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Research Article

Shorebird Abundance Estimates in Interior Alaska

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ABSTRACT Interior Alaska, USA, is the least-studied region in Alaska for breeding shorebirds because of challenging accessibility and expectations of low densities and abundances. We estimated lowland and upland shorebird population sizes on 370,420 ha of military lands in interior Alaska boreal forest from May–July 2016 and 2017. We modified the Program for Regional and International Shorebird Monitoring (PRISM) protocol used elsewhere in Alaska and incorporated a probability-based sampling design and dependent double-observer methods. We pooled all lowland shorebird and all upland shorebird observations and estimated abundance using Huggins closed captures models in Program MARK. Estimated abundances of all lowland and upland shorebirds were 42,239 ± 13,431 (SE) and 3,523 ± 494, respectively. The survey area is important for shorebirds in Alaska. We estimate that military lands in interior Alaska support 45,762 ± 13,925 shorebirds, including 7 species of conservation concern. Higher abundance of lowland shorebirds was best explained by lower elevation, lower percent scrub canopy, and higher percent water on plots. Higher abundance of upland shorebirds was best explained by higher elevation and increased distance to wetland. Our modified Arctic PRISM protocol was effective for surveys in the boreal forest and we recommend continued use of method modifications for future shorebird surveys in boreal forests. Identifying baseline abundances of shorebirds using interior Alaska is an important step in monitoring distributional shifts and potential future population declines. © 2020 The Authors. The *Journal of Wildlife Management* published by Wiley Periodicals LLC on behalf of The Wildlife Society.

KEY WORDS abundance, Alaska, boreal forest, dependent double-observer, Huggins closed capture models, shorebirds, survey design.

We have empirically measured population sizes for only 52% of 37 shorebird species (*Charadriiformes*, excluding gulls, terns, and seabirds; Page and Gill 1994) recognized as typical Arctic and subarctic breeders (Meltofte et al. 2007). Of species with estimated population sizes, 44% are decreasing (Morrison et al. 2001, Alaska Shorebird Group 2019). Few studies have been conducted on shorebird status and trends and no design-based studies exist estimating shorebird population sizes in the difficult-to-access interior Alaska, USA, boreal forest (Andres et al. 2016, Alaska Shorebird Group 2019). The sheer size and inaccessibility of the Alaskan interior forest compound to make this the least-studied region in Alaska for shorebirds and a high priority for design-based surveys (Alaska Shorebird Group 2019). This region is suspected to provide breeding habitat for >21 species of shorebirds, several of which are of conservation concern (e.g., whimbrel [*Numenius phaeopus*] and lesser yellowlegs [*Tringa flavipes*]; Andres et al. 2012, Alaska Shorebird Group 2019).

The United States Department of Defense (DoD) is a large public land management agency in interior Alaska. The DoD manages approximately 500,000 ha of interior Alaska boreal forest including the United States Army Garrison (USAG) Alaska Army training lands. Shorebirds are seen frequently throughout military lands in interior Alaska, and although not densely concentrated on the landscape, the large expanse of available, mostly undeveloped military lands in interior Alaska boreal forest could contain large numbers of shorebirds. Ultimately, interior Alaska boreal forest could host a sufficient number of birds to be considered an important breeding area by meeting criteria designated by the Western Hemisphere Shorebird Reserve Network (WHSRN; Duncan 2006). The WHSRN defines a site of regional importance as one that receives ≥20,000 shorebirds annually or ≥1% of a species' biogeographic population (Duncan 2006). Surveys to

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understand species composition and to estimate baseline abundances of species are first needed to determine if the site meets WHSRN abundance thresholds.

Efforts by the United States and Canada to develop a shorebird sampling protocol specifically for high-latitude areas have resulted in the Program for Regional and International Shorebird Monitoring (PRISM; Bart and Earnst 2005, Bart et al. 2012). Large-scale survey efforts on the Arctic coasts and southern coasts of Alaska have documented key breeding habitat and high concentrations of shorebirds (Bart et al. 2005, 2012; Andres 2006). The PRISM protocol has not been modified for the unique challenges of shorebird surveys in the Alaska boreal forest, with most studies in the state occurring on the easier-to-access coastal regions where shorebirds congregate in higher densities and a standard survey protocol exists (Alaska Shorebird Group 2019). No design-based survey like PRISM has been conducted specifically on shorebirds in the interior Alaska boreal forest.

Species of shorebirds in interior Alaska can generally be considered as either lowland or upland based on breeding habitat (Alaska Shorebird Group 2019). Lowland species (e.g., spotted sandpiper [*Actitis macularius*]) breed and forage in low elevation (<600 m) riverine corridors with no to medium density woody vegetation and in wetlands, both of which support large amounts of insect biomass (Galbraith et al. 2014, Saalfeld et al. 2016). Upland species (e.g., whimbrel) nest in higher elevation (≥600 m) habitat characterized by low, dense scrub and tundra hummocks (Harwood et al. 2016), or on rocky ridge tops with low ground cover to hide nests from predators (e.g., surfbird [*Calidris virgate*]). Many upland species use higher elevation plateaus that have shallow water or are mostly composed of high elevation wetlands (Viereck et al. 1992). Beyond elevation, other covariates such as percent scrub canopy, percent water, distance to wetland, and dominant land cover classification are all suspected to be important in predicting bird use of an area and therefore hypothesized to be important determinants of abundances in the interior Alaska boreal forest (Dorazio and Royle 2005, Dorazio et al. 2015, Amundson et al. 2018, Savage et al. 2018). Identifying shorebirds and their associated habitat characteristics in the interior Alaska boreal forest will fill this information gap.

In May–July 2016 and 2017 we surveyed military lands in interior Alaska. Our study objectives were to estimate abundances of shorebirds breeding on lowland and upland military lands of interest in interior Alaska, explain variation in plot-level abundances with habitat covariates, and develop and assess the applicability of our modified Arctic PRISM protocol for boreal forest shorebird surveys. We hypothesized that interior Alaska was important for shorebirds because of its large size and potential to have species of conservation concern using the diverse land cover types. We predicted that lowland shorebirds used interior Alaska military lands in larger numbers than upland shorebirds. We predicted that detection during surveys would be high because of the suspected low density of birds on plot, and that detection probability would most likely be influenced by habitat covariates that made birds easier to see and hear (e.g., scrub canopy, dominant land cover classification). We also hypothesized that habitat covariates such as distance to wetland, percent scrub canopy, and elevation would be important explanatory variables in differences in plot-level abundances.

STUDY AREA

Our study took place in May–July 2016 and 2017 on USAG Alaska Army lands in interior Alaska, specifically the Tanana Flats Training Area (TFTA) and the Donnelly Training Area (DTA). The TFTA, south of Fairbanks, Alaska, spanned 258,900 ha. The DTA, south of Delta Junction, Alaska, spanned 267,000 ha (Fig. 1). Mean monthly temperatures in May–July 2016 and 2017 in our study area ranged from 9.89°C (May 2017) to 18.72°C (Jul 2017; Alaska Climate Research Center 2003). Cumulative monthly precipitation in May–July 2016 and 2017 in our study area ranged from 14.99 mm (May 2017) to 126.24 mm (Jul 2016; Alaska Climate Research Center 2003). June 2016 was the third wettest June on record in interior Alaska and (83.57 mm compared to the long-term average of 34.80 mm). July 2016 (126.24 mm) and June 2017 (43.94 mm) had significantly above-average rainfall (compared to long-term averages of 54.86 mm and 34.80 mm in July 2016 and June 2017, respectively; Alaska Climate Research Center 2003). Dominant vegetation on the study area was closed boreal forest of black spruce (*Picea mariana*), white spruce (*P. glauca*), and aspen (*Populus tremuloides*), both tall (alders [*Alnus* spp.], willows [*Salix* spp.], dwarf birch [*Betula nana*]) and low scrub (lingonberry [*Vaccinium vitis-idea*], dwarf birch, bog blueberry [*V. uliginosum*]), and ground cover such as moss and lichen.

The TFTA was a lowland (<600 m elevation), wet, riverine ecosystem with the Tanana River and tributiaries flowing through the landscape. Elevations in TFTA ranged from 120 m to 360 m. The majority of DTA was in uplands (≥600 m elevation) and contained the Delta River, which quickly gained steep elevation on both banks, leveling out to upland scrub hills. The eastern segment of DTA contained lowlands and uplands. The foothills of the Alaska Range began on the south boundary of the training area where there were numerous alpine ridges. Elevations in DTA ranged from 360 m to 1,860 m (Gallant et al. 1995). Both TFTA and DTA were a mosaic of diverse boreal land cover types. For example, 79 different dominant land cover classifications were identified by Viereck et al. (1992) on military lands, including thick white spruce forests, alpine wetlands, and lichen-covered slopes.

The landscape was relatively undeveloped, and forest fire was the main source of natural disturbance within the study area and the surrounding areas (Viereck et al. 1992). Military training was the main land use activity that took place in our study area. There was moderate military, recreational, and forestry activity year-round, with trapping and hunting in the fall (Sep–Nov) and winter (Dec–Feb) and aerial gunnery in the spring (Mar–May) and summer (Jun–Aug). The time period of peak military training and exercise use generally coincided

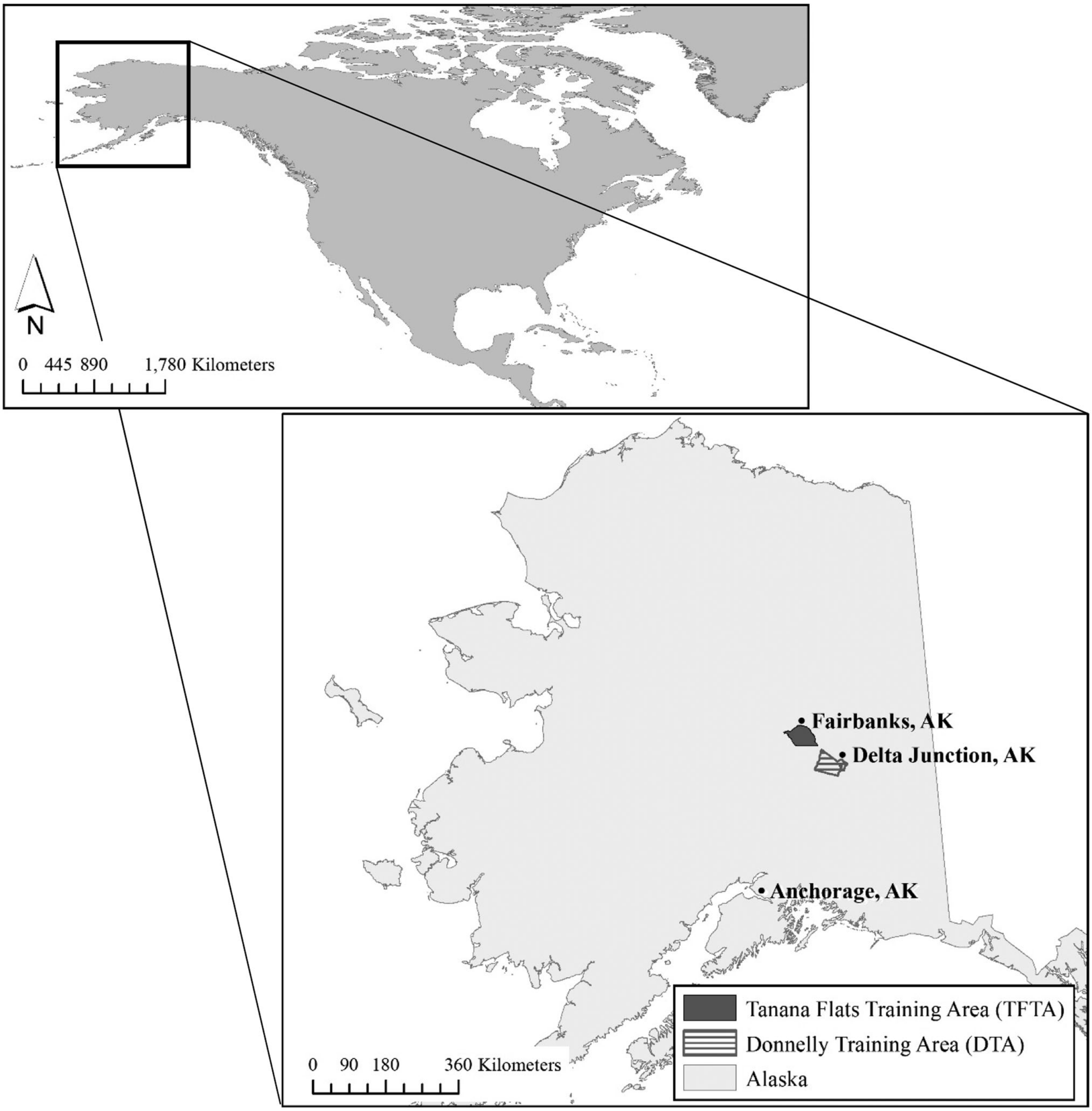

Figure 1. Study area within North America and Alaska, USA. Select United States Army Garrison Alaska Army lands in interior Alaska, Tanana Flats Training Area (TFTA) and Donnelly Training Area (DTA), shown within boundaries of Alaska. We initiated shorebird surveys on 7 May 2016 and 9 May 2017, and ended surveys on 14 July 2016 and 14 July 2017.

with shorebird nest initiation and breeding territory establishment (USAG Fort Wainwright 2013). Training on TFTA and DTA is expected to increase in frequency and intensity because of home-stationing and collaborative large-scale training exercises (USAG Fort Wainwright 2013).

METHODS

Vegetation and Plot Selection

We divided the training areas into 4 strata for plot allocation (TFTA Lowlands, TFTA River, DTA East, and DTA West) based on accessibility limitations and already existent training area boundaries (Fig. 2). The TFTA Lowlands and DTA West survey plots were only accessible via helicopter, TFTA River survey plots only via plane, motorboat, or inflatable canoe, and DTA East survey plots only via truck and 4-wheeler. To define our sampling frame (i.e., available area on military lands within which plots could be generated) within each stratum, we evaluated dominant land cover classifications (i.e., third-level Viereck vegetation classifications; Viereck et al. 1992). Third-level Viereck vegetation classifications describe land cover types by dominant vegetation

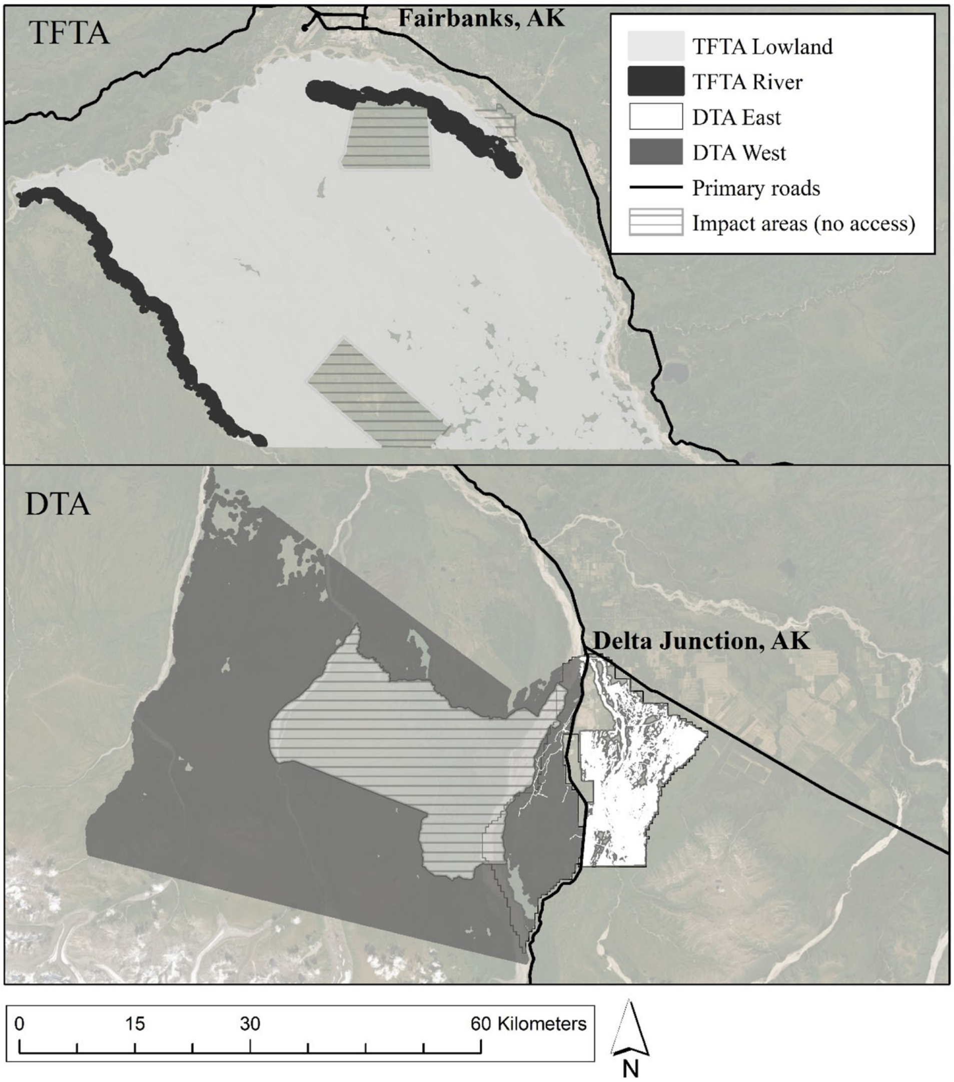

Figure 2. Four different strata within our study area: Tanana Flats Training Area (TFTA) Lowlands, TFTA River, Donnelly Training Area (DTA) East, and DTA West. The TFTA is south of Fairbanks, Alaska, USA, with no primary roads within the training area boundary. The DTA is south and west of Delta Junction, Alaska, with 1 primary road dividing the training area into east and west sections. We initiated shorebird surveys in the 4 strata on 7 May 2016 and 9 May 2017, and ended surveys on 14 July 2016 and 14 July 2017.

species, percent canopy cover, and ground condition (e.g., mesic, wet, dry). We used an existing military lands land cover map to exclude unsuitable areas from our sampling frame (Viereck et al. 1992). The land cover map was created from Landsat 5 imagery and verified via ground truthing at >7,000 vegetation plots (U.S. Army Environmental Division Fort Wainwright 2017). Land cover classifications included as suitable shorebird habitat were open and woodland forest, low density scrub cover, high density scrub cover, grassland, sedge meadows, moss and lichen, water, and barren ground cover (Andres et al. 2012). In addition to excluding unsuitable areas (i.e., closed spruce forest) from the sampling frame, we excluded impact areas, where the DoD prohibited ground-based activity because of the potential to encounter unexploded ordnances (Fig. 2; 23,000 ha of impact area excluded in TFTA; 70,131 ha of impact area excluded in DTA).

Following Arctic PRISM plot size recommendations, we used a spatially balanced sampling design to randomly select 400 × 400-m (16 ha) plots from grids overlaying each of the 4 strata (Stevens and Olsen 2004, Theobald et al. 2007, Bart and Johnston 2012). A spatially balanced sampling framework allowed us to survey plots proportionally within each stratum. Spatially balanced sampling enforces maximal spatial coverage within a probability-based method and encourages independence of samples (Stevens and Olsen 2004). In addition to implementing a spatially balanced sample across the 4 strata, we constrained TFTA River plots to within 1 km of 2 tributaries (Salchaket Slough and Wood River) of the Tanana River for access and logistical reasons.

Survey Protocol and Field Methods

Traditionally, Arctic PRISM is a double-sampling protocol (Bart and Earnst 2002) that includes rapid and intensive surveys over a fixed amount of time on randomly selected 400 × 400-m plots. Rapid survey PRISM protocol dictates a 98-minute, single-observer survey of the 400 × 400-m plot.

A subset of these 400 × 400-m plots is selected for intensive surveys, where 2 observers remain camped near a plot and conduct daily surveys for up to 1 month. Counts from intensive surveys assume all individuals are detected and are used to adjust density estimates on the rapidly surveyed plots for detection <1 (Bart et al. 2005). We first modified the Arctic PRISM protocol to allow for variable plot completion time to account for differences in ease of maneuverability across different land cover types in the boreal forest. Our modified method enforced a standard 6 transects, each 50–60 m apart and approximately 390 m long to ensure adequate coverage. Transects typically started in the northeast corner of each plot and continued north to south or east to west following topographical navigational aids (e.g., ridgelines or large bearing trees).

Our next modification allowed us to estimate detection probability of shorebird species by using a dependent double-observer sampling approach instead of the subset of intensively surveyed plots per Arctic PRISM surveys (Nichols et al. 2000). This dependent double-observer protocol used 2 surveyors on plot. A primary observer navigated using the ArcPad tool (version 10.2; Esri, Redlands, CA, USA) on an iPad and walked ahead of a secondary observer. The primary observer indicated verbally where they detected shorebirds (visually or auditorily), species name, and number in each group (defined as >1 shorebird within 10 m of another). The secondary observer recorded the shorebirds detected by the primary observer and any shorebirds that the primary observer missed. Dependent double-observers surveyed each plot, and primary and secondary observer roles were reversed on alternating plots. Both observers stopped periodically to scan the plot with binoculars to keep the primary observer independent. There was rarely more than 1 bird on plot, so double counting was not an issue. Once flushed, birds typically remained active in flight or vocalized for the duration of the surveys. These methods were carried out under an animal welfare exemption from the Institutional Animal Care and Use Committee at Colorado State University (IACUC; exemption 2016-10).

We initiated surveys on 7 May 2016 and 9 May 2017 to correspond with shorebird arrival and the beginning of breeding activities. Surveys ended 14 July 2016 and 14 July 2017 to align with historical shorebird departure from the area (Kessel and Gibson 1978). We visited each plot twice per field season, with dates for repeat visits dependent on training area access. We visited the same 78 plots in 2016 and 2017. We visited an additional 64 plots in 2017, bringing the number of plots surveyed in 2017 to 142. Areas within each training area were temporarily closed to the public and to research if they were actively being used for training activities with live ammunitions. We visited plots in ascending numerical order as designated by the spatially balanced sampling survey design. Plot access in the 4 strata was highly dependent on helicopter scheduling, weather, and availability of motorized vehicles. We surveyed TFTA River and DTA East at a higher proportion because we accessed these strata via boat, car, or on foot, which proved to be more time efficient than surveying exclusively with a helicopter in TFTA Lowlands and DTA West.

At the end of each plot survey, observers collaboratively collected habitat data within a 50-m radius of the center of each plot. Observers walked the area and collected data on dominant land cover classification (i.e., Viereck third-level classification), percent scrub canopy, percent water on plot, distance to wetland, and elevation. For data analysis on detection and plot abundance variation, we included 6 covariates from these habitat surveys (i.e., elevation, percent scrub canopy, percent water on plot, distance to wetland, and 2 land cover classifications).

Data Analysis

Unbiased estimates of abundance correct for detection probability of an individual, assume closure, and use a probability-based sampling design to allow extrapolation over the entire area of interest (Thompson 2012). For abundance estimation, we used data collected on first visits to plots in 2016 and 2017. These data are most likely to meet the closure assumption (i.e., a population is constant over the period of investigation; Otis et al. 1978) because of the territoriality and site fidelity breeding shorebirds exhibit early in the breeding season. Observing >1 shorebird on plot was uncommon, so there was little possibility of confusing an individual shorebird with another (i.e., double counting). To further avoid misidentification problems, technicians spent >1 week conducting training surveys and spent >2 weeks learning shorebird auditory and visual cues.

We estimated and modeled detection probability (p) and derived plot-level abundance (N) using Huggins closed captures models in Program MARK (Huggins 1989, 1991; White and Burnham 1999). One advantage to using the Huggins model is that individual covariates are used to model capture and recapture probabilities. *A priori*, we constructed candidate models representing hypotheses on plot-level abundance and detection for each species. We derived our hypotheses (Table 1) from existing literature, personal communication with biologists familiar with the study area and species, and personal observations (Latour et al. 2005, Meltofte et al. 2007, Harwood et al. 2016). We examined correlation among all habitat covariates and ran goodness-of-fit tests using a median c-hat ($\hat{c}$) procedure (Cooch and White 2006).

For each group (i.e., all lowland shorebirds and all upland shorebirds) we used Akaike's Information Criterion (AIC; Burnham and Anderson 2002) with a small sample size correction (AIC_c) to select the most parsimonious detection model. Because of sparse data, we were unable to investigate plot-varying detection. We set recapture probability (c) in the Huggins closed captures models to zero to account for the dependence of the second observer during surveys. We investigated all possible combinations of habitat covariates on detection (Burnham and Anderson 2002), and summed Akaike weights (w_i) across all models containing a specific variable to determine relative importance of covariates (Burnham and Anderson 2002). We used the model containing all variables with cumulative AIC_c weights ≥0.50 as

Table 1. Lowland and upland shorebird covariate predictions for variation in plot-level abundance and detection. Land cover classifications are from Viereck et al. (1992). We generated hypotheses prior to plot surveys in Tanana Flats Training Area and Donnelly Training Area, Alaska, USA, in May–July 2016 and 2017.

Response and group	Species	% water on plot (0–100%)	Distance to wetland (0–5,300 m)	% scrub canopy (0–100%)	Elevation (m)	Highest abundance land cover classification
Abundance						
Lowland shorebirds	Dunlin (*Calidris alpina*)	+	−	−	−	Wet, grassland and open mudflat
	Least sandpiper (*Calidris minutilla*)					
	Lesser yellowlegs (*Tringa flavipes*)					
	Semipalmated plover (*Charadrius semipalmatus*)					
	Short-billed dowitcher (*Limnodromus griseus*)					
	Solitary sandpiper (*Tringa solitaria*)					
	Spotted sandpiper (*Actitis macularius*)					
	Wilson's snipe (*Gallinago delicata*)					
Upland shorebirds	American golden-plover (*Pluvialis dominica*)	+	−	−	+	Low scrub
	Baird's sandpiper (*Calidris bairdii*)					
	Black-bellied plover (*Pluvialis squatarola*)					
	Pectoral sandpiper (*Calidris melanotos*)					
	Surfbird (*Calidris virgata*)					
	Upland sandpiper (*Bartramia longicauda*)					
	Wandering tattler (*Tringa incana*)					
	Whimbrel (*Numenius phaeopus*)					
Detection						
Lowland shorebirds		+	−	−	None	Wet, grassland and open mudflat
Upland shorebirds		+	−	−	None	Wet, grassland and open mudflat

our predictive model to derive abundance estimates for the study area (Barbieri and Berger 2004). We derived plot-level densities and extrapolated abundances for each group to all surveyable habitat for each of the 4 strata (TFTA River, TFTA Lowlands, DTA East, and DTA West). We calculated plot-level variance estimates following the methods of Bowden et al. (2003) to account for detection covariance structures across plots within strata.

To assess the applicability of our modified Arctic PRISM protocol for future boreal forest shorebird surveys, we used our estimate of the average density of shorebirds/ha to calculate plot-level abundance for all lowland shorebirds under different plot size scenarios. This can be helpful to managers to determine optimal plot survey size for future surveys to achieve a target coefficient of variation.

Variance components analysis allowed us to separate sampling variance from biological process variance and focus on investigating the plot-level process variance explained by each habitat covariate. In the Huggins model, abundance (N) is a derived parameter, meaning the effect of habitat factors cannot be assessed using model selection; instead we used an analysis of deviance approach (White and Burnham 1999). We ran a variance components analysis in Program MARK on the derived abundance estimates from the mean model for each group (i.e., model with no covariates, intercept model) to determine the maximum biological process variability possible in the data (White and Burnham 1999). From this maximum variability, we subtracted the amount of process variance explained by each covariate individually and divided by total variance to determine the percent of variability explained by each habitat covariate.

RESULTS

We surveyed 78 plots in 2016 and 142 plots in 2017 twice (Table 2); 100 were classified as lowland plots and 42 were classified as upland plots. Field crews observed 107 shorebirds on plots in 2016 and 344 shorebirds on plots in 2017. The species observed with the highest frequency were Wilson's snipe (*Gallinago delicata*; $n = 41$ and 153

Table 2. Distribution of plots and amount of area of the 4 study strata used to estimate the abundance of shorebirds on military lands in interior Alaska, USA. Plots available in stratum are the number of available plots within in each strata that could have been surveyed. Lowland and upland plots surveyed are the number of plots surveyed in 2017 within each strata separated by classification as an upland plot or a lowland plot. Percent of plots surveyed is the number of lowland and upland plots surveyed in 2017 divided by the plots in the sampling frame. We collected data on shorebird occupancy and abundance from plots surveyed in Tanana Flats Training Area and Donnelly Training Area, Alaska, May–July 2016 and 2017.

Strata	Plots available in stratum	Lowland plots surveyed	Upland plots surveyed	% of plots surveyed
Tanana Flats Training Area River	563	20	0	3.54
Tanana Flats Training Area Lowlands	11,684	33	0	0.28
Donnelly Training Area East	968	16	32	4.95
Donnelly Training Area West	9,934	31	10	0.41

Table 3. Lowland and upland shorebird species presence on plots from 2016 and 2017 and status as a species of conservation concern from Alaska Shorebird Conservation Plan and the United States Fish and Wildlife Service (USFWS) Birds of Conservation Concern list. We collected data from plots surveyed in Tanana Flats Training Area and Donnelly Training Area, Alaska, USA, in May–July 2016 and 2017.

				Status as species of conservation concern	
Group	Species	2016 count	2017 count	Alaska Shorebird Conservation Plan	USFWS
Lowland shorebirds	Lesser yellowlegs	43	144	✓	✓
	Wilson's snipe	41	153		
	Spotted sandpiper	10	21		
	Solitary sandpiper	4	5	✓	✓
	Dunlin	1	0	✓	
	Least sandpiper	0	1		
	Semipalmated plover	0	0		
	Short-billed dowitcher	0	0		
Upland shorebirds	Whimbrel	5	11	✓	✓
	Black-bellied plover	2	3		
	Upland sandpiper	1	3	✓	✓
	American golden-plover	0	1	✓	
	Baird's sandpiper	0	1		
	Pectoral sandpiper	0	1		
	Surfbird	0	0	✓	
	Wandering tattler	0	0		
	Total	107	344		

observations in 2016 and 2017, respectively), lesser yellowlegs ($n = 43$ and 144 observations in 2016 and 2017, respectively), and spotted sandpiper ($n = 10$ and 21 observations in 2016 and 2017, respectively). We recorded more observations of lowland shorebirds ($n = 99$ and 324 observations in 2016 and 2017, respectively) than upland shorebirds ($n = 8$ and 20 observations in 2016 and 2017, respectively) in 2016 and 2017 (Table 3). Average density of shorebirds across the 4 strata was 0.032 shorebirds/ha.

Lowland Shorebird Abundance Estimates

Variables with cumulative weights ≥0.50 for detection for all lowland shorebirds were distance to wetland, elevation, and dominant land cover classification (Table 4; Table A1). We did not detect any goodness-of-fit issues

Table 4. Cumulative Akaike's Information Criterion with a small sample size correction (AIC_c) weights for habitat covariates analyzed for detection probability for all lowland shorebirds and all upland shorebirds. We used AIC_c for model selection and cumulative variable weights (w_i) to identify the most important covariates. Although elevation had a cumulative AIC_c $w_i > 0.50$ in the upland shorebird models, the β value for this covariate spanned zero ($\beta = -0.017 \pm 0.016$ [SE]) and we identified it as a non-biologically significant pretending variable. We collected habitat data from plots surveyed in Tanana Flats Training Area and Donnelly Training Area, Alaska, USA, in May–July 2016 and 2017.

Habitat covariate	All lowland shorebirds cumulative AIC_c w_i	All upland shorebirds cumulative AIC_c w_i
Elevation	0.691	0.536
Distance to wetland	0.758	0.165
Land cover (forest; scrub; barren, forb, lichen)	0.565	0.075
% scrub canopy	0.301	0.207
% water on plot	0.275	0.133

(median $\hat{c}$ values ≤1) and did not need to adjust our model set.

We calculated all lowland shorebird abundances using the model p(distance to wetland + elevation + dominant land cover classification) N_{plot}. Distance to wetland ($\beta = -0.005 \pm 0.003$ [SE]), elevation ($\beta = -0.006 \pm 0.003$), and dominant land cover classification ($\beta = -2.029 \pm 1.180$) had weak relationships with detection (all 95% CI extend to zero). For every 1-m increase in distance to wetland, probability of habitat use decreased by 0.5%. Similarly, for every 1-m increase in elevation, probability of habitat use decreased by 0.6%. Average detection probability for lowland shorebirds was 0.883 ± 0.033. Estimated number of all lowland shorebirds on occupied plots ranged from 1 to 10 birds. We estimated that $42{,}239 \pm 13{,}431$ lowland birds used our study area in interior Alaska in 2017 (Table 5). Variance components analysis suggested that elevation explained the most variation in all lowland shorebird plot abundance (5.38%), followed by percent scrub canopy (4.72%), and percent water on plot (0.10%; Table 6).

Upland Shorebird Abundance Estimates

The only variable with a cumulative weight ≥0.50 for detection for all upland shorebirds was elevation (Table 4; Table A2); however, upon further inspection of beta values, we identified elevation to be a non-biologically significant pretending variable ($\beta = -0.017 \pm 0.016$; Anderson 2008). We used constant detection in our model to estimate abundance. We did not detect any goodness-of-fit issues (median $\hat{c}$ values ≤1) and did not need to adjust our model set.

We estimated that the number of all upland shorebirds on occupied plots ranged from 1 to 4 birds. Average detection probability for upland shorebirds was 0.938 ± 0.064. In 2017 on our study area, estimated

Table 5. Lowland and upland shorebird abundance estimates on the study area in interior Alaska, USA. We derived estimates from data collected from plots surveyed in Tanana Flats Training Area and Donnelly Training Area, Alaska, May–July 2017.

		Number/plot		Density (birds/ha)		Abundance	
Group	Strata	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Lowland shorebirds	Tanana Flats Training Area River	3.369	0.184	0.211	0.011	1,900	135
	Tanana Flats Training Area Lowland	3.097	0.106	0.194	0.007	36,192	13,005
	Donnelly Training Area East	0.526	0.034	0.033	0.002	510	112
	Donnelly Training Area West	0.366	0.024	0.023	0.002	3,637	179
	Total					42,239	13,431
Upland shorebirds	Tanana Flats Training Area River	0		0		0	
	Tanana Flats Training Area Lowland	0.061	0.007	0.004	0.001	712	183
	Donnelly Training Area East	0.146	0.011	0.009	0.001	142	24
	Donnelly Training Area West	0.269	0.019	0.017	0.001	2,669	287
	Total					3,523	494

abundance of all upland birds was 3,523 ± 494 (Table 5). Variance components analysis suggested that elevation explained the most variation in all upland shorebird plot abundance (13.01%), followed by distance to wetland (4.95%; Table 6).

To achieve a coefficient of variation of 0.30 using our plot size of 400 × 400 m, a sample size of 160 plots sampled twice is needed. With our current plot sample size of 220 over both years, our calculated coefficient of variation for this study was 0.24. To achieve a coefficient of variation of 0.10, a sample size of 1,441 plots is needed, whereas smaller sample sizes could be used if the study had a greater target coefficient of variation ($n = 640$ for CV of 0.15, $n = 360$ for CV of 0.20, $n = 230$ for CV of 0.25).

Table 6. The variation in lowland and upland shorebird abundance (σ^2) explained by each habitat covariate and corresponding standard errors (SE) from variance components analysis in Program MARK. Beta (β) estimates and corresponding standard errors explain relationships between abundance and habitat covariates. Asterisks indicate the percent variance explained was a negative value, meaning it explained no variance. We derived estimates from data collected from plots surveyed in Tanana Flats Training Area and Donnelly Training Area, Alaska, USA, May–July 2017.

Habitat covariate	σ^2	SE	β	SE	Percent variance explained
Lowland shorebirds					
Intercept model	9.615	1.556	3.966	0.462	
Elevation	9.097	1.456	−0.003	0.001	5.388
% scrub canopy	9.161	1.464	−0.030	0.016	4.724
% water on plot	9.605	1.533	0.024	0.021	0.100
Distance to wetland	9.750	1.561	−0.003	0.003	*
Land cover	9.888	1.592			*
Forest			1.014	1.290	
Scrub			1.184	1.200	
Upland shorebirds					
Intercept model	1.119	0.305	1.702	0.336	
Elevation	0.973	0.273	0.002	0.001	13.008
Distance to wetland	1.064	0.303	0.001	0.001	4.947
% scrub canopy	1.131	0.290	−0.004	0.014	*
% water on plot	1.131	0.290	−0.004	0.014	*
Land cover	1.131	0.290	−0.004	0.014	*
Forest			−0.998	0.923	
Scrub			−0.248	0.754	

DISCUSSION

We report abundance estimates of shorebirds in interior Alaska. These results are informative for future research in the boreal forest. Densities and abundances of shorebirds on plot were low but when extrapolated to the entire sampling frame of 370,420 ha, abundances were 45,762 ± 13,925 shorebirds.

Of our 4 strata, the TFTA Lowland stratum had the highest estimated abundance of shorebirds and the DTA East stratum had the lowest estimated abundance of shorebirds. Our hypothesis that lowland training areas such as TFTA Lowland and TFTA River have higher abundances than upland training areas such as DTA East and DTA West was supported. Shorebirds are known to select lowland, wetland systems because of the increased availability of food biomass (Taft and Haig 2006, Meltofte et al. 2007). The TFTA Lowland and River strata contain more wetland land cover than DTA East and West. Although DTA contains 324, 273 ha of wetlands, (307,600 ha in DTA West; 16,673 ha in DTA East), TFTA contains 28% more wetland area (547,578 ha in TFTA).

These estimated abundances qualify our study area as a site of regional importance and meet the WHSRN criteria of use by >20,000 shorebirds annually. Currently, most sites designated as important by WHSRN are those that provide important migratory habitat for shorebirds. As of publication, only 5 sites of importance are on Alaskan breeding grounds, none of which are in the interior (Duncan 2006). The WHSRN designates important migratory habitat on the criteria of high shorebird densities in these areas. Conversely, in interior Alaska, a large number of birds are using a much larger breeding area, leading to a low density of birds. We suggest that the WHSRN consider factors other than shorebird densities and abundances as designation criteria. There is high species richness on our study site and we identified 7 species of conservation concern, a metric currently not taken into account by WHSRN. We suggest that WHSRN criteria should include species richness, habitat extent, and geographic boundaries, and not exclusively consider the density of birds using a site. Further, we suggest the number of species of conservation concern identified in an area should be considered.

There are no previous shorebird abundance estimates for the interior boreal forest of Alaska against which we could compare our survey estimates. Surveys conducted by researchers throughout coastal areas of Alaska have reported higher densities of breeding shorebirds. On the North Slope of Alaska, Andres et al. (2016) estimated an average density of 1.26 shorebirds/ha (126 shorebirds/km^2), and in Arctic National Wildlife Refuge, Brown et al. (2007) estimated 0.266 shorebirds/ha (26.6 shorebirds/km^2). Research conducted by Gill and Handel (1990) at the Yukon-Kuskokwim River Delta estimated densities of 9.50 shorebirds/ha (950 shorebirds/km^2). Compared to other shorebird sites of importance, our densities are low. Our study, however, provides novel abundance estimates that can be used to update state and continental shorebird population estimates and inform species-specific research. In addition, the methodology used in our study can be used in the design of boreal-wide shorebird surveys planned for the future (Alaska Shorebird Group 2019).

We found that distance to wetland explained some process variance in all upland shorebird abundance but no process variance in lowland shorebird abundance. *A priori*, we hypothesized that water-related habitat covariates (i.e., distance to wetland and percent water on plot) would explain variation in plot abundances, with proximity to wetland correlated to increased abundances for both lowland and upland species. Although distance to wetland did not explain process variance in lowland shorebird abundance on plot, as expected, it was a top predictor variable of occupancy of a site. Our results align with current literature. Webb et al. (2010), and Gillespie and Fontaine (2017) reported that for shorebird species typically classified as lowland shorebirds (e.g., stilts and sandpipers), wetland availability and proximity were the top predictor variables for occupancy and species richness. Wetland and open water provide foraging opportunities for shorebirds and are regularly found to be top predictors of site use (Taft and Haig 2006, Reiter et al. 2015).

We found that percent scrub canopy explained a moderate amount of process variance in lowland bird abundance on plots. As hypothesized, a higher percent scrub canopy on a survey plot was correlated to decreased abundance of lowland shorebirds. A possible reason for this result is that these birds are selecting for other land cover types that provide nest crypsis or protection from aerial predators. Lowland birds use a large range of vertical vegetative structural diversity (Colwell and Oring 1990). Taller grasses and trees available for nest crypsis could preclude the need for scrub (Colwell and Oring 1990). A predator defense strategy attributed to many species of lowland shorebirds is early detection of aerial and ground-based predators (Colwell and Oring 1990). Lower percent scrub on plot and less vegetative obstruction aligns with this defensive strategy.

As expected, elevation explained a large amount of process variance in all upland shorebird abundance, and to a lesser extent, in lowland shorebird abundance. In our study area, upland and lowland species were distributed along an elevational gradient. Land cover types and landforms at upland and lowland sites are consistent with species-specific associations noted in previous studies and are not surprising but represent a useful confirmation of land cover and elevational associations found by Savage et al. (2018) and Brown et al. (2007).

Relative to previous studies (Farmer and Durbian 2006, Smith et al. 2009), we report a consistently high probability of detection for both groups of shorebirds, confirming our hypothesis that this survey method would detect more birds. We did not examine differences in detection among observers because detection was high and technicians went through 2 weeks of training prior to the beginning of surveys in 2016 and 2017.

Our modifications to the Arctic PRISM protocol enabled crews to effectively survey in the diversity of boreal land cover types with 2 technicians always working closely together. The time taken to complete plot surveys in the boreal forest varied because of habitat differences and difficulty in maneuverability and deviated from Arctic PRISM protocol, which limits surveys to 98 minutes. In open lichen interspersed with low scrub, 2 observers needed as few as 38 minutes to adequately survey a plot. In wet tussock with tall dense scrub, 2 observers needed up to 178 minutes to adequately survey a plot. Our method allowed each plot to be searched in its entirety, because there were many plots that would not have been completely surveyed in challenging land cover types if survey time was restricted to 98 minutes.

Following Arctic PRISM protocol, our selected 400 × 400-m (16 ha) plots had a low perimeter-to-area ratio (i.e., edge effect) and minimized bias of estimates related to identifying individuals as in or out of the plot (Thompson et al. 1998). In the boreal forest, where shorebird densities are lower than the Arctic or Southcentral coast, a 400 × 400-m plot contains few birds. We did not detect birds on 75 of 142 plots surveyed in 2017. Increased plot size will increase likelihood of shorebirds detected on plot. For future shorebird studies in the boreal forest, we suggest increasing the sample size to 360 plots that are >16 ha to help achieve a target goal coefficient of variation of 0.20.

Our plot surveys were considered partial counts with incomplete detectability. Our modifications to Arctic PRISM protocol enabled an estimation of detection probabilities from dependent double-observers instead of the subset of intensive plots typical for Arctic PRISM surveys. For safety reasons (e.g. remoteness of survey sites in areas with brown bears [*Ursus arctos*]), technicians were not able to survey independently. In simulation studies, double-observer methods have been shown to be accurate when detection probabilities are >0.20 (Golding et al. 2017). In the boreal forest, detection probabilities were substantially higher than this, ranging from 0.75 to 0.94. Based on our results, we recommend the application of dependent double-observer methods in the boreal forest for safety and for more time-efficient sampling. Evaluating the tradeoffs between plot size and sample size is an important consideration when designing and planning shorebird surveys in the interior boreal forest. Given enough resources, larger plot sizes and increasing sample sizes should be investigated in further studies.

MANAGEMENT IMPLICATIONS

We identified large numbers of shorebirds using our study area during breeding season. Although estimated densities are low compared to other sites, our study area hosts important numbers of poorly studied species of conservation concern. We have identified areas that are important breeding habitat for key groups of lowland shorebirds to assist with best management practices for shorebird habitat conservation throughout interior Alaska. In addition, our work serves as a foundation for future studies in the region and raises questions about how to classify an important shorebird site. Recognizing our study area as a WHSRN site of importance for breeding shorebirds would likely lead to the continued monitoring and evaluation of the large number of shorebirds using this area. Compared to other shorebird breeding sites of importance (e.g., Yukon-Kuskokwim River Delta or New York Bay), military lands within the interior boreal forest are small. If we extrapolated our minimum site density estimates to the boreal forest in interior Alaska as a whole (~145 million ha), the boreal forest would contain approximately 4.6 million shorebirds. The scale of designation of a site of importance becomes a relevant question because more intensive habitat use surveys need to occur throughout the interior boreal forest to determine if specific land cover types or areas within the boreal forest (i.e., Tanana River) are important or if the entire boreal forest meets the qualification to be designated as a site of importance. Establishing collaborative research between the different management units and land managers and promoting continued monitoring in the interior boreal forest would help to confirm that the ecoregion supports a regionally important abundance of shorebirds. We recommend continued and collaborative monitoring of the many species of conservation concern that we identified to breed in Alaskan boreal forest.

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APPENDIX A. MODEL SELECTION RESULTS

Our study area in interior Alaska, USA, is a site of importance for shorebirds; shorebirds are using military lands in high abundances (45,762 ± 13,925[SE]). Our modified Arctic Program for Regional and International Shorebird Monitoring protocol was effective for surveys in the boreal forest and we recommend continued use of method modifications for future shorebird surveys in boreal forests of interior Alaska.

Table A1. Model selection results for all lowland shorebird models of detection probability (p) and abundance (N). We used Akaike's Information Criterion with a small sample size correction (AIC_c) for model selection and used cumulative variable weights (w_i) and a change in AIC_c (ΔAIC_c) to identify most important covariates. We present all models with $\Delta AIC_c < 5$. We collected data from plots surveyed in Tanana Flats Training Area and Donnelly Training Area, Alaska, USA, May and July in 2016 and 2017.

Model	AIC_c	ΔAIC_c	AIC_c weights	Model likelihood	Number of parameters	Deviance
p (elevation + land cover classification + distance to wetland) N (plot)	144.24	0.00	0.16	1.00	5	132.01
p (elevation + land cover classification + distance to wetland + % scrub canopy) N (plot)	145.87	1.63	0.07	0.44	6	131.57
p (elevation + land cover classification + % water on plot + distance to wetland) N (plot)	146.15	1.91	0.06	0.39	6	131.85
p (land cover classification + distance to wetland) N (plot)	146.24	2.00	0.06	0.37	4	136.08
p (elevation + % scrub canopy + distance to wetland) N (plot)	146.50	2.26	0.05	0.32	5	136.34
p (distance to wetland) N (plot)	146.74	2.50	0.05	0.29	3	140.68
p (elevation + % water on plot + distance to wetland) N (plot)	146.93	2.69	0.04	0.26	5	136.76
p (elevation + land cover classification) N (plot)	147.31	3.08	0.04	0.21	4	137.15
p (elevation) N (plot)	147.50	3.26	0.03	0.20	3	141.44
p (land cover classification) N (plot)	147.64	3.41	0.03	0.18	3	139.54
p (elevation + land cover classification + % scrub canopy + % water on plot + distance to wetland) N (plot)	147.86	3.63	0.03	0.16	7	131.48
p (.) N (plot)	148.17	3.94	0.02	0.14	2	144.14
p (land cover classification + % scrub canopy + distance to wetland) N (plot)	148.22	3.98	0.02	0.14	5	136.00
p (land cover classification + % water on plot + distance to wetland) N (plot)	148.29	4.06	0.02	0.13	5	136.07
p (% scrub canopy + distance to wetland) N (plot)	148.50	4.26	0.02	0.12	4	140.39
p (elevation + % scrub canopy + % water on plot + distance to wetland) N (plot)	148.54	4.31	0.02	0.12	6	136.32
p (% water on plot + distance to wetland) N (plot)	148.71	4.48	0.02	0.11	4	140.61
p (elevation + % scrub canopy) N (plot)	149.00	4.76	0.02	0.09	4	140.90
p (elevation + land cover classification + % scrub canopy) N (plot)	149.02	4.78	0.02	0.09	5	136.79

Table A2. Model selection results for all upland shorebird models of detection probability (*p*) and abundance (*N*). We used Akaike's Information Criterion with a small sample size correction (AIC_c) for model selection and used cumulative variable weights (w_i) and a change in AIC_c (ΔAIC_c) to identify most important covariates. We present all models with $\Delta AIC_c < 5$. We collected data from plots surveyed in Tanana Flats Training Area and Donnelly Training Area, Alaska, USA, between May and July in 2016 and 2017.

Model	AIC_c	ΔAIC_c	AIC_c weights	Model likelihood	Number of parameters	Deviance
p (elevation) *N* (plot)	10.115	0.000	0.312	1.000	3	3.315
p (.) *N* (plot)	11.993	1.877	0.122	0.391	2	7.606
p (% scrub canopy) *N* (plot)	13.393	3.277	0.060	0.194	3	6.593
p (land cover classification + elevation) *N* (plot)	13.529	3.413	0.056	0.181	4	1.386
p (% scrub canopy + % water on plot elevation) *N* (plot)	13.529	3.413	0.056	0.181	5	1.386
p (% scrub canopy + distance to wetland + elevation) *N* (plot)	13.529	3.413	0.056	0.181	5	1.386
p (% water on plot + distance to wetland + elevation) *N* (plot)	13.529	3.413	0.056	0.181	5	1.386
p (% water on plot) *N* (plot)	14.281	4.165	0.038	0.124	3	7.481
p (% scrub canopy) *N* (plot)	14.962	4.846	0.027	0.088	3	2.819