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Shorebirds Breed in Unusually High Densities in the Teshekpuk Lake Special Area, Alaska

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ABSTRACT. On the Arctic Coastal Plain of the National Petroleum Reserve-Alaska (NPR-A), the Teshekpuk Lake Special Area (TLSA) was recognized to protect outstanding wildlife values. Although information has accumulated on the TLSA's value to caribou and waterfowl, its importance to breeding shorebirds remains largely unquantified. Therefore, we undertook a broad-scale ground study to estimate the population size and density of shorebirds breeding in the TLSA. From a series of plot surveys conducted from 2006 to 2008, we estimated a detection-adjusted total breeding population of more than 573 000 shorebirds and an overall density of 126 shorebirds/km^2. Most shorebird species had their greatest densities on the Outer Coastal Plain or had approximately equal densities on Outer and Inner Coastal Plains; only two species had their greatest densities on the Inner Coastal Plain. The greatest densities of breeding shorebirds occurred immediately around Teshekpuk Lake. The TLSA supported more than 10% of the biogeographic populations of black-bellied plover (*Pluvialis squatarola*), semipalmated sandpiper (*Calidris pusilla*), and dunlin (*C. alpina*). Breeding shorebird density in the TLSA is one of the highest in the NPR-A, on Alaska's North Slope, and throughout the circumpolar Arctic. Our results, coupled with previous information on waterfowl and caribou, indicate that the area around Teshekpuk Lake and the recognized goose molting area northeast of the lake should be protected from oil and gas development.

Key words: abundance, Alaska, breeding, density, National Petroleum Reserve, populations, shorebirds, surveys

RÉSUMÉ. Sur la plaine côtière arctique de la réserve pétrolière nationale-Alaska (NPRA), la région spéciale du lac Teshekpuk (TLSA) a été créée dans le but de protéger les valeurs exceptionnelles de la faune. Même s'il existe beaucoup d'information sur la valeur du caribou et de la sauvagine de la TLSA, l'importance qu'elle revêt en matière d'oiseaux de rivage nicheurs demeure peu quantifiée. Nous avons par conséquent entrepris de faire une étude sur le terrain à grande échelle pour estimer la taille et la densité de la population d'oiseaux de rivage nichant dans la TLSA. À partir d'une série d'enquêtes réalisées de 2006 à 2008, nous avons estimé que le total redressé en fonction de la détection de la population nicheuse s'établissait à plus de 573 000 oiseaux de rivage, et que la densité générale s'élevait à 126 oiseaux de rivage/km^2. Les plus grandes densités de la plupart des espèces d'oiseaux de rivage se trouvaient sur la plaine côtière extérieure ou encore, les densités étaient environ égales entre les plaines côtières intérieure et extérieure. Seulement deux espèces avaient leurs plus fortes densités sur la plaine côtière intérieure. Les plus grandes densités d'oiseaux de rivage se manifestaient immédiatement autour du lac Teshekpuk. La TLSA accueillait plus de 10 % des populations biogéographiques de pluviers argentés (*Pluvialis squatarola*), de bécasseaux semipalmés (*Calidris pusilla*) et de bécasseaux variables (*C. alpina*). La densité d'oiseaux nicheurs dans la TLSA est l'une des plus élevées de la NPR-A, sur le versant nord de l'Alaska et à l'échelle de l'Arctique circumpolaire. Nos résultats, jumelés à l'information obtenue antérieurement au sujet de la sauvagine et du caribou, indiquent que la région autour du lac Teshekpuk et la région reconnue pour la mue des oies au nord-est du lac devraient être protégées contre la mise en valeur pétrolière et gazière.

Mots clés : abondance, Alaska, nicheur, densité, réserve pétrolière nationale, populations, oiseaux de rivage, enquêtes

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INTRODUCTION

Each spring, millions of shorebirds (Sub-order Charadrii) return to the tundra of northern Alaska to nest and raise young during the brief Arctic summer. Shorebirds are the dominant component of the avifauna throughout the Arctic (Boyd and Madsen, 1997), and almost one-half (49%) of all shorebird species breeding in North America can be found in northern Alaska (Johnson and Herter, 1989; Morrison et al., 2006). Shorebirds arriving in northern Alaska migrate there from a wide range of non-breeding areas, which include northern and southern South America, Mexico,

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Southeast Asia, Pacific Ocean islands, and New Zealand (Alaska Shorebird Working Group, 2008).

Within northern Alaska, the 95 000 km² National Petroleum Reserve - Alaska (NPR-A) is one of the largest tracts of undeveloped land and the largest public land management unit in the United States. As the name implies, the NPR-A was suspected of holding substantial petroleum assets when it was set aside as a federal military energy reserve in 1923. Descending from heights of more than 1300 m in the Brooks Range to sea level along the Beaufort Sea coast, the NPR-A also provides a diversity of habitats for Arctic-breeding birds.

Systematic aerial surveys have long provided ample evidence of the NPR-A's importance to waterfowl, loons, and other large birds (King, 1979). Much less information is available for shorebirds, which generally require ground surveys to identify species accurately and count individuals. However, Johnson et al. (2007) found greater shorebird species richness in the NPR-A than in areas farther to the east, and Bart et al. (2012a), in a broad-scale study across northern Alaska, reported that the highest densities of breeding shorebirds occurred in the NPR-A.

Although oil production in northern Alaska began in 1977 (Gilders and Cronin, 2000), it has only recently expanded into the NPR-A, where most leases for oil and gas were purchased within the eastern portion of the NPR-A (the Northeast Planning Unit). 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 (Auerbach et al., 1997). Furthermore, oil field infrastructure may increase 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); however, separating natural variability in nest survival from predation effects can be difficult (Liebezeit et al., 2009). 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 significant negative cumulative effects on shorebirds breeding on the Arctic Coastal Plain.

In the Northeast Planning Unit of the NPR-A, oil and gas development will likely increase in the next few years (Bureau of Land Management, 2008). Within this unit, the Teshekpuk Lake Special Area (TLSA) was created in 1977 to assure maximum protection of important nesting, staging, and molting habitat for a large number of waterfowl, and critical calving, migration, and insect-relief habitat for the Teshekpuk Lake caribou herd. The special area designation included some development restrictions during exploration,

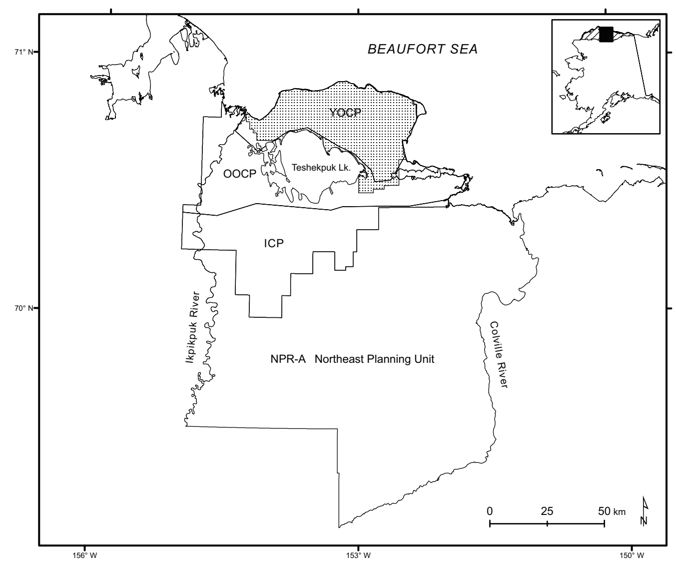

FIG. 1. Location of the National Petroleum Reserve-Alaska and boundaries of the Northeast Planning Unit, Teshekpuk Lake Special Area, and restrictive Goose Molting Area (shaded). Also shown are ecological divisions between the Inner Coastal Plain (ICP), Old Outer Coastal Plain (OOCP), and Young Outer Coastal Plain (YOCP). Insert map shows location of the study area and the Arctic Coastal Plain.

and leasing activity was deferred until recently. Although the value of the TLSA to waterfowl has been clearly established (Bureau of Land Management, 2008), little information is available to assess its value to breeding shorebirds. Where shorebird studies were completed within the eastern NPR-A, fieldwork was generally confined to small areas (at only six sites) and focused on determining nest density or local-scale habitat use (Derksen et al., 1981; Cotter and Andres, 2000; Burgess et al., 2003; Liebezeit et al., 2011). Although ground surveys were conducted to estimate regional shorebird abundance (Bart et al., 2012a), sampling in the eastern NPR-A was either clustered in particular areas or was not intense enough to permit reliable inference to specific areas such as the TLSA. To assess the value of the TLSA to breeding shorebirds, we undertook a study to estimate the density and abundance of these species prior to any large-scale development. We compared abundances from the TLSA to those in other Alaska and Holarctic regions to assess importance and compared densities within the TLSA to determine high-value landscapes and habitats.

METHODS

The TLSA, located in the northeastern corner of the NPR-A, is contained mostly within the 18 620 km² Northeast Planning Unit (NEPU) and lies within the Arctic Coastal Plain (ACP) ecoregion (Nowicki et al., 2001; Fig. 1). The TLSA (6880 km²) is dominated by Teshekpuk Lake, which has a surface area of about 854 km². Northeast of the lake is a series of smaller, similarly oriented, oblong thaw lakes, which are unique to this part of the ACP. The northern boundary of the TLSA is formed by Smith Bay

TABLE 1. Percentage of cover types (other than water) on all plots and those sampled for breeding shorebirds (2006–08) on the Outer and Inner Coastal Plains of the Teshekpuk Lake Special Area, northern Alaska.

	Aquatic	Flooded tundra	Wet tundra	Sedge meadow	Tussock tundra/ dwarf shrub	Other
Outer Coastal Plain						
Entire area	10	36	11	21	16	6
Plots (n = 118)	10	35	11	21	20	3
Inner Coastal Plain						
Entire area	5	12	6	23	47	7
Plots (n = 49)	8	14	8	25	42	3

and the open coast of the Beaufort Sea, and the Ikpikpuk and Colville Rivers form its western and eastern boundaries. South of the lake, the landscape is drier and is dominated by tussock tundra. The TLSA shows many features typical of an Arctic tundra landscape underlain with continuous permafrost.

We overlaid the TLSA (Fig. 1) with a grid of 16 ha plots (400 × 400 m, about 44 000 total units) to form our spatial sampling frame. From the grid, we randomly selected plots, without replacement, for sampling breeding shorebirds in 2007 (40 plots) and 2008 (119 plots). We also included an additional eight plots surveyed in 2006, which were originally randomly selected and surveyed in 2001. To maximize efficiency in our ground surveys, we restricted the sample to include only those plots with less than 50% open water or ice (see below). Because we knew from previous studies that breeding shorebird density would increase from south to north (B. Andres, unpubl. data), we used geomorphological divisions of the ACP to allocate sample plots among the Young Outer Coastal Plain (YOCP), Old Outer Coastal Plain (OOCP), and Inner Coastal Plain (ICP; Fig. 1). For most statistical analyses, we considered the combined YOCP/OOCP as the Outer Coastal Plain (OCP), which received a higher allocation of sample plots.

To characterize shorebird habitats, we collapsed the 16 earth cover types defined from remotely sensed imagery (30 m^2 resolution) by the Bureau of Land Management and Ducks Unlimited Inc. (2002) into seven tundra vegetation classes (hereafter, cover types) that we thought were relevant to shorebirds: 1) water (clear water + turbid water + ice), 2) aquatic (*Arctophila* + *Carex aquatilus*), 3) flooded (low-centered polygons + non-patterned flooded tundra + moss-lichen), 4) wet tundra, 5) sedge meadow, 6) tussock tundra/dwarf shrub, and 7) other (dry dunes + sparsely vegetated + low shrub + unclassified). Although moss-lichen is considered a moist type, we found it was more strongly correlated with flooded earth cover types and therefore included it in the flooded cover type. Dwarf shrub is relatively rare in the TLSA, and the "other" cover type generally includes those earth cover types not used by nesting shorebirds. Proportional representation of these seven cover types was generated for every plot in our sampling frame. Overall classification accuracy of the 16 original earth cover types ranged from 75% to 85% (Bureau of Land Management and Ducks Unlimited Inc., 2002).

To determine shorebird density on each sampled plot, we calculated the land area as the sum of all cover types except water. On the basis of land area of all plots, cover types differed in their proportional representation between the OCP and the ICP (Table 1), suggesting that shorebird density could potentially differ between regions. However, considering our bias toward not including plots completely covered by water, our selected plots were representative of the cover types available to shorebirds in the ecoregions of the TLSA (Table 1).

Plots were accessed one time by helicopter and were surveyed by a single observer within 1.25 hours. In all years, plots were surveyed between 9 and 23 June, which was the period when shorebirds were establishing territories and initiating nests and were therefore most actively displaying and detectable (Lanctot et al., 2000). Survey methods followed those of the Program for Regional and International Shorebird Monitoring (PRISM) outlined by Bart and Earnst (2002) and Bart et al. (2012b). Briefly, an observer systematically traversed the plot and recorded the location and number of all nests, probable nests, pairs, males, females, birds of unknown sex, and groups of shorebirds on a plot map, which was summarized on data forms after the survey was completed. Each shorebird encounter was placed in only one of the breeding evidence categories described above. The observer differentiated those shorebird activities that occurred within and outside of the plot boundary and indicated behaviors of individuals not using the plot (e.g., birds flying over the plot). The observer used natural changes in cover types, satellite photos, and handheld GPS units to stay within plot boundaries and ensure the entire plot was surveyed. All observers in this study had previous Arctic experience and were familiar with breeding shorebird behavior.

Two methods were used to enumerate the number of birds present on plots (Table 2). For monogamous species, we followed the protocol outlined in Bart et al. (2012b) and used an "indicated breeders" metric that determined the total number of adults on the plot by summing and then doubling each instance of a pair, nest, probable nest, and territorial male. For example, a plot coded as one pair, one probable nest, and two territorial males would equal eight indicated breeders (the sum of four encounters multiplied by two). Here we assumed that all single males appearing to have territories on the plot were already mated or would

TABLE 2. Method of estimating the number of breeding shorebirds recorded on plots and the detection ratios (and SEs) used to adjust raw counts on surveys of the Teshekpuk Lake Special Area, northern Alaska. Detection ratios below 1.00 and all SEs are taken from Bart et al. (2012a).

Common name	Scientific name	Count method[1]	Detection ratio	SE (ratio)
Black-bellied plover	*Pluvialis squatarola*	indicated breeders	0.85	0.17
American golden-plover	*P. dominica*	indicated breeders	0.88	0.26
Bar-tailed godwit	*Limosa lapponica*	indicated breeders	0.75	0.26
Ruddy turnstone	*Arenaria interpres*	indicated breeders	0.83	0.00
Semipalmated sandpiper	*Calidris pusilla*	indicated breeders	0.75	0.13
Baird's sandpiper[2]	*C. bairdii*	indicated breeders	0.84	0.14
Pectoral sandpiper	*C. melanotos*	adjusted total	1.00	0.10
Dunlin	*C. alpina*	indicated breeders	0.90	0.16
Stilt sandpiper	*C. himantopus*	indicated breeders	0.61	0.11
Buff-breasted sandpiper	*Tryngites subruficollis*	adjusted total	1.00	0.10
Long-billed dowitcher	*Limnodromus scolopaceus*	indicated breeders	1.00	0.10
Red-necked phalarope	*Phalaropus lobatus*	adjusted total	1.00	0.10
Red phalarope	*P. fulicarius*	adjusted total	1.00	0.10

[1] The indicated breeders value was determined by summing each instance of a territorial male, pair, probable nest, or nest estimated for each plot and then doubling this value. Adjusted total was calculated by doubling each instance of a nest, probable nest, and pair and adding the number of single birds to this total.

[2] Where data were lacking, we used the mean detection ratio (and SE) for monogamous species.

be soon. For non-monogamous species, we deviated from Bart et al. (2012b) and used an "adjusted total" metric that consisted of doubling the number of nests, probable nests, and pairs determined by field observers and adding in all other individuals recorded. Here, individuals detected alone were not doubled because it was not easy to determine how many mates each of these individuals had. For example, females of polyandrous species and males of polygynous species might have no mate or multiple mates (see Lanctot et al., 1997; Schamel et al., 2004). Because adult sex ratios in shorebirds are not likely to be 1:1 (Székely et al., 2006), we felt it was inappropriate to assume there was always one mate for the single birds observed. Scientific names of shorebird species followed current taxonomy of the American Ornithologists' Union (see http://www.aou.org/checklist/north/) and are presented in Table 2.

We adjusted our plot counts by applying Bart et al.'s (2012a) species-specific detection rates to the indicated breeders metric for the monogamous species (Table 2). The detection ratios were based on the indicated breeders metric, which included all encounter types (e.g., pairs, nests, territorial males). Because we were unsure whether these detection ratios would be similar to values that would have been generated using the adjusted total metric, we did not adjust counts of the polygamous (polygynous and polyandrous) species and assumed perfect detection (detection rate = 1.0). Because we were uncertain about the actual detection rate for the polygamous species, we incorporated a 10% standard error into variance calculations, which was the error rate of Bart et al.'s (2012a) overall detection rate. Detection rates were applied to species on each plot and used to adjust densities within the OCP and ICP regions and across the entire TLSA. To compare our results directly to Bart et al.'s (2012a) study, we also generated the indicated breeders metric for all species (including non-monogamous species) and applied Bart et al.'s (2012a) average detection ratio of (0.81 ± 0.08) across all species to estimate density.

To determine density and abundance of shorebirds breeding within the OCP and ICP regions, we used the compound ratio estimator described by Brown et al. (2007: 6–7); the only difference was that our plots were primary sampling units, so no estimates of covariance were needed. The compound ratio estimator incorporates information on counts, land area of plots, and detection ratio to determine density. A density estimate for the entire TLSA was obtained by weighting regional estimates in proportion to their land area. Tests for differences between regions were conducted using a t-test and Satterthwaite's approximation for degrees of freedom, which accounts for unequal variances and sample sizes (Snedecor and Cochran, 1980:97).

Regression tree procedures (Venables and Ripley, 2002:251–270) were used to determine if proportional representation of cover types could further explain differences in breeding shorebird density within a region. Shorebird density on individual plots was generated on the basis of land cover types as described above and included species-specific adjustments for imperfect detection (Table 2). To validate regression tree results, we calculated mean shorebird density (of ecological species assemblages) within the identified cover type groups and tested for differences between groups using the t-test procedure described above. We did not include variances associated with detection in these calculations.

To illustrate the spatial variation in shorebird densities across the TLSA, we mapped the individual plot densities (by density categories and adjusted for detection) for all species combined and for select ecological species assemblages. We plotted densities and chose natural break points to define density categories; maps depicted the delineation

TABLE 3. Mean density (birds/km^2) and abundance (± 1 SE) of shorebirds breeding in the Teshekpuk Lake Special Area (TLSA). Estimates were generated from surveys conducted on 167 plots in 2006–08. Total land area in the TLSA is 4550 km^2.

	Density		
	Mean ± SE	CV	Abundance
Black-bellied plover	5.85 ± 1.14	0.19	26 623 ± 5165
American golden-plover	3.98 ± 1.12	0.28	18 113 ± 5079
Bar-tailed godwit	0.22 ± 0.16	0.73	998 ± 730
Ruddy turnstone	0.44 ± 0.19	0.44	2016 ± 887
Semipalmated sandpiper	32.94 ± 4.93	0.15	149 889 ± 22 443
Baird's sandpiper	0.26 ± 0.19	0.73	1200 ± 874
Pectoral sandpiper	15.11 ± 1.92	0.13	68 732 ± 8736
Dunlin	20.93 ± 3.69	0.18	95 245 ± 16 785
Stilt sandpiper	1.19 ± 0.41	0.34	5394 ± 1860
Buff-breasted sandpiper	0.28 ± 0.14	0.50	1258 ± 635
Long-billed dowitcher	7.18 ± 1.04	0.14	32 678 ± 4725
Red-necked phalarope	15.19 ± 1.91	0.13	69 103 ± 8711
Red phalarope	22.42 ± 2.96	0.13	102 026 ± 13 478
All species	125.99 ± 8.51	0.07	573 274 ± 38 718

of the Young Outer Coastal Plain, Old Outer Coastal Plain, and Inner Coastal Plain.

RESULTS

We estimated a total population of over 0.5 million shorebirds of 13 species breeding in the TLSA (Table 3). Individually, species populations ranged from the low thousands (bar-tailed godwit, Baird's sandpiper, buff-breasted sandpiper) to 100 000 or more (semipalmated sandpiper, dunlin, and red phalarope; Table 3). Frequency of encounter of species on plots ranged from 1% to 74% of the 167 sample units. In general, species with the lowest densities were also found on the fewest plots, which led to high coefficients of variation (CVs; Table 3).

On the OCP, black-bellied plovers had a significantly lower density on the YOCP (mean birds/km^2 = 1.41 ± 0.67) than on the OOCP (8.91 ± 2.27; t = 3.179; p = 0.0022, df = 68), whereas red phalaropes showed the opposite pattern (YOCP = 45.64 ± 7.04, OOCP = 21.75 ± 3.57; t = 3.027, p = 0.0033, df = 85). Bar-tailed godwits, Baird's sandpipers, buff-breasted sandpipers, and stilt sandpipers were all absent from the YOCP. Because most species had similar densities in the YOCP and the OOCP, we combined these two regions into one geographic group (the OCP) for subsequent analysis.

As predicted, mean density of all species was significantly greater (p = 0.0001) on the OCP than on the ICP (Table 4). Species could be categorized into one of four groups on the basis of similar patterns of density (Table 4): 1) a coastal group that had higher densities on the OCP and included the ruddy turnstone, dunlin, pectoral sandpiper, and red phalarope; 2) a widespread group that had approximately equal densities on the OCP and ICP and included the black-bellied plover, semipalmated sandpiper, long-billed dowitcher, and red-necked phalarope; 3) an inland group that had higher densities on the ICP and included the American golden-plover and stilt sandpiper; and 4) a group of species encountered in low numbers that could not be compared between regions, and which have high uncertainty associated with their estimates (bar-tailed godwit, Baird's sandpiper, and buff-breasted sandpiper). Because stilt sandpipers were encountered on only six plots and differed from American golden-plovers in their association with wet and dry cover types, we considered only the American golden-plover as the inland group representative.

Except for the American golden-plover, densities of breeding shorebirds were lowest in the southwesternmost portion of the TLSA (Fig. 2). Plots located adjacent to the coast had only moderate shorebird densities, whereas plots with the highest densities were located west, east, and slightly north of Teshekpuk Lake (Fig. 2). Mean shorebird density on plots bounded by 70.417˚ and 70.750˚ N was 195.40 ± 12.35 birds/km^2, which was significantly higher than mean density on plots either north or south of this area (122.11 ± 13.01; t = 4.086, p = 0.0001, df = 162).

We used ecological assemblages of shorebirds to assess differences in density relative to cover type groups identified through the regression tree analysis. On the OCP, all species combined, coastal, and widespread species had significantly higher densities on plots where the aquatic cover type was above 14% (Table 5). American golden-plovers had a significantly higher density on plots where flooded tundra was below 10% (Table 5). On the ICP, all species had significantly higher densities on plots where wetlands (aquatic + flooded tundra + wet tundra) were over 43%, coastal species had a significantly higher density on plots where flooded tundra was over 17%, and widespread species had a significantly higher density on plots where the aquatic cover type was above 8% (Table 5). American golden-plovers tended to have higher, but quite variable, densities on plots where flooded tundra was 6% or lower (Table 5).

DISCUSSION

Our study is the first to provide population estimates of 13 shorebird species breeding in the TLSA (≈ 600 000 total breeding shorebirds). Although not encountered on our surveys, white-rumped sandpipers (*Calidris fuscicollis*) were recorded breeding in the TLSA on plots (only on the YOCP) surveyed in 2001 (Johnson et al., 2007). In addition, whimbrels (*Numenius phaeopus*) and semipalmated plovers (*Charadrius semipalmatus*) were recorded on the Ikpikpuk River within the TLSA in June 2000, and Wilson's snipes (*Gallinago delicata*) were found along the river just south of the TLSA border (B. Andres, unpubl. data). Thus, we suspect that up to 17 species of shorebirds breed within the TLSA.

A major benefit of our survey design was the random selection and an adequate number of surveyed plots (with the constraint of having < 50% water), which allowed us to estimate population size with relatively good precision

TABLE 4. Mean density (birds/km^2) and abundance (± 1 SE) of shorebirds breeding in ecoregions of the Teshekpuk Lake Special Area estimated from surveys conducted in 2006–08. Estimates are adjusted for detection.

	Outer Coastal Plain (n = 118 plots, area = 2770 km^2)		Inner Coastal Plain (n = 49 plots, area = 1780 km^2)		
	Density	Abundance	Density	Abundance	p-value, df (density)
Black-bellied plover	5.12 ± 1.31	14 175 ± 3639	6.99 ± 2.06	12 448 ± 3665	> 0.1, 88
American golden-plover	1.79 ± 0.71	4944 ± 1956	7.40 ± 2.63	13 169 ± 4687	0.0442, 55
Bar-tailed godwit	0.14 ± 0.14	398 ± 398	0.34 ± 0.34	600 ± 600	> 0.1, 64
Ruddy turnstone	0.73 ± 0.32	2016 ± 887	0.00 ± 0.00	0 ± 0	0.0244, 117
Semipalmated sandpiper	36.89 ± 6.93	102 191 ± 19 185	26.80 ± 6.54	47 698 ± 11 646	> 0.1, 142
Baird's sandpiper	0.00 ± 0.00	0 ± 0	0.67 ± 0.49	1200 ± 874	> 0.1, 48
Pectoral sandpiper	21.08 ± 2.96	58 403 ± 8202	5.80 ± 1.69	10 329 ± 3010	0.0001, 163
Dunlin	29.94 ± 5.87	82 928 ± 16 249	6.92 ± 2.36	12 316 ± 4236	0.0004, 148
Stilt sandpiper	0.43 ± 0.26	1195 ± 726	2.36 ± 0.96	4199 ± 1712	0.0575, 55
Buff-breasted sandpiper	0.18 ± 0.11	502 ± 292	0.42± 0.32	756 ± 564	> 0.1, 59
Long-billed dowitcher	7.25 ± 1.39	20 081 ± 3862	7.08 ± 1.53	12 596 ± 2723	> 0.1, 125
Red-necked phalarope	17.58 ± 2.68	48 697 ± 7410	11.46 ± 2.57	20 406 ± 4581	0.1016, 140
Red phalarope	33.83 ± 4.68	93 713 ± 12 974	4.67 ± 2.05	8314 ± 3652	0.0001, 152
All species	154.96 ± 11.88	429 245 ± 32 902	80.91 ± 11.47	144 031 ± 20 409	0.0001, 140

for most species (CV of mean abundance of all shorebirds = 7%). Geographic partitioning within the TLSA improved our ability to differentiate species-specific densities between coastal plain regions. Further, we statistically differentiated high-density and low-density areas for shorebird species assemblages in each cover type group within coastal plain regions.

In ICP landscapes dominated by tussock tundra and other moist cover types, many shorebird species occurred in higher densities on wet and flooded cover types. At their 50 km^2 study site 10 km southeast of Teshekpuk Lake (at the boundary between the OCP and ICP), Leibezeit et al. (2011) found a disproportionate use of wetland cover types by nesting shorebirds. These results correspond with our results for the ICP, where coastal and widespread shorebird groups had higher densities on plots with greater amounts of flooded and aquatic cover types; only American golden-plovers had higher densities on plots with less moisture. Cotter and Andres (2000) found a similar result of high shorebird densities in wetlands at their inland Inigok site, where the ecotone between wetlands and uplands was abrupt.

In comparing coastal and inland species at study sites in the NEPU, Derksen et al. (1981) generally found density patterns similar to ours. Pectoral sandpiper, red phalarope, and dunlin were the most abundant species at their coastal sites (located on the YOCP within the TLSA), whereas the red-necked phalarope, semipalmated sandpiper, and pectoral sandpiper were most abundant inland at Square Lake (51 km south of the TLSA's southern boundary). At their coastal East Long Lake site, density of pectoral sandpipers (36.3 birds/km^2) exceeded our estimate for the entire OCP, dunlins (12.8) and semipalmated sandpipers (6.3) were below our OCP-wide estimate, and red phalaropes were about the same (32.5). All species at their coastal Island Lake site had densities below our estimate for the entire OCP. Note that they did not adjust their estimate by any detection ratios; if detection ratios were similar to ours for dunlins and semipalmated sandpipers, our densities would still be higher.

If we assume that our population density estimates are approximately twice the estimates of nest density, then we can also make comparisons to the limited number of nesting studies conducted in the NEPU. Our estimates of total shorebird density on the TLSA exceeded estimates at Inigok (42 birds/km^2; Cotter and Andres, 2000) and in the vicinity of Uvlutuuq and Iqalliqpuk (77–100 birds /km^2; Burgess et al., 2003; Johnson et al., 2004, 2005; Liebezeit et al., 2009). Even if we adjusted the estimates for the average detection ratio of 0.81, the densities reported above would all be lower than those generated from our study. One study within the TLSA at the boundary of the OCP and ICP (Liebezeit et al., 2009) had an overall nest density (99 birds/km^2) that exceeded our estimate for the ICP but was lower than our estimate for the OCP. Our plots on the ICP extended to the southern boundary of the TLSA and included large areas of moist to dry upland tundra.

Using the metric of indicated breeders to compare directly to Bart et al.'s (2012a) study, we found that total shorebird density in the TLSA (139 shorebirds/km^2) was higher than regional estimates from elsewhere on Alaska's North Slope (Table 6). Six of eight well-surveyed species had higher point-estimate densities in the TLSA than in other regions of the North Slope (Table 6). Our indicated breeders estimate for the TLSA was 11% of the total population of shorebirds estimated for the entire North Slope (Bart et al., 2012a). When we used recent shorebird population estimates (Bart et al., 2012a; Bart and Smith, 2012), we found that the TLSA was particularly important for nesting black-bellied plovers (10% of *P. s. squatarola*), semipalmated sandpipers (10% of the western breeding population), dunlins (19% of *C. a. arcticola*), red-necked phalaropes (12% of the northern Alaska population), and red phalaropes (16% of the northern Alaska population). The highest densities of dunlins reported elsewhere on the North Slope were only about one-half to one-third of those on the TLSA (Table 6). The proportional representation of plovers, semipalmated sandpipers, and dunlins would qualify the TLSA for recognition as a site of international importance under

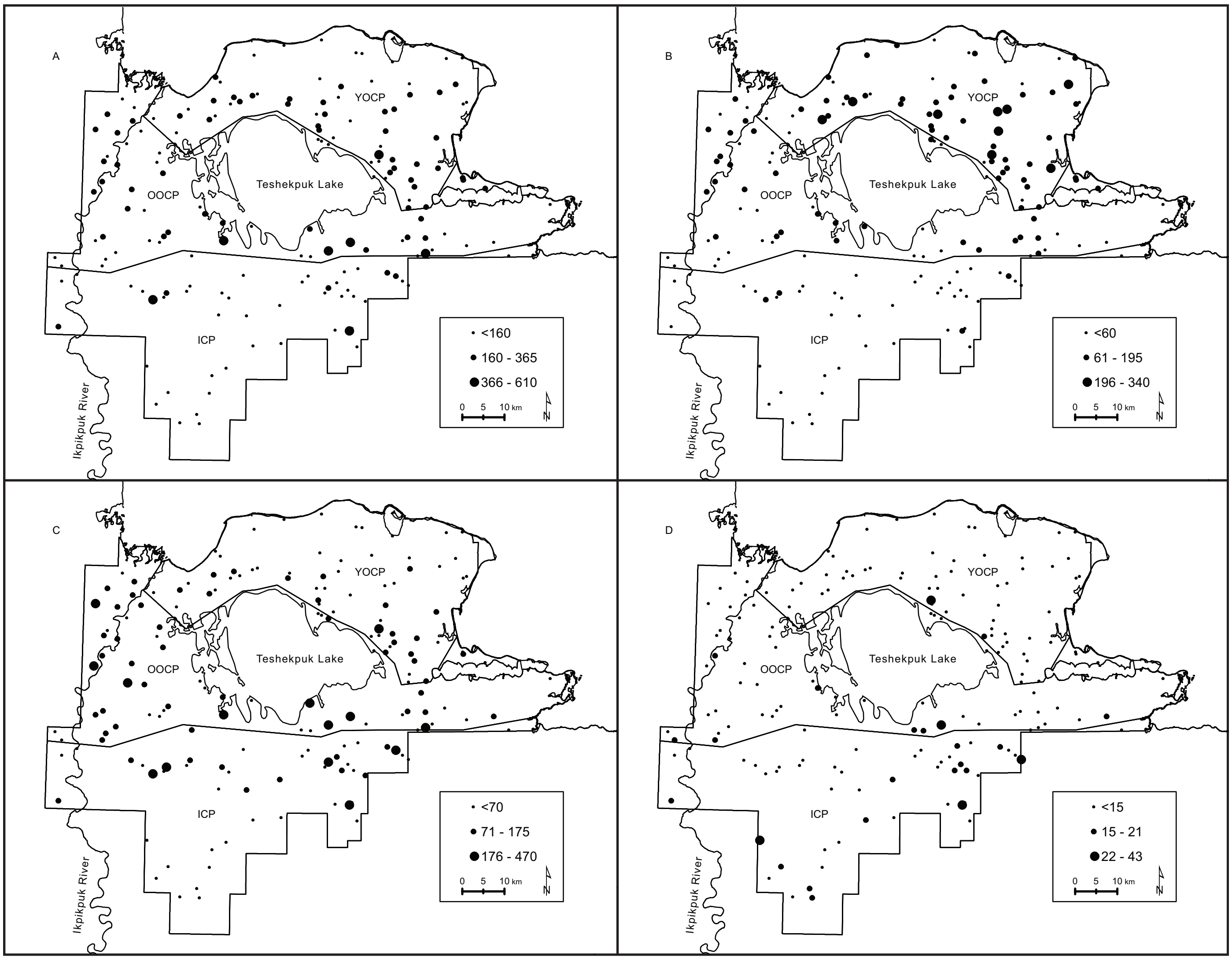

FIG. 2. Categorical density of shorebirds (birds/km^2) breeding in the Teshekpuk Lake Special Area (2006–08) for A) all shorebirds, B) coastal species (ruddy turnstone, dunlin, pectoral sandpiper, red phalarope), C) those distributed evenly between Young/Outer and Inner Coastal Plains (black-bellied plover, semipalmated sandpiper, long-billed dowitcher, red-necked phalarope), and D) American golden-plover.

the Western Hemisphere Shorebird Reserve Network (see www.whsrn.org) and the RAMSAR convention (see www.ramsar.org). Our use of adjusted total metric produced an overall shorebird density that was more conservative (≈ 10% for all shorebirds) than the estimate produced with the indicated breeders metric of Bart et al. (2012a).

A comparison of our results to findings at other locations in the circumpolar Arctic indicates that the overall density of shorebirds in the TLSA is among the highest in the world. Johnston and Pepper (2009) provided shorebird density estimates from 15 low and mid-Arctic sites in Alaska and Canada, of which none had total shorebird densities greater than our estimates (based on those in Table 3) for the TLSA, even considering the generic adjustment of + 23% for imperfect detection (rate = 0.81). Breeding shorebird densities as high as 100–150 pairs/km^2 have been reported at a limited number of sites in northern and northeastern Siberia, but more typical shorebird densities in the low Arctic ranged from 15–100 pairs/km^2 (Meltofte et al., 2007). Among our plots, 25% on the OCP exceeded 250 birds/km^2, and 10% of all of our plots had densities that exceeded those reported in Siberia (assuming 300 birds/km^2).

Shorebird density in the TLSA, particularly on the OCP portion, is atypically high for low Arctic sites. Differences in density among cover types for almost all species indicate the importance of landscape wetness to breeding shorebirds. Elevation is related to tundra wetness, and elevations in the TLSA are much lower than those at the same latitude in the western NPR-A. Although sample sizes were lower in the ICP, differences in the point estimates of density between wet and moist cover types were more marked than on the OCP. As elevation increases, there is a more abrupt ecotone between wetland and upland habitats. The lower density of shorebirds in other parts of the Arctic may also be related to differences in food availability, lemming numbers and cycles, predator density, or other unknown factors.

Our results clearly demonstrate that the TLSA is one of the most important shorebird breeding sites in the

TABLE 5. Effects of cover type on densities (mean ± 1 SE (*n*)) of breeding shorebirds in Outer and Inner Coastal Plains of the Teshekpuk Lake Special Area, northern Alaska, from surveys conducted in 2006–08. Coastal species include ruddy turnstone, dunlin, pectoral sandpiper, and red phalarope; Widespread species include black-bellied plover, semipalamated sandpiper, long-billed dowitcher, and red-necked phalarope; and Inland species are represented by American golden-plover.

Shorebird group	Region/cover type characterization		*p*-value, df
Outer Coastal Plain:			
	Aquatic ≤ 14%	*Aquatic > 14%*	
All species	155.42 ± 9.13 (88)	268.66 ± 25.30 (30)	0.0002, 36
Coastal	87.11 ± 6.46 (87)	130.27 ± 14.75 (31)	0.0105, 42
Widespread	63.70 ± 4.71 (87)	134.39 ± 19.63 (31)	0.0013, 33
Inland	*Flooded < 10%*	*Flooded ≥ 10%*	
	5.19 ± 1.72 (27)	1.00 ± 0.44 (91)	0.0252, 29
Inner Coastal Plain:			
All species	*Wetlands ≤ 43%*	*Wetlands >43%*	
	60.26 ± 7.62 (35)	219.17 ± 47.93 (14)	0.0061, 13
Coastal	*Flooded ≤ 17%*	*Flooded > 17%*	
	10.63 ± 3.00 (32)	44.80 ± 12.22 (17)	0.0147, 17
Widespread	*Aquatic ≤ 8%*	*Aquatic > 8%*	
	27.95 ± 5.20 (31)	141.54 ± 25.82 (18)	0.0004, 18
Inland	*Flooded ≤ 6%*	*Flooded > 6%*	
	10.74 ± 2.64 (20)	5.75 ± 1.68 (29)	0.1212, 33

TABLE 6. Density of breeding shorebirds, listed by ecological assemblages, in the Teshekpuk Lake Special Area (TLSA, this study) and those in other regions of Alaska's North Slope, including the entire National Petroleum Reserve-Alaska (NPR-A), Central Arctic Coastal Plain, and the Arctic National Wildlife Refuge (NWR; from Bart et al., 2012a). Density is calculated using the indicated breeders method and assuming an average detection rate of 0.81 ± 0.08 (SE) for all species at all locations.

	TLSA	Entire NPR-A	Central	Arctic NWR
Coastal:				
Pectoral sandpiper	20.76 ± 2.59	21.61 ± 4.81	19.88 ± 4.42	8.04 ± 1.65
Dunlin	23.26 ± 2.76	10.91 ± 2.29	5.68 ± 2.01	0.67 ± 0.30
Red phalarope	25.07 ± 3.24	12.42 ± 2.30	6.67 ± 2.57	2.05 ± 0.78
Widespread:				
Black-bellied plover	6.14 ± 0.92	4.13 ± 1.03	3.09 ± 1.41	0.00 ± 0.00
Semipalmated sandpiper	30.50 ± 3.19	26.18 ± 4.77	22.57 ± 5.99	6.87 ± 1.52
Long-billed dowitcher	8.87 ± 1.28	14.46 ± 2.95	4.97 ± 1.61	0.79 ± 0.34
Red-necked phalarope	16.96 ± 2.19	11.67 ± 3.13	5.52 ± 2.50	5.49 ± 1.43
Inland:				
American golden-plover	4.32 ± 0.77	3.82 ± 1.08	2.22 ± 0.71	2.46 ± 0.56
All species	139 ± 13	120 ± 18	76 ± 17	32 ± 6

circumpolar Arctic. Lease sales of oil and gas have been offered in seven of the past 13 years, with most of the successful purchases within the Northeast Planning Unit (some of which are within the TLSA). The Army Corps of Engineers also recently permitted the first bridge over the Colville River, which will accelerate development of oil and gas leases in the area by allowing easy access from the Prudhoe Bay and Kuparuk oil fields (Joling, 2011). Current protections in the TLSA, including the restrictive development alternative suggested for the Goose Molting Area in the Bureau of Land Management's (2008) Environmental Impact Statement, would benefit several breeding shorebirds, particularly dunlins and red phalaropes, by minimizing habitat modification and disturbance and the resultant higher predation rates that have been documented in both phalarope species (National Research Council, 2003; Liebezeit et al., 2009). Expanding the restrictions to a buffer around the entirety of Teshekpuk Lake (bounded by 70.417˚ and 70.750˚ N) would provide benefits to additional shorebird species. In August 2012, the U.S. Secretary of the Interior announced the preference for an NPR-A management plan that would expand the historic boundary of the TLSA and make leasing unavailable in most of the expanded area (Bureau of Land Management, 2012). Given the exceptionally high densities of shorebirds, the importance of the area for geese and caribou, and the fact that only 2% of the entire Arctic Coastal Plain is protected, permanent protection for the TLSA is certainly warranted.

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