Populations and breeding performance of divers, geese and ducks at Zackenberg, northeast Greenland, 1995–2005

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Abstract

Monitoring at Zackenberg (74°30'N, 20°30'W) since 1995 has provided for the first time long-term data on population trends and breeding performance for a number of high-arctic waterbird species in Greenland. Breeding populations of Red-throated Diver *Gavia stellata* and Long-tailed Duck *Clangula hyemalis* were relative stable from year to year, whereas breeding success varied with the abundance of Arctic Fox *Alopex lagopus* and Collared Lemming *Dicrostonyx groenlandicus*. Average nest survival in Red-throated Diver was 18% between 1996 and 2005, and at least five pairs produced a total of about 29 potentially fledged young, or at least 0.5 per pair per year – most of them in two years with few Arctic Foxes. Long-tailed Duck bred successfully in only one year, a year with many Arctic Foxes but also much alternative prey in the form of Collared Lemmings. Few pairs of King Eider *Somateria spectabilis* were found, and these had poor breeding success. Between four and 32 pairs of Barnacle Geese *Branta leucopsis* brought their goslings into the study area from nearby colonies each year. An average of about 0.6% of the goslings disappeared per day during the fledging period. More than 500 immature Icelandic Pink-footed Geese *Anser brachyrhynchus* moulted in the study area at the beginning of the study period, but most disappeared after a few years in spite of attempts to protect them from human disturbance. There is some indication that numbers of both Pink-footed Goose and Long-tailed Duck at Zackenberg have declined since the 1960s.

Key words: waterfowl, *Gavia stellata, Gavia immer, Anser brachyrhynchus, Branta leucopsis, Somateria mollissima, Somateria spectabilis, Clangula hyemalis,* population trends, breeding success, arctic birds, Zackenberg, Greenland.

Many species of waterfowl nest in the High Arctic, but only a few have been studied at their arctic breeding grounds (cf. Soloviev & Tomkovich 2004). The Zackenberg Research Station (74°30'N, 20°30'W), established at Wollaston Forland in the south central part of northeast Greenland in 1995, aims to provide long-term data on a range of ecological variables in a pristine high-arctic environment. Among birds, the focus is on studying waders and skuas *Stercoriarus* spp. (e.g. Meltofte 2006; Meltofte *et al.* 2006), but waterfowl are also included in the biological monitoring programme (Meltofte & Berg 2006). No other long-term terrestrial monitoring programmes exist in Greenland, but a parallel programme in the low-arctic southwestern part of the country is at the planning stage.

In this paper, waterfowl population sizes and breeding performance during the first 11 years of the programme are presented and discussed in relation to the onset of spring (e.g. the timing of ice melt on ponds and lakes), together with the abundance of Arctic Fox *Alopex lagopus* and Collared Lemming *Dicrostonyx groenlandicus*, which are all recorded during the general biological monitoring undertaken at the site (Meltofte & Berg 2006). Data on the entire programme are presented in annual reports from Zackenberg Ecological Research Operations, the latest being by Rasch & Caning (2005).

Study Area and Methods

The study area in Zackenbergdalen is a typical valley for the south central region of high-arctic northeast Greenland. This region is relatively well vegetated and productive in comparison with the more arid 'arctic deserts' to the north, but it is not as lush as the low-arctic southern parts of Greenland. The valley is a c. 25-km^2 area of lowland tundra surrounded by 1,000 m to 1,300 m-high mountains to the northeast and west, respectively, and the Young Sund ('sund' = sound; here a fjord) to the south (Fig. 1). A multitude of lakes and ponds are found in the valley, ranging from shallow ponds and tarns to lakes several metres deep. The lakes freeze to a depth of about 1.5 m in winter, and ponds become totally frozen.

The bird census area extends over 19.3 km^2 of the valley, from the coast of Young Sund up the slopes of Aucellabjerg to an altitude of 600 m (Fig. 1). Below 50 m a.s.l., the land is relatively flat, with extensive areas of dwarf scrub heath and wet fens. Many ponds are found in the fen areas, together with one lake, Lomsø (Diver Lake), close to the coast (Figs. 1 & 2). The low-lying ponds are often surrounded by lush vegetation, and they become free of ice between late May and mid-June (cf. Table 1). Similar habitats continue to the east and north of the census area, while to the northwest, between 50 m and 100 m a.s.l., the terrain changes into an undulating moraine landscape, Morænebakkerne, with numerous, often relatively deep lakes (Figs. 1 & 2). Several of these lakes are so deep that they do not become free of ice until late in the season, sometimes not thawing until the end of July.

In most years, snow covers around 80% of Zackenbergdalen in early June, but it usually thaws rapidly during the month.

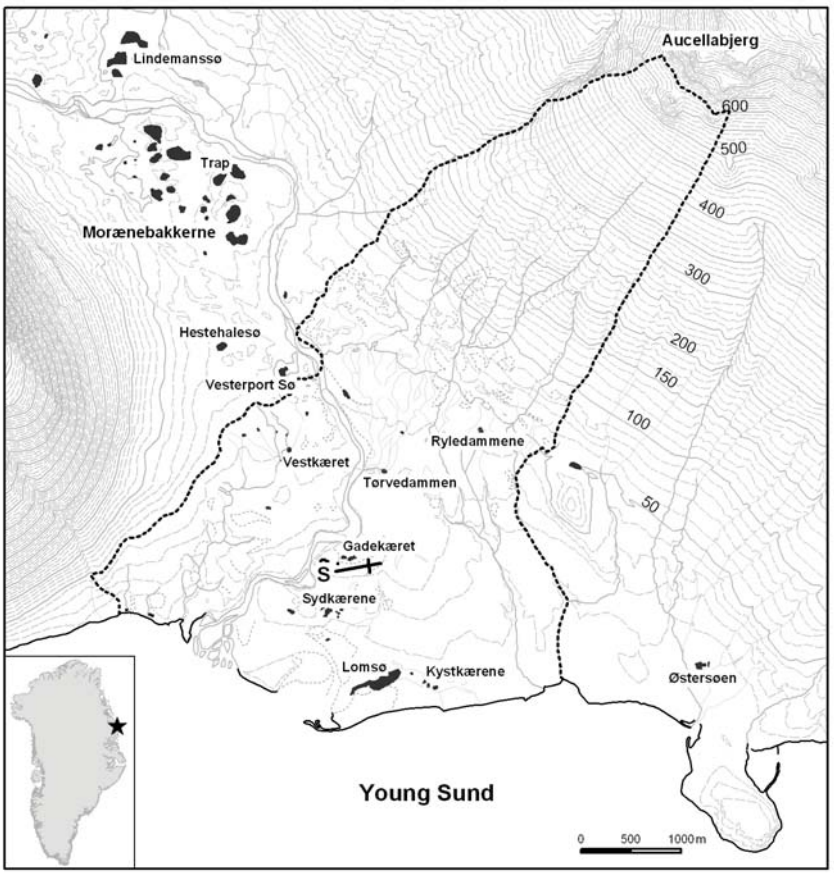

Figure 1: Map of the Zackenbergdalen valley with the bird census area demarcated together with the names and positions of lakes and ponds mentioned in the text and in Table 2. 'S' denotes the position of the research station and runway. Names ending 'sø' or 'søen' mean lake, 'dammen' or 'dammene' mean ponds, and 'kæret' or 'kærene' mean fens. The Mt. Zackenberg ('the ragged mountain') is to the west of the valley. Heights are in metres.

In late seasons, extensive snow cover may persist into early July (Meltofte 2005).

Each year from 1996 to 2005 inclusive, from around 1 June to around 1 September, bird numbers were recorded on almost daily ground surveys of the census area made by one or two observers. Each day, the surveys covered different parts of the area, in such a way that all lowland parts were visited every few days. Nests were marked on field maps and also checked for eggs or young every few days. A limited number of surveys were also made in adjacent parts of the valley. In 1995, observations did not commence until 13 July, so data from this year were excluded from some of the analyses.

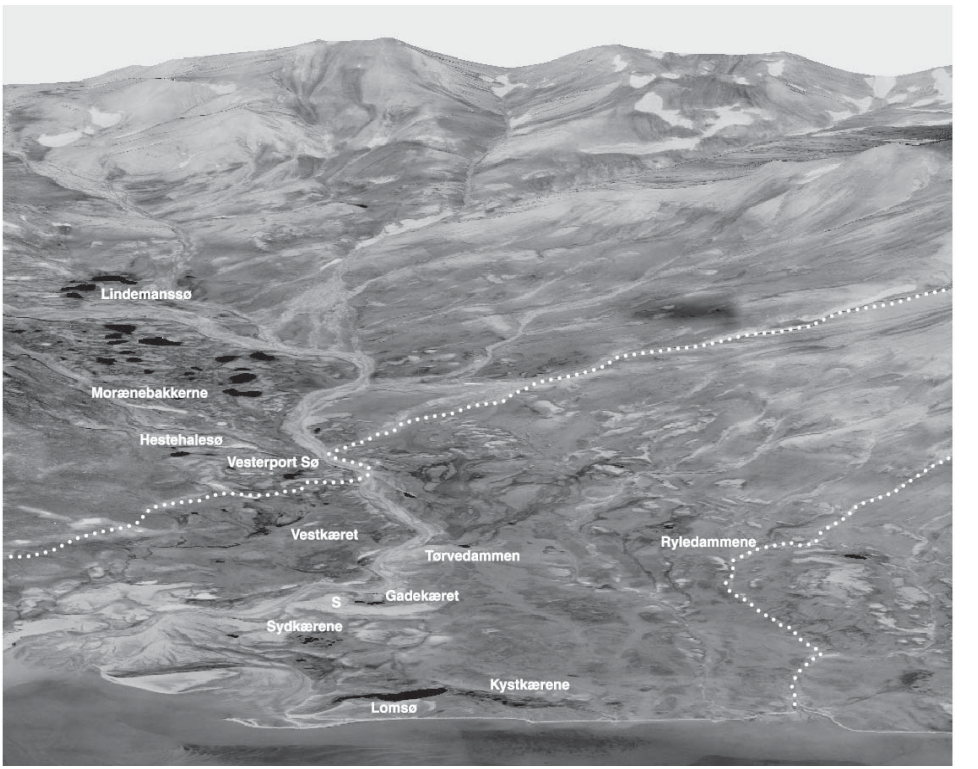

Figure 2. Manipulated aerial photo of the Zackenbergdalen valley with the bird census area demarcated together with the names and positions of lakes and ponds mentioned in the text and in Table 2. 'S' denotes the position of the research station and runway.

The Store Sødal valley, which extends c. 25 km to the west of Morænebakkerne and holds the 27-m-deep lake Store Sø, together with several shallower lakes, was covered during a single survey in mid-July or late July each year, as was the coastal fringe of lowland stretching 20 km to the southeast of Zackenbergdalen.

The observation procedures are described in detail in a comprehensive manual available on the internet (Meltofte & Berg 2006). Numbers of pairs of waterbirds in the census area were estimated from observations of birds that occurred regularly.

Moulting Pink-footed Geese are extremely shy and may flee at a distance of more than 1 km from the observer (Meltofte 1975; Meltofte *et al.* 1981; Madsen & Mortensen 1987). Therefore, a 'goose reserve' was established in 1996 stretching from Lomsø 10 km east along the coast, where human activity is prohibited between 20 June and 10 August in a zone 1 km either side of the coastline.

Red-throated Diver	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Sydkærene 50% ice free	-	≤ 3.6	30.5	7.6	12.6	1.6	8.6	3.6	8.6	≤ 26.5	≤ 21.5
First record	-	≤ 3.6	30.5	3.6	4.6	6.6	3.6	1.6	≤ 4.6	≤ 1.6	≤ 29.5
First on pond	-	≤ 4.6	2.6	5.6	8.6	6.6	9.6	1.6	7.6	≤ 1.6	29.5
1st egg dates (initial clutch)	-	19.6-P.7	13–30.6	18.6–5.7	17–U.6	18.6–P.7	19–≤ 24.6	16.6–≤ 2.7	14.6–P.7	16–20.6	14.6–23.6
Latest re–nesting recorded	20.7	24.7	14.7	–	–	11.7	7.7	17.7	10.7	16.7	19.7
No. of pairs in census area	–	1–2	3	3	2–3	2–3	2	3	2	3–4	4–5
No. of pairs in entire valley	–	4–5	5	5	4–6	5	5	6	6	6–7	5–7
Breeding attempts recorded	–	5	6	4	2–3	4	3	7–8	9	8–9	4–5
Broods recorded	1	1	4	4	0	2	1	2	4	2	0
Chicks recorded	1	1	5	8	0	2	2	3	7	2	0
Fledged young	–	≤ 1	≤ 7	≤ 8	0	≤ 2	≤ 2	≤ 3	≤ 4	≤ 2	0
Fox encounters	–	14	5	7	13	11	14	21	11	16	18
Lemming winter nests	285	161	366	721	331	192	326	287	95	431	232
Lakes ice covered in autumn	–	–	19–22.9	21–29.9	24–26.9	19–24.9	16–17.9	26–29.9	28–30.9	29–30.9	–

Table 1. Number of pairs and breeding performance of Red-throated Diver in the bird census area and the whole of the Zackenbergdalen valley from 1995 to 2005 inclusive. Also given are the dates of 50% ice cover on the largest pond in Sydkærene, the number of Arctic Fox *Alopex lagopus* encounters by one bird census worker during June and July, the number of Collared Lemming winter nests in a 2-km^2 lemming monitoring area in the centre of the valley, and the date on which the lakes in the valley become completely covered with ice. The number of lemming nests are taken as a measure of lemming abundance early in the season. First observation dates include birds flying over, while 'First on pond' is the first date that birds were recorded on a pond. Egg-laying dates refer to the first egg in the clutch, and have an estimated uncertainty of +/- 2–3 days. They were calculated as the date on which a bird was first sitting on a nest minus an egg-laying period, or as the first sighting of a chick minus an egg-laying, incubation and early nestling period of 29 days (cf. Barr *et al.* 2000). Monthly decades are given as P = primo (1–10), M = medio (11–20) and U = ultimo (21–31). 'Breeding attempts recorded' include number of clutches re-laid. Ice cover in autumn was recorded for Lomsø and Vesterport Sø from daily digital photographs taken automatically from 480 m a.s.l. on Mt. Zackenberg.

Pearson's correlation was used for all statistical tests. Daily and total nest survival rates were calculated using the moderated Mayfield method (Johnson 1979).

Annotated Species Accounts

Red-throated Diver *Gavia stellata*

The Red-throated Diver breeds at ponds and lakes all over the ice-free lowlands of Greenland, predominantly in the low-arctic area. The total population is estimated to be at least 5,000 pairs and, furthermore, to be stable (Boertmann 1994, 2000; Tucker & Heath 1994). Greenlandic breeding birds winter in west European waters (Lyngs 2003).

In northeast Greenland, Red-throated Divers appear – often in pairs – in polynyas and open water 'leads' between the fast coastal ice and the drifting polar pack ice from late May (Meltofte 1976a; Meltofte *et al.* 1981). From here they make reconnaissance flights – calling intensively – over the breeding grounds from around 1 June, and they usually land on tundra ponds when they become sufficiently free of ice (Table 1). At Zackenberg, first observation date both of reconnaissance flights (birds seen flying over the area without landing) and, particularly, of birds alighting on ponds are correlated with ice melt, i.e. the date of 50% ice cover on Sydkærene ($r = 0.697$, $n = 10$, $P < 0.03$ and $r = 0.879$, $n = 10$, $P = 0.0008$, respectively). In other parts of high-arctic Greenland, the birds' arrival on breeding ponds has also been recorded in early or mid-June in most years (Meltofte 1975, 1976b, 1977; Meltofte *et al.* 1981; Elander & Blomqvist 1986).

The number of Red-throated Divers nesting in Zackenbergdalen was around 5–6 pairs during most of the study period, with perhaps a slight increase to seven pairs in more recent years (Table 1). The lakes in northern Morænebakkerne were not surveyed each year, so one or two pairs may have been missed there (a pair bred successfully at Trap in 2003; Table 2). The species was also seen in 1964, when pairs were recorded on a lake in Morænebakkerne, on Lomsø and in the Zackenbergelven delta (Rosenberg *et al.* 1970 and expedition diaries kept at the Arctic Institute, Copenhagen). None was found in Sydkærene or Gadekæret in that year.

From 1995 to 2005, breeding was attempted at most of the ponds and lakes in the valley that are large and ice-free sufficiently early, but some are clearly more suitable for Red-throated Divers than others (Table 2). Only two sites in the census area were utilised almost every year: Sydkærene and Lomsø/Kystkærene. Outside the bird census area, the divers nested at Lindemanssø and possibly also at Østersøen in most years. The large pond in Sydkærene, where young were recorded in four out of 11 years (Table 2; no young were produced here in 1995) thaws early, and has islets and vegetation tufts away from the shore that may be used to avoid ground-based predators. This is also the only site where egg laying has been so early each year (13–19 June) that the young fledged before the end of the observation period on 1 September; a total of six young were seen, five flying and one nearly able to fly.

Table 2. Breeding performance of Red-throated Diver on individual ponds and lakes from 1996 to 2005 inclusive. Ponds and lakes inside the bird census area were monitored closely every year and are shown in the top half of the table, while ponds and lakes below the line are situated outside the census area and were therefore less intensively monitored (see Fig. 1 and the text). Time of ice melt is given as the monthly decade with 50% ice cover during the study years. Monthly decades are given as P = primo, M = medio and U = ultimo. * Kystkaerene ice free primo/medio June.

Pond	50% ice	1st egg date	No. of years with breeding pairs	No. of nests or broods seen	No. years when eggs hatched	No. chicks	No. fledged
Large pond in Sydkærene	U.5/M.6	13–19.6	9	9–10	4	6	≤6
Lomsø/ Kystkærene	U.6/P.7*	19.6–1.7	9	16	4	6	≤5
Ryledammene	M/U.6	23.6–5.7	4	4	1	2	≤2
Tørvedammen	U.6/M.7	M.6	3	3	1	1	≤1
East pond in Gadekæret	U.5/M.6	14.6	2	2	0	0	0
Vestkæret	M.6/P.7	20.6	1	1	0	0	0
Lindemanssø	M.6	M.6	≥ 5	–	≥ 4	≥ 4	≤ 6
Vesterport Sø	M.6/P.7	22.6–P.7	6	6	2	4	≤4
Østersøen	–	30.6	≥ 3	≥ 3	≥ 2	≥ 3	–
Hestehalesø	U.5/U.6	–	2–3	2–3	1	2	≤2
Trap	P/M.7	P.7	≥ 1	≥ 1	≥ 1	≥2	–

In contrast, Lomsø thaws late and has no islets. Here the pair nests later and is forced to nest initially on the lakeshore or in Kystkærene, where young have never been known to hatch (Table 2). This pair generally re-nests after losing the first clutch, however, enabling them to produce almost as many young as the pair in Sydkærene. The second clutch is laid in July, when the ice has melted and the divers are able to build a mud nest on a shallow part of the lake.

Since none of these birds is marked, it is only possible to estimate that, for example, the pair using the centre of the valley has either nested initially or re-nested in Hestehalesø, Vesterport Sø, Vestkæret, Tørvekæret and possibly even Ryledammene, while the pairs in Sydkærene and Lomsø, for example, have nested at the same pond or lake every year. Ponds and lakes that thaw too late for the first breeding attempt become ice free later in the year, and are then accessible to the birds for nesting (Table 2). Initial clutches were apparently produced until early July, while re-nesting took place as late as 24 July (Table 1). Replacement clutches are laid 6–18 days after loss of the initial clutch (Barr *et al.* 2000).

While egg laying was clearly delayed on late-thawing ponds and lakes, it was

unaffected by the timing of ice melt on the early-thawing ponds such as the large pond in Sydkærene (r = 0.443, n = 10, P = 0.20, n.s.), and egg laying at this pond constitutes the earliest laying recorded each year (Tables 1 & 2).

The number of Red-throated Diver broods recorded in the valley varied between years, and was negatively correlated with the number of Arctic Foxes seen in the terrain (r = -0.650, n = 10, P = 0.04; Table 1). The best two breeding years were 1997 and 1998, when relatively few Arctic Foxes were recorded. Foxes were seen swimming out to islets that held diver nests, so even on the islets the birds are not safe.

Only in 2003 was there evidence of loss of young (Table 1), but several 1-chick broods may originally have comprised two chicks. Chick survival after the last observations made each year is unknown, but is probably influenced by the onset of lake freezing. Although new ice begins to form on ponds from late August in some years, digital photographs taken automatically daily from 480 m a.s.l. on Mt. Zackenberg indicate that Lomsø and Vesterport Sø did not freeze until the second half of September in the study years (Table 1). Small areas of open water may have remained after these dates, but this is unlikely. Unfledged divers may therefore be unable to find water on the lakes after mid-September, whereas older chicks would be able to walk some 100 m over land to other ponds or to the coast (Barr *et al.* 2000). If the birds re-lay in mid-July, the chicks will not fledge until late September (cf. Barr *et al.* 2000), which may be critically late in most years.

The overall daily survival of clutches for 34 breeding pairs followed regularly between 1995 and 2005 was 0.94, giving a total survival for the whole clutch of 18%. A maximum production of 14 fledged young by an average of 2.75 pairs in the census area over 10 years (Table 2) gives 0.51 young per pair per year. Similarly, 29 young possibly fledged from an average of about 5.4 pairs in the entire valley gives 0.54 young per pair per year. This is close to the success rate in very large studies in arctic North America, where the average was between 0.44 and 0.63 young per pair per year (Barr *et al.* 2000).

The exceptionally late spring of 1999 resulted in the lowest number of nesting attempts during the study years, and 1999 and 2005 were the only years in which no hatched chicks were recorded (Table 1). Any occurrence of adult or immature non-breeders is not known.

Up to three pairs of Red-throated Divers were encountered on lakes in the upper part of Store Sødal valley in July, where nesting has also been recorded.

The Red-throated Divers of Zackenbergdalen feed primarily on the fjord. Until the ice breaks up during July they utilise the open water formed off the river delta during June. Here, up to ten adults and one juvenile were recorded during August. Most birds leave during September, and the latest that individuals have been recorded in northeast Greenland is October (Meltofte 1977; Boertmann 1994).

Great Northern Diver *Gavia immer*

The Great Northern Diver is primarily a low-arctic breeder in Greenland, but scattered pairs may breed as far north as Dove Bay (c. 76°30'N) in northeast Greenland (Boertmann 1994). At Zackenberg, the species was recorded several times in uppermost Store Sødal, about 27 km west of the research station. In 1998, 2000, 2004 and 2005, a pair was seen in July on a small lake in the northeast of the watershed. In 2000, this pair produced one chick.

Pink-footed Goose *Anser brachyrhynchus*

About 2,500–5,000 pairs of Pink-footed Geese breed in East Greenland up to a latitude of 78°N, having expanded their range northwards by about 250 km during the 20th century (Boertmann 1994, and *in litt.*). The Greenland birds belong to the much larger Icelandic population, which increased from around 20,000–30,000 individuals to about 200,000–250,000 individuals during the second half of the 20th century (Mitchell *et al.* 1999). The population winters in Scotland and England (Mitchell *et al.* 1999; Lyngs 2003).

Breeding pairs arrive in northeast Greenland from mid-May (Rosenberg *et al.* 1970; Meltofte 1976a), with 8 May being the earliest record to date (de Korte 1988). At around this time, maximum daily temperatures rise above 0 °C in southern high-arctic Greenland (Meltofte 1976b).

In midsummer, tens of thousands of immature Pink-footed Geese from the Iceland population undertake a moult migration to northeast and North Greenland, where flocks now appear as far north as Pearly Land (Christensen 1967; Boertmann 1991). The number of Pink-footed Geese moulting in northeast and North Greenland has increased substantially in parallel with the increase in size of the population, and their moulting grounds have expanded at least 1,000 km to the north (Meltofte 1975; Boertmann & Glahder 1999).

Only a few pairs of Pink-footed Geese breed at Zackenberg. Inside the bird census area 1–2 nests and broods per year were found in four out of ten study years, but breeding may also have been attempted in other summers. Hatching occurred between 26 and 29 June in the few nests recorded, whereupon the families moved down to the coast of the fjord. Pink-footed Geese typically lay about five eggs that have an incubation period of 26–27 days (Cramp 1977). Thus egg laying began around 25 May, or at the same time as the Barnacle Geese nesting in the area (see below).

The first Pink-footed Geese were reported breeding at Zackenberg in 1955 (Conradsen 1957), and a total of 8-10 pairs of Pink-footed Geese produced at least six broods at Zackenberg in 1964 (Rosenberg *et al.* 1970; see further in Discussion).

In most years up to 5–12 apparently immature Pink-footed Geese roamed the valley prior to the moult migration. At Zackenberg, the moult migration of Icelandic Pink-footed Geese began between 14 and 18 June in most of the study years, although in the last two years of the study flocks migrating north were observed as early as 6 and 10 June, respectively. If these geese were from Iceland, this implies that the moult migration began so early that it

is difficult to separate it from the spring migration of birds local to Greenland. The main moult migration passage occurred during the second half of June, when up to 784 individuals were counted in one day. Most birds passed along the slopes of Aucellabjerg, which were visited less regularly during the surveys. Good coverage was obtained in 2003, however, when a second team worked at Aucellabjerg for about 8 h a day during the migration period (T. Piersma & J. Reneerkens, *in litt.*). In that year, a total of 2,092 individuals were recorded, with a mean flock size of 23 and a maximum of 123 (n = 91).

Most birds were seen from 19 to 27 June – in the last few years even as early as 16–22 June, which may be somewhat earlier than during the 1950s, 1960s and 1970s, when peak numbers were recorded during the last five days of June (Rosenberg *et al.* 1970; Meltofte *et al.* 1981; Elander & Blomqvist 1986).

Migrating flocks often land on the mountain slopes, where they feed for some hours. A few latecomers passed north during early July during the study period, and the last migrating flocks were seen between 2 and 12 July. Flightless individuals were recorded from early July, and the last flying birds were seen on 15 July.

More than 500 flightless birds were found along the fjord coast at Zackenberg in mid-July 1995, when work began at Zackenberg and observers arrived in the middle of the moulting period (Table 3). In subsequent years, no geese moulted immediately south of the research station, and numbers decreased substantially even in the protected zone (see Study Area and Methods) after a few years (Table 3). Most birds in this zone were found around the peninsula to the southeast, about 4–8 km from the research station, hence well inside the 'goose reserve'. Occasional visits in the zone by people not involved in the research, sometimes bringing loose dogs, and aerial traffic in the form of both planes and helicopters still occur and cause significant disturbance (cf. Mosbech & Glahder 1991). The only other part of the study area that now has moulting Pink-footed Geese is the seldom-visited Store Sødal, where a small flock still occurs (Table 3). A total of c. 140 Pink-footed Geese moulted in Zackenbergdalen in 1964 (Rosenberg *et al.* 1970 and expedition diaries kept at the Arctic Institute, Copenhagen).

In northeast Greenland, the birds moult their remiges in flocks numbering up to 1,340 individuals (mean 15–52 in different areas) off river mouths and on large lakes, where they can escape onto open water (Madsen *et al.* 1984; Bay & Boertmann 1989; Boertmann 1991; Boertmann, pers. comm.; this study). Ice often remains on fjords and large lakes well into July and often throughout the summer in North Greenland. The main threats to the flightless geese are Arctic Fox and Arctic Wolf *Canis lupus* (Marquard-Petersen 1998 and observations from Zackenberg). In this region, goose remains occurred in about one third of wolf faeces (Marquard-Petersen 1998).

The birds begin to regain flight capacity in late July, but flightless birds are still seen in early August. During the first years of the study, when birds were still moulting on the coast, up to 300 Pink-footed Geese fed in the fens of the inland valley from early August. Furthermore, numbers of Pink-footed

Study area	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Pink-footed Goose											
Closed moulting area and further east	310	246	247	5	127	35	0	30	41	31	17
Coast west of closed area	230	40	60?	0	29	0	0	0	0	10	0
Upper Zackenbergdalen	0	0	15	0	0	0	0	0	0	0	0
Lower Store Sødal	20	12	21	0	5	0	16	8	11	0	2
Upper Store Sødal	20	55	144	123	21	56	69	28	27	–	34
Pink-footed Goose total	> 580	> 353	< 487	128	182	91	85	66	79	> 41	53
Barnacle Goose											
Closed area at Lomsø and Kystkærene	21	0	29	21	60	84	137	86	120	81	87
Remaining coast of Zackenbergdalen	> 120	150?	96	55	66	30	109	80	45	0	32
Upper Zackenbergdalen	41	85	2	75	< 57	27	60	0	14	0	25
Lower Store Sødal	114	46	97	114	117	150	150	81	78	81	161
Upper Store Sødal	> 19	61	63	184	87	78	46	57	71	–	108
Barnacle Goose total	> 315	< 342	287	449	< 387	369	502	304	328	< 162	406

Table 3. Numbers of immature Pink-footed Goose and Barnacle Goose moulting in the study area at Zackenberg, 1995–2005. The closed moulting area is a protected zone extending 1 km landwards and 1 km seawards from Lomsø along the coast to a point 10 km to the east. No human activity is allowed in this area from 20 June to 10 August. The areas noted in the table vary slightly between the two species because they use different parts of the Zackenberg valley. Coverage of upper Store Sødal has also varied between years.

Geese staging in the valley during autumn migration have decreased from a maximum of 455–800 during 1995–1999 to 100–180 more recently. Flocks of up to 76 individuals migrating in a southerly direction have been recorded from around 20 August.

Barnacle Goose *Branta leucopsis*

An estimated total of at least 10,000 pairs of Barnacle Geese breed in high-arctic northeast Greenland between 70°N and 79°N (Boertmann 1994; M. Ogilvie, *in litt.*). Together with juveniles and immature birds, they constitute the entire Greenland population of about 56,000 individuals wintering in Ireland and Scotland (Worden *et al.* 2004). The population has increased from a mere 8,400 in the late 1950s (Ogilvie *et al.* 1999). In Greenland the species breeds in colonies, usually of fewer than 25 pairs, on cliff ledges along fjord and valley sides, but colonies of up to 100 pairs exist (Boertmann & Glahder 1999; Ogilvie *et al.* 1999). A few birds also nest on islets in ponds (e.g. Forchhammer 1990).

The birds arrive in Greenland from about 20 May, with 8 May being the earliest record (Rosenberg *et al.* 1970; Meltofte 1975; Elander & Blomqvist 1986; de Korte 1988; Forchhammer 1990).

At Zackenberg, Barnacle Goose colonies are found on basalt pillar cliffs on Basaltø (7–8 pairs in 1964) and the northeast coast of Clavering Ø (20–30 pairs in 1964) on the south side of Young Sund (Rosenberg *et al.* 1970), where they still breed. Furthermore, small numbers of Barnacle Geese were recorded by this study on Eiger and on the south side of Mt. Zackenberg, more than 500 m a.s.l., and Barnacle Geese probably also breed on cliffs along Store Sødal (see below). Several colonies have been known to breed here since the first half of the 20th century (Rosenberg *et al.* 1970).

During the last five days of June, with relatively little variation between years, pairs of Barnacle Geese with newly hatched goslings begin to arrive to Zackenbergdalen from colonies probably up to 17 km away after having walked over the fjord ice or swum in open 'leads' (Table 4). Barnacle Geese typically lay about five eggs that have an incubation period of 24–25 days (Cramp 1977). At Zackenberg the young appear about 2–3 days after hatching (Cabot *et al.* 1988). Egg laying therefore commenced around 25 May or very close to the initiation date in Pink-footed Goose (see above). The last newly hatched goslings were recorded on 11 July.

Considering that some pairs fail, the maximum number of broods appearing at Zackenberg (Table 4) corresponds relatively well with the expected numbers of breeding pairs in the colonies mentioned above. It is very likely that the lower numbers in other years mean that many families stay along the coasts of Clavering Ø and Wollaston Forland.

Most families are found in the 'goose reserve' around Lomsø and Kystkærene (see Study Area and Methods), from where they run to the lake or the fjord if threatened by foxes, wolves or humans. These families also utilise the saltmarsh in the old Zackenbergelven delta, just west of Lomsø, and families have also been seen along the remaining part of the coast and at Østersøen. In most years, 2–5 families that

Table 4. Average brood sizes of Barnacle Goose in Zackenbergdalen during July and early August, 1995–2005, together with snow cover on 10 June (measured from photos taken 480 m a.s.l. on Mt. Zackenberg), date of the first observed brood and the total number of broods brought to the valley. Samples of fewer than 10 broods are given in brackets, fewer than five are omitted. Data from autumn on the Isle of Islay in Scotland are given for comparison, including percentage of juveniles in the population (Ogilvie 2005, and *in litt.*).

Barnacle Goose	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Snow cover on 10 June (%)	84	82	76	80	91	53	84	79	83	48	28
Date of first brood	–	–	29.6	26.6	1.7	27.6	28.6	28.6	29.6	30.6	26.6
No. of broods	≥7	6–7	19–21	≥18	29	11	4	32	8	26	14
Fox dens with pups	–	2	0	1	0	2	2	0–1	2	3	0
Primo (1–10) July	–	(3.0)	3.1	(2.9)	1.9	(3.2)	(1.8)	2.4	(1.8)	2.6	(1.7)
Medio (11–20) July	–	(2.3)	2.7	2.3	1.8	(3.1)	(1.7)	2.4	(1.2)	2.3	2.7
Ultimo (21–31) July	(2.0)	(3.0)	2.6	2.2	1.7	3.1	–	2.3	(1.1)	2.3	(2.2)
Primo (1–10) August	(2.3)	(2.3)	2.4	–	1.8	–	(2.0)	2.2	(1.2)	(1.9)	–
Scotland	2.00	2.30	1.95	2.28	1.92	2.20	1.94	2.23	1.59	2.35	1.67
Percentage juv. in Scotland	7.2	10.3	6.1	10.5	8.1	10.8	7.1	12.5	6.4	15.9	6.3

probably come from a colony in the upper part of the valley are found along the river and at lakes in Morænebakkerne. When the study began in the valley in 1995, several families utilised the ponds and fens in Vestkæret, but they have been driven away. Finally, up to 14 families have been recorded at lakes in both lower and upper Store Sødal. Families normally remain separate from the flocks of moulting immature birds at the same sites (see below), but failed pairs often remain with the family groups.

The average brood size varied from year to year (Table 4), and there was a significant correlation between the brood size in late July and that recorded during autumn and winter on the Isle of Islay in Scotland ($r = 0.657$, $n = 11$, $P < 0.03$). A negative correlation between average brood size in mid-July, when all the broods had arrived, and spring snow cover was not statistically significant ($r = -0.594$, $n = 11$, $P = 0.07$, n.s.), but since other variables may also influence breeding success this warrants further analysis. If future monitoring confirms the association, it concords with results from Svalbard, where Prop & de Vries (1993) found that feeding conditions for the adult females during pre-laying, laying and incubation influenced breeding success. Similarly, Fox & Gitay (1991) found that snowfall in northeast Greenland in the second half of May, when the geese arrive, had a significant negative effect on reproductive success.

The average brood size decreased a little during the season (Table 4). For the four years when at least 10 broods were followed, the average brood size decreased from 2.50 in early July to 2.30 in mid-July, and further to 2.23 in late July, or by 0.57% per day. If

early August is included (mean = 2.08, but this includes one sample of fewer than 10 broods), the mean decrease was 0.61% per day. These mortality rates are minimum figures, since some broods are lost entirely or taken over by other families (indicated by observations of goslings of different sizes in the same brood). Finds of gosling remains in fox dens in the area demonstrate the reason for at least part of the mortality. Furthermore, heavy losses may already have occurred between departure from the cliff ledges and arrival on safe water (Cabot *et al.* 1988).

In early and mid-June, groups of up to 50 immature Barnacle Geese fed on early snow-free patches in the valley, probably together with off-duty breeding birds. From late June they gathered at Lomsø, where increasing numbers of Barnacle Geese moulted during the years of the study (Table 3). This increase occurred simultaneously with and most likely as a result of the decrease in numbers of Pink-footed Geese moulting on the coast close to the research station (Table 3). Hence, the numbers of Barnacle Geese moulting at Lomsø showed a significant negative correlation with the numbers of moulting Pink-footed Geese along the coast of Zackenbergdalen (r = -0.671, n = 11, P = 0.02). Studies in Jameson Land have demonstrated that Pink-footed Geese compete successfully with Barnacle Geese for resources (Madsen & Mortensen 1987). Sedges and grasses were the preferred diet, but mosses were eaten by both species where they competed for forage. In Kystkærene and around Lomsø, the vegetation appears to be heavily grazed, so that mosses predominate.

Although the numbers of moulting Barnacle Geese around the peninsula in the southeastern part of the valley were low in recent years (detailed under 'Remaining coast of Zackenbergdalen' in Table 3), the total numbers of moulting immature Barnacle Geese in the study area remained remarkably constant at 300–500 individuals during the entire study period (Table 3). In 1947, "large flocks" of Barnacle Geese were also moulting in fens along the coast of Zackenbergdalen (Møhl-Hansen 1949), and in 1964 a total of 112 immature Barnacle Geese were moulting at Lomsø (26), Østersøen (56) and on the coast (30) (Rosenberg *et al.* 1970 and expedition diaries kept at the Arctic Institute, Copenhagen). This is much the same as in the present study. Bay & Boertmann (1989) recorded 300 Barnacle Geese in an aerial survey at Zackenbergdalen in July 1988, but these may have been a mixture of Pink-footed Geese and Barnacle Geese, since both species were present when the long-term observations commenced in 1995.

The immature birds loose their remiges during the last few days of June and early July, and during the flightless period they occur in flocks close to lakes, rivers or coastal areas with open water. They occupy smaller lakes and waterbodies and remain in smaller flocks (maximum 350 and mean between 6 and 35 in different areas in northeast Greenland) than the moulting Pink-footed Geese, and they are less shy than the Pink-footed Geese (Meltofte 1975; Madsen & Mortensen 1987; Bay & Boertmann 1989; this study). Once they are able to fly again, from late July and early August, the Barnacle Geese at Zackenberg move to grassy fen areas not utilised during the moult. Here flocks

numbering up to 300 were recorded during August. A few skeins of Barnacle Geese were seen heading south during late August.

Common Eider *Somateria mollissima*

Except in northernmost Greenland, where the coasts are often icebound throughout the summer, the Common Eider is a common breeder on islands across Greenland. In East Greenland it breeds north to 81°N (Boertmann 1994), which may be a range extension of several hundred kilometres further north than 100 years ago (Hjort *et al.* 1983). The Greenland population is estimated at 15,000–20,000 pairs (D. Boertmann, *in litt.*). Most Eider are found in West Greenland, where they have suffered a serious decline from probably over 100,000 pairs in the early 19th century to 12,000-15,000 pairs today due to overexploitation (Salomonsen 1967; Merkel 2004). Some authors consider the East Greenland birds to be a separate sub-species, *islandica*, together with the Iceland (western Norway and Svalbard) birds, in accordance with their main wintering areas in Icelandic waters (Goudie *et al.* 2000; Lyngs 2003). The West Greenland *borealis* birds remain in Southwest Greenland during the winter, and the two populations do not mix.

In northeast Greenland, small numbers of pairs breed singly on the mainland coasts and even beside large rivers and lakes, but at Daneborg, 21 km southeast of Zackenberg, more than 2,300 pairs breed among 60–80 tethered huskies (Meltofte 1978, in press). A similar colony of about 100 pairs is found at Danmarkshavn Weather Station, 265 km north of Zackenberg (Meltofte 1977, 1978; Forchhammer 1990; this study).

In East Greenland, the Common Eiders arrive in polynyas and open water 'leads' between the fast coastal ice and the drifting polar pack ice during April and May (Rosenberg *et al.* 1970; Meltofte 1976a, 1978; Meltofte *et al.* 1981; Elander & Blomqvist 1986; Falk *et al.* 1997; Lyngs 2003). From here they perform reconnaissance flights over the breeding sites from late May or early June. At Daneborg, egg laying takes place from early or mid-June, and the young hatch from early July until early August (Meltofte 1978; this study).

At Zackenberg, Common Eiders are regularly seen on ponds and open water off river mouths from early or mid-June in most years. In 2000 and 2001 single nests were found on the sandy coast near the river delta and on tundra 3 km from the coast (200 m from the River Zackenbergelven), respectively. Both nests had been depredated.

From mid-July – the earliest date being 15 July – females with ducklings, probably originating from the Daneborg colony, appear along the fjord coast of Zackenbergdalen. Up to 200 ducks, ducklings and immature ducks were counted in late July and during August off Zackenberg. The last males are normally seen in early or mid-July, but single males were recorded into August.

Most males probably moult their remiges in Icelandic waters, but some may moult in East Greenland (Meltofte 1976a, 1978; Hjort *et al.* 1983; Lyngs 2003). Female Eiders with young have been recorded until late September in northeast Greenland, where some may even overwinter in southern areas (Meltofte 1975; Boertmann 1994).

King Eider *Somateria spectabilis*

In Greenland, the King Eider is a fairly common high-arctic breeding bird with an estimated population of a few thousand pairs (Boertmann 1994, and *in litt.*). Since nests are usually scattered across the tundra in areas with ponds that are ice-free early, which are not widespread in mountainous Greenland, breeding is limited to relatively restricted areas.

A few King Eider pairs were recorded at Zackenberg during June in each of the study years (Table 5). Numbers varied somewhat, which may be due both to real variation and to varying numbers of prospecting birds subsequently moving to other sites.

Most pairs arrived on ponds and in river deltas between early June and midsummer (Table 5), and this was the same in other parts of high-arctic North and northeast Greenland, (Meltofte 1975, 1976b; Meltofte *et al.* 1981; Elander & Blomqvist 1986). Like Common Eiders, King Eiders appear in openwater areas and 'leads' on the outer coast from early April (Rosenberg *et al.* 1970; Meltofte *et al.* 1981; Elander & Blomqvist 1986; Falk *et al.* 1997).

Egg laying was initiated in late June or early July in the few nests and broods that were recorded (Table 5). In other parts of the Greenland breeding range, egg laying has been recorded between mid-June and early July (Meltofte 1976b, 1977; Meltofte *et al.* 1981; Elander & Blomqvist 1986).

Three out of five nests were successful, and a further two broods were recorded (Table 5). A cumulative total of 19–28 potential breeding pairs produced a total of 18 ducklings during the 10 years of the study. Although a few broods may have been missed, this seems to be a very low figure. The two unsuccessful nests at Zackenberg were depredated by Arctic Foxes. Breeding success at Danmarks Havn, 265 km north of Zackenberg, appeared much higher with seven broods hatched by nine potential breeding pairs in 1975, and large family parties recorded on the fjords (Meltofte 1975, 1977; see also Suydam 2000). As in other parts of the Arctic (Suydam 2000), the females moved with their broods from pond to pond, and then out to the fjord coast, within a few days or weeks. Thus it was not possible to monitor the survival of the brood after hatching.

The last males are normally seen on the ponds in early or mid-July, and during July and August groups of females have often been recorded in lakes or along the fjord coasts (Rosenberg *et al.* 1970; Meltofte 1975, 1976b, 1977; Meltofte *et al.* 1981; Elander & Blomqvist 1986; this study). A few single males were even seen on the fjord in July and August, and elsewhere in North and northeast Greenland concentrations of up to 70–100 birds have been recorded in July (Meltofte 1975, 1976a, 1976b). The last King Eiders in northeast Greenland were recorded in late September, but a few have even been seen in winter (Meltofte 1975; Boertmann 1994).

In 1964, a pair of King Eiders was seen on Lindemanssø in mid-June, and five females were recorded on Lomsø and two to three on Østersøen in mid-July (Rosenberg *et al.* 1970 and expedition diaries kept at the Arctic Institute, Copenhagen). Similar sightings are occasionally made today.

Table 5. Date of initial observation, and numbers of potential breeding pairs in the bird census area together with first egg dates and records of nests and broods for King Eider in Zackenbergdalen, 1995–2005. Egg-laying dates were calculated from an incubation period of 22–24 days and a clutch of about five eggs (Suydam 2000), and they refer to the first egg in the clutch with an estimated uncertainty of +/- 2–3 days. Broods include those seen where the nest site was not found.

King Eider	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
First record	–	12.6	4.6	15.6	16.6	≤ 22.6	9.6	11.6	≤ 13.6	14.6	21.6
No. of pairs	–	2–3	2	1	2–3	2–4	3–4	4–6	1	1–2	1–2
1st egg dates	–	–	22.6	–	8.7	2.7	30.6	≥ 23.6	–	–	–
Nests recorded	–	1	0	0	1	1	1	1	0	0	0
Successful nests	–	0	0	0	1	1	1	0	0	0	0
Broods recorded	0	0	1	0	0	1	2	0	0	0	0
No. of ducklings	0	0	5	0	0	6	7	0	0	0	0

The moulting (in males) and wintering grounds of the northeast Greenland population are largely unknown, but groups of moulting males have been recorded on the coasts of northeast Greenland, and wintering birds have been recorded in Icelandic waters, with a few in northeast Greenland (Boertmann 1994; Lyngs 2003).

Long-tailed Duck *Clangula hyemalis*

The Long-tailed Duck is a common breeding species on ponds and islets across Greenland, with an estimated population of more than 10,000 pairs (Boertmann 1994, and *in litt.*). Most Long-tailed Ducks winter off southwest Greenland, but wintering birds are also found in Icelandic and Newfoundland waters and maybe further afield (Lyngs 2003). It is not known whether the movements of East Greenland birds differ.

Long-tailed Ducks arrive at Zackenberg and in other parts of northeast Greenland predominantly in pairs in late May or the first half of June. Larger concentrations do not appear on the outer coast prior to the arrival of the pairs on lakes and ponds (Table 6; Rosenberg *et al.* 1970; Meltofte 1975, 1976a, 1977; Meltofte *et al.* 1981; Elander & Blomqvist 1986; de Korte 1988; Falk *et al.* 1997). The birds tended to arrive at Zackenberg earlier in years when the ice melted early on Sydkærene, but this correlation was barely significant ($r = 0.631$, $n = 10$, $P = 0.0505$).

Each year, about 5–8 pairs were seen in the bird census area at Zackenberg by mid-June, with little variation from year to year (Table 6). Early in the season, the birds were concentrated in Sydkærene, Kystkærene and Gadekæret, where ice melt is early, but later pairs also appeared on other ponds and lakes. The maximum count was of 10 pairs in early June 1996, but some of these birds were considered to be migrants. On 12 June 1964, 17 pairs plus one male were counted in Gadekæret, Sydkærene and in

Table 6. Date of initial observation and numbers of potential breeding pairs in the bird census area together with first egg dates and records of nests and broods of Long-tailed Duck at in Zackenbergdalen, 1995–2005. Egg-laying dates were estimated from an incubation period of about 26 days and a clutch of about five eggs (Robertson & Savard 2002; this study), and they refer to the first egg in the clutch with an estimated uncertainty of +/- a few days. Broods include those seen from hatched nests already recorded.

Long-tailed Duck	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
First record	–	≤ 1.6	30.5	2.6	6.6	6.6	7.6	3.6	7.6	2.6	1.6
Population (pairs)	–	5–8	4–6	6–8	7–8	5–8	5–7	6–7	7–9	5–7	6–8
1st egg dates	≤ 29.6	–	≤ 1.7	≤ 29.6	–	≤ 29.6–1.7	–	≤ 26–28.6	≤ 16.6	≤ 15.6–2.7	–
Nests recorded	1	1	0	0	3	3	1	2	3	2	0
Successful nests	0	0	–	–	0	0	0	0	0	1	0
Broods recorded	1	0	1	1	0	1	0	2	0	5–9	0
No of chicks	6–8	0	2	4	0	5	0	7	0	29–48	0

the Zackenbergelven delta (Rosenberg *et al.* 1970 and expedition diaries kept at the Arctic Institute, Copenhagen). Kystkærene was not visited on this occasion (see Discussion).

Egg laying took place in the second half of June and the first few days of July (Table 6). A pair was also found breeding in upper Store Sødal. A total of 16 nests were found by the study, including nests found after depredation (Table 6). None of these eggs hatched – mostly due to depredation – but a further 11–15 broods were recorded over the years. It is interesting to note that half the broods were recorded in 2004, when Arctic Foxes were plentiful and Collared Lemmings abundant (cf. Table 1). This is the only year in which the 'classic' situation was observed at Zackenberg, where abundance of alternative prey offset high predator levels, and even waders incurred low predation (cf. Pehrsson 1986; Underhill *et al.* 1993; Meltofte 2005; see also Discussion).

As with King Eider, broods were brought from pond to pond and down to Lomsø or the fjord coast soon after hatching. At the same sites, flocks of moulting Long-tailed Ducks build up during July to reach a maximum of about 50 individuals in August. Males and females stay in separate groups, to some extent. In other parts of northeast Greenland, concentrations of up to 500 birds have been recorded on lakes and fjords during this period (Manniche 1910; Meltofte 1975, 1977; Ferns & Mudge 1976; Hjort 1976; Meltofte *et al.* 1981; Elander & Blomqvist 1986; Forchhammer 1990). The last Long-tailed Ducks are seen in northeast Greenland in October, but a few may winter in southern areas (Meltofte 1975; Boertmann 1994).

Discussion

After 10–11 years of monitoring of breeding waterbirds at Zackenberg, the most pronounced impression is one of stability. In contrast to many numerically highly fluctuating arctic animals, divers and ducks were found in relatively stable numbers during the study years.

Over a longer time perspective, the lower numbers of breeding Pink-footed Geese at Zackenberg today than in 1964 is possibly the result of recent recolonisation by Arctic Wolves in northeast Greenland (Dawes *et al.* 1986; Marquard-Petersen 1995), which may have caused the geese to cease breeding colonially, as on the open tundra at Zackenberg. Wolves or fresh wolf tracks have been seen at Zackenberg in nine out of eleven study years. In 1964, at least two nests were close to each other on islets in the ponds in Sydkærene and eight on a rocky promontory on the coast 4 km west of the valley (Rosenberg *et al.* 1970 and expedition diaries kept at the Arctic Institute, Copenhagen). At the latter site, 1–2 nests were also found in 1997, whereas not even old nests were found in the fens in the bird census area during the study years.

The only other indication of long-term change was the record of twice as many Long-tailed Ducks in 1964 as there are at present. A possible explanation for this is the cessation of fox trapping in 1960. Until 1960, Zackenberg was the site of a very active trapping station, with 1–3 trappers working in the area all year round (Mikkelsen 2001). This may have reduced the Arctic Fox population to such an extent that waterbird populations benefited from reduced nest depredation.

In a larger geographical perspective (i.e. high-arctic Greenland), the most pronounced changes in both Pink-footed Geese and Barnacle Geese have been the increasing numbers and geographical expansion of their breeding and moulting ranges. These increases, which correspond with an increase in total population size since the 1960s (Mitchell *et al.* 1999; Worden *et al.* 2004), may be due to improved survival on the staging and wintering grounds. At Zackenberg, however, the number of breeding and moulting Barnacle Geese appeared to be stable. The recent decline in the number of Pink-footed Geese moulting at Zackenberg is probably due to the increase in human activity in the area.

Another pronounced feature is the erratic breeding success of divers and ducks, in that most years showed moderate or low breeding success, while just a few years stood out in this respect. This is clearly related to varying levels of hunting effort by Arctic Foxes, so that fox predation was obviously low in years with few foxes, such as 1997 and 1998, but also low in years with many foxes and much alternative prey in the form of lemmings, such as 2004. In such years, the foxes' home range and hunting effort is reduced (Zakrzewski *et al.* 1999; see also Underhill *et al.* 1993). Hence, the Red-throated Divers enjoyed good breeding success in 1997 and 1998 – particularly 1998 – when few foxes were seen and lemming numbers were high (cf. Underhill *et al.* 1993). In 1997 there was also low depredation of wader nests; a similarly low depredation of wader nests in 2004 (Meltofte 2005), a year with many foxes and many lemmings, resulted in record high breeding success in Long-tailed Ducks but not in divers.

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