# FEDERAL AID
# FINAL PERFORMANCE REPORT

**ALASKA DEPARTMENT OF FISH AND GAME**
**DIVISION OF WILDLIFE CONSERVATION**
**PO Box 115526**
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## Alaska Department of Fish and Game
## State Wildlife Grant

**a) Grant Number: T-16** **Segment Number: 1**

**Project Number:** 2.0

**Project Title:** Decadal changes in the demography of sandpipers near Nome, Alaska

**Project Duration**: May 1, 2010 to June 30, 2013

**Report Duration**: May 1, 2010 to September 1, 2013

**Report Due Date:** September 1, 2013

**Principal Investigator:** Brett K. Sandercock, Kansas State University (*bsanderc@ksu.edu*)

**Project Location:** A 4 km$^2$ study plot on coastal tundra located between Cape Nome and Safety Sound, and 21 km east of Nome, Alaska (64°21'N, 164°56'W).

### b) The problem or need that prompted this research

The goal of this project was to examine the effects of environmental change on the breeding ecology and demographic performance of two migratory shorebirds, Western Sandpipers (*Calidris mauri*) and Semipalmated Sandpipers (*C. pusilla*). Concerns about ongoing population declines and the potential impacts of climate change on migratory shorebirds have prompted field observations on the timing of breeding in birds in relation to their main food supply. However, we still lack empirical studies on community interactions under climate change. Despite ongoing population declines in long-distance migratory birds and potential impacts of climate change on Arctic ecosystems, the effects of phenological mismatch on shorebird population dynamics are poorly understood. We tested for long-term changes in the timing of life-history events and demographic performance, for phenological mismatches between shorebird breeding and prey availability, and investigated the migratory movements and nonbreeding distributions for two species o arctic-breeding shorebirds.

### c) Evidence of a review of prior research and studies in progress

Our project was based on an intensive population study of the breeding biology of sandpipers at field sites near Cape Nome, 13 miles east of Nome on the Seward Peninsula of Alaska. Intensive demographic data were collected during two 4-year periods: 1993-1996 and 2010-2013. Funding from this ADFG State Wildlife Grant provided partial funding for field work during the second period for our field study. Use of standardized research protocols by the same team of investigators working at the same field site have facilitated direct comparisons after 14 years of environmental change. Studies of the reproductive ecology of these birds included nest monitoring for timing of clutch initiation, reproductive investment in clutch size and egg size, and nest survival rates. Bird attending nests were captured and uniquely marked to determine migratory movements, annual survival, and site fidelity rates. In 2010-2013, we also collected detailed information on environmental conditions including daily climatic conditions, surveys of seasonal snowmelt, measurement of water levels in tundra ponds, sampling of invertebrates in terrestrial and aquatic habitats, live trapping of lemmings and other small mammals, and daily counts of predators encountered during field activities (primarily jaegers, falcons, arctic and red fox).

Our Nome field site is one of 11 sites participating in the Arctic Shorebird Demographic Network that includes sites in Russia, Alaska and northern Canada. From west to east, sites in the Arctic Shorebird Demographic Network include our study site at Nome, Cape Krusenstern, Barrow, Ikpikpuk, Colville River, Canning River and Prudhoe Bay in Alaska, the MacKenzie Delta in the Northwest Territories, Churchill in Manitoba, and East Bay on Southhampton Island and Bylot Island in Nunavut. To test our second objective in this project, we have included data for additional species and sites from collaborating participants in the ASDN network. In addition to the data collected for the objectives of this State Wildlife Grant, we have collected a large set of biological samples for participant projects in the ASDN network, including blood samples for population genetics, prevalence of avian malaria, and mercury exposure, feather samples for stable isotopes, and fecal samples for a molecular study of the gut microbial fauna of migratory shorebirds.

## d) The objectives addressed

The goal of this project was to conduct a three year population study of Western and Semipalmated Sandpipers at an established field site near Nome, Alaska. We set out to determine three major objectives:

*i*) the extent to which **demographic parameters** of Western and Semipalmated Sandpipers have changed in a population near Nome, Alaska studied 15-20 years ago,

*ii*) whether or not **breeding ground conditions** are responsible for any changes in demographic performance, as opposed to ecological conditions elsewhere in the migratory or nonbreeding range,

*iii*) and to obtain **direct evidence of migration movements** and non-breeding locations for these birds, in aid of demographic and population ecology analyses.

## e) Procedures used and findings related to the project objectives

### *Objective 1: Demographic Parameters*

In the 4-year period from 1993-1996, we located 238 nests of Western Sandpipers and 208 nests of Semipalmated Sandpipers. In the 4-year period from 2010-2013, we located 259 nests of Western Sandpipers and 229 nests of Semipalmated Sandpipers. Renests after loss of a first clutch were rare: only 8 of 497 (1.6%) nests of Western Sandpipers and 10 of 437 (2.3%) nests of Semipalmated Sandpipers were known renesting attempts. We pooled first nests and renests for all analyses of fecundity. Sample sizes vary among analyses because a subset of nests were manipulated as part of other experiments, and complete data were not available for all nesting attempts.

*Timing of clutch initiation*.-Changes in the timing of reproductive events are one of the main responses of arctic organisms to changing environmental conditions. We estimated date of clutch initiation for all nests by backdating from the start of incubation for nests found during laying, from the estimated stage of incubation for nests that failed or from the date of hatching successful nests. We calculated the duration of egg-laying as 5 days for a 4-egg clutch and the duration of incubation as 20 days for Semipalmated Sandpipers and 21 days for Western Sandpipers. We analyzed variation in the timing of clutch initiation with linear mixed effects models using the `lme()` and `lmer()` functions of packages `nlme` and `lme4` in Program R. We examined timing of clutch initiation as the response variable, and explored the fixed effects of species and period, and a random effect of year. Variance components showed that year accounted for 12% of the variance among the random effects, but we retained year as a random effect to control for the potential lack of independence among years within the two study periods.

Western Sandpipers nested earlier in the season than Semipalmated Sandpipers in both periods of our field study, and timing of clutch initiation varied among years (Fig. 1). In 1993 to 1996, the median date of clutch initiation ranged from 20-24 May (julian dates 140-144) for Western Sandpipers, and from 24-30 May (144-150) for Semipalmated Sandpipers. In 2010 to 2013, median date of clutch initiation was later and ranged from 25-31 May (julian dates 145-151) for Western Sandpipers, and from 27 May-2 Jun (147-153) for Semipalmated Sandpipers.

Contrary to the predicted effects of climatic warming in the arctic, we found that **both species of arctic-breeding sandpipers showed delays in the timing of clutch initiation**. There was a significant interaction between species and period because long-term changes in timing of clutch initiation were greater in Western than Semipalmated Sandpipers (spec×period: $\beta = 2.64$, $SE(\beta) = 0.75$, df = 862, $t = 3.5$, $P < 0.001$). The main effects of the fixed factors indicated there was a ~5-day difference in timing of clutch initiation between the two species (spec: $\beta = -4.65$, $SE(\beta) = 0.55$, df = 862, t = -8.4, $P < 0.001$), and sandpipers nested about four days later in 2010-2013 (period: $\beta = 4.02$, $SE(\beta) = 1.53$, df = 6, $t = 2.6$, $P = 0.039$). Pooling years, the median date of clutch initiation was delayed by 7 days for Western Sandpipers from 22 May in 1993-1996 to 29 May in 2010-2013. Similarly, the median date of clutch initiation was delayed by 5 days for Semipalmated Sandpipers from 27 May in 1993-1996 to 1 Jun in 2010-2013.

*Clutch size*.-Western and Semipalmated Sandpipers are determinate egg-layers and both species had a modal clutch size of four eggs in all years of the project (Table 1). Overall, 80-90% of all clutches contained four eggs in 1993-1996 and 2010-2013. Clutches of 1-2 eggs included abandoned nests and nests destroyed by predators during egg-laying. Clutches of 3 eggs were more prevalent later in the breeding season and in some years, including Western Sandpipers in 2012 (28.0%, $n = 60$) and Semipalmated Sandpipers in 1994 (32.2%, $n = 59$). We analyzed variation in clutch size with generalized linear mixed effects models (GLMM) using the `glmmPQL()` function of package `MASS` in Program R. We fit a model with clutch size as the response variable, fixed effects of species and period, and a random effect of year. The random effect of year had a relatively low variance (SE(int) = 0.009). **Our analyses of clutch size revealed a significant interaction between species and study period** (spec×period: $\beta = -0.045$, $SE(\beta) = 0.017$, df = 912, $t = -2.64$, $P = 0.008$). Mean clutch size of Western Sandpipers was 4% larger in 1993-1996 (3.87 vs. 3.73), but clutch size of Semipalmated Sandpipers was 1.1% larger in 2010-2013 (3.77 vs. 3.81, Table 1). Overall, clutch sizes of

Western ($\bar{x}$ = 3.80, SD= 0.51, $n$ = 488) and Semipalmated Sandpipers ($\bar{x}$ = 3.79, SD= 0.47, $n$ = 434) were not significantly different (β = -0.024, SE(β) = 0.012, df = 912, $t$ = 1.92, $P$ = 0.055). The fixed effect of study period was nonsignificant (β = 0.009, SE(β) = 0.014, df = 6, $t$ = 0.63, $P$ = 0.55).

*Nest survival*.-We monitored sandpiper nests on a 2-4 day check interval and considered nests successful if one or more eggs produced chicks that departed the nest, and failed if nest contents were destroyed by predators. We did not include nests in the nest survival analysis if they were manipulated as part of incubation experiments, abandoned due to observer disturbance, or if we were missing information on dates of failure or nest fate. Our sample size for nest survival analyses was 348 nests of Western Sandpipers and 339 nests of Semipalmated Sandpipers. We analyzed daily survival rates of sandpiper nests with the nest survival model of Program Mark by using functions in package `RMark` of Program R. We fit eight candidate models that included the main effects of species (Western vs. Semipalmated), study period (1993-1996 vs. 2010-2013), year (8 years), and also a constant model (i.e., ~1). Models that separated daily survival rates by study period received essentially no support among the candidate models ($w_i$ < 0.0001, Table 2). **We found no evidence for long-term changes in the nest survival of arctic-breeding sandpipers.** The minimum-AICc models included year and species in main effects or factorial models (i.e., ~Yr+Spec and ~Yr*Spec, Table 2). Nest survival rates were calculated for 25 or 26-day exposure periods that included the duration of egg-laying and incubation. Nest survival varied among years from 30.0 to 72.4% in Western Sandpipers and from 16.2 to 79.0% in Semipalmated Sandpipers (Table 3). Overall, Western Sandpipers had higher nest survival (pooled estimates: 48.5 to 51.0%) than Semipalmated Sandpipers (32.5 to 40.3%).

### *Objective 2: Breeding Ground Conditions*

Responses to climate change have been shown to vary across functional groups and trophic levels, which can cause decoupling of biological interactions or a ‘phenological mismatch’. Recent studies testing the phenological mismatch hypothesis have been limited to model systems, small spatial scales with a single breeding population, and simple comparative analyses. We quantified the occurrence and geographic extent of phenological mismatches between breeding shorebirds and their invertebrate prey, and evaluated geographic variation in the frequency and extent of phenological mismatches among six shorebird species. For this project objective, we expanded our study project to include data from five arctic sites participating in the Arctic Shorebird Demographics Network.

Six species of shorebirds were selected based on wide breeding distributions (found at > 5 ASDN sites) and relative abundance (> 20 nesting pairs at each site), including Semipalmated Sandpiper (*Calidris pusilla*), Western Sandpiper (*C. mauri*), Dunlin (*C. alpina*), Pectoral Sandpiper (*C. melanotos*), Red Phalarope (*Phalaropus fulicarius*), and Red-necked Phalarope (*P. lobatus*). Timing of breeding and seasonal changes in invertebrate abundance were monitored at ten sites during 2010-2012: Nome, Cape Krusenstern, Barrow, Ikpikpuk, Colville Delta, Canning River, Prudhoe Bay, Mackenzie Delta, East Bay and Churchill (Fig. 2). A total of 1,928 nests were monitored over three years at six sites (data collection is on process for the remaining four sites) for our six study species; Nome, $n$ = 544 nests, Cape Krusenstern, $n$ = 257, Barrow, $n$ = 916, Mackenzie Delta, $n$ = 68, Churchill, $n$ = 107, East Bay, $n$ = 36. Semipalmated

Sandpipers had the highest number of nests monitored across sites (*n* = 426 for 2010-2012) and Pectoral Sandpipers had the least number monitored (*n* = 245, Fig. 2).

Here, we present our initial results from five of ten sites for comparison of the phenology of shorebird nesting and invertebrate abundance in 2010. Processing of invertebrate samples is continuing slowly, but we anticipate adding additional years and sites to examine annual and geographic variation in invertebrate food resources. We selected 11 invertebrate taxa to be our focal groups based on their absolute abundance at the five five sites. The 11 taxa included Araneae, Brachycera, Carabidae, Chironomidae, Hymenoptera, Collembola, Staphylinidae, Sciaridae, Mycetophilidae, Tipulidae, and Ceratopogonidae. Eight of these taxa have been previously identified in the gut contents of six shorebird species. Ordination analysis showed that the invertebrate community compositions were similar among the five sites, but that the timing of emergence differed. The timing of peak invertebrate biomass differed by 33 days among sites ranging from Jun 21 in Nome in the subarctic to Jul 24 at Barrow on the North Slope of Alaska.

Onset of shorebird hatching coincided with initial increases in the abundance of Chironomidae (midges) which was the most abundant prey source in all sites (Fig. 3). Mean hatch dates of each shorebird species preceded the peak prey biomass by up to 15 days at most sites. **We found evidence of phenological mismatches between shorebird hatching and availability of food resources in 2010.** We defined the ‘degree of mismatch’ as the temporal difference between the date of food peak and five days after the estimated hatch date. We used five days as the period when food requirements of the shorebird chicks should be at a maximum. We then estimated the degree of phenological mismatch for each nest. The degree of mismatch varied significantly among sites, with the greatest potential mismatch at Churchill where nests hatched >15 days earlier than peak invertebrate availability. The degree of mismatch was also significantly variable among species. Western Sandpipers matched their timing of hatching to local food peaks better than Dunlin (Fig. 4). Juvenile survival is a difficult demographic variable to measure for all wildlife species, and it remains unclear if phenological mismatches have a negative impact on survival of young chicks after they depart the nest but before they reach independence at ~14-21 days of age.

### *Objective 3: Migratory Movements and Nonbreeding Grounds*

Migratory movements and nonbreeding grounds for Western and Semipalmated Sandpipers were investigated through observer reports of resightings of birds with alphanumeric flags, and from applications of new geolocator technology. We summarize our data on sandpiper movements from both sources of information.

*Resightings*.-During 2010-2013, we recaptured one foreign-marked sandpiper and a total of 7 Western Sandpipers banded at Nome were either resighted or recaptured elsewhere in the migratory range. On 27 May 2012, we recaptured a Western Sandpiper on a nest which had been previously banded on 20 March 2011 as a nonbreeding bird at a coastal site in Bahia Santa Maria, Mexico (band# 140166492). Two Western Sandpipers banded in 2009 were resighted during spring migration in Rink Creek, Gustavus and Odiak Slough in Alaska on April 28 and May 14, 2012. A Western Sandpiper banded in 2010 was resighted during fall migration the same year in South San Diego National Wildlife Refuge on July 25 (band# 140165991). Another Western Sandpiper banded in 2010 was resighted during spring migration of 2013 in California, Alameda, 1.9 miles NW of Russell City on April 21 (band# 140165997). A Western Sandpiper banded in 2011 was resighted the following spring at a nonbreeding site in West Raccoon Island, Terrebonne Parish, Louisiana on March 18 (band# 140465833). In 2013, a Western Sandpiper banded as a chick on a nest was resighted on its fall migration in Sidney Island, British Columbia on August 17 (band# 193102608). In addition, one Western Sandpiper from Nome was resighted in Tramway Wetlands near Albuquerque, New Mexico on April 17, 2013 without complete identification. There were also local resighting reports taken near our study plot by local birders of one Red-necked Phalarope in 2013 (band# 140165790), and one Semipalmated Sandpiper in 2012 (band# 257152431). Given the long-term effort of banding both adult and juvenile shorebirds on our study plot, we will continue to receive reports of resightings and recaptures during migratory periods. The accumulated location data collected through bird watchers and local biologists will contribute to ground-truthing of our migration tracks reconstructed from light-loggers. Resightings may also be used to identify staging areas and nonbreeding sites of juvenile shorebirds where we have not yet used geolocators.

*Geolocators and Light Data Processing*.-We used Mk20A geolocators provided by the British Antarctic Survey and Intigeo-W65 geolocators provided by the Migrate Technology for deployment in 2011 and 2012 respectively. Western Sandpipers and Semipalmated Sandpipers are small-bodied shorebirds commonly found on the Western Hemisphere. During breeding period, both sexes share incubation duties and some of the pairs change shift every 7-8 hours. We placed geolocators on the tibia by using leg bands shaped from heat-shrinking PVC tubes (Fig. 5). This attachment technique was previously developed for RFID tags but we are the first to have used it to attach geolocators to small-bodied shorebirds. Breeders sit tightly on the clutch and rarely leave the nest during incubation. Therefore, exposure to sunlight can be dependent on the incubation activity during breeding period. However, during non-breeding period including both spring/fall migration and wintering period, both sandpiper species inhabit open habitat and mainly feed on mudflats.

A total of 14 and 39 birds were tagged with loggers in 2011 and 2012 (total 21 Western Sandpipers and 32 Semipalmated Sandpipers). Mean body mass of Western and Semipalmated Sandpipers at capture was 27.8 ± 0.4 g ($n$ =21) and 26.3 ± 0.3 g ($n$ = 32). The Mk20A and Intigeo-W65 models weigh 0.8 g and 0.65 g (~1.03 g and 0.85 g with harness) corresponding to an average of 3.1-3.8% of the mean body mass of a sandpiper. In 2012 and 2013, we recaptured 12 out of 53 birds with loggers. Recapture rates were 29% in 2012 and 21% in 2013. Apparent survival rates of both sandpiper species on our breeding population have been previously estimated as 0.57 ± 0.05 for Western Sandpipers and 0.66 ± 0.06 for Semipalmated Sandpipers (1993-1996, Sandercock et al. 2000). During the same survey period, encounter rates ranged between 0.658-0.819 for both species. Return rates for 2010-2011 were not different from the historic records and estimated as 0.69 and 0.66 for Western and Semipalmated Sandpipers (Kwon and Sandercock, unpublished data). Comparing to the high recapture rates of our breeding population, return rates of birds equipped with geolocators were lower than birds that only received leg bands. Nevertheless, we did not find negative impacts of geolocators on the breeding performance of sandpipers. A total of 294 nests were monitored during 2011-2012. A subset of 38 nests had one of the breeders banded with geolocator, and 7 nests both male and female parents marked with geolocators. The probability of hatching at least one chick did not significantly differ among nests with parents with 0, 1 or 2 geolocators deployed (Pearson Chi-Square = 5.37, *P* = 0.72, Fig. 6).

Geolocators were retrieved from sandpipers by capturing birds one year later and after they returned to our field site at Nome. All recovered geolocators contained a complete set of movement data. Two geolocators were damaged but we successfully extracted the data with the help from the manufacturer. Light resolution was 5 minute and 1 minute for Mk20A and Intigeo-W65 model respectively. In-habitat calibrations for sun angle and light sensitivity were conducted using the data logged during the period either before initiation of clutch or after the nest fate was determined but while the bird was still on the arctic study plot. At total of 12 migration tracks were recovered, and nine tracks are presented in Figs. 7-8. Variation in light levels leads to greater uncertainty in latitude than longitude. Nonbreeding sites for wintering sandpipers are unlikely to be in pelagic waters or terrestrial habitats, but would most likely be at continental margins where the distribution of locations intersects coastal estuaries.

From the Mk20A geolocators deployed in 2011, the recovered tracks indicated that one Western Sandpiper departed Seward Peninsula on 29 June, and 13 days after it successfully hatched three chicks. This Western Sandpiper staged in sw Alaska during 1-14 July and then took non-stop flight from Alaska to the Fraser River Delta where it spent the nonbreeding season. In the following spring, the bird made three coastal stops during northward migration and reunited with its mate to lay its first egg on 22 May 2012 (Fig. 7a). All three Semipalmated Sandpipers used mid-continental flyway and stopped at several locations during the southward migration. Stop-over sites were located in Alaska, Alberta, Saskatchewan, North Dakota, Oklahoma, and Texas. Two Semipalmated Sandpipers spent the nonbreeding season in Panama, while a third individual wintered in Colombia. Northward migration in spring 2012 involved similar migration routes from the previous southward migration in autumn (Fig. 7b-c).

From the Intigeo-W65 geolocators deployed in 2012, similar migration routes have been constructed for Western and Semipalmated Sandpipers. Two Semipalmated Sandpipers used the Central flyway through mid-Continent and wintered along the coasts of Colombia (Fig. 7a-b). Three of four Western Sandpipers followed the Pacific coast, staged near northern Pacific coast around Vancouver, and wintered in southern California or western Mexico (Fig. 8c,e-f). One Western Sandpiper showed evidence of a potential elliptic migration flying out over the Pacific Ocean and then moving east to spend the nonbreeding season on the Gulf Coast in the southeast. The latter migration route and wintering location for Western Sandpipers has not been previously documented.

Our sample size of migratory tracks from geolocators is relatively small but provides more detailed information on migratory movements and nonbreeding range than resightings or recaptures of color-marked birds. **Our movement data provide evidence of weak migratory connectivity for the two species of arctic-breeding sandpipers**. All birds were captured and marked within a 2 $km^2$ breeding site near Nome, Alaska. Nevertheless, migratory routes and nonbreeding sites of a small set of birds spanned the nonbreeding distribution for both sandpiper species. Nonbreeding sites for Western Sandpipers included the Fraser River Delta in southern British Columbia, the Pacific Coast of Mexico, and one bird on the Gulf Coast of the southeast

US. Semipalmated Sandpipers travelled farther south than Western Sandpipers to nonbreeding sites in Central and South America but may have had a more restricted nonbreeding distribution.

## f) Management implications

We compared the demographic performance of Western and Semipalmated Sandpipers breeding at Nome, Alaska between 1993-1996 and 2010-2013. We found evidence of long-term changes in the timing of clutch initiation with changes in timing of nesting from 5 to 7 days after a 14-year period. Unexpectedly, and contrary to the predictions of global warming, the timing of clutch initiation has not advanced and instead sandpipers are nesting an average of 5 to 7 days later in the springs of 2010-2013 than in 1993-1996. Changes in the timing of breeding do not appear to have a negative impact on reproductive investment or reproductive success because we found no evidence of changes in clutch size or nest survival between the two study periods. We investigated the ecological mechanisms underlying the change in reproductive timing. For this objective, we expanded our analysis to include six shorebird species breeding at five arctic sites. We found some evidence of phenological mismatches between the timing of hatching of shorebird nests and the timing of emergence among major taxa of invertebrate prey in terrestrial environments. We have pioneered the use of new geolocator technologies and have obtained the first detailed movement data on the migratory movements of small-bodied arctic-breeding shorebirds. Migratory tracks have revealed that Western Sandpipers primarily use Pacific flyways whereas Semipalmated Sandpipers use continental flyways in the midwest. Western Sandpipers overwinter at a wide range of coastal sites in the U.S. and Mexico, whereas Semipalmated Sandpipers are travelling farther to northern South America. Despite capture and marking of birds at a single site in western Alaska, our study population showed weak migratory connectivity to nonbreeding sites with individual birds showing great variation in migratory distance and timing of spring and autumn migratory movements.

## g) Future goals

Data collection and analyses for this field project have not been completed and will be continuing for another field season in 2014. The demographic analyses in this report address nest survival as the main demographic variable that drives population dynamics of shorebirds. However, we will explore additional demographic factors including long-term changes in body size, egg mass, and adult survival. Our test of seasonal phenology was based on a complete set of invertebrate samples from 2010. We are continuing to process invertebrate samples collected in 2011-2013 and will be expanding our comparisons to include additional years of information for a stronger test of the phenological mismatch hypothesis. We have detailed daily climatic data and will also compare timing of shorebird breeding and invertebrate availability in relation to annual variation in seasonal climatic conditions. Our movement data is based on a good sample size of recovered geolocators. However, we will have a final field season of data collection at Nome, Alaska in Summer 2014. We deployed a third set of geolocators on sandpipers in Summer 2013 and will be returning to Nome to recapture birds and recover tags to increase our sample size for analyses of migratory movements. Our field efforts in Summer 2014 will be focused on nest monitoring and resighting of returning color-marked birds which will provide an additional year of data on reproductive timing, nest survival, and adult survival. Final products for this project will include the PhD dissertation of Ms. Eunbi Kwon which will be completed in Spring 2015, and manuscripts based on this project report.

### h) Conference Presentations

Our research output from this project has included a series of presentations at national and international conferences on the ecology of migratory birds.

Perkins, M., L. Ferguson, R.B. Lanctot, I.J. Stenhouse, D.C. Evers, N. Basu, J. Bety, S. Brown, R. Gates, S. Kendall, J.-F. Lamarre, J. Liebezeit, and **B.K. Sandercock**. Quantifying mercury exposure for multiple shorebird species across the North American Arctic using blood and feather samples. *Society for Environmental Toxicology and Chemistry (34th),* Nashville, Tennessee. November 2013.

**Kwon, E.,** and **Sandercock, B.K.** Tracking annual movement of long-distance migratory sandpipers using light logging geolocator. *International PhD course in Ecology of Animal Migration*, Lund, Sweden. October 2013.

Brown, S.C., R.B. Lanctot, and **B.K. Sandercock**. The Arctic Shorebird Demographics Network: understanding causes of shorebird declines. *Western Hemisphere Shorebird Group (5th),* Santa Marta, Colombia. September 2013.

**English, W.B., B.K. Sandercock**, and **D.B. Lank**. Weather and the consequences of extended incubation in a uniparental arctic-breeding shorebird, the Red-necked Phalarope (*Phalaropus lobatus*). *Western Hemisphere Shorebird Group (5th),* Santa Marta, Colombia. September 2013.

**English, W.B.**, D. Tracey, D. Westneat, and **D.B. Lank**. Unexpected sex-biased egg size allocation in the Red-necked Phalarope (*Phalaropus lobatus*). *Western Hemisphere Shorebird Group (5th),* Santa Marta, Colombia. September 2013.

**Kwon, E., D.B. Lank**, R.B. Lanctot, and **B.K. Sandercock**. Temporal gradient of prey availability and shorebird breeding phenology in the Arctic. *Western Hemisphere Shorebird Group (5th),* Santa Marta, Colombia. September 2013.

**Kwon, E., D.B. Lank**, and **B.K. Sandercock**. Changes in breeding phenology and reproductive success of long-distance migratory shorebirds. *Division of Biology BioForum, Kansas State University,* Manhattan, Kansas. March 2013.

**English, W.B., B.K. Sandercock**, and **D.B. Lank**. Incubate or eat: patterns in differential nest attentiveness by Red-necked Phalaropes. *Pacific Seabird Group Meeting (40th),* Portland Oregon. February 2013.

**Kwon, E.**, and **B.K. Sandercock**. Age-specific demography and population dynamics of the Western Sandpiper (*Calidris mauri*). *Kansas Ornithological Society Fall Meeting*, Winfield, Kansas. September 2012.

**Kwon, E., Lank, D.B.,** and **B.K. Sandercock**. Changes in breeding phenology and reproductive success of long-distance migratory shorebirds: comparative study over two decades. *North American Ornithological Conference (5th).* Vancouver, British Columbia. August 2012.

Gates, R., Stephen, B., Lanctot, R., and **B.K. Sandercock**. The arctic shorebird demographics network: understanding causes of shorebird declines. *North American Ornithological Conference (5th).* Vancouver, British Columbia. August 2012.

**Kwon, E.**, and **B.K. Sandercock**. Changes in breeding phenology of arctic-breeding shorebirds: comparative study over two decades. Kansas Natural Resources Conference. Wichita, Kansas. January 2012.

**Kwon, E.**, and **B.K. Sandercock**. Population dynamics of arctic-breeding shorebirds under environmental change. Invited talk at Ewha Women's University, Seoul, Korea. December 2011.

**Kwon, E.**, and **B.K. Sandercock**. Changes in breeding phenology of arctic-breeding shorebirds: comparative study over two decades. KOS 2011 Fall Meeting. Great Bend, Kansas. September 2011.

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**Table 1.** Clutch size of Western and Semipalmated Sandpipers at Nome, Alaska, 1993-1996 and 2010-2013.

| | Clutch size (no. eggs) | | | | | Clutch size (no. eggs) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | 1-2 | 3 | 4 | *n* | Year | 1-2 | 3 | 4 | *n* |
| **Western Sandpipers** | | | | | | | | | |
| 1993 | 2.1% | 6.3% | 91.7% | 48 | 2010 | 6.8% | 11.4% | 81.8% | 44 |
| 1994 | 3.3% | 15.0% | 81.7% | 60 | 2011 | 5.6% | 7.8% | 86.7% | 90 |
| 1995 | 0.0% | 9.8% | 90.2% | 51 | 2012 | 4.0% | 28.0% | 68.0% | 75 |
| 1996 | 0.0% | 10.0% | 90.0% | 70 | 2013 | 6.0% | 12.0% | 82.0% | 50 |
| Pooled | 1.3% | 10.5% | 88.2% | 229 | Pooled | 5.4% | 15.1% | 79.5% | 259 |
| | $\bar{x} = 3.87 \pm 0.38$ | | | 229 | | $\bar{x} = 3.73 \pm 0.59$ | | | 259 |
| **Semipalmated Sandpipers** | | | | | | | | | |
| 1993 | 1.5% | 15.2% | 83.3% | 66 | 2010 | 0.0% | 13.3% | 86.7% | 30 |
| 1994 | 1.7% | 32.2% | 64.4% | 59 | 2011 | 2.9% | 19.1% | 77.9% | 68 |
| 1995 | 1.8% | 12.3% | 86.0% | 57 | 2012 | 3.3% | 15.0% | 81.7% | 60 |
| 1996 | 8.0% | 0.0% | 92.0% | 25 | 2013 | 2.9% | 5.7% | 91.4% | 70 |
| Pooled | 2.4% | 17.4% | 79.7% | 206 | Pooled | 2.6% | 13.2% | 84.2% | 228 |
| | $\bar{x} = 3.77 \pm 0.47$ | | | 206 | | $\bar{x} = 3.81 \pm 0.47$ | | | 228 |

**Table 2.** Model selection for nest survival of Western and Semipalmated Sandpipers at Nome, Alaska, 1993-1996 and 2010-2013.

| Model | npar | AICc | DeltaAICc | weight | Deviance |
|---|---|---|---|---|---|
| S(~YR + SPEC) | 9 | 1982.7 | 0.0 | 0.6043 | 1964.6 |
| S(~YR * SPEC) | 16 | 1984.2 | 1.6 | 0.2742 | 1952.2 |
| S(~YR) | 8 | 1985.9 | 3.2 | 0.1215 | 1969.8 |
| S(~SPEC) | 2 | 2027.2 | 44.6 | 0.0000 | 2023.2 |
| S(~Per + SPEC) | 3 | 2028.7 | 46.1 | 0.0000 | 2022.7 |
| S(~Per * SPEC) | 4 | 2029.3 | 46.6 | 0.0000 | 2021.3 |
| S(~1) | 1 | 2036.9 | 54.2 | 0.0000 | 2034.9 |
| S(~Per) | 2 | 2038.1 | 55.5 | 0.0000 | 2034.1 |

*Notes*: Model factors included species (SPEC), period or year of study (PER, YR), and main effects (+) or factorial models (*).

**Table 3.** Estimates of daily nest survival (DSR) of Western and Semipalmated Sandpipers at Nome, Alaska, 1993-1996 and 2010-2013. Parameter estimates were taken from unconstrained models S(YR*SPEC) and S(PER*SPEC).

| Year | DSR | SE(DSR) | Exp | n | Year | DSR | SE(DSR) | Exp | n |
|---|---|---|---|---|---|---|---|---|---|
| **Western Sandpiper (26-d exposure)** | | | | | | | | | |
| 1993 | 0.9678 | 0.0106 | 42.7% | 23 | 2010 | 0.9800 | 0.0057 | 59.1% | 34 |
| 1994 | 0.9738 | 0.0072 | 50.1% | 33 | 2011 | 0.9766 | 0.0049 | 54.0% | 64 |
| 1995 | 0.9571 | 0.0092 | 32.0% | 39 | 2012 | 0.9741 | 0.0051 | 50.6% | 65 |
| 1996 | 0.9876 | 0.0039 | 72.4% | 46 | 2013 | 0.9547 | 0.0089 | 30.0% | 44 |
| Pooled | 0.9744 | 0.0035 | 51.0% | 141 | Pooled | 0.9725 | 0.0030 | 48.5% | 207 |
| **Semipalmated Sandpiper (25-d exposure)** | | | | | | | | | |
| 1993 | 0.9719 | 0.0074 | 49.0% | 40 | 2010 | 0.9906 | 0.0054 | 79.0% | 22 |
| 1994 | 0.9397 | 0.0099 | 21.1% | 45 | 2011 | 0.9621 | 0.0085 | 38.1% | 47 |
| 1995 | 0.9439 | 0.0105 | 23.6% | 45 | 2012 | 0.9823 | 0.0047 | 63.9% | 55 |
| 1996 | 0.9823 | 0.0079 | 63.9% | 23 | 2013 | 0.9299 | 0.0102 | 16.2% | 62 |
| Pooled | 0.9561 | 0.0048 | 32.5% | 153 | Pooled | 0.9643 | 0.0039 | 40.3% | 186 |

*Notes*: Annual nest survival for a 25 or 26-day exposure period was calculated as Exp = $DSR^{25}$ or $DSR^{26}$.

**Fig. 1.** Long-term changes in the timing of clutch initiation of Western and Semipalmated Sandpipers at Nome, Alaska, 1993-1996 and 2010-2013. Box plots indicate medians and interquartile ranges, and whiskers indicate 95%CI.

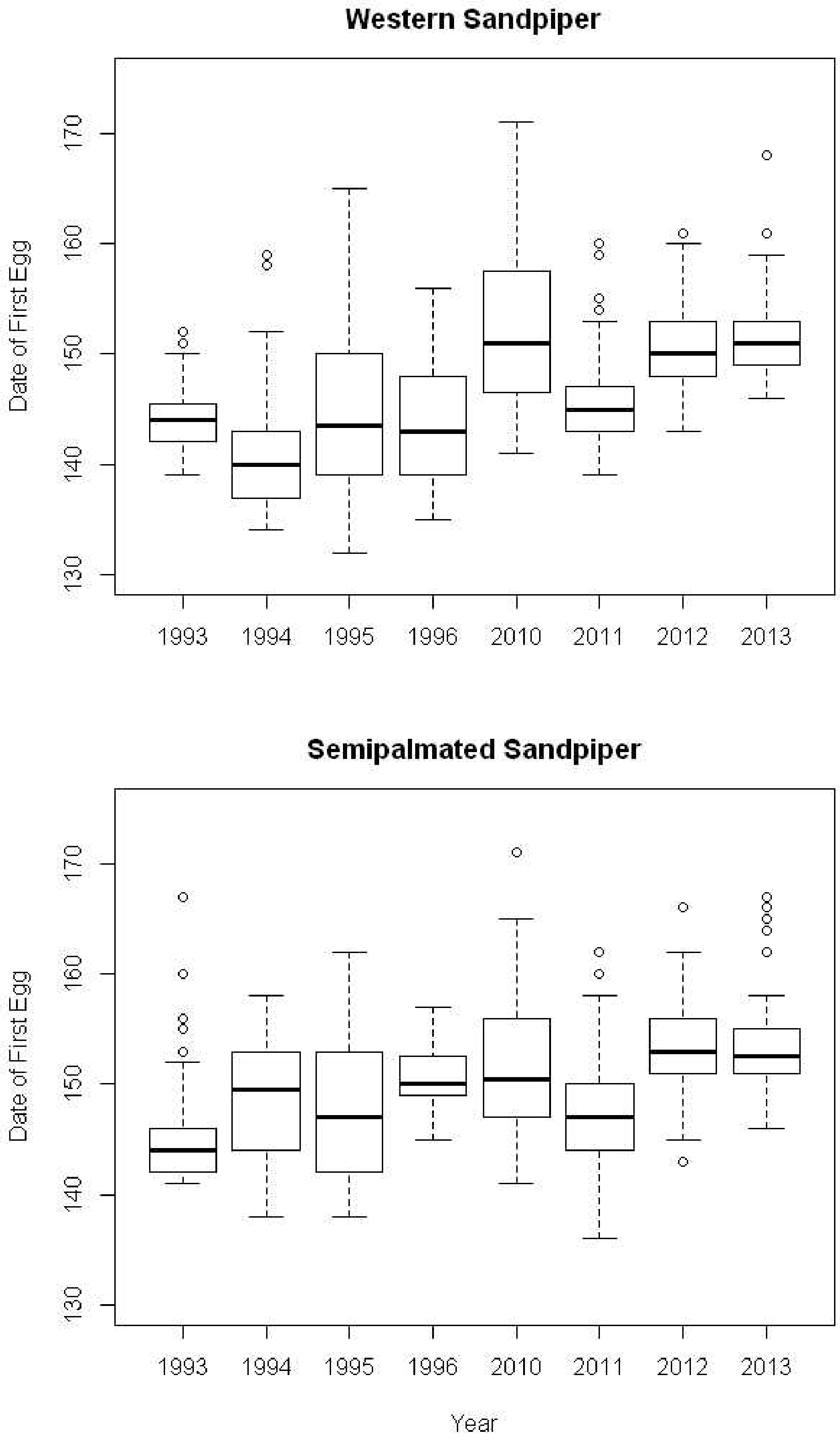

**Fig. 2.** Participating sites in the Arctic Shorebird Demographics Network and the number of shorebird nests monitored in each site in 2010. Abbreviations for site names include: NOME, Nome; CAKR, Cape Krusenstern; BARR, Barrow; IKPI, Ikpikpuk; CARI, Canning River; PRBA, Prudhoe Bay; MADE, Mackenzie Delta; CHUR, Churchill; EABA, East Bay.

| | NOME | CAKR | BARR | MADE | CHUR | EABA | Species Total |
|---|---|---|---|---|---|---|---|
| Dunlin | 5 | 57 | 99 | . | 87 | 4 | 252 |
| Pectoral Sandpiper | 1 | . | 234 | 10 | . | . | 245 |
| Red Phalarope | . | . | 376 | . | . | 32 | 408 |
| Red-necked Phalarope | 170 | 37 | 43 | 32 | 20 | . | 302 |
| Semipalmated Sandpiper | 159 | 108 | 133 | 26 | . | . | 426 |
| Western Sandpiper | 209 | 55 | 31 | . | . | . | 295 |
| **Site Total** | 544 | 257 | 916 | 68 | 107 | 36 | 1928 |

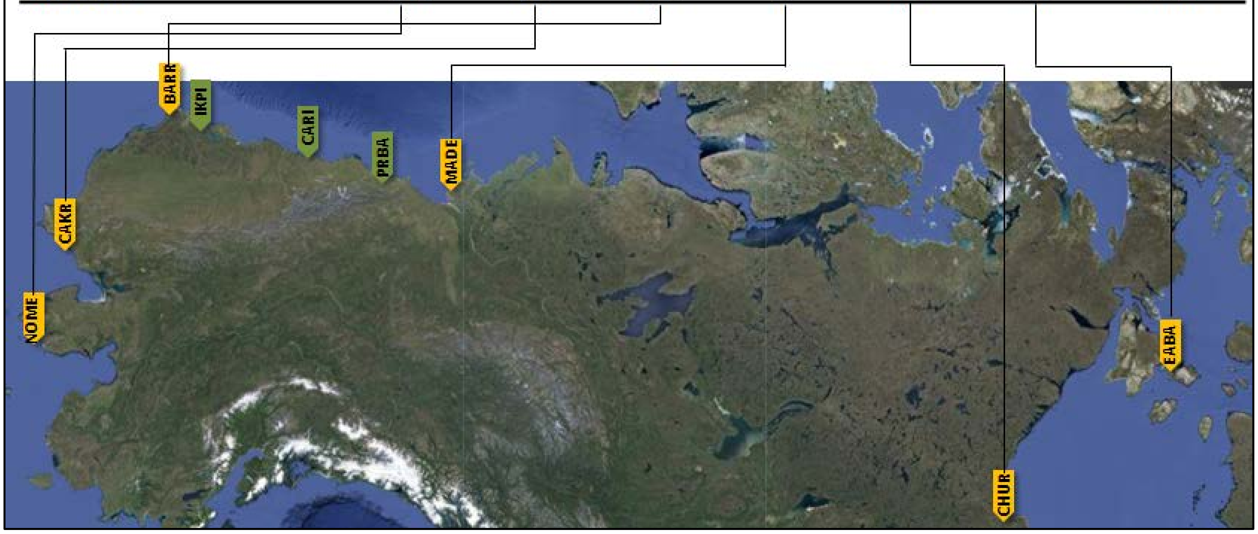

**Fig. 3.** Seasonal variation in the accumulated number of shorebird nests at hatching (orange), total biomass of invertebrates (green), and abundance of Chironomid midges (blue) at five arctic field sites, 2010. Timing of hatching of nests is presented for six species of shorebirds: Dunlin (DUNL), Pectoral Sandpiper (PESA), Red Phalarope (REPH), Red-necked Phalarope (RNPH), Semipalmated Sandpiper (SESA), and Western Sandpiper (WESA).

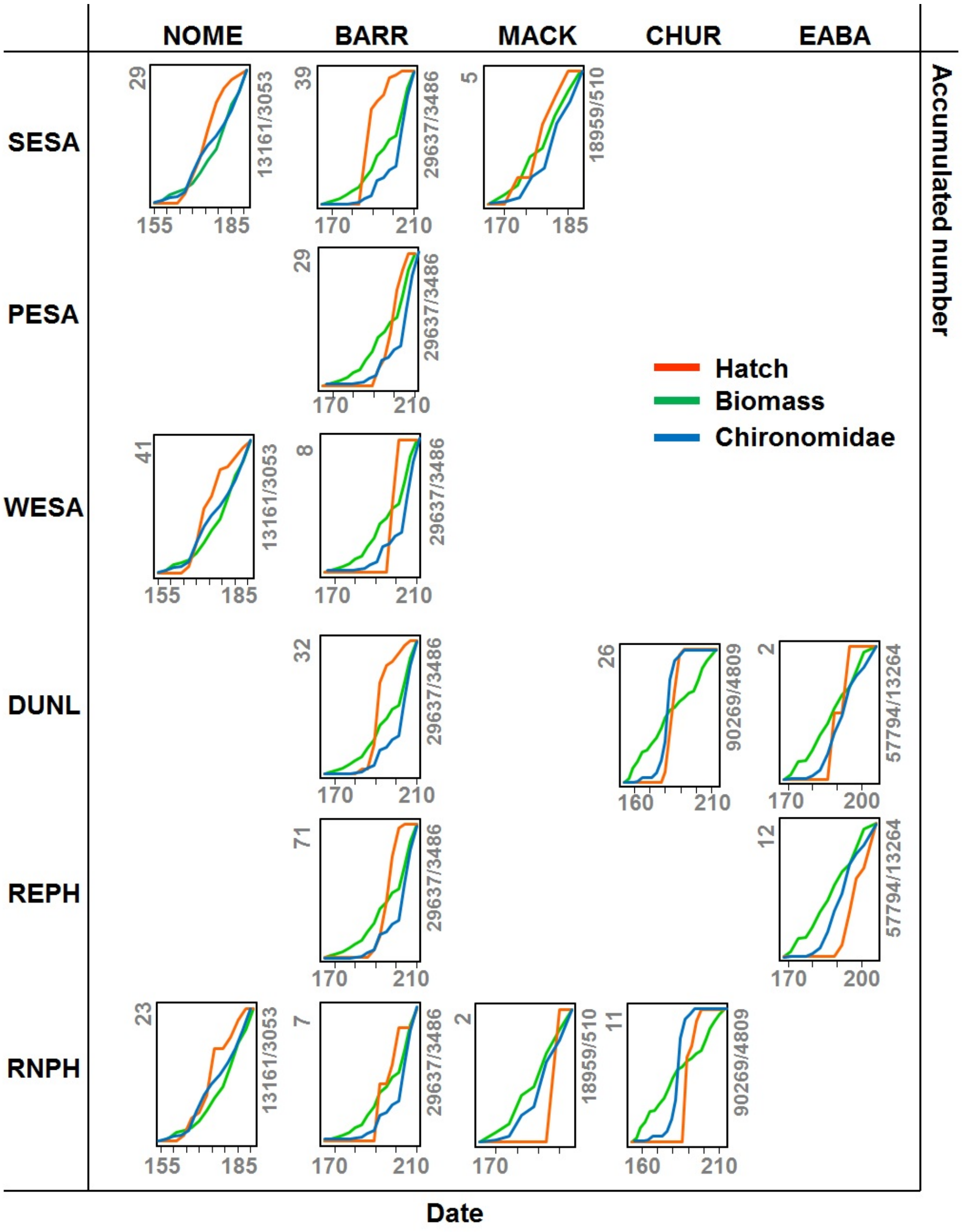

**Fig. 4.** Degree of phenological mismatch between the timing of hatching in arctic-breeding shorebirds and the peak timing of food availability at four arctic sites, 2010. Study species of shorebirds included: Dunlin (DUNL), Pectoral Sandpiper (PESA), Red Phalarope (REPH), Red-necked Phalarope (RNPH), Semipalmated Sandpiper (SESA), and Western Sandpiper (WESA).

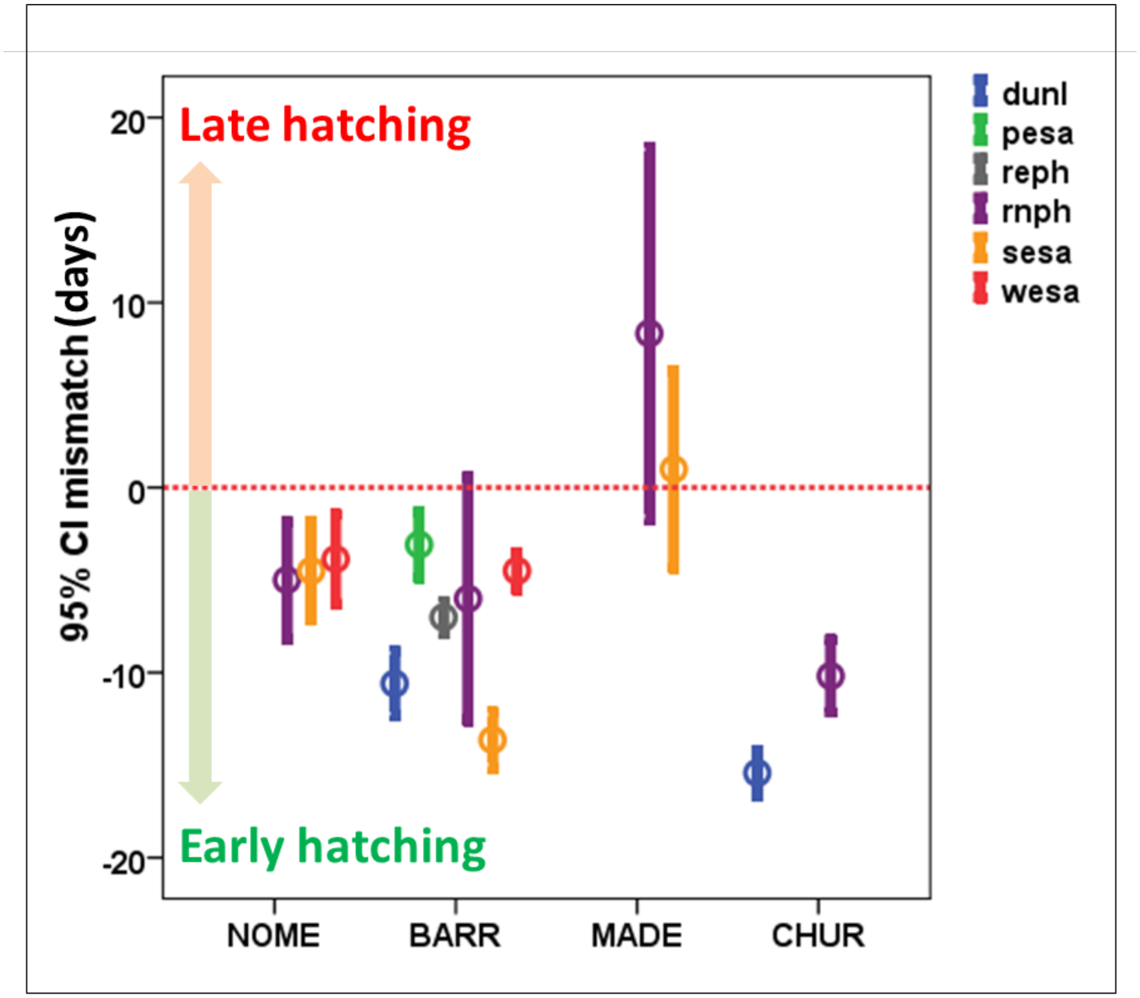

**Fig. 5.** Methods for attachment of geolocator tags (a), and an example of a geolocator tag deployed on a Western Sandpiper (b).

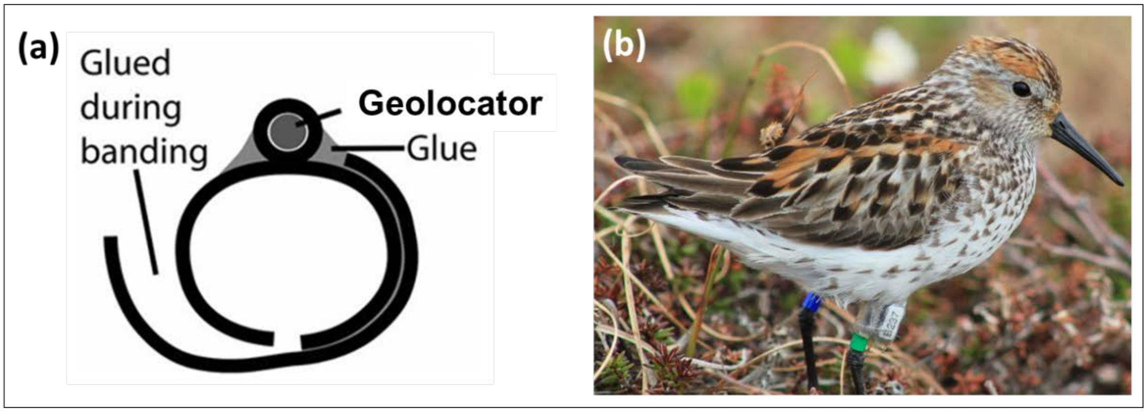

**Fig. 6.** Frequency of breeding success with 0, 1 or 2 geolocators deployed on pairs of sandpipers attending nests at Nome, Alaska, 2011-2012.

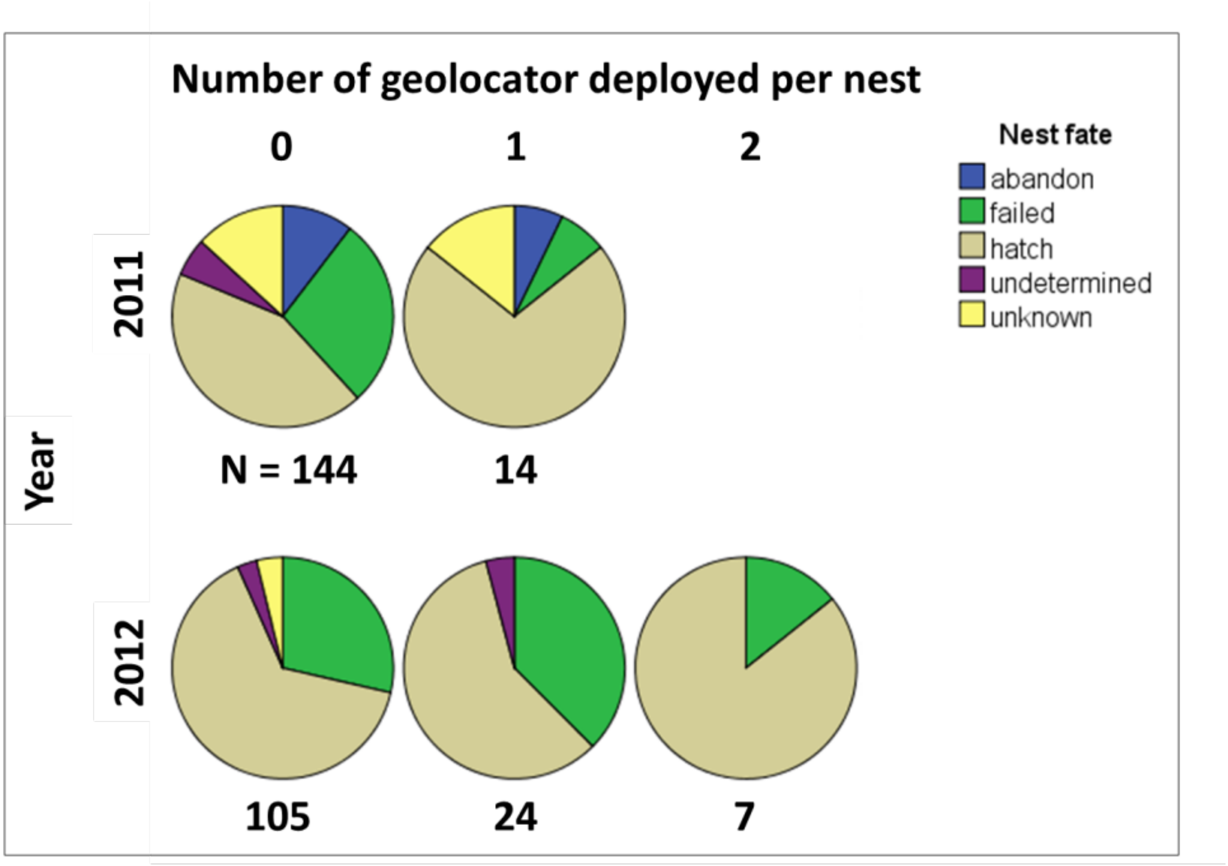

**Fig. 7.** Three migration tracks and nonbreeding locations retrieved from Western and Semipalmated Sandpipers marked with Mk20A geolocators at Nome, Alaska, 2011-2012.

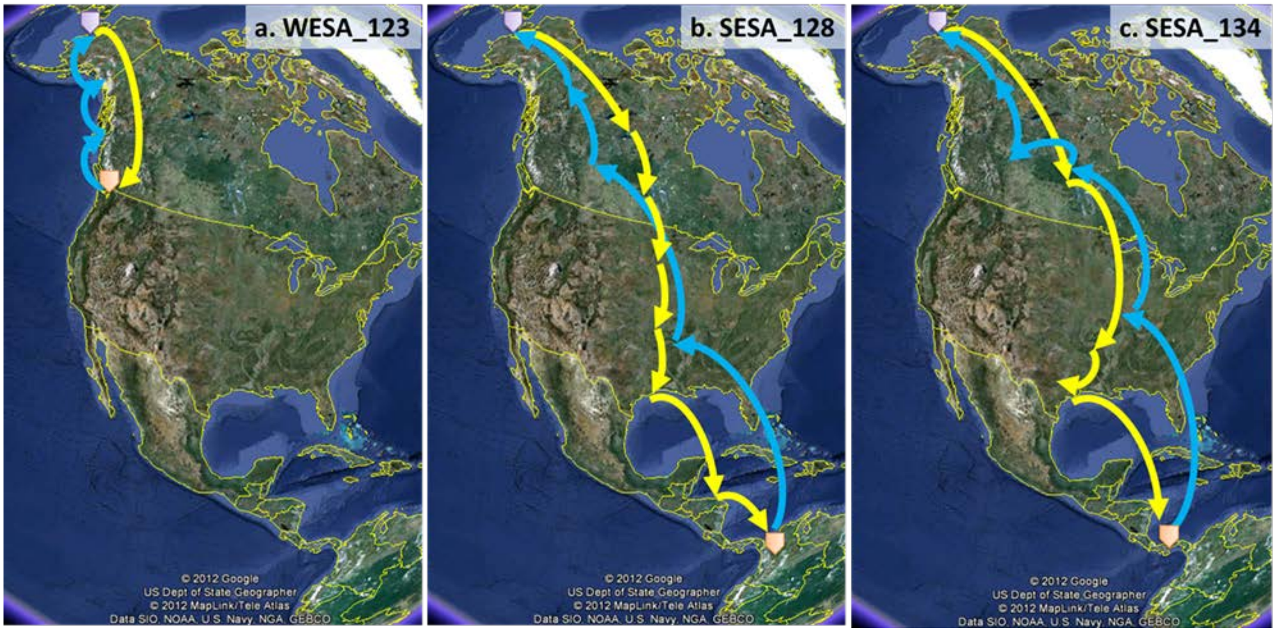

**Fig. 8.** Six migration routes and nonbreeding sites retrieved from Western and Semipalmated Sandpipers marked with Intigeo-W65 geolocators at Nome, Alaska, 2012-2013.