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Migrant shorebird use of Akimiski Island, Nunavut: a sub-arctic staging site

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Abstract Determining the importance of stopover and staging areas to migrating shorebirds (Aves: Charadriiformes) is essential if such habitats are to be successfully protected. Migration chronology, species composition, length of stay, body condition, and estimated total abundance of shorebirds during spring and fall migratory periods of 2008 and 2009 were documented on Akimiski Island, Nunavut, Canada. Fourteen shorebird species were observed during spring point counts and 18 during fall. Semipalmated (*Calidris pusilla*) and White-rumped (*C. fuscicollis*) Sandpipers comprised about 80 % of all individuals observed. A greater number of species and individuals were observed during fall than spring in both years. Radio-transmitters attached to juvenile Semipalmated and Least (*C. minutilla*) Sandpipers indicated highly variable lengths of stay ranging up to 26 days in both species (Semipalmated Sandpiper averaged 6.5 ± 2.67 days, $n = 12$; Least Sandpipers averaged 7.25 ± 3.79 days, $n = 8$). In 2009, Semipalmated Sandpipers captured and weighed later in the season were significantly heavier than those captured earlier suggesting that this species is refueling while on Akimiski Island. A fall migration seasonal density of 5,267 (2,193–8,341) shorebirds/km^2 was estimated given a residence probability (i.e., the probability of an individual being present in consecutive counts) of 0.906 ± 0.181. Assuming similar habitat value and shorebird density, an extrapolation of the seasonal plot density of 5,267 birds/km^2 to the total 192 km^2 mudflat habitat on Akimiski Island yields an estimate of 1,011,264 (421,098–1,601,429) shorebirds during fall migration, making Akimiski Island of Hemispheric importance as a staging site for migrant arctic-breeding shorebirds.

Keywords Staging site · Length of stay · *Calidris pusilla* · *Calidris fuscicollis* · Population modeling · Nunavut

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Introduction

The Canadian Arctic provides breeding grounds for millions of shorebirds, with the majority of species traveling thousands of kilometers to reach these highly productive areas (Morrison 1984; Wilson 1990). These long-distance migrations would not be feasible without the presence of stopover and staging sites along migration routes where individuals regain depleted fat reserves (Wilson 1990; Atkinson et al. 2007; Morrison et al. 2007). Stopover sites are areas with adequate food resources, where individuals refuel for a brief period and perform short flights between multiple sites; whereas staging areas provide prey-rich habitats, allowing individuals to fuel over a longer time period before performing long-distance flights (Warnock 2010). Understanding stopover and staging site ecology is an important aspect of planning for shorebird conservation as large numbers of shorebirds congregate at a small number of specific sites (Recher 1966; O'Reilly and Wingfield 1995; Bart et al. 2007). Geographic bottlenecks during migration make shorebird species especially vulnerable to habitat changes at both small and large spatial scales (Piersma and Baker 2000). With more than 40 % of Canadian species declining on surveys (Morrison et al. 2001a; Baker et al. 2004; Bart et al. 2007) and in light of recent increasing global coastal habitat loss (Nicholls et al. 2007), identifying and protecting critical shorebird habitat is essential for their conservation.

Stopover and staging ecology research has focused on a few well-known primary sites (Hicklin 1987; Myers 1987; Morrison et al. 2001b) and displays a bias toward easily accessible areas along the populated coastlines of North America. The Western Hemisphere Shorebird Reserve Network (WHRSN) has identified many of these sites for conservation purposes, with classifications of Hemispheric importance encompassing sites that support at least 500,000 shorebirds annually; international importance including sites supporting at least 100,000 annually, and regional importance for sites supporting at least 20,000 annually (Manomet Center for Conservation Sciences 2005). Delaware Bay, which has Hemispheric ranking, is a primary site for shorebirds that potentially use James Bay during spring migration including Red Knots (*Calidris canutus*), Semipalmated Sandpipers (*C. pusilla*) and others (Myers 1987; Baker et al. 2004). The Bay of Fundy, Canada, is also of Hemispheric importance due to large numbers of Semipalmated Sandpipers that use, specifically, the abundant benthic invertebrates during their fall migration en route to their wintering grounds (Hicklin 1987; MacDonald et al. 2012), with individuals likely stopping at James Bay beforehand (Morrison 1984). Biases toward well-known and accessible sites leave many remote but potentially important northern sites unevaluated and unprotected.

The Western Hemisphere Shorebird Reserve Network (WHSRN) estimates abundance at stopover and staging sites using either the peak one-day count observed in a season or count data along with turnover rates (i.e., the percentage of individuals present in consecutive surveys; Frederiksen et al. 2001; Manomet Center for Conservation Sciences 2005; Cohen et al. 2009). If peak count data were only used, the total number of birds using a site would be underestimated as this method neglects individuals who arrive and leave before or after the peak. Adjusting count data using daily residence probability (i.e., turnover rates) calculated from mark–recapture data of individuals outfitted with radio-transmitters provides greater accuracy in shorebird estimation (Frederiksen et al. 2001; Cohen et al. 2009). Although these abundance estimate corrections are becoming more common (Hicklin 1987; Andres and Browne 1998; Bishop et al. 2000; Farmer and Durbian 2006; Skagen et al. 2008), many researchers still rely on peak count data due to financial, logistic, and time constraints (Clark et al. 1993; Alexander and Gratto-Trevor 1997; Warnock et al. 1998; Ma et al. 2002; Hands 2008).

Using a combination of field point counts, aerial surveys, remote sensing and advancements in estimation of abundance, we studied the importance of Akimiski Island, Nunavut, Canada, to migrant shorebirds. This sub-arctic island is situated in the migratory funnel created by the shorelines of Hudson Bay and James Bay, approximately midway between arctic nesting areas and temperate coastal staging areas in eastern North America (Fig. 1). Observations over the course of a long-term goose ecology study (K. F. Abraham, unpublished) suggested that Akimiski Island may be an important site for shorebird migration. Our objectives were to (a) assess migration chronology, (b) determine species composition, (c) estimate total abundance of shorebirds corrected for length of stay, and (d) examine whether shorebird body mass increased through time on Akimiski Island.

Study area

Shorebirds were surveyed along the northern coastline of Akimiski Island, Nunavut, Canada (53°10′N, 80°96′W) (Fig. 1) between the months of May and September in 2008 and 2009, periods that encompassed most of the spring and fall migrations. Akimiski Island is the largest island in James Bay with an approximate area of 3,800 km^2. The island has no permanent inhabitants and contains the Akimiski Island Migratory Bird Sanctuary (Canadian Wildlife Service, Environment Canada). The 130 km northern coastline is composed of extensive mudflats, beaches, and intertidal and supratidal marshes interspersed with gravel beach ridges. The dominant plant species in these habitats are creeping alkaligrass

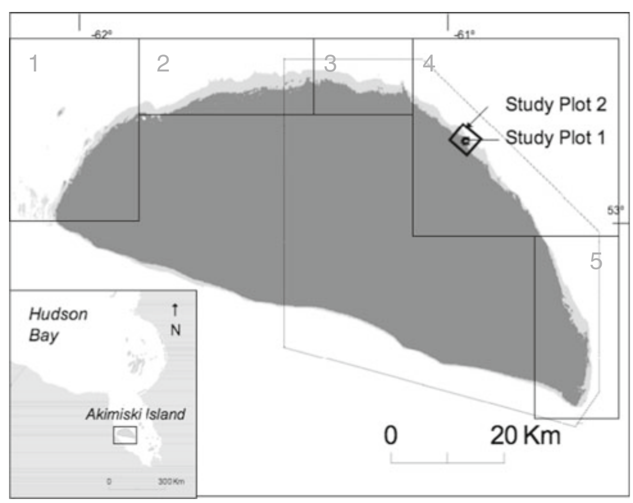

Fig. 1 Study area on Akimiski Island, Nunavut and Study Plots 1 and 2. *Light gray* shading represents coastal mudflats and *dark gray* all other habitat types. The *boxes* 1–5 represent the sections of shorelines into which the aerial survey was divided for shorebird density comparisons. The large polygon represents the boundaries of the Akimiski Island Migratory Bird Sanctuary (MBS) (IUCN World Commission on Protected Areas 1941)

(*Puccinellia phryganodes*) and red fescue (*Festuca rubra*), with Baltic rush (*Juncus balticus*) and willows (*Salix spp.*) also found in supratidal habitats (Blaney and Kotanen 2001; Nguyen et al. 2006). Freshwater creeks flow from the interior of the island into James Bay. Average temperatures range from 6.2 °C during spring migration to 12.5 °C during fall migration.

Materials and methods

Migration chronology

We performed two kinds of ground surveys during the study period from 25 May–23 June and 19 July–25 August in 2008, and from 31 May–14 June and 5 July–10 September in 2009. First, we performed daily 15-min surveys (total = 115) within one hour of high tide in a 0.321 km^2 study plot (Fig. 1, Study Plot 1) to determine shorebird migration chronology, with birds observed from an observation point outside of the study plot. Second, we performed 10-min point count surveys (total = 63) every other day at low tide along 6 transects at 18 locations within a 1.35 km^2 plot, to provide data to model shorebird abundance across the island and to calculate average use (Fig. 1: Study Plot 2). A 20–60× spotting scope and 8× binoculars were used to scan the area and count all foraging birds within a 100 m radius semi-circle area around each location (measured using a rangefinder). Each study plot was chosen due to its proximity to the established field camp as surveys were conducted on foot. Surveys were not conducted during periods of heavy rain or fog as visibility was reduced. Shorebirds were identified to species and aged when possible. Weighted average use dates were calculated for each species by multiplying the number of individuals in each survey at the beginning of the migration period by the date they were observed in Study Plot 2 and dividing the sum of this by the total number of individuals counted [e.g., ((1 bird*1 June) + (14 birds*4 June) + (20 birds*5 June) + (55 birds*6 June))/90 birds = 5 June].

Semipalmated Plovers (*Charadrius semipalmatus*), Killdeer (*Charadrius vociferus*), Marbled Godwits (*Limosa fedoa*), Least Sandpipers (*Calidris minutilla*), Lesser Yellowlegs (*Tringa flavipes*), and Wilson's Snipe (*Gallinago delicata*) breed on Akimiski Island. If individuals of these species were exhibiting breeding displays, alarm calls, or a nest was located, they were excluded from analyses.

Aerial survey

On 23 July 2009, a helicopter aerial shorebird survey of the entire northern coastline (from the east tip to the west tip) of Akimiski Island was conducted along the mudflats (by R. K. Ross, R. I. G. Morrison, Environment Canada, and LAP). Shorebirds were classified as small shorebirds ("peeps"), medium shorebirds, and large shorebirds when observers were unable to identify individuals to species. Peeps include Semipalmated, White-rumped (*Calidris fuscicollis*) and Least Sandpipers, Sanderlings (*Calidris alba*), and Semipalmated Plovers; medium shorebirds include Black-bellied (*Pluvialis squatarola*) and American Golden (*Pluvialis dominica*) Plovers, Killdeer, Dunlin (*Calidris alpina*), Lesser Yellowlegs, Ruddy Turnstone (*Arenaria interpres*), Red Knot, and Pectoral Sandpiper (*Calidris melanotos*); and, large shorebirds include Whimbrel (*Numenius phaeopus*), Hudsonian (*Limosa haemastica*) and Marbled Godwits, and Greater Yellowlegs (*Tringa melanoleuca*). Shorebirds on the ground as well as flying flocks were counted from both sides of the low-flying helicopter.

The northern shoreline was divided into five sections (Fig. 1) based on a limited number of waypoints provided from the aerial survey. The mudflat area for each section was calculated using ArcMAP. The density of shorebirds (individuals/km^2) in each shoreline section was calculated using the area of mudflats and the number of shorebirds counted per section.

Capture techniques

Shorebirds were captured during the incoming tide, using mist nets (35 mm mesh) positioned around intertidal pools located within Study Plot 2, from 5 to 22 August in 2008 and from 3 August to 4 September in 2009. Shorebird silhouettes were placed around mist nets to attract birds. We measured shorebird body mass (nearest 0.1 g), tarsus length and exposed culmen (nearest 0.1 mm), natural wing chord (non-flattened, nearest 1 mm), and scored furcula fat on a scale from zero (no fat) to eight (excessive fat, Pyle 1997). Shorebirds were aged as juvenile or adult according to their plumage and molt stage (Pyle 1997), but we were unable to sex any shorebird. A Canadian Wildlife Service aluminum band and a white darvic flag were placed on the upper left leg of each shorebird and 1–2 color bands in a unique combination were placed on the upper right leg. Instant adhesive (Loctite 495 Super Bonder) and accelerant (Loctite Tak Pak 7452) were used to attach 0.42 g radio-transmitters (Model BD-2 N, Holohil Systems Limited, Ontario; detection range of 1 km) onto the backs of 12 juvenile Semipalmated Sandpipers and 8 juvenile Least Sandpipers. The transmitters represented approximately 1.6 % of Semipalmated Sandpiper and 1.9 % of Least Sandpiper total body weights, in accordance with the AOU guidelines for safe handling of birds (Fair et al. 2010). Daily ground surveys were conducted within the study plot using a hand-held Yagi antennae and 150–154 MHz receiver (R-1000 Telemetry Receiver, Communications Specialists Inc., California) to detect radio-marked birds. Radio surveys were largely conducted from one transect nearest camp in Study Plot 2 due to extremely high polar bear activity in August and September, and along the 6 transects in Study Plot 2 when possible to increase the detection range. We calculated length of stay as the number of days between date of capture and last detection. We assigned a length of stay of one day to birds detected only on the same day of release. We also performed band-sighting surveys to count banded individuals.

Data analyses

Linear regression was used to analyze the relationship between Semipalmated Sandpiper mass and capture date. Semipalmated Sandpiper fat score data were not normally distributed, so we analyzed fat scores as a function of year banded using a Mann–Whitney *U* test.

Residence probability during fall migration was calculated from radio-marked juvenile Semipalmated and Least Sandpiper presence-absence data using program MARK (White 1999). Residence probability (ϕ_r) is the probability that an individual in a current count (C_i) was also present in the previous survey (C_{i-1}). We calculated ϕ_r using the Cormack Jolly-Seber mark–recapture model for recaptures only using the logit function. Model selection was performed using Akaike's Information Criterion corrected for small sample size ($\mathrm{AIC_c}$) in program MARK. Models with ϕ_r and detection rate (p) held constant and varying over time were evaluated. Species was added to the models. As a significant interaction between species and residence probability was found in the top models, we analyzed each species separately. The ϕ_r was used to estimate the total number of shorebirds using Study Plot 2. This residence probability is only applicable to juveniles in the radio-survey period; residence probability during the remaining time period and adult turnover rates are unknown.

To estimate the total number of birds stopping over in Study Plot 2 during the fall migration period, the following formula was used:

$$N_{\mathrm{est}} = C_1 + \sum_{i=2}^{n} (C_i - C_{i-1}(\phi_r))$$

where N_{est} is the estimated total number of birds, n is the number of surveys, C_1 is the initial shorebird survey, C_i is the shorebird count in survey i, C_{i-1} is the shorebird count of the previous survey, and ϕ_r is the mean daily residence probability (Frederiksen et al. 2001).

Shorebird counts were used in the N_{est} model to calculate a fall seasonal estimate using Study Plot 2. Given that we measured residence probabilities for only two species, and that probabilities may vary among species and age groups, the estimated total number of shorebirds using the stopover site (N_{est}) was determined using a random sample of residence probabilities from a normal distribution curve based on the mean and standard deviation of calculated ϕ_r (ranging from 0.26 to 0.99). In program R (Urbanek and Iacus 2009), 10 million random values of ϕ_r were obtained from a normal distribution and any value greater than one was excluded from the analysis, as residence probability cannot be greater than 100 %. A random sample of 10,000 ϕ_r was used to calculate N_{est} using a Monte-Carlo Simulation in program R. A range of population estimates based on the standard deviation around the mean is provided along with the average shorebird population estimate.

The seasonal estimate of shorebirds from Study Plot 2 was extrapolated to the entire northern mudflat complex of Akimiski Island. Area of the mudflat was determined using LANDSAT satellite data (LANDSAT28, National-scale Ontario Land Cover, NAD27, resolution 100 m, latitude/longitude projection) with ArcMAP 9.2 (ESRI, Redlands CA).

Results

Species composition

Fourteen shorebird species were observed during spring migration and 18 species were observed during fall migration in both study plots. Semipalmated and White-rumped Sandpipers comprised approximately 80 % of all shorebirds observed. There were slight differences in relative species use by season (Table 1). In spring, Black-bellied Plovers, Hudsonian Godwits, Dunlin, Semipalmated Plovers, and Semipalmated Sandpipers composed the majority of birds observed. In addition to Semipalmated and White-rumped Sandpipers, Pectoral Sandpipers and Dunlins made up the majority of birds observed during fall migration.

In total, 73,317 shorebirds were counted during the aerial survey on 23 July 2009 (Table 2). Of these, 72,523 (98.9 %) were classified as peeps, 533 (0.7 %) as medium and 231 (0.3 %) as large shorebirds. Shorebird density varied across the northern shore, with the lowest density occurring in the same section as our study plot (Fig. 1, Table 2).

Migration chronology

During spring migration, most adult shorebirds of species that breed further north than Akimiski Island arrived in late May (Table 3) and departed by mid-June (29-day duration). Peak daily numbers of shorebirds in Study Plot 1 in

Table 1 Maximum and average (± standard error) shorebird counts observed in the 0.321 km^2 study plot 1 on Akimiski Island, Nunavut, during spring migration from 25 May–23 June in 2008, and 31 May–14 June in 2009 and fall migration from 19 July–25 August in 2008, and 5 July–14 September in 2009

Species	Years	Spring				Fall			
		Max daily Count	Date max Count	Average Count ± SE	DP	Max daily Count	Date max Count	Average Count ± SE	DP
Black-bellied Plover	2008	72	2 June	31.3 ± 20.7	3	4	27 July	3.3 ± 0.33	3
	2009	0		0	0	8	6 Aug	4.2 ± 0.69	14
American golden-Plover	2008	0		0	0	30	26 July	12 ± 9.02	3
	2009	0		0	0	29	14 Sept	7.8 ± 3.23	7
Semipalmated Plover	2008	5	26 May		1	9	17 Aug	3.3 ± 0.33	3
	2009	25	3 June	13 ± 6.24	3	50	18 Aug	12 ± 2.39	27
Killdeer	2008	8	12 June	1.33 ± 0.33	3	3	26 July		1
	2009	3	2 June	1.25 ± 0.25	4	4	11 July	2.3 ± 0.88	3
Greater Yellowlegs	2008	2	10 June	1.5 ± 0.5	3	33	27 July	6.1 ± 3.07	10
	2009	1	10 June		1	85	31 July	11.6 ± 2.59	43
Lesser Yellowlegs	2008	8	10 June		1	17	5 Aug	7 ± 2.18	9
	2009	0		0	0	55	9 Aug	12 ± 2.60	27
Hudsonian Godwit	2008	62	10 June	59 ± 3.0	2	21	8 Aug	6.29 ± 2.75	7
	2009	9	9 June		1	82	30 July	21.8 ± 6.84	14
Marbled Godwit	2008	0		0	0	10	26 July	5.5 ± 4.5	2
	2009	0		0	0	15	15 Aug	7.3 ± 2.78	4
Whimbrel	2008	0		0	0	13	17 Aug	4.4 ± 2.36	5
	2009	0		0	0	396	13 Aug	47.4 ± 29.52	15
Red Knot	2008	3	6 June	3	3	85	18 Aug	63 ± 20.03	3
	2009	0		0	0	600	17 Aug	104.8 ± 99.04	6
Ruddy Turnstone	2008	29	8 June	19.3 ± 5.78	3	28	17 Aug	15.7 ± 6.94	5
	2009	11	6 June		1	49	13 Aug	9.4 ± 2.5	24
Short-billed Dowitcher	2008	12	10 June		1	3	5 Aug	2.33 ± 0.33	3
	2009	1	15 June		1	4	12 Aug		1
Dunlin	2008	67	2 June	44 ± 23	2	45	18 Aug	19 ± 13.20	3
	2009	0		0	0	701	13 Sept	94.9 ± 51.21	18
Pectoral Sandpiper	2008	0		0	0	116	1 Aug	34.25 ± 27.53	4
	2009	0		0	0	58	27 July	14.5 ± 4.17	16
Sanderling	2008	0		0	0	0		0	0
	2009	0		0	0	16	5 Sept	5.6 ± 1.21	13
Least Sandpiper	2008	0	31 May	0	0	310	26 July		1
	2009	16			1	25	18 Aug	5.4 ± 1.80	16
Semipalmated Sandpiper	2008	136	2 June	60.5 ± 27.2	4	1,051	30 July	209.9 ± 57.32	10
	2009	55	6 June	16.5 ± 12.84	6	2,250	30 July	169.7 ± 68.79	40
White-rumped Sandpiper	2008	55	2 June	15.2 ± 27.2	5	558	30 July	163.3 ± 47.91	11
	2009	10	4 June	7 ± 3.0	6	1,775	31 July	303.9 ± 55.05	43

DP = the number of survey days each species were present

spring were observed in early June ($n = 522$ on 2 June 2008 and $n = 86$ on 5 June 2009) (Fig. 2). Fall migration was longer (minimum 73-day duration; July–September; likely into October but researchers left mid-September) and shorebird abundance was substantially greater in the fall compared to the spring. Adult shorebirds were present on Akimiski Island from mid-July through late August with a few individuals observed into early September (Fig. 3). Juvenile shorebirds started to arrive in late July with the majority passing through in August and September. Peak daily numbers in Study Plot 1 during fall migration occurred at the end of July ($n = 1{,}520$ on 30 July 2008 and $n = 3{,}695$ on 31 July 2009 density). In September, most Semipalmated and White-rumped Sandpipers had departed

Table 2 Number of shorebirds counted during an aerial survey conducted on 23 July 2009 on Akimiski Island, Nunavut. The shoreline was divided into five sections (Fig. 1), each with corresponding mudflat area (km^2), number of shorebirds, and shorebird density (individuals/km^2). Study Plots 1 and 2 were in Sect. 4

Shoreline section	Mudflat area (km^2)	Number of shorebirds (aerial survey)	Shorebird density (birds/km^2)
1	20.15	9,935	493.13
2	62.89	34,574	549.75
3	40.93	15,681	383.13
4	31.95	2,257	70.63
5	35.96	10,870	302.27

Table 3 First date sighted and weighted average use dates for 18 shorebird species in Study Plot 2 on Akimiski Island, Nunavut

Species	Years	Date first sighted		Weighted average use dates	
		Spring	Fall	Spring	Fall
Black-bellied Plover	2008	2 June	27 July	5 June	14 Aug
	2009	4 June	28 July	11 June	15 Aug
American golden Plover	2008		26 July		
	2009		6 Aug		19 Aug
Semipalmated Plover	2008	25 May[a]	19 July		27 July
	2009	31 May[a]	5 July	4 June	26 July
Killdeer	2008	25 May[a]	26 July		
	2009	2 June	5 July		15 July
Greater yellowlegs	2008	29 May	19 July	10 June	23 July
	2009	9 June	5 July		20 July
Lesser Yellowlegs	2008	29 May	19 July		23 July
	2009	31 May[a]	5 July		19 July
Hudsonian Godwit	2008	25 May[a]	19 July	14 June	25 July
	2009	2 June	5 July	8 June	28 July
Marbled Godwit	2008	2 June	19 July		
	2009	31 May[a]	6 July		20 July
Whimbrel	2008	23 June	26 July		27 July
	2009		5 July		17 July
Red Knot	2008	6 June	18 Aug	8 June	21 Aug
	2009		29 July		17 Aug
Ruddy Turnstone	2008	2 June	28 July	7 June	15 Aug
	2009	31 May[a]	24 July	7 June	12 Aug
Short-billed Dowitcher	2008	2 June	19 July		13 Aug
	2009	15 June	5 July		
Dunlin	2008	2 June	22 July	4 June	16 Aug
	2009	31 May[a]	11 July	6 June	
Pectoral Sandpiper	2008		19 July		25 July
	2009		15 July		26 July
Sanderling	2008				
	2009	11 June	4 Aug		16 Aug
Least Sandpiper	2008	25 May[a]	22 July		
	2009	31 May[a]	6 July	5 June	20 July
Semipalmated Sandpiper	2008	29 May	19 July	4 June	30 July
	2009	31 May[a]	11 July	7 June	29 July
White-rumped Sandpiper	2008	2 June	22 July	8 June	10 Aug
	2009	31 May[a]	19 July	10 June	30 July

Surveys were conducted 25 May–23 June and 19 July–25 August in 2008, and 31 May–14 June and 5 July–15 September in 2009

Blank spaces represent species that were not present during the season or in too few (observed ≤ 2 days) numbers to calculate weighted average arrival dates

[a] First day in field; species likely arrived before observer

from, and a substantial number of adult and juvenile dunlins had arrived in, the study area. Migration timing was similar between years, with the weighted average use dates of all species of 7 June 2008 and 8 June 2009 during spring migration, and 28 July 2008 and 29 July 2009 during fall migration; however, the chronology distributions differed between years (K–S stat = 0.368, $P = 0.012$). In 2008 and 2009, adult migration appears to have similar timing; however, the second peak in migration (i.e., juvenile) appears to have occurred slightly later and more defined in 2008 compared to 2009.

The average mass of juvenile Semipalmated Sandpipers in 2008 was 25.3 g ± 0.4 ($n = 63$) and in 2009 was 26.7 g ± 0.5 ($n = 54$). A significant positive relationship was found between juvenile Semipalmated Sandpiper mass at capture and date in the fall of 2009 ($R^2_{\mathrm{adj}} = 0.18$, $F_{1,53} = 12.69$, $P < 0.001$, Mass = 17.88 + 0.37*Date) (Fig. 4) but not in 2008. Also, in 2009 (1.96 ± 0.18, $n = 55$), individuals had significantly higher fat scores than birds in 2008 (1.13 ± 0.11, $n = 129$) (Mann–Whitney $U = 2{,}363.5$, $P < 0.001$).

Length of stay (color-banded birds)

In 2009, 44 Semipalmated Sandpipers were marked with unique color band combinations but not radio-marked (Table 3). Of these, only five individuals (11.4 %) were re-sighted, and their lengths of stay ranged from 3 to 13 days. In addition, 12 White-rumped Sandpipers and three Semipalmated Plovers were color-banded. Only one individual of each species was re-sighted. The single White-rumped Sandpiper (an adult) was observed over a 17-day period, while the single Semipalmated Plover was observed for 9 days.

Length of stay (radio-marked birds)

During fall migration in 2009, 11 out of 20 (55 %) radio-marked juvenile Semipalmated and Least Sandpipers were detected after initial capture. Both species had lengths of stay ranging from 1 to 26 days (Table 4), with averages of 6.5 ± 2.67 days ($n = 12$) and 7.25 ± 3.79 days ($n = 8$),

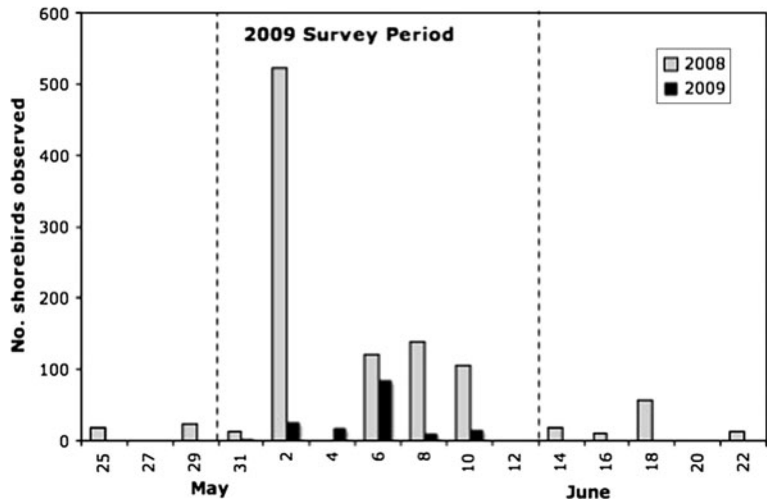

Fig. 2 Two-day shorebird counts in a fixed area study plot (Study Plot 1) on Akimiski Island, Nunavut, during spring migration from 25 May–22 June in 2008 (*gray bars*) and 31 May–14 June in 2009 [*black bars* between *dashed lines*)]. The maximum count within each 2-day period was used

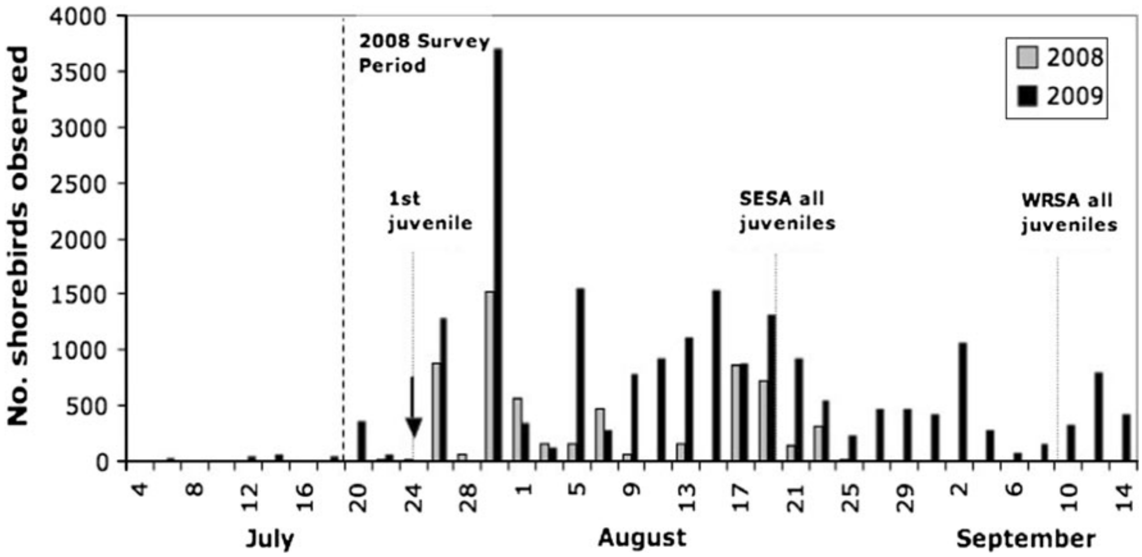

Fig. 3 Two-day shorebird counts in a fixed area study plot (Study Plot 1) on Akimiski Island, Nunavut, during fall migration from 19 July–25 August in 2008 (*gray bars* between *dashed lines*) and 5 July–15 September in 2009 (*black bars*). The maximum count within each 2-day period was used. *Gray lines* represent the dates when the first juvenile shorebird was observed as well as when all Semipalmated (SESA) and White-rumped Sandpipers (WRSA) were juveniles. The *arrow* represents the date of the aerial survey (23 July 2009)

respectively. One Semipalmated Sandpiper was still present in Study Plot 2 on the day that we left the island (15 September 2009) and, therefore, could have remained longer than the 26 days recorded. Radio-transmitters did not appear to affect individuals, as length of stay did not differ significantly between radio-marked and color-banded Semipalmated Sandpipers (*t* test unequal variance, $t = 0.03$, $P = 0.97$).

Estimated shorebirds study plot 2

Using the length of stay from radio-marked birds, the top models for estimating the residence probability for Semipalmated ($\phi_r(.)p(t)$ model weight $= 0.992$) and Least Sandpiper varied slightly, with those for Least Sandpipers containing a time effect ($\phi_r(t)p(t)$ model weight $= 0.983$). Residence probabilities averaged 0.905 ± 0.110 SE for Semipalmated Sandpipers and 0.908 ± 0.252 SE for Least Sandpipers, with an average for the two species of 0.906 ± 0.181. Because at least one species has a changing turnover rate over time, and, as we estimated abundance for multiple species, we incorporated time effects into the simulated N_{est} by using random ϕ_r values taken from the distribution of actual residence probabilities. These simulations resulted in an average seasonal shorebird abundance estimate (N_{est}) of 7,110 in the 1.35 km^2 study plot.

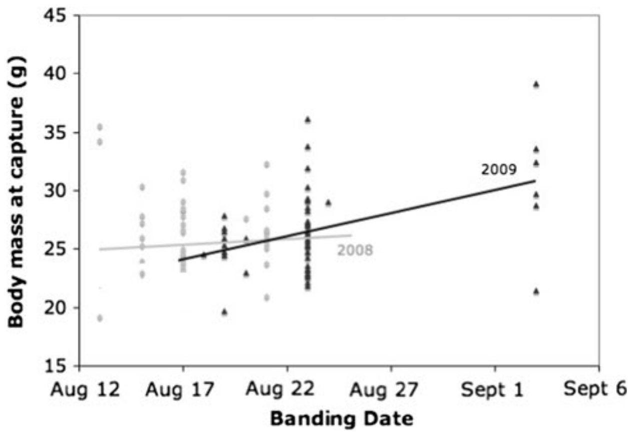

Fig. 4 Juvenile Semipalmated Sandpiper mass (grams) displaying a positive relationship between banding date (August–September) and weight at capture in 2009 but no relationship in 2008

Extrapolation to north shore of Akimiski Island

The seasonal shorebird density estimate for the 1.35 km^2 of Study Plot 2 was 5,267 (2,193–8,341) individuals/km^2. We calculated that Akimiski Island had 192 km^2 of mudflats along the northern shore at mid-to-low tide, and assuming shorebirds were equally distributed along the northern shoreline and homogeneous habitat composition, we extrapolated the study plot density and obtained an average estimate of 1,011,264 (421,098–1,601,429) shorebirds using the north shore mudflats of Akimiski Island during fall migration. Similarly, extrapolating Semipalmated and White-rumped Sandpiper seasonal densities from the focal plot to the entire northern shore gave estimates of 349,013 and 252,444, respectively.

Discussion

We estimate that Akimiski Island may support over 1 million shorebirds of 18 species during fall migration. For juvenile Semipalmated Sandpipers, the island appears to provide enough food resources to result in weight gain for staging in some years. Fall migrants from arctic areas would encounter the north shore of Akimiski Island while following the coastline of James Bay, presenting a broad contiguous extension of the coast to south or southeast bound migrants. Fall environmental conditions are favorable; warm temperatures and tidal action in July and August allow a consistent supply of invertebrates (Pollock 2011) for shorebirds to refuel and continue their fall flights south to their wintering grounds.

In contrast, 14 species of spring migrants used the island to a much lesser extent, a pattern that was consistent in both years of our study. Total spring seasonal estimates were not calculated because of the lack of length of stay information. Akimiski Island's lesser importance in spring is probably due to the interaction of average environmental conditions and the birds' migration and pre-breeding

Table 4 Age, date of capture, and minimum length of stay for radio-transmitter marked and color-banded shorebird species in 2009. The capture period occurred from Aug 14–Sept 4, 2009 and the radio-telemetry surveys were conducted from Aug 18–Sept 14, 2009

Species	Marking technique	Age	Date of capture	Date of Last detection	Length of stay (days)
Semipalmated Sandpiper	Radio-transmitter ($n = 12$)	All Juveniles	Aug 18	Aug 19	1
			Aug 19	Aug 24	5
			Aug 19	Aug 26	7
			Aug 19	Aug 27	8
			Aug 19	Sept 13	25
			Aug 19	Sept 14	26
	Color bands ($n = 44$)	All Juveniles	Aug 20	Sept 2	13
			Aug 23	Aug 26	3
			Aug 23	Aug 28	5
			Aug 23	Aug 28	5
			Aug 23	Aug 30	7
Least Sandpiper	Radio-transmitter ($n = 8$)	All Juveniles	Aug 19	Aug 19	1
			Aug 19	Aug 19	1
			Aug 19	Aug 23	4
			Aug 19	Set 14	26
			Aug 20	Sept 12	23
White-rumped Sandpiper	Color bands ($n = 12$)	Adult	Aug 23	Sept 9	17
Semipalmated Plover	Color bands ($n = 3$)	Juvenile	Sept 3	Sept 12	9

ecology (e.g., physiological demands and urge to reach breeding areas). The island experiences cold temperatures and slow melting ice on the shoreline during some springs, which may inhibit birds from accessing benthic invertebrates. James Bay ice melts sequentially from south to north, with the south becoming ice-free by the end of May while ice is present north of Akimiski Island until mid-to-late June (NOAA 2006). Additionally, many northern breeding shorebirds may bypass the northeastern shore of Akimiski Island where our study plots were located because of its geographic position in the bay. While we may have missed some of the spring passage because we only started surveying birds in late May, our data on benthic invertebrates (Pollock 2011) also suggests that there is low prey availability until early June.

Fall juvenile migrants spend a significant amount of time on Akimiski Island, with some juvenile Semipalmated and Least Sandpipers staying 26 days. The average length of stay on Akimiski Island was approximately 7 days, which is similar to lengths found at other sites. At another northern site in Alaska, Semipalmated Sandpipers remained on average only 4.3 days (Taylor et al. 2011). In Maine, juvenile Semipalmated Sandpipers captured late in the fall remained 8–13 days, with mean length of stays of 11.6 and 9.1 days in two consecutive years (Dunn et al. 1988). Semipalmated Sandpipers remained at the Bay of Fundy staging areas for an average 15 days (Hicklin 1987), with a maximum length of stay of 31 days; however, these calculations are not based on individually marked birds, but rather 5-day cohorts. Length of stay may vary depending on factors such as species, age, sex, body condition, resource availability, arrival times, and wind direction (Holmgren et al. 1993; Skagen and Knopf 1994; Lyons and Haig 1995; Farmer and Wiens 1999; Lehnen and Krementz 2005). Length of stay may also be biased high due to handling, as Warnock and Bishop (1998) found birds remained longer at banding sites. Longer lengths of stay for banded birds could then lead to conservative estimates of shorebird abundance. Restrictions of our surveys due to polar bear activity could potentially have biased our length of stay estimates low, resulting in inflated shorebird population estimates. Inexperienced individuals are thought to remain longer at a site than adults (e.g., Lehnen and Krementz 2005); however, one adult color-banded White-rumped Sandpiper remained in our study area for a minimum of 17 days, so long stays are not limited to juveniles. Given that residence probabilities between 25.7 and 100 % were used to estimate shorebird abundance, much of the individual variation due to shorebird age, species, and time of arrival was incorporated in our models to provide a realistic estimate of total seasonal density.

For Semipalmated Sandpipers, a significant positive relationship was found between capture date and weight, with heavier individuals caught later in the 2009 season. This weight increase suggests this species is likely refueling while on Akimiski Island, assuming that birds caught were representative of birds present on those capture dates. The period when many of the heavier birds were captured occurred when Semipalmated Sandpiper numbers were declining. This suggests that individuals were leaving rather than arriving, providing additional evidence that birds are potentially gaining weight on the island. Combined with length of stay, the weight gain suggests that this island has high value in the fall migration ecology of Semipalmated Sandpipers. We may have left too early to detect a significant weight gain in 2008. More intensive banding of this species and others will strengthen the conclusion that migrants are using Akimiski Island as a staging area.

Our modeled estimate of shorebird numbers that incorporated turnover rates was almost double that of our peak visual count. Peak counts frequently used in abundance surveys at staging areas underestimate the true number of shorebirds using a site because they do not account for immigration and emigration (Cohen et al. 2009). The initial peak in the presence of birds on Akimiski Island in the fall is short lived, and adult/juvenile ratios decrease after the peak, suggesting high turnover rates of these mostly adult birds during this period.

Our extrapolation of shorebird densities from Study Plot 2 to an estimate for the northern shore of Akimiski was based on similar mudflat composition and equal shorebird density across the northern shore of Akimiski. However, significant heterogeneity in shorebird distribution was revealed by the aerial survey, and during the aerial survey, the lowest counts of shorebirds were obtained from sector 4, which contained our two intensively studied focal plots. Thus, our seasonal estimate for the northern shore may be a conservative one. Uncertainty in these extrapolated estimates could be reduced by performing ground surveys at several sites throughout the season along the northern coast of Akimiski Island to measure the variation in use of mudflats by shorebirds, though, survey coverage was limited as an extremely high polar bear density in the late summer created a danger to researchers. Approximately, 60 % of shorebirds observed during the aerial survey used the western portion of the northern coast of the island. Thus, future work should include performing ground surveys of shorebird abundance in this location, as it would further refine abundance estimates. Blood sampling would also be beneficial in determining whether individuals are gaining weight while on the island or arriving with body stores already intact (Williams et al. 2007). Monitoring population abundance of shorebirds on Akimiski Island over time will be an important contribution to range-wide shorebird population conservation.

On aerial surveys completed by Environment Canada scientists in 1997 and 2009, approximately 100,000 and 73,300 (R. K. Ross and R. I. G. Morrison, unpublished data) shorebirds were counted, respectively, along the northern shoreline of the island. With one-day counts such as these, Akimiski Island is at least of international importance according to the WHSRN classification. As the aerial survey occurred at the beginning of fall migration in 2009, these are likely low relative to the peak of the season. Our model suggesting that Akimiski Island potentially hosts over 1,000,000 shorebirds annually during fall migration makes it of Hemispheric importance. Additionally, it is part of a complex of western James Bay coastal sites that provide important resources for migrant arctic-breeding shorebirds (Morrison and Harrington 1979; Pollock 2011).

The island's migrant shorebirds were numerically dominated by two species, Semipalmated and White-rumped Sandpiper. The North American breeding population of Semipalmated Sandpipers is currently estimated to be 2,000,000 birds (Morrison et al. 2006), down from a previous estimate of 3,500,000 (Morrison et al. 2001b). Given the recent population decline, protecting primary sites used by this species is critical to their conservation. Extrapolating densities estimated for Semipalmated Sandpipers in our study plot to that of the northern shore produced a minimum estimate of 349,013 individuals (or 17 % of the population) potentially using the extensive mudflat system of Akimiski Island. During fall migration, approximately 1,000,000 Semipalmated Sandpipers use the Bay of Fundy, Nova Scotia (Hicklin 1987; Manomet Center for Conservation Sciences 2005) and some of these may be staging at Akimiski Island before departing to the east coast (Morrison 1984). Similarly, White-rumped Sandpiper population estimates by Morrison et al. (2006) suggest a total population of 1,120,000 individuals breeding in North America. The modeled estimate indicates a minimum of 252,444 individuals use Akimiski Island. These values suggest that up to 22.5 % of the North American breeding population of this species may use Akimiski Island as a staging site during fall migration, making it extremely important to that species. For both species, the proportions may be slight overestimates as they include both adult and juvenile shorebirds, while Morrison's population estimates are likely based on adult numbers only. Northern sites such as Akimiski Island located between the breeding grounds and known major sites (i.e. Bay of Fundy, Delaware Bay) allow individuals to refuel more frequently (Skagen and Knopf 1994) and may be especially important to juveniles.

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