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The breeding ecology of Broad-billed Sandpipers in northern Norway

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The breeding ecology of the Broad-billed Sandpiper *Calidris falcinellus* was investigated in a long-term study in Finnmark, north Norway during 1993–2019. Nests were mostly located and monitored during the incubation period. We found a total of 173 nests with annual variation of 2–14 nests per year. All nests were located in wet quaking fens in aapa mires. The mean laying date was 10 June (annual mean estimates: 1–24 June) and was earlier in years with warmer temperatures in early June. Most clutches contained four eggs (94%). Daily nest survival was 0.9838 ± 0.0057 SE (Mayfield method, 8 losses in 494 days of exposure), which gave a high probability of nest success of 0.665 ± 0.096 SE for a 25-day nesting cycle. Most nest failures were due to flooding. The cause of annual variation in the number of breeding pairs was unclear, although nest success was correlated with weather and associated environmental conditions. Broad-billed Sandpipers started breeding in their second calendar year, and returning birds showed strong pair and nest-site fidelity, often breeding in subsequent years with the same partner in the same mire and reusing the same nest scrape. Broad-billed Sandpipers are elusive in their breeding behaviour and occupy a highly distinctive and localised breeding habitat, which was often treacherous to survey. General wader surveys based on transect methods are likely to be ill-suited for estimating population numbers for this species.

Keywords

aapa mires

Calidris falcinellus

Finnmark

nesting success

site fidelity

wader survey

INTRODUCTION

The global distribution of Broad-billed Sandpiper *Calidris falcinellus* consists of two distinct breeding populations: a European subspecies *C. f. falcinellus* in Fennoscandia and western Russia, and an Asian subspecies *C. f. sibirica* in central and eastern Russia (van Gils *et al.* 2020). The global population trend is decreasing and the conservation status in Europe is unfavourable (BirdLife International & EBCC 2000), but the species has been listed as Least Concern because it has a broad geographic range and a large population size (BirdLife International 2015, 2022). Populations of Broad-billed Sandpiper have been estimated as 1,650–1,800 pairs in Norway (Shimmings & Øien 2015), 3,000–5,000 pairs in Sweden, and 10,000–20,000 pairs in Finland (BirdLife International & EBCC 2000). Nevertheless, the species is rarely encountered in national surveys of breeding birds in Fennoscandia (72 of 1,505 routes, 4.8%; Lindström *et al.* 2019). Recent trends have indicated a regional population decline of –5.4% per year during 2006–2018, primarily due to losses during 2011–2012 with declines of –7.5% per year within the core breeding range in Finland. Census and monitoring programmes are needed to reliably determine the species' distribution, population size and trends (BirdLife International 2022). Research on its habitat requirements and reproductive success on the breeding grounds should also be undertaken to help inform conservation actions (Tucker & Heath 1994).

The Broad-billed Sandpiper is one of a suite of migratory waders, including Spotted Redshank *Tringa erythropus* and Jack Snipe *Lymnocryptes minimus*, that are characteristic species of mires and associated habitats in the sub-Arctic taiga biome (Nisbet 1961, Järvinen & Väisänen 1978, Rae *et al.* 1998). The mire complexes are a heterogeneous mixture of open water, wet fen habitats dominated by sedges (*Carex* spp.), and bounded by upland areas with heath or birch woodland (Tahvanainen 2011, Borge *et al.* 2017, Hofgaard *et al.* 2020). Broad-billed

Sandpipers breed in mires ranging from below 100 m in altitude in northern Norway and Russia (Thingstad 1995, Rae *et al.* 1998), to alpine mires at 780 m in central Scandinavia (Green *et al.* 2009, Østnes & Kroglund 2015), and historically they also bred in meadows in southern Sweden (Bangjord 1994). The species has been poorly studied in northern Europe with few records of nesting birds and no demographic data from breeding populations. Further, few species-specific surveys have been conducted for Broad-billed Sandpipers in Fennoscandia (Hildén 1981, Østnes & Kroglund 2015). Breeding birds are difficult to monitor due to their cryptic plumage, skulking behaviour, and the difficulty of accessing and traversing their nesting habitat, which is restricted to wet quaking fen in aapa mires (string bogs; Rae *et al.* 1998, Ratcliffe 2005).

The goals of our long-term field study were to assess patterns of habitat use, survey numbers of nesting pairs in specific areas, monitor their nesting success, and assess site and mate fidelity of individually marked birds. Here, we provide some of the first data on aspects of habitat use, behaviour, and reproductive ecology for a breeding population of Broad-billed Sandpipers. Basic information on the habitat requirements and breeding behaviour will aid development of survey and monitoring techniques and guide conservation efforts for Broad-billed Sandpipers and their breeding habitats in the taiga biome.

METHODS

Study area and study species

Our field study of nesting birds was conducted during the 27-year period of 1993–2019 in the Kautokeino Municipality in Troms and Finnmark, north Norway (68°55'N; 23°10'E, altitude 350–400 m asl). Descriptions of the breeding habitat and preliminary data from the first four years (1993–1996) were previously published by Rae *et al.* (1998). We ringed incubating birds during 1995–2019, recorded nesting data from 2000–2019, and conducted intensive monitoring with repeated visits to nests to estimate nest survival in 2009–2019. The study area was surveyed for 10–14 days each year in the 3-week period between 15 June and 8 July. The study area consisted of three areas of mire in adjacent valleys within 2 km of each other and another area of mire 30 km to the south. The mires varied in size, approximately 10–100 ha, and there were only small areas of suitable nesting habitat within these mires (Fig. 1). Climatic data were taken from the nearest weather station at Kautokeino which is <30 km from all study sites (Station SN93700; Norwegian Meteorological Institute 2021).

Broad-billed Sandpipers are the last of the breeding waders to arrive on their Finnmark breeding grounds at the end of May and the beginning of June (Svensson 1987,

Fig. 1. Searching for Broad-billed Sandpipers nesting in wet quaking fen, Finnmark, Norway. The main breeding habitat is in the foreground, wet quaking mesotrophic fen. The dominant plants are sedges *Carex* spp. and Cottongrass *Eriophorum angustifolium* above a floating mat of dark brown bryophytes, mostly *Sphagnum lindbergi* (Rae *et al*. 1998). There was often open water in the centre of these stands, and heath and woodland cover the surrounding drier peaty ridges. The dominant heath species are Lingonberry *Vaccinium vitis-idaea* and Cloudberry *Rubus chamaemorus*. The main trees are Downy Birch *Betula pubescens,* Dwarf Birch *B. nana*, and willows *Salix* spp. (photo: Stuart Rae).

Fig. 2. (a) A Broad-billed Sandpiper nest set on a mossy hummock in a wet mire. The pink flowers are Bog Rosemary *Andromeda polifolia*, and the bright green leaves are Dwarf Birch *Betula nana*. **(b)** A Broad-billed Sandpiper sneaking off its nest upon the approach of an observer (photos: Stuart Rae).

Ratcliffe 2005). North-bound migrating birds leave the Sivash marshes in the Black Sea from the 24 May onwards (Verkuil *et al.* 2006). Spring migration has been recorded through Ottenby, southern Sweden and coastal sites in Estonia during 17 May–7 June (Waldenström & Lindström 2001, Pehlak 2008). By the time Broad-billed Sandpipers arrived at our study area, most of the other species of waders were already incubating eggs, including Ruff *Philomachus pugnax*, Spotted Redshank and Wood Sandpiper *Tringa glareola* (Ratcliffe 2005). The main nesting period for Broad-billed Sandpipers was June and chicks hatched from late June onwards (R. Rae pers. obs.).

General field methods

The breeding habitat was searched by walking across a mire, watching for birds or nests in a meandering route to cover all potentially suitable nesting habitat. Nests (Fig. 2a) and incubating birds were difficult to locate because Broad-billed Sandpipers are secretive, tight-sitting, and solitary (Bannerman 1961, Ratcliffe 2005). Some birds flushed off their nest when approached within *ca.* 10 m, while others sat tight on their nests even when a person was standing over them. Each observer carried a 2 m stick for aid in walking across the mire, and used the stick to wave over or tap nearby vegetation to increase the likelihood of flushing any tight-sitting birds from their nest. Some birds gave distraction displays and calls when they left the nest while others crept silently off their nests (Fig. 2b), with the nest and eggs sometimes found before the incubating bird was observed. Some nests were only viewed from a distance of several metres, because many nests were located in treacherous locations (Rae *et al.* 1998) and could not be reached safely for the observer or the nest contents. We prioritized safety and reducing disturbance and did not collect measurements for some eggs and birds.

The GPS coordinates of the nest sites were recorded and mapped precisely with respect to distinctive vegetation or moss hummocks. Nest sites were all rechecked in subsequent years to locate pairs reusing the same nest scrape. All areas were searched by experienced observers at least twice every breeding season. No surveys were conducted on days with rain or high winds because Broad-billed Sandpipers and other nesting waders are difficult to detect in such weather. We avoided inclement weather to reduce disturbance and any risk of the eggs being chilled. We also monitored nests of other wader species that were found in adjacent mire and heath habitats.

The length and breadth of eggs were measured using dial vernier callipers to the nearest 0.1 mm, and egg mass was measured with a digital balance 0–150 g at 0.01 g increments. The mean measurements were determined for all eggs within each clutch before calculating the mean for all clutches. Egg volume was calculated as $V = kLB^2$ where L and B were the length and breadth of the eggs and the shape coefficient $k = 0.47$ for the conical eggs of *Calidris* sandpipers (Sandercock 1998, Governali *et al.* 2012). We used egg volume to test whether older or larger females laid larger eggs. We estimated clutch mass for a 4-egg clutch based on a specific gravity of *ca.* 1.06 g per mL for fresh-laid eggs (Hoyt 1979, van Paassen *et al.* 1984). When the nest was first discovered, eggs were floated in water to determine the incubation stage to within *ca.* three days (Mabee *et al.* 2006, Ackerman & Eagles-Smith 2010). All nests were checked at least twice to ensure the clutch was complete and there was no partial clutch loss. Birds did not generally commence incubation until they had laid at least three eggs, so the number of eggs could be counted during the laying period with minimal disturbance. Eggs were checked for signs of hatch such as tapping, cracking, or pipping whenever a nest was examined, and around the expected date of hatching.

Capture and ringing

Breeding birds were caught by laying a mist net over them in the latter stage of incubation or when they were brooding chicks (Fig. 3a), and all birds were watched until they returned to the nest after ringing to ensure no adverse effects of capture. All captured birds were fitted with a unique combination of colour rings (Fig. 3b) that allowed individuals to be identified in the field without need for recapture and disturbance at the nest. There were no desertions of eggs or broods following capture and ringing. Sexes were differentiated with biometrics, using bill lengths, where the larger birds in mated pairs were assumed to be females. Bill was used as a structural measure of female size (Jönsson 1987, Sandercock *et al.* 2022). Birds were aged as second calendar year (hatched in the previous year, EURING age code 5) or older (EURING age code 6; Redfern & Clark 2001) using partial primary wing moult; second years had moult limits in the wing with greater contrast between worn inner and fresh outer primaries, whereas older birds had primary feathers that were uniform in coloration and wear (Prater *et al.* 1977, Fry 1989, Sandercock *et al.* 2022). Not all birds were captured, and the subsequent re-sighting rates of pairs were regarded as a conservative estimate of mate fidelity because pairs might have been together in the years prior to capture.

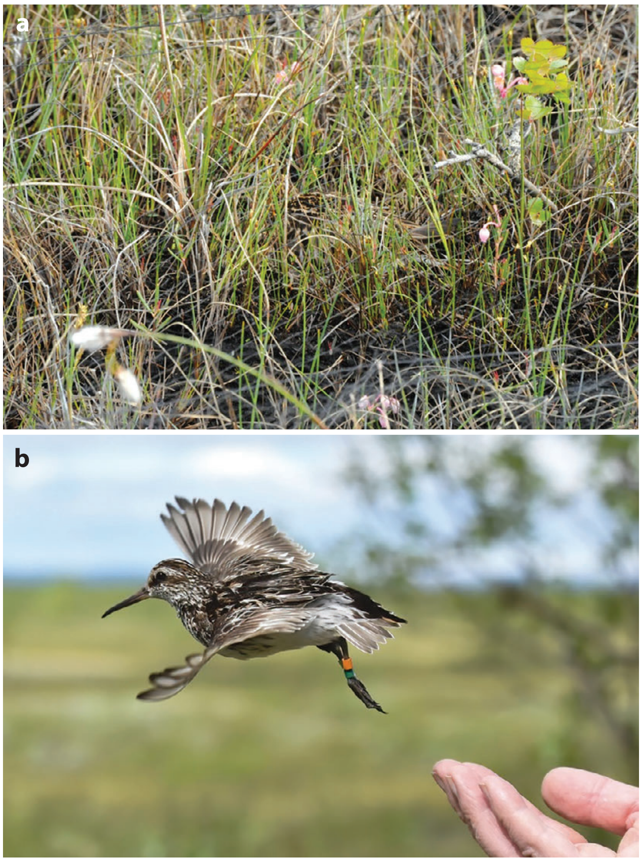

Fig. 3. (a) Capture of a Broad-billed Sandpiper with a mist nest laid over an incubating bird at the nest. **(b)** Release of a Broad-billed Sandpiper after colour-ringing (photos: Stuart Rae).

Reproductive parameters

We assessed the effect of weather conditions on laying date using Pearson's correlation tests. We compared laying dates versus the mean minimum temperature, number of days with temperature below 0° and rainfall during 16–31 May and 1–7 June, which represent the 2-week period prior to arrival of the birds on the breeding grounds and the first week when the birds begin nesting and laying eggs.

The date of the first egg laid in each clutch was calculated by back-counting the number of days of incubation from known hatching dates of chicks. Eggs were laid at a rate of approximately one per 18-hour period, as measured during the study, with a total laying period of 4 days and an incubation period of 21 days (Cramp & Simmons 1983). Our estimates of duration for the stage of incubation, through egg-flotation and consequent predictions of hatch dates were consistent with the expected incubation period. Thus, we used a total exposure period of 25 days to calculate nest success for our study population.

Sample sizes of nests per year were relatively low in 2009–2019 and we calculated daily nest survival rates with the Mayfield method (Mayfield 1961, Johnson 1979). Daily survival rates (DSR) and the standard error of the estimate were calculated from the total number of clutch losses (loss) and the cumulative number of days of exposure (exp) for the sample of nests:

$$DSR = 1 - \frac{\text{loss}}{\text{exp}} \qquad \text{SE}(DSR) = \sqrt{\frac{(\text{exp–loss}) \times \text{loss}}{-(\text{exp})^3}}$$

Days of exposure were calculated for each nest as the number of days between the first and last visit for successful nests, or as the number of days between the first visit and the midpoint between the penultimate and last visit for unsuccessful nests. The daily survival rate was then extrapolated to a 25-day period for laying and incubation to estimate the probability of a clutch hatching (S_{25}), and the standard error of the estimate was calculated with the delta method (Powell 2007):

$$S_{25} = DSR^{25} \qquad \text{SE}(S_{25}) = \sqrt{625 \times \text{SE(DSR)}^2 \times \text{DSR}^{48}}$$

The causes of nest failure were identified when possible, and effects of weather conditions and depredation on nest survival were assessed. As the study visits were generally in the latter part of the incubation period, egg loss at the beginning of the incubation period was not always known. As most chicks hatched after the surveys, hatching success was not calculated for the eggs. Any chicks that were found were weighed and ringed, and foot length was measured as tarsus plus toe for a sample of birds. The chicks that were found were all young captured in or near their nests. Chicks left their nests when 1–2 days old to disperse widely in the mires and were seldom seen again; hence brood survival after nest departure could not be measured.

RESULTS

Observations of local ecological conditions

Potential mammalian predators observed in the area included Red Fox *Vulpes vulpes* and Stoat *Mustela erminea,* which were seen with voles as prey but never with birds. One adult Broad-billed Sandpiper was found dead on a breeding mire on 20 Jun 2007. It was evident from the plucked feathers and body parts left that it had been eaten by a raptor, presumably a Merlin *Falco columbarius* which was the most frequently observed raptor in the study area. In most years, we encountered egg fragments of other wader species that were suspected to have been eaten by birds. The main potential nest predators observed were Hooded Crow *Corvus cornix* and Common Raven *C. corax.* Common Crane *Grus grus* and Long-tailed Skua *Stercorarius longicaudus* were also potential predators but were less frequently observed in the area.

Norway Lemmings *Lemmus lemmus* and Grey-sided Voles *Myodes rufocanus* were abundant at our study area in only one year (2011), when unusually high numbers were also recorded at Joatka, a long-term monitoring site northeast of our study site (69.8°N, 23.9°E, site 35 of Ehrich *et al.* 2020). Local residents observed high numbers of rodents in October 2010 and the encounters lasted through the following summer of 2011. Single birds and pairs of Raven and Hooded Crow were frequently seen hunting rodents, by flying low or from perches on the larger tussocks (45–60 cm high) in the marshes. Such tussocks are often used as nest sites by Ruff and Wood Sandpiper and many eggs of these wader species were found depredated in 2011. However, we found no Broad-billed Sandpiper eggshells that might have been depredated by corvids in this season. The lemming and vole populations apparently crashed in late autumn 2011, and we found frozen corpses exposed when the snow melted in 2012. Flocks of up to 30 Hooded Crows were observed hunting the area and eating the thawed remains, and again, there were many depredated eggs of both Ruff and Wood Sandpiper. In 2013, no carcasses or live lemmings or voles were observed, and the abundance of Hooded Crows was low.

Habitat selection

Broad-billed Sandpipers were found in the study area in wet quaking mesotrophic fen within larger expanses of aapa mire (Fig. 1), which birds used for both feeding and nesting. The mire habitat overlays a permafrost layer which thawed as the breeding season progressed and the water depth around the nests increased. The last snow cover usually disappeared from the breeding grounds by mid-May (Norwegian Meteorological Institute 2021). Broad-billed Sandpipers sang while performing aerial courtship displays directly over the breeding mires at a height of 10–25 m, most usually about 15–20 m and both sexes appeared to take part in these displays. Flight displays in our study area lasted for 2–5 minutes at a time, occasionally up to an hour, and were observed at all times of the day except around noon. Displaying birds would also fly repeatedly around a mire giving trilling song displays. We observed flights of up to five birds of unknown sex or origin in rapid chasing displays where the birds flew in tight formation with partially swept wings. Some breeding areas were found after observing birds display over a part of a mire, and nests were subsequently found in these locations. Song was most often heard prior to and during egg laying, although display continued through incubation when short bursts of song were sometimes heard following a changeover between an incubating pair. Birds made several scrapes in close proximity to the actual nest site selected, which provided a clue to the likely presence of an active nest.

Nesting ecology

A total of 173 Broad-billed Sandpiper nests were found in the main survey areas in the years 2000–2019, with an average of eight nests per year (range: 2–16; Fig. 4). There were two peaks in numbers of Broad-billed Sandpiper nests, in 2002 and 2016, and the largest drop in numbers was in 2012. A further 19 nests were found in nearby mires although none of the incubating birds at these nests were ringed. All nests were located in or on the edge of wet quaking mesotrophic floating fen within larger stands of aapa mire. The immediate nesting habitat around a nest was usually an area of floating bog vegetation with drier tussocks of String Sedge *Carex chordorrhiza* and Bog Rosemary *Andromeda polifolia.* Nests were typically set in a shallow scrape on a tussock of vegetation or mossy hummock and lined with dry dead sedge (Fig. 2a). The nests were set *ca.* 5–10 cm above the water level. Broad-billed Sandpipers were not recorded nesting or feeding in any other habitat than the wet fens (Rae *et al.* 1998). Wood Sandpiper, Ruff and Spotted Redshank were observed feeding in the wet fens. The only other bird nest found in the same habitat was a single nest of a Red-necked Phalarope *Phalaropus lobatus* but a total of 532 wader nests of 18 other wader species were found in adjacent wetland and heath habitats.

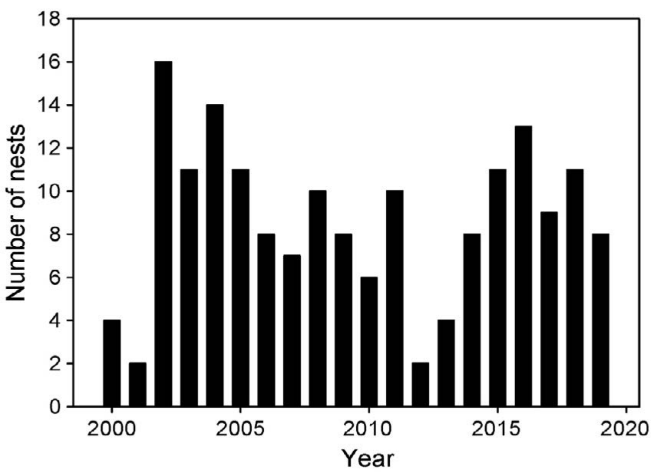

Fig. 4. The number of nests of Broad-billed Sandpipers found per year at Kautokeino, Norway in 2000–2019 (*n* = 173).

The closest nests of Broad-billed Sandpipers that were simultaneously active were only 2 m apart but that was observed only once. Clusters of up to five nests were found in different areas of *ca.* 300 m^2 on two occasions, but most nests were solitary and >100 m from their nearest neighbour. Some nesting areas were abandoned completely, including the nesting area where five pairs had previously bred, when the underlying ice rose and the mire drained. The opposite situation also occurred when pairs colonized two nesting areas after the ice level in a mire dropped. One of these areas subsequently held up to five pairs per year.

Clutch size and egg size

A total of 156 complete clutches were attended by incubating birds: 146 of four eggs (94%), five of three eggs, two of two, one of one, one of five eggs and one of six. We observed no cases of egg loss due to partial clutch predation during repeated visits to nests. The clutch of six eggs included two sets of three eggs with distinct patterns of egg colouration that could have been due to two females laying in the same nest scrape. The clutch of five eggs was in a nest 10 m from a nest with a clutch of three eggs, and one egg in the larger clutch was different in colouring from the others in the nest but similar to those in the smaller clutch. Therefore, one bird was considered to have laid one egg in the neighbouring nest. The three nests were omitted from further analyses.

The dimensions of 365 eggs of 95 clutches (mean ± SD) were: egg length = 31.7 ± 1.01 mm (range: 29.0–34.1 mm) and egg breadth = 22.7 ± 0.05 mm (range: 21.2–24.4 mm). One abnormal egg was excluded because it was noticeably deformed with a long and narrow shape (33.3 x 20.0 mm). The mean volume per egg of those laid by second-year (8.65 ± 0.23 cm^3) and older females (8.79 ± 0.43 cm^3) did not differ significantly (ANOVA: $F_{5,11}$ = 0.472, P = 0.503). Egg volume was not related to female size (R^2 = 0.011, P = 0.70, df = 1,14). Based on a specific gravity of 1.06 g per mL for fresh-laid eggs, the mean mass of a 4-egg clutch of Broad-billed Sandpipers was estimated to be *ca.* 37.0 g. The mean clutch mass measured during incubation was lighter at 31.6 g (n = 68), which was expected because eggs normally lose mass during embryonic development.

Laying dates

The mean date for the initiation of clutches in years 2009–2019 was 10 June (range: 1–24 June, n = 91; Table 1). One replacement clutch of four eggs, following nest failure of a previous nesting attempt by marked birds, was initiated on 22 June 2015. Small clutches with fewer than 4 eggs were initiated significantly later: mean 20 June (ANOVA, $F_{7,79}$ = 19.3, P = 0.001). Clutches of three eggs were initiated on 17, 20 and 22 June, two eggs on 14, 20 and 21 June and the single egg clutch on 24 June. Birds also initiated laying earlier in years with higher minimum temperatures in the first week of June (Pearson's correlation: r_p = −0.75, P < 0.01, n = 11). Late May temperatures and rainfall in May and June had no significant effect on laying date. There were too few records of known age birds within any year to test whether older birds laid earlier or later.

Table 1. Annual variation in temperature and rainfall, laying dates when clutches were estimated to have been initiated, and Mayfield estimates of daily survival rates for nests of Broad-billed Sandpipers at Kautokeino, Norway, 2009–2019.

	Mean minimum temperature (°C)		Total rainfall (mm)		Laying date in June			Mayfield estimates of daily survival rate (DSR)		
Year	May 16–31	June 1–7	May 16–31	June 1–7	Mean	Range	Nests	Losses	Exposure	DSR ± SE
2009	2.3	1.2	27.9	51.1	11	1–24	8	0	57	1.0000
2010	3.1	1.8	23	111.4	14	10–16	6	0	35	1.0000
2011	4.5	4.7	39.9	77.5	9	1–17	10	0	45	1.0000
2012	–3.3	3.5	21.6	23.9	3	2–3	3	0	-	-
2013	4.2	8.2	26.3	37.2	2	1–3	4	0	9	1.0000
2014	1.1	7.3	34.9	48.5	7	3–11	8	0	63	1.0000
2015	1.4	3.8	61.5	33	8	3–22	11	1	65	0.9846 ± 0.0153
2016	3.6	3.3	18.6	100.5	10	2–22	13	4	91	0.9560 ± 0.0215
2017	-0.3	1.2	10.7	55.9	15	12–24	9	3	47	0.9362 ± 0.0357
2018	3.3	3.2	24.4	75.3	9	2–24	11	0	48	1.0000
2019	1.5	4.6	54	91.9	5	2–20	8	0	34	1.0000
All							91	8	494	0.9838 ± 0.0057

Fig. 5. (a) An unsuccessful nest of a Broad-billed Sandpiper that failed due to flooding, with three dead chicks and one unhatched egg (photo: Ian Francis). **(b)** A successful brood of newly hatched chicks of Broad-billed Sandpipers (photo: Stuart Rae).

Nest success and cause of failure

In 2009–2019, we monitored and determined nest fate for 91 nests and recorded eight losses in a total of 494 days of exposure (Table 1). The median number of days of exposure per nest was 6 days (range: 1–17 days). Overall Mayfield estimates of daily nest rates were 0.9838 ± 0.0057 SE (95% CI = 0.9727–0.9949). When extrapolated to a 25-day exposure period for the duration of a nesting attempt, and assuming that daily survival rates were constant across the incubation period, the estimated nest success was high at 0.665 ± 0.096 SE (95% CI = 0.476–0.853). The highest failure rate was in 2016 when three of four cases of nest loss were due to flooding and one to depredation. Two nests were flooded in June when rainfall for the month was particularly high (100.5 mm vs. a mean of 58.5 mm in 1991–2020). Almost half of the total rain fell on one day within the main incubation period (18 June). The third nest was found flooded with three dead chicks and an unhatched egg on 7 July (Fig. 5a), the third of three days of rain totalling 58.4 mm. The second highest annual failure rate occurred in 2017 when three losses were due to flooding while birds were incubating. A total of 50.2 mm of rainfall (*ca.* 86% of the month) fell during a prolonged wet period during 19–27 June. One nest was lost to an unknown cause in 2015.

Newly hatched chicks

The surveys were generally completed before chicks hatched but we recorded measurements for six recently hatched broods (Fig. 5b). Newly hatched chicks were ringed from two broods on 29 June 2014, one on 1 July 2007, two on 2 July 2007, and one on 7 July 2016. Foot length was measured for two broods; the mean length was 39 mm (range: 38–40). The mean mass of five broods of hatchling Broad-billed Sandpipers was 5.72 g (range: 4.9–6.4 g; Table 2). Broods 4 and 5 were still in their nests when measured, and all of the others within 5 m of their nest. A total of 34 chicks were ringed from eight broods but none were subsequently observed returning to the study area or nearby sites.

Table 2. Biometrics of newly hatched chicks of Broad-billed Sandpipers at Kautokeino, Norway.

Brood	Foot of each chick (mm)	Mean foot (mm)	Mass of each chick (g)	Mean mass (g)
1	39, 40, 39, 39	39.3	6.4, 6.4, 5.8, 6.4	6.25
2	39, 39, 38, 39	38.8	5.8, 5.7, 5.3, 5.5	5.58
3			5.8, 5.3, 5.4, 5.3	5.50
4			6.2, 6.3, 6.0, 6.2	6.18
5			5.0, 4.9, 5.4, 5.1	5.10
Means		39		5.72

Site and pair fidelity

Breeding birds that returned in subsequent years usually nested in the same mire (97%). Only two birds moved between mires: one was a second-year female that had a single egg clutch at the first mire and moved approximately 1,320 m. The other, also a female, moved 740 m to a new nest site when the previously used mire dried out. A minimum of six pairs of birds were faithful to each other, among 31 pairs marked prior to the last year of study: one pair were together for a minimum of two years, one pair were recorded together in their third year but were not observed in the second year, three pairs were together for three consecutive years, and one pair for five years. There were two cases where one member of a pair had previously been paired with a different partner, but in both cases the absent bird was not seen again. A total of 14 nest scrapes were repeatedly reused in multiple years: five for two years, five for three, one for four, one for five and one for nine, and one nest was used for two years then there was a year's gap followed by three more years of use. The nest site that was used for nine years was used each time by the same male. After the bird was killed by a predator, the nest scrape was not used again although the local nesting area was used again by another breeding pair.

DISCUSSION

Our long-term field study of the breeding ecology of Broad-billed Sandpipers in northern Norway provides some of the first estimates of reproductive parameters for a poorly known species of Palearctic wader. The species is unusual among the wader species that breed in the taiga ecosystem because its breeding strategy involves two special features: it is one of the last migratory species to arrive to the breeding ground, and it is the only bird species that nests in the floating vegetation of aapa mires. The combination of late arrival and synchronous breeding in June, inconspicuous behaviour while nesting, and use of a treacherous nesting habitat in the wettest parts of mire complexes at a distance from trees and other perches appears to result in low levels of nest loss to mammalian and avian predators. The breeding strategy does leave the species vulnerable to flooding of nests through changes in the hydrology of their nesting habitat, from shifting water levels with underlying ice levels and also unusually heavy rainfall during incubation (Kivinen *et al.* 2017). Hydrological effects through changes in the underlying permafrost can also apparently lead to complete loss of breeding habitat by natural drainage dynamics (Borge *et al.* 2017). Such weather-related factors were indicated by our study, which suggests that Broad-billed Sandpipers may be especially vulnerable and an indicator species for deleterious effects of climate change.

Broad-billed Sandpipers began laying earlier in warmer years when their nesting habitat was more likely to be snow-free, as with other Arctic-breeding waders (Smith & Wilson 2010). Early laying would have given the birds a higher chance to successfully breed, as migrant birds that arrive early on their breeding grounds generally have higher breeding success (Morrison *et al.* 2019). In Northern Wheatear *Oenanthe oenanthe*, older males that return to the breeding territories first are more likely to pair and breed (Currie *et al.* 2000) and many Arctic wader species show seasonal declines in reproductive traits (Weiser *et al.* 2018). Individual birds showed strong fidelity to the aapa mire habitat described by Rae *et al.* (1998), often returning to pair with the same mate and frequently reusing the same nest scrape. Most pairs nested solitarily but also sometimes in loose clusters. The clutch size was typical of most waders with a modal clutch of four eggs. Similarly, the estimated total mass of a fresh-laid 4-egg clutch (37.0 g) was a large investment at *ca.* 96% of the average body mass of females (38.6 g; Sandercock *et al.* 2022). Smaller clutches mainly occurred later in the season. We confirmed at least one renesting attempt and smaller clutches were likely to be repeat clutches. Repeat clutches were also more likely to be smaller in a suite of Arctic breeding waders (Weiser *et al.* 2018). We found no difference between the laying dates or clutch sizes of second-year and older birds.

Broad-billed Sandpipers had high nest survival with no nest losses in many of the study years. Estimates of nest survival based on constant estimates can be biased if daily nest survival varies with nest age due to changes in nest concealment or predation risk (Weiser 2021). Bias was unlikely to be an issue here because daily nest survival was high and the main cause of nest failure was flooding, which was often due to high rainfall in June. Broad-billed Sandpipers build their nests low in the mires, often little more than wet scrapes on floating vegetation and seldom more than 10 cm above the water (Rae *et al.* 1998). Such nests would be vulnerable to flooding if water levels were to rise. Although nest flooding was uncommon in the study period and did not occur in most years, if climate change continues, increases in extreme summer rainstorms could become a threat to their breeding success (Kivinen *et al.* 2017). Losses to egg depredation were rare, which is unusual compared to many other species of waders (Kubelka *et al.* 2018, Weiser *et al.* 2018). Nests of Broad-billed Sandpipers may have low predation risk because breeding pairs nest at low densities in an unusual habitat that contains few other species of breeding birds. The mire habitats may be less rewarding for foraging predators than adjacent habitats where other nesting waders and passerines were more abundant. Predators were seldom observed hunting the wet fens used by Broad-billed Sandpipers, presumably because mammals have difficult access and few perches are available for corvids to hunt from. Alternatively, predation risk may be low because Broad-billed Sandpipers are late breeders in the taiga ecosystem. Predation risk declines seasonally in Arctic-breeding waders (Weiser *et al.* 2018), possibly because nest predators shift their attention to alternative food sources as the season progresses (Smith & Wilson 2010).

The breeding habitat of Broad-billed Sandpipers is dynamic and can change over years, due either to drying out or to water levels rising (Borge *et al.* 2017, Hofgaard *et al.* 2020). Changes in hydrology likely affect the habitat suitability of these marshes for breeding pairs of Broad-billed Sandpipers. Such changes could have led to the observed fluctuations in the numbers of breeding birds per year, when sites that had been occupied for a number of years were abandoned and then reoccupied in future years. If local breeding conditions are not favourable because of early snow melt or drought, the birds could move elsewhere to breed or may not breed. Only two birds were recorded moving between mires, both to adjacent marshes less than 2 km distant. Birds nesting in mires in our study area could also have been using sites that were inaccessible for surveys. Our estimates of dispersal are likely conservative because it is possible that some nests were not found within the survey area or beyond. If Broad-billed Sandpipers can live for 5+ years (Sandercock *et al.* 2022), they might forego breeding attempts in an unfavourable year to return and breed the following year.

Implications for monitoring and conservation

Line transect surveys for waders typically rely on flushing birds to detect them. Broad-billed Sandpipers breed in a habitat which few other species of birds use, and which is difficult, often unsafe, for surveyors to access. The species is largely silent, secretive, and tight-sitting, and off-duty birds never give alarm calls when they or the nest are approached. The Norwegian name for the Broad-billed Sandpiper is 'fjellmyrløper', which translates as 'mountain mire runner', which is an apt description of how the birds prefer to run through the mire instead of flying, and are thus less likely to be detected with standard survey methods. In a comparison between line transects and complete census of mire birds in Finland, the Broad-billed Sandpiper had one of the lowest efficiencies of detection among ten bird species at 32% (Hildén 1981). Therefore, results of any standardized survey protocol based on line transects or point counts, and any subsequent baseline numbers for the species established by this method, could be misleading. Given the fluctuations in annual numbers recorded in this study through standardized focussed survey methods, it would be difficult to determine if population numbers are stable with monitoring conducted once every several years. The methods described in this paper give repeatable results, but are also time-consuming and not suitable for inexperienced observers. We suggest the Broad-billed Sandpiper is a species which needs a specific survey method to ensure accurate monitoring of population numbers.

The Broad-billed Sandpiper is classified as Least Concern on the IUCN Red List (BirdLife International 2015, 2022), but remains one of three wader species with long-term population declines in Fennoscandia (Lindström *et al.* 2019). No large-scale threats to Broad-billed Sandpipers or their breeding habitat were identified in Europe during the 1990s (Tucker & Heath 1994, BirdLife International & EBCC 2000), although loss of mire habitats has likely caused local extinctions in Fennoscandia (van Gils *et al.* 2020). Drainage and conversion of mires to agricultural or forestry production remains a threat in the core breeding range in Finland (Lindholm & Heikkilä 2006). Loss of permafrost due to climate change is affecting the hydrology and vegetative succession of mire habitats in Finnmark (Borge *et al.* 2017, Hofgaard *et al.* 2020), which will likely affect the suitability of breeding mires for nesting sandpipers. Much of the remote breeding habitat still remains intact, but our estimates of nest survival and causes of nest failure show that reproductive success could be impacted by future changes in hydrology or weather patterns. The survival of young and juvenile recruitment remain the main unknown elements in the breeding ecology of Broad-billed Sandpipers, although these demographic parameters will be difficult to assess for a bird that is challenging to study. Conservation efforts in the breeding grounds should be focused on habitat preservation, particularly maintaining the natural hydrology of the breeding mires.

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