Spring staging in the Svalbard-breeding Pink-footed Goose *Anser brachyrhynchus* population: site-use changes caused by declining agricultural management?

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Abstract

This study used remote sensing data to assess changes in the extent of different habitats at spring staging sites for Pink-footed Geese *Anser brachyrhynchus* in northern Norway over the years 1975–2005. Shifts in goose distribution were analysed in relation to the habitat changes. Abandonment of livestock grazing and mowing of pastures, which has led to re-growth of rough pasture and scrub, is considered to be a major reason for changes in Pink-footed Goose distribution along the flyway in recent decades. The study demonstrates that migrating geese may respond to habitat change by switching to sites where intensive agricultural management has been maintained.

Key words: habitat changes, Pink-footed Geese, remote sensing, spring migration.

Site fidelity is well documented amongst many bird species (Greenwood 1980). Arctic nesting geese show high degrees of site fidelity to sites throughout their flyways (Gullestad *et al.* 1984; Black *et al.* 1991; Madsen 2001) and to their breeding territories (Cooch *et al.* 1993; Black 1998; Loonen *et al.* 1998; Tombre *et al.* 1998a, b; Fowler 2005). For populations with discrete and restricted staging areas, following traditional migration routes is considered an optimal strategy for minimising travel time (Owen & Gullestad 1984). Likewise, fidelity to breeding sites is considered to save time otherwise spent acquiring knowledge of unfamiliar areas (Greenwood 1980), which is supported by studies showing that birds with greater site fidelity have higher reproductive success (MacInnes & Dunn 1988; Gauthier 1990).

Although many goose populations are site-loyal, distributional changes may occur over time as environmental factors influence site suitability. An increase in food availability on the wintering grounds, due to the establishment of managed refuges (Owen *et al.* 1987), or enhancement of the quality and extent of arable and improved pasture through intensification of farming practices (Fox *et al.* 2005), has apparently effectively expanded the winter habitat for several populations. In contrast, long-term societal trends, which include human depopulation in marginal agricultural regions combined with changes in agricultural policies, have led to the abandonment of farmland in some parts of Europe (Bolliger *et al.* 2007). Regeneration of scrub and woodland in formerly open-land habitats has affected plant and animal diversity in these areas. There is also a general trend in Norway for the margins of agricultural land to be progressively abandoned, and thus become overgrown and rank (Dramstad *et al.* 2002; Tombre *et al.* 2005a); several studies have assessed the consequences of this for biodiversity (Norderhaug *et al.* 2000; Jensen *et al.* 2001; Sickel *et al.* 2004; Tømmervik *et al.* 2004). Neglect of formerly exploited agricultural areas may force the geese to utilise new agricultural sites and reduce the use of their traditional areas, such as natural meadows, wetlands and shore vegetation (Black *et al.* 1991). Increased use of agricultural habitats has intensified the conflict between geese and agricultural interests (reviewed in van Roomen & Madsen 1992). Goose scaring campaigns, organised either as a part of a management plan or through local initiatives by farmers, may exacerbate the transition to farmland by altering traditional site use and migration strategies of the geese (Béchet *et al.* 2004; Tombre *et al.* 2005b; Klaassen *et al.* 2006).

The Svalbard breeding population of Pink-footed Goose *Anser brachyrhynchus* migrates from wintering areas in Belgium and the Netherlands, through spring staging sites in Denmark and Norway. In northern Norway, geese migrate through coastal landscapes subject to changes in agricultural management. At present, two main staging areas exist for this population; one in central Norway (Trøndelag) and one in northern Norway (Vesterålen/Lofoten, Madsen *et al.* 1999; Tombre *et al.* 2008).

In the present study, Pink-footed Goose abundance and distribution from the 1970s, 1980s and today (2007–2009) during their spring migration period in Nordland County, northern Norway, are considered in relation to site use. In the 1970s and 1980s, Pink-footed Geese were reported from a long list of sites (n = 54); for the current study the nine sites with the highest mean goose counts recorded in those years were selected. Vegetation changes at these sites in recent decades were quantified from satellite images. Satellite data is increasingly being used to generate model inputs to evaluate primary production, phenology and land cover classes, both regionally (Hill *et al.* 1999; Running 1990; Paruelo *et al.* 1997) and globally (Tucker & Sellers 1986; Williams *et al.* 1997; Karlsen *et al.* 2006), including for goose habitats (Reeves *et al.* 1976; Morrison 1997; Jano *et al.* 1998; Tombre *et al.* 2005a, b; Jensen *et al.* 2008; Speed *et al.* 2009).

Remotely sensed data, especially from satellites, are spatially explicit, achieve large-scale coverage, are uniform for the entire area sampled (following radiometric and geometric pre-processing), are repeatable over time, and offer the possibility of appraising entire landscapes simultaneously (Roughgarden *et al.* 1991). Accordingly, remotely sensed data can offer the best means of evaluating the effects of changes in vegetation and biodiversity in general (DeFries *et al.* 1999). In the current paper it is hypothesised that, at present, fewer geese are using sites where abandonment of pasture has occurred compared to sites where agricultural practice has been relatively stable and provide the geese with a more consistent food supply. It is therefore expected that a loss of high quality habitats over the years will correspond with a reduction in the number of geese using these particular sites.

Study area

Pink-footed Geese stage in the coastal zone of Nordland County, Norway, which consists of offshore islands of variable size, and mainland areas that are partly cultivated, with small settlements in more central parts. A combination of fishing and farming is common, but numbers of part-time farmers have declined over the last few decades (Statistics Norway http://www.ssb.no/en/). Sheep farming is the main agricultural activity, along with hay-making for feeding to cattle. The geese graze on pasture fields, but also roost on the seashore and feed on shoreline vegetation, although the availability of this natural food source is relatively limited.

Nine spring staging sites for Pink-footed Geese were selected for study (listed in Appendix 1), based on their having the most geese (*i.e.* on averaging the maximum goose counts recorded for each site each winter) in the 1970s and 1980s. Only feeding areas within each site were included in the analysis. Sites 2 (total area = 1.2 km^2) and 3 (toal area = 18 km^2) are archipelagos; the other sites are parts of larger areas where geese feed on cultivated fields (Fig. 1).

With increases in population size, Pink-footed Geese in Norway have become increasingly subject to scaring on the most agriculturally sensitive fields. As the scaring of geese from high-quality fields also may reduce goose numbers, only goose data from years where there was known to have been no scaring activity at the study site were included in the analyses.

Methods

Applying remote sensing data to quantify vegetation changes

Landsat images from 1975 (MMS), 1985 and 1994 (5 TM) and 2002 and 2005 (7 ETM+) were used to detect and monitor vegetation changes at the nine selected sites. Available vegetation maps, digital orthophotos and agricultural survey data were used for fine-grained interpretation of the images and to assess the reliability of habitat classification. A summary of the remote sensing sources is presented in Table 1. Habitat changes were analysed over slightly different time periods for different sites, depending on the years in which satellite images were available for each site: between 1975, 1989 and 2002 for three sites

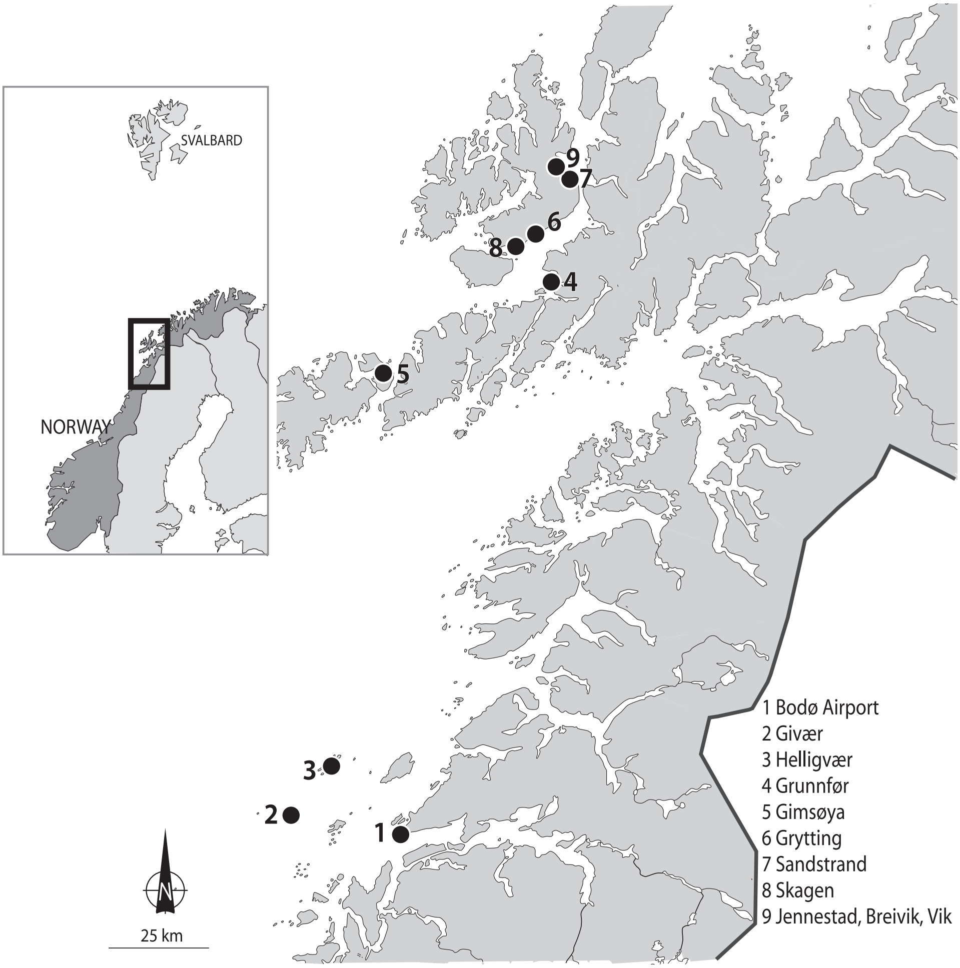

Figure 1. Map showing the study area with the nine named staging sites (black dots) for Pink-footed Geese in northern Norway.

and between 1989 and 2005 for six sites (see later).

Satellite image processing

All satellite data were geo-rectified to a common UTM format (WGS-84, zone33N) with a spatial resolution of 30 × 30 m. A six channel image, composed of the blue, green, red, two near-IR (infra red) and a mid-IR channel, was used for an unsupervised classification of the nine staging sites. A similar method has been used in vegetation monitoring projects in the Nikel area at the Kola Peninsula, Russia (Tømmervik *et al.* 2003) and for previous goose habitat mapping in Vesterålen

Table 1. An overview of land use data used to quantify the trends in vegetation and land cover at nine spring staging sites in northern Norway for Pink-footed Geese in 1975, 1985, 1989, 2002 and 2005. [1]From Rekdal *at el.* 1999, 2001. [2]From Statistics Norway 2001. [3]1975 = Landsat 1 MSS; 1985 and 1994 = Landsat 5 TM 2002 and 2005 = Landsat 7 ETM+.

Source	Period	Municipality	Site no.	Track & frame	Scale/spatial resolution
Topographical maps	2000–2007	Sortland, Hadsel	4, 6, 7, 8, 9		1: 50,000
Vegetation map[1]	1995–1997	Sortland, Hadsel	4, 6, 7, 8, 9		1: 50,000
Agricultural survey[2]	1989, 1999	Sortland, Hadsel	4, 6, 7, 8, 9		
Satellite imagery[3]	July 27 1975	Bodø	1–3	215/13	60 × 60 m
	June 26 1985	Sortland, Hadsel, Vågan	4–9	199/012	30 × 30 m
	July 10 1989	Bodø	1–3	198/013	30 × 30 m
	July 13 2002	Bodø	1–3	199/013	30 × 30 m
	July 5 2005	Sortland, Hadsel, Vågan	4–9	199/012	30 × 30 m
Aerial orthophotos	2004–2009	Total area	1–9		

(Tombre *et al.* 2005a, b). The Iterative Self-Organizing Data Analysis Technique (ISODATA) was used for data processing, described in Tømmervik *et al.* (2003) and Tombre *et al.* (2005a). The initial number of spectral classes was set at 255 in order to detect and differentiate the different vegetation types. By using many initial classes, the algorithm is comparable to hyper-clustering (Myers & Shelton 1998). This procedure exploits the spatial structure of landscapes through image compression by hyper-clustering to detect patterns of vegetation cover types or environmental change (Myers & Shelton 1998).

Interpretation and analyses of the classified maps

The interpretation of the spectral classes was carried out using digital aerial-based vegetation maps for two municipalities in the Nordland County: Hadsel and Sortland. These vegetation maps were produced by The Norwegian Institute for Land Survey (Rekdal *et al.* 1999, 2001) from fieldwork undertaken in 1995–1997. Moreover, recently acquired aerial orthophotos (taken in 2004–2005) of these same two areas were used. The satellite-based maps from 1985 and 2005 were assessed and compared with these vegetation maps. Five of the nine sites were covered by aerial-based vegetation maps, but agricultural survey data from Statistics Norway (2001) and Anonymous (2004) was available for all sites. These were used for quality assessment along with 160 and 234 field plots from 2001 and 2005–2007 respectively. For the four remaining sites (sites 1, 2, 3 and 5), the digital aerial orthophotos for the years 2004–2009) were used for the interpretation of satellite image-based classifications. The latter data were also used for interpretation and analysis of the satellite-based maps for all sites. Classes interpreted as being of the same vegetation type were merged whilst classes reflecting different succession stages were kept separate for further interpretation and analysis. Finally, from the maps produced for each site, land cover area statistics (% cover) for each habitat were computed.

Accuracy assessments

Assessment of the accuracy of the Landsat 5 TM and Landsat 7 ETM+ based maps covering the study area sites 4–9 (Tombre *et al.* 2005a, b) was carried out by using an area comparison, which is a non-site-specific method (Reichert & Crown 1984). The traditional aerial photography-based vegetation maps (Rekdal *et al.* 1999, 2001) have incomplete coverage of the agricultural areas in Hadsel and Sortland (*e.g.* the areas around site 8 were not mapped) since they focused on the natural vegetation and land cover types in their mapping, and hence the site-specific method (Reichert & Crown 1984; Janssen & van der Wel 1994) was inconvenient to use. This method compares the percentage cover of the different land and vegetation types extracted from the satellite-based vegetation maps with the same areas of the aerial-based vegetation maps, following the procedure used by Tombre *et al.* (2005a, b). The percentage of the number of pixels classed correctly, expressed as the total accuracy of classified maps for Sortland and Hadsel, is presented in Table 2. The area approach is considered to provide a good level of accuracy as the classification scheme is not biased towards the smaller habitat classes (Congalton 1991).

Vegetation classes

The remotely sensed information was classified into four vegetation classes thought to be relevant to geese. Each class represents a consecutive stage of sward management, from: 1) intensively managed grasslands, to 2) low-intensity managed fields including Tufted Hair Grass *Deschampsia caespitosa* pasture, 3) abandoned meadows and pasture where there is no longer agricultural activity, to the final stage of 4) scrub, woodland and heath. An extra class was included for the area around Bodø Airport to allow for the presence of airport infrastructure, which is not suitable for geese. The airport was extended between 1975 and 1989, over which period the area of airport infrastructure increased considerably.

The Pink-footed Goose population and goose monitoring

The Svalbard Pink-footed Goose population has increased from *c.* 20,000 in the 1970s to a hitherto unprecedented peak of *c.* 63,000 in 2009 (Madsen *et al.* 1999; J. Madsen, unpubl. data). Goose count data in the early years (from the 1970s and 1980s) were recorded during annual surveys made at sites where Pink-footed Geese were reported staging (determined from previous surveys and local reports). During 2007–2009, goose counts made at sites 6–9 (Appendix 1) were recorded as part of a detailed monitoring programme, during which geese were counted on a daily basis whilst staging in the area. For sites 1–5 local information was gathered by contacting relevant local observers, and by accessing web-pages where observers can report their findings (*e.g.* www.fugler.net and www.artsobservasjoner.no). As observation intensity and frequency differed between sites and across time periods, the average numbers of geese recorded (per site per year) were calculated between 7 May and 20 May, the main migration period, and it was assumed that the numbers produced were comparable. These averages were calculated for the years 1974–1984 and 2007–2009 in order to have data periods approximately comparable to those of the habitat classification analyses. Although remote sensing data were available from 2002 (three sites) and 2005 (six sites) in recent years, it was decided to use goose data from 2007–2009 because goose scaring by farmers (which was common at many sites earlier in the decade) was absent in these years due to the implementation of a compensation scheme in the region. It was therefore assumed that the habitat distribution in 2002–2005 is representative and reflective of the 2007–2009 goose distribution, at least in comparison to the situation 20–30 years ago. From our own observations, we did not notice much change in agricultural management during the 2000s.

The annual changes in area of the most (fields of high productivity) and least (scrub, woodland, heath, mire) preferred habitats by geese were calculated between the first and last year of land cover data for each site. Annual changes in goose numbers between the two time periods (*i.e.* between 1974–1984 and 2007–2009) were also determined. Linear regression analysis was used to test the relationship between changes in land cover and the number of geese using a site. Two sites did not have any geese recorded in the second time period (sites 2 and 3); they were not included in this analysis because the lack of geese was potentially missing values rather than zero counts.

Results

Accuracy assessments of the vegetation maps

Accuracy assessments for interpretation of the Landsat images, on comparing them with the vegetation maps, are presented in Table 2. The Landsat-based classifications showed an overall accuracy of > 90% (Sortland) and > 96% (Hadsel) on verifying these land use categories against vegetation maps derived from the aerial photos (Table 2). Accuracy in classifying pasture and abandoned meadows ranged from 69–85%, and accuracy in classifying woodland (dry types) from Landsat images was > 85% while wet deciduous woodland was 75% in Sortland and 87% in Hadsel.

Area distributions of vegetation classes

The percentage of cover for each of the vegetation classes at the nine study sites is presented in Figure 2. At sites 1–4, a reduction in the area of intensely managed pasture was recorded, whereas the area of less intensively managed fields increased. The extent of abandoned fields decreased at sites 1, 2 and 3, probably due to the increase in scrub in sites 2 and 3, and due to the airport expansion for site 1. At site 4, the area of abandoned fields increased. Conditions at site 1 differed from those at the other sites, due to expansion of the airport. The extent of the airport infrastructure has doubled since 1975, and now covers almost 50% of the site.

The general pattern of fields being abandoned by farmers was different for sites 5–9. Although the area of low-intensity fields and abandoned fields increased at all of these sites, there was little change in the area of intensively managed pasture, suggesting that the agricultural activity has remained relatively stable when the total area is considered. The extent of scrub coverage has fallen at all of these sites.

Goose numbers

Average goose numbers for the different sites and time periods are presented in Figure 3.

For sites 2 and 3, no geese were registered during 2007–2009. This does not necessarily mean that there were no geese staging there, but probably reflects low numbers sporadically using these sites. Few records and low counts from sites 1 and 4 (Fig. 3) are probably also attributable to fewer geese using these sites at present, with the limited availability of productive land to provide feeding habitat at these four sites (Fig. 2) being a possible reason for this. At sites 5 and 6 there was a considerable increase in the average number of geese counted, perhaps reflecting the relatively high proportion of intensively managed fields (40–50% of the available area; Fig. 2) providing scope for an increase in goose numbers. The increase in goose numbers at

Table 2. Percentage accuracy assessments on comparing habitat area estimates from Landsat 5 TM and Landsat 7 ETM+ based classifications with vegetation maps (Rekdal *et al.* 1999, 2001) for two municipalities, Sortland and Hadsel, in northern Norway.

	Sortland			Hadsel		
Vegetation type	**Landsat Area (km^2)**	**Veg. map Area (km^2)**	**Accuracy (%)**	**Landsat Area (km^2)**	**Veg. map Area (km^2)**	**Accuracy (%)**
Woodland (birch *Betula pubescens*, alder *Alnus incana* and willow *Salix* sp. forests)	223.8	198.2	88.6	150.5	177.7	84.7
Wet deciduous woodland	11.1	8.3	74.9	10.5	9.2	87.3
Bog and fen vegetation	82.4	71.9	87.3	46.1	40.2	87.2
Coastal heath	22.9	28.4	80.7	16.1	19.1	87.2
Shore vegetation	0.8	0.6	75.5	0.9	0.8	90.9
Agricultural land	14.7	15.1	97.2	15.8	15.7	99.4
Pasture land and old "cultivated" meadows	22.0	25.1	84.9	16.3	11.3	69.3
Total accuracy			90.3			96.8

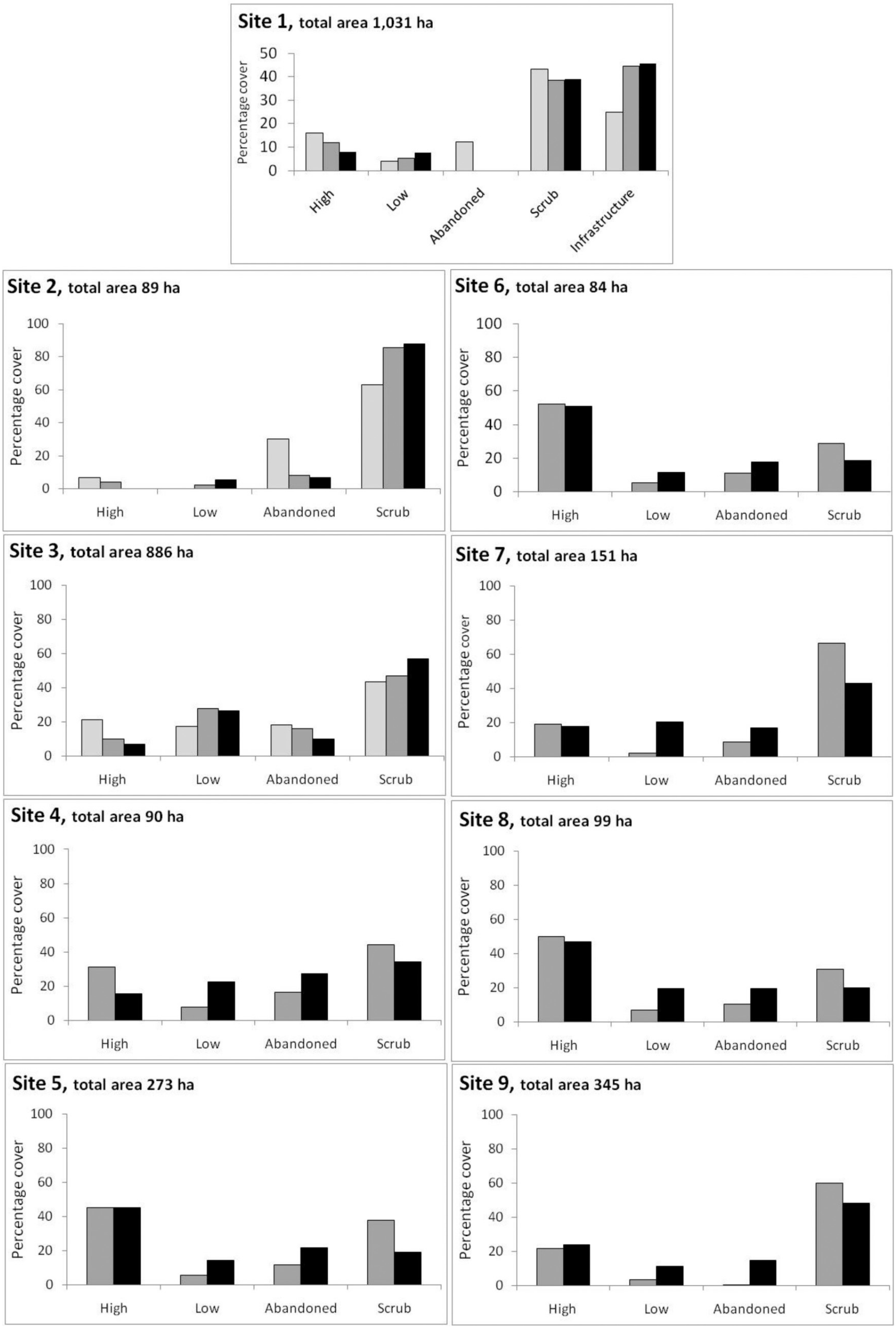
Site 1, total area 1,031 ha
Percentage cover
50
40
30
20
10
0
High
Low
Abandoned
Scrub
Infrastructure
Site 2, total area 89 ha
Site 3, total area 886 ha
Site 4, total area 90 ha
Site 5, total area 273 ha
Site 6, total area 84 ha
Site 7, total area 151 ha
Site 8, total area 99 ha
Site 9, total area 345 ha
100
80
60
40
20
0
Percentage cover
High
Low
Abandoned
Scrub

Figure 2 (opposite). Extent (in percentages of total area) of land cover at nine different spring staging sites (see Appendix 1 for specific location names) for Pink-footed Geese in Nordland County, northern Norway. Coverage is based on remote sensing data. For sites 1–3, pale grey columns = 1975 data, dark grey columns = 1989 data and black columns = 2002 data. For sites 4–9, grey columns = 1985 data and black columns = 2005 data. "High" and "Low" refer to different production levels for the agricultural fields, where low production also includes sites with Tufted Hair grassland. "Abandoned" refers to abandoned meadows and pastureland, and "Scrub" refers to scrub, woodland, heath and mire. Note the different scale on the y-axis at site 1, the area around Bodø Airport, which also includes an extra category ("Infrastructure") to allow for the development of the airport over the study period. The total area of the site is shown in each case.

site 5 may correspond with the decrease at site 4 (Fig. 3). Intensive scaring campaigns organised at site 4 in the late 1980s and early 1990s (F. Sortland, pers. comm.) may have made the intensively managed fields at site 5 seem even more attractive to the birds.

Average goose numbers at sites 7–9 have remained remarkably stable (Fig. 3). This coincides with consistent and stable availability of intensively managed fields over the same period, suggesting that these sites have reached their carrying capacity in goose numbers. This argument is supported by the fact that numbers appear to have stabilised despite the considerable increase in the Svalbard Pink-footed Goose population size over the study period.

There was a significant positive relationship between the annual rate of change in the area of land given to

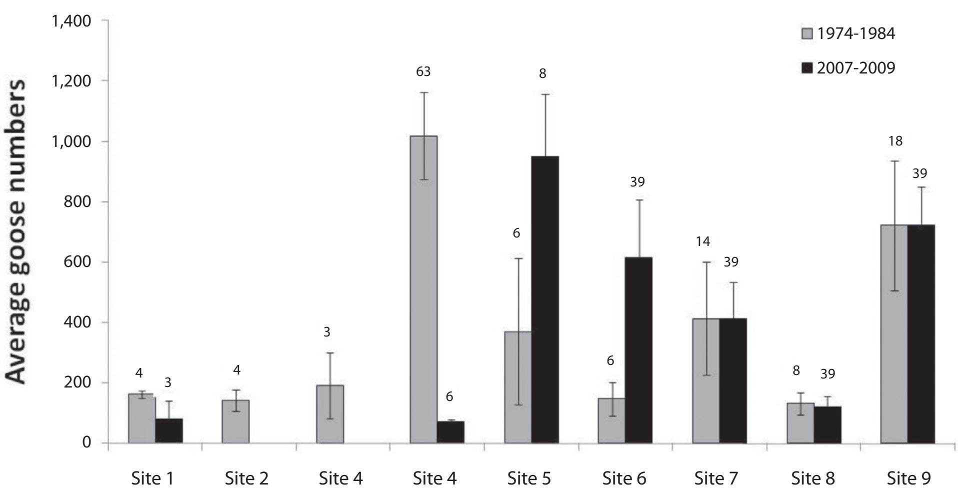

Figure 3. The average number of Pink-footed Geese recorded at nine staging sites (see Appendix 1 for specific location names) in Nordland County, northern Norway. Averages are calculated for two time periods; 1974–1984 (grey) and 2007–2009 (black). Vertical lines are s.e. bars, numbers above each column are the number of observations (*n* values).

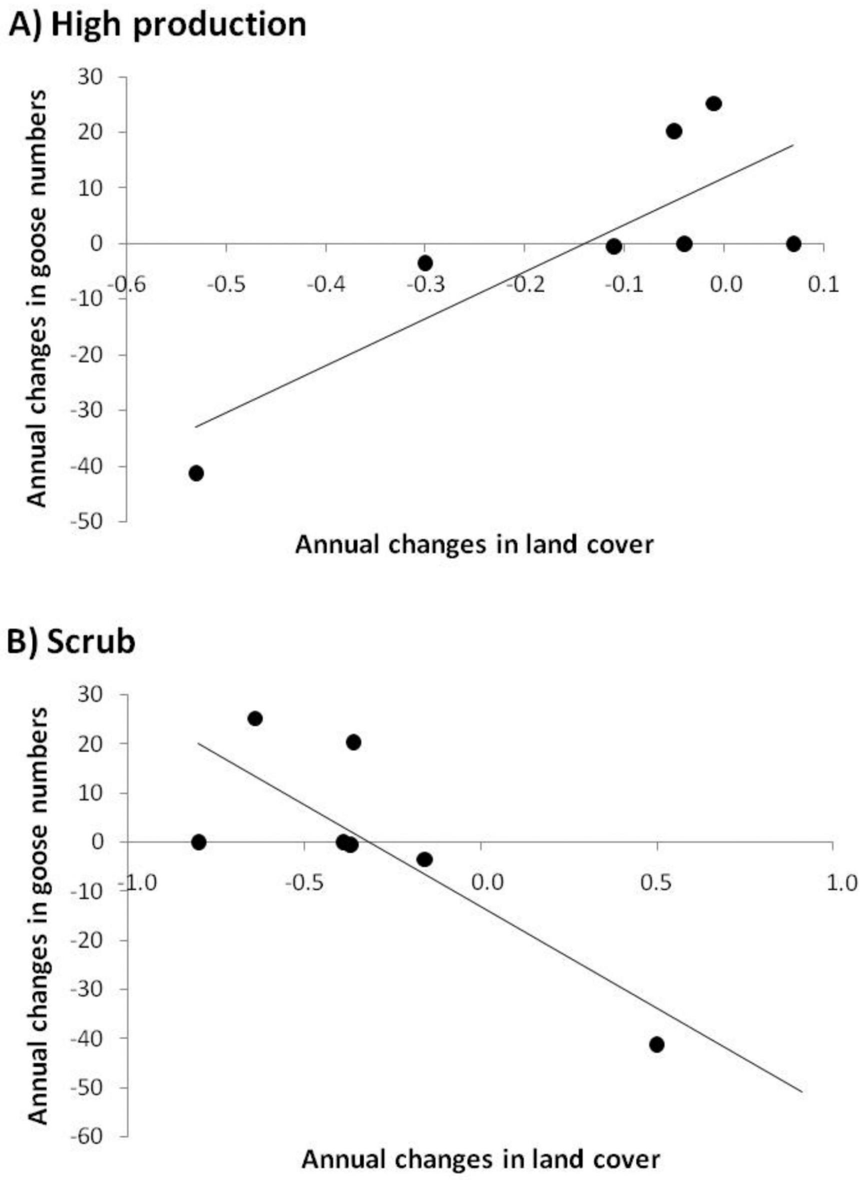

Figure 4. The relationship between the annual change in land cover and annual change in Pink-footed Goose numbers at seven study sites in northern Norway. The change in goose numbers was measured as the difference between the average numbers of geese recorded in 1974–1984 with the annual number recorded in 2007–2009 (*i.e.* taking the mid point for each time period). A) Agricultural fields of high productivity, and B) Scrub, including woodland, heath and mire. Both regressions are significant (see text for statistics).

intensively managed pasture and the annual changes in goose numbers ($r^2_{1,6}$ = 0.66, P = 0.026; Fig. 4). Conversely, there was a significant negative relationship between the area of scrub habitat and goose use of the sites ($r^2_{1,6}$ = 0.65, P=0.028, Fig. 4).

Discussion

In the present study, agricultural abandonment of grassland at several spring staging sites for Pink-footed Geese in northern Norway was documented. Although the observation frequency of goose counts differs between the early years of the study (1970s and 1980s) and more recent years (2007–2009), our compilation of the data suggests that sites suffering a reduction in pasture management are used to a lesser extent by the geese today than formerly. This view was reinforced by discussions with local people. Although the goose numbers (average counts) reported here for each site should not be taken as being definitive, due to differences between past and present survey methods and to the substantial increase in population size, the general pattern of changes in goose numbers within each site follows the pattern of abandonment of farmland fields observed over the same time period. Moreover, regardless of site, as the areas of highly productive fields were reduced and scrub increased, goose numbers decreased correspondingly.

Despite their general site loyalty, geese do respond to changes in available feeding habitats due to changes in agricultural practice or human disturbance which may force geese to modify their traditions of site use. Switching to a neighbouring site has been documented on several occasions (Black *et al.* 1991) and probably happened at two sites in the present study (sites 4 and 5), where the switch in goose numbers and availability of preferred feeding areas coincided. At least this was the general explanation locally (F. Sortland, pers. comm.). Site 4, Grunnfør, was an important staging site for the Pink-footed Geese in the 1970s (Koren 1975) with over one thousand geese observed on pasture fields in mid May 1975, causing dissatisfaction among the local farmers (Koren 1975), and culminating in later scaring campaigns. Scaring, in combination with a reduction in habitat quality (Fig. 2), has probably been the main reason for fewer geese using this site at present (Fig. 3).

Geese feeding at sites 6–9 in Vesterålen have been exposed to human disturbance and scaring in the late 1990s and early 2000s. A subsidy scheme was established in 2006, which minimised the conflicts between geese and agricultural interests. During 2007–2009, no scaring was practised at these sites, which was probably the main reason for the remarkably similar goose numbers recorded in the two time periods compared in the study.

The general abandonment of marginal agricultural land in Norway and the resultant regeneration of scrub and woodland (Dramstad *et al.* 2002) may be one of the main reasons for the changes in migratory pattern observed in the Svalbard Pink-footed Goose population. From Jutland in Denmark, the geese move to their next staging site, Trøndelag in central Norway (Madsen *et al.* 1999; Tombre *et al.* 2008), and from there to the Vesterålen and Lofoten region of northern Norway where sites 5–9 from the present study are located. During the last 20 years, the geese have stayed longer in Trøndelag, departing earlier from Denmark in response to earlier springs (Tombre *et al.* 2008), while the length of stay in north Norway has not changed significantly. However, the staging area in north Norway has contracted due to abandonment of pasture. This combined with scaring campaigns in some areas, as well as increasing numbers of Barnacle Geese *Branta leucopsis* which compete for the same grass, has had the result that the Pink-footed Geese have, at least in terms of the proportion of the population, reduced their use of north Norway.

The sites selected for our study were based on previous goose observations. Today many sites in central parts of Vesterålen, and at some places in Lofoten, are used by an increasing number of geese. Agricultural practice at the spring staging sites is an important environmental factor for this population, as increasing abandonment of pasture will result in a loss of their feeding habitats, which in turn may reduce their ability to utilise the sites optimally.

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References

Anonymous 2004. Nærings- og miljøvirkemidlene i landbruket. Strategisk plan for Lofoten og Vesterålen 2005–2008. http://www.boe.kommune.no/dokumenter/2005/03/Lo-Ve_Plan_22.12.200436.pdf

Béchet, A., Giroux, J.–F. & Gauthier, G. 2004. The effects of disturbance on behaviour, habitat use and energy of spring staging snow geese. *Journal of Applied Ecology* 41: 689–700.

Black, J.M. 1998. Movement of barnacle geese between colonies in Svalbard and the colonisation process. *Norsk Polarinstitutt Skrifter* 200: 115–127.

Black, J.M., Deerenberg, C. & Owen, M. 1991. Foraging behaviour and site selection of barnacle geese *Branta leucopsis* in a traditional and newly colonised spring staging habitat. *Ardea* 79: 349–358.

Black, J.M., Prop, J. & Larsson, K. 2007. *Wild Goose Dilemmas*. Branta Press, Groningen, The Netherlands.

Bolliger, J., Kienast, F., Solivar, R. & Rutherford, G. 2007. Spatial sensitivity of species habitat patterns to scenarios of land use change (Switzerland). *Landscape Ecology* 22: 773–789.

Cooch, E.G., Jefferies, R.L., Rockwell, R.F. & Cooke, F. 1993. Environmental changes and the cost of philopatry: an example in the lesser snow goose. *Oecologia* 93: 128–138.

Congalton, R. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37: 35–46.

DeFries, R.S., Field, C.B., Fung, I., Collatz, G.J. & Bounoua, L. 1999. Combining satellite data and biogeochemical models to estimate global effects of human-induced land cover change on carbon emissions and primary productivity. *Global Biogeochemical Cycles* 13: 803–815.

Dramstad, W.E., Fjellstad, W.J., Strand, G.H., Mathiesen, H.F., Engan, G. & Stokland, J.N. 2002. Development and implementation of the Norwegian monitoring programme for agricultural landscapes. *Journal of Environmental Management* 64: 49–63.

Fowler, A.C. 2006. Fine-scale spatial structuring in cackling Canada geese related to reproductive performance and breeding philopatry. *Animal Behaviour* 69: 973–981.

Fox, A.D., Madsen, J., Boyd, H., Kuijken, E., Norriss, D.W., Tombre, I.M. & Stroud, D.A. 2005. Effects of agricultural change and abundance, fitness components and distribution of two arctic-nesting goose populations. *Global Change Biology* 11: 881–893.

Gauthier, G. 1990. Philopatry, nest-site fidelity, and reproductive performance in buffleheads. *Auk* 107*:* 126–132.

Greenwood, P.J. 1980. Mating systems, philopatry and dispersal in birds and mammals. *Animal Behaviour* 28: 1140–1162.

Gullestad, N., Owen, M. & Nugent, M.J. 1984. Numbers and distribution of barnacle Geese *Branta leucopsis* on Norwegian staging islands and the importance of the staging area to the Svalbard population. *Norsk Polarinstitutt Skrifter* 181: 57–65.

Hill, M.J., Vickery, P.J., Furnival, E.P. & Donald, G.E. 1999. Pasture land cover in eastern Australia from NOAA-AVHRR NDVI and classified landsat TM. *Remote Sensing and Environment* 67: 32–50.

Jano, A.P., Jefferies, R.L. & Rockwell, R.F. 1998. The detection of vegetational change by multitemporal analysis of LANDSAT data: the effects of goose foraging. *Journal of Ecology* 86: 93–99.

Janssen, L. & van der Wel, F. 1994. Accuracy assessment of satellite derived land cover data: a review. *Photogrammetric Engineering and Remote Sensing* 60: 419–426.

Jensen, C., Vorren, K.D., Eilertsen, S.M. & Samuelsen, R. 2001. Successionary stages of formerly cultivated grassland in northern Norway, abandoned for 10, 20 and 35 years. *Nordic Journal of Botany* 21: 305–320.

Jensen, R.A., Madsen, J., O'Connell, M., Wisz, M.S., Tømmervik, H. & Mehlum, F. 2007. Prediction of the distribution of Arctic nesting pink-footed geese under a warmer climate scenario. *Global Change Biology* 12: 349–359.

Karlsen, S.R., Elvebakk, A., Høgda, K.A. & Johansen, B. 2006. Satellite-based mapping of the growing season and bioclimatic zones in Fennoscandia. *Global Ecology and Biogeography* 15: 416–430.

Klaassen, M., Bauer, S., Madsen, J. & Tombre, I. 2006. Modelling behavioural and fitness consequences of disturbance for geese along their spring flyway. *Journal of Applied Ecology* 43: 92–100.

Koren, C.W.R. 1975. *Rapport om KORTNEBBGÅS (Anser f. Brachyrhynchus) på Grunnfør i Lofoten 1975*. Report to the County Governor of Nordland and the University College, Bodø, Norway. [In Norwegian.]

Loonen, M.J.J.E., Tombre, I.M. & Mehlum, F. 1998. The development of an arctic barnacle goose colony: Interaction between density and predation. *Norsk Polarinstitutt Skrifter* 200: 67–79.

MacInnes, C.D. & Dunn, E.H. 1988. Component of clutch size variation in arctic-nesting Canada geese. *Condor* 90: 83–89.

Madsen, J. 2001. Spring migration strategies in pink-footed geese *Anser brachyrhynchus* and consequences for spring fattening and fecundity. *Ardea* 89: 43 –55.

Madsen, J., Cracknell, G. & Fox, T. (eds.) 1999. *Goose Populations of the Western Palearctic. A Review of Status and Distribution*. Wetlands International Publication No. 48, Wetlands International, Wageningen, The Netherlands and National Environmental Research Institute, Rönde, Denmark.

Morrison, R.I.G. 1997. The use of remote sensing to evaluate shorebird habitats and populations on Prince Charles Island, Foxe Basin, Canada. *Arctic* 50: 55–75.

Myers, W. & Shelton, R. 1998. *Survey Methods for Ecosystem Management*. Wiley-Interscience, New York, USA.

Norderhaug, A., Ihse, M. & Pedersen, O. 2000. Biotope patterns and abundance of meadow plant species in a Norwegian rural landscape. *Landscape Ecology* 15: 201–238.

Owen, M. & Gullestad, N. 1984. Migration routes of Svalbard Barnacle Geese *Branta leucopsis* with preliminary report on the importance of the Bjørnøya staging area. *Norsk Polarinstitutt Skrifter* 181: 67–77.

Owen, M., Black, J.M., Agger, M.K. & Campbell, R.G. 1987. The use of the Solway Firth, Britain, by Barnacle Geese *Branta leucopsis* Bechst. in relation to refuge establishment and increases in number. *Biological Conservation* 39: 63–81.

Paruelo, J.M., Epstein, H.E., Lauenroth, W.K. & Bruke, I.C. 1997. ANPP estimates from NDVI for the central grassland region of the United States. *Ecology* 78: 953–958.

Reeves, H.M., Cooch, F.G. & Munro, R.E. 1976. Monitoring arctic habitat and goose production by satellite imagery. *Journal of Wildlife Management* 40: 532–541.

Reichert, G.C. & Crown P.H. 1984. Identification of winter wheat using Landsat MSS data. *Canadian Journal of Remote Sensing* 10: 111–120.

Roughgarden, J., Running, S.W. & Matson, P.A. 1991. What does remote sensing do for ecology? *Ecology* 72: 1918–1922.

Rekdal Y., Bjørklund, P. & Angeloff, M. 1999. *Vegetasjon og beite i Hadsel kommune – rapport frå vegetasjonskartlegging*. The Norwegian Forest and Landscape Institute Report (NIJOS) 3/99: 1–80, Ås, Norway.

Rekdal Y., Bjørklund P. & Angeloff, M. 2001. *Vegetasjon og beite i Sortland kommune – rapport frå vegetasjonskartlegging*. The Norwegian Forest and Landscape Institute Report (NIJOS) 6/01: 1–75, Ås, Norway.

Running, S.W. 1990. Estimating terrestrial primary productivity by combining remote sensing and ecosystem simulation. *In* R.J. Hobbs & H.A. Mooney (eds.), *Remote Sensing Biosphere Functioning,* pp. 65–68. Springer Verlag, New York, USA.

Sickel, H., Ihse, M., Norderhaug, A., & Sickel, M.A.K. 2004. How to monitor semi-natural key habitats in relation to grazing preferences of cattle in mountain summer farming areas – An aerial photo and GPS method study. *Landscape and Urban Planning* 67: 67–77.

Speed, J, D. M., Wooding, S. J., Tømmervik, H. & van der Wal, R. 2009. Extrapolating herbivore-induced carbon loss across an arctic landscape. *Polar Biology* 33: 789–797.

Statistics Norway 2001. *Jordbrukstelling 1999 Nordland*. Report NOS C 664, Statistics Norway, Oslo, Norway.

Tombre, I.M., Black, J.M. & Loonen, M.J.J.E. 1998a. Critical components in the dynamics of a barnacle goose colony: a sensitivity analysis. *Norsk Polarinstitutt Skrifter* 200: 81–89.

Tombre, I.M., Mehlum, F. & Loonen, M.J.J.E. 1998b. The Kongsfjorden colony of barnacle geese: Nest distribution and the use of breeding islands 1980–1997. *Norsk Polarinstitutt Skrifter* 200: 57–65.

Tombre, I.M., Tømmervik, H. & Madsen. J. 2005a. Land use changes and goose habitats, assessed by remote sensing techniques, and corresponding goose distribution in Vesterålen, Northern Norway. *Agriculture, Ecosystems & Environment* 109: 284–296.

Tombre, I.M., Madsen. J., Tømmervik, H., Haugen, K.-P. & Eythórsson, E. 2005b.

Influence of organized scaring on distribution and habitat choice of geese on pastures in Northern Norway. *Agriculture, Ecosystems & Environment* 111: 311–320.

Tombre, I.M., Høgda, K.A., Madsen, J., Griffin, L.R., Kuijken, E., Shimmings, P., Rees, E. & Verscheure, C. 2008. The onset of spring and timing of migration in two arctic nesting goose populations: the pink-footed goose *Anser brachyrhynchus* and the barnacle goose *Branta leucopsis*. *Journal of Avian Biology* 39: 691–703.

Tucker, C.J., & Sellers, P.J. 1986, Satellite remote sensing of primary production. *International Journal of Remote Sensing* 7*:* 1395–1416.

Tømmervik, H., Høgda, K.A. & Solheim, I. 2003. Monitoring vegetation changes in Pasvik (Norway) and Pechenga in Kola Peninsula (Russia) using multitemporal Landsat MSS/TM data. *Remote Sensing of Environment* 85: 370–388.

Tømmervik, H., Johansen, B., Tombre, I.M., Thannheiser, D., Høgda, K.A., Gaare, E. & Wielgolaski, F.E. 2004. Vegetation changes in the Nordic Mountain Birch Forests: the influence of grazing and climate change. *Arctic, Antarctic & Alpine Research* 36: 323–332.

van Roomen, M. & Madsen, J. 1991. Waterfowl and agriculture: Review and future perspective of the crop damage conflict in Europe. *In* M. van Roomen & J. Madsen (eds.), *Proceedings of the International Workshop "Farmers and Waterfowl: Conflict or Coexistence", Lelystad, the Netherlands, 6–9 October 1991*, pp. 21–32. IWRB Special Publication No. 21, International Waterfowl & Wetlands Research Bureau, Slimbridge, UK.

Williams, M., Rastetter, E.B., Fernandes, D.N., Goulden, M.L., Shaver, G.R. & Johnson, L.C. 1997. Predicting gross primary productivity in terrestrial ecosystems. *Ecological Applications* 7: 882–894.

Appendix 1. Nine spring staging sites for Pink-footed Geese *Anser brachyrhynchus* in Nordland County, northern Norway, where habitat changes were quantified by the use of remote sensing data. Site names, municipality and total area are given for each location.

	Site name	Municipality	Area (ha)
Site 1	Area around Bodø Airport	Bodø	1,031
Site 2	Givær	Bodø	89
Site 3	Helligvær	Bodø	886
Site 4	Grunnfør	Hadsel	90
Site 5	Gimsøya	Vågan	273
Site 6	Grytting	Hadsel	84
Site 7	Sandstrand	Sortland	151
Site 8	Skagen	Hadsel	99
Site 9	Jennestad, Breivik, Vik	Sortland	345

