Eastward moult migration of non-breeding pink-footed geese (*Anser brachyrhynchus*) in Svalbard

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Abstract

Six adult male pink-footed geese (*Anser brachyrhynchus*), tagged with satellite transmitters, were tracked in Svalbard during the period of June–September in 2003 and 2004. The purpose of the study was to describe the movements and staging periods of individual geese during the post-breeding period to investigate a possible moult migration among pink-footed geese in Svalbard. All geese moved about 200 km east from their potential breeding (summering) areas in western Spitsbergen. The preferred moulting area was the island of Edgeøya, where four geese staged prior to a southward autumn migration. Five geese left potential breeding areas between 11 and 30 June, and remained for more than 25 days in eastern areas during most of July, which we interpret as the moult migration of either failed or non-breeders. Geese left moulting areas in mid-August, using an average of 1.4 staging areas before the autumn migration, suggesting that moult sites support pre-migration hyperphagia. Only one goose remained at the suspected breeding site from early June to early September. Mean monthly temperatures in the summering and moulting ranges of the geese were calculated from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data. The mean June moult range temperature (−0.9°C) was significantly lower than that of the summering ranges (4.6°C). The July mean moult range temperature did not differ significantly from that in June on the summering ranges. We contend that failed or non-breeding pink-footed geese move eastward in Svalbard to exploit the early stages of summer plant growth as a result of the delayed thaw compared with central and southern Spitsbergen.

Moult migration in post-breeding waterfowl, first described by Ekman (1922), is a well known event that takes place between the breeding season and the autumn migration. Among goose species it mostly involves subadult birds, but may also include non-breeding and failed breeding birds, and even successful breeders (Hohman et al. 1992). Movements of Palaearctic and Nearctic goose species are in most cases northwards (Salomonsen 1968; Hohman et al. 1992). Exceptions include barnacle geese (*Branta leucopsis*) in Greenland and probably to some extent greater snow geese (*Anser caerulescens atlantica*), which move south within their breeding ranges (Madsen et al. 1984; Reed et al. 2003). The migration distance can vary from a few hundred kilometres to more than

1200 km in the case of pink-footed geese in Iceland and Greenland (Madsen et al. 1984; Boertmann 1994). There is much speculation as to why geese and other waterfowl undertake a moult migration. Obviously there is an energy cost involved in the movement, but the benefits include access to abundant food resources, protection from predators and refuge from disturbance (Hochbaum 1955; Salomonsen 1968). Food may be restricted on the breeding grounds, as suggested by Madsen & Mortensen (1987), and because breeders are often behaviourally dominant over non-breeders, there are benefits to the latter if they move to habitats outside the breeding range (Salomonsen 1968; Raveling 1970). In July, more northern habitats support the progressively delayed early

growth phases of grass and sedge shoots, which have the highest protein content of the annual cycle at this time (Whitten & Cameron 1980; Davis et al. 1985). Hence, the forage quality in northerly areas with a growth season too short to support breeding birds may offer the spring-like early season plant growth that is highly attractive to moulting geese. The Greenland white-fronted goose (*Anser albifrons flavirostris*) exhibits no marked moult migration, but may take advantage of the progressive development in availability of nutrient-rich food along an altitudinal gradient within the same general summering area (Fox et al. 1983).

In Svalbard there is a west–east temperature gradient that mainly results from the influence of the "warm" North Atlantic current on the west coasts of Svalbard and the "cold" current from Siberia on the eastern Svalbard coastline. Non-breeding pink-footed geese in Svalbard moult within the breeding range (Spitsbergen west of 17°E), and also in the eastern parts of Svalbard mainly on the islands of Edgeøya and Barentsøya (Madsen et al. 1992; Mehlum 1998). According to Mehlum (1998), less than 10% of the winter population (ca. 30 000 in the 1990s; Madsen et al. 1999) were accounted for on Edgeøya and Barentsøya during the period of late July–September.

This paper describes the movements and staging periods of individual pink-footed geese during the breeding and post-breeding period in Svalbard based on data from birds fitted with small satellite transmitters. The geese were tracked from their possible breeding areas in June to their moulting grounds in July and their post-moulting areas prior to the onset of the autumn migration in mid-September. We test the hypothesis that moulting geese, freed from the association with nest sites and young, undertake a moult migration to areas where the delayed thaw offers spring-like feeding conditions away from breeding areas. We used satellite remote sensing to estimate surface temperatures of breeding and moulting areas to look for support for this hypothesis at larger spatial scales. Food quality on the moulting grounds was inferred on the basis of the average monthly temperatures on Spitsbergen, Edgeøya and Barentsøya.

Methods and study area

Satellite telemetry

Platform Transmitting Terminals (PTTs; Microwave Telemetry Inc., Columbia, MD, USA) were attached to 14 adult male pink-footed geese (seven in March 2003 and seven in March 2004), which had been cannon netted over bait at Vest Stadil Fjord, Denmark (56°12′N; 08°08′E; see Glahder et al. in press for further details). Six of these

geese were tracked through to autumn migration. Five of the PTTs were 30-g battery powered units (for individual birds A2F, A4T, A4Z and A5E in 2003 and B6K in 2004) and one was a 45-g solar powered unit (bird C1T in 2004). All the transmitters were mounted on the backs of the birds with glue. In addition, they were secured either with knicker elastic harnesses (Glahder et al. 1997) or, in the case of the solar powered unit, with Teflon straps (R. Malecki, pers. comm.). The transmitters and harnesses constituted 1.3% (in the case of the 30-g PTTs) and 1.7% (in the case of the 45-g PTT) of the body weights of the birds (average 2871 g, SD = 172 g, $n = 14$). The 30-g transmitters were programmed to transmit for 8 h and during three different periods to "rest" for 15 h (79 cycles, from about 1 April to 15 June), 159 h (11 cycles, from about 16 June to 31 August) or 111 h (until the battery power ran out). With a typical battery lifetime of 750 h estimated by microwave telemetry we expected our programmed PTTs to transmit until at least late September of the same year. The solar powered PTT was programmed to transmit for 10 h and to "rest" for 21 h. Details about the PTT transmissions, receptions, position calculations and accuracy are given in Fox et al. (2003). Positions were filtered using an Argos Filter V5.0 SAS program developed by Dave Douglas (USGS, Alaska Science Center, Anchorage, AK, USA). With this program we excluded locations in the poorest quality classes (<class 1) unless their locations were within 5 km of a previous or subsequent location.

The areas, duration and timing of summering and staging

For each staging area of a tracked bird, 50% dispersion ranges were calculated as harmonic means (with outliers removed and cell sizes optimized; Dixon & Chapman 1980) using Range Manager (1998 Data Solutions; a MapInfo Professional application, http://solutionsgroup.tripod.com). The size of the dispersion range is a function of (1) the movements of the goose and (2) the position inaccuracy, i.e. the difference between the true location and the position derived from the calculated location. We defined a summering area as a potential breeding area. A staging area was described by at least eight valid positions, and if more than one staging area was used by the goose no overlap was accepted between 50% dispersion ranges. A moulting area was defined as a particular "staging" area if the tagged goose remained there for a minimum of 25 consecutive days (the average flightless period of nine goose species according to Hohman et al. 1992), during most of July, when non-breeding pink-footed geese are considered to be flightless (Madsen et al. 1984).

Table 1 Summering and moulting sites for satellite-tagged pink-footed geese. Mean June and July temperatures are shown for the two sets of areas. The number of 1-km squares (pixels) inside each 50% dispersion range is given for each of the two types of sites. The summering and moulting periods are minimum periods as defined in the text, and dates are given in day and month (e.g., 27/5 is 27 May). The migration distance is the great circle route in kilometres from west (W) to east (E) between the two areas.

Goose ID	Dist. W–E (km)	Summering site dates	No. pixels	Position °N, °E	Mean June temp. (°C)	Mean July temp. (°C)	Moulting site dates	No. pixels	Position °N, °E	Mean June temp. (°C)	Mean July temp. (°C)
A2F	215	27/5–11/6	98	78.7, 15.3	−1.06	11.13	02/7–30/7	55	77.5, 22.8	−0.23	4.68
A4T	180	23/5–30/6	22	78.2, 13.5	3.70	9.55	13/7–17/8	33	78.9, 20.9	−4.70	2.16
A4Z	162	08/6–15/6	11	78.2, 17.0	10.0	14.54	28/6–08/8	25	77.5, 22.8	2.40	9.72
A5E	180	21/5–14/6	22	78.2, 17.4	8.28	10.59	24/6–25/8	42	79.9, 16.8	−1.41	6.50
C1T	163	23/5–29/6	14	77.0, 15.4	1.94	8.70	03/7–11/9	48	77.5, 21.7	−0.36	4.51
B6K	251	01/6–05/9[a]	11	78.5, 11.0	3.58	11.03	10.9[b]	142[c]	78.2, 22.1	1.96	5.05

[a]The goose moulted in the summering area, and [b]stayed only briefly on northern Edgeøya before the autumn migration. [c]The autumn range of B6K was poorly defined by data from one day only (six positions).

Minimum staging periods were calculated for each location by subtracting the time from the first position from that of the last position. Because of the programmed "resting" periods of 21 h (solar powered transmitter) and 159 h (battery powered transmitters) during most of the post-breeding period, the actual staging period could be 42–318 h (about 2–14 days) longer than estimated.

The summering and moulting areas were all located below 100 m a.s.l. (Norwegian Polar Institute 1996), and all were near-shore areas, except for one summering area (river plain, A5E). Most of the summering areas were in the *Cassiope tetragona* and *Dryas octopetala* zones of the Mid Arctic vegetation region defined by Rønning (1996). Habitats were tundra, except for one delta area. Most of the moulting areas were in the *Papaver dahlianum* zone of the High Arctic vegetation region defined by Rønning (1996). The moulting areas were either deltas or tundra with large lakes or lagoons.

Temperature data

The Moderate Resolution Imaging Spectroradiometer (MODIS) is a remote-sensing instrument on board the TERRA (EOS AM) and AQUA (EOS PM) satellites, providing a range of environmental data at three spatial scales: 250, 500 and 1000 m (Friedl et al. 2002; Petitcollin & Vermote 2002). For the present study, the MOD11 product within the larger MODIS dataset was used to generate information on mean monthly land surface temperatures (±0.5°C) across the entire Svalbard area (USGS EROS Data Center 2002). These data were imported into ArcGIS version 9.0 and converted to raster format at a 1-km resolution. For each goose staging area, defined by a 50% dispersion range, average monthly temperatures were calculated for June and July. To calculate differences in mean temperatures between summer-

ing sites (areas in western Spitsbergen) and moulting sites (areas mainly in eastern Svalbard), we averaged the mean temperatures on each type of site for five of the geese. The goose B6K was omitted because it moulted at the summering site (Table 1). The two averages that had similar variances (*F*-test, two-tailed) were tested with a two-tailed Student's *t*-test.

Results

Movements and staging areas

Upon arrival to Svalbard in late May, the geese fitted with satellite transmitters moved to summering sites in central, western or northern parts of Spitsbergen (Glahder et al. in press). Five of the six geese left these areas between 11 and 30 June, while the sixth goose (B6K) stayed on the island of Prins Karls Forland until 5 September (Fig. 1; Table 1). All five geese went east and four geese staged at eastern localities until the autumn migration. The average arrival date at the eastern sites was 28 June (SD = 11 days, range = 16 June–13 July). Birds used either one or no staging areas before the moult (Fig. 1). One of the five geese (A5E) stayed on Edgeøya from 16 to 22 June and then proceeded to northern Spitsbergen, where it stayed during the moulting period. The last signal from A5E was received from northern Spitsbergen on 9 September (Fig. 1). On average, the five geese moved 180.0 km (great circle route, SD = 21.4 km, $n = 5$) from summering to moulting areas; the direction was east with an average summering position of 78.1°N, 15.7°E ($SD_N = 0.6°$, $SD_E = 1.6°$, $n = 5$) and an average moulting position of 78.3°N, 21.0°E ($SD_N = 1.1°$, $SD_E = 2.5°$, $n = 5$). The five geese stayed at a moulting area for an average of 47.2 days (SD = 17.8 days, $n = 5$) (Table 1), and after that period they moved between an average of 1.4 staging

(a)

(b)
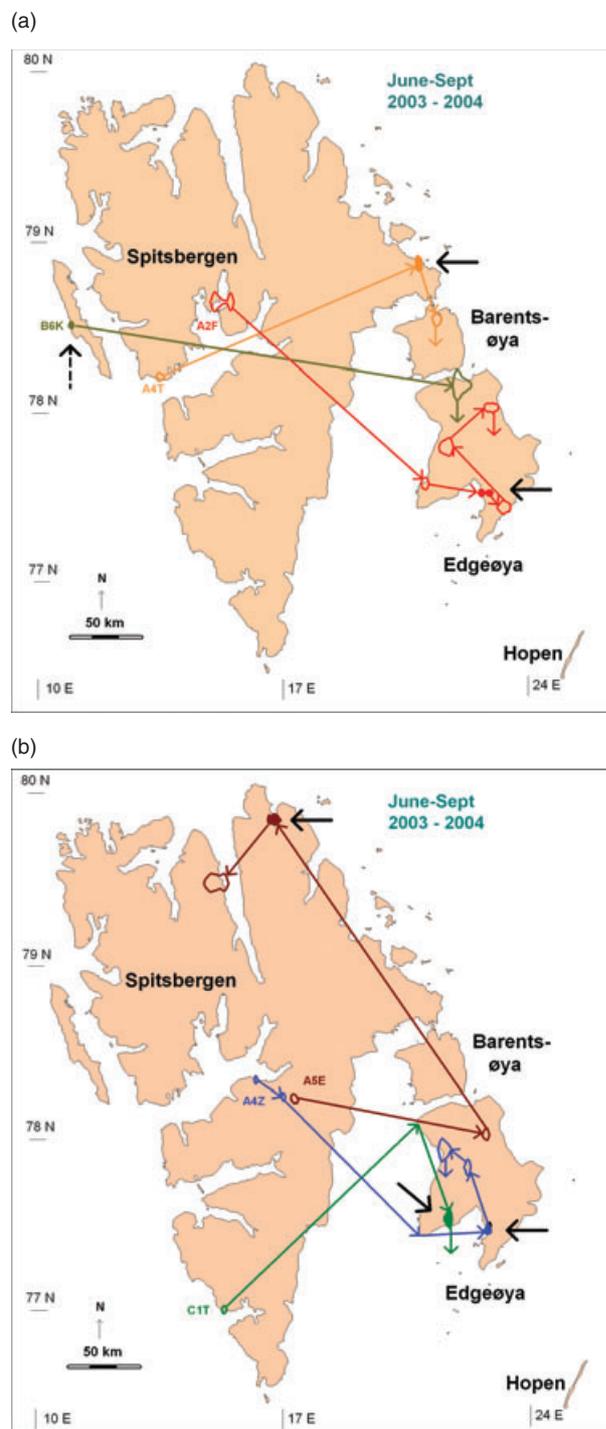
Figure 1 Movements and staging areas of transmitter-tagged pink-footed geese in Svalbard during the period of June–September in 2003 and 2004. Dispersion ranges (50%) and movements are shown for six individual geese: (a) A2F, A4T and B6K; and (b) A4Z, A5E and C1T (identification numbers indicated at summering sites). Arrows pointing at filled-in dispersion ranges indicate moulting sites. B6K probably moulted on the summering site and it staged only briefly at the post-moulting site on Edgeøya before the autumn migration.

areas (range 0–3) before they started their autumn migration. The average departure date from the moulting areas was 18 August (SD = 16.5 days, $n = 5$; Table 1). B6K went east to stage on Edgeøya for between 1 (minimum) and 9 (maximum) days before its autumn migration. B6K was observed on wintering grounds in the Netherlands; the individual was associated with a female goose but without any juveniles (F. Cottaar, pers. comm.). The date of the last signal transmitted from the geese in Svalbard before the onset of the autumn migration was 11 September (SD = 2.2 days, $n = 6$, variation: 9–15 September). The dataset comprised in total 1362 positions (average = 227, SD = 161, $n = 6$, variation: 107–507).

Mean temperatures at staging areas

The differences in mean temperatures between western Spitsbergen (summering sites) and eastern Svalbard (moulting sites on Edgeøya and Barentsøya and in eastern and northern Spitsbergen) were illustrated by calculating mean temperatures at 50% dispersion ranges during June and July (Table 1; Figs 2, 3). In June, the mean temperature in the western areas was 4.6°C (SD = 4.5°C, $n = 5$) and −0.9°C (SD = 2.6°C, $n = 5$) in the eastern areas—a significant difference of 5.4°C (Student's t-test, $P = 0.05$, $t = 2.39$, $df = 8$). In July, the mean temperature in the western areas was 10.9°C (SD = 2.2°C, $n = 5$) and 5.5°C (SD = 2.8°C, $n = 5$) in the eastern areas, a significant difference of 5.4°C (Student's t-test, $P = 0.01$, $t = 3.39$, $df = 8$). The difference of 0.9°C (5.4–4.6°C) between mean July temperatures in the eastern areas and mean June temperatures in the western areas was not significantly different (Student's t-test, $P > 0.1$, $t = 0.38$, $df = 8$).

Discussion

To our knowledge, this paper is the first to document an eastward moult migration in Northern Hemisphere goose populations. Pink-footed geese arriving in Svalbard in late May need good foraging conditions to replenish body reserves lost during the ca. 1100 km migration—much of it over the open sea—prior to the initiation of egg-laying. In our study, pink-footed geese arriving in Svalbard in mid-May encountered air temperatures below 0°C, and were therefore almost entirely restricted to feeding on above-ground grass litter from the previous year (Fox et al. in press). Following initial staging for about one week, the geese moved to summering sites in western Spitsbergen (Glahder et al. in press). The areas used by pink-footed geese fitted with PTTs had mean June temperatures of 4–5°C. Temperatures above 0°C spur the growth of fresh shoots of tundra plants, and the thawing ground gives the geese access to below-ground plant storage organs.
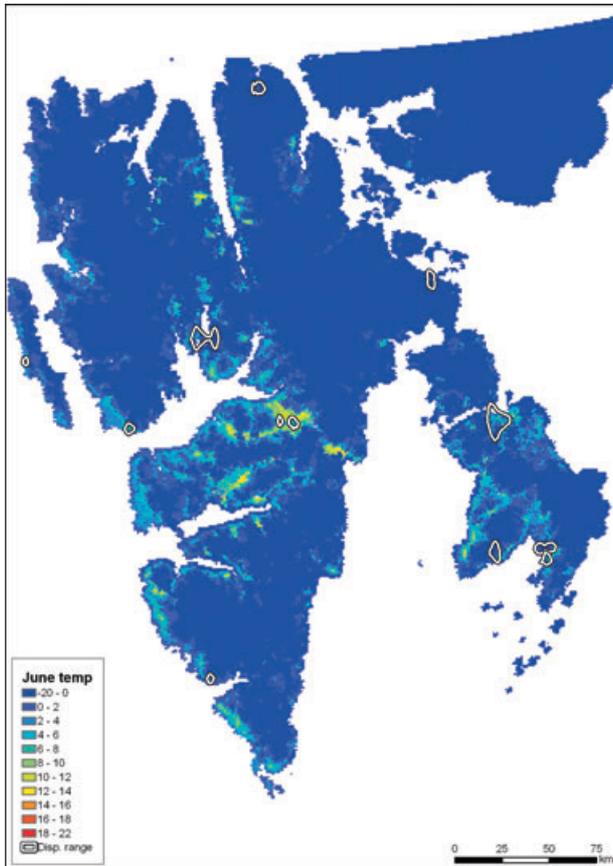
Figure 2 Mean June temperatures (°C) on Svalbard in 1-km squares. Temperatures are given in 2°C intervals except for temperatures below 0°C and above 18°C, each of which are pooled in one category. The dispersion ranges (50%) (Disp. range) covering summering and moulting sites are shown for the six geese attached with Platform Transmitting Terminals (PTTs) (see Fig. 1).
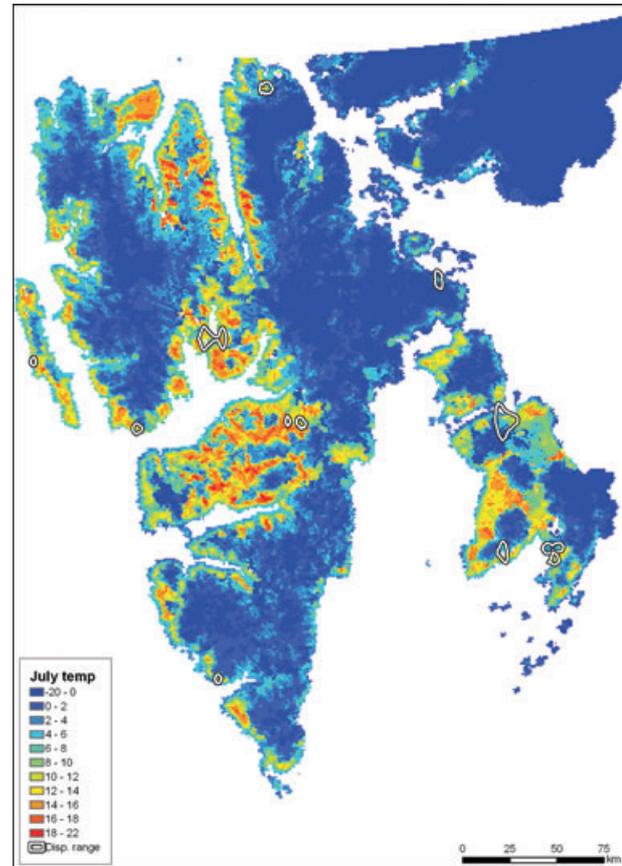
Figure 3 Mean July temperatures (°C) on Svalbard in 1-km squares. Temperatures are given in 2°C intervals except for temperatures below 0°C and above 18°C, each of which are pooled in one category. The dispersion ranges (50%) (Disp. range) covering summering and moulting sites are shown for the six geese attached with Platform Transmitting Terminals (PTTs) (see Fig. 1).

During the second part of June, five of the six pink-footed geese tagged with PTTs moved about 200 km eastwards, while the sixth goose stayed at the summering site until shortly before the autumn migration. As the pink-footed goose moults remiges during most of July (Madsen et al. 1984) and the five geese moved out of their summering sites prior to that period, we interpret this movement as a moult migration of either failed or non-breeding geese. This interpretation is supported by the fact that the average staging period lasted more than 25 days and covered most of July. The mean July temperature in the moulting areas increased from below the freezing point in June to 5.5°C in July. This means that the geese are likely to have encountered soil conditions and plant growth stages (and hence forage conditions) similar to those experienced at the western summering sites in June. With the relatively modest energy expendi-

ture of a 200-km flight, the geese regained access to optimal forage conditions with fresh new growth of grasses and sedges. They also gained access to below-ground storage organs, although these may not be of main importance in the diet if the feeding behaviour during their moult is similar to that of pink-footed geese in Iceland and Greenland (Madsen & Mortensen 1987).

The geese moved out of their moulting areas around mid-August to stage at relatively few other areas in Svalbard before the autumn migration. This suggests that exploitation of moulting areas extends through the greater part of the pre-migration fattening period, when energy demands are high. Because the plant growing season begins too late to sustain breeding attempts in these areas, another advantage of using eastern moulting sites is that the moulters meet comparatively little intraspecific competition from breeding geese here.

Interspecific competition from barnacle geese and brent geese (*Branta bernicla*) is unlikely because these species are scarce in this part of Svalbard (Madsen et al. 1992; Mehlum 1998). The moulting grounds on Edgeøya and Barentsøya (Fig. 1) have relatively high densities of Svalbard reindeer (*Rangifer tarandus platyrhynchus*) (Kovacs & Lydersen 2006), on which the Arctic fox *(Alopex lagopus)* is highly dependant all year round (Eide 2002). On the other hand, densities of breeding birds are low in these areas so the predation pressure from the foxes is probably relatively low.

Acknowledgements

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