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FEATURE ARTICLES

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SHOREBIRD ABUNDANCE AND DISTRIBUTION ON THE COASTAL PLAIN OF THE ARCTIC NATIONAL WILDLIFE REFUGE

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Abstract. The coastal plain of the Arctic National Wildlife Refuge hosts seven species of migratory shorebirds listed as highly imperiled or high priority by the U.S. Shorebird Conservation Plan and five species listed as Birds of Conservation Concern by the U.S. Fish and Wildlife Service. During the first comprehensive shorebird survey of the 674 000 ha "1002 Area" on the coastal plain, we recorded 14 species of breeding shorebirds at 197 rapidly surveyed plots during June 2002 and 2004. We also estimated detection ratios with a double counting technique, using data collected at 37 intensively studied plots located on the North Slope of Alaska and northern Canada. We stratified the study area by major habitat types, including wetlands, moist areas, uplands, and riparian areas, using previously classified Landsat imagery. We developed population estimates with confidence limits by species, and estimated the total number of shorebirds in the study area to be 230 000 (95% CI: 104 000–363 000), which exceeds the biological criterion for classification as both a Western Hemisphere Shorebird Reserve Network Site of International Importance (100 000 birds) and a Ramsar Wetland of International Importance (20 000 birds), even when conservatively estimated. Species richness and the density of many species were highest in wetland or riparian habitats, which are clustered along the coast.

Key words: *1002 Area, Arctic National Wildlife Refuge, coastal plain, shorebirds.*

Abundancia y Distribución de Aves Playeras en el Llano Costero del Refugio Nacional Ártico de Vida Silvestre

Resumen. En el llano costero del Refugio Nacional Ártico de vida silvestre se encuentran siete especies de aves playeras migratorias identificadas como en peligro o de alta prioridad por el Plan de Conservación de Aves Playeras de Estados Unidos, y cinco especies identificadas como aves con prioridad de conservación por el Servicio de Pesca y Fauna de los Estados Unidos. Durante el primer inventario completo de aves playeras en las 674 000 ha del "Área 1002" del llano costero, se registraron 14 especies en reproducción en 197 cuadrantes muestreados durante junio de 2002 y 2004. También se

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estimaron las tasas de detección con una técnica de doble muestreo de manera intensiva en 37 cuadrantes ubicados en Ladera Norte de Alaska y norte de Canadá. Se clasificó el área de estudio en categorías correspondientes a los tipos de hábitat más importantes, incluyendo humedales, áreas húmedas, tierras altas y áreas ribereñas, con base a imágenes Landsat previamente clasificadas. Para cada especie se estimó el tamaño de la población con límites de confianza. El número estimado total de aves playeras para el área de estudio fue de 230 000 (95% IC: 104 000–363 000), el cual excede los criterios biológicos para la clasificación como un sitio de Importancia Internacional de la Red Hemisférica de Reservas para Aves Playeras (100 000 aves) y como un humedal de Importancia Internacional para Ramsar (20 000 aves), incluso utilizando la estimación más conservadora. La riqueza de especies y la densidad de varias especies fueron altas en humedales o hábitats ribereños, los cuales presentan una distribución conglomerada a lo largo de la costa.

INTRODUCTION

The Arctic National Wildlife Refuge (Arctic Refuge) encompasses 7.8 million ha, and includes a variety of arctic and subarctic habitats. Almost 3.3 million ha are federally designated wilderness (U.S. Congress 1964), and most of the remainder consist of wildlands with minimal management. However, Section 1002 of the Alaska National Interest Lands Conservation Act (U.S. Congress 1980) required that the "1002 Area" of the coastal plain, located in the northern part of the Arctic Refuge, be evaluated for both its fish and wildlife resources and the potential for petroleum reserves. Long-term studies have been conducted on many of the large herbivores and predators found on the Arctic Refuge coastal plain, including caribou (*Rangifer tarandus*), muskox (*Ovibos moschatus*), polar bear (*Thalarctos maritimus*), grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), and Golden Eagle (*Aquila chrysaetos*; Douglas et al. 2002). Snow Geese (*Chen caerulescens*) congregate in large numbers on the coastal plain, and have also been the subject of extensive study (Douglas et al. 2002). However, distribution and abundance data are lacking for most of the 157 bird species that have been recorded on the coastal plain (Johnson and Herter 1989, U.S. Fish and Wildlife Service 2005).

Eighteen species of shorebirds have been documented breeding on the Arctic Refuge coastal plain, and there are at least four additional species which may breed there (U.S. Fish and Wildlife Service 2005). Of the confirmed breeding species, seven are listed as Highly Imperiled or as species of High Concern in the U.S. Shorebird Conservation Plan and updated status lists (Brown et al. 2001, U.S. Fish and Wildlife Service 2004), and five species are listed as Birds of Conservation Concern by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 2002) because of small or declining populations.

Between 1982 and 1985, terrestrial bird investigations were conducted in seven distinct habitat types distributed over eight study sites (Garner and Reynolds 1986). This project provided baseline data on habitat use by birds. However, study sites covered a small portion of the coastal plain area (<0.01%), and the results could not be extrapolated to the entire coastal plain because sites were not randomly selected. The data suggested that high numbers and diversity of birds occurred in riparian and wetland tundra areas (Garner and Reynolds 1986). Much of this habitat type is distributed along river drainages and in coastal areas.

Information about critical breeding and migration stopover sites is needed to guide and support conservation activities because many species of shorebirds appear to be declining (Brown et al. 2001, International Wader Study Group 2003; Bart et al., in press). In addition, baseline data on shorebird population sizes and distributions are essential for evaluating effects of climate change, which is projected to cause significant loss of habitats critical to shorebirds through northward expansion of shrubs into tundra habitats and inundation and erosion of coastal habitats (Sturm et al. 2001, Arctic Climate Impact Assessment 2004).

The coastal plain of the Arctic Refuge has been the subject of intense debate regarding potential development of oil and gas reserves believed to occur there (U.S. Geological Survey 1998, Ross 2000). Impacts of oil and gas development on birds may include direct effects such as loss of habitat through construction of roads, drilling pads and associated infrastructure, and exposure to oil from spills (Meehan

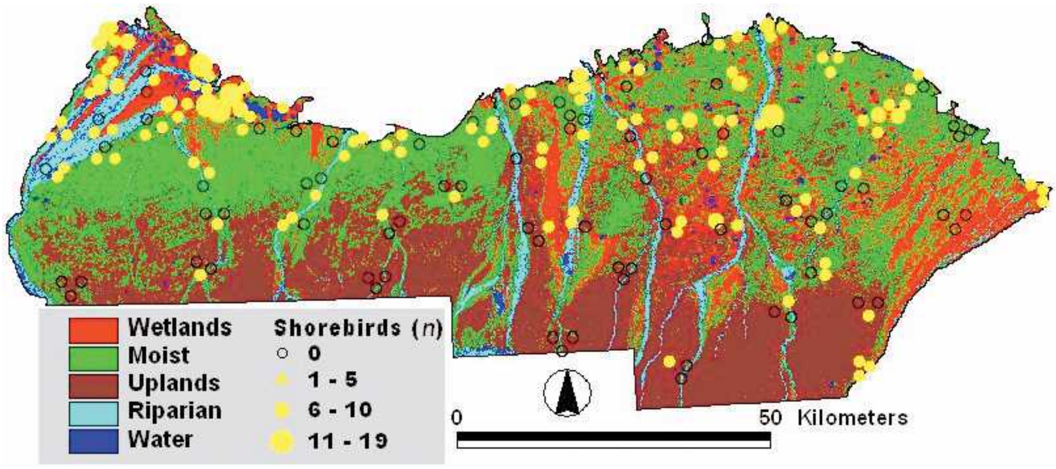

FIGURE 1. Study area in the Arctic National Wildlife Refuge with habitat types, locations surveyed in 2002 and 2004, and relative numbers of shorebirds detected during rapid surveys. The study area is bounded by the Canning River to the west, the Aichilik River to the east, the Beaufort Sea to the north, and the Brooks Range foothills to the south.

1986, Troy 2000). Potential secondary impacts from access roads and drilling pads include increased dust, changes in hydrology, thawing of permafrost, and roadside snow accumulation (National Research Council 2003). Other effects of oil and gas development are more difficult to measure, but may include reduced nesting effort due to disturbance, as well as changes in predation rates due to anthropogenic enhancement of predator populations (Troy 2000, National Research Council 2003). How these factors affect birds is likely to vary by species and by external factors such as weather, availability of alternative prey sources, and habitat-use patterns relative to site installations (Summers 1986). Existing studies are insufficient to predict or mitigate the potential impacts of development on shorebirds within the coastal plain because population sizes and the distribution of nesting shorebirds are unknown. This study provides baseline data essential for evaluating the importance of the Arctic Refuge coastal plain for shorebirds, which is necessary before the effects of potential development can be accurately predicted or mitigated.

In addition to providing data on shorebirds in the Arctic Refuge, this project contributed to the Program for Regional and International Shorebird Monitoring (PRISM; Skagen et al. 2004, Bart et al. 2005). PRISM protocols call for periodic, comprehensive surveys of breeding shorebirds across the entire U.S. and Canadian Arctic to estimate population sizes and provide information on distribution, abundance, and habitat relationships. In combination with migration surveys in the lower 48 states, these surveys are designed to estimate changes in shorebird populations through time.

METHODS

STUDY AREA

Our study area consisted of the 674 000 ha 1002 Area on the coastal plain of the Arctic Refuge (Fig. 1). The 1002 Area is bounded by the Canning River to the west and the Aichilik River to the east. The northern boundary is the Beaufort Sea, the southern boundary is in the Brooks Range foothills, and the area is contiguous with the Arctic Refuge Wilderness area to the south. A portion of the coastal plain east of the Aichilik River is designated as wilderness, and was not surveyed in this study.

We used a land cover map derived from Landsat data (Jorgenson et al. 1994) to define habitats. Fourteen habitat classes described by Jorgenson et al. (1994) were combined into four general habitat types: wetland, moist, upland, and riparian (Table 1, Fig. 1). A fifth habitat type, water, included areas classified as water and ice. This habitat type was excluded from analysis because it did not provide potential shorebird breeding habitat. Wetlands included low-centered polygons and strangmoor dominated by

TABLE 1. Land cover categories derived from Landsat scenes of the coastal plain of the Arctic National Wildlife Refuge, Alaska (Jorgenson et al. 1994), and habitat type categories used in this study.

Land cover category	Designated habitat type[a]
Wet graminoid tundra	Wetland
Wet graminoid tundra with moist inclusions	Wetland
Moist sedge–willow tundra with wet inclusions	Moist
Moist sedge–willow tundra	Moist
Moist sedge–*Dryas* tundra	Moist
Moist sedge–tussock tundra	Upland
Moist shrub–tussock tundra	Upland
Moist low–shrub tundra	Upland
Moist shrub tundra on high-centered polygons	Upland
Dryas–graminoid alpine tundra	Upland
Riparian shrub	Riparian
Dryas river terrace	Riparian
Partially vegetated	Riparian
Barren	Riparian
Ice	Water
Water	Water

[a] Proportion of the study area in each habitat type excluding water: Wetland = 0.18, Moist = 0.39, Upland = 0.34, Riparian = 0.08.

sedges (*Carex aquatilis*, *C. chordorrhiza*, and *Eriophorum angustifolium*) with some inclusions of moist areas. Moist areas included flat-centered polygons, gentle slopes, and other areas with better drainage than wetlands. These moist areas were dominated by mosses (*Tomenthypnum nitens* and *Hylocomium splendens*), sedges (*E. angustifolium* and *Carex bigelowii*), willows (*Salix planifolia* and *S. reticulata*), and *Dryas integrifolia*. Upland areas included high-centered polygons and higher elevation areas, and were dominated by tussock sedge (*Eriophorum vaginatum*) and shrubs (*Betula nana* and *S. planifolia*). Uplands were typically well drained, although moist inclusions with shrubs were occasionally present. Riparian habitats were dominated by gravel bars and floodplains consisting of riparian shrubs (*Salix lanata*, *S. alaxensis*, and *S. glauca*), *D. integrifolia* river terraces, and dry sand and river cobbles that were either partially vegetated (10%–50% cover) or barren (<10% cover). Detailed descriptions of each plant community are provided by Jorgenson et al. (1994).

SHOREBIRD SURVEYS

We used a form of double sampling (Cochran 1977) involving a large sample of plots surveyed a single time (rapid survey plots) and a smaller sample of plots surveyed throughout the shorebird breeding season (intensive survey plots) to estimate numbers of shorebirds present. The only assumptions required in double sampling are that the nominal sampling plan is followed and that the estimates from the intensive surveys are unbiased, both of which were met. We followed the methods described by Bart and Earnst (2002, 2005). Our 16 ha (400 m × 400 m) rapid survey plots were always placed in clusters of three due to safety and logistical constraints associated with being transported by helicopter to remote areas. The initial starting point of each cluster was selected with a simple random sampling approach in 2002, and a stratified random sampling approach in 2004. To stratify the area in 2004, we first overlaid the study area with a grid of plot-sized cells. The amount of each habitat in each plot was measured, and plots were assigned to the habitat type that covered the largest area. We determined the number of plots to be surveyed in each habitat by the relative abundance of shorebirds in each habitat type reported by Garner and Reynolds (1986). After the initial plot was selected, the other two plots were randomly located 3–5 km from the first plot, with clusters of plots situated approximately in a triangle. For analysis we partitioned the study area into 299 compartments, which contained at most one cluster of surveyed plots. Thus, for 2004, the sampling plan involved stratification by habitat, and selection of plots by habitat within compartments.

Rapid surveys of 197 plots were conducted by a single observer (i.e., one surveyor per plot) who spent 1.25 hr per plot documenting the identity and abundance of shorebirds that, based on criteria described below, appeared to be nesting within the boundaries of the plot. Rapid survey plots were visited once during a 9–11 day period between 8 and 20 June when shorebirds were highly visible due to their aerial and ground breeding displays (Lanctot et al. 2000). Because of the short display period of arctic-nesting shorebirds, surveys were conducted in most weather unless high winds, fog, or heavy precipitation grounded the aircraft by either reducing visibility or causing ice buildup during travel. All rapid surveyors were trained in the visual and auditory cues of each shorebird species prior to the field season, practiced identification skills in the field for several days prior to collecting data, and had previous experience with arctic shorebirds. Surveyors estimated the number of "territorial" males (or females for polyandrous species) within each plot based on presence and behavioral cues indicative of territory establishment or nesting (e.g., vocalizations, aerial and ground displays, territorial chases, and broken-wing displays).

To estimate total breeding populations, we multiplied our counts of territorial males (or females for polyandrous species) by 2, assuming an equal sex ratio. For polygynous or polyandrous species, some displaying individuals may represent more than one nest, while others may fail to attract a mate, but the expected average will be one pair per displaying bird unless the sex ratio is uneven within the study area. There are strong theoretical reasons to assume the sex ratio is close to 50:50 (Fisher 1958), and we do not know of any evidence to suggest a biased sex ratio among the species we studied. We did not consider birds to be nesting within the confines of our plots if they failed to exhibit territorial or nesting behaviors, since these birds were likely nonbreeders passing through the area, and our goal was to delineate the distribution and density of breeding birds.

We defined detection ratios for each species as the average number of birds estimated by rapid surveyors to occur on intensive survey plots divided by the actual number of birds found on these plots by intensive surveyors. Detection ratios were estimated using data from a total of 37 intensive survey plots at seven sites across northern Alaska and two sites in Canada. Three of the Alaska sites were within the 1002 Area of the Arctic Refuge and four were in northwestern Alaska (three on the Colville delta, one near Barrow on the coastal plain), and the two Canadian sites were on the Kent Peninsula in northwestern Nunavut. All were in coastal tundra habitats, and the rapid and intensive survey methods used at these sites were identical to those in our study at the Alaska sites and similar in Canada, where plot searches included a second person for safety reasons who also recorded data.

Ideally, intensive survey plots would be a random subsample of the rapid survey plots. This was impractical, however, due to logistical constraints and the expense of helicopter access to sites. Our experience has shown that when intensive survey sites are located randomly, they frequently lack a suitable location for a camp, require expensive helicopter support to access, and may have few species or low numbers of birds. Therefore, sites for intensive survey plot camps were selected nonrandomly, based on accessibility and geographic features such as the presence of a diverse array of habitat types visible in Landsat imagery, including uplands and wetlands.

For the intensive surveys, a base camp was set up at each site and a team of biologists spent 3–4 weeks repeatedly surveying the plots (usually four plots per camp, although one camp had two and another had seven). Because of this sampling design, in analyses the sampling unit for the intensive surveys was the camp. The goal of these surveys was to determine the actual number of nesting birds. Observers typically visited each plot for 4–8 hr a day and visited each plot at least eight times during the survey period. The main objective was to find all nests, but we also made intensive efforts to include males (or females of polyandrous species) without nests and birds whose nests failed before we could find them. We counted such birds if the centroid of their territory or utilized area was within the plot. An evaluation of the intensive survey method for sites in the Arctic Refuge indicated that surveyors found approximately 67% of the total number of nests eventually detected on an intensive survey plot during their first visit (SB and JB, unpubl. data). The number of nests found subsequently quickly dropped off, until no new nests were located well before the scheduled end of the search period. The intensive survey plots were also surveyed one or more times by the crews conducting rapid surveys to estimate detection ratios. Rapid surveyors had no knowledge of the identity and numbers of each species present. For additional information on methods see Bart and Earnst (2005). Overall detection ratios were calculated as the mean of the detection ratios across camps. Sample size for each species' detection ratio was thus the number of camps with the species present on at least one plot.

We used two *a priori* decision rules in determining what values to use for detection ratios. First, we planned comparisons of detection ratios among all species that occurred on the intensive survey plots, and the use of an average detection ratio for species where an analysis of variance and multiple comparisons did not reveal significant differences among detection ratios. We also decided to use this average detection ratio as an estimate of the detection ratio for species that did not occur on our intensive survey plots. We hypothesized that detection ratios for adult breeding birds of conspicuously displaying species were likely to be similar, since rapid surveys relied on detecting individuals using their territorial and mate-seeking behaviors, as opposed to relying on cryptic nests to determine their presence.

Shorebird species richness was calculated and mapped separately for each plot by summing the total number of species detected either nesting or exhibiting territorial behavior.

STATISTICAL ANALYSES

The estimate of population density, d, was

$$d = \frac{\hat{\hat{X}}}{\hat{R}}, \qquad (1)$$

where $\hat{\hat{X}}$ was an estimate of the density (per km^2) of birds that would be recorded if rapid surveys covered the entire study area and $\hat{R}$ was an estimate of the detection ratio (birds recorded per birds present) on the rapid survey plots. $\hat{\hat{X}}$ was obtained from the rapid surveys and $\hat{R}$ was obtained from the intensive surveys. Rapid surveys of intensive survey plots were not used in calculating $\hat{\hat{X}}$ (because intensive survey plots were not randomly selected), so $\hat{\hat{X}}$ and $\hat{R}$ were independent. Using the standard formula for the estimated variance of a ratio (Cochran 1977, chapter 6) yields:

$$\hat{V}(d) = d^2\left(\frac{\hat{V}\left(\hat{\hat{X}}\right)}{\hat{\hat{X}}^2} + \frac{\hat{V}(\hat{R})}{\hat{R}^2}\right). \qquad (2)$$

The estimated population size was $\hat{Y} = Ad$, where A was the size of the study area (i.e., the area covered by all plots in all regions). The variance of $\hat{Y}$ was estimated as $\hat{V}(\hat{Y}) = A^2\hat{V}(d)$.

Formulas for the components of d and $\hat{V}(d)$ are provided below. As noted above, each plot was assigned to a habitat (*stratum*), the study area was partitioned into 299 *compartments*, and one *cluster* of plots (usually of three plots) was selected within a sample of compartments. Let:

$\bar{z}_{hi}$ = mean number of birds recorded per plot in cluster i of stratum h,
$\bar{b}_{hi}$ = mean area covered by the surveyed plots in cluster i of stratum h,
a_{hi} = area covered by all plots in compartment i of stratum h,
n_h = number of surveyed clusters in stratum h, and
N_h = number of clusters in stratum h.

The following quantities are needed:

$\hat{Z}_{hi} = a_{hi}\bar{z}_{hi}\bar{b}_{\mathrm{hi}}{}^{-1}$ = estimated number of birds that would be recorded if all plots in cluster i were surveyed,

$$\hat{\bar{Z}}_h = \sum \hat{Z}_{hi}n_h^{-1} = \text{sample mean of the } \hat{Z}_{hi},$$
$$\bar{a}_h = \sum a_{hi}n_h^{-1} = \text{sample mean of the } a_{hi}.$$

$\hat{\hat{X}}$ was estimated using the "combined approach" Cochran (1977:165) for ratios with stratification:

$$\hat{\hat{X}} = \frac{\hat{Z}}{a} = \frac{\sum_h^H N_h\hat{\bar{Z}}_h}{\sum_h^H N_h\bar{a}_h}. \qquad (3)$$

The variance of $\hat{\hat{X}}$ was estimated using the formula for the estimated variance of a ratio,

$$\hat{V}\left(\hat{\hat{X}}\right) = \left(\frac{\hat{Z}}{a}\right)^2\left(\frac{\hat{V}(\hat{Z})}{\hat{Z}^2} + \frac{\hat{V}(a)}{a^2} - \frac{2C\hat{o}v(\hat{Z}, a)}{\hat{Z}a}\right). \qquad (4)$$

Because plots in different habitats (and thus in different strata) were often surveyed in the same cluster, sampling in different strata was not independent. To acknowledge this dependence, we used the subscripts g and h for habitat and we let n_{gh} = the number of clusters in which at least one type g plot and one type h plot were surveyed. With this notation,

$$\hat{V}(\hat{Z}) = \sum_g^H\sum_h^H N_gN_hC\hat{o}v\left(\hat{\bar{Z}}_g, \hat{\bar{Z}}_h\right),$$
$$C\hat{o}v\left(\hat{\bar{Z}}_g, \hat{\bar{Z}}_h\right) = \frac{n_{gh}}{n_gn_h}cov\left(\hat{Z}_{g.hi}, \hat{Z}_{h.gi}\right), \qquad (5)$$

$$\hat{V}(a) = \sum_g^H\sum_h^H N_gN_hC\hat{o}v(\bar{a}_g, \bar{a}_h),$$
$$C\hat{o}v(\bar{a}_g, \bar{a}_h) = \frac{n_{gh}}{n_gn_h}cov\left(a_{g.hi}, a_{h.gi}\right), \qquad (6)$$

$$C\hat{o}v\left(\hat{Z},a\right) = \sum_{g}^{H}\sum_{h}^{H} N_g N_h C\hat{o}v\left(\hat{\bar{Z}}_g, \bar{a}_h\right),$$
$$C\hat{o}v\left(\hat{\bar{Z}}_g, \bar{a}_h\right) = \frac{n_{gh}}{n_g n_h} cov\left(\hat{Z}_{g.hi}, a_{h.gi}\right). \quad (7)$$

Because sampling is not independent in different habitats we used the general formula for the variance of a sum,

$$V\left(\hat{Z}\right) = V\left(\sum_{h}^{H} N_h \hat{\bar{Z}}_h\right) = \sum_{g}^{H}\sum_{h}^{H} N_g N_h Cov\left(\hat{\bar{Z}}_g, \hat{\bar{Z}}_h\right).$$

In equation 5, $\hat{\bar{Z}}_g$ and $\hat{\bar{Z}}_h$ are the means from a simple random sample of clusters, so the usual formula for their covariance (Cochran 1977) applies, except that the estimate is based on clusters in which both plot types, g and h, were surveyed. This accounts for the $n_{gh}/n_g n_h$ which reduces to the familiar $1/n_h$ if $g = h$. The same rationale applies to expressions 6 and 7.

The detection ratio, R, was also estimated using a combined approach, $\hat{R} = \bar{x}\bar{y}^{-1}$, where $\bar{x}$ was the mean number of birds recorded on rapid surveys of the intensive survey plots and $\bar{y}$ was the mean number of birds determined to be present on these plots through intensive surveys. These means were calculated using the camp as the primary unit. Thus, if plots at m camps were surveyed, $\bar{x}_i$ = the mean number recorded per rapid survey on plots at camp i, and $\bar{y}_i$ = the mean number actually present at all plots in camp i, then $\bar{x} = \sum \bar{x}_i/m$ and $\bar{y} = \sum \bar{y}_i/m$. The $\bar{x}_i$ were calculated as the simple means of the means per plot because sometimes plots at a camp were not all surveyed the same number of times by rapid surveyors. The $\bar{y}_i$ were calculated as the simple mean of the numbers present per plot at the i^{th} camp.

The variance of $\hat{R}$ was estimated as:

$$\hat{V}\left(\hat{R}\right) = \hat{R}^2\left(\frac{\hat{V}(\bar{x})}{\bar{x}^2} + \frac{\hat{V}(\bar{y})}{\bar{y}^2} - \frac{2C\hat{o}v(\bar{x},\bar{y})}{\bar{x}\bar{y}}\right), \quad (8)$$

where:

$$\hat{V}(\bar{x}) = \frac{1}{m}s^2(\bar{x}_i), \quad \hat{V}(\bar{y}) = \frac{1}{m}s^2(\bar{y}_i),$$
$$C\hat{o}v(\bar{x},\bar{y}) = \frac{1}{m}cov(\bar{x}_i,\bar{y}_i).$$

Differences in habitat-specific densities were evaluated by carrying out a one-way analysis of variance followed by pairwise t-tests using $\alpha = 0.05$. We ignored the covariance due to different habitats occurring in the same clusters. This produced conservative P-values because the pairing tended to help us detect differences but was not acknowledged in the ANOVA or pairwise tests. We did not have sufficient data for a two-way ANOVA with habitats and clusters as the factors. Degrees of freedom were calculated as df = $n_g + n_h - 2$. Values reported for densities and population estimates are means ± SE.

RESULTS

We conducted rapid surveys on 197 plots (73 wetland, 62 moist, 28 upland, and 34 riparian) located in 67 clusters. A total of 415 shorebirds of 14 species were recorded (Table 2). Of these, 268 were observed in wetland habitats, 86 in moist areas, six in uplands, and 55 in riparian areas. We located 362 shorebirds of 10 species on intensively surveyed plots, and also conducted 162 rapid surveys of these plots to calculate detection ratios (Table 2).

Among the five species with a total of >20 nests or territorial birds present on the intensive survey plots, estimated detection ratios varied from 0.56–0.95 (Fig. 2). An analysis of variance to determine whether any detection ratios were significantly different from the others was nonsignificant (one-way ANOVA, $F_{4,12} = 1.7$, $P = 0.21$). Therefore, we combined data from all species and estimated the overall detection ratio to be 0.77 ± 0.05.

The five most abundant species had estimated densities of approximately 2–6 birds per km^2 (average for the entire study area with water excluded) and estimated population sizes of 16 000–53 000 (Table 3). The total estimated number of shorebirds of all species in the study area, obtained by summing the species-specific estimates, was approximately 230 000 (95% CI: 104 100–363 000), or approximately 1.7% (95% CI: 0.8%–2.6%) of the combined total estimated population of the species we observed (Morrison et al. 2001; R. Morrison et al., Canadian Wildlife Service, unpubl. data). The population size estimate for the Pectoral Sandpiper (*Calidris melanotos*) was greater than 10% of the estimated total population size for the species. Including all species, population size point

TABLE 2. Number of shorebirds recorded on rapid surveys of plots in the 1002 Area of the Arctic National Wildlife Refuge, Alaska, in 2002 and 2004, number recorded at intensive survey plots on the North Slope of Alaska and in northern Canada, number of base camps where plots were intensively surveyed at which ≥1 individual of each species was recorded, and conservation status of each species.

Species	Number recorded: Rapid surveys	Number recorded: Intensive surveys	Number of base camps	Conservation status[a]
American Golden-Plover (*Pluvialis dominica*)	31	10	3	CC, HC
Semipalmated Plover (*Charadrius semipalmatus*)	7	0	0	
Whimbrel (*Numenius phaeopus rufiventris*)	4	0	0	CC, HC
Ruddy Turnstone (*Arenaria interpres interpres*)	5	7	1	HC
Semipalmated Sandpiper (*Calidris pusilla*)	90	115	8	
Western Sandpiper (*Calidris mauri*)	1	4	1	HC
Baird's Sandpiper (*Calidris bairdii*)	4	0	0	
Pectoral Sandpiper (*Calidris melanotos*)	111	82	8	
Dunlin (*Calidris alpina arcticola*)	16	24	4	CC, HC
Stilt Sandpiper (*Calidris himantopus*)	16	2	2	CC[b]
Buff-breasted Sandpiper (*Tryngites subruficollis*)	8	0	0	CC, HI
Long-billed Dowitcher (*Limnodromus scolopaceus*)	9	6	3	
Red-necked Phalarope (*Phalaropus lobatus*)	75	61	8	
Red Phalarope (*Phalaropus fulicaria*)	38	51	6	
All	415	362	–	

[a] Birds listed as being of Conservation Concern (CC) within Bird Conservation Region 3 (Arctic Plains and Mountains), Alaska, and for the entire U.S. (U.S. Fish and Wildlife Service 2002), or as being Highly Imperiled (HI) or of High Concern (HC) by the U.S. Shorebird Conservation Plan (U.S. Fish and Wildlife Service 2004).

[b] Listed as a species of Conservation Concern for the U.S. only.

estimates were greater than 1% of the estimated total North American population for 12 species.

We used the average detection ratio for all other species to calculate estimated population sizes for the four species that were detected on rapid survey plots but did not occur on intensive survey plots. All four species had lower confidence interval bounds of 0. Population size estimates were 3208 (95% CI: 0–6600) for Semipalmated Plover (*Charadrius semipalmatus*), 3312 (0–8224) for Baird's Sandpiper (*Calidris bairdii*), 4598 (0–11 862) for Whimbrel (*Numenius phaeopus*), and 7684 (0–17 812) for

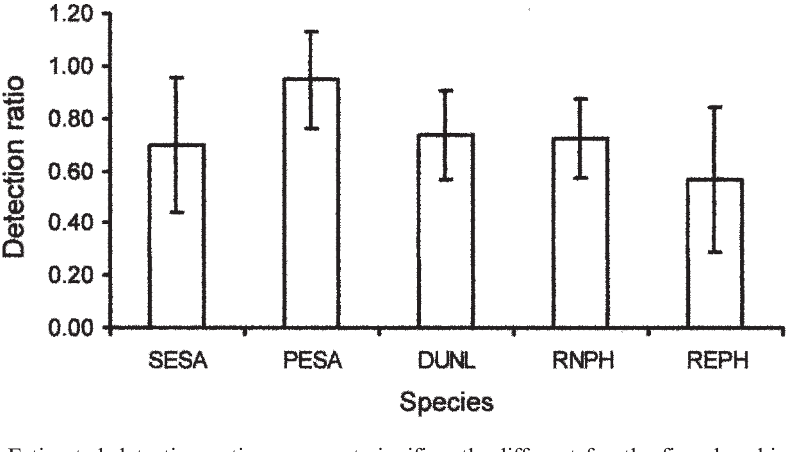

FIGURE 2. Estimated detection ratios were not significantly different for the five shorebird species with >20 individuals present on intensive survey plots on the North Slope of Alaska and northern Canada. Error bars indicate 95% confidence intervals. Values given are estimated numbers from rapid surveys of intensively surveyed plots, and species include Semipalmated Sandpiper (SESA), Pectoral Sandpiper (PESA), Dunlin (DUNL), Red-necked Phalarope (RNPH), and Red Phalarope (REPH).

TABLE 3. Estimated densities, population sizes, and percentage of each species' total estimated population size within the 1002 Area of the Arctic National Wildlife Refuge, Alaska. Estimates are grouped according to the number of intensive survey plot detections for each species.

	Density (per km^2)		Population size		Percent of population estimate (95% CI)[b]
	Estimate ± SE	CV[a]	Estimate ± SE	95% CI	
Species with ≥10 occurrences on intensive plots					
American Golden-Plover	1.8 ± 0.4	0.21	15 686 ± 3340	9142–22 232	7.8 (4.6–11.1)
Semipalmated Sandpiper	5.7 ± 1.4	0.25	49 698 ± 12 300	25 590–73 804	1.4 (0.7–2.1)
Pectoral Sandpiper	6.1 ± 1.1	0.17	52 978 ± 9176	34 992–70 962	13.2 (8.7–17.7)
Dunlin	1.2 ± 0.5	0.39	10 506 ± 4112	2448–18 564	1.4 (0.3–2.5)
Red-necked Phalarope	4.9 ± 1.0	0.21	42 762 ± 8814	25 488–60 038	1.7 (1.0–2.4)
Red Phalarope	2.7 ± 1.1	0.43	23 226 ± 9874	3872–42 580	1.9 (0.3–3.4)
Species with <10 occurrences on intensive plots					
Ruddy Turnstone	0.3 ± 0.2	0.50	2984 ± 1484	76–5892	5.4 (0.1–10.7)
Western Sandpiper	0.02 ± 0.02	1.00	252 ± 252	0–748	0.01 (0.00–0.02)
Stilt Sandpiper	0.7 ± 0.3	0.35	6218 ± 2194	1920–10 518	0.8 (0.2–1.3)
Long-billed Dowitcher	0.8 ± 0.4	0.47	6848 ± 3190	594–13 102	1.7 (0.1–3.3)
All species	26.6 ± 2.6	6.76	229 960 ± 22 487	104 122–362 938	1.7 (0.8–2.6)

[a] Coefficient of variation.

[b] Percent of population estimate compares the number of birds of each species estimated to occur within the 1002 Area of the Arctic National Wildlife Refuge coastal plain and the estimated total population size reported in Morrison et al. (2001), as revised (R. Morrison et al., Canadian Wildlife Service, unpubl. data).

Buff-breasted Sandpiper (*Tryngites subruficollis*).

Five species showed significant differences in density among the four habitat types defined in the study (Table 4). American Golden-Plover (*Pluvialis dominica*) densities were significantly lower in uplands compared to all other habitat types. Semipalmated Sandpipers (*Calidris pusilla*) had significantly higher densities in wetlands than moist or upland areas, and Pectoral Sandpipers had significantly higher densities in wetland and moist habitats than upland or riparian areas. Densities of Red-necked Phalaropes (*Phalaropus lobatus*) and Red Phalaropes (*Phalaropus fulicaria*) were significantly higher in wetlands than in any other habitat type. Red-necked Phalaropes were most abundant in wetlands but present in all habitats, while Red Phalaropes only occurred in wetland and moist habitats. Red Phalaropes showed the highest fidelity to wetlands of any of the more abundant species. Their density in wetlands was 12 birds per km^2, and they were absent or nearly absent in all other habitats. The species was also nearly always found within 10 km of the coast, the only exception being that birds occurred a few km farther south along the Canning River on the west side of the Arctic Refuge.

The density of all shorebirds combined was significantly higher in wetlands, and 2–3 times higher in this habitat than in riparian or moist habitats, respectively. Plots with higher shorebird numbers and species richness were also clustered in areas with greater wetland density, including the northwest corner of the study area along the Canning River (Fig. 1, 3).

For several species, the low number of observations was insufficient to detect statistically significant habitat associations; however, there were suggestive patterns in their distributions. Individuals of many species were recorded more frequently in riparian habitats, including seven of eight Buff-breasted Sandpipers, four of five Ruddy Turnstones (*Arenaria interpres*), three of four Baird's Sandpipers, and all seven Semipalmated Plovers detected on rapid survey plots. All 16 Stilt Sandpipers (*Calidris himantopus*) occurred either in wetlands or in moist habitats. Only four Whimbrels were found, but all were well south of the coast in the elevated portion of the study area where uplands predominated. Dunlin (*Calidris alpina arcticola*) did not show habitat specificity but were restricted geographically, occurring only in the northwest corner of the study area.

During the analysis we noticed that overall shorebird densities appeared substantially

TABLE 4. Estimated densities (birds per km^2) for shorebird species with significant differences in estimated abundances among four habitat types within the 1002 Area of the Arctic National Wildlife Refuge, Alaska. Numbers of birds recorded on rapid survey plots are shown in parentheses. Within rows, density estimates with the same superscript are not significantly different. Habitats are defined in the text.

Species	$F_{3,110}$ (P)[a]	Wetland	Moist	Upland	Riparian
American Golden-Plover	3.3 (0.022)	2.36 ± 0.84 (11)^{A}	2.10 ± 0.62 (10)^{A}	0.00 ± 0.00 (0)^{B}	4.84 ± 1.46 (10)^{A}
Semipalmated Sandpiper	7.2 (< 0.001)	16.28 ± 2.94 (59)^{A}	2.84 ± 1.08 (15)^{B}	0.00 ± 0.00 (0)^{C}	8.82 ± 4.84 (16)^{ABC}
Pectoral Sandpiper	11.0 (< 0.001)	16.68 ± 3.08 (72)^{A}	9.20 ± 2.18 (35)^{A}	1.44 ± 1.40 (1)^{B}	1.32 ± 0.80 (3)^{B}
Red-necked Phalarope	6.9 (< 0.001)	13.42 ± 2.90 (57)^{A}	4.20 ± 1.56 (14)^{B}	2.56 ± 1.52 (3)^{B}	1.14 ± 1.14 (1)^{B}
Red Phalarope	4.0 (0. 009)	12.20 ± 4.94 (37)^{A}	0.16 ± 0.16 (1)^{B}	0.00 ± 0.00 (0)^{B}	0.00 ± 0.00 (0)^{B}
All species	10.8 (< 0.001)	69.38 ± 7.46 (268)^{A}	20.44 ± 3.04 (86)^{B}	5.68 ± 2.41 (6)^{C}	28.68 ± 6.67 (55)^{B}

[a] Values from a one-way ANOVA testing the null hypothesis that densities did not differ among habitats.

higher in the northwest portion of the study area. We quantified this difference by delineating a small area, the "Canning region," which included the northern part of the Canning River and the areas directly east where lakes and wetlands are common, and comparing the density in this region with that in the rest of the study area. Most plots located in the Canning region were in wetlands, so we compared densities only between the Canning region wetland plots and the wetland plots in the rest of the study area. Within the wetland habitat class, shorebird densities were 75.0 ± 12.5 per km^2 in the Canning region and 33.3 ± 5.0 in the rest of the study area (t = 3.1, P < 0.01). We also tested for gradients in density and richness with distance to the coast and did not find any statistically significant relationships when habitat was also taken into account.

DISCUSSION

This study provides the first estimates of the abundance of shorebirds and their distribution among habitats in the 1002 Area of the Arctic National Wildlife Refuge coastal plain. The total population size estimate of approximately 230 000 shorebirds (95% CI: 104 000–363 000) in the 1002 Area is higher than the biological criterion for designating this area as a site of International Importance under both the Western Hemisphere Shorebird Reserve Network (100 000 birds; Western Hemisphere Shorebird Reserve Network 2006) and the Ramsar Convention (20 000 birds; Ramsar 1999). We have high confidence that the true population size is at least 104 000 birds, the lower limit of the 95% confidence interval for the estimate of all shorebirds combined. In addition, the percentage of North America's Pectoral Sandpiper population that is estimated to breed in the study area is greater than the 10% criterion for particular species used to define WHSRN sites of International Importance for shorebirds (Western Hemisphere Shorebird Reserve Network 2006). The population estimate for American Golden-Plovers, which are thought to be declining (Bart et al., in press), exceeds 1% of the estimated population size for North America. Overall, our population estimates for shorebirds indicate that, under WHSRN criteria, the Arctic Refuge coastal plain is an important shorebird breeding area, and the association of many species with wetland and

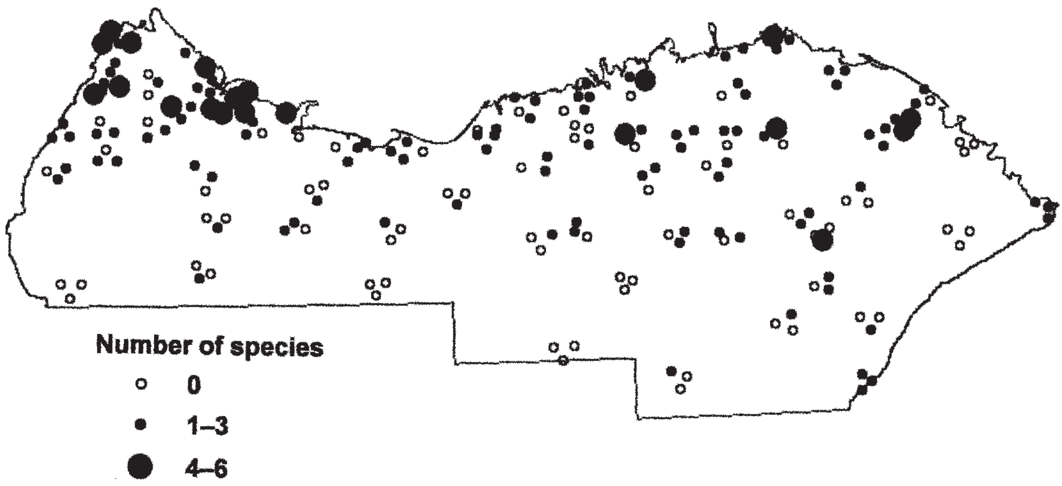

FIGURE 3. Shorebird species richness was higher near the Canning River Delta and other riparian and wetland areas near the coast, based on rapid surveys of plots located on the coastal plain of the Arctic National Wildlife Refuge, Alaska, surveyed in 2002 and 2004.

riparian habitats indicates that these areas are of particularly high value.

For species that are relatively rare in the study area, we detected too few individuals to precisely estimate population size. Small sample sizes resulted in large confidence intervals around our point estimates, which included zero for five of the rare species. The confidence intervals for the population estimates for Whimbrels and Buff-breasted Sandpipers are particularly large because of the small number of detections and the variance in densities within plots of similar habitat types. Thus, we suggest interpreting the population estimates for rare species cautiously. Our ability to detect differences among species detection ratios was limited by small sample sizes due to the low number of intensive survey plot camps. In addition, calculating population estimates for species that did not nest on any of the intensive survey plots required that we estimate population sizes with detection ratios calculated for other species, which could have affected the estimates if the actual detection ratio for a particular species varied substantially from the average ratio. The estimates for species that did not occur on intensive survey plots therefore have potential error in addition to the confidence intervals reported, and additional data on detection ratios for all species would be valuable to allow tests for differences with higher power.

Estimating population sizes and identifying important areas for species that are rare and of conservation concern, like the Buff-breasted Sandpiper, is generally difficult because of the inability to gather sufficient sample sizes. Accordingly, the presentation of such data here represents a starting point for future work. For example, our data suggest that Buff-breasted Sandpipers may prefer riparian areas, such as those along the Canning River, and this association should be investigated further so that the population of this species in the study area can be measured more precisely, and important habitats determined.

Shorebird densities in previous studies were generally higher to the west of the Arctic Refuge (Moitoret et al. 1996, Troy 1996) and lower to the east in Canada (Forbes et al. 1992, Johnston et al. 2000). Our data are consistent with this pattern, because densities for most species are higher in the Arctic Refuge than those reported from similar habitats in Canada, but lower than those reported from areas like Prudhoe Bay and parts of the National Petroleum Reserve–Alaska (NPR–A) to the west. For example, American Golden-Plovers were found at a density of 0.8 per km^2 in the Rasmussen Lowlands (Johnston et al. 2000), 1.8 per km^2 in this study, and an average of 2.1 per km^2 in plots in the NPR–A (Derksen et al. 1981). Similarly, Semipalmated Sandpipers occurred at a density of 1.7 per km^2 in the

Rasmussen Lowlands (Johnston et al. 2000), 5.7 per km^2 in this study, and an average of 7.1 per km^2 in the NPR–A (Derksen et al. 1981). The densities reported here are generally lower for most species than the average of values reported from the 1002 Area in the mid-1980s (Garner and Reynolds 1986). These differences may result simply from different methodology in the earlier study, including sampling only eight sites that were not randomly selected, and counting all birds observed regardless of behavior. In contrast, our estimated density for Dunlin is higher than an average of the estimates in Garner and Reynolds (1986), but their study did not survey the western portion of the Refuge where Dunlin occurred in our surveys, so we would expect our estimates to be higher.

Some studies have suggested that shorebird densities decrease with distance from the coast along the North Slope of Alaska (Johnson and Herter 1989; Troy Ecological Research Associates, unpubl. data). We did not find a similar pattern in the Arctic Refuge when habitat was taken into account. Wetland habitats are clustered along the coast in the Arctic Refuge, so shorebird densities are highest near the coast, but the gradient is best explained by habitat association and when habitat is taken into account in multivariate analyses distance is not a significant factor. The significant coastal gradient noted elsewhere may be due to the more extensive inland wetland habitat in the western parts of the Alaskan North Slope relative to the Arctic Refuge.

Two species, Dunlin and Red Phalarope, appear to have an east–west gradient in density (Warnock and Gill 1996, Tracy et al. 2002), and occur predominantly in the western portion of the Arctic Refuge coastal plain. As a result, while our overall estimates of total population for these species are unbiased, their densities are likely higher than our average value in appropriate habitats along the western edge of the Arctic Refuge and lower in the eastern portion of the coastal plain.

Our observations of species associations with particular habitats in the Arctic Refuge are generally similar to patterns found previously. For example, our study supports significant associations found in earlier work with wetland tundra for both phalarope species (Parmelee et al. 1967, Garner and Reynolds 1986, Johnson and Herter 1989) and Semipalmated Sandpipers (Gratto et al. 1983, Godfrey 1986), and with riparian areas for Semipalmated Plovers (Nol and Blanken 1999). Of the species that showed habitat preferences, we found the highest densities in wetlands or riparian areas. Wetland areas had two to three times higher shorebird densities than riparian and moist areas, respectively. Our data do suggest that the large areas of moist habitats present on the coastal plain collectively provide important habitat for some species. The relatively rare riparian habitats appear to be important for several species found predominantly in these areas. We stratified our survey by habitat type only in the second year, when it became clear that the relatively rare habitats were of particular significance, so our sample sizes were small in riparian areas. Further study, including finer discrimination among the variety of habitat types included in the riparian class, is needed to more accurately determine shorebird abundances in these areas, particularly for the relatively rare species.

Our data indicate that nesting shorebirds tend to associate with wetland and riparian habitats that are unevenly distributed on the coastal plain. These habitats typically occur along the coast and near rivers and deltas that bisect the Refuge. The importance of these habitats for breeding shorebirds, many of which have declining populations, should be considered when making management decisions. Any future changes occurring in these habitats could have disproportionate effects on breeding shorebirds, and the impact of habitat loss would be disproportionately large if it affected areas closest to the coast where wetland habitats are more abundant. Our results further suggest that shorebird density is highest in wetland areas in the Canning River Delta region. This is the portion of the Arctic Refuge closest to existing and proposed oil development on contiguous state-managed lands. Future research should address the importance of the Canning Delta wetlands for shorebirds and potential effects and mitigation of anthropogenic activities in the region.

Further work is also needed to understand the factors contributing to the variation in shorebird abundance within the major habitat types included in this study. The scale of our survey was too broad to include detailed habitat measurements and additional study is needed to determine the relationship of shorebird numbers to wetland complexity, polygon geomorphology, pond abundance, and vegetation density. All of these factors have been shown to be related to shorebird habitat selection at fine scales in different locations on the arctic coastal plain of Alaska (Jones 1980, Myers and Pitelka 1980, Derksen et al. 1981, Martin 1983). Studies of fine-scale shorebird-habitat associations would help reduce the confidence limits around population estimates for species of conservation concern on the Arctic Refuge coastal plain, and would also help to identify at a finer scale areas that are particularly important for shorebirds.

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