








RESEARCH NOTE

First breeding events of the pectoral sandpiper (*Calidris melanotos*) in north-east Greenland: a harbinger of breeding range expansion?

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Abstract

Tundra ecosystems are increasingly affected by the warming associated with climate change and the resulting poleward shift of animal and plant populations. The breeding ranges of some migratory waders nesting in the Arctic already appear to be shifting or expanding in response to the rising temperatures. The pectoral sandpiper (*Calidris melanotos*) is a wader whose breeding range normally extends from western Siberia to eastern Canada. However, three breeding events (involving three different females) have been documented since 2016 in north-east Greenland at two sites with long-term monitoring. These are the first records of breeding of this species in east Greenland, a region that is 1700 and 2800 km from the two nearest known breeding populations in north-east Canada and western Siberia, respectively. The three nests contained four eggs each, which were incubated normally; they did not hatch and were probably unfertilized. The origin of the birds is unknown, but these recent and repeated events, in a region where observation effort is generally limited, could indicate an ongoing expansion of the pectoral sandpiper's breeding range in the North-east Atlantic region.

Keywords

Climate change; distribution; range shift; tundra; waders

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Abbreviations

GPS: Global Positioning System
IBCAO: International Bathymetric Chart of the Arctic Ocean
IUCN: International Union for Conservation of Nature

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Introduction

The breeding ranges of species are dynamic and some are shifting in response to ongoing global warming (Thomas 2010; Walther 2010). Climate change-induced modifications in the availability of breeding habitats and biotic interactions, such as predation or competition, lead to movements and therefore to new distributions (Blois et al. 2013; Platts et al. 2019). In most species, range boundaries are expected to expand to higher altitudes or latitudes, or eventually in east-west directions across longitudes, when and where breeding conditions become suitable for these species (Chen et al. 2011; Lenoir & Svenning 2015). Such range expansions can be rapid, e.g., in species with high dispersal ability (Berggren et al. 2009).

Since polar habitats are heavily impacted by the ongoing climate change, and range shifts are mainly poleward, Arctic terrestrial ecosystems are projected to be affected in their species composition (van Beest et al. 2021). In Arctic birds, there is little evidence that shifts in their distribution are currently underway (reviewed by Lameris et al. 2021). Nevertheless, among Arctic-breeding waders, range shifts have recently been documented in some species, including the pectoral sandpiper (*Calidris melanotos*; Anderson et al. 2023). This species, characterized by strong sexual size dimorphism and a polygynous mating system, usually breeds on the flat and wet tundra found in coastal plains (Pitelka et al. 1974). The nest, a steep-sided scrape containing a large amount of lining material, is located in relatively dry spots (e.g., hummocks) within the marshy tundra (Cotter & Andres 2000; Reid

et al. 2002). Parental care, i.e., incubation and chick rearing, is provided exclusively by the female (Farmer et al. 2013).

The current breeding range of the pectoral sandpiper is vast and extends from the Yamal Peninsula to the Chukotka Peninsula in north-eastern Siberia in Russia and from western Alaska to eastern Canada in North America (O'Brien et al. 2006; Fig. 1a). The American part of the breeding range has recently expanded eastward to several sites in north-east Canada (Lecomte & Giroux 2015; Richards & Gaston 2018; Fig. 1a). Occasional breeding also likely occurs in the western Palearctic, in European Russia (Hagemeijer & Blair 1997; Lappo et al. 2012). The northernmost breeding sites are on Devon Island (Canada) and the Taimyr Peninsula (Russia).

The North American population winters in southern South America, from southern Bolivia to the southernmost Argentina, and migrates southwards along a narrow flyway through the interior of North America (del Hoyo et al. 1996; Skagen et al. 1999). Siberian breeders apparently also use the same wintering grounds and therefore first migrate eastwards in autumn to join the North American flyway (Paulson 1993). However, a small

number of pectoral sandpiper, presumably from Siberian populations, use an alternative migratory route through East Asia and winter in south-east Australia, New Zealand and some central Pacific islands (Geering et al. 2007; Marchant et al. 2010). The pectoral sandpiper is also described as a global vagrant, with annual observations in Europe, Africa, the Middle East and the Indian Subcontinent (see Rajeevan et al. 2014), which may facilitate its range expansion in a context of climate change.

Here, we document the first known breeding events for this species in north-east Greenland, far away from their known breeding range, and discuss a possible ongoing range expansion.

Materials and methods

To gain a detailed picture of the sightings and breeding records of pectoral sandpiper in north-east Greenland for the period 1975–2024, we began by summarizing information collected by three ongoing long-term ecological monitoring programmes at Hochstetter Forland (75.1°N, 19.7°W; since 2010), Zackenberg (74.4°N, 20.5°W;

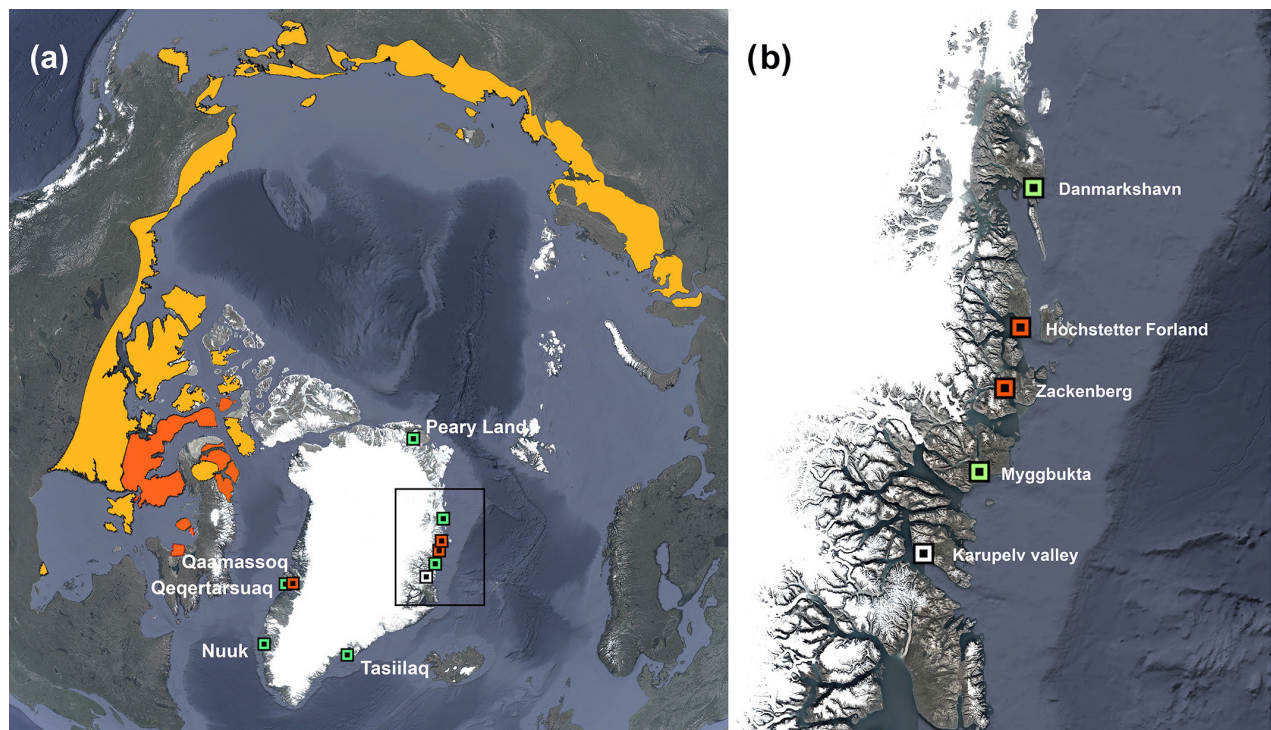


Fig. 1 (a) The known breeding range of the pectoral sandpiper, according to the IUCN Red List of Threatened Species (yellow) and the recent range expansion in eastern Canada (orange), with coloured squares indicating all sites in Greenland where the species has been observed during the period 1975–2024. The locations where non-breeding birds were reported are represented by green squares, breeding sites by orange squares, and the Karupelv valley monitoring site—where none was observed in 1988–2024—by a white square. (b) A close-up of north-east Greenland. Background maps were extracted from Google Earth Pro 7.3.6 (2024; map data: Google, Landsat/Copernicus, IBCAO).

since 1996) and Karupelv valley (72.5°N, 24.0°W; since 1988; Fig. 1b). The study sites consist of flat coastal plains with sandy shores and broad valleys with partially bare hills. They are covered by a mosaic of dry tundra with dwarf scrub heath (e.g., *Cassiope tetragona*, *Dryas octopetala*, *Salix arctica*) and wet fens (Elberling et al. 2008). At each site, nests of all species in the genus *Calidris* are searched for and monitored throughout the summer. Located nests are georeferenced using GPS and eggs are floated to determine laying date (Mabee et al. 2006; Liebezeit et al. 2007). The floatation method does not affect egg hatchability (Hansen et al. 2011). In nests of pectoral sandpiper, eggs were also measured—length and breadth to the nearest 0.1 mm with a vernier calliper and volume estimated following Governali et al. (2012)—to assess the female's investment in breeding. Eggs unhatched by the end of the breeding season were opened to check embryo development. If birds were trapped (using a clap net or a walk-in trap) and ringed (under the Danish ringing scheme) as part of our long-term monitoring, we measured bill, total head and tarsus lengths with a vernier calliper (0.1 mm accuracy), wing length with a stop ruler (accuracy: 0.5 mm) and weight with a Pesola scale (accuracy: 1 g). To monitor incubation behaviour, i.e., parental investment, we additionally deployed a temperature probe (Flylead thermistor PB 5009 with 60 cm cable) in each nest, attached to a wooden skewer and placed at the centre of the clutch, coupled to a Tinytag Plus2 TGP-4020 data logger (Gemini Data Loggers Inc.; see, e.g., Meyer et al. 2020; Meyer et al. 2021; Etchart et al. 2024). The probe is levelled with the top of the eggs to be in contact with the adult's brood patch. We used Tinytag Explorer 5.2 software to export and visualize the data.

We then browsed and reviewed all the data available in the ornithological literature and in the Danish Rarity Committee reports (available on the internet at <https://www.dof.dk/aktiv-i-dof/grupper-og-udvalg/sjaeldenhedsudvalget/su-arsrapporter>).

Lastly, we mapped the new breeding sites and all sightings in Greenland to compare them to the known breeding distribution of the pectoral sandpiper (BirdLife International 2024).

Results

Sightings of individuals and discoveries of nests of pectoral sandpiper occurred at two of the three study sites (Fig. 1b). At Hochstetter Forland, we recorded three single adults in three different years between 2010 and 2024 (Fig. 2). The first bird was seen on 27 July 2015 in a marshy area with no evidence of breeding. We discovered a first nest with four eggs on 18 July 2023 (location:

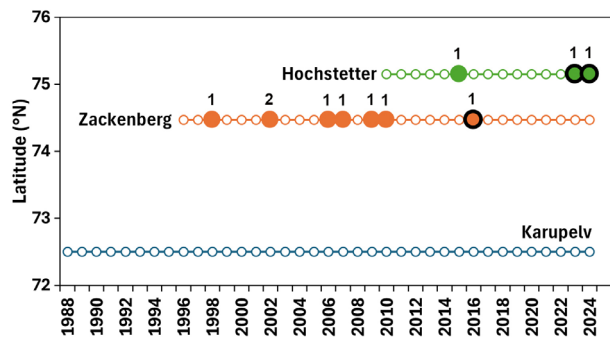


Fig. 2 Temporal and latitudinal sequence of observations of pectoral sandpiper made at the three long-term study sites in north-east Greenland (i.e., with constant annual observation effort). Circles represent surveyed years, filled circles years with bird record(s) and black-bordered circles years with a breeding event. Numbers above circles indicate the number of individual observed.

75.14988°N, 19.75587°W) after following a female whose discreet behaviour suggested it was returning to its nest. The female was ringed the next day and was still incubating when we left the study site on 29 July, despite a hatching date estimated on 23 July. We revisited the nest the following summer and found that it contained unhatched eggs—without embryos—from the previous year. On 12 July 2024, we found another nest with four eggs (location: 75.16539°N, 19.75785°W) being incubated by an unringed female. Hatching was expected on 29 July, but the nest was abandoned that day, after an irregular incubation pattern that included two long recesses the previous day. Here again, eggs had no embryos. Both breeding events took place in the transition zone between dry and wet tundra, and were located 900 and 2600 m from the shore, respectively.

At Zackenberg, eight individuals were recorded over seven seasons between 1996 and 2024, i.e., one per season except for 2002, which had two (Fig. 2). All but one of the birds were adult females. In 2007, a male pectoral sandpiper was observed displaying close to a female dunlin (*Calidris alpina*; Hansen et al. 2009). A nest with three eggs was discovered on 16 June 2016 (location: 74.48512°N, 20.55600°W), about 5 km from the shore. On the next visit, the nest contained a full clutch of four eggs. The laying sequence suggested that the first egg was laid on 14 June and hatching would be expected around 8 July. A male dunlin—a species with biparental incubation—alarmed nearby and performed a “rodent run” distraction display but was chased away by the incubating female pectoral sandpiper. The female was ringed on 7 July. The eggs did not hatch on the expected date and were incubated until at least 12 July, which was the end date of the Tinytag recording, making this incubation

minimally 26 days long. The average duration of incubation in this species is 22 days (O'Brien et al. 2006). The nest was found empty on 17 July, likely predated. Since eggs were lost before examination, their fertility is unknown, but the extended duration of the incubation period suggests that eggs were unfertilized. The nest was in an area of fens near drier low ridges dominated by sedges and grasses.

At both nesting sites, eggs were incubated following a classical uniparental pattern (Moreau et al. 2018; Meyer et al. 2021; Supplementary Fig. S1) and were assumed to be unfertilized on the basis of the absence of an embryo and the extended duration of the incubation period. The egg sizes and morphometrics for the three breeding females were comparable to those reported from Alaska (Supplementary Tables S2, S3).

In Karupelv valley, further south, no individual or nest was ever observed between 1988 and 2024 (Fig. 2).

The Danish Rarity Committee reports and Boertmann (1994; unpublished) mentioned 11 other records of pectoral sandpipers in Greenland. The only other known sightings in north-east Greenland are from Myggbukta (1979 and 1982) and Danmarkshavn (1975 and 1990). All occurred during the breeding season (between 9 June and 10 July), but no sign of breeding was reported (Fig. 1b). In west Greenland, all but one of the five known records refer to migrating birds (August and September, including juveniles): an adult with a brood was reported at Qaamassoq on Disko Island on 18 and 19 July 1983 (Nordin 1985). Only two other sightings are known from elsewhere in Greenland: one in Peary Land in northern Greenland (June–July 1995) and one with three likely migrating adults in Tasiilaq, in south-east Greenland (May 2001; Fig. 1a).

Discussion

Until now, the pectoral sandpiper has been considered an occasional breeder in west Greenland and a rare visitor in east Greenland (Boertmann 1994). However, sightings have apparently become more frequent over the past 30 years and three different females have been found nesting in north-east Greenland since 2016, about 1700 and 2800 km from the two nearest known breeding populations on Devon Island, Canada, and the Yamal Peninsula, Russia, respectively. These cases could indicate the ongoing establishment of a small breeding population in the region. However, none of the discovered clutches has hatched.

Overall, the pectoral sandpiper appears to occur more and more regularly in Greenland. Although the recent apparent extension of this species' distribution into

eastern Canada may be attributed to greater observation efforts and better documentation in this area (Lecomte & Giroux 2015), it could also reflect an actual eastward extension now reaching north-east Greenland, an area relatively little impacted by climate change for now (Abermann et al. 2017) and where breeding conditions are particularly favourable to Arctic sandpipers (Gilg & Yoccoz 2010). In a context in which the distributions of avian species respond to climate-related environmental changes along longitudinal and latitudinal gradients (Curley et al. 2020; Lawlor et al. 2024), warmer conditions in the southern fringe of its North American breeding range are probably already modifying local breeding habitats and conditions (with presumably negative consequences on breeding success) and leading to a northward range shift (Anderson et al. 2023). Hence, a spillover of Canadian populations to north-east Greenland is likely if suitable breeding conditions are found there. Female pectoral sandpipers seem to be fairly opportunistic and flexible in choosing breeding sites, although they have a preference for dry-to-moist dwarf shrub-graminoid tundra with microrelief, and they show extremely low breeding site fidelity (Saalfeld & Lanctot 2015; Cunningham et al. 2016). This behaviour makes mating opportunities for males spatially variable and therefore unpredictable, requiring nomadic movements to sample multiple potential breeding sites (Kempnaers & Valcu 2017; Krietsch et al. 2020). Such behaviours, combined with the need to seek new suitable breeding sites, could foster a range expansion to parts of north-east Greenland that are favourable for the species. However, a Canadian origin is not the only possibility. Lees & Gilroy (2004) suggested that there might be a small population of pectoral sandpipers (from unknown origin) wintering in western Africa and using the East Atlantic flyway. If so, a few of these birds could easily end up in north-east Greenland when migrating northward, searching for Arctic breeding areas. The number of birds wintering in western Africa seems to be on the rise (Barlow et al. 2022), which could explain the apparent increase in the number of birds reaching north-east Greenland. Unfortunately, we know very little about this small wintering population. Since the pectoral sandpiper is a monotypic species (del Hoyo et al. 1996), there are no significant morphometric differences between regional populations that would allow us to determine their origin.

Although some individuals settled here to breed, all found clutches failed to hatch. As no obvious abnormalities were observed in the incubation patterns or egg sizes, problems with egg fertilization can be seen as a likely cause. It seems unlikely that physiological factors in females, e.g., endocrine disorders or diseases, were

responsible for the failure of several clutches laid by different females. The absence of breeding males rather suggests that these females were not mated. Indeed, no males were observed nearby the three nest sites. In birds, dispersal is often biased in favour of females, but females have a constrained ability to seek out potential mates and may settle in areas empty of males (Dale 2001). Nevertheless, it is known that the males of this species are extraordinarily nomadic and, more importantly, that the length of their stay at a potential breeding site depends on the local mating opportunities and affects their local return probability, although very low, the next year (Kempnaers & Valcu 2017; Santema et al. 2025). Although there are a few records of male pectoral sandpipers visiting Greenland, it is reasonable to hypothesize that in north-east Greenland, where the number of females attempting to breed could be increasing, males simply do not stop yet because the females are still too few and too scattered. In polygamous waders, the return rate is often low and uncorrelated with former site experiences (Kwon et al. 2022). We might continue to find nests holding unfertilized eggs in the coming years until the density of females reaches the density threshold at which males are likely to find them, eventually resulting in a local population producing young. In addition, the case of the male dunlin that was alarming near the pectoral sandpiper nest at Zackenberg could suggest a mating attempt with a male from another (related) species as a possible consequence of this lack of mating opportunity. Although hybridization between *Calidris* species is very rare, there are a few documented records of pectoral sandpipers hybridizing with other sandpiper species (McCarthy 2006; Bisschop & Ebels 2019).

Notwithstanding the nesting failures and the low site fidelity in this species, the three recent breeding records reported in this study could very well be the first signs of an ongoing formation of a new breeding area in the North-east Atlantic region. Similar records were documented in Manitoba (south central Canada) in the 1980s and 1990s, although they did not lead to the establishment of a permanent breeding population (Richards 2022). The scantiness of the data collected in Greenland due to the very small number of sites where terrestrial birds are monitored in the long-term, may distort our perception of any range extension (Shoo et al. 2006). Since species ranges are often composed of spatially discontinuous breeding sites (Fortin et al. 2005) and can also vary from year to year (Fredston-Hermann et al. 2020), reporting any new breeding sites and continuing long-term and large-scale monitoring are both essential to detecting lasting changes in breeding ranges.

Conclusion

This study shows some harbingers of a potential breeding range expansion of the pectoral sandpiper far from its historical range, possibly related to climate change. This current trend could reflect a new dynamic underway in the Arctic. Despite limited spatial coverage, our long-term programmes provide crucial baseline information for assessing changes in the breeding distributions of Arctic species and highlight the need to continue reporting opportunistic records of any rare species in remote regions.

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Disclosure statement

The authors declare no conflicts of interest.

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References

- Abermann J., Hansen B., Lund M., Wacker S., Karami M. & Cappelen J. 2017. Hotspots and key periods of Greenland climate change during the past six decades. *Ambio* 46, 3–11, doi: 10.1007/s13280-016-0861-y.

- Anderson C.M., Fahrig L., Rausch J., Martin J.L., Daufresne T. & Smith P.A. 2023. Climate-related range shifts in Arctic-breeding shorebirds. *Ecology and Evolution* 13, e9797, doi: 10.1002/ece3.9797.
- Barlow C.R., Keita B. & Cuvelier E. 2022. More pectoral sandpipers *Calidris melanotos* in Senegal, and the first record in the Gambia. *Malimbus* 44, 66–67.
- Berggren Å., Björkman C., Bylund H. & Ayres M.P. 2009. The distribution and abundance of animal populations in a climate of uncertainty. *Oikos* 118, 1121–1126, doi: 10.1111/j.1600-0706.2009.17558.x.
- BirdLife International 2024. *Calidris melanotos*. The IUCN Red List of Threatened Species. e.T22693408A255807787. Accessed on the internet at <https://dx.doi.org/10.2305/IUCN.UK.2024-2.RLTS.T22693408A255807787.en> on 17 November 2024.
- Bisschop J. & Ebels E.B. 2019. Presumed hybrid sanderling x pectoral sandpiper on Ameland, Netherlands, in August 2017. *Dutch Birding* 41, 80–84.
- Blois J.L., Zarnetske P.L., Fitzpatrick M.C. & Finnegan S. 2013. Climate change and the past, present, and future of biotic interactions. *Science* 341, 499–504, doi: 10.1126/science.1237184.
- Boertmann D. 1994. *An annotated checklist of the birds of Greenland. Meddelelser om Grønland Bioscience* 38. Copenhagen: Commission for Scientific Research in Greenland.
- Chen I.C., Hill J.K., Ohlemüller R., Roy D.B. & Thomas C.D. 2011. Rapid range shifts of species associated with high levels of climate warming. *Science* 333, 1024–1026, doi: 10.1126/science.1206432.
- Cotter P.A. & Andres B.A. 2000. Nest density of shorebirds inland from the Beaufort Sea coast, Alaska. *The Canadian Field-Naturalist* 114, 287–291, doi: 10.5962/p.363962.
- Cunningham J.A., Kesler D.C. & Lanctot R.B. 2016. Habitat and social factors influence nest-site selection in Arctic-breeding shorebirds. *The Auk: Ornithological Advance* 133, 364–377, doi: 10.1642/AUK-15-196.1.
- Curley S.R., Manne L.L. & Veit R.R. 2020. Differential winter and breeding range shifts: implications for avian migration distances. *Diversity and Distributions* 26, 415–425, doi: 10.1111/ddi.13036.
- Dale S. 2001. Female-biased dispersal, low female recruitment, unpaired males, and the extinction of small and isolated bird populations. *Oikos* 92, 344–356, doi: 10.1034/j.1600-0706.2001.920217.x.
- del Hoyo J., Elliott A. & Sargatal J. 1996. *Handbook of the birds of the world. Vol. 3. Hoatzin to auks*. Barcelona: Lynx Editions.
- Elberling B., Tamstorf M.P., Michelsen A., Arndal M.F., Sigsgaard C., Illeris L., Bay C., Hansen B.U., Christensen T.R., Steen Hansen E., Jakobsen B.H. & Beyens L. 2008. Soil and plant community-characteristics and dynamics at Zackenberg. *Advances in Ecological Research* 40, 223–248, doi: 10.1016/S0065-2504(07)00010-4.
- Etchart L., Lecomte N., Dechaume-Moncharmont F.X., Moreau J., Lang J., Pagnon T., Sittler B., Teixeira M., Bollache L. & Gilg O. 2024. Extended incubation recesses in sanderlings are impacted by temperature and body condition. *Proceedings of the Royal Society B* 291, article no. 20232264, doi: 10.1098/rspb.2023.2264.
- Farmer A., Holmes R.T. & Pitelka F.A. 2013. Pectoral sandpiper (*Calidris melanotos*), version 2.0. In A. Poole (ed.): *The birds of North America online*. Ithaca, NY: Cornell Lab of Ornithology, doi: 10.2173/bna.348.
- Fortin M.J., Keitt T.H., Maurer B.A., Taper M.L., Kaufman D.M. & Blackburn T.M. 2005. Species' geographic ranges and distributional limits: pattern analysis and statistical issues. *Oikos* 108, 7–17, doi: 10.1111/j.0030-1299.2005.13146.x.
- Fredston-Hermann A., Selden R., Pinsky M., Gaines S.D. & Halpern B.S. 2020. Cold range edges of marine fishes track climate change better than warm edges. *Global Change Biology* 26, 2908–2922, doi: 10.1111/gcb.15035.
- Geering A., Agnew L. & Harding S. 2007. *Shorebirds of Australia*. Collingwood: Csiro Publishing.
- Gilg O. & Yoccoz N.G. 2010. Explaining bird migration. *Science* 327, 276–277, doi: 10.1126/science.1184964.
- Governali F.C., Gates H.R., Lanctot R.B. & Holmes R.T. 2012. Egg volume can be accurately and efficiently estimated from linear dimensions for Arctic-breeding shorebirds. *Wader Study Group Bulletin* 119, 46–51.
- Hagemeyer W.J. & Blair M.J. 1997. *The EBCC atlas of European breeding birds*. London: Poyser.
- Hansen J., Meltofte H. & Schmidt N.M. 2009. Bird monitoring at Zackenberg, northeast Greenland, 2006. *Bird Populations* 9, 1–12.
- Hansen J., Schmidt N.M. & Reneerkens J. 2011. Egg hatchability in High Arctic breeding wader species Charadriiformes is not affected by determining incubation stage using the egg flotation technique. *Bird Study* 58, 522–525, doi: 10.1080/00063657.2011.601411.
- Kempnaers B. & Valcu M. 2017. Breeding site sampling across the Arctic by individual males of a polygynous shorebird. *Nature* 541, 528–531, doi: 10.1038/nature20813.
- Krietsch J., Valcu M. & Kempnaers B. 2020. Wind conditions influence breeding season movements in a nomadic polygynous shorebird. *Proceedings of the Royal Society B* 287, article no. 20192789, doi: 10.1098/rspb.2019.2789.
- Kwon E., Valcu M., Cragolini M., Bulla M., Lyon B. & Kempnaers B. 2022. Breeding site fidelity is lower in polygamous shorebirds and male-biased in monogamous species. *Behavioral Ecology* 33, 592–605, doi: 10.1093/beheco/arac014.
- Lameris T.K., Hoekendijk J., Aarts G., Aarts A., Allen A.M., Bienfait L., Bijleveld A.I., Bongers M.F., Brasseur S., Chan Y.-C., de Ferrante F., de Gelder J., Derksen H., Dijkgraaf L., Dijkhuis L.R., Dijkstra S., Elbertsen G., Ernsten R., Foxen T., Gaarenstroom J., Gelhausen A., van Gils J.A., Grosscurt S., Grundlehner A., Hertlein M.L., van Heumen A.J.P., Heurman M., Huffeldt N.P., Hutter W.H., Kamstra Y.J.J., Keij F., van Kempen S., Keurttjes G., Knap H., Loonstra A.H.J., Nolet B.A., Nuijten R.J.M., Mattijssen D., Oosterhoff H., Paarlberg N., Parekh M., Pattyn J., Polak C., Quist Y., Ras S., Reneerkens J., Ruth S., van der Schaar E., Schroen G., Spikman F., van Velzen J., Voorn E., Vos J., Wang D., Westdijk W., Wind M., Zhemchuzhnikov M.K. & van Langevelde F. 2021. Migratory vertebrates shift

- migration timing and distributions in a warming Arctic. *Animal Migration* 8, 110–131, doi: 10.1515/ami-2020-0112.
- Lappo E.G., Tomkovich P.S. & Syroechkovskiy E.E. 2012. *Atlas of breeding waders in the Russian Arctic*. Moscow: Publishing House Ofsetnaya Pechat.
- Lawlor J.A., Comte L., Grenouillet G., Lenoir J., Baecher J.A., Bandara R.M.W.J., Bertrand R., Chen I.-C., Diamond S.E., Lancaster L.T., Moore N., Murienne J., Oliveira B.F., Pecl G.T., Pinsky M.L., Rolland J., Rubenstein M., Scheffers B.R., Thompson L.M., van Amerom B., Villalobos F., Weiskopf S.R. & Sunday J. 2024. Mechanisms, detection and impacts of species redistributions under climate change. *Nature Reviews Earth & Environment* 5, 351–368, doi: 10.1038/s43017-024-00527-z.
- Lecomte N. & Giroux M.A. 2015. New avian breeding records for Igloodik Island, Nunavut. *The Canadian Field-Naturalist* 129, 194–196, doi: 10.22621/cfn.v129i2.1702.
- Lees A.C. & Gilroy J.J. 2004. Pectoral sandpipers in Europe. *British Birds* 97, 638–646.
- Lenoir J. & Svenning J.C. 2015. Climate-related range shifts—a global multidimensional synthesis and new research directions. *Ecography* 38, 15–28, doi: 10.1111/ecog.00967.
- Liebezeit J.R., Smith P.A., Lanctot R.B., Schekkerman H., Tulp I., Kendall S.J., Tracy D.M., Rodrigues R.J., Meltofte H., Robinson J.A., Gratto-Trevor C., McCaffery B.J., Morse J. & Zack S.W. 2007. Assessing the development of shorebird eggs using the flotation method: species-specific and generalized regression models. *The Condor* 109, 32–47, doi: 10.1093/condor/109.1.32.
- Mabee T.J., Wildman A.M. & Johnson C.B. 2006. Using egg flotation and eggshell evidence to determine age and fate of Arctic shorebird nests. *Journal of Field Ornithology* 77, 163–172, doi: 10.1111/j.1557-9263.2006.00037.x.
- Marchant J., Hayman P. & Prater T. 2010. *Shorebirds*. London: Bloomsbury Publishing.
- McCarthy E.M. 2006. *Handbook of avian hybrids of the world*. London: Oxford University Press.
- Meyer N., Bollache L., Dechaume-Moncharmont F.-X., Moreau J., Afonso E., Angerbjörn A., Bêty J., Ehrich D., Gilg V., Giroux M.-A., Hansen J., Lanctot R., Lang J., Lecomte N., McKinnon L., Reneerkens J., Saalfeld S., Sabard B., Schmidt N.M., Sittler B., Smith P., Sokolov A., Sokolov V., Sokolova N., van Bemmelen R. & Gilg O. 2020. Nest attentiveness drives nest predation in Arctic sandpipers. *Oikos* 129, 1481–1492, doi: 10.1111/oik.07311.
- Meyer N., Bollache L., Galipaud M., Moreau J., Dechaume-Moncharmont F.-X., Afonso E., Angerbjörn A., Bêty J., Brown G., Ehrich D., Gilg V., Giroux M.-A., Hansen J., Lanctot R., Lang J., Latty C., Lecomte N., McKinnon L., Kennedy L., Reneerkens J., Saalfeld S., Sabard B., Schmidt N.M., Sittler B., Smith P., Sokolov A., Sokolov V., Sokolova N., van Bemmelen R., Varpe Ø. & Gilg O. 2021. Behavioural responses of breeding Arctic sandpipers to ground-surface temperature and primary productivity. *Science of the Total Environment* 755, article no. 142485, doi: 10.1016/j.scitotenv.2020.142485.
- Moreau J., Perroud L., Bollache L., Yannic G., Teixeira M., Schmidt N.M., Reneerkens J. & Gilg O. 2018. Discriminating uni- versus biparental breeding strategies by monitoring nest temperature. *Ibis* 160, 13–22, doi: 10.1111/ibi.12507.
- Nordin T. 1985. Fåglerna på Disko. (The birds of Disko.) *Fauna och Flora* 80, 159–168.
- O'Brien M., Crossley R. & Karlson K. 2006. *The shorebird guide*. New York: Houghton Mifflin Co.
- Paulson D.R. 1993. *Shorebirds of the Pacific Northwest*. Seattle: University of Washington Press.
- Pitelka F.A., Holmes R.T. & MacLean S.F., Jr 1974. Ecology and evolution of social organization in Arctic sandpipers. *American Zoologist* 14, 185–204, doi: 10.1093/icb/14.1.185.
- Platts P.J., Mason S.C., Palmer G., Hill J.K., Oliver T.H., Powney G.D., Fox R. & Thomas C.D. 2019. Habitat availability explains variation in climate-driven range shifts across multiple taxonomic groups. *Scientific Reports* 9, article no. 15039, doi: 10.1038/s41598-019-51582-2.
- Rajeevan P.C., Khaleel K.M., Thomas J. & Sangha H.S. 2014. First records of pectoral sandpiper *Calidris melanotos* and Caspian plover *Charadrius asiaticus* from Kerala. *Indian Birds* 9, 64–67, doi: 10.17087/bnhs/2014/v11i1/56531.
- Reid J.M., Cresswell W., Holt S., Mellanby R.J., Whitfield D.P. & Ruxton G.D. 2002. Nest scrape design and clutch heat loss in pectoral sandpipers (*Calidris melanotos*). *Functional Ecology* 16, 305–312, doi: 10.1046/j.1365-2435.2002.00632.x.
- Richards J.M. 2022. First nest records of the pectoral sandpiper (*Calidris melanotos*) for Manitoba. *Blue Jay* 80, 21–23, doi: 10.29173/bluejay6339.
- Richards J.M. & Gaston A.J. 2018. *Birds of Nunavut. Vol. 1. Non-passerines*. Vancouver: UBC Press.
- Saalfeld S.T. & Lanctot R.B. 2015. Conservative and opportunistic settlement strategies in Arctic-breeding shorebirds. *The Auk: Ornithological Advance* 132, 212–234, doi: 10.1642/AUK-13-193.1.
- Santema P., Eberhart-Hertel L., Aulsebrook A.E., Kwon E., Valcu M. & Kempenaers B. 2025. Factors associated with breeding site fidelity in a nomadic shorebird with extremely low local return rates. *Animal Behaviour* 223, article no. 123151, doi: 10.1016/j.anbehav.2025.123151.
- Shoo L.P., Williams S.E. & Hero J.-M. 2006. Detecting climate change induced range shifts: where and how should we be looking? *Austral Ecology* 31, 22–29, doi: 10.1111/j.1442-9993.2006.01539.x.
- Skagen S.K., Sharpe P.B., Waltermire R.G. & Dillon M.B. 1999. *Biogeographical profiles of shorebird migration in mid-continental North America. Biological Science Report 2000-0003*. Denver: U.S. Geological Survey.
- Thomas C.D. 2010. Climate, climate change and range boundaries. *Diversity and Distributions* 16, 488–495, doi: 10.1111/j.1472-4642.2010.00642.x.
- van Beest F.M., Beumer L.T., Andersen A.S., Hansson S.V. & Schmidt N.M. 2021. Rapid shifts in Arctic tundra species' distributions and inter-specific range overlap under future climate change. *Diversity and Distributions* 27, 1706–1718, doi: 10.1111/ddi.13362.
- Walther G.R. 2010. Community and ecosystem responses to recent climate change. *Philosophical Transactions of the Royal Society of London B* 365, 2019–2024, doi: 10.1098/rstb.2010.0021.