# Relative Shorebird Densities at Coastal Sites in the Arctic National Widlife Refuge

Authors: Brown, Stephen, Kendall, Steve, Churchwell, Roy, Taylor, Audrey, and Anna-Marie, Benson

Source: Waterbirds, 35(4) : 546-554

Published By: The Waterbird Society

URL: https://doi.org/10.1675/063.035.0405

# Relative Shorebird Densities at Coastal Sites in the Arctic National Wildlife Refuge

Stephen Brown[1,*], Steve Kendall[2], Roy Churchwell[3], Audrey Taylor[4] and Anna-Marie Benson[5]

[1]Manomet Center for Conservation Sciences, P.O. Box 1770, Manomet, MA, 02345, USA

[2]Hakalau Forest National Wildlife Refuge, 60 Nowelo Street, Suite 100, Hilo, HI, 96720, USA

[3]Department of Biology and Wildlife, University of Alaska, Fairbanks, AK, 99775, USA

[4]Windbird Resources, P.O. Box 407, Conway, WA, 98238, USA

[5]U.S. Fish & Wildlife Service,National Wildlife Refuge System, 101 12th Ave., Fairbanks, AK, 99708, USA

*Corresponding author; E-mail: sbrown@manomet.org

**Abstract**.—In the first comprehensive survey of post-breeding shorebirds conducted along the remote deltaic mudflat habitats on the coastline of the Arctic National Wildlife Refuge, six species of shorebirds were documented aggregating prior to southbound migration. Energy reserves gained while foraging in these areas may be critical for southbound migration of long-distance migrant shorebirds, but these habitats are vulnerable to potential effects of oil and gas development and climate change. The study objective was to assess the relative density and species composition of shorebirds . Surveys were conducted at 13 major river deltas on the coast between late July and mid-August each year from 2006 to 2010. Double-observer methods were used in 2010 to estimate the detection rate in surveys of randomly-selected transect sections. Shorebird density varied significantly between years and among river deltas. Peak relative density estimates at three deltas, the Jago (247.8 birds/km$^2$), the Kongakut (100.6 birds/km$^2$) and the Hulahula (49.5 birds/km$^2$), were significantly higher than the estimate for the Canning (16.0 birds/km$^2$). Because shorebird density and abundance vary significantly among sites and years, and individuals likely move among multiple sites within a given year, shorebird conservation strategies for these habitats should consider them to be spatially and temporally interconnected. *Received 7 April 2012, accepted 30 July 2012.*

**Key words**.—Arctic National Wildlife Refuge, coastal, relative densities, shorebirds.

Waterbirds 35(4): 546-554, 2012

In arctic Alaska, little is known about shorebird use of coastal areas during the post-breeding period, prior to migration (Taylor *et al.* 2010). Preliminary work indicated that shorebirds depend on the food resources found in specific coastal areas to acquire fat necessary for southward migration (Connors *et al.* 1979). Shorebirds move from inland tundra breeding areas (Brown *et al.* 2007) to coastal mudflats and other littoral habitats as the breeding season progresses, and have been found in higher densities at coastal sites after the breeding season (Connors *et al.* 1979; Connors *et al.* 1981; Smith and Connors 1993). Post-breeding shorebirds using the Arctic Refuge coastline are likely sequestering fuel reserves critical for southbound migration (Connors 1984; Lyons and Haig 1995).

Many species of shorebirds are of conservation concern due to ongoing population declines (Brown *et al.* 2001; Morrison *et al.* 2001; International Wader Study Group 2003; Bart *et al.* 2007). Several species of particular conservation concern use stopover sites within the Arctic Refuge, including four species (Whimbrel (*Numenius phaeopus*), Bar-tailed Godwit (*Limosa lapponica*), Dunlin (*Calidris alpina*) and Buff-breasted Sandpiper (*Tryngites subruficollis*)) on the USFWS Birds of Conservation Concern list for Bird Conservation Region 3, Arctic Plains and Mountains (U.S. Fish and Wildlife Service 2008), and 16 species listed by the Alaska Shorebird Conservation Plan as moderate or high concern (Alaska Shorebird Group 2008). Placement of birds on these lists is intended to stimulate collaborative proactive conservation actions among federal, state, and private partners. Our study implemented such a partnership, and will help develop measures to conserve shorebirds by increasing our understanding of their use of vulnerable habitats during a critical phase in their life cycle.

The primary goal of this study was to assess the relative density and species composition of shorebirds using coastal areas of the Arctic Refuge prior to fall migration, which is critical information so that impacts of future habitat changes can be measured and potentially managed or mitigated. Understanding the factors affecting the relative density of shorebirds at these coastal habitats is an important step in managing populations. There is particular concern for the coastal resources of the Arctic Refuge because these areas are vulnerable to potential effects of offshore oil development in the eastern Beaufort Sea and to changing sea and weather conditions associated with climate change (Kendall *et al.* 2011; Nolan *et al.* 2011). A major objective of the Alaska Shorebird Conservation Plan (Alaska Shorebird Group 2008) is to ensure that adequate quantity and quality of habitat is identified and maintained to support shorebirds. Understanding habitat use is a critical first step in meeting this objective.

The relative importance for shorebirds of foraging sites along the coastline of the Arctic National Wildlife Refuge, Alaska, has never been measured. Aggregations occur in mudflats and associated wetlands, but most of these areas have never been systematically surveyed for shorebirds using the same methodology within or between years. These coastal mudflats are extremely remote and difficult to access because they are isolated by large expanses of shallow water and barrier islands, so no ground surveys have previously been conducted for shorebirds at most of these sites.

Pre-migration sites have commonly been eferred to as staging areas, but Warnock (2010) suggested the use of this term be restricted to sites where birds prepare for long flights requiring large energy reserves. Since the length of stay and accumulation of fat were not determined in this study, and the migration strategies used likely vary among the many species using these sites, we refer to the mudflat habitats simply as foraging areas, and determine the relative abundance at the many sites within the study area.

## METHODS

### Study Area and Field Methods

Our study area included the entire coastline of the Arctic National Wildlife Refuge, from the Staines River on the western boundary of the Refuge, to Demarcation Bay on the border with Canada (Fig. 1). We surveyed the mudflats of all river deltas as they enter the lagoons behind the barrier islands. The mudflats are extensive areas of very low gradient alluvial deposits from north-

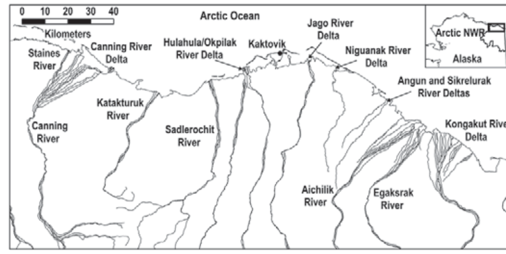


**Figure 1. The study area along the coastline of the Arctic National Wildlife Refuge, Alaska, showing 13 major river deltas where shorebird surveys were conducted between 2006 and 2010.**

ward flowing arctic rivers, almost completely bare of vegetation. We did not survey the salt marsh habitats along the coast between river deltas, nor the barrier islands that form the outer edge of the coast over much of the area.

We established transects at all river deltas along the coastline. We used satellite imagery (Digital Globe 2003) to identify river deltas with mudflats, and explored all deltas during the first year of the survey in 2006 to determine if mudflat habitat was actually present. We identified a total of 13 river deltas with mudflats, and surveyed all of them in each year from 2006 to 2010. No mudflat habitat was located at the Turner River or in the rest of Demarcation Bay, so these were excluded from future surveys.

Within each river delta, we randomly selected from one to seven starting points for 0.5 km transects depending on the size of the delta, oriented generally east-west. We selected one transect segment for each 1 km of river delta width measured east to west, and laid out waypoints every 100m. Transect starting points were random with respect to longitude, but were constrained to be approximately 100m from the edge of the water. During the surveys, we allowed the transect waypoints to vary north or south to maintain the 100m distance from the edge of the water because the water level varied due to a small lunar tide and larger effects of wind. The total length of the survey transect on each delta varied between years due to changing water levels, so we recorded the total survey distance each year to use in density calculations. Transects were often moved inland due to high water levels at the time of the surveys, shortening the unsurveyed distance between them. The survey width was truncated to 300 m on each side of the observer, and birds detected beyond this distance were excluded from the analysis. The area surveyed on each transect, therefore, was the survey length multiplied by the survey width (600 m), and included the very shallow water at the ocean edge of the mudflat and the moist mudflat habitat inland, which were both used by foraging birds.

Three river deltas were divided into multiple segments because they had separate outflows that were not crossable on foot and had to be surveyed separately. These included the Jago, Aichilik and Kongakut. The segments were surveyed separately, but combined for the overall analysis by river delta. The total number of transects at each delta were as follows: Achilik 4, Canning 2, Egaksrak 2, Hulahula 6, Jago 6, Katakturuk 2, Kongakut 7, Niguanak 1, Okpilak 3, Sadlerochit 2 and Staines 1. We surveyed all transects once in each of the five study years, from 2006 to 2010, and all surveys were well after the peak of hatching in early July. Survey periods were as follows: 8/10/06 to 8/21/06; 7/25/07 to 8/5/07; 7/20/08 to 8/6/08; 7/28/09 to 8/5/09 and 7/28/10 to 8/4/10.

We usually worked in pairs, with one person observing and a second recording data and waypoints. On some surveys where access was difficult or time consuming, surveyors worked individually and observations were made and recorded by one observer. We recorded the species and counted the number of birds observed singly or in groups foraging on the ground, and their perpendicular distance from the survey line. Birds that flew over the transect and did not land were recorded as fly-overs, but not included in the analysis of density. We recorded age as hatch-year (HY) or after hatch-year (AHY) if it was possible to determine from plumage.

Standard distance-sampling methods (Buckland *et al.* 2001) were initially considered, but were determined to be inappropriate for the study because birds were not distributed uniformly across the landscape with respect to the survey transects, and therefore did not conform to the assumption of declining detectability with increasing distance from the transect. Because the birds were in open habitat and sometimes concentrated along the waterline, and therefore relatively easy to count, we instead analyzed the data using strip transect methods (simply dividing our count of all birds in the 600m wide transect by the area surveyed).

To estimate detection rate within the entire strip, we used standard double observer methods in 2010 to calculate an overall rate for all surveys. We randomly selected two waypoints in each transect to conduct double observer counts on a 50 m long section of the transect. If there were no birds present at the first location, we used the second location. The primary observer used a spotting scope from a vantage point outside of the transect to count all the birds within the marked-off 50 m section. The secondary observer then surveyed the area with binoculars using the normal techniques, and similar survey effort to the overall survey. The primary observer continued to watch the strip during the secondary observer's survey, and reduced the count if birds left the area before the secondary observer reached their location, because these birds would not be available for the secondary observer to count. We calculated detection rate as birds detected on the normal survey by the secondary observer / birds detected on the perpendicular count by the primary observer. We expected these rates to be high because the habitat is open and the birds are clearly visible.

### Statistical Analysis

We used a one-way analysis of covariance (ANCOVA) to analyze differences in shorebird densities among river deltas. We transformed the response (shorebird density expressed as birds/km$^2$), by taking the natural logarithm (ln), to improve normality. Because our primary interest was whether shorebird densities differed among deltas, our one-way ANCOVA had delta as the factor effect and included three covariates known to affect shorebird counts: Year, Julian Date and Julian Date$^2$. We included the squared term to account for nonlinearity that occurs during shorebird occupancy, with numbers peaking and then falling off as the season progresses. When the second-order polynomial was included in the model, we made certain the lower-order term "Julian Date" was also included (Kutner *et al.* 2005).

We considered several models (Table 1) and selected the "best" model using Akaike's Information Criterion (AIC; (Akaike 1974; Burnham and Anderson 2002)) where the model with the smallest AIC value and largest model weight was considered the best model. Our base model included only the "River Delta" factor and the full model included River Delta, Julian Date, Julian Date$^2$, Year and an interaction between Year and Julian Date$^2$. Standard diagnostics for non-constant variance, normality of error terms and evaluation of outliers were conducted on the final model.

Our "best" model was used to estimate ln(density) for each delta adjusted for covariates (i.e. the factor-level means from the ANCOVA). These least-square means were computed by setting all covariate effects to their mean values. We evaluated confidence intervals for density estimates and used a Tukey-Kramer multiple comparison procedure to examine among-delta differences in shorebird densities (SAS Institute Inc. 2011). We back-transformed ln(density estimates) for each river delta to aid in interpretation.

**Table 1. Model selection results for candidate models comparing ln(shorebird density) on Arctic Refuge coastal mudflats, 2006-2010, as a function of explanatory variables, including Δ AIC values, models compared, and number of parameters in each model. Minimum AIC for this model set was 227.6.**

| Model | AIC Weight | Δ AIC | Parameters |
|---|---|---|---|
| logShorebird ~ Delta + Year + Jdate + Jdate$^2$ | 0.6 | 0.0 | 18 |
| logShorebird ~ Delta + Jdate$^2$ + Jdate | 0.2 | 2.1 | 14 |
| logShorebird ~ Delta + Year + Jdate + Jdate$^2$ + Year:Jdate$^2$ | 0.1 | 3.1 | 22 |
| logShorebird ~ Delta + Year + Jdate | 0.0 | 13.8 | 17 |
| logShorebird ~ Delta + Year | 0.0 | 14.6 | 16 |
| logShorebird ~ Delta | 0.0 | 49.9 | 12 |

## RESULTS

We documented that six species of shorebirds aggregate on the coastal plain of the Arctic National Wildlife Refuge after their breeding season and prior to fall migration, and another 13 species occur in smaller numbers. The number of shorebirds detected on transects at each river delta varied widely among years, as did the total number of birds observed across all deltas combined. We observed a total of 629 shorebirds in 2006; 4,469 in 2007; 8,984 in 2008; 5,277 in 2009 and 5,556 in 2010. The highest densities occurred in 2006 at the Katakturuk delta, in 2007 at the Kongakut delta, in 2008 at the Jago and Hulahula deltas, and in 2009 and 2010 at the Jago delta.

The most common species was Semipalmated Sandpiper, which accounted for more than 80% of the individuals observed in all years except 2006 (43%), and 83% of individuals detected across all years. Most Semipalmated Sandpipers observed were juveniles (78% of birds with age identified). The next most common species were Red-necked Phalarope (*Phalaropus lobatus*, 6%), Black-bellied Plover (*Pluvialis squatarola*, 4%), Dunlin (2%), Stilt Sandpiper (*Calidris himantopus*, 2%) and Pectoral Sandpiper (*Calidris melanotos*, 2%). All of these species except for Pectoral Sandpiper are listed as either moderate or high concern in the Alaska Shorebird Conservation Plan. All other species observed in our surveys each accounted for less than 1% of the total individuals recorded. These rarer species, listed in decreasing order of abundance, included: Sanderling (*Calidris alba*), American Golden-Plover (*Pluvialis dominica*), Ruddy Turnstone (*Arenaria interpres*), Long-billed Dowitcher (*Limnodromus scolopaceus*), Baird's Sandpiper (*Calidris bairdii*), Western Sandpiper (*Calidris mauri*), Semipalmated Plover (*Charadrius semipalmatus*), Buff-breasted Sandpiper, Red Phalarope (*Phalaropus fulicarius*), Bar-tailed Godwit, White-rumped Sandpiper (*Calidris fuscicollis*), Least Sandpiper (*Calidris minutilla*) and Whimbrel.

We conducted 47 comparisons of primary and secondary observer counts along randomly- selected 50m transect sections. Our mean detection rate for all species combined was 0.986 (SE 0.021). Because the detection rate was close to 1, we did not adjust our counts for detectability.

The top-ranked model for shorebird density chosen via AIC included a main effect of River Delta, and Year, Julian Date, and Julian Date$^2$ as covariates (Table 1). While the best model included River Delta ($F_{18,198}$, P = 0.0041, Table 2) and also a year effect, individual parameter estimates for each year were not statistically different from zero. We tested for differences among pairs of river deltas using Tukey-Kramer multiple comparisons and found three significant comparisons (Jago vs. Canning, P = 0.0006, Hulahula vs. Canning, P = 0.0271, Kongakut vs. Canning, P = 0.0452; Fig. 2). The higher densities in the Hulahula, Jago and Kongakut compared with the Canning were also supported by non-overlapping confidence intervals. Density estimates for each delta were back-transformed from the log scale for ease of interpretation (Table 3).

## DISCUSSION

Our results show that relative densities of shorebirds differ significantly among river deltas on the Arctic Refuge coastline. The Jago River delta had the highest average density of any river delta, and the Jago, Kongakut and Hulahula deltas had significantly higher densities than the Canning River delta. These comparisons were likely significant because of the relatively low density at the Canning compared to all other deltas. The low density at the Canning may be a result of low availability of food resources at this site, and we are exploring the densities of invertebrates in related work that is currently underway. Some of the very small deltas, like the Staines, Angun and Sadlerochit, had relatively high densities of birds, although not significantly higher relative densities compared to other deltas, and small total numbers of birds because of their small size. Conversely, some other large deltas, like the Okpilak, Aichilik and Egaksrak, did not have significantly higher densities

**Table 2. Parameter estimates from ANCOVA models used to estimate ln(shorebird density) from data collected in the Arctic National Wildlife Refuge, Alaska (2006-2010). River Delta was modeled as the factor effect in the ANCOVA model and Year, Julian Date and Julian Date$^2$ were modeled as covariates.**

| River Delta | Estimate | SE | *t*-value | *P* |
|---|---|---|---|---|
| Aichilik | -639.60 | 162.20 | -3.944 | 0.0001* |
| Angun | -639.20 | 162.10 | -3.942 | 0.0001* |
| Canning | -641.40 | 162.30 | -3.953 | 0.0001* |
| Egaksrak | -639.90 | 162.20 | -3.946 | 0.0001* |
| Hulahula | -640.20 | 162.20 | -3.947 | 0.0001* |
| Jago | -638.60 | 162.10 | -3.940 | 0.0001* |
| Katakturuk | -639.80 | 162.30 | -3.943 | 0.0001* |
| Kongakut | -639.50 | 162.20 | -3.942 | 0.0001* |
| Niguanak | -640.60 | 162.20 | -3.950 | 0.0001* |
| Okpilak | -640.20 | 162.20 | -3.947 | 0.0001* |
| Sadlerochit | -639.50 | 162.30 | -3.941 | 0.0001* |
| Sikrelurak | -640.70 | 162.20 | -3.951 | 0.0001* |
| Staines | -639.50 | 162.20 | -3.942 | 0.0001* |
| Year (2006 is the reference category) | | | | |
| 2007 | 0.06 | 1.31 | 0.044 | 0.9649 |
| 2008 | 1.02 | 1.31 | 0.776 | 0.4385 |
| 2009 | 0.05 | 1.25 | 0.037 | 0.9702 |
| 2010 | 0.04 | 1.27 | 0.031 | 0.9757 |
| Julian Date | 5.93 | 1.52 | 3.907 | 0.0001* |
| Julian Date$^2$ | -0.01 | 0.00 | -3.855 | 0.0002* |

*$P < 0.001$

than other deltas, but still had high total numbers of birds because of their large area.

While some deltas had significantly higher densities than others, all of the river delta mudflats supported shorebirds, and there was high variability in maximum counts among sites and years at all sites. Taylor *et al.* (2011) found that shorebirds on the North Slope did not necessarily move across the landscape systematically in the direction of their normal fall migration, thus it seems likely that birds may be using different sites as resource availability or environmental conditions change. Taylor *et al.* (2011) also showed that shorebirds move widely among

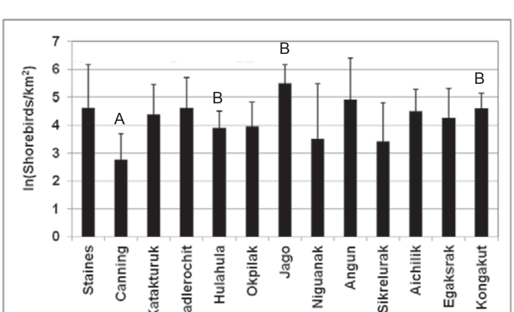


**Figure 2. ln(density estimates) and associated 95% confidence intervals for river deltas on the coast of the Arctic National Wildlife Refuge, Alaska, from surveys conducted between 2006 and 2010. Deltas with different letters had significantly different density estimates in the Tukey-Kramer multiple comparisons test.**

**Table 3. Relative shorebird density estimates (least-squares means back-transformed from the log scale) for single annual surveys at coastal mudflats in 13 river deltas along the Arctic National Wildlife Refuge coastline, 2006-2010.**

| Delta | Estimated Density | Confidence Interval | |
|---|---|---|---|
| | | Lower | Upper |
| Aichilik | 91.6 | 42.9 | 195.3 |
| Angun | 135.9 | 30.1 | 613.3 |
| Canning | 16.0 | 6.3 | 40.5 |
| Egaksrak | 71.0 | 24.5 | 205.4 |
| Hulahula | 49.5 | 27.1 | 90.3 |
| Jago | 247.8 | 129.2 | 475.1 |
| Katakturuk | 80.5 | 27.7 | 234.2 |
| Kongakut | 100.6 | 59.2 | 171.0 |
| Niguanak | 34.2 | 4.9 | 239.9 |
| Okpilak | 53.3 | 22.5 | 126.5 |
| Sadlerochit | 103.9 | 35.6 | 303.2 |
| Sikrelurak | 30.5 | 7.6 | 123.2 |
| Staines | 103.1 | 22.4 | 474.4 |

north slope coastal sites within years, and found that Semipalmated Sandpipers moved more frequently than several other species.

We cannot compare variability at sites within years in our data set, because the extreme remoteness of these sites and the time needed to travel between them limited us to only a single visit to each delta within each study year. However, the large variability within sites among years suggests that deltas are more or less valuable for foraging shorebirds at different times, and may be part of a complex that supports birds moving among sites as habitat quality varies. Although the overall fit of the model improved by including a year effect, the large standard errors of the year parameter estimates indicate it is not as useful for estimating relative shorebird densities compared with the other variables included in our best model.

The density values presented here are conservative. The model estimates densities averaged for the date of the single survey, and future work should model stopover time and estimate total numbers of birds using each site during the entire season (Frederiksen *et al.* 2001; Cohen *et al.* 2009). However, these density values are the first data ever presented that allow detailed comparisons among river deltas within the study area. Comparing the deltas to each other is an important first step toward development of management plans for these deltas, because this comparison helps determine the relative importance of each site within the Arctic Refuge. Additional work currently underway will help determine if the abundance patterns reported here persist with repeated measurements throughout the migration season.

There are very few other studies that measure densities of foraging shorebirds on the Arctic Refuge coastline or at nearby sites. The high abundance of Semipalmated Sandpipers on coastal mudflats in our surveys corresponds with results reported by Smith and Connors (1993) who found that the species most commonly used mudflat habitats near Barrow. Semipalmated Sandpipers are thought to have declined (Hitchcock and Gratto-Trevor 1997) as measured by significantly reduced counts on the wintering grounds (Andres *et al.* 2012; Morrison *et al.* 2012), so identification of key migration foraging areas is important. Andres (1994) reported overall densities for all shorebirds of 149.9/km$^2$ in repeated surveys on the Colville River Delta, higher than all of the sites reported here for the Arctic Refuge except for the Jago. The predominant species at the Colville was Dunlin, which may be underrepresented in our sample due to survey timing being earlier than the peak of Dunlin migration. Dunlin are known to migrate later in the season (Warnock and Gill 1996), and preliminary data from our ongoing research at the sites with repeated measurements shows a late pulse of Dunlin moving through the area that we likely missed due to the timing of our coastal surveys. Dunlin were the most abundant species in the surveys conducted later in the season on the Colville river delta (Andres 1994), and adding Dunlin missed in our surveys as well as conducting repeated counts at each site would likely make the densities more comparable.

Taylor *et al.* (2010) found the same general pattern of high single counts at the Jago and the Kongakut river deltas in their surveys, and also found highly variable counts between years. Their results were based on different methods, including aerial surveys and counts that were not corrected for detectability, so only general comparisons are possible. Our maximum raw count at the Kongakut in 2007 was over two times the maximum count reported in their surveys, and our Jago count in 2008 was over nine times their maximum. Comparing our maximum counts to others from the North Slope in their much wider surveys, the Jago and the Kongakut would rank as the largest and second-largest concentration areas, followed by the Sagavanirktok in the Central Beaufort and the Ikpikpuk in the West Beaufort, which suggests that these Arctic Refuge foraging areas attract concentrations of birds that are large on the scale of the entire North Slope.

Shorebirds are known to depend on stopover sites during migration to regain depleted fat reserves, and survival has been shown to be correlated with body condition before long migratory flights (Wilson 1990; Baker *et al.* 2004; Atkinson *et al.* 2007; Morrison *et al.* 2007). Understanding the relative densities of birds using coastal sites to prepare for these southbound migrations will aid in planning conservation priorities in the face of changing environmental conditions. A major management concern at the coastal mudflat sites in this study is that reduced habitat quality could impact shorebird populations. Potential impacts could arise through effects of human-caused or natural events, including disturbance from increasing oil and gas development (National Academy of Sciences 2003), which could cause displacement of foraging shorebirds, or impacts from spills.

The habitats surveyed in this study are also likely vulnerable to effects of a changing climate. Climate change has been more pronounced in the Arctic than at lower latitudes, and the Arctic has experienced twice the warming of the global average (McCarty 2001; ACIA 2005; Hinzman *et al.* 2005; Serreze and Francis 2006; IPCC 2007). Warming has been particularly pronounced in northern Alaska (Martin *et al.* 2009). Climate change could affect shorebird habitats on the northern coast of Alaska in many ways, including trophic mismatch with invertebrate food sources (Visser and Both 2005; Tulp and Schekkerman 2008; Van Der Jeugd *et al.* 2009), habitat loss or shifts (Maclean *et al.* 2008), and extreme weather events or changes in inland hydrology or sea level (ACIA 2005; Martin *et al.* 2009). Determining the relative abundance of birds at coastal sites will help support conservation efforts to mitigate these impacts.

Sea level rise is predicted to accelerate, and could have significant impacts on foraging areas for shorebirds on the Arctic coastline. Similar concerns were reported by Galbraith *et al.* (2002) for shorebird stopover sites in temperate zones. Accessibility of appropriate habitats, which is controlled by water depth, is critical to their value for foraging shorebirds (Collazo *et al.* 2002). Because arctic coastal mudflats have very low gradients, small changes in sea level from increased ice melting and thermal expansion (IPCC 2007) can inundate large areas, making them accessible for shorter periods of time or inaccessible during the migration window. In some storms during our surveys, large mudflats like the Jago river delta were completely inundated, and shorebirds were displaced from a significant foraging area for approximately eight days during the period when they would normally be preparing for migration. Increases in sea level or increases in the severity or frequency of storms could have negative impacts on the ability of many species to utilize critical foraging habitats.

Our results document the relative density of shorebirds across a very large area of coastal mudflat habitat at a critical stage in their life cycle: their preparation for southbound migration. In general, our results suggest two overall conclusions relevant to management of coastal habitats. First, the large sites with consistently high average densities may attract a larger proportion of the post-breeding shorebird population than sites with lower densities, and should be managed to protect shorebird foraging habitat. Future work should be designed to confirm whether the total abundances of birds using each site follow the patterns found here for single counts. Second, because all sites were used heavily in at least one year of the study, management of the Arctic Refuge coastal areas should consider these sites as part of a habitat complex within which each site may be important at various times in preparing shorebirds for southbound migration. Taylor *et al.* (2010) suggested the same approach for the broader coastal environment of the northern Alaska coast, of which our study area was a small part. Managing these sites as part of an interconnected resource for foraging shorebirds will improve their ability to support shorebird abundance and diversity at a critical time of year, and provide a more resilient habitat in the face of predicted changes in climate and sea level.

## ACKNOWLEDGMENTS

We are grateful to the ornithologists who participated in these surveys. In addition to the authors, surveys were conducted by R. Burner, H. Craig, L. DeCicco and B. Winn. J. Reynolds helped design the surveys. We acknowledge the Kaktovik Inupiat Corporation for permission to conduct surveys on their lands. We staged our survey out of Kaktovik, AK, and appreciate the support of the people of Kaktovik. Major funding for this study was provided by donors of Manomet Center for Conservation Sciences, by the U.S. Fish and Wildlife Service Challenge Cost Share Program, and by the Arctic National Wildlife Refuge.

## LITERATURE CITED

ACIA. 2005. Arctic Climate Impact Assessment. New York, New York.

Akaike, H. 1974. A new look at statistical model identification. IEEE Transactions on Automatic Control 19: 716-723.

Alaska Shorebird Group. 2008. Alaska Shorebird Conservation Plan, Version II. Alaska Shorebird Group, Anchorage, Alaska.

Andres, B. A. 1994. Coastal zone use by postbreeding shorebirds in northern Alaska. Journal of Wildlife Management 58: 206-213.

Andres, B. A., C. Gratto-Trevor, P. Hicklin, D. Mizrahi, R. I. G. Morrison and P. A. Smith. 2012. Status of the Semipalmated Sandpiper. Waterbirds 35: 146-148.

Atkinson, P. W., A. J. Baker, K. A. Bennett, N. A. Clark, J. A. Clark, K. B. Cole, A. Dekinga, A. Dey, S. Gillings, P. M. Gonzalez, K. Kalasz, C. D. T. Minton, J. Newton, L. J. Niles, T. Piersma, R. A. Robinson and H. P. Sitters. 2007. Rates of mass gain and energy deposition in Red Knot on their final spring staging site is both time- and condition-dependent. Journal of Applied Ecology 44: 885-895.

Baker, A. J., P. M. Gonzalez, T. Piersma, L. J. Niles, I. D. S. do Nascimento, P. W. Atkinson, N. A. Clark, C. D. T. Minton, M. K. Peck and G. Aarts. 2004. Rapid population decline in Red Knots: Fitness consequences of decreased refueling rates and late arrival in Delaware Bay. Proceedings of the Royal Society of London Series B - Biological Sciences 271: 875-882.

Bart, J., S. Brown, B. Harrington and R. I. G. Morrison. 2007. Survey trends of North American shorebirds: Population declines or shifting distributions? Journal of Avian Biology 38: 73-82.

Brown, S., J. Bart, R. B. Lanctot, J. A. Johnson, S. Kendall, D. Payer and J. Johnson. 2007. Shorebird abundance and distribution on the coastal plain of the Arctic National Wildlife Refuge. Condor 109: 1-14.

Brown, S., C. Hickey, B. Harrington and R. Gill. 2001. United States Shorebird Conservation Plan, 2nd Edition, Manomet Center for Conservation Sciences, Manomet, Massachusetts.

Buckland, S. T., D. R. Anderson, K. P. Burnham and J. L. Laake. 2001. Introduction to Distance Sampling. Oxford University Press, Oxford, UK.

Burnham, K. P. and D. R. Anderson. 2002. Model Selection and Multimodal Inference, 2$^{nd}$ ed. Springer-Verlag, New York, New York.

Cohen, J. B., S. M. Karpanty, J. D. Fraser, B. D. Watts and B. R. Truitt. 2009. Residence probability and population size of Red Knots during spring stopover in the Mid-Atlantic region of the United States. Journal of Wildlife Management 73: 939-945.

Collazo, J. A., D. A. O'Hara and C. A. Kelly. 2002. Accessible habitat for shorebirds: Factors influencing its availability and conservation implications. Waterbirds 25: 13-24.

Connors, P. G. 1984. Ecology of shorebirds in the Alaskan Beaufort littoral zone. Pages 403-416 *in* The Alaskan Beaufort Sea: Ecosystems and Environments (P. W. Barnes, D. M. Shell and E. Reimnitz, Eds.). Academic Press, New York, New York.

Connors, P. G., C. S. Connors and K. G. Smith. 1981. Shorebird Littoral Zone Ecology of the Alaska Beaufort Coast. Final Report of Principal Investigators, Outer Continental Shelf Environment Assessment Program, National Oceanic and Atmospheric Administration 23: 297– 396.

Connors, P. G., J. P. Myers and F. A. Pitelka. 1979. Seasonal habitat use by Arctic Alaskan shorebirds. Studies in Avian Biology 2: 101-111.

DigitalGlobe. 2003. QuickBirdImagery. Longmont, Colorado.

Frederiksen, M., A. D. Fox, J. Madsen and K. Colhoun. 2001. Estimating the total number of birds using a staging site. Journal of Wildlife Management 65: 282-289.

Galbraith, H., R. Jones, R. Park, J. Clough, S. Herrod-Julius, B. Harrington and G. Page. 2002. Global climate change and sea level rise: Potential losses of intertidal habitat for shorebirds. Waterbirds 25: 173-183.

Hinzman, L. D., N. D. Bettez, W. R. Bolton, F. S. Chapin, M. B. Dyurgerov, C. L. Fastie, B. Griffith, R. D. Hollister, A. Hope, H. P. Huntington, A. M. Jensen, G. J. Jia, T. Jorgenson, D. L. Kane, D. R. Klein, G. Kofinas, A. H. Lynch, A. H. Lloyd, A. D. McGuire, F. E. Nelson, W. C. Oechel, T. E. Osterkamp, C. H. Racine, V. E. Romanovsky, R. S. Stone, D. A. Stow, M. Sturm, C. E. Tweedie, G. L. Vourlitis, M. D. Walker, D. A. Walker, P. J. Webber, J. M. Welker, K. Winker and K. Yoshikawa. 2005. Evidence and implications of recent climate change in northern Alaska and other arctic regions. Climatic Change 72: 251-298.

Hitchcock, C. L. and C. Gratto-Trevor. 1997. Diagnosing a shorebird local population decline with a stage structured population model. Ecology 78: 522-534.

International Wader Study Group. 2003. Wader study group workshop 26 September 2003: Are waders world-wide in decline? Conclusions from the 2003 International Wader Study Group Conference, Cadiz, Spain. Wader Study Group Bulletin 101: 8-12.

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.

Kendall, S., D. Payer, S. Brown and R. Churchwell. 2011. Impacts of climate change and development on shorebirds of the Arctic National Wildlife Refuge. Pages 1-10 *in* Gyrfalcons and Ptarmigan in a Changing World (R. T. Watson, T. J. Cade, M. Fuller, G. Hunt and E. Potapov, Eds.).The Peregrine Fund, Boise, Idaho. .http://dx.doi.org/10.4080/gpcw.2011.0109, accessed 17 February 2012.

Kutner, M. H., C. J. Nachtsheim, J. Neter and W. Li. 2005. Applied Linear Statistical Models. McGraw-Hill Irwin, Boston, Massachussetts.

Lyons, J. E. and S. M. Haig. 1995. Fat content and stopover ecology of spring migrant Semipalmated Sandpipers in South Carolina. Condor 97: 427-437.

Maclean, I. M. D., G. E. Austin, M. M. Rehfisch, J. Blew, O. Crowe, S. Delany, K. Devos, B. Deceuninck, K. Gunther, K. Laursen, M. Van Roomen and J. Wahl. 2008. Climate change causes rapid changes in the distribution and site abundance of birds in winter. Global Change Biology 14: 2489-2500.

Martin, P. D., J. L. Jenkins, F. J. Adams, M. T. Jorgenson, A. C. Matz, D. C. Payer, P. E. Reynolds, A. C. Tidwell and J. R. Zelenak. 2009. Wildlife response to environmental Arctic change: Predicting future habitats of Arctic Alaska. U.S. Fish and Wildlife Service, Fairbanks, Alaska.

McCarty, J. P. 2001. Ecological consequences of recent climate change. Conservation Biology 15: 320-331.

Morrison, R. I. G., Y. Aubry, R. W. Butler, G. W. Beyersbergen, G. M. Donaldson, C. L. Gratto-Trevor, P. W. Hicklin, V. H. Johnston and R. K. Ross. 2001. Declines in North American shorebird populations. Wader Study Group Bulletin 94: 34-38.

Morrison, R. I. G., N. C. Davidson and J. R. Wilson. 2007. Survival of the fattest: body stores on migration and survival in Red Knots *Calidriscanutusislandica*. Journal of Avian Biology 38: 479-487.

Morrison, R. I. G., D. S. Mizrahi, R. K. Ross, O. H. Ottema, N. De Pracontal and A. Narine. 2012. Dramatic declines of Semipalmated Sandpipers on their major wintering areas in the Guianas, Northern South America. Waterbirds 35: 1-184.

National Academy of Sciences. 2003. Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. National Academies Press, Washington, D.C.

Nolan, M., R. Churchwell, J. Adams, J. McClelland, K. D. Tape, S. Kendall, A. Powell, K. Dunton, D. Payer and P. Martin. 2011. Predicting the Impact of Glacier Loss on Fish, Birds, Floodplains, and Estuaries in the Arctic National Wildlife Refuge. US Geological Survey Scientific Investigations Report 2011-5169, Reston, Virginia.

SAS Institute Inc. 2011. SAS 9.2. Cary, North Carolina.

Serreze, M. C. and J. A. Francis. 2006. The arctic amplification debate. Climatic Change 76: 241-264.

Smith, K. G. and P. G. Connors. 1993. Postbreeding habitat selection by shorebirds, water birds, and land birds at Barrow, Alaska - A multivariate analysis. Canadian Journal of Zoology 71: 1629-1638.

Taylor, A. R., R. B. Lanctot, A. N. Powell, F. Huettmann, D. A. Nigro and S. J. Kendall. 2010. Distribution and community characteristics of staging shorebirds on the northern coast of Alaska. Arctic 63: 451-467.

Taylor, A. R., R. B. Lanctot, A. N. Powell, S. J. Kendall and D. A. Nigro. 2011. Residence time and movements of postbreeding shorebirds on the northern coast of Alaska. Condor 113: 779-794.

Tulp, I. and H. Schekkerman. 2008. Has prey availability for arctic birds advanced with climate change? Hindcasting the abundance of tundra arthropods using weather and seasonal variation. Arctic 61: 48-60.

U.S. Fish and Wildlife Service. 2008. Birds of Conservation Concern 2008. Arlington, VA.

Van Der Jeugd, H. P., G. Eichhorn, K. E. Litvin, J. Stahl, K. Larsson, A. J. Van Der Graaf and R. H. Drent. 2009. Keeping up with early springs: Rapid range expansion in an avian herbivore incurs a mismatch between reproductive timing and food supply. Global Change Biology 15: 1057-1071.

Visser, M. E. and C. Both. 2005. Shifts in phenology due to global climate change: The need for a yardstick. Proceedings of the Royal Society of London Series B-Biological Sciences 272: 2561-2569.

Warnock, N. 2010. Stopping vs. staging: the difference between a hop and a jump. Journal of Avian Biology 41: 621-626.

Warnock, N. D. and R. E. Gill. 1996. Dunlin (*Calidrisalpina*), *in* The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology. http://bna.birds.cornell.edu/bna/species/203 doi:10.2173/bna.203, accessed 17 February 2012.

Wilson, W. H. 1990. Relationship between prey abundance and foraging site selection by Semipalmated Sandpipers on a Bay of Fundy mudflat. Journal of Field Ornithology 61: 9-19.