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ORIGINAL PAPER

Barnacle geese *Branta leucopsis* breeding on Novaya Zemlya: current distribution and population size estimated from tracking data

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Abstract
The Russian breeding population of barnacle geese *Branta leucopsis* has shown a rapid increase in numbers since 1980, which has coincided with a southwest-wards breeding range expansion within the Russian Arctic. Here barnacle geese also started to occupy coastal and marsh land habitats, in which they were not know to nest on their traditional breeding grounds. While these changes have been well documented by studies and observations throughout the new breeding range of barnacle geese, observations are lacking from the traditional breeding grounds on Novaya Zemlya, as this area is remote and difficult to access. This is especially relevant given rapid climate warming in this area, which may impact local distribution and population size. We used GPS-tracking and behavioural biologging data from 46 individual barnacle geese captured on their wintering grounds to locate nest sites in the Russian Arctic and study nesting distribution in 2008–2010 and 2018–2020. Extrapolating from nest counts on Kolguev Island, we estimate the breeding population on Novaya Zemlya in 2018–2020 to range around 75,250 pairs although the confidence interval around this estimate was large. A comparison with the historical size of the barnacle goose population suggests an increase in the breeding population on Novaya Zemlya, corresponding with changes in other areas of the breeding range. Our results show that many barnacle geese on Novaya Zemlya currently nest on lowland tundra on Gusinaya Zemlya Peninsula. This region has been occupied by barnacle geese only since 1990 and appears to be mainly available for nesting in years with early spring. Tracking data are a valuable tool to increase our knowledge of remote locations, but counts of breeding individuals or nests are needed to further corroborate estimates of breeding populations based on tracking data.

Keywords Novaya Zemlya · Branta leucopsis · Population estimate · Animal tracking · Accelerometer · Breeding distribution

Introduction

Until the mid-twentieth century, the barnacle goose *Branta leucopsis* of the Barents Sea population was a relatively rare migratory bird in Russia with its breeding grounds confined mostly to Novaya Zemlya (Uspensky 1951) and a small population on Vaygach Island (Dorofeev et al. 2018). At these sites the geese were known to breed on steep cliffs and small offshore islands (Uspensky 1951), as well as under slopes or under protection of nesting gulls (*Larus spp.*), where their nests were safe from predation by terrestrial predators such as the Arctic Fox (*Vulpes lagopus*). In the last 35 years the Russian barnacle goose population has rapidly increased from 70,000 individuals in 1980 to 1.2 million individuals in 2015 (Fox and Leafloor 2018). This increase in population size coincided with a northwest- and southwest-ward expansion of the breeding grounds within the Russian Arctic. In the late eighties and early nineties of the twentieth century, barnacle geese established breeding colonies on the Yugorsky Peninsula (Mineev 1984), Kolguev Island (Ponomareva 1992), the Kanin Peninsula (Filchagov and Leonovich 1992), Dolgy and Goletz Island (Anufriev 2006) and along

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the Barents Sea coast (Syroechkovsky 1995; Dorofeev et al. 2013). Although barnacle geese have also settled to breed in their former staging and wintering sites in the Baltic and along the North Sea in the same period (van der Jeugd et al. 2009), the largest part of the population (> 80%) still breeds in the Russian Arctic (Rozenfeld et al. 2021).

With the range expansion in the Russian Arctic at the end of the twentieth century, barnacle geese also started to breed in new nesting habitats including coastal salt marshes and on sandy islands (Syroechkovsky 1995; van der Jeugd et al. 2003). With a continuing population increase in the start of the twenty-first century the geese colonized more habitats, and colonies appeared under steep slopes with breeding peregrine falcons (*Falco peregrinus*) and rough-legged buzzards (*Buteo lagopus*), as well as in inland sedge-moss bogs (Kondratyev et al. 2013, 2019, 2021; Glazov et al. 2021). This has coincided with rapid growth of local breeding populations, as can be observed on Kolguev Island, where the breeding population has grown from 200 nesting pairs observed in 1994 (Syroechkovsky 1995) to 86,000 pairs in 2019 (Kondratyev et al. 2021). Also in the southern part of their traditional breeding grounds, on Vaygach Island, local breeding colonies of barnacle geese have increased, and with newly established colonies near river mouths the current population totals at least 9000 breeding pairs (Dorofeev et al. 2018).

The exponential growth of goose populations wintering in Europe, among which the Barents Sea barnacle goose population, has mostly been attributed to the release from hunting pressure as well as the availability of abundant and high-quality resources in man-made pastures (Fox and Madsen 2017). Especially for Arctic-breeding goose species, climate warming (being particularly pronounced in the Arctic, Cohen et al. 2014) may also have strong positive effects on population growth. Springs in which the snow melts earlier may increase reproductive success in the nesting phase via higher breeding propensity, clutch size and nest success (Nolet et al. 2020) and increase nesting possibilities at the northern edge of the breeding grounds, and even open up new breeding grounds further north (Jensen et al. 2008; Lameris et al. 2021). This raises the question how the barnacle goose population has developed on the most important part of their traditional breeding grounds, the southern island of Novaya Zemlya (Yuzhny Island), and whether this has been affected by earlier springs.

The distribution of barnacle geese on Novaya Zemlya has been mapped several times during the last century. Up to the middle of the twentieth century, barnacle geese showed a narrow distribution along the west coast of Yuzhny Island, and to a lesser extent on Vaygach Island and the northern island of Novaya Zemlya (Severny Island), breeding exclusively on cliffs (Uspensky 1951). In the end of the twentieth century, barnacle geese moved into new habitats on Yuzhny Island, where they started to nest in lowland tundra in the southwest as well as the western part of the island (Gusinaya Zemlya Peninsula or “Goose Land”, Kalyakin 1995). While the geese were known to be breeding up to Russkaya Gavan in the northern half of Severny Island, significant numbers of barnacle geese were only found up to the southern edge of Severny Island (Kalyakin 1995; Anker-Nilssen et al. 2000). Surveys in 2015–2017 partly confirmed these distribution patterns, with barnacle geese being present at three survey sites on Yuzhny Island, but absent on Severny Island including Russkaya Gavan (Spitsyn et al. 2020). As access to Novaya Zemlya for field surveys is largely prohibited since the middle of the twentieth century (Spitsyn et al. 2020) little is known on changes in the distribution and population size of locally breeding barnacle geese especially in the past 20 years, apart from limited surveys around a restricted number of study sites as mentioned above (Spitsyn et al. 2020, 2021). During this period the Barents Sea region has also seen rapid climate warming (Rozenfeld et al. 2021), potentially affecting distribution and population size on Novaya Zemlya.

Although we lack on-the-ground data on barnacle geese on Novaya Zemlya from the last 20 years, over the last decade increasing numbers of barnacle geese have been tracked on their northward migrations to their breeding grounds by GPS-tracking devices (Kölzsch et al. 2015; Lameris et al. 2018b). GPS-tracking data are increasingly being shown as a valuable tool to obtain information of animal’s space use in remote areas (Kays et al. 2015). Here we use a recently established method to estimate breeding locations from tracking data (following Schreven et al. 2021) to show the distribution and breeding habitats of barnacle geese breeding in different parts of the Russian Arctic in 2008–2020. Based on the proportion of geese nesting on Novaya Zemlya, as well as the proportion of geese breeding in a section of the Russian Arctic for which we know the breeding population size based on nest counts, we then provide estimates for the number of geese breeding on Novaya Zemlya. Using climatic data, we specifically ask whether recent changes in distribution and population size can be attributed to earlier springs in a warming climate.

Methods

Tracking data collection

Female barnacle geese were captured and equipped with tracking devices on their wintering grounds in Fryslân, the North of the Netherlands, in 2008 and 2009 (de Boer et al. 2014) and in 2018–2020, as well as in Lower Saxony, North-West Germany, in the winter of 2016–2017. Catches were conducted in mid- to late winter (December–March) on agricultural fields, the habitat in which the majority of barnacle geese reside during this part of the year (Pot et al. 2019). During both catching efforts in 2008 and 2009 (one catch each year), 17 birds were equipped with solar-powered PTT satellite transmitters using cordura-nylon backpack harnesses (Ens et al. 2009), while during four catching efforts in 2016–2017 and 12 catching efforts in 2018–2020, 82 birds were equipped with MadebyTheo (2016–2017) and 78 with Ornitela (2018–2020) solar-powered GPS-GSM loggers using Teflon harnesses (Lameris et al. 2017b). Tracking devices attached with backpack harnesses seem not to hamper barnacle geese in their breeding behaviour, with the exception of a slight delay in the timing of nest initiation (Lameris et al. 2018a). Tracking devices collected GPS-positions every 30 min (PTT satellite) or every 5–60 min (GPS-GSM loggers, depending on battery charge). Ornitela GPS-GSM loggers also collected tri-axial acceleration data (ACC) every 5 min in 20 Hz bursts of 1 s as long as battery level was high enough. While most data were collected in the year after deployment, some tracking devices delivered data for several years after deployment.

Determining nest locations

We determined nest locations either based on GPS and ACC data, or GPS-data only (when ACC was not available, since not all transmitters collected ACC data), following methods outlined by Schreven et al. (2021). This method is specifically designed for waterfowl species and uses the typical incubation behaviour of geese: low mobility (low daily variation in GPS locations) and little activity (i.e. body motion, derived from the ACC data (Dokter et al. 2018; Wilson et al. 2020)).

We analysed data from the period between April 1 and July 31, which includes the dates during which barnacle geese in the Arctic start nesting (van der Jeugd et al. 2009). We excluded tracks for which no data were available in the Russian Arctic (East of 30°E Longitude) during this period. In addition, only tracking data for the years 2008–2010 and 2018–2020 were included, as very little data were available outside these years. This dataset consisted of tracks from 11 individuals for the cohort tracked in 2008–2010 and tracks from 72 individuals for the cohort tracked in the 2018–2020 period.

For periods during which GPS-data were collected at high frequencies, GPS-data were down-sampled to one GPS-fix for every 15 min, where we used ACC measurements that were taken within 10 min of the GPS-fix. When ACC data were available, we defined the nest location as the median coordinates of the GPS-fixes during which the goose was inactive, on days when the goose was mainly inactive (Schreven et al. 2021). Activity was determined by calculating the Vectorial Dynamic Body Acceleration (VeDBA), which proved to be a reliable measure of activity and can be used to distinguish inactive behaviour (Dokter et al. 2018). VeDBA thresholds used to distinguish inactive from active behaviour were determined as 16.5 for the Ornitela transmitters. When ACC data were not available, we used the GPS-only method outlined by Schreven et al. (Schreven et al. 2021), which defines a potential nest location as the median coordinates on days when the standard deviation in latitude was less than 50 m. Subsequently, we calculated the time spent per day within 50 m for all potential nest locations (based on the GPS + ACC and GPS-only method), and the potential nest location was considered a nest when this nest attendance was > 75% for 3 consecutive days or more. In this way we also included nests that failed early in the incubation period.

Counts of nesting barnacle geese on Kolguev Island

The number of nesting barnacle geese on Kolguev Island has been monitored irregularly since 1989 and annual monitoring has been conducted since 2006 (Kondratyev et al. 2013, 2019, 2021; Glazov et al. 2021). Using a combination of area counts and counts on transect lines, estimates were made for the number of breeding birds in the large breeding colony at the Peschanka River mouth in 2006 and 2019. The number of inland colonies (and number of breeding birds within these colonies) were monitored almost annually, as well as the number of nests in several of these colonies in a smaller section of the island. Methods are described in detail in Kondratyev et al. (2013). A combination of nest counts in the Peschanka River mouth and inland colonies indicate that the number of breeding pairs on Kolguev Island has increased from 50,000 in 2006 to 86,000 in 2019 (Kondratyev et al. 2021).

Nest locations

We were able to locate 53 nests from 45 individual geese in our dataset (12 nests from 9 geese in 2008–2010 and 41 nests from 36 geese in 2018–2020, 8 individuals which nested in multiple years). We considered data from the 2008–2010 cohort and the 2018–2020 cohort as two separate sampling moments of the breeding distribution of barnacle geese in the Russian Arctic. For both datasets, we calculated the proportion of individuals breeding in the following regions: Kolguev Island, Novaya Zemlya (Yuzhny and Severny Islands combined), Vaygach Island and the Russian mainland coast in the Nenets Autonomous District (stretching from the Kanin Peninsula in the West to the Yugorsky Peninsula in the East, named Nenets District mainland from here on, Fig. 1). In case individuals were found to be nesting in multiple years, we only used the first nesting location for the entire period. Such individuals (n = 8) were site-faithful in

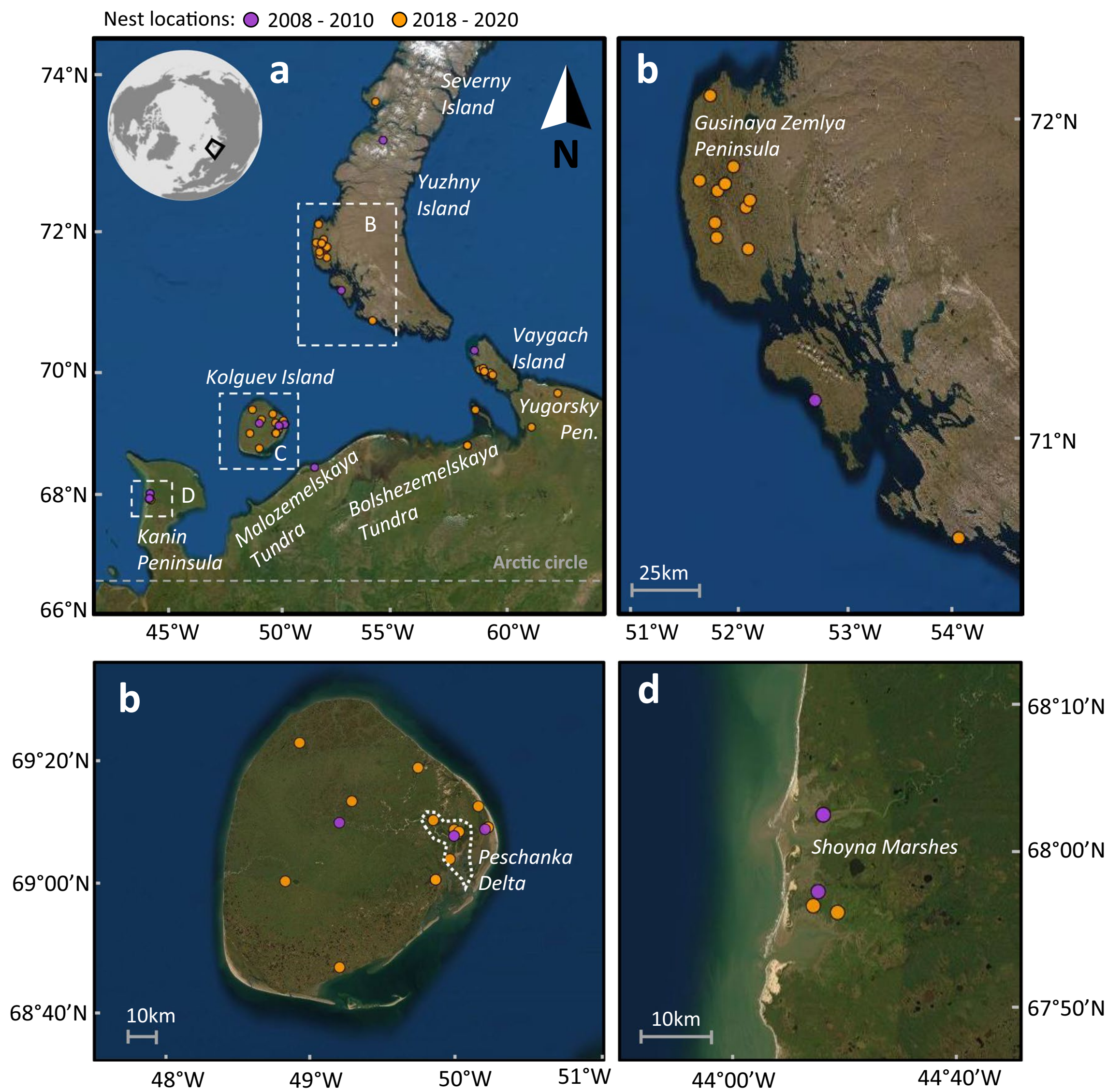

Fig. 1 Nest locations of tracked barnacle geese in the Barents Sea region. **a** Locations from the tracked cohort of 2008–2010 (purple) and 2018–2020 (orange) are shown, including an inset showing the location of the study region on a global map. Detailed maps show **b** the west coast of Yuzhny Island (Novaya Zemlya) including the peninsula Gusinaya Zemlya Peninsula, **c** Kolguev Island including the Peschanka Delta which hosts a large colony (Kondratyev et al. 2013) and **d** Shoyna Marsh where a large breeding colony is situated (Rozenfeld et al. 2011). The map can be viewed online at https://thomaslameris.carto.com/viz/09a194f7-7d36-4946-bf48-2871ff121615/public_map

nest location (within 1 km) and thus never switched between the areas described above. We conducted a Chi-square test to analyse if the distribution of breeding individuals in the various regions differed between the 2008–2010 and the 2018–2020 cohort.

Breeding habitats

We used a combination of vegetation maps based on intensive field surveys (Aleynikov et al. 2014, Komarov Botanical Institute 1948; Main authority Geodesy and Cartography 1987; Lavrinenko 2015, 2016) and satellite imagery (Google Maps 2022) to classify nest locations via visual inspection, as situated in traditional habitats (i.e. habitats known to be used by nesting barnacle geese up to 1980) or new habitats. We defined traditional habitats to include rocky or river cliffs / banks and rocky offshore islands. Any other habitats could be defined as being 'new', including salt marshes, floodplain habitats, boggy tundra and tundra habitats.

Estimating breeding population size

We used the proportion of tracked individuals breeding on Kolguev (pr_k) in combination with the counts of breeding individuals on Kolguev (N_k) and the proportion of tracked individuals breeding on Novaya Zemlya (pr_{nz}) to obtain a median estimate of breeding individuals on Novaya Zemlya ($\widetilde{N_{nz}}$) as $\widetilde{N_{nz}} = \left(pr_{nz}/pr_k\right) \cdot N_k$. In order to determine the uncertainty of this estimation we randomly sampled 10.000 times from the distribution of nesting locations among the three sites (Kolguev, Novaya Zemlya and elsewhere) and calculated its 95% confidence interval. We used the total counts of nests on Kolguev (N_k) in 2006 for the median estimate in 2008–2010, and the total count of nests in 2019 for the median estimate in 2018–2020.We estimated the number of breeding individuals on Vaygach Island in a similar fashion. These results can be found in Online Resource 1.

Onset of spring

The onset of spring may be an important determinant of breeding propensity and thus the chance of locating nests, especially at high latitudes (Prop and de Vries 1993). To assess whether differences in the proportions of breeding individuals in different regions between the 2008–2010 and the 2018–2020 cohort could have been affected by a change in the onset of spring, we extracted daily air temperature data for every nest location for the years 2008–2020 from the NCEP database (Kalnay et al. 1996). Using these data, we followed the methods described in van Wijk et al. (2012) to calculate the daily growing degree days (GDD) and the derived GDD jerk (third derivative). GDD play an important role in the start of vegetation growth (van der Graaf et al. 2006; Lameris et al. 2017a, b) and GDD jerk has been found as a good measure for the peak in forage plant quality, and therefore the onset of spring as relevant for herbivorous waterfowl (van Wijk et al. 2012; Smith et al. 2020). GDD jerk was then Z-transformed for every nest site for the period 2008–2020. As there may exist considerable variation in the onset of spring between western and eastern parts of the Nenets District mainland, we subdivided the nests in this region further into the Kanin Peninsula, Malozemelskaya Tundra (Barents Sea coast between the Kanin Peninsula and the Russky Zavorot Peninsula) and Bolshezemelskaya Tundra (Barents Sea coast from the Pechora Delta to the Yugorsky Peninsula, Fig. 1).

Results

Nesting locations

For both the 2008–2010 cohort (nine nests) and the 2018–2020 cohort (36 nests), geese were found to be nesting on Kolguev Island, Novaya Zemlya, Vaygach Island and on the Nenets District mainland (Fig. 1, Table 1). The proportion of nesting individuals on Kolguev Island was high (pr_k = 0.33 for 2008–2010 and 0.36 for 2018–2020) and most nests were located within the Peschanka Delta and the Peschanka floodplain (2 in 2008–2010 and 6 in 2018–2020). The proportion of nests on Novaya Zemlya was only slightly lower or similar to Kolguev Island, with 2 nests for the 2008–2010 cohort (pr_{nz} = 0.22) and 12 nests for the 2018–2020 cohort (pr_{nz} = 0.33) (Table 1). For the 2018–2020 cohort, the majority (8/12) of nests were located on the Gusinaya Zemlya Peninsula ("Goose Land", Yuzhny Island), where no nests were located for the 2008–2010 cohort (Fig. 1). The one nest located at Severny Island was at the southern edge of the island. On Vaygach Island, most nests were located inland along the west coast (5 out of 6, Fig. 1). Nests on the Nenets District mainland (3 in 2008–2010 and 6 in 2018–2020) were located in the Shoyna Marsh on the Kanin Peninsula for both cohorts (2 out of 3 in the 2008–2010 cohort and 2 out of 6 in the 2018–2020 cohort), while in the 2018–2020 cohort 3 other nests were located on the eastern part of the Nenets District mainland, namely on the Bolshezemelskaya Tundra and at the Yugorsky Peninsula. One nest was situated on Golets Island in the Barents Sea. In 2008–2010, one other nest was located along the Nenets District mainland south of Kolguev Island. The

Table 1 Number of nests and proportion of the total nests from tracked geese

	2008–2010		2018–2020		2008–2010 and 2018–2020	
	#Nests	Fraction	#Nests	Fraction	#Nests	Fraction
Kolguev Island	3	0.33	13	0.36	16	0.36
Novaya Zemlya	2	0.22	12	0.33	14	0.31
Vaygach Island	1	0.11	5	0.14	6	0.13
Nenets District mainland	3	0.33	6	0.17	9	0.20
Total	9	1.00	36	1.00	45	1.00

Numbers are given for separate cohorts (2008–2010 and 2018–2020) for separate regions: Kolguev Island, Novaya Zemlya, Vaygach Island and the Nenets District mainland distribution of nests across the different regions did not differ between the 2008–2010 and 2018–2020 cohorts (Chi-square test: $X_{(1,3)} = 1.34$, $p = 0.72$).

Nesting habitats

Only few nests (3 out of 9 in 2008–2010 and 5 out of 36 in 2018–2020) were considered to be situated in traditional habitats: two nests on river cliffs / banks on Kolguev Island, two nests on rocky cliffs on Novaya Zemlya, two nests on a small offshore islands (near Vaygach Island and Golets Island) and two nests on river cliffs on the Nenets District mainland (Yugorsky Peninsula). Most nests (6 out of 9 in 2008–2010 and 31 out of 36 in 2018–2020) were located in new habitats: salt marshes, tundra, boggy tundra and floodplain habitats on Kolguev Island, tundra and boggy tundra habitats on Novaya Zemlya, tundra habitat on Vaygach Island and saltmarshes on the Nenets District mainland (Online resource 2).

Estimating the population size on Novaya Zemlya

As the proportion of nests from tracking data on Kolguev Island and Novaya Zemlya did not differ between 2008–2010 and 2018–2020, we used the combined proportions (Table 1) for population estimates. We estimate a median of 43,750 (95% CI: 20,000–91,667) breeding pairs on Novaya Zemlya for 2008–2010 and a median of 75,250 (95% CI: 35,406–156,363) breeding pairs in 2018–2020.

Onset of spring

In the period 2008–2010, the onset of spring was relatively late in 2008 and 2009, and relatively early in 2010 in all regions (i.e. positive and negative values, respectively, in Table 2). In the period 2018–2020, the onset of spring was relatively late in 2018 and relatively early in 2020 in all regions. In 2019 the onset of spring was relatively early on Kolguev and the western part of the Nenets District mainland (Malozemelskaya Tundra), but relatively late on Novaya Zemlya, Vaygach and the eastern part of the Nenets District mainland (Bolshezemelskaya Tundra). On average, the onset of spring in 2008–2010 was relatively late (0.64 on Kolguev Island and 0.64 on Novaya Zemlya) and relatively early in 2018–2020 (− 0.28 on Kolguev Island and − 0.10 on Novaya Zemlya).

Discussion

In our study we provide a first estimate of barnacle geese breeding pairs on Novaya Zemlya for the twenty-first century, which we find to range around 75,250 pairs. While this shows that the Novaya Zemlya population has more than doubled since 1980, our data also suggest an increase in the last 15 years coinciding with earlier springs.

Our estimation of individual barnacle geese nesting on Novaya Zemlya rests on the assumption that our samples of tracked individuals show unbiased distribution over their Arctic summering range. For this reason, we limited our tracked individuals to birds caught in their wintering range, and not at stopover, breeding or moulting sites (e.g. Zhu et al. 2022). Both in 2008–2010 and in 2018–2020, we found individual geese nesting in all four regions known to host breeding barnacle geese: Novaya Zemlya, Vaygach Island, Kolguev Island and the Nenets District mainland. Many of these nests were located in known colonies, for example in the large colony in the Shoyna Marsh on the Kanin Peninsula (Rozenfeld et al. 2011) or close to Lyamchina Bay on Vaygach Island (Dorofeev et al. 2018). Also, on Kolguev Island the distribution of nests in both cohorts was in line with the known distribution of nesting barnacle geese, with most of the nests located in the Peschanka Delta. While the sample size of nests located with tracking devices is arguably small (especially for the cohort of 2008–2010) relative to nest counts in the field, the match of nest locations with

Table 2 Onset of spring (GDD jerk) relative to the period 2008–2020 (by Z-transformation) for all regions

Year	Kanin	Kolguev	Malozemels-kaya tundra	Bolshezemel-skaya tundra	Novaya Zemlya	Vaygach
2008	0.71	0.29	0.77	0.86	0.69	0.73
2009	1.30	1.62	1.20	1.12	1.89	1.29
2010	− 0.02	0.02	− 0.54	− 0.85	− 0.66	− 0.95
Average 2008—2010	0.66	0.64	0.48	0.38	0.64	0.36
2018	0.89	0.89	1.02	1.08	0.41	0.92
2019	− 0.83	− 0.47	− 0.28	0.29	0.25	0.34
2020	− 1.00	− 1.26	− 0.88	− 0.93	− 0.96	− 1.06
Average 2018—2020	− 0.32	− 0.28	− 0.05	0.15	− 0.10	0.06

The Nenets District mainland region is subdivided into the Kanin Peninsula, Malozemelskaya tundra and Bolshezemelskaya tundra. Positive values indicate springs later than average for the period 2008–2020, while negative values indicate springs earlier than average. Due to Z-transformation numbers are unitless known colonies gives confidence that our methods give a reasonable estimate of the distribution of nesting barnacle geese in the Russian Arctic.

Our estimate of the number of breeding pairs on Novaya Zemlya in 2018–2020 was 75,250 (95% CI: 35,406–156,363), which would equal 150,500 breeding birds. The estimate of 43,750 (95% CI: 20,000–91,667) for the number of breeding pairs in 2008–2010 being lower suggests an increase in the nesting population on Novaya Zemlya between 2010 and 2020, although the confidence intervals for both estimates are large and do overlap. An increase of the local breeding population would be in line with the observed population growth of barnacle geese, yet differences may also arise due to varying breeding propensity with annual differences in the onset of spring. The onset of spring was relatively early in 2020, during which many of the nests in our dataset were located, and which may have caused the larger number of breeding pairs in the period 2018–2020. At the same time, a trend towards earlier onsets of spring may also give rise to the observed population increase (Rozenfeld et al. 2021), and hence these processes are likely not independent. While we cannot conclusively show an increase in breeding pairs, our estimate of 150,500 breeding birds probably gives a good idea of the current breeding population on Novaya Zemlya. Together with the increase in the total barnacle goose population, our data suggest that the local breeding population on Novaya Zemlya has also increased since 1980. In this period the total population was largely confined to Novaya Zemlya and Vaygach and consisted of 70,000 individual birds (Fox and Leafloor 2018). When considering that the total population also includes juveniles and non-breeding birds, this suggests that between 1980 and 2020 the breeding population on Novaya Zemlya has more than doubled.

Our data suggest an ongoing increase in nesting barnacle geese on Novaya Zemlya between the period 2008–2010 and 2018–2020, coinciding with earlier springs. Such an increase could be facilitated by birds occupying new habitats which become available earlier in the season. A large part of the tracked nests in 2018–2020 on Novaya Zemlya were located on Gusinaya Zemlya Peninsula. Nesting barnacle geese have been reported here first by Kalyakin (1995) in the early nineties of the twentieth century, who described that “nesting sites were noted in areas of lowland tundra with an abundance of water bodies, somewhat reminiscent of nesting sites in the area of the Shoyna River [Kanin Peninsula]”. Our results suggest that a large part of the barnacle goose population on Novaya Zemlya now nest in new habitats on lowland tundra bogs rather than on the traditional cliffs, although cliff-nesting birds still appear among our tracked birds. The large proportion of nests on Gusinaya Zemlya Peninsula in the 2018–2020 cohort contrasts with the absence of such nests in the 2008–2010 cohort, though the sample size in these years was low. As springs were also earlier in 2018–2020, this could suggest that while nesting in late springs would be restricted to cliff habitats, abundant nesting on tundra bogs in Novaya Zemlya is mainly possible in years with early springs, when such nesting sites become snow-free early in the season. Snow cover data from Novaya Zemlya indeed suggests that nesting sites on Gusinaya Zemlya Peninsula were free of snow earlier in 2018–2010 compared to 2008–2010 (Online resource 3). Where in past decades barnacle geese chose to nest almost exclusively on cliffs to avoid predation, predation danger currently does not seem to limit them to initiate nesting in low-lying tundra habitats. Predation danger on Novaya Zemlya could currently be low, and observations in tundra habitats on Kolguev Island show that barnacle geese can fend of avian predators when nesting large colonies (Kondratyev et al. 2013).

Taken together, our data provide a new estimate of breeding pairs of barnacle geese on Novaya Zemlya, showing that is has doubled in size since 1980. In addition, our data suggest an increase of the population since 2008. The increase in breeding pairs could well be driven by barnacle geese nesting in new habitats, most notably on lowland tundra on Gusinaya Zemlya Peninsula, which has become possible in years with an early spring. A trend for earlier springs in the West Russian Arctic (Lameris et al. 2018b, 2019; Rozenfeld et al. 2021) would then contribute to the suggested increase in the nesting population on Novaya Zemlya. With ongoing climate warming, northern regions like Novaya Zemlya could provide increasingly suitable nesting regions for Arctic bird species (Jensen et al. 2008) such as barnacle geese, and we may expect a further increase of local breeding population size. This also means that availability of nest sites, and possibly also feeding grounds for goose families, is unlikely to form a limiting factor for further growth of the barnacle goose Barents Sea population.

Our study shows again that accelerometer and GPS-tracking data provide valuable tools to increase our knowledge of remote and difficult to access locations, such as Novaya Zemlya. However, it is important to note that our results are based on a limited number of tracked birds. To verify the number of breeding barnacle geese on Novaya Zemlya, as well as the suggested effect of earlier springs on nesting geese, counts of nesting individuals would be needed, for example using aerial transects (Rozenfeld et al. 2021) and field counts of nests during the breeding period.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00300-022-03110-8.

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Author contributions TL and MB conceived the idea for this study. NB, HJ, SM, GM and HK caught geese in Germany and The Netherlands. OP, AK, YA, PG, JL and EZ collected nest count data on Kolguev Island. TL, OP, CK, HS, KS and MB analysed data. TL wrote the manuscript with input from all other authors. All authors read and approved the final manuscript.

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Data availability All tracking data are stored in Movebank (www.movebank.org) in the projects "Barnacle goose from Netherlands to Russia" and "Disturbance of BG by IFV and IWWR". Climate data from NCEP are freely downloadable from NOAA (https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html).

Declarations

Conflict of interest The authors declare to have no competing interests.

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