apparent. The percentage of clusters with western sandpipers was significantly higher in the west (21.6% \pm 6%) than in the east (0.3% \pm 0.5%; *t* = 3.54, *df* = 49, *p* = 0.001). Dunlins followed a similar pattern, occurring in a significantly higher percentage of clusters in the west (62.8% \pm 11.6%) than in the east (28.1% \pm 9.1%; *t* = 2.35, *df* = 96, *p* = 0.021).

Species occurrences in the Brooks Foothills ecoregion were, in general, more evenly distributed among strata; however, some substantial differences were noteworthy. For example, the occurrences of bar-tailed godwits and western sandpipers were nearly significantly higher in the western foothills than in the eastern foothills (Table 1). Conversely, American golden-plover, semipalmated plover, and pectoral sandpiper occurrences were significantly higher, and the occurrences of Baird's sandpipers and stilt sandpipers were nearly significantly higher, in the eastern foothills stratum (Table 1). The closeness of the Brooks Foothills to the coast in the eastern portion of our study area likely influences the occurrence of breeding shorebirds there.

Eight species occurred more frequently (*p* < 0.05) in the Beaufort Coastal Plain than in the Brooks Foothills (Table 2). Only one species, the semipalmated plover, occurred more frequently (*p* < 0.05) in the Brooks Foothills (Table 2). For the remaining species, there were no significant differences in occurrence between the Beaufort Coastal Plain and Brooks Foothills clusters (Table 2).

TABLE 2. Percent (\pm SE) of species occurrence in clusters within the Beaufort Coastal Plain and the Brooks Foothills ecoregions, Arctic Coastal Plain of Alaska.

Species	Beaufort Coastal Plain (n = 107)	Brooks Foothills (n = 37)	t^1	df	p -value
Black-bellied plover	27.0 \pm 8.3	1.1 \pm 1.1	3.093	109	0.002
American golden-plover	23.7 \pm 7.8	27.6 \pm 8.4	-0.340	99	0.734
Semipalmated plover	0.3 \pm 0.1	3.6 \pm 1.6	-2.059	36	0.047
Whimbrel	0.1 \pm 0.1	8.2 \pm 4.9	-1.653	36	0.107
Bar-tailed godwit	12.9 \pm 7.4	11.7 \pm 5.2	0.133	137	0.895
Ruddy turnstone	2.9 \pm 2.1	0.5 \pm 0.5	1.112	117	0.268
Sanderling	0.1 \pm 0.001	–	1.000	118	0.320
Semipalmated sandpiper	70.9 \pm 9.0	7.4 \pm 4.5	6.311	139	0.0001
Western sandpiper	16.5 \pm 4.6	13.8 \pm 7.6	0.304	64	0.762
White-rumped sandpiper	4.6 \pm 2.6	0.5 \pm 0.5	1.549	113	0.125
Baird's sandpiper	4.0 \pm 2.6	1.5 \pm 0.9	0.909	127	0.365
Pectoral sandpiper	81.7 \pm 6.3	11.2 \pm 5.1	8.700	128	0.0001
Dunlin	54.3 \pm 10.7	–	5.075	106	0.0001
Stilt sandpiper	16.2 \pm 5.7	2.2 \pm 1.0	2.419	112	0.017
Buff-breasted sandpiper	8.9 \pm 5.3	–	1.679	106	0.096
Long-billed dowitcher	53.8 \pm 10.1	16.0 \pm 7.6	2.991	133	0.003
Wilson's snipe	0.6 \pm 0.006	3.9 \pm 0.03	-0.929	38	0.359
Red-necked phalarope	39.3 \pm 8.9	15.1 \pm 7.5	2.079	124	0.040
Red phalarope	55.7 \pm 9.3	3.3 \pm 3.3	5.310	128	0.0001
Mean Species Richness	4.7 \pm 0.4	1.3 \pm 0.3	7.080	118	0.0001

¹ t -tests were used to determine whether species occurrence differed between ecoregions.

Comparisons of Species Richness by Longitude and Ecoregion

Species richness patterns were evident at multiple longitudinal scales. The mean number of species in the Beaufort Coastal Plain was significantly higher in the Icy Cape to Colville River stratum (5.0 \pm 0.37 species) than in the Colville River to Aichilik River stratum (3.9 \pm 0.41 species; $t = 2.07$, $df = 104$, $p = 0.041$). In addition, the mean number of species decreased from west to east and was more than twice as high in the Nalimiut Point to Ikpiqpuq River stratum (5.6 \pm 0.40 species) as in the Canning River to Aichilik River stratum (2.6 \pm 0.19 species; Table 3). Pair-wise comparisons indicated that the Canning River to Aichilik River stratum had significantly lower species richness values than all other strata (all $p < 0.004$; Table 3). The remaining strata did not significantly differ from each other (Table 3, $p > 0.005$) when accounting for multiple comparisons. The mean number of species in the two longitudinal strata within the Brooks Foothills did not differ significantly (1.2 \pm 0.42 and 1.3 \pm 0.2, $t = 0.24$, $df = 15$, $p = 0.809$).

The mean species richness observed in the Beaufort Coastal Plain clusters (4.7 \pm 0.4 species) was nearly four times as high as that in the Brooks Foothills clusters (1.3 \pm 0.3; $t = 7.08$, $df = 118$, $p = 0.0001$).

The species richness map of the study area (Fig. 1) shows that mean species richness was highest in the Beaufort Coastal Plain and lowest in the Brooks Foothills. Areas with high mean species richness include Icy Cape in the west, Admiralty Bay, the Alaktak River, the Ikpiqpuq River and delta, Teshekpuk Lake, and Fish Creek in the central portion of the NPR-A, and Prudhoe Bay and the Canning River delta in the eastern portion of the study

area. Within the NPR-A, mean species richness was typically lower on the coast compared to inland areas.

Distribution of Individual Species

Distribution maps for the 19 shorebird species recorded in this study are presented in taxonomic order in Figures 2–8. Below, we briefly summarize the distribution pattern for each species and compare it to published references.

Black-bellied plover (*Pluvialis squatarola*): Black-bellied plovers occurred on 15.4% of our survey clusters (Table 1). The majority of observations were located in the central portion of the NPR-A and the north-central region of the Coastal Plain (e.g., Prudhoe Bay Oil Field; Fig. 2, Table 1). We rarely observed black-bellied plovers on the Arctic Refuge. Detections of the species occurred primarily in the Beaufort Coastal Plain (Table 2). This distribution pattern is consistent with that reported by Bailey (1948), Gabrielson and Lincoln (1959), and Johnson and Herter (1989), but the range of sightings appears to be more restricted than that indicated by Paulson (1995).

American golden-plover (*Pluvialis dominica*): Surveyors encountered American golden-plovers on 25.4% of clusters (Table 1). The species was distributed throughout the Beaufort Coastal Plain (Fig. 2, Table 1), with the notable exception of a paucity of sightings west of Nalimiut Point. This pattern coincides with statements by other authors indicating that the species occurs throughout the Coastal Plain east of Point Barrow (Gabrielson and Lincoln, 1959; Johnson and Herter, 1989; Johnson and Connors, 1996). Unlike many other species, which occurred more frequently in the Beaufort Coastal Plain, American golden-plovers occurred slightly more frequently in the Brooks Foothills (Table 2). Additionally, the species

TABLE 3. Pairwise comparisons of mean number of species (\pm SE) and sample sizes (plots, clusters) by longitudinal strata within the Beaufort Coastal Plain ecoregion, Arctic Coastal Plain of Alaska.

	Icy – Nal ¹ 5.15 \pm 0.29 (20, 10)	Nal – Ikp 5.56 \pm 0.40 (50, 21)	Ikp – Col 4.39 \pm 0.38 (59, 19)	Col – Can 4.28 \pm 0.41 (36, 12)	Can – Aic 2.62 \pm 0.19 (135, 45)
Icy – Nal	—				
Nal – Ikp	0.412 ²	—			
Ikp – Col	0.128	0.042	—		
Col – Can	0.101	0.033	0.841	—	
Can – Aic	0.0001	0.0001	0.003	0.002	—

¹ Icy-Nal = region between Icy Cape and Nalimiut Point, Nal-Ikp = region between Nalimiut Point and Ikpikpuk River, Ikp-Col = region between the Ikpikpuk and Colville rivers, Col-Can = region between the Colville and Canning rivers, Can-Aic = region between the Canning and Aichilik rivers.

² Results of t-tests are deemed significantly different if $p \leq 0.005$.

occurred more frequently in the eastern Brooks Foothills stratum than the west. It was especially prevalent in the Brooks Foothills within the Arctic Refuge (Fig. 2). This pattern may be best explained by the propensity of this species to nest in upland habitats near wetlands; this juxtaposition of habitats occurs most frequently in the eastern portion of the study area, where the Brooks Foothills are close to the coast.

Semipalmated plover (*Charadrius semipalmatus*): We rarely observed this species during our study (1.8% of clusters; Table 1). All sightings were along riparian areas within the Arctic Refuge (Fig. 2). The use of riparian areas, especially along inland rivers, was reported by Bailey (1948), Magoun and Robus (1977), and Johnson and Herter (1989). Had we sampled riparian areas in greater frequency in other parts of the study area, we suspect we would have documented the species over a larger area. Nevertheless, the large distribution area reported by Nol and Blanken (1999) certainly overestimates the occurrence of this species on the Coastal Plain, given its use of this restricted habitat type.

Whimbrel (*Numenius phaeopus*): Our data suggest the distribution of the whimbrel is much more restricted than that reported by Skeel and Mallory (1996). We recorded the species on 3.7% of clusters, which were located primarily in the Brooks Foothills within the NPR-A and Arctic Refuge (Table 1, Fig. 3). This distribution, primarily within upland habitats, matches that described by Johnson and Herter (1989).

Bar-tailed godwit (*Limosa lapponica*): This species occurred on 12.4% of the clusters, with almost all observations west of the Colville River delta, including the northeast and central portions of the NPR-A (Table 1, Fig. 3). We detected bar-tailed godwits evenly in both Beaufort Coastal Plain and Brooks Foothills ecoregions (Table 2), and they occurred more frequently in the western portion of the foothills ecoregion (Table 1). This distribution is consistent with that reported by Bailey (1948) and Gabrielson and Lincoln (1959), but is much reduced from that reported by McCaffery and Gill (2001).

Ruddy turnstone (*Arenaria interpres interpres*): Ruddy turnstones occurred on 1.9% of clusters in a patchy

distribution along the coast, in or near major river corridors, and at a few inland sites (Table 1, Fig. 3). This distribution is similar to that reported by Johnson and Herter (1989). Our observations of ruddy turnstones along gravel bars of major rivers and coastal vegetated mudflats agree with reports by Magoun and Robus (1977). The paucity of sightings of this species may be due to the small number of plots in coastal and riparian areas, which are preferred habitats for the species. Nevertheless, the breeding distribution reported by Nettleship (2000) likely overestimates the species presence in the western Arctic.

Sanderling (*Calidris alba*): We recorded sanderling only once in the western portion of the Arctic Refuge (Table 1, Fig. 4). Our lack of observations is consistent with the fact that the species breeds primarily in the eastern Arctic of North America; however, it was previously reported to be a casual breeder at Point Barrow (Kessel and Gibson, 1978; MacWhirter et al., 2002).

Semipalmated sandpiper (*Calidris pusilla*): The semipalmated sandpiper was the second most commonly observed species in our study. It occurred on 42.6% of the clusters surveyed (Table 1). We observed this species more frequently in the west than in the east, and primarily in the Beaufort Coastal Plain (Fig. 4, Tables 1 and 2). This distribution pattern and common occurrence are consistent with reports by Bailey (1948), Gabrielson and Lincoln (1959), Johnson and Herter (1989), and Gratto-Trevor (1992).

Western sandpiper (*Calidris mauri*): This species breeds primarily on the Yukon–Kuskokwim delta, and is thought to be a rare breeder on the Coastal Plain (Gabrielson and Lincoln, 1959; Johnson and Herter, 1989). Wilson (1994) lists the species as breeding in only three small areas near Icy Cape, Barrow, and Camden Bay. Our data suggest the western sandpiper is much more common than previously reported, especially in the western portion of the NPR-A (Fig. 4). Indeed, we recorded the species on 15.3% of all clusters, and all but two observations were west of the Ikpikpuk River (Table 1, Fig. 4).

White-rumped sandpiper (*Calidris fuscicollis*): We rarely observed this species during our study (2.8% of surveyed clusters, Table 1) and detected it only in extreme

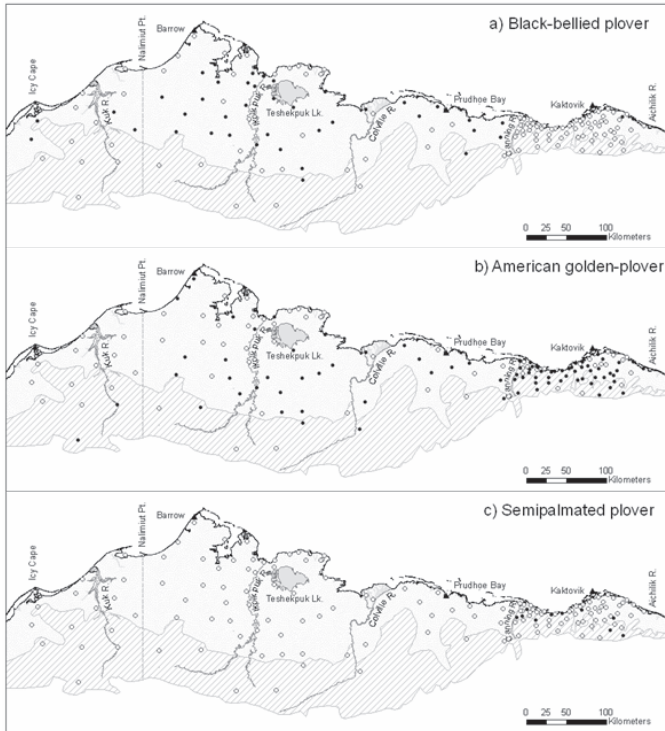


FIG. 2. Distribution of the a) black-bellied plover, b) American golden-plover, and c) semipalmated plover detected on clusters surveyed between 1998 and 2004. Points represent locations where the species was detected (black) or not detected (white).

coastal sites at Cape Simpson and Cape Halkett in the NPR-A and one inland site on the Arctic Refuge (Fig. 5). These observations are consistent with published reports that described this species as a rare or uncommon breeder on the Coastal Plain (Gabrielson and Lincoln, 1959; Kessel and Gibson, 1978; Johnson and Herter, 1989). We did not observe any birds near Prudhoe Bay even though numerous spring records have been documented there (Johnson and Herter, 1989). As with the other rarer species, the distribution appears to be far more restricted than that indicated by Parmelee (1992).

Baird's sandpiper (*Calidris bairdii*): We rarely detected this species during our surveys (2.9% of all clusters), and the observations occurred in very disjunct locations (Table 1, Fig. 5). We recorded the species on the western side of the Arctic Refuge, in the Prudhoe Bay area, and near Pitt Point and the Meade River in the NPR-A. Our data suggest that the distribution of Baird's sandpipers is much more restricted than suggested by Moskoff and Montgomerie (2002), probably because of the species' preference for well-drained, stony ridges and riparian habitats for nesting (Johnson and Herter, 1989). Our observations might have increased if we had sampled these habitats more intensively.

Pectoral sandpiper (*Calidris melanotos*): The pectoral sandpiper was the species encountered most frequently during our surveys and occurred on 50% of clusters (Fig. 5, Table 1). The species' frequency of occurrence decreased from west to east and was almost eight times as

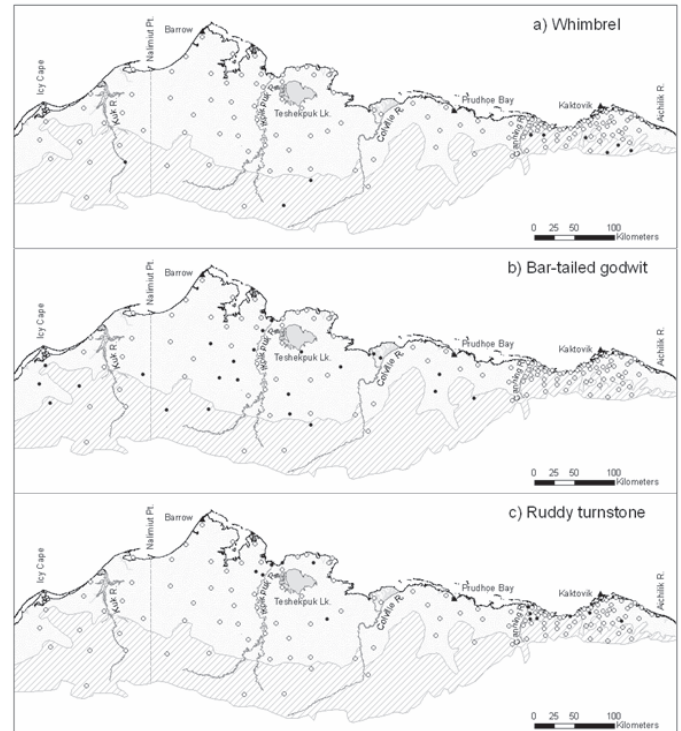


FIG. 3. Distribution of the a) whimbrel, b) bar-tailed godwit, and c) ruddy turnstone detected on clusters surveyed between 1998 and 2004. Points as in Figure 2.

high on the Beaufort Coastal Plain as in the Brooks Foothills (Tables 1 and 2). This distribution closely mirrors those previously reported for the species (Bailey, 1948; Gabrielson and Lincoln, 1959; Johnson and Herter, 1989; Holmes and Pitelka, 1998). Although the abundance of this species fluctuates dramatically from year to year in any one location (Holmes and Pitelka, 1998), the fact that the species shows up over such a large geographic area sampled over a six-year period suggests that it is widely distributed and that annual population changes do little to affect our detection of the species at a cluster level.

Dunlin (*Calidris alpina arctica*): This subspecies of dunlin was the fifth most common shorebird observed and was present on 30% of clusters (Table 1). It was entirely absent from the Brooks Foothills but was found on the majority of coastal plots within the NPR-A and the north-central portions of the Coastal Plain (Fig. 6, Tables 1 and 2). The majority of detections in the Arctic Refuge were in coastal areas west of Camden Bay or along the Canning River (Fig. 6). The lack of observations in the eastern portions of the Arctic Refuge is similar to that reported by Magoun and Robus (1977), and the overall distribution is mostly consistent with that reported by Johnson and Herter (1989) and Warnock and Gill (1996).

Stilt sandpiper (*Calidris himantopus*): We recorded stilt sandpipers on 10% of clusters (Table 1). The species was evenly distributed at coastal sites in central and eastern portions of the Coastal Plain, but was notably absent west of Cape Barrow (Fig. 6). This distribution is consistent

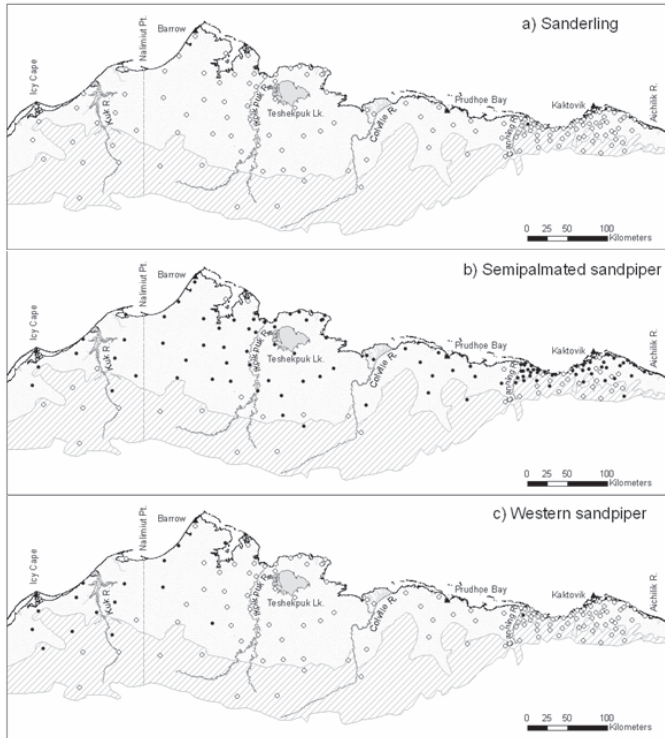


FIG. 4. Distribution of the a) sanderling, b) semipalmated sandpiper, and c) western sandpiper detected on clusters surveyed between 1998 and 2004. Points as in Figure 2.

with that reported by Garner and Reynolds (1986), who described the species as being a fairly common breeder in the coastal areas of the Arctic Refuge. The species also occurred (although not frequently) at inland locations, which is outside the suspected breeding range reported by Klima and Jehl (1998).

Buff-breasted sandpiper (*Tryngites subruficollis*): This species occurred on nearly 5% of clusters during our surveys (Table 1). We observed buff-breasted sandpipers near the Ikpikpuk, Canning, and Hulahula rivers and at a small number of inland sites (Fig. 6). These limited observations and sporadic distribution are consistent with the reported rarity of this species on the Coastal Plain (Kessel and Gibson, 1978; Johnson and Herter, 1989). Our observations do not support Lanctot and Laredo's (1994) view that the species occurs throughout the coastal portion of the Coastal Plain, but are consistent with the contention that the species occurs only east of Barrow. The limited number of observations is also likely due to the species' very specific habitat preferences, such as river bluffs and terraces, which are rare and were not sampled intensively. Furthermore, buff-breasted sandpipers, like pectoral sandpipers, vary in density from year to year (Lanctot and Weatherhead, 1997). This species was one of three species (see sanderling and dunlin) observed only in the Beaufort Coastal Plain (Tables 1 and 2).

Long-billed dowitcher (*Limnodromus scolopaceus*): Long-billed dowitchers were the third most frequently encountered species (37% of clusters; Table 1). The species

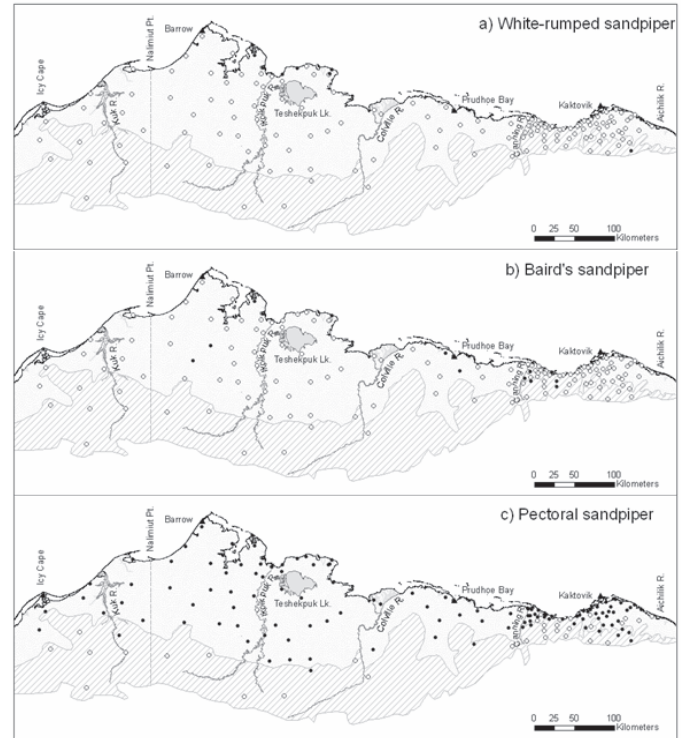


FIG. 5. Distribution of the a) white-rumped sandpiper, b) Baird's sandpiper, and c) pectoral sandpiper detected on clusters surveyed between 1998 and 2004. Points as in Figure 2.

occurred more frequently in the western strata of the coastal plain ecoregion than in the east and was recorded primarily in the Beaufort coastal plain (Table 2). It was found throughout most of the NPR-A and the north-central region and occurred on only a small number of sites in the Arctic Refuge (Fig. 7). This agrees with the distribution pattern described by Bailey (1948), Gabrielson and Lincoln (1959), and Takekawa and Warnock (2000). Our observations, however, disagree with those of Johnson and Herter (1989), who indicated that the species was present in many sites in the Arctic Refuge.

Wilson's snipe (*Gallinago delicata*): Mueller (1999) described Wilson's snipe breeding throughout the Coastal Plain, whereas earlier reports indicated the species occurs in discrete areas, including the Colville River delta, Prudhoe Bay, and the coastal plain of the Arctic Refuge (Gabrielson and Lincoln, 1959; Johnson and Herter, 1989). Our data (2.1% of clusters) support the earlier reports of a more restricted range, although the majority of our records were in the Brooks Foothills across the entire Coastal Plain (Table 1, Fig. 7). The snipe was one of the few species that were more frequently observed in the Brooks Foothills than in the Beaufort Coastal Plain (Table 2).

Red-necked phalarope (*Phalaropus lobatus*): Red-necked phalaropes occurred on 28.5% of our clusters (Table 1). The distribution of the two phalarope species was similar, although red-necked phalaropes were less likely to be seen near the coast on the NPR-A, occurred farther east in the Arctic Refuge, and were more frequently

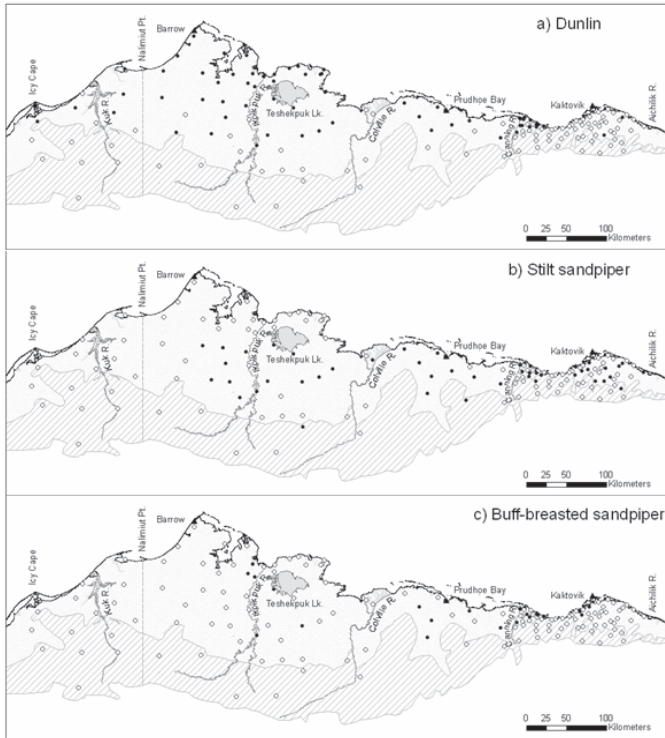


FIG. 6. Distribution of the a) dunlin, b) stilt sandpiper, and c) buff-breasted sandpiper detected on clusters surveyed between 1998 and 2004. Points as in Figure 2.

detected in the Brooks Foothills ecoregion (Table 2, Figs. 7, 8). The widespread distribution of this species was previously reported by Gabrielson and Lincoln (1959) and Rubega et al. (2000), but its propensity to occur more frequently at inland wet-tundra locations than at coastal sites was reported only by Johnson and Herter (1989).

Red phalarope (*Phalaropus fulicarius*): This species was the fourth most commonly observed species, present on 32.4% of clusters (Table 1). Although detected throughout the Coastal Plain, the species was rarer east of the Colville River and was found primarily in coastal areas (Fig. 8, Tables 1 and 2). Other authors have indicated that red phalaropes tend to occur in coastal sites throughout the Coastal Plain (Bailey, 1948; Gabrielson and Lincoln, 1959; Tracy et al., 2002), but only Johnson and Herter (1989) also reported the species' becoming rarer farther east and inland. We do not believe that the tendency of this species to shift its primary breeding area from year to year (Schamel and Tracy, 1977) affected the overall distribution pattern of the species, although it may have affected detection of the species at a given plot.

Summary of Shorebird Distribution

Comparison of species occurrences revealed several prominent patterns. The first pattern includes three of the most commonly observed species, semipalmated sandpiper, pectoral sandpiper, and red-necked phalarope; all occurred throughout the Beaufort Coastal Plain and were

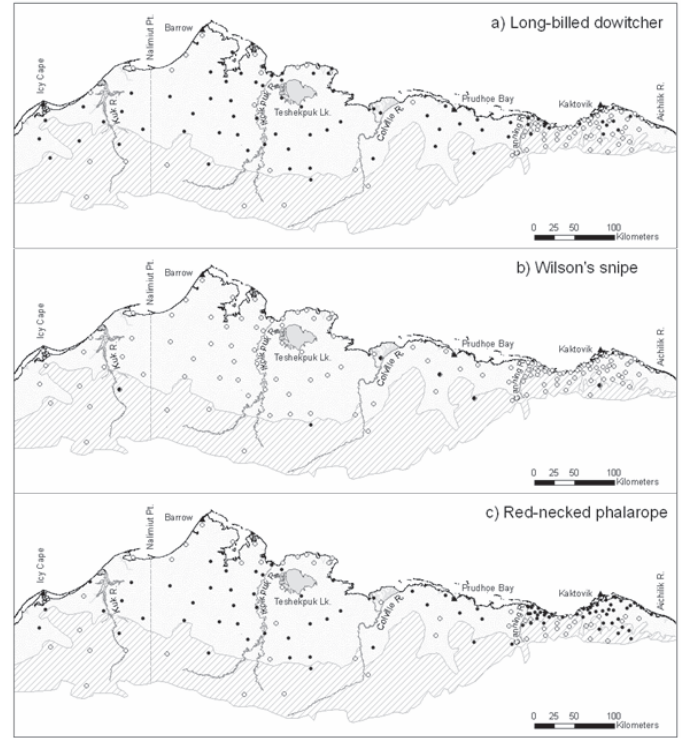


FIG. 7. Distribution of the a) long-billed dowitcher, b) Wilson's snipe, and c) red-necked phalarope detected on clusters surveyed between 1998 and 2004. Points as in Figure 2.

infrequently detected in the foothills. The long-billed dowitcher and red phalarope came close to following this pattern, but were less prevalent in the Arctic Refuge. A second pattern includes three species, the black-bellied plover, dunlin, and stilt sandpiper, that occurred less frequently in the Brooks Foothills but were concentrated in the central portion of the Beaufort Coastal Plain (e.g., Colville River delta, eastern NPR-A, Prudhoe Bay region). The American golden-plover had a third distribution pattern; it increased in occurrence from west to east and was one of the few species to occur equally in the Beaufort Coastal Plain and Brooks Foothills ecoregions. A fourth pattern includes species found in more limited regions or habitats. These included the western sandpiper, found principally in the western Coastal Plain, where it occurred equally in the Beaufort Coastal Plain and Brooks Foothills ecoregions; white-rumped sandpiper, Baird's sandpiper, and buff-breasted sandpiper, found in disjunct regions of the Coastal Plain; semipalmated plover and ruddy turnstone, found along riparian or gravel coastal areas; and whimbrel and Wilson's snipe, found in disjunct regions close to major rivers and in the Brooks Foothills ecoregion. We suspect that these patterns may be influenced by spring migration routes. For example, species that migrate to the Coastal Plain from the Central Flyway (e.g., American golden plover, stilt sandpiper) occurred more frequently in the eastern and central portions of the study area. Conversely, species that migrate to the Coastal Plain from the Pacific Flyway (e.g., bar-tailed godwit and

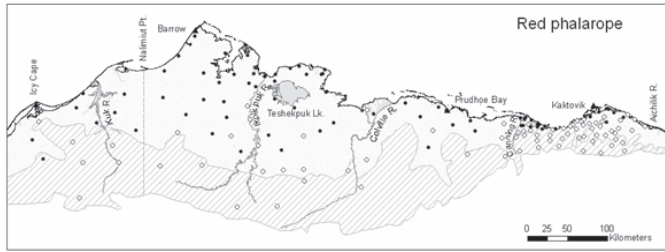


FIG. 8. Distribution of the red phalarope detected on clusters surveyed between 1998 and 2004. Points as in Figure 2.

western sandpiper) primarily occurred in the western portion of the Coastal Plain (S. Johnson, pers. comm. 2006).

Mean species richness values also indicated several prominent spatial patterns in shorebird species occurrence. The proportion of clusters in the Beaufort Coastal Plain ecoregion with high mean values for species richness (i.e., > 5.5 species/cluster) was substantially greater west of the Colville River (54.0%) than to the east (5.3%). Prominent sites with high values included the central portion of the NPR-A, including Admiralty Bay, the Alaktak River, the Ikpikpuk River and delta, and the area surrounding Teshekpuk Lake. East of the Colville River, high species richness values occurred near Prudhoe Bay and either in or just west of the Canning River delta. In contrast, there were only two clusters (1.3%) with moderate species richness values (i.e., > 2.7) in the Brooks Foothills ecoregion.

Species Missed in Our Study

We did not detect seven species that had been reported previously as breeding on the Coastal Plain (Johnson and Herter, 1989). Most of these species were described as breeding only rarely and usually in only one or two locations. These “missed” shorebirds can be classified into three categories. The first category includes the Asiatic species such as the Eurasian dotterel (*Charadrius morinellus*), red-necked stint (*Calidris ruficollis*), curlew sandpiper (*Calidris ferruginea*), and ruff (*Philomachus pugnax*), which occasionally cross the Bering Strait from Russia to breed in Alaska. The second category includes the least sandpiper (*Calidris minutilla*) and spotted sandpiper (*Actitis macularia*), which breed at lower latitudes within Alaska and occasionally occur in the northern foothills of the Brooks Range. The third category includes the red knot (*Calidris canutus roselaari*), which is described as breeding in extreme coastal areas between Icy Cape and Point Barrow (Harrington, 2001). For all but the red knot, we suspect that these species were missed simply because they occur so rarely. In the case of the red knot, we believe that the low number of plots located within the species’ reported breeding range and the limited number of samples in its preferred breeding habitat (i.e., rocky ridges) reduced our chances of encountering it. This species, along with a few others that were rarely seen (e.g.,

semipalmated plover and ruddy turnstone), might have been recorded more frequently if we had stratified habitats at a finer scale (i.e., not just wetland areas versus upland areas) and sampled more intensively.

Summary and Future Research Needs

Our shorebird distribution and species richness maps represent a significant step in monitoring shorebird diversity within the circumpolar Arctic as prescribed by the Committee for Holarctic Shorebird Monitoring (2004), and they provide a baseline for comparison to future studies. These maps will be helpful for documenting large-scale shifts in species ranges through time due to anthropogenic or other factors, although more detailed, habitat-based maps will be needed to document subtler changes in distribution. Future studies will also need to concentrate surveys in habitats that cover small fractions of the landscape, such as riparian areas. Other factors should also be considered when evaluating shorebirds on the Arctic Coastal Plain, such as shorebird density, the conservation status of the species, and the amount of suitable habitat available.

Additional sampling is also needed in the western portion of the Coastal Plain, where our sampling intensity was far lower than in other areas (Fig. 1). Because of the potential effects of oil and gas development, climate change, and to a lesser degree subsistence hunting, more studies of bird-habitat associations are needed to better document critical areas for shorebirds and other avian resources on the Coastal Plain. Future sampling should focus on wetland habitats (where most birds are located) and on the rarer habitats where few prior data are available.

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