Post-hatch survival and migratory movements of juvenile Bar-tailed Godwits in Alaska

Photo by D. Ruthrauff

Project Report – April 2023

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INTRODUCTION

Bar-tailed Godwits *Limosa lapponica* are globally considered Near Threatened on the IUCN Red List (BirdLife International 2022), and within the East Asian-Australasian Flyway (EAAF) the Alaska-breeding subspecies *L. l. baueri* meets the requirements for Red List status based on observed population declines (Conklin *et al.* 2014, 2016). This subspecies breeds cryptically and at low densities in remote regions of Alaska, which has impeded detailed study of its breeding ecology. Consequently, breeding-related demographic rates for the population are largely unknown. Although adult annual survival rates are well-described from the non-breeding grounds in New Zealand (Conklin *et al.* 2016), little is known about the 2–3 year life stage between hatching and recruitment to the adult migratory population (Battley *et al.* 2020). Certain knowledge gaps (e.g., fledging success rates, post-fledging survival rates within Alaska, juvenile mortality associated with the first trans-Pacific migration) have inherent theoretical importance in the context of partitioning survival across life-history stages, while others (e.g., pre-migratory movement and site use of juvenile godwits in Alaska) obscure potential conservation actions. Bar-tailed Godwits have experienced loss and degradation of key habitats in parts of their range (Murray *et al.* 2014), but the habitats they use in Alaska are largely unaltered and ecosystem processes across the region are largely intact. Thus, considering active management actions to improve the reproductive output of godwits in Alaska is probably impractical. Nonetheless, a lack of information on the reproductive ecology of godwits in Alaska represents an important knowledge gap that inhibits informed species management.

Alaska-breeding Bar-tailed Godwits have received global attention for their impressive annual migration of >30,000 km, which includes three trans-oceanic flights of 5,000–13,000 km each (Gill *et al.* 2009, Battley *et al.* 2012, Conklin *et al.* 2017). In particular, the direct flight from post-breeding staging sites in western Alaska to non-breeding sites in New Zealand and eastern Australia is the longest non-stop flight recorded for any landbird (Conklin *et al.* 2017), and has challenged our understanding of the limits of avian endurance (Hedenström 2010, Piersma *et al.* 2022). However, the timing, routes, and survival of juvenile godwits on this southbound journey, performed when they are just 3–4 months old, is completely unknown.

This report describes the results of a pilot study designed to achieve two complementary goals: (1) to gather the first data on the movements, growth, and survival of Bar-tailed Godwit chicks at the breeding grounds in Alaska, and (2) to assess the feasibility of tracking juvenile Bar-tailed Godwits on their first southbound migration by deploying satellite-transmitters on nearly-fledged birds at the breeding grounds.

METHODS

Tracking the movements of newly-fledged Bar-tailed Godwits away from the breeding grounds requires locating and capturing young godwits just prior to the time of fledging, when the birds have grown large enough to carry a satellite-transmitter but are still possible to capture (i.e. are not yet, or only poorly, flying). Previous work suggested that godwit broods quickly disappear from nesting areas, because adults lead the chicks up to several kilometers away within the first 1–2 weeks after hatch (pers. obs., Larsen 1992, Lanctot *et al.* 1995, McCaffery & Gill 2001). Therefore, the goals of this study required: (1) locating young broods in or near nesting areas, (2) capturing adults and chicks to deploy radio-transmitters, (3) tracking brood movements and recapturing chicks periodically to monitor growth, and (4) deploying satellite-transmitters once chicks have grown to a sufficient size to carry them.

Locating broods

Fieldwork by myself and colleagues in May–July in 2009 and 2011 identified a number of Bar-tailed Godwit breeding territories along the road system near Nome, Alaska, primarily along Teller Road (mileposts 18–35) to the northwest and Council Road (mileposts 6–10) to the southeast. During that fieldwork, we found four godwit nests during incubation, encountered numerous pairs with broods, and individually marked 13 adult godwits with engraved alphanumeric flags. In 2022, we focused our efforts primarily on areas where godwit breeding activity was recorded in 2009/2011. The earlier work showed that, whereas nests are cryptic and extremely difficult and time-consuming to locate, pairs with mobile broods are relatively easy to detect, locate, and capture during the first week after hatch, when the attending adults are very vocal and aggressive toward predators and intruders (see also McCaffery & Gill 2001). Therefore, we aimed to begin fieldwork on 17 June, shortly before the majority of nests hatch (which was observed to occur *ca.* 21–26 June in

2009/2011), in order to locate and capture mobile broods as soon as possible after hatch. However, due to a COVID-related travel delay, our first day in the field was 25 June.

Starting 25 June, two observers searched previously identified godwit breeding areas close to the road system, or nearby areas of similar habitat (moist, grassy tundra with low to moderate topology and sparse, low shrubs; Fig. 1; McCaffery & Gill 2001); we also investigated any godwit observations we made from the road while driving, and reports by other researchers in the area, who occasionally observed godwits during their work. Each day, generally during the hours 08:00–20:00 with some exceptions, we walked individually or in roughly parallel transects through large expanses of appropriate habitat, watching and listening for signs of godwit breeding activity. We also occasionally attempted to elicit responses from adult godwits using a recording of Bar-tailed Godwit chick distress calls (recorded from 1–3-day-old chicks in the hand on the Colville River, Alaska in 2009) played back in a continuous loop from a mobile phone.

Fig. 1. Typical Bar-tailed Godwit breeding habitat on the Seward Peninsula, Alaska.

If we encountered no godwits, we typically spent 1–2 hours in a single location before moving to another location. If we encountered godwits, we noted number, sex (based on plumage and size), and behavior of the birds, recorded a waypoint with a handheld GPS (Garmin, USA), and remained until we had discerned the likely breeding status of the birds (transient/non-breeding, territorial/nesting, or defending/accompanying a brood). When we encountered a brood, we generally observed from a distance of *ca.* 20–50 m, to determine the number and location of all chicks, and noted the size and feather development of chicks to help estimate their approximate age. If this was insufficient to fully assess the situation and enable capture (see below), we moved further away, up to *ca.* 100 m, until the brood felt safe to move again and be observed.

Capture and marking

Godwit chicks were captured opportunistically by hand. Sometimes, this involved simply running toward a chick before it had time to hide. Other times, it involved one observer watching the hiding spot of one or more chicks from a distance and guiding the other observer toward the location. Alternatively, it involved one or two observers systematically searching an area defended by an adult, in hopes of discovering hiding chicks. When captured, chicks were placed immediately in a cloth bag with any captured siblings if they were very young (<5–6 d), or in separate bags if they were larger and self-thermoregulating (Visser & Ricklefs 1993).

For each captured chick, we made the following standard measurements with calipers or a flat ruler: exposed culmen (0.1 mm), total head + culmen (mm), tarsus (0.1 mm), tarsus + toe (mm), and wing cord (flattened and straightened, mm). To assess primary feather development, we also measured the total length and length of sheath of P10 (mm) and photographed spread wings. We measured mass (g) with a hanging Pesola spring scale. We marked each chick with a numeric USFWS metal band on the left tibia (Fig. 2). We additionally marked older chicks (>180 g) with a black engraved alphanumeric flag on the right tibia. On each chick's first capture, we took a small blood sample (*ca.* 10–50 μl) from the tarsus for molecular sexing. Opportunistically, we collected fecal samples from the holding bags for molecular analysis of chick diet (see below). We preserved blood and fecal samples in 90% lysis buffer. Additionally, we deployed radio-transmitters and satellite-transmitters as described below.

Fig. 2. Bar-tailed Godwit chick marked with a numeric USFWS metal band.
Photo by D. Ruthrauff.

Adult godwits with young broods (<10 d old) can be captured by two people carrying a mobile mist-net secured between two poles, by sweeping the net in front of birds flying aggressively to defend the brood (pers. obs.). After capture of one or more chicks from a brood, we attempted to capture at least one of the parents in this manner, using the bag containing captured chicks as a lure. We intended to mark captured adults with an engraved alphanumeric flag and fit them with a radio-transmitter, to help us follow and assess survival of broods. However, we captured no adult godwits in 2022.

Radio-tracking

Upon initial capture, we fitted chicks with VHF radio-transmitters (Model BD-2, Holohil Systems, Ltd., Canada). These units are 6.5 mm in length, weigh 0.75 g (<3% of chick mass), and have an expected battery life of 3–5 weeks. First, we used sewing scissors to trim a small area (1 x 1 cm) of feathers above the uropygial gland (lower back) to a length of *ca.* 1 mm. We then adhered a small (1 x 1 cm) square of medical gauze to the underside of the transmitter using Loctite cyanoacrylate super glue (Henkel Corp., USA). Once that was firmly bonded, we applied additional glue and adhered the assembly to the area of trimmed feathers and gently held it in place until bonded, ensuring that gauze corners were firmly secured. After testing the radio frequency and evaluating the condition of the bird and the attachment (Fig. 3), we released chicks back to the attending adults.

Fig. 3. Radio-transmitter attached to Bar-tailed Godwit chick.

We monitored all deployed VHF frequencies using a hand-held R-1000 telemetry receiver (Communications Specialists, Inc., USA) and a Yagi directional antenna (Fig. 4). We followed brood movements by monitoring frequencies from the road near the last known location, and then moving toward received signals or other likely locations on foot. For distant signals, we triangulated toward locations using two receivers or by making multiple stops along the road. Once close to a radio signal, we used signal strength to eventually discover and recapture a chick from its hiding spot, often nearly invisible under grass or dense willow (*Salix* spp.) shrubs. We monitored frequencies of all radio-tagged chicks daily, and attempted to locate and recapture radio-tagged chicks every 1–3 days to take body measurements and check the radio attachment.

Fig. 4. Radio-tracking Bar-tailed Godwit chicks along the Teller Road in July 2023. Photo by D. Ruthrauff.

Satellite-tracking

When chicks were sufficiently large (>180 g), we removed the radio-transmitter (by gently cutting away the degraded attachment to the back feathers) and replaced it with a solar-powered Platform Transmitter Terminal (PTT) satellite-transmitter (Model PTT-100, Microwave Telemetry, Inc., USA; Fig. 5). These units are 2.5 cm in length, weigh 5 g (<3% of fledgling mass), and have an expected operating life of 2+ years. The units were programmed for continuous operation (i.e., no on-off duty cycle), and so transmit data whenever satellites and sufficient battery charge are available. Doppler-shift PTT location data are recorded by the Argos Data Collection System and downloaded via ArgosWeb (*www.argos-system.org*).

Fig. 5. Upper: A 5-g satellite-transmitter with silicon leg-loop harness. Lower: Satellite-transmitter deployed on Bar-tailed Godwit chick B6 on 15 July.

We attached satellite-transmitters using a leg-loop harness method developed by M. Valcu at Max Planck Institute for Ornithology, Germany, which we have deployed with great success on juvenile and adult Bar-tailed Godwits in New Zealand since 2019 (Conklin *et al.* unpubl. data). The harnesses, fitted to size in the field, are constructed from silicon tubing (outside diameter 1.6 mm; Reichelt Electronics GmbH & Co., Germany; Fig. 5) that is sufficiently elastic to accommodate body and mass changes expected with subsequent growth of fledglings and pre-migratory fueling. The material is also extremely resistant to temperature, UV-exposure, salt, water, and stretching (M. Valcu unpubl. data).

We used the R package *animotum* (Jonsen *et al.* 2023) to fit a continuous-time correlated random walk (CTCRW) model to Argos tracking data. Before fitting the model, we removed obvious outlier locations based on a speed filter (threshold 400 km/hr). The CTCRW model is a parametric model that takes into account the Argos error class of each point (3,2,1,0,A,B,Z). In a CTCRW model, the bird's position at any given time is described as a combination of (1) its previous position, (2) a random component that represents the bird's movement in an unpredictable way (partly taken from the Argos error class), and (3) a correlated component that represents the bird's tendency to move in a certain direction and at a certain speed. We then used the fitted model to predict the location of the bird at 15-min intervals. All predicted locations formed a track which we then used to map, compute distance, speed, etc.

Estimation of chick age

With one exception, godwit broods were first encountered having already left the nest, and therefore were of unknown age. There are no published growth curves for Bar-tailed Godwits with which to estimate age of growing chicks based on measurements. Therefore, to estimate the age of chicks, we adapted a Gompertz growth curve for body mass developed for captive-reared Black-tailed Godwit chicks in the Netherlands (Beintema & Visser 1989).

The Gompertz equation: $W = A * \exp(-\exp(-K(t - T)))$, where W = body mass, A is asymptotic body mass, K is the growth coefficient, T is the inflexion point, and t is the age in days. For this, we assumed a hatch mass (day zero) of 26 g (this study), a K of 0.10, and a T of 16.8. Following Beintema & Visser (1989), we calculated A as 95% of the expected breeding mass of adult Bar-tailed Godwits, using the mean adult mass (sexes combined) specific to this breeding region (Conklin *et al.* 2011); therefore, A = 267 * 0.95 = 253 g.

Diet analysis

We characterized chick diet from preserved fecal samples using the DNA bar-coding method described in Verkuil *et al.* (2022). Briefly, DNA was extracted from fecal samples using the Invitrogen PureLink Microbiome DNA Purification Kit (Thermo Fisher Scientific, Inc., USA) and amplified using invertebrate-specific custom Cytochrome c oxidase I (COI) PCR primers, and the PCR products were sequenced on the MiSeq Sequencer (Illumina, USA) at the Department of Human Genetics, Leiden University Medical Centre, The Netherlands. Using a custom bioinformatics pipeline, unique identified bar-codes were compared to COI sequences available on the GenBank database (Benson *et al.* 2009) using the BLAST function in the program Geneious v.8.1.7 (Kearse *et al.* 2012). We generally identified common prey species to the taxonomic level of family, but sometimes to order or genus, depending on available reference sequence libraries.

RESULTS & DISCUSSION

Discovery and monitoring of godwit broods

We found one godwit nest close to Teller Road on the morning of 2 July, through observation of an adult female, who appeared near a defensive adult male and then sat on the nest to incubate. Upon discovery, one egg was pipped with a 1-mm hole, two eggs were starred, and one showed no evidence of hatching. Later that day, we returned to attempt to capture the attending adults, but failed; at this time, three eggs were pipped and one remained unstarred (Fig. 6). Early on 3 July, we returned for another capture attempt, but found the male dead at the side of the road, apparently having been shot with a small-caliber rifle; the female was attending the nest. We abandoned the adult capture attempt, but banded and weighed three hatched chicks in the nest (Brood1; see Table 1); the fourth egg was still not pipped (Fig. 6). On 4 July, we found the female with the brood of three chicks 212 m from the nest (Table 2); the fourth egg remained unhatched in the nest. We weighed the three chicks and deployed a radio-transmitter on the largest of them (28 g). On 5 July, we used radio-telemetry to locate the brood across the road and *ca.* 520 m from the previous location; we recaptured the chicks and took the whole suite of measurements. On 7 July, we used radio-telemetry to locate the brood *ca.* 533 m from the previous location, but back near the road; the female appeared to be escorting only the radio-tagged chick, with no evidence of the other two chicks. On 8 July, we used radio-telemetry to locate the chick <20 m from the 7 July encounter; the chick was dead and unattended by the adult female.

Fig. 6. Upper: The nest of Brood1 on 2 July. Lower: Three hatched chicks and one unhatched egg in the nest on 3 July.

Table 1. Details of Bar-tailed Godwit broods found during July 2022.

Brood	First encounter	Road & milepost	Last encounter	Nest found?	*n* chicks confirmed	*n* chicks radio-tagged	*n* chicks satellite-tagged	*n* chicks fledged	Estimated hatch date
1	2 July	Teller 18.8	8 July	yes	3	1	0	0	3 July
2	5 July	Council 7	7 July	no	1	0	0	unknown	unknown
3	9 July	Teller 30.8	16 July	no	3	1	0	unknown	20 June
4	9 July	Teller 29.5	13 July	no	1	1	0	unknown	19 June
5	11 July	Teller 31.5	16 July	no	4	1	0	unknown	22 June
6	11 July	Teller 31.5	15 July	no	3	3	3	1–3	19 June
7	16 July	Teller 30.5	16 July	no	1	0	0	unknown	2 July

Table 2. Distances moved by radio-tracked Bar-tailed Godwit broods in July 2022. Distances were calculated from GPS coordinates.

Brood	Estimated age (d)	Date	Time	Time (hr) since previous encounter	Distance (m) from previous	Time (hr) cumulative	Distance (m) cumulative
1	1	4 July	15:03	30.8	212	30.8	212
1	2	5 July	17:08	26.1	520	56.9	732
1	4	7 July	9:45	40.6	533	97.5	1,265
1	5*	8 July	13:52	28.1	18	125.6	1,283
3	23	12 July	11:51	43.6	597	43.6	597
4	21	10 July	14:48	25.3	1,823	25.3	1,823
4	23	12 July	10:19	43.5	1,245	68.8	3,068
6	26	15 July	12:34	91.4	3,485	91.4	3,485

* = Chick found dead.

During 5–16 July, we discovered six additional godwit broods (Broods 2–7; Table 1), all attended by both parents after leaving the nests. Five broods were first encountered in the same valley, along Teller Road, mileposts 29–32 (Fig. 7). For one brood (Brood2), we observed only one chick (visually estimated at ≥14 d old), which we were unable to capture in multiple attempts during 5–7 July. For three broods (Broods 3–5), we observed multiple chicks but were able to capture only one chick per brood for deployment of radio-transmitters. For one brood (Brood6), we captured and deployed radio-transmitters on all three observed chicks. For one late-hatching brood (Brood7), we observed and captured one chick on 16 July, but did not deploy a radio-transmitter, as we had only one day remaining in our field season.

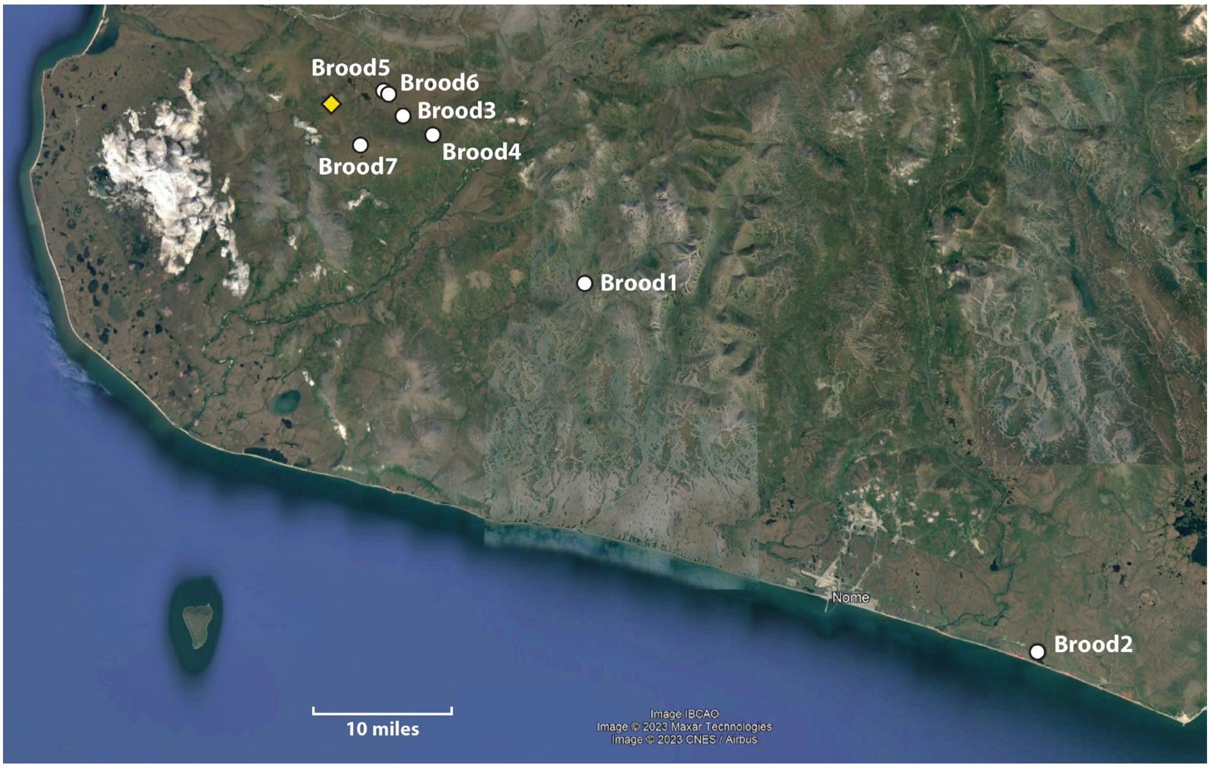

Fig. 7. Locations of first encounters with Bar-tailed Godwit broods in the Nome area in 2022 (white circles) and the location of the 15 July satellite-transmitter deployment on Brood 6 (yellow diamond). Image: Google Earth.

We used radio-telemetry to follow the movements of four broods (Broods 3–6) for 3–6 d after initial capture. For three broods (Broods 3,4,6), we recaptured chicks to collect growth data and additional fecal samples. We followed one brood (Brood6) to a sufficient size and age to deploy satellite-transmitters on all three chicks. We lost radio-telemetry contact with the other broods before they were old enough for satellite-transmitters; this could have resulted from tag loss, death of the chicks, or brood movements beyond the range of the radio-transmitters.

Chick age estimates and breeding phenology

With age estimates derived from the Gompertz curve of body mass, we discovered Broods 3–6 when the chicks were 20–22 d old. The last-discovered brood (Brood7) was the youngest upon initial capture (14 d). Calculating back from these age estimates, the nests from Broods 3–6 are estimated to have hatched fairly synchronously during 19–22 June (Table 1). The estimated hatch date for Brood7 was 2 July, the same date Brood1 was discovered with pipping eggs; these two later-hatching nests were perhaps re-nesting attempts by a pair after failure of a first nest.

Based on body mass (181–200 g), Brood6 was estimated to be 26 d old when we individually-marked the chicks (engraved flags 'B3', 'B4', and 'B6') and deployed the satellite-transmitters on 15 July (Fig. 8). At that time, based on behavior and the state of wing and primary feather development (Fig. 8), we judged that they would likely fledge with a few days. According to Beintema & Visser (1989), Black-tailed Godwit chicks fledged at approximately 70% of asymptotic body mass. Applying this coarse 'rule', we would expect Brood6 to fledge 2–4 days after we deployed the satellite-transmitters, similar both to our judgement and to the expected Bar-tailed Godwit fledging age of 28–30 d (McCaffery & Gill 2001). We have not yet performed molecular sexing of the godwit chicks in this study; however, sexual dimorphism in godwits (females larger than males) is expected to be evident by the age of fledging (see Loonstra *et al.* 2018). Therefore, we expect that Brood6 consisted of one female (B3 = 200 g on 15 July) and two males (B4 = 181 g; B6 = 186 g).

Fig. 8. Upper: Bar-tailed Godwit chick B6 with satellite transmitter attached on 15 July. Lower: Wing development of B6 on 15 July, estimated 26 d old.

Brood movements and habitat

Godwit broods made surprisingly large daily movements, even at a very young age (Table 2). Brood 1 moved at least 212 m in the first day after leaving the nest, and had moved well over 1.2 km by the age of 4 d; as these are minimum straight-line distances between encounters, the actual distances moved are likely to be much greater. Older broods regularly moved more than 1 km per day, and possibly up to *ca.* 3 km. It was not unusual for parents to move older chicks >400 m during an encounter with observers. On all encounters with broods, both parents were present, although on at least two occasions chicks from one brood were separated by *ca.* 100–400 m and attended by different parents.

On the Seward Peninsula, Bar-tailed Godwits typically nest in moist, grassy tundra dominated by herbaceous vegetation and dwarf shrubs (willow and birch), with relatively shallow topological variation (pers. obs.; McCaffery & Gill 2001). Brood1 remained in this type of habitat for the 4 days we followed them. Brood 2, which was *ca.* 2.5 weeks old during our encounters, was mostly on drier tundra dominated by tall (>25 cm) grass; this habitat was downhill from more typical nesting habitat and adjacent to wetter coastal habitat, and so the parents may have been leading the brood toward better foraging habitat when we encountered them. Broods 3–6, first encountered at age 20–23 d, were in a very different habitat: low-lying areas (*ca.* 100–150 m elevation) of greater topological diversity, interspersed with very wet *Juncus*-dominated marshy areas (Fig. 9) and taller (up to *ca.* 50–60 cm), dense willow thickets. This habitat type seems to offer a beneficial combination of foraging and hiding places for older chicks, and high perches for watchful parents. Indeed, we found that locating godwit chicks in this habitat was challenging even with the help of radio-telemetry, and next to impossible without it. After about 13 July (and when most chicks were >3.5 weeks old), it seemed that godwit broods had moved out of the valleys and up onto ridges (*ca.* 200–280 m elevation). On our last encounter with Brood6, they were on a high, open ridge, interspersed with wet, marshy areas and shrub thickets. These habitat changes with brood age are similar to that described by McCaffery & Gill (2001). However, we observed no evidence of intra- or inter-specific brood amalgamation, as described by Lanctot *et al.* (1995), or of abandonment of older broods by one of the adult parents.

Fig. 9. Bar-tailed Godwit chick hiding in tall-grass marsh, located through radio-telemetry.

Chick diet

We analyzed godwit chick diet from eight fecal samples collected 4–15 July, representing chicks from four broods of ages 2–26 d. Each sample yielded *ca.* 5,000–70,000 DNA bar-coding reads that were reliably identified to Metazoan taxa in 5 taxonomic Classes (Fig. 10); this included 4 Classes of likely Bar-tailed Godwit invertebrate prey taxa, plus a small proportion of Mammalia, likely representing secondary DNA present in invertebrates such as flies. The 16 most common invertebrate taxa combined accounted for 96% of all taxonomically-assigned reads (Fig. 10). The most common and abundant prey taxa were sawflies of the family Tenthredinidae and parasitoid wasps of the family Icneumonidae; these are both common residents of northern Alaska tundra during the godwit breeding season (MacLean & Pitelka 1971). The remainder of the diet consisted primarily of other flying insects, beetles, and some small gastropods. There is some indication that diet becomes more diverse with age of the chicks (Fig. 10), but this requires more in-depth study. Although bar-coding cannot identify the life-stage of the prey taxa, it is known that shorebird chicks rely mostly on adult insect prey during the first weeks of life (Holmes & Pitelka 1968).

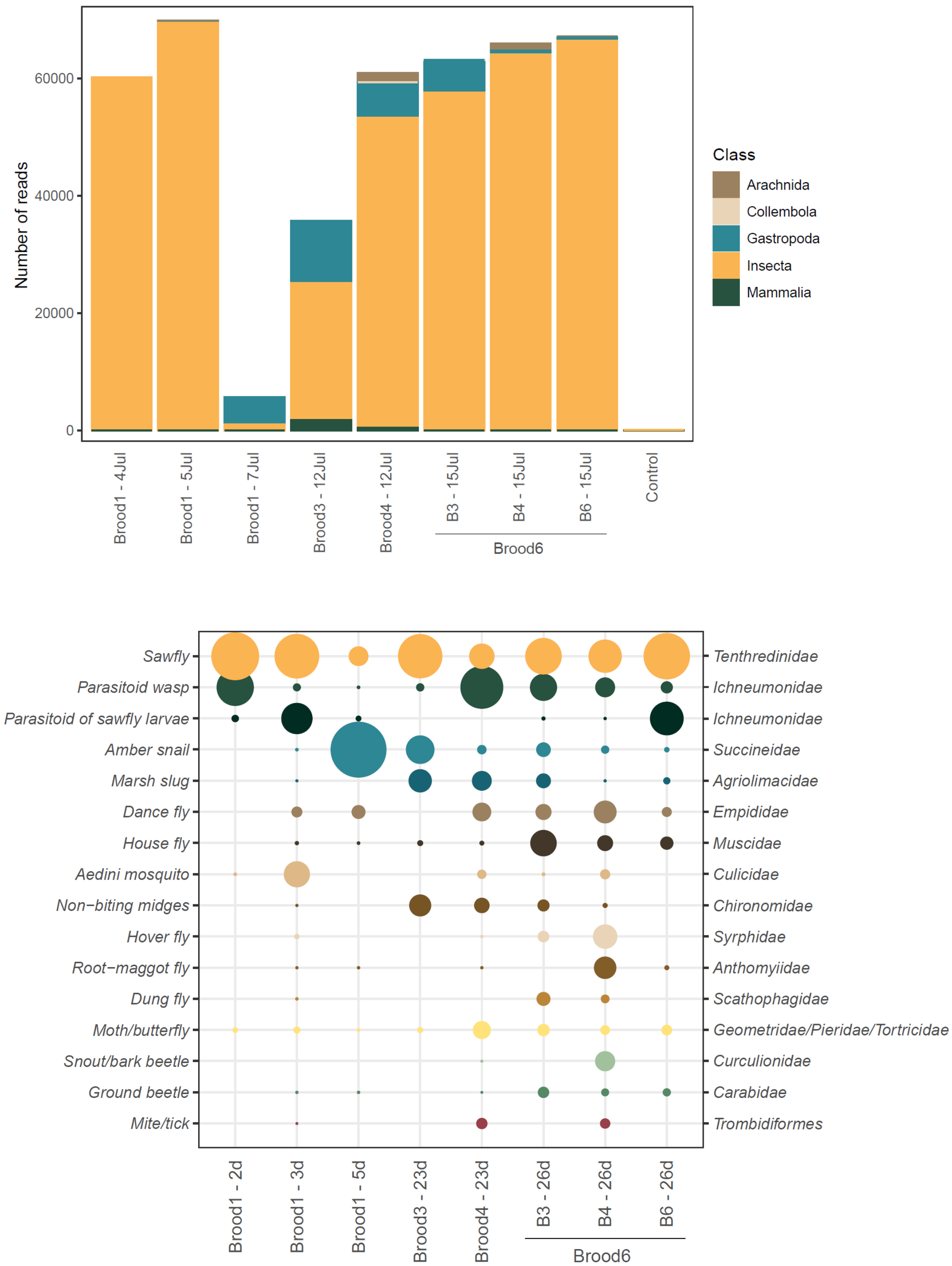

Fig. 10. Upper: Number of bar-coding reads in eight fecal samples of Bar-tailed Godwit chicks from four broods and the proportions assigned to 5 taxonomic Classes. Lower: Proportional representation of the 16 most common prey taxa across the eight fecal samples. Age of godwit chicks (2–26 d) increases from left to right.

Satellite-tracking of Brood6

The low precision of Argos PTT data is not appropriate for describing movements on the scale of hundreds of meters, and therefore we cannot precisely describe the local movements of Brood6 in the days after we deployed satellite-transmitters on 15 July. For the first three days, B3, B4 and B6 all transmitted locations within *ca.* 1.5 km of the deployment site, after which all three provided no location data during 18–21 July; we expect this resulted from the initial charge of the transmitters expiring, and the young birds being insufficiently active to expose the solar panels for charging. As of 22 July, B3 and B6 provided locations daily, but B4 did not transmit again until 5 August.

By 22 July, B3 and B6 appeared to have drifted west *ca.* 2.5–3 km from the deployment site, and remained within *ca.* 1 km of each other through 2 August, probably moving together. We can only speculate about whether they were still accompanied by one or both parents – little is known about the age of independence in Bar-tailed Godwits. There was no discernible movement from the area until B6 moved *ca.* 9.5 km eastward on 3 August (estimated age 45 d). We expect that the brood was capable of flight long before this, but this was the first flight of sufficient distance to be clearly identifiable with PTT data.

On 5 August, B4 resumed transmitting from the same area as B3, but neither bird clearly moved from the area subsequently. B4 transmitted daily from this area through 17 August, after which it was not heard from again. B3 continued transmitting from the same area, increasingly sporadically, through 20 October. Given the movements of B6 and the expected local phenology of the species, we suspect that B3 and B4 either shed their transmitters or were depredated at some point before *ca.* 10 August.

B6 remained close to Teller Road, near milepost 29, through 5 August. On 6 August, he flew southeast across Norton Sound, landing near St. Michael Island on the northern Yukon-Kuskokwim Delta (Fig. 11); this was a direct flight of *ca.* 225 km, including 180 km of open water, in *ca.* 4 hours. B6 stayed in that area for less than 10 hours, quickly moving >250 km southwest to the delta at Kokechik Bay. From there, B6 made explorations of inland reaches of the Kashunuk, Kokechik, and Manokinak Rivers for ten days, before finally settling near the mouth of the Ninglick River on 18 August. B6 remained along a 30-km stretch of coast centered on the Ninglick River and Kigigak Island for the next 56 days. This was >100 km

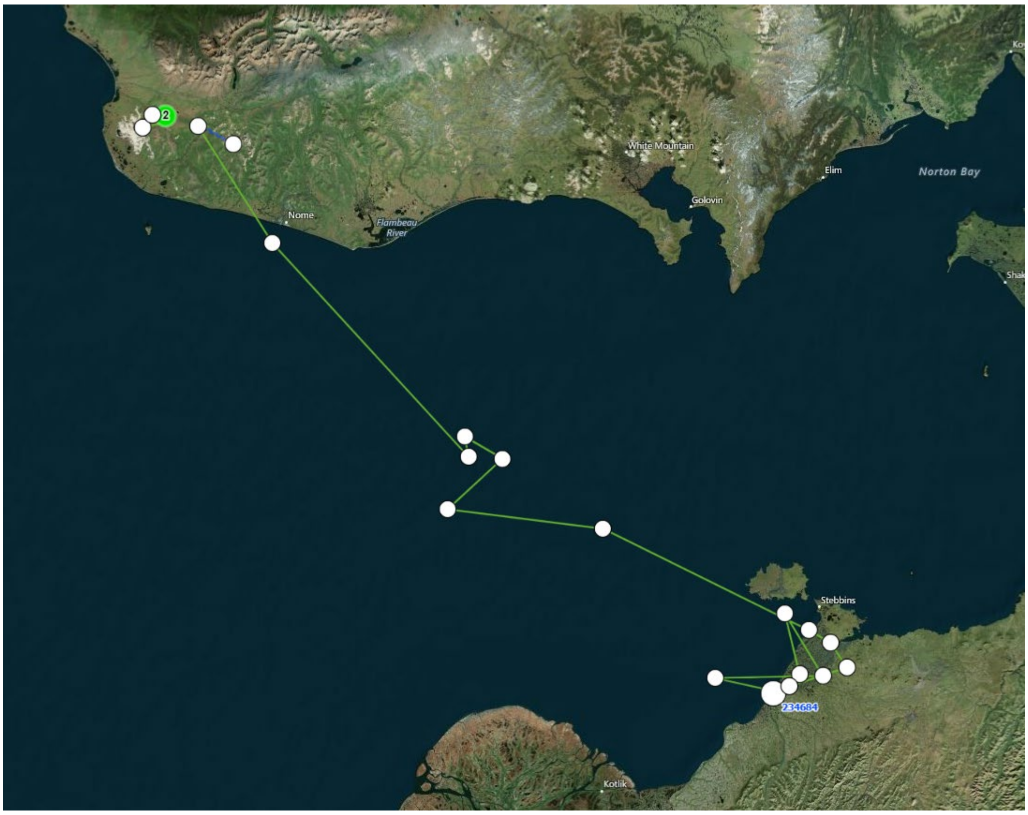

Fig. 11. The first significant move from B6 across Norton Sound on 6 August, while his two siblings remained in the area where they were satellite-tagged.

north of Kuskokwim Shoals, where the vast majority of Alaska-breeding Bar-tailed Godwits stage during July–September for their southbound trans-Pacific flight (Gill & McCaffery 1999, Ruthrauff *et al.* 2021).

On 13 October, B6 departed from Kigigak Island and flew southwest toward the outer Aleutian Islands (Fig. 12); this flight direction gave him very strong tailwinds (Fig. 13) and a very high ground speed, exceeding 100 km/hr (Fig. 12). He then turned southeast toward Hawaii for more than a day, before settling on a south-southwesterly course though the mid-Pacific. He continued flying through benign weather conditions all the way to the Tasman Sea between Australia and New Zealand (two plausible non-breeding destinations for this Bar-tailed Godwit population) by 22 October. It appeared that B6 would miss both land-masses, until he hit very strong easterly winds at 41°S on 24 October (Fig. 13). He turned west with the wind, and increased speed to *ca.* 90 km/hr toward Tasmania. B6 made landfall near Ansons Bay in northeast Tasmania on 24 October (Fig. 14).

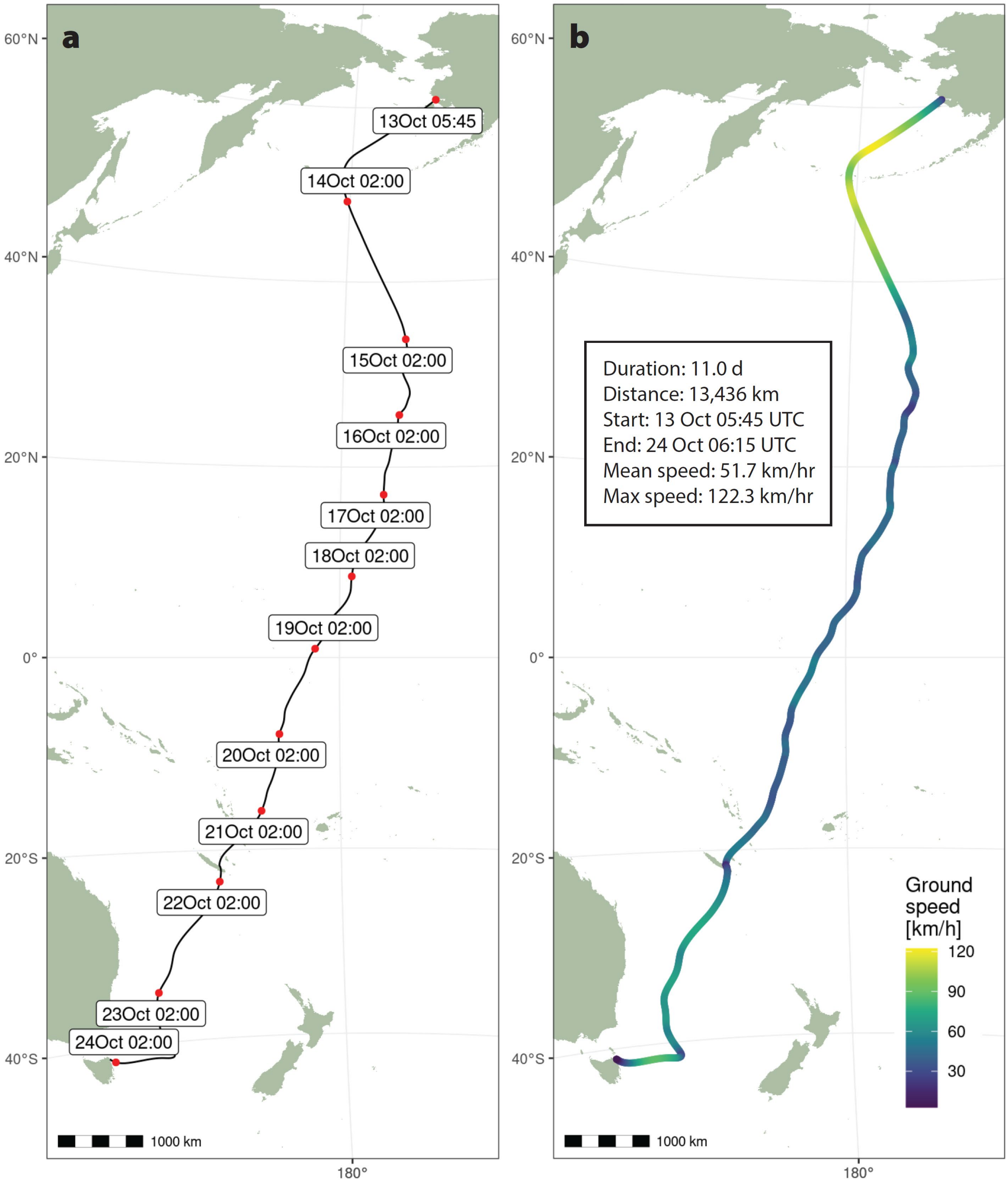

Fig. 12. Modeled southbound migration track of B6 from Alaska to Tasmania, 13–24 October 2022. Left: estimated positions at 1-day intervals across the 11-d flight. Right: Estimated ground speeds along the flight path.

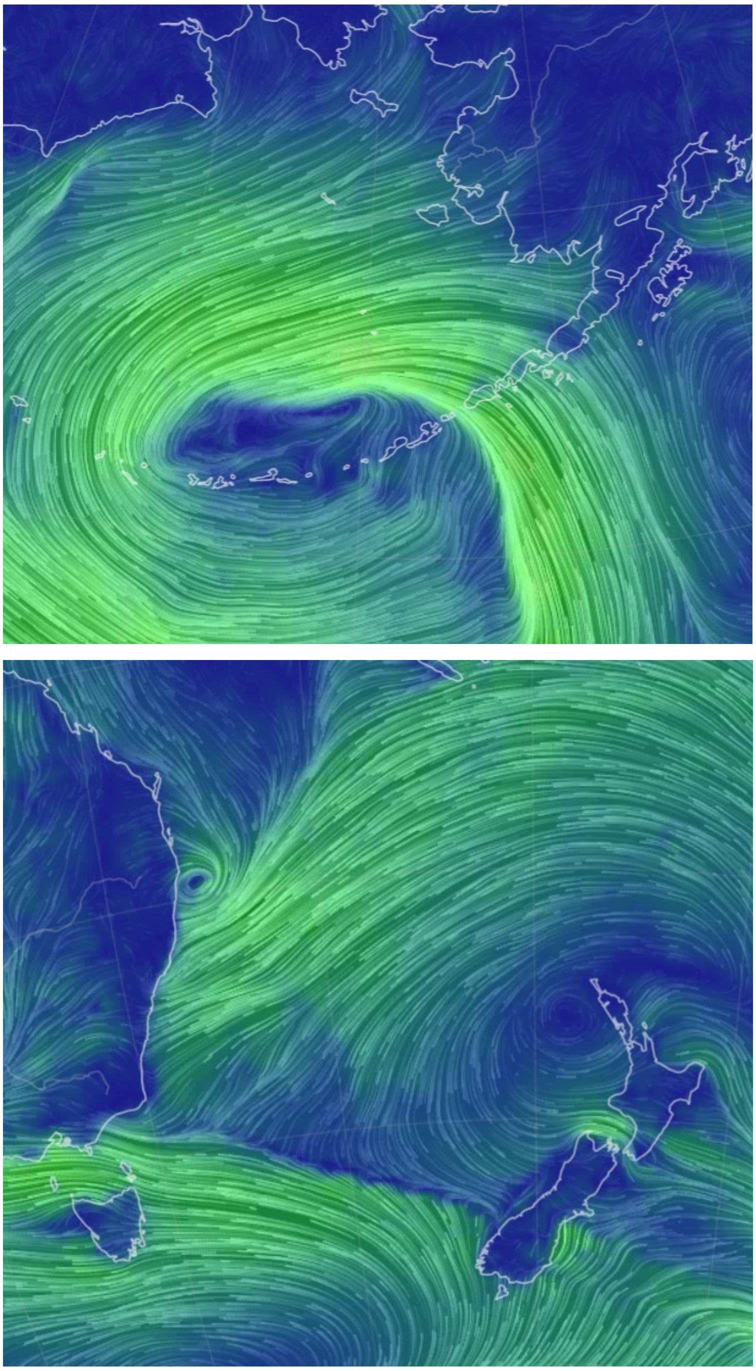

Fig. 13. Upper: Strong easterly winds encountered by B6 upon departure from Alaska on 13 Oct 2022. Lower: Strong easterly winds in the southern Tasman Sea on 24 October 2022 that carried B6 to Tasmania. Images: *earth.nullschool.net*.

Fig. 14. Locations of B6 in northeast Tasmania 24–28 October 2022.

B6 flew an estimated 13,436 km from Alaska to Tasmania (Fig. 12), which is the longest non-stop flight ever recorded for a landbird (see review in Conklin *et al.* 2017), surpassing all previously tracked adult flights in this species (up to *ca.* 13,000 km; Conklin *et al.* unpubl. data). He flew non-stop for 11.0 days at an average ground speed of 51.7 km/hr, and reaching a maximum speed of 122.3 km/hr (Fig. 12).

B6 transmitted locations from the Ansons Bay area (Fig. 14) until 9 November, and then stopped, giving only one more transmission on 2 December. The transmitter has not reported since. We do not know whether this resulted from failure of the tag, shedding of the harness, or death of the bird.

CONCLUSIONS

The main goals of this project were (1) to gather the first data on the movements, growth, and survival of Bar-tailed Godwit chicks at the breeding grounds in Alaska, and (2) to assess the feasibility of tracking juvenile Bar-tailed Godwits on their southbound migration by deploying satellite-transmitters on nearly-fledged birds at the breeding grounds. We knew these two goals required finding and radio-tagging young godwit chicks, following them until they were large enough to carry satellite-transmitters, and then having them survive and carry the satellite-transmitters for at least three months during pre-migratory staging and the trans-Pacific journey to the non-breeding grounds; any one of these challenges were potentially insurmountable. In this sense, this pilot project was a success: we were able to collect local movement and morphometric data, and tracked one young godwit (B6) from Nome to Tasmania. This showed that our methods do generally work, and proved that juvenile godwits are capable of making the non-stop migrations that adult godwits make every year. To our surprise, B6 even exceeded the non-stop distance flown by any adult godwit (or any bird of any species) that has yet been tracked.

However, several difficulties prevented greater success of the project. First was the difficulty of finding godwit broods in this particular year. Despite targeting known breeding areas identified in fieldwork in 2009 and 2011, we detected little or no godwit breeding activity in most of these areas. Based on previous experience, we had envisioned encountering at least 10 recently-hatched godwit broods, allowing us to radio-track entire families including adults. In practice, we encountered no mobile broods <14 d old, which meant we had little chance of capturing adults or even locating all the chicks in any broods. The only young chicks we found were Brood1, which unluckily suffered the loss of the adult male, making the likelihood of the female raising them to fledging very low. The Nome area is a relatively low-density godwit breeding area (pers. obs.), susceptible to widespread breeding failure in any given year (this was observed locally in 2010; D. Melville pers. comm.), and therefore not a reliable place to encounter large numbers of broods, despite the significant convenience of working from a road system. We believe the project has a greater chance of success in a denser breeding population, such as that found on the Yukon-Kuskokwim Delta.

A second challenge was the surprisingly large distances traveled by godwit chicks, which made following them on a daily basis nearly impossible, even with radio-telemetry. The dramatic topography of the Nome area meant that radio-tagged broods could easily escape detection from the roads, either in low ravines or over high ridges. Once the older broods started moving away from the roads, at well over a kilometer per day, hiking in and locating them for recapture became unreliable. We consider ourselves quite lucky to have relocated and deployed satellite-transmitters on the three chicks from Brood6. To more reliably follow godwits broods to near-fledgling in these condition may require radio-telemetry conducted from a helicopter. Again, the project might have better prospects on the Yukon-Kuskokwim Delta, where the flat topography would be more conducive for longer-range radio-detection, and broods would not have ravines and dense shrubbery to hide in.

A third major challenge to the project is more difficult to address: inherently low survival of godwit chicks. Bar-tailed Godwits are long-lived and do not rely on high annual reproductive output for population stability (Conklin *et al.* 2016) or individual fitness; the first four months of life between hatching and reaching the non-breeding grounds are likely the primary demographic bottleneck, and this period involves multiple significant survival challenges for young godwits (see Conklin *et al.* 2017). There are few data on survival of Arctic shorebird chicks either pre- or post-fledging, but it may be unrealistic to expect greater than 33% success satellite-tracking godwit chicks from breeding grounds to the non-breeding grounds (as we achieved with Brood6). We don't consider 5-g satellite transmitters (<3% of fledgling mass) a significant burden to growing godwits that will more than double their mass in the 1–2 months after tagging. Therefore, the best way to increase the survival probability of satellite-tagged chicks is to capture them at pre-migratory staging areas, after they have passed most other early-life challenges. However, working at these areas, such as Kuskowkim Shoals (Ruthrauff *et al.* 2021), is logistically difficult and capturing godwits has yet to be attempted there.

In conclusion, we consider this pilot season very instructive and a qualified success. We will seek to replicate and expand on these efforts in 2024, after addressing as many of these challenges as possible.

ACKNOWLEDGEMENTS

I am indebted to many people and organizations who made this work possible. Dan Ruthrauff (USGS Alaska Science Center) and Jim Johnson (USFWS Migratory Bird Division, Alaska) helped conceive and plan the project, and provided logistical support both before and during the field season. Valerie Amundson and staff of Bering Land Bridge National Preserve provided additional logistical support. I was assisted in full-time fieldwork during 25 June–3 July by Evan Griffis (USFWS) and during 4–19 July by Dan Ruthrauff. The research teams from the Royal Netherlands Institute of Sea Research and University of South Carolina provided camaraderie, local assistance, and helpful tips on daily godwit activity. Nick Hajdukovich saved our season with his report of broody godwits, just when we had given up hope of finding any. Nathan Senner provided helpful advice on radio-transmitter attachment. Mihai Valcu (Max Planck Institute of Ornithology, Germany) designed the silicon harness for satellite-transmitter attachment, and performed the analysis of the B6 migration track. Yvonne Verkuil (University of Groningen, The Netherlands) conducted the labwork and chick diet analysis.

The EAAFP Small Grant Fund supported the purchase of radio-transmitters for the project. Bart Kempenaers (Max Planck Institute of Ornithology, Germany) provided the satellite-transmitters, covered Argos data costs, and provided moral support to give it a try. USGS Alaska Science Center supported airfare, lodging, and supplies, and provided capture, banding and telemetry equipment. Christiaan Both (University of Groningen, The Netherlands) funded the DNA sequencing.

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