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An evaluation of the temporal changes, distribution and abundance of the UK overwintering population of pink-footed geese (*Anser brachyrhynchus*) and an assessment of the North Norfolk population wintering foraging ranges

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Abstract

Pink-footed geese (*Anser brachyrhynchus*) is a high arctic breeder, breeding in Greenland, Iceland and Svalbard. There are two distinct sub-populations, both of which migrate and winter in North West Europe. The largest of these populations' breeds in Iceland and over-winters in the UK, accounting for c. 85% of the world population. In the UK the species is listed as amber in status in the BOCC, Birds of Conservation Concern 4 list. Since early records began in the middle of the last century their numbers have been shown to increase substantially, with a UK wintering population now in excess of half a million individuals.

This study reviews the latest population data available, based on data collated as part of the annual Icelandic breeding goose census (IGC) surveys, to further review the UK wintering distribution and abundance of pink-footed geese. As a species of conservation concern, pink-footed geese are monitored by statutory conservation bodies, who are required to assess any potential impact on the population size that land-use change may have. Concern exists within Natural England that potential loss of agricultural and foraging areas in proximity to known roosts of pink-footed geese, may result in a reduction of available foraging resources. Quantifying the impacts of any such loss is complex to model and requires an understanding of a number of factors, including the species energetic needs, daily food intake, resource availability, but also a better understanding of the species daily movements in relation to daily energetics and the ranges in which they forage. This study quantified the daily distances pink-footed geese travelled and their home range size during their wintering stay in North Norfolk.

A review of the annual records, supplied by the Wildfowl and Wetlands Trust (WWT), provided evidence of population growth and changes in the UK wintering distribution, with a focus on changes between 1990 and 2018 for which site-specific datum existed and has been analysed. These data provided strong evidence of population growth from an estimated 52,000 individuals in 1951, to an estimated UK wintering population size of 510,000 individuals in 2018. Evidence showed that there had been limited range expansion into new sites with relatively few new sites adopted in place of rising abundances at existing sites, in particular those in England.

Targeted capture and marking of pink-footed geese in North Norfolk, over the winters of 2017-2018 and 2018-2019, enabled a total of 18 individuals to be fitted with GPS / GSM neck collars. The annual movements of these birds were summarised, along with a detailed examination and presentation of their home ranges and daily distances travelled within North Norfolk over the two winters. The mean daily distance travelled was calculated to be 12 km in year 1 of the study and 20.2 km in year 2 of the study. Correspondingly, the wintering ranges in North

Norfolk also varied from 20.4 km^2 to 100.8 km^2 between years 1 and 2 respectively. The varied results between years demonstrated the species' ability to be both able and willing to move substantial distances to find suitable food resources.

The complexities of understanding the factors affecting population growth were reviewed, as were the potential pressures arising due to the increased reliance on agricultural crops as a food resource across their range. Analysis of the availability and abundance of the harvested remains of sugar beet, determined by the crop coverage in the study area, provided insight into the number of pink-footed geese that can be sustained by this resource in North Norfolk.

Pink-footed geese populations overwintering in the UK have been shown to increase substantially, between 1990 – 2018, with a 3.1% annual compound growth rate. Tracking recorded the ability of individual pink-footed geese to move over large areas with a maximum range of 795.8 km^2 recorded for one individual in the study area. In North Norfolk, given the substantial annual crop cover of sugar beet initial calculations suggest that the carrying capacity of North Norfolk for pink-footed geese has not been reached. The species population size also does not appear highly vulnerable to the loss of functionally linked land. Theoretically it was estimated that the annual crop of sugar beet in North Norfolk could support a wintering population in excess of 200,000 individuals. The geese studied appeared to be adaptable at seeking out and foraging on food resources and were shown to be highly mobile as demonstrated by their wide-ranging movements between North Norfolk and the Norfolk Broads and Hickling Broad.

Estimations of the wintering home range sizes and daily distances travelled by pink-footed geese within North Norfolk contribute valuable new data that can be applied and used in further assessments of the daily energetic requirements of the geese in Individual Based Models (IBM). Studies utilising IBM techniques are on-going and have been commissioned by Natural England, involving the WWT, Bournemouth University and Manchester University, and aim to help build applied tools capable of assisting in the assessment of the vulnerability of a number of swan and geese species in relation to the potential loss of functionally linked land.

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Abbreviations

APHA	Animal and Plant Health Agency
BBMM	Brownian Bridges Movement Model
BTO	British Trust for Ornithology
HGOWF	Humber Gateway Offshore Windfarm
GPS	Global Positioning System
GSM	Global System for Mobile communication
IBA	Important Bird Area
IBM	Individual Based Model
IGC	Icelandic-breeding Goose Census
JNCC	Joint Nature Conservation Committee
KBBM	Kernel Brownian Bridges Model
MMO	Marine Management Organisation
NEWS	Non-Estuarine Waterbird Survey
PCMP	Post Construction Monitoring Plan
RAMSAR	Ramsar convention on Wetlands of International Importance especially as Waterfowl Habitat
RSPB	Royal Society for the Protection of Birds
SNCB	Statutory Nature Conservation Body
SPA	Special Protection Areas
SMTP	Special Methods Technical Panel
SSSI	Site of Special Scientific Interest
UNFCC	The United Nations Framework Convention on Climate Change
WeBS	Wetland Bird Survey
WWT	Wildfowl and Wetland Trust

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Chapter 1 : Introduction

1.1 The conservation of migratory geese

An estimated 1,600 or 19% of all bird species, totalling some 9,856 extant species are migratory, including many waterbirds and around 360 species of duck, geese and swans (Kirby et al., 2008). These migratory species include Arctic breeding geese whose conservation may be impacted both by changes in their breeding grounds, but also wintering grounds and along their connective flyways (Scott, 1998).

Across their range Arctic breeding geese wintering in Europe are protected by the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) (Genovesi & Shine, 2004). Additional international protection is provided through the EC Birds Directive and the Convention on the Conservation of European Wildlife and Natural Habitats (Mitchell, 2004). The EC Birds Directive includes the identification and designation of Specially Protected Areas (SPAs) for birds which together forming part of the Natura 2000 or N2K framework of sites, including Special Areas of Conservation (SACs) whose identified species or features are listed. This enables site conservation objectives to be set for those features with the overall objective of the directive being to ensure that biodiversity is both promoted and maintained for the identified species at individual sites. Both within Europe but also outside and across the world Important Bird and Biodiversity Areas (IBA's) have been identified as places of international significance for the conservation of birds and other biodiversity by BirdLife International and in several countries form the basis for national legislation that protects identified species or features (Donald et al., 2019). Collectively these conservation initiatives have enabled the implementation of national legislation, single species action plans, habitat conservation, management of human activities and include also long-term monitoring and research (Mitchell, 2004). Beyond Europe further protection and conservation measures are afforded by the Convention on Migratory Species, and in particular its Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) which provides measures to conserve identified species occurring within an identified range and including species such as Arctic breeders wintering in the UK.

Specifically within the UK in 1947 it was recognised that there was a potential threat to a number of wildfowl and geese species due to the loss of wetlands arising from developments and land use change in a post war era (Cranswick et al., 1997). Consequently, a national scheme to monitor wildfowl populations in the UK was instigated and subsequently managed and co-ordinated by the Wildfowl and Wetlands Trust (WWT) from 1954 onwards. The WWT instigated and now manage the long-term monitoring of UK wintering geese species and their populations, including annual goose counts (Mitchell et al., 1996).

1.2 European geese populations

An estimate of the 2009 wintering populations of geese in the Western Palearctic totalled approximately 5.03 million geese, of which some 4.77m were considered to be wild (Fox et al., 2010). This estimate, although now a decade old, showed a marked increase in the number of geese estimated from a decade prior where a total population of 3.30 million was estimated (Madsen & Cracknell, 1999). This rapid rise of some 1.73m geese in a decade is substantial representing a 52% increase.

Eight of the world's 15 species of geese naturally occur in the Western Palearctic region and are ascribed to two genera (*Anser* and *Branta*). Across the world there are 27 recognised "populations" or "flyways" defined comprehensively (Madsen & Cracknell, 1999), of which in the Western Palearctic, the White-fronted goose (*Anser albifrons albifrons*), wintering in North West Europe is the most abundant species totalling 1.2m individuals. This species has shown the biggest increase in estimated population size with an extra 700,000 individuals estimated in 1999 versus 1990. Three other species of geese have also grown in estimated population size over the same period; Barnacle geese (*Branta leucopsis*), having grown by 433,000, European Greylag geese (*Anser anser*) by 410,000 and 100,000 additional Icelandic Pink-footed geese (*Anser brachyrhynchus*) (Fox et al., 2010).

Across the defined populations of geese in the Western Palearctic the majority have large population sizes and are of least concern as regards their European Conservation Status. The most recent European population estimates available are based on estimates in 2009 (Fox et al., 2010; Frost et al., 2019). Both of these estimates are shown in (Table 1) for comparison, however interpretation of the estimates should be approached with caution since the European and UK estimates were made ten years apart. As a result, there are instances where the 2019 UK reported estimate of a species is now greater than the previous 2009 European record. None the less both estimates are useful for contextualising the relative size of individual species on both a UK and European scale. Only two species populations numbered less than 10,000 individuals (Scandinavian Lesser white-fronted goose (*Anser erythropus*) and Svalbard/Greenland light-bellied brent goose) (Table 1).

Within the UK six species of migratory, wild geese winter in Britain: pink-footed geese (*A. brachyrhynchus*), greylag geese (*Anser anser*), Greenlandic and Eurasian white-fronted geese (*Anser albifrons*), bean geese (*Anser fabalis*), barnacle geese (*Branta leucopsis*) and dark-bellied and light-bellied brent geese (*Branta bernicla*). In addition, there is also a native re-established population of greylag geese resident in southern Britain, estimated to be in excess of 30,000 individuals and also a population of re-established Canada geese previously estimated to be in excess of 82,000 individuals (Rehfisch et al., 2002), but more recently estimated at 160,000 individuals (Frost et al., 2019). Both the re-established population of Greylag and Canada geese are considered as feral and pose challenges in both estimating and distinguishing their population from protected migratory populations of the same species (Owen & Salmon, 1988; Brown & Dick, 1992) and also their management in respect of conflicts in urban areas, in particular of Canada geese, originally introduced from North America (Allan et al., 1995; Baxter et al., 2010).

Of the six migratory populations the pink-footed goose, greylag goose, Greenland white-fronted and dark-bellied brent feed to differing extents on agricultural land (Fox et al., 2010). Bean geese are restricted in number and range and are a relatively scarce visitor, confined to the Yare Valley in Norfolk and Carran and Avon valleys in Scotland. The light-bellied brent, from Svalbard is confined to north-east England and the coast around Lindisfarne, and the native population of greylags largely restricted to the Western Isles and northern Scotland. The majority of the Greenlandic white-fronted geese and the Greenland population of barnacle geese winter on the Inner Hebridean island of Islay. Icelandic greylag geese are predominantly found in Scotland. Dark-bellied brent geese are found largely to the southern and eastern coasts of England, whilst the Svalbard population of barnacle geese winters on the Solway coast (Vickery & Gill, 1999).

Table 1: UK geese population estimates, 2012/13 to 2016/17. (Frost et al.., 2019), and European estimates of goose populations in the Western Palearctic, 2009 (Fox et al.., 2010)

Species	Scientific name	UK Estimate (2019)	European Estimate (2009)
Pink-footed Goose			
Pink-footed Goose (Icelandic/Greenland)	*Anser brachyrhynchus*	510,000	350,000
Pink-footed Goose (Svalbard)	*Anser brachyrhynchus*	-	63,000
Greylag Goose			
Greylag Goose (British)	*Anser anser*	140,000	85,000
Greylag Goose (Icelandic)	*Anser anser*	91,000	98,000
Greylag Goose (European)	*Anser anser*	-	851,000
Canada Goose			
Canada Goose	*Branta canadensis*	160,000	220,000
Brent Goose			
Brent Goose (Dark bellied)	*Branta bernicla bernicla*	98,000	245,000
Brent Goose (Svalbard Light-bellied)	*Branta bernicla hrota*	3,400	40,000
Brent Goose (Nearctic Light-bellied)	*Branta bernicla hrota*	1,600	7,600
Barnacle Goose			
Barnacle Goose (Greenland)	*Branta leucopsis*	56,000	70,500
Barnacle Goose (Svalbard)	*Branta leucopsis*	43,000	30,000
Barnacle Goose (Naturalised)	*Branta leucopsis*	4,400	-
Barnacle Goose (Russia)	*Branta leucopsis*	-	770,000
White-fronted Goose			
White-fronted Goose (NW Europe)	*Anser albifrons albifrons*	2,100	1,200,000
White-fronted Goose (Central and E Europe)	*Anser albifrons albifrons*		310,000
White-fronted Goose (Greenland)	*Anser albifrons flavirostris*	12,000	23,200
Lesser White-fronted Goose			
Lesser White-fronted Goose	*Anser erythropus*	-	10,500
Bean Goose			
Tundra Bean Goose	*Anser serrirostris*	300	550,500
Taiga Bean Goose	*Anser fabalis*	230	63,000
Snow Goose			
Snow Goose	*Anser caerulescens*	75	-
Red-breasted Goose			
Red-breasted Goose	*Branta ruficollis*	-	44,000
Total		**1,122,105**	**5,031,300**

1.3 Pink-footed geese global range and population size

The world population of Pink-footed geese is confined to the northern hemisphere where the species breeds in Iceland, East Greenland and Svalbard (Mitchell, 2004). The Greenland / Icelandic population is distinct from the Svalbard population, the latter of which winters in North West Europe (Madsen, 1984; Madsen et al., 2012). Extensive ringing and marking of birds and pulli on their breeding grounds and their subsequent recapture or recovery found only one Greenland/Icelandic bird in north west Europe and a total of four Svalbard breeding individuals recovered in the UK from some 14,000 captured and marked (Boyd & Scott, 1955; Scott et al., 1955). As such the Greenland / Icelandic and Svalbard populations are considered distinct from each other, although not taxonomically. By far the larger population is the Greenland / Icelandic population that is estimated to account for 85% of the world population and winters in the UK with an estimate of 510,000 individuals (Frost et al., 2019). The majority of this population breed in Iceland, with Greenland only supporting a much smaller proportion of the breeding population and an estimated 13,000 birds, confined to the East of Greenland (Madsen, 1984), although East Greenland is recognised as an important destination for moulting birds, when by mid-summer areas previously covered by snow become available for foraging and moulting (Jepsen et al., 1996; Madsen & Cracknell, 1999). The Svalbard breeding population previously estimated at 37,000 individuals in the 1990's (Fox et al., 2010) has more recently been estimated to be 72,000 individuals following co-ordinated counts across its north west Europe wintering grounds in 2017/2018 where the majority of individuals were recorded in Jutland, Denmark (75%), Belgium (15%) and the Netherlands (8%) and smaller numbers in Sweden and Norway (Madsen et al., 2012).

Estimates of the UK population size have been well chartered since the 1960's with relatively frequent estimates presented in a series of published research literature. Early estimates of the population size totalled 65,304 individuals in 1968 (Boyd & Ogilvie, 1969), but were soon surpassed by a higher estimate of 73,200 in 1975 (Ogilvie & Boyd, 1976). These estimates were substantially revised with an estimate of 241,000 in 2003 (BirdLife, 2004) and continued to increase rapidly to some 360,000 individuals in 2011 (Musgrove et al., 2011) and now surpassing half a million individuals (Frost et al., 2019).

The distribution of wintering Pink-footed geese in the UK is dictated by the presence of suitable roosting sites, such as coastal marshes, estuaries or lakes from which the birds can depart and return daily to nearby areas for foraging (Newton et al., 1973). This clear association with the use of waterbodies, estuaries and the proximity of suitable agricultural areas for foraging largely dictates and defines the wintering distribution of the geese in the UK.

(Mitchell, 2004). Distributions in the early winter and October counts undertaken as part of the Icelandic-breeding Goose Census (IGC) reveal the greatest estimates of individuals in East Central Scotland (31%), North Scotland (14%), North East Scotland (15%), East England (14%) and West England (10%) (Brides et al., 2018). The 2017/2018 October counts recorded concentrations of populations estimated to account for 81.4% of the total population at the top 32 sites. The highest individual numbers were recorded at in Scotland at Montrose Basin; Angus, Beauly Firth; Highland, Carsebreck and Rhynd Lochs; Perth & Kinross and Findhorn Bay, whilst in England the highest counts were recorded at the Alt Estuary; Lancashire and at Holkham Bay; Norfolk with a further significant count at Read's Island; Humberside (Brides et al., 2018).

1.4 Pink-footed geese ecology

1.4.1 Physical size and weight

For some, pink-footed geese (*Anser brachyrhynchus*) are an iconic species and integral part of the winter landscape, being fondly referred to as 'pinks', as a result of their diagnostic pink coloured legs. In North Norfolk, where there are a number of reserves that attract both geese and visitors alike, their daily movements are captured by local artists such as James McCallum (McCallum, 2001; 2009). Their arrival on UK overwintering grounds and daily movements, are a visual spectacle. With a distinct call, observers are alerted to the shape and formations of skeins moving across the sky, accompanied by the definitive 'wink, wink' call of pink-footed geese in flight (Figure 1). Pink-footed geese are a medium sized species with an adult wing length of 434.7mm (± 28.7) (n=59) and by comparison to other species recorded in the UK have an average adult estimated weight of 2.5 kg, compared to the more diminutive Brent goose (1.25 kg), Barnacle goose (1.83 kg), Greylag goose (3.34 kg) and heavier Canada goose (3.96 kg) (BTO, 2020).

Figure 1: Skeins of pink-footed geese coming into roost at Holkham, December 2018 (Photograph by Mikal Ball, with permission).

1.4.2 Adult survival

The annual return of the geese each autumn in large numbers at individual sites has enabled the species to be observed at close quarters and individuals identified through their plumage as juveniles through their distinctive first winter colouration detected by methodical field scanning of wintering flocks (Lynch & Singleton, 1964) . Long-term trends (1970-1995) have identified the mean percentage of young in the populations studied to be 17.9% (Madsen & Cracknell, 1999). Whilst there have been large variations in the breeding success estimated in this way, varying from 5.6% to 48.8% of juveniles detected in individual years, these changes have largely been correlated to variations in meteorological variables in both the wintering and breeding grounds (Fox et al., 1989a; Fox et al., 1989b). Adult survival of pink-footed geese is relatively high, varying from 0.829 (± 0.009) (Madsen et al., 2002) to 0.88 (± 0.02) (Madsen & Cracknell, 1999; Mitchell, 2004) with a typical lifespan estimated to be eight years (BTO, 2020). Adult survival of pink-footed geese is similar to that of Greylag geese 0.83 (Nilsson & Persson, 1993) although not quite as high as that recorded for Brent geese 0.90 (± 0.036) (Sedinger et al., 2002) or Barnacle geese 0.91 (Ebbinge et al., 1991).

1.4.3 Productivity

Between 1970 and 1995 within family parties the mean brood size was estimated to be 2.09 (± 0.07) (Madsen & Cracknell, 1999), with more recent estimates by the WWT detecting around two juveniles per family party and a mean brood size of 1.99 (± 0.66) between 2009 and 2018

(Brides et al., 2018). Breeding occurs in the remote wet meadows of central Iceland where the initial summer melt of snow first occurs, in particular around burns and rivers, albeit the geese also use cliffs that are less accessible by predators for breeding also (Madsen & Cracknell, 1999). Pink-footed geese reach breeding maturity around three years of age and have only one brood each year, laying on average 4-5 eggs per clutch and which are incubated for between 26-27 days before fledging which occurs over a period of 50-60 days (Mitchell, 2004; BTO, 2020). Post-hatching with the young around 10-20 days old and mobile the geese aggregate in large numbers totalling several hundred or more and at a time the adults also begin their moult and become flightless (Madsen & Cracknell, 1999).

1.4.4 Behaviour

The social nature of Pink-footed geese, gregarious in their habits outside of the breeding season have been both described and depicted in detail following years of field observations (McCallum, 2001). These observations describe how despite an initial impression of a large homogenous flock there appear to be certain levels of order within feeding flocks resulting in recognisable patterns of posturing and the detection of paired individuals with the gander of the species being distinguished by its bulkier and heavier neck versus the female. Dominant pairs are evident from both their own upright postural behaviour with bills held also slightly upwards, but also detected too by the submissive behaviour of others who keep their heads low and appear to move respectfully away leaving distance between pairs. Family parties appear to arrive later than non-breeding adults and exhibit close nit tight movements often locating themselves towards the edges of larger feeding flocks. Movements to and from roosts include hundreds if not thousands of individual birds whose ordered flights form the distinctive V shaped skein patterns organised and grouped by the frequent calls between individuals. These social classes, parental behaviours and behavioural dynamics are similar to those recorded in other studies of not only pink-footed geese (John & Inglis, 1978) but also other geese species including greylag geese (Kotrschal et al., 1993) Canada geese (Raveling, 1969) and Snow geese (Prevett & MacInnes, 1980).

1.4.5 Diet

Pink-footed geese have a varied diet across their range. When they arrive in Iceland each Spring they typically arrive across a broad front along the southern coast and feed on lowland sedge rich-meadows and areas that are the first to be exposed by early thaws from the wintering snow cover (Madsen & Mortensen, 1987). Here the spend almost half of their time, 46% of a 24-hour period, actively foraging, and show a preference for using water bodies, such as lakes, rivers and the sea as refuges from where they can forage only a few hundred metres away. Once they mover further inland and into the central breeding areas of Iceland the geese feed on the green parts, roots and fruits of a wide variety of tundra plants. The main foods include rhizomes and the seeds of Alpine Bistort (*Polygonum viviparum*), shoots of Horsetail (*Equisetum variegatum*) and Cotton grass (*Eriophorum*), and in the autumn, the seed heads of sedge (*Carex*) species. Adult's feed first on leaves and catkins of Willow (*Salix glauca*), switching gradually to graminoids (*Carex, Calamagrostis stricta*) which form nearly the whole diet in July and early August. At first, goslings take more herbs and Equisetum than adults. From August, the leaves and ripened fruit of crowberries (*Empetrum nigrum*) and Empetrum hermaphroditum become increasingly important, coinciding with the movements of geese from marshes to higher and drier areas (Madsen & Cracknell, 1999). The geese leave their breeding locations directly for their wintering grounds without stopping in southern Iceland as they did on their arrival. In the UK the geese utilise stubble fields I the autumn, foraging on spilt grain, but also foraging on grasslands before moving onto root crops in midwinter, including the harvested remains of sugar beet, carrots and potatoes (Newton & Campbell, 1973; Giroux & Patterson, 1995; Gill, 1996). In late winter and spring winter cereals are selected, although the geese feed mainly on grass in spring, especially *Lolium perenne*, which is the main constituent of the sown sward. In doing so they respond and utilise an identified gradient of plant growth that is high in protein content and associated with the onset of growth, known as the 'spring bite' (Fox et al., 1994). This forms the largest part of their diet in the northern staging areas of the UK, prior to returning once again to their high arctic breeding grounds by mid-April (Mitchell, 2004).

1.5 The conservation status of pink-footed geese

Globally, the species is considered of Least Concern in the BirdLife International (2020) IUCN red list for birds, due to its large range size, (>20,000 km^2) increasing population and overall population size (>10,000 individuals) (BirdLife, 2020). In the UK pink-footed geese are currently a species of conservation concern, listed as amber in the Birds of Conservation Concern (BOCC4), (Eaton et al., 2015). The UK amber conservation status classification for pink-footed geese is a result of the relatively limited range of the species in northwest Europe and further concentration or localisation of those occurrences within a small number of sites. The UK hosts up to 85% of the Global population (Frost et al., 2019), and is considered of international importance, exceeding the threshold of >20% of the non-breeding population occurring in the UK criterion for amber status. Furthermore, during the non-breeding season in the UK more than 50% of the population occurs at 10 or fewer sites, another criterion for qualifying the species as of amber status (Gregory et al., 2002). On-going monitoring of pink-footed geese and other geese and wildfowl helps ensure that any unacceptable or negative changes can be identified. In the UK millions of migratory waterbirds are protected by international treaty obligations including the EU Birds Directive, the Ramsar Convention on Wetlands, and the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (Frost et al., 2019). Consequently, the populations of waterbirds, including waders, wildfowl, swans and geese are closely monitored with trends published annually by the BTO/RSPC/JNCC derived from the Wetland Bird Survey (WeBS) results.

Within Iceland, the main breeding ground, site protection is limited. There are three Important Bird Areas (IBA's) for pink-footed geese identified, providing protection in two areas for breeding populations and one for populations undertaking moulting (Heath et al., 2000). Only one of these sites is formally protected through being a Ramsar site and National Nature Reserve, for which there is no access between the 1st of May and 10th June, and no low-level flying, i.e., below 1,000m permitted (Clausen et al., 2017). A close season, between the 16th March and 19th August also protects full-grown birds during their breeding season, with further protection of eggs being harvested for human consumption being limited, with a minimum of two eggs per nest being required to be left in any egg collecting (Mitchell, 2004).

Greenland, which supports a much smaller proportion of the breeding population with an estimated 13,000 birds, confined to the East of Greenland, has two sites that are protected as Ramsar Sites. Whilst only having a relatively small population these sites are important destinations for moulting birds (Jepsen et al., 1996). In particular Greenland offers suitable foraging and grazing opportunities at a time where competition from other goose species is at a maximum.

Within the UK remains a species of conservation concern and Natural England, whose statutory responsibility is to ensure that unacceptable losses in that population do not occur, have sought to understand further a number of potential impacts on the species. These include assessments of the anthropogenic impacts on the population following a series of commission reports by Natural England and undertaken by the WWT; Pink-footed goose anthropogenic mortality review: *Avoidance rate review* (NECR 196); *Collision risk modelling* (NECR 197); and *Population model* (NECR 198).

A number of factors, to differing extents, potentially influence the species population size, productivity and distribution. These include changes in breeding habitat resulting from climate change, changes in agricultural intensification, land use and policy, and also further anthropogenic impacts such as the level or change in hunting practice (Fox & Madsen, 2017).

1.6 Changes benefitting pink-footed geese

1.6.1 Agriculture

Herbivorous pink-footed geese have historically relied on foraging amongst diverse swards of saltmarsh and low intensity pasture for the most nutritionally rewarding grass blades or other sources of wild foods (Madsen, 1985; Fox & Abraham, 2017). These relatively low energy sources have to be sought out making them comparatively less profitable than food resources available from agricultural crops leading to an abandonment of traditional habitats in favour of farmland, a factor considered to have contributed greatly to the growth of pink-footed geese populations (Reed, 1976; Therkildsen & Madsen, 2000; Fox et al., 2005; Fox & Abraham, 2017; Fox & Madsen, 2017). To what extent these food resources can further advance the carrying capacity and population size of pink-footed geese has not been estimated, however in discussion over the potential future population size the pink-footed geese have been described as potentially becoming super abundant, versus one of conservation concern (Fox & Madsen, 2017).

Pink-footed geese return to winter in the UK from early September, subsequently leaving towards the end of the winter and early spring, as late as early May (Boyd & Ogilvie, 1969). Their arrival coincides with early autumn when grass growth has slowed substantially, but also a time shortly after cereal crops, such as wheat and barley, have been harvested. Residual spilt grain left after harvests are available to geese for feeding (Newton & Campbell, 1973). Waste root crops are more readily available during the depth of winter as Sugar Beet (*Beta vulgaris*) is harvested along with other root crops, typically in December and January. The nutritious ‘tops’ of beet offer a ready supply of energy source, as the fields are harvested in rotation over the winter to provide a steady flow of beet to the refining factories. The beet tops are a bi-product of the beet being lifted, harvested and the tops left on the field surface which, if not eaten, rot into the ground to provide nutrient for the next season’s crop - typically cereal, grown in rotation with sugar beet (Newton & Campbell, 1973). In North Norfolk the abundance of sugar beet, which during the winters of 1990 to 1993 had a ratio of cereal to sugar beet of approximately 2:1; was identified as the main food resource being consumed by pink-footed geese and identified as a major factor attributable to the rise of pink-footed geese in the county (Gill et al., 1996).

Whilst farming practices make available food resources that aid growth in population size for pink-footed geese they also by default logically also make the same population largely dependable on those resources and therefore susceptible to changes that may result in their loss, e.g., changes in land use, crop regimes or harvesting efficiencies. Recent advances in farming technology have resulted in a greater efficiency in reducing the size of the crown or residual tops left to a mere fraction of those historically discarded, contributing to record yields being achieved (Day, 2018). In addition, with the advent of warmer springs and more favourable ploughing conditions, it has become increasingly common to immediately plough and directly drill sugar beet fields being lifted with spring cereal crops (Christian & Ball, 2017). This single change, if employed widely, could not just reduce the availability of beet tops, due to a reduction in the biomass of what is left as a harvested bi-product, but actually remove the availability of any bi-product at all by immediately ploughing it in and sowing spring cereal.

In Norway, changes to farming subsidies, that are calculated on a farm's size, rather than its' productivity have led to less intensive farming, where fields are more commonly left ungrazed by livestock and overgrowing occurs (Kery et al., 2006). These changes have, in effect, altered the agricultural landscape and inadvertently reduced the foraging opportunities by both reducing the total acreage and level of energy value of the resources available for the geese to forage on. As a consequence, the number of geese that can be supported per unit area of land has been reduced resulting in goose numbers in two municipalities of Norway decreasing (Tombre et al., 2005). This highlights the likely interdependence and reliability of the species on agricultural practices and/or policies which may affect it.

Changes in agricultural practices can also have unintended consequences in influencing and determining the foraging behaviour and crop selection by the geese, if one food resource becomes unavailable (Madsen, 1985; Therkildsen & Madsen, 2000; Tombre et al., 2005). If beet tops are unavailable, then geese are equally adaptable at switching to emerging cereal crops, again also more readily available with the rise in the sowing of winter crops (Gill et al., 1996). Cereal crops are of much higher commercial value than beet crops and the damage that a large flock can have on a single field can be substantial (Owen, 1972; Reed, 1976; Flegler et al., 1987; Owen, 1990). Damage to crops arises not just from the foraging by the geese and grazing of the grasses, but also by the sheer weight and damage caused by large numbers paddling and walking for hours or days in a single field. In fact, evidence suggests that the grazing of cereal crops, early on in their growth, does not ultimately affect future yield, since the majority of the plant's growth occurs later in the spring (Flegler, 1987). However, cereal crops can be seriously and permanently damaged in wet conditions when the paddling and trampling by thousands of geese in one field over even a few days can destroy large acreage of crops, as witnessed during fieldwork near Weybourne, North Norfolk in 2017/2018. As a consequence of these changes there is a greater propensity for human conflict and for farmers to understandably be less tolerant of the presence of geese now damaging yields and livelihoods to the point whereby the geese are seen as pests responsible for economic impact and require management (Bainbridge, 2017).

There have been many attempts to try and manage conflict and divert geese from foraging on commercially valuable crops to areas less valuable. In the Netherlands, farmers were initially compensated for the loss or damage to crops that totalled 7 million euro in 2003/2004. Due to the rising cost, a new policy was enacted whereby geese were actively scared from areas they are not wanted, until they relocate on designated foraging or nature areas where they were left undisturbed to forage. This policy was not effective, with costs associated with actively disturbing and moving the geese on doubling versus the payments previously issued for compensation and totalling 17 million euro. Anticipated learning by the geese of sites they were being actively scared and discouraged from, did not occur, with the geese repeatedly attempting to return to cropped areas offering higher nutritional value (Koffijberg et al., 2017).

1.6.2 Climate change

Early studies of pink-footed geese populations highlighted that environmental conditions in Iceland and Greenland, rather than in Britain, were primarily responsible for determining the size of the population. These remarks followed productivity analysis between 1951 and 1953 in which there were marked climatic differences on the breeding grounds and resulting marked differences in breeding success (Boyd & Scott, 1955).

The variation and resulting influence of climatic conditions affect pink-footed geese since, similar to other high Arctic-nesting birds, they have only a short window in which to find suitable nest sites, breed, moult and then get in condition for their long flights back to more southerly wintering grounds. In Svalbard, pink-footed geese arrive in late May, breed throughout the summer and migrate south again from early September (Madsen, 1984). This presents only a relatively narrow window, a period of less than 4 months, in which to complete the breeding cycle (Jensen et al., 2008). As such, the current nesting distribution is limited or defined by climatic factors. In years of lower snow cover and earlier snow melt or thaw, the number of pink-footed geese attempting to nest has greatly increased with corresponding earlier egg laying. Although, these changes have also resulted in lower productivity with smaller clutch sizes, presumably as younger and more relatively inexperienced birds have entered the breeding population for the first time and are less successful. However, the nett effect of being able to nest earlier as a result of less snow cover and increased nesting site availability has been shown to influence the probability of nest success by 3% per day. As a consequence of rising global climate temperatures, it is predicted that range expansions will occur with modest increases of 1-2° Celsius. In Svalbard these changes predicted an increase of 84% and 217% in potential distribution, under a scenario of increases by 1 and 2°C, respectively (Fox et al., 1989a; Madsen et al., 2007; Jensen et al., 2008).

Rising temperatures therefore, as well as increasing the length of the season with frost-free conditions, result in higher temperatures in May as individuals attempt to nest and also provide increases in suitable feeding habitats by exposing vegetation. These changes will also present opportunities for other geese species, a factor that may limit the success of any resulting range expansion. However, competition between species is relatively limited and, in the case of Barnacle geese and pink-footed geese in Svalbard, the two species occupy different niches demonstrating different feeding habitats and food plant selectivity when occurring sympatrically (Madsen & Mortensen, 1987; Fox et al., 2007). In East Greenland and Iceland, pink-footed and Barnacle geese have expanded in population size but largely occupy different ranges and habitats. The two species are able to exploit different plant phonologies and food plant qualities, resulting in minimal inter species competition (Van der Graaf et al., 2006).

1.7 Changes negatively impacting pink-footed geese

1.7.1 Hunting

Throughout their range pink-footed geese are a quarry species, yet the true impact of hunting on the population size and the numbers shot each year are difficult to ascertain. Whilst a species of conservation concern, the rise in population levels is increasingly bringing the species into conflict with some farmers (Owen, 1990). It is therefore important to understand the impact of hunting on the population of the species in context of their conservation status and existing protection across their range.

Within the UK, under the Wildlife and Countryside Act 1981 (as amended), pink-footed geese are legal quarry and can be shot between 1st September and the 31st January (with an extension until 20th February in areas below the high-water mark). However, the sale of dead geese is prohibited thereby offering no commercial value from the sale of their meat as game. Accurate records of the number of individual birds shot each season are not available in the UK since there is no obligation for hunters to document or report the numbers shot.

In Iceland, a mandatory bag recording system was introduced in 1995 which helped more accurately record the number of birds shot. Indirect estimates of the number of birds shot by hunters in Iceland based on the recorded Icelandic bag figures and the population estimates at the time have been calculated. They estimate that between 1996-2000, using the known Icelandic bag sizes, and a combination of reported ringing recoveries, that an average of 14,000 birds were being shot in Iceland each year and an estimated 25,000 individuals shot in the UK (Frederiksen, 2014). At the time of these estimations in birds being shot, the total estimated UK population of pink-footed geese from surveys was 230,000 individuals. Therefore, the total number estimated as being shot of 39,000 annually represents almost 17% of the population. This is particularly high, especially compared to previous estimates estimated annual losses in the UK of 6.5% to shooting (Boyd & Scott, 1955) and most recently 8%; Pink-footed geese anthropogenic mortality review: population model (2015), Natural England. To both compensate for the combined mortality associated with shooting and natural mortality, and for the total population to grow in size, productivity would need to increase at a greater level than total mortality. With an annual survival rate calculated at 89%, between 1960 and 1987, the population size of pink-footed geese rose from 48,000 to 172,000 individuals, indicating that increases in productivity have more than outstripped annual mortality rates (Fox et al., 1989a; Fox et al., 1989b).

Throughout their range, pink-footed geese are afforded some protection, but not extensively. The challenges in accurately quantifying or even estimating the true annual numbers of birds shot in turn makes accurate population modelling, attempting to account for the anthropogenic impact on the species, uncertain. The ability to accurately predict future populations is highlighted by one estimate of pink-footed geese estimating populations stabilising at around 220,000 by 2015, yet now known to actually be in excess of half a million individuals (Frost et al., 2019). A contributing factor to this rise in population is actually a more likely lower annual number of birds being shot in the UK, than the 25,000 estimated. There have been substantial reductions in the number of Greylag geese shot in the UK, by almost one third, over the last decade, which if also applicable to pink-footed geese would represent a substantial reduction in anthropogenic impacts, from hunting (Trinder et al., 2005).

Despite the difficulty in predicting future populations and understanding fully the impact of shooting, pink-footed geese and other goose species are under constant review with varied call to manage numbers. Optimal practices for shooting or 'harvesting' geese have been advocated (Jensen et al., 2016) in an effort to strike a balance or compromise between conservationists, farming practices, and commercial impact. Unanticipated rises in populations of geese have been neither simple or comfortable to manage, with a balance between conservation and management often contentious (Bainbridge, 2017). The need to approach any such harvesting methodically and scientifically is highlighted by research into hunting of the Svalbard population of pink-footed geese. In Svalbard evidence has shown that any harvesting or shooting needs to take into account the impact of timing and location along the migratory corridor of any activity since these factors can affect the age and sex ratio being shot, which in turn influences the impact on the overall population size (Clausen et al., 2017). Further evidence of the adaptive management techniques, which have been employed in Northern Europe, to manage the population size of Svalbard geese emphasise the need for continual dialogue, consensus building, as well as ongoing monitoring between NGO's and statutory agencies (Madsen et al., 2017). These seem to have been successful in meeting their objectives with ongoing monitoring reporting annually (Heldbjerg et al., 2020). Ways of setting sensible targets, against a background of uncertainty, through the use of a conceptual modelling has been advocated by others to effectively control non-native or problem species (Ward et al., 2020).

1.7.2 Functional linkage

UK statutory conservation bodies, in particular Natural England, have sought to understand any likely impact arising from potential or proposed land use change and loss of agricultural land known to be used for foraging by both pink-footed geese and a number of other geese and swan species. Whilst this agricultural land is out with the traditional and protected SPA sites, that are typically the roost sites of the species, they are critical to the species survival since they now form the main source of foraging (Newton & Campbell, 1973; Newton et al., 1973; Reed, 1976; Gill, 1994; Fox & Abraham, 2017). As such, these important agricultural areas have been termed 'functionally linked' and recognised as important to various SPA site populations. Functionally linked land has been defined as land that is essential for the ecological function and population size of a species (Chapman & Tyldesley, 2016).

Pink-footed geese within North Norfolk are protected since the aggregations of wintering birds represent 6% or more of the European wintering population (England, 2007). As such, the species is a qualifying feature of the North Norfolk SPA (Figure 2). The aim of the SPA is to maintain or restore the population size, distribution and also the extent and distribution of the habitats and the structure and function of those habitats for the qualifying features, of which pink-footed geese are one species cited within the designation; European Site Conservation Objectives for North Norfolk Coast SPA (2019), Natural England. Principally, these designations protect the main roost sites for pink-footed geese, for which the five main roost sites within the North Norfolk Coast SPA are i) Holkham Bay, ii) Holme, iii) Burnham/Norton Marsh, iv) Scolt Head and v) Wells (Brides, 2013).

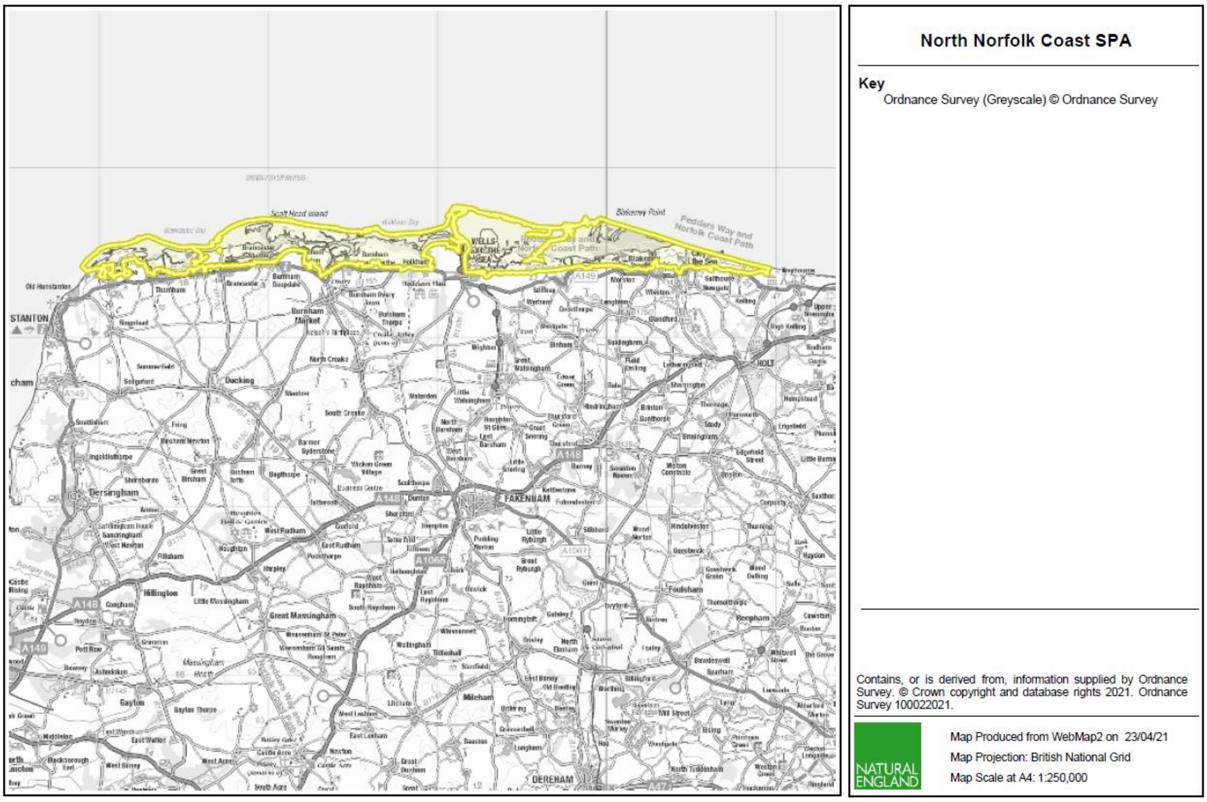

Figure 2: North Norfolk Coast SPA boundary (Produced with permission from Natural England, source: WebMap2).

Beyond the confines of the SPA, land is not protected by statutory designation. Therefore, for example, whilst pink-footed geese may roost within the marshes of Holkham NNR that lie adjacent to the coast and within the North Norfolk SPA, once they leave and fly inland onto open farmland, they move away from these protected sites to unprotected areas. However, the agricultural land is clearly of vital importance to fulfilling their ecological needs and for the significant numbers of birds foraging providing suitable foraging habitat and nutrition to sustain the local wintering population.

The potential loss, degradation or change in land use of functionally linked land lying outside the designations of protected areas could therefore potentially impact goose populations by changing or removing essential foraging habitat. Land loss may be the result of urbanisation and continued growth in housing development, or result from a change in land use and the siting of on-shore wind-farms or solar energy schemes. Equally, as has been presented, changes in agricultural subsidies have resulted in changes in agricultural practice and a reduction in the availability of suitable food resources offered by agricultural crops (Tombre et al., 2005). Quantifying the impact of potential or proposed land loss is the subject of ongoing research and modelling by Natural England who are seeking to determine how much land, in theory, could be lost before impacting the ecological function and population of UK wintering geese species.

One model of the potential impacts on pink-footed geese wintering distribution for the year 2050 in relation to scenarios of land use change predicted that rising conflict with agriculture and associated commercial interests are likely to occur (Wisz et al., 2008). The scenarios modelled were primarily focused on either global or local changes in land use resulting from a more environmentally concerned world. In these scenarios grasslands and croplands are partially substituted for alternate energy sources, biofuel crops, forestry or continued urbanisation and differing levels of land conversion. The squeeze and reduction in preferable agricultural grassland and croplands is amplified by pink-footed geese site preferences in foraging areas. These are associated with proximity to roosts, the coast and in part also to a particular fields aspect and elevation that are believed to offer safer and more preferable locations in which to graze whilst also surveying for predators. Whilst geese will favour and return to specific sites, the preferences are refined further to avoid sites exposed to disturbance. In particular sites with close proximity to roads, relatively small field sizes in which safe vantages are not available and where predators can get closer, or where hunting pressure is more prevalent are either avoided or only temporarily used with corresponding low levels of available sugar beet depletion (Gill, 1996).

The dependency on agricultural land use has been illustrated by the study of Svalbard populations of pink-footed geese, which overwinter in northern Europe. There, like elsewhere in Europe the geese have successfully switched and been tempted to forage on energy rich agricultural food sources, moving away from traditional food sources. Whilst doing so, traditional food sources and sites have undergone habitat change and loss raising the question as to whether these traditional resources exist now in sufficient quantity to support the increased populations that exist today should our own anthropogenic farming practices also change again and crops become less available (Fox et al., 2005). This work further highlights the ensuing dependency of European populations of geese on our own choices, decisions and policies for future agricultural land use and its development.

Change in land use within the breeding grounds is also a future possibility, although for now the change in land use in Iceland, whilst dramatic, has been confined to lowland wet areas adjacent to the coast. In South Iceland conversion of natural landscapes to artificial man-made surfaces increased by 30% between 2000 and 2006, which combined with extensive draining of wetlands has implications predominantly for wader (Charidrii) species (Jóhannesdóttir et al., 2014).

1.7.3 Potential collision risk and mortality associated with offshore windfarms

Pink-footed geese are known to migrate between their breeding grounds in Iceland, to wintering grounds in the UK, including North Norfolk (Gill et al., 1997). Their migratory routes are not fully understood, however are believed to include movements both off-shore and near shore. Therefore off-shore windfarms along both the east and west coast of the UK may lie within the migratory corridor used by pink-footed geese and their installation and operation within the marine environment pose potential new risks for benthic ecology, marine mammals, epifauna and fish, and birds (Gray et al., 2005; Houghton, 2009). These risks include the potential for fatal collisions and additional mortality, above naturally occurring baseline mortality rates that could impact the populations viability of individual avian species (Langston & Pullan, 2004; Percival, 2005). If a series of operational wind-farms lie in between an individual and its' foraging area this risk can be increased and present a cumulative barrier effect (Brabant et al., 2015). Whilst these risks are assessed in the UK as part of statutory Environmental Impact Assessments (EIA's), the risks posed are not exclusive solely to marine bird populations but also include migratory species, such as pink-footed geese (Hüppop et al., 2006; Furness et al., 2013). Since individual avian species vary in their physical size, flight speed and also flight height, the potential for collision with an individual turbine, or turbine blade varies by species (Marques et al., 2014). A variety of approaches have therefore been derived to help undertake Environmental Impact Assessments, as part of the statutory obligations for off-shore wind developers (Masden & Cook, 2016), along with standardised ways of modelling collision risk (Band & Band, 2012), and for assessing seabird abundance, distribution and temporal changes (Camphuysen et al., 2004).

The need to evaluate the risks posed by off-shore windfarms is a relatively new requirement given the also relative infancy of the industry and off-shore windfarm sector whose growth has been recognised as a key way of achieving renewable energy targets (Ackermann et al., 2001; Higgins & Foley, 2014). Over the last decade, the UK has become a leader in offshore wind development and installed capacity with both support and subsidy from the UK government and support from environmental NGO's, taking advantage of the suitability of the UK's offshore waters and established ports (Toke, 2011; Kern et al., 2014). The UK is currently the largest single market for offshore wind energy, delivering 38.4 GW annually of a total 121 GW produced globally (Norris, 2019). Across Europe by the end of 2019 there were a total of 5,047 individual grid connected wind turbines were located off shore. These comprised a total of 110 wind farms, operated by 12 countries, with 45% of all installations being in the UK (Ramirez et al., 2020). Windfarm sizes have doubled in a decade, between 2010 and 2019, with the UK having the largest windfarms as a result of the extensive Exclusive Economic Zone (EEZ) surrounding the countries coastline (Ramirez et al., 2020).

The efforts to limit future global temperature growth associated with recent climate change have given rise to the focus and need for lower carbon energy resources, which emit lower or no CO_2 gases (Godfray et al., 2010). Within the EU this has led to the development of an energy and climate emergency strategy, to be achieved through the use of renewable energies, and target contribution of 20% of all energy coming from renewable resources by 2020 (da Graça Carvalho, 2012). New ambitious targets have now been set for 2050 which include expanding further and increasing the UK's capability of producing energy from off-shore wind (Analytica; Livingston & Lundquist, 2020). The potential risk for avian collision therefore is likely to only increase and requires on-going evaluation by statutory conservation bodies.

1.8 Aims and objectives and thesis structure

The overall aims of this thesis were twofold; firstly, to review the UK population size, trends and distribution of pink-footed geese, with particular focus on the assessment of changes occurring between 1990 and 2018 (a period for which historic site survey count data has been inputted and stored electronically by the WWT and which has been shared for this study). The second aim was to utilise the GPS tagging data, collated over two winters, from two samples of nine pink-footed geese each, to quantify the daily distances travelled by the geese and establish wintering foraging home range sizes, within the study area of North Norfolk.

Chapter 2 reviews the population size, distribution and trends undertaken by a combination of reviewing historic literature and published survey data, dating back to the early 1950's. More detailed analysis of survey count data, conducted between 1990-2018, and collated as part of the annual IGC survey counts, has been mapped and the changes occurring during this period quantified. An assessment of whether changes in the population have resulted in changes in the range and distribution of pink-footed geese across the UK includes an evaluation of the relative significance of key sites and changes in abundance at sites where the species has been recorded.

Chapter 3 reviews the existing knowledge of pink-footed geese movements based on colour ringing, observational and use of radio telemetry, with the results of the GPS / GSM tracking analysed. Detailed also are the methods used to successfully capture samples of the geese and an overview of the capability of the tags employed and variances in the data recorded between years. The results include, for context, the mapping and presentation of the annual movements and migratory movements recorded across the entire range for birds tagged in the study. More detailed mapping and analysis of each birds' movements within the study area, North Norfolk, is presented for the two cohort samples of birds tagged. Step analysis of these movements quantifies the minimum, maximum and mean distances travelled by each bird and compares the variances recorded between the two samples and two years of the study. Further analysis presents both the mapping and winter foraging range sizes of each bird and a summary of the data for again both samples, years of the study and a comparison of the data between years. Further examination maps and quantifies the amount of sugar beet crop coverage in both North Norfolk in total, but also within the recorded wintering foraging ranges. An initial review of the daily energetic requirements, daily food intake and the factors affecting habitat choice and selection provided insight into quantifying the availability of sugar beet as a food resource and possible population size that could be supported by the resource.

In Chapter 4, a summary of the key findings, their significance and potential to be incorporated into ongoing modelling and assessment tools are synthesised in a series of conclusions and discussions. These include a discussion of the improvements possible in undertaking ongoing monitoring, through rapidly advancing and ever more capable technology, and also a review of the merits of the conservation status of the species.

It is anticipated that the outputs and findings of this research will be shared with and further aid Natural England in the development of an evidence led planning tool, currently modelled largely on desk-based analysis, by providing quantifiable field-based data. To date, the planning tool commissioned by Natural England, has not been published and requires further validation of a number of parameters, for which it is hoped the results of this MSc will provide a valuable contribution.

Chapter 2 : Changes in abundance and spatial distribution of over-wintering pink-footed geese in the UK

2.1 Introduction

Knowledge of the abundance and spatial distribution of over-wintering pink-footed geese across the UK is required to assess the species selection and use of agricultural crop areas for foraging and food resources. In particular areas used for foraging by geese that are moving from their roosts at SPA sites are deemed as functionally linked since they are deemed to be providing food resources that are essential for the ecological function and population size of the species (Chapman & Tyldesley, 2016). Rises in the population size are likely to result in greater foraging resources being consumed which may lead to constraints in the foraging resources available versus those required for an increasing population. Increases in population size and / or a decrease in the foraging resources available within a defined area and foraging range are likely to create food resource pressures that could be limiting for a species population and its size and are therefore of potential conservation concern.

2.2 Research aims and objectives

This chapter quantifies the changes in the recorded abundance and distribution of overwintering pink-footed geese in the UK between 1960 and 2018 by:

i) Quantifying temporal changes in the population size, between 1990-2018 from site specific records provided by the WWT, and historically from 1960 onwards utilising a literature review.

ii) Mapping and quantifying more recent changes in the UK temporal and spatial distribution using site specific IGC WWT survey data for 1990-2018.

iii) Examining and reviewing the abundances by IGC survey site to further evaluate changes in the UK temporal and spatial distribution to establish whether patterns or correlations in changes in abundance with changes in distribution exist.

2.3 Historic efforts used to assess the population size and trends of pink-footed geese in the UK

The population of UK wintering pink-footed geese in the UK has grown substantially since being first systematically recorded by the Wildfowl Trust in the 1950's (Boyd & Scott, 1955) and has most recently been estimated as 510,000 individuals (Frost et al., 2019). This estimate and the annual estimates recorded and dating back to 1960 are the result of long-term monitoring and the autumn 'grey goose' counts which subsequently evolved and became known as the Icelandic-breeding Goose Census (IGC). Subject to some minor revisions, implemented in 1991 (Mitchell, 2004), these counts have formed the core of long-term monitoring by the WWT.

The WWT estimates of the population size of pink-footed geese have focused on an assessment of the UK wintering populations.   Efforts to monitor the population size on their breeding grounds have been deemed impractical due to the survey effort required, following attempted surveys of breeding numbers using aerial surveys in central Iceland in 1963 and 1964 (Boyd & Ogilvie, 1969).

The robustness of survey design and effort evolved following years of monitoring which commenced in the 1940's and which were initiated following growing concerns over possible declines in wildfowl numbers resulting from the development and loss of wetlands (Cranswick et al., 1997).   During this period, it was recognised that accurate scientific data would need to be gained to begin documenting both numbers and the distribution of wildfowl. To do this, a national scheme to count wildfowl was introduced in 1947 and shortly after in 1954 with the passage of the Protection of Birds Act into law the need to determine the size of wildfowl populations during the winter and to identify important sites for these species became a necessity. Given the need for accurate data, support has been provided by the UK government to undertake counts, initially by the Nature Conservancy and to the present day by the Joint Nature Conservation Committee (JNCC).

While the count of wildfowl, in particular ducks on open water, can be undertaken using a 'look and see' methodology, the counting of geese is more challenging. Wintering pink-footed geese utilise more frequently the relatively less accessible habitats of estuaries, saltmarsh or marshland to roost (Newton & Campbell, 1973). During the day, and also on occasion at night, especially when there is sufficient moonlight, the birds leave the roosts, dispersing to feed on farmland (Giroux, 1991). Being sensitive to disturbance, gaining close access to survey and count the geese is a challenge (Owens, 1977). Once the geese have left a roost to seek suitable foraging areas it is a challenge to practically track the movements of the geese across large areas, let alone relocate individual flocks and also avoid disturbing them on feeding areas.   Given the frequent inaccessibility of roost sites, reliably attaining close enough proximity to the geese, without disturbing them, and potentially trying to observe individuals obscured by either each other or vegetation is a challenge. To circumnavigate these challenges, it was deemed more accurate to count the birds in flight as skeins of geese arrived or departed known roost sites in large parties around dawn or dusk.

With a focus on assessing populations on their wintering grounds, efforts were made to ascertain the spatial distribution of the geese across Britain with the Trust undertaking further aerial surveys and visiting recorded sites. Early in the winter, pink-footed geese were found to be confined largely to a relatively small number of sites and around two dozen roosting places, 8 in England and 14 in Scotland (Boyd & Ogilvie, 1969). Therefore, it was practical, with effort, to attempt counting each site simultaneously in a co-ordinated autumn count. Whilst it was recognised that annual estimates would only be the result of a single count by using experienced observers, most of whom were involved in counts over many successive years, a high degree of consistency could be achieved. Employing these methodologies, whilst not 100% accurate, certainly helped to analyse trends in overall abundance and spatial distribution used to determine those sites of significant importance for the geese.

Up until 1990 the census involved a co-ordinated single count undertaken in November by local volunteer co-ordinated regionally (Cranswick et al., 1997). Counts were initially undertaken in November, since this month was deemed the optimum month for estimating the population size which would have all arrived in the UK by that time, but not yet dispersed into smaller groups or populations that would be more problematic to locate and count. From 1990 a second count was undertaken in October to assess whether counts in that month would record higher abundances in the belief that the birds were returning earlier in the autumn and validate a decision to focus count efforts in the month of October versus November ongoing. From 1990 goose count co-ordinators were also recruited to help improve the organisation of the census in particular areas and also improve the coverage of counts across Britain (Mitchell et al., 1996; Mitchell, 2004).

In 1998 the grey goose counts were extended to include Ireland, with further extensions in 2001 to also include the Faroe Islands, Norway and additional sites in Iceland. Since 2001 the grey goose counts have been redefined and named as the Icelandic breeding Goose Census (ICG) (Mitchell, 2004).

An alternative considered, in place of using the count data obtained by the IGC, to assess the population size and distributions of pink-footed geese for this study was to use BTO data from The Wetland Bird Survey (WeBS), itself a core count methodology (Cranswick et al., 1997). However, WeBS data was discounted as a suitable data source due to the count methodology requiring counts to be conducted at or near high water, at varying times of the day, depending upon tidal cycles, and therefore potentially when pink-footed geese are absent, having departed roost sites for foraging areas, which are not covered in the WeBS counting.

2.3.1 Knowledge of pink-footed geese abundance and distribution from WWT / IGC surveys and data

Annual count data collated by the WWT, including the IGC data represent one of the longest time series of standardized data on waterfowl abundance (Mitchell, 2004) and are considered to provide an accurate assessment of abundance (Frederiksen et al., 2004). Further studies conducted by the WWT have mapped the distribution of feeding pink-footed geese in England and Scotland in order to help assess any potential impact proposed on-shore wind-farm developments may have (Mitchell, 2012; Brides, 2013). Whilst the studies utilised IGC count data they also use much more extensively data from other sources including colour ringing records, county records, data from the Goose and Swan Monitoring Programme, RSPB reserve site data, WeBS and also from the BTO Birdtrack and a total of 20,009 records in England (Brides, 2013). Just over half of these records - 50.4% - were provided by the BTO and collated through the Bird Track app which allows any observer to record and submit records of sightings for all avian species. Colour ring re-sightings of individually marked geese contributed the second highest number of records, totalling 20.6% of all records analysed. BTO Bird Track records, and other sightings may be of only a single bird, and do not necessarily always record whether the bird(s) were in flight or on the ground feeding, loafing or preening. In practice, records will include sightings of any number of birds, undertaking any form of activity, including migratory passage and dispersal from roosts. The mapping of these records, using a minimum count of 10 as a record, reveals many individual sites where the geese are present (Figure 3). However, the number of sites where geese were recorded in higher abundances, of greater than 500 in number using the IGC count data, revealed a much more refined pattern of distribution at a much lower number of sites (Figure 4).

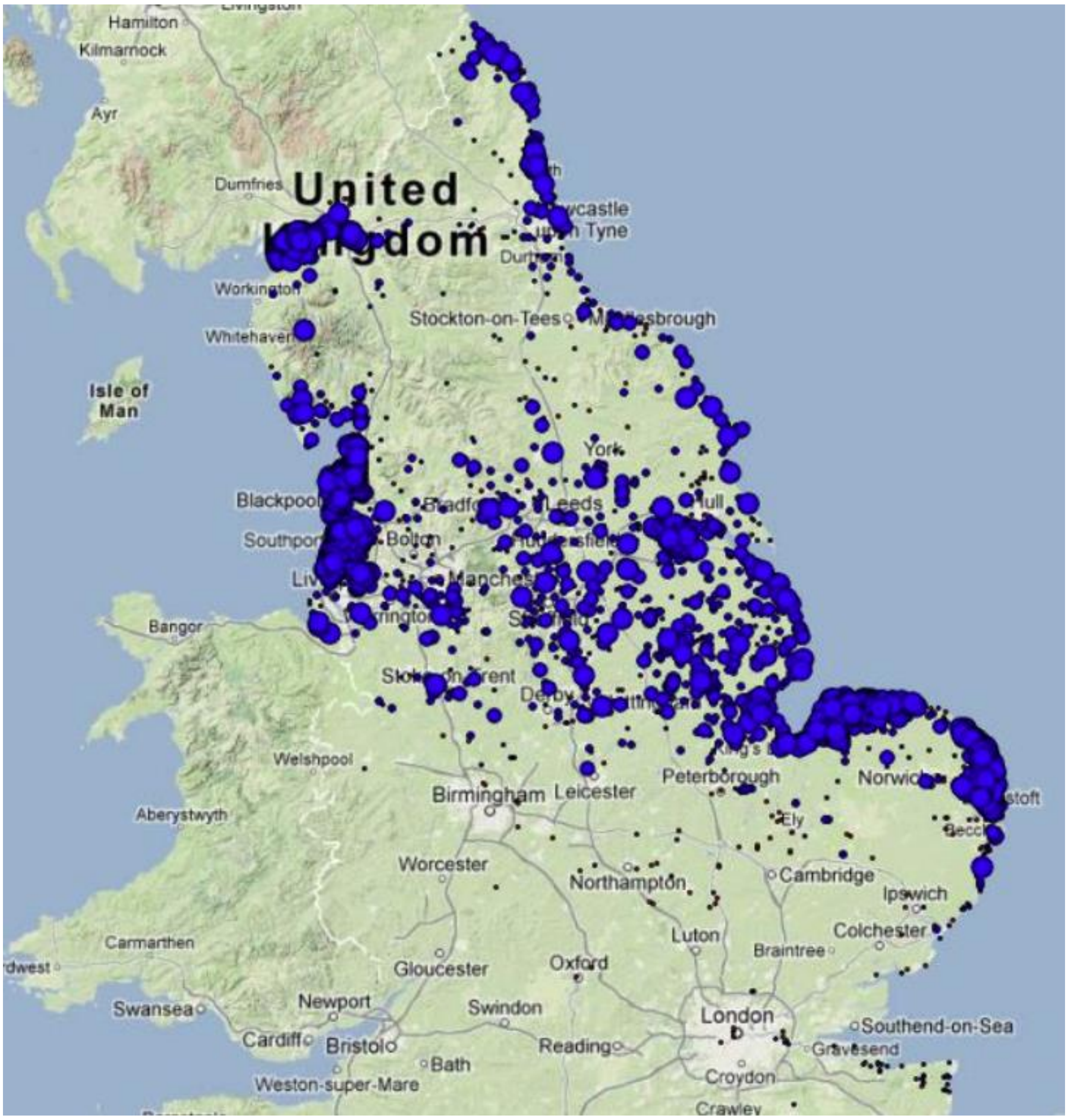

Figure 3: The distribution of feeding records of pink-footed geese in England. Based on all data (1986/87 to 2012/13) (Brides, 2013)

Figure 4: Distribution of Icelandic/Pink-footed Geese population during the non-breeding season (based on autumn IGC counts, five year mean peak counts 2007/08 to 2011/12) (Brides, 2013).

2.4 Methods

Following a research request for data, two sets of data were provided by the WWT. The first of these was a simple Excel spreadsheet detailing the annual count estimates by year, for pink-footed geese, between 1960 and 2018. This data has informed a simple chart line plot of the annual changes and abundances to be presented and compared to periodic reporting of population estimates within a series of key publications and literature.

Between 1990 and 2018, more detailed IGC data exists in electronic format and was also provided in Excel. The raw data includes site specific records including; unique site code; year; OS grid reference; site name; county; time, date and month of count; count total; and meteorological data. In total there were 7,316 individual site records included in the data set. This richer data set allowed for site specific data to be analysed further to examine spatial and temporal changes in population size and distribution recorded during this period. A total of 53 records, which were outside of the scope of the study, including occasional records across all years for the Faroe Islands, Norway, Iceland and Ireland were removed before the data set was analysed. Whilst each record has headings for the variables listed above, not all records were fully populated. In particular a number of records were missing OS National Grid references which were required to map the spatial distribution of the geese in Arc GIS. Locations for these sites were individually populated by using OS Digi Maps to locate the site from their description and noting the OS 8-digit grid reference. For all sites the latitude and longitude were determined by locating the site in OS Digi Maps using OS National Grid references and looking up the latitude and longitude. Each record was also given a country label and populated to allow data to be manipulated and summarised by country. For the majority of records, the count time and meteorological data were missing, and presumably not submitted by counters as part of their records. This data was then analysed using pivot tables in Excel to create summary outputs of data including; by site, by country, by year and by county. A series of results were further manipulated and filtered to create additional tables and outputs, e.g., the maximum October count, by site, by year. To facilitate the mapping of spatial changes, and to allow temporal changes to be more readily assessed, 29 years of population data were grouped into six-year bands; 1990-93, 1994-98, 1999-2003, 2004-08, 2009-2013, 2014-2018. Since the 29-year period is not divisible into groups of years of equal size, the year bands were grouped into periods of 5 years each, with the exception of the most historical year band, 1990-93, which covered a 4-year period. The mean of count data was calculated across all year bands and the results used for comparative mapping and analysis between year bands.

To assess the spatial distribution of pink-footed geese across the UK, the 5-year mean count for each site was calculated using the year bands previously described. The count data were sorted by site in descending order, and the number of sites recording abundances of >100 individuals, >500, >1,000 and >2,250 used to further sub-divide the site data into groups for ease of interpretation and analysis. The number of sites in each grouping was calculated and presented in a table. A maximum break point of 2,250 individuals was used for consistency with the same figure used by the WWT for analysis of sites based on 1% of the international population estimate, i.e., 2,250 individuals (Rose & Scott, 1997; Mitchell, 2004). The distribution of sites where the 5-year mean count was >100 individuals was mapped using ArcGIS 10.6, creating a time series set of six maps, in the year bands described across the 29 years of count data available.

To assess temporal changes in the abundance of pink-footed geese across the UK, the count data were used to map and plot the 5-year mean count estimate for all sites, using 10 groupings and proportional symbology, ranging from sites with counts between 0 – 10 individuals to sites with >50,000 individuals estimated. These estimates were again mapped on ArcGIS 10.6 in a time series set of six maps, in the year bands described across the 29 years of count data available. To help further illustrate the significance of key sites, and those that supported a mean of >2,250 individuals, between 1990-2018, an additional single map was created presenting proportional symbology in 5 groupings, thereby removing sites with counts below 2,250 individuals and focusing on clearer visual illustration of key sites, as defined. A final map, assessing the changes in distribution, between 1990-93 and 2014-2018, illustrated the change in mean annual abundance between the two time periods using a coloured gradient scale to show sites with negative (blue) changes in abundance, graduating to sites with positive (red) changes in abundance.

2.5 Results

2.5.1 WWT IGC Data (1990-2018) summary

Evaluation of site-specific IGC count data available for the years 1990-2018 showed positive count results for a total of 508 individual sites. In total, 9,466,246 observations were recorded across the 29 years when analysing the maximum site count data for October (Table 2). This total count does not represent a total population size or estimate, since individual birds will have been counted multiple times throughout any season or year. Counts for England, Scotland and Wales were recorded across 479 sites and represented 98.6% of the total records across all sites. The remaining sites in Ireland, Norway and the Faroe Islands totalled 69,281 individuals, across all years, and 0.73% of the total count data.

2.5.2 Spatial distribution across the UK

Analysis of the most recent 5-year mean IGC count estimates (2014-2018), shows population size of 482,828 individuals across a total of 129 sites. A total of 103 sites recorded an annual mean over100 individuals across this period, totalling 482,130 individuals (Figure 5). The remaining sites, 26 in total, recorded < 100 individuals with a total 5-year mean count of 698 individuals and were not mapped or illustrated due to their relatively low contribution to the overall total.

In Scotland, pink-footed geese range from the Isles of Shetland and Orkney down, primarily, the East Coast extending from the Moray Firth, through Aberdeenshire, to the Tay estuary and the Firth of Forth estuary, in the counties of Perthshire, Fife and the Lothians. A total of 57 sites in Scotland recorded >100 individuals on a 5-year mean count, between 2014-18 (Table 2). Perthshire has the greatest number of individual sites (10), followed by Aberdeenshire (7) and Fifeshire (8). To the West, by comparison, there were fewer sites with the most abundant counties being Dumfriesshire (5), Roxburghshire (3) and Kirkcudbrightshire (2).

In England, pink-footed geese were shown to be present in sites recording >100 individuals on a 5-year mean count between 2014-2018 in a total of 46 sites (Table 2). These sites were distributed across four main areas; the border counties of Northumberland (5), Berwickshire (4) and Cumbria (5), the west coast of Lancashire (9), and the North Norfolk coast (15). In addition, there were notable sites in Yorkshire (2) and North Lincolnshire (4) (Figure 5).

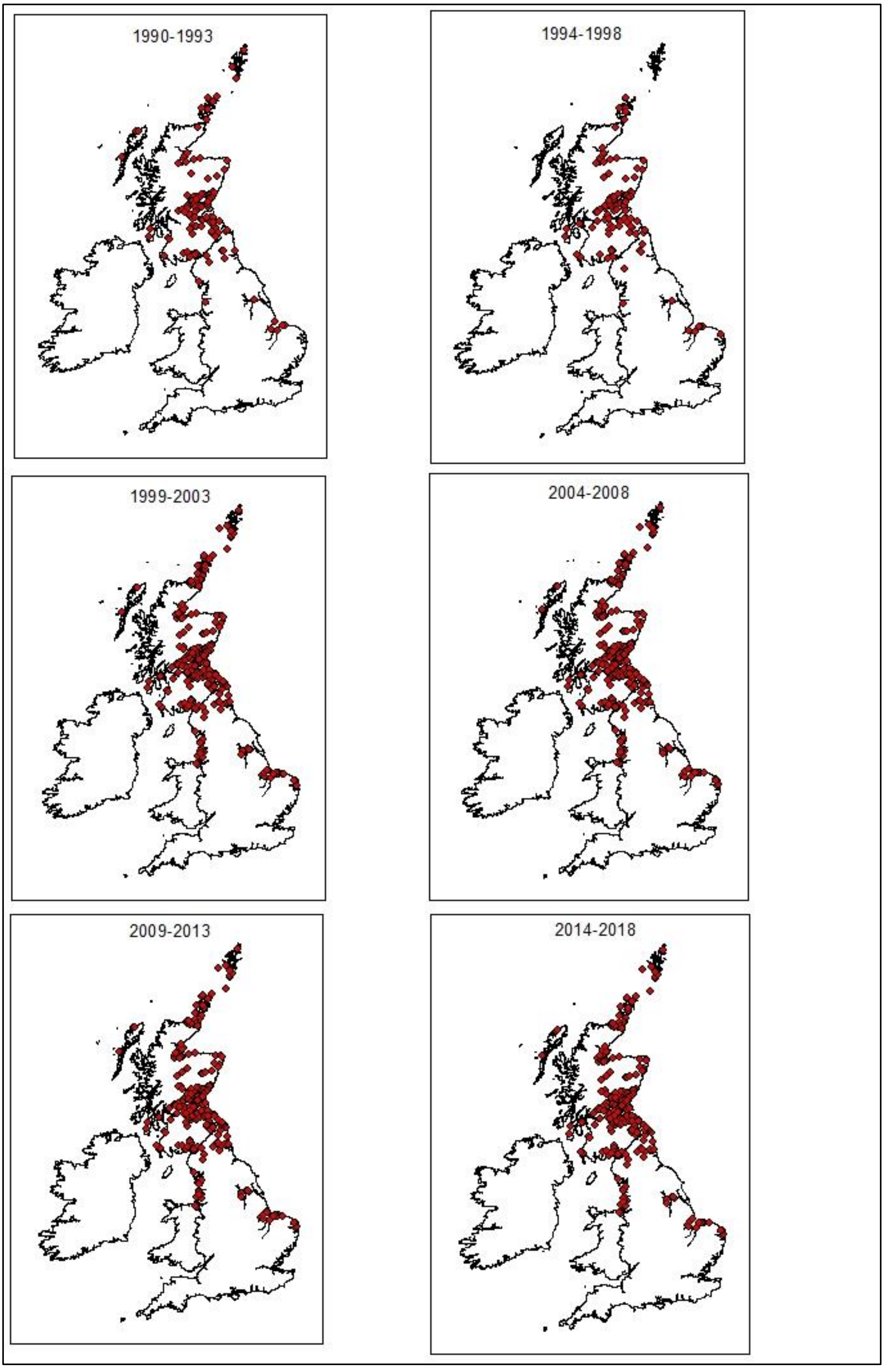

Figure 5: UK distribution of pink-footed geese, 1990-2018 (for sites where the 5 year mean annual count was >100 individuals)

Table 2: IGC 5-year mean count estimate by county and country, 2014-2018

County	Number of sites	5 Year mean count 2014-2018	Percentage of total
Angus	2	88,707	18.4%
Aberdeenshire	7	58,173	12.1%
Peeblesshire	1	37,688	7.8%
Ross & Cromarty	6	35,041	7.3%
Perthshire (West)	10	27,469	5.7%
Fifeshire	8	18,719	3.9%
Moray	1	13,080	2.7%
Lothian (East)	3	8,555	1.8%
Dumfriesshire	5	8,314	1.7%
Stirlingshire	2	6,710	1.4%
Midlothian	4	6,379	1.3%
Roxburghshire	3	5,918	1.2%
Kirkcudbrightshire	2	4,061	0.8%
Inverness-shire (East)	1	1,014	0.2%
Sutherland (East)	1	367	0.1%
Caithness	1	273	0.1%
Sub-total Scotland	**57**	**320,467**	**66.4%**
Lancashire	9	78,081	16.2%
Norfolk	15	36,867	7.6%
Berwickshire	4	18,278	3.8%
Lincolnshire (North)	4	7,347	1.5%
Yorkshire (South-east)	2	8,082	1.7%
Cumbria	5	5,317	1.1%
Northumberland (North)	5	6,260	1.3%
Cheshire	2	2,049	0.4%
Sub-total England	**46**	**162,281**	**33.6%**
Total	**103**	**482,747**	

2.5.3 Changes in abundance, between 1960 and 2018

Results from the annual WWT / IGC survey counts show a rising trend in the estimate of the UK over-wintering population size, with an increase from 48,000 individuals in 1960 to a maximum of 515,852 in 2017 (Figure 6).

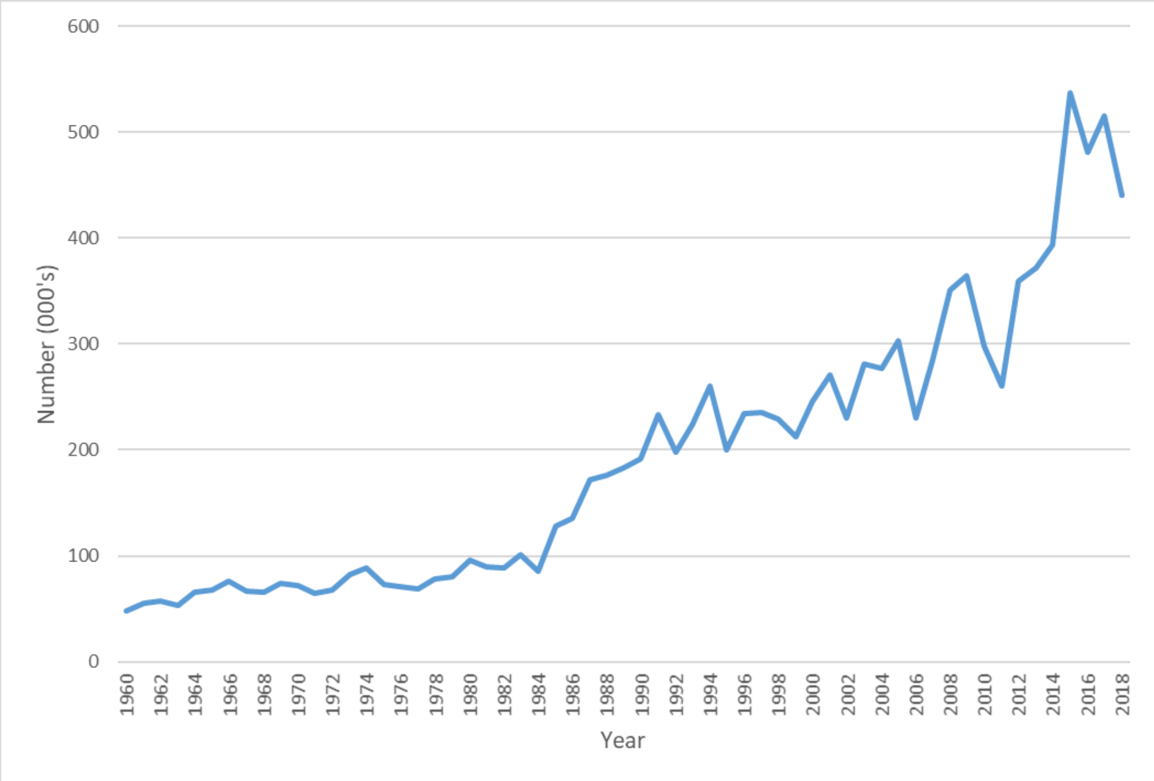

Figure 6: Estimated numbers of wintering pink-footed geese in the UK (1960-2018), based on annual recorded IGC / WWT survey data.

2.5.4 Changes in abundance, between 1960-2018

In 1990 a total of 188,084 individuals were recorded during the month of October based on the maximum count for any individual site where multiple counts were undertaken. By 2018 this figure had risen considerably to 451,226, representing a 140% growth in abundance since 1990 - albeit the highest annual count total recorded was 540,624 in 2017, which represented a 187.4% increase in abundance compared to 1990 (Table 3) and (Figure 7).

The compound annual growth rate, between 1990 and 2018 is 3.1%. This has been calculated as: (population estimate 2018 / population estimate 1990) ^ (1/number of survey years)-1, i.e., (451,226/188,084) ^ (1/29)-1.

A marked increase in the estimated population size is evident from the mid 1980's, where the compound annual growth rose to 10.1% between 1985 and 1994. This rise has been largely associated with the species adaptability to foraging on agricultural crops during a period of agricultural intensification, resulting in a step change in the population size (Gill et al., 1997).

However more recent compound annual growth rates suggest a steadier rate of growth with a growth of 3.5% recorded over the last 10 years, 2009 to 2018, slowing slightly to 2.6% over the last five years. Changes in meteorological conditions have been identified as accounting for >50% of individual between year fluctuations in population estimates of pink-footed geese (Fox et al., 1989a). However the exact causes of population change and their relative impacts have been determined undistinguishable as individual differences due to a number of factors affecting the population at any one time and highlighted as requiring further research to fully understand (Madsen & Cracknell, 1999).

Rises in abundance were evident in both England and Scotland. Counts for Scotland were greater than counts in England in all years with Scotland accounting for 72.4% of all records between 1990 and 2018. Recorded increases in abundance in Scotland show an increase in the population from 176,380 individuals to 340,906 over the 29-year period, a rise of 93%. A larger rise in abundance was recorded in England over the same period with the 1990 count of 11,704 surpassed by a count of 110,320 in 2018, a rise of 843%. In both England and Scotland even, higher maximum counts were recorded in the two years prior to 2018 and the last count data, with 156,472 individuals in England in 2016 and 384,152 in Scotland in 2017, representing increases of 1,335% and 118% respectively (Table 3).

In total, between 1990 and 2018 the highest counts were recorded in the month of October (Figure 8). Counts in the month of October were in total 18.3% higher than the next nearest count total by month, November, with count totals in December and January being much lower still, representing only 50.6% and 35% of the highest October count respectively. The decision by the WWT to move the focus of counts to the month of October in 1991, having previously undertaken the IGC census in the month of November, was justified since it is clear that October is the optimum month for counting peak numbers of geese.

Table 3 : Maximum October count of pink-footed geese, across all sites, totalled by country

Year	England	Scotland	Wales	Total	Annual Change	Annual Change %
1990	11,704	176,380	-	188,084		
1991	23,730	215,616	-	239,346	51,262	27.3%
1992	29,788	226,696	-	256,484	17,138	7.2%
1993	35,123	265,825	-	300,948	44,464	17.3%
1994	50,380	262,422	-	312,802	11,854	3.9%
1995	54,899	200,433	-	255,332	- 57,470	-18.4%
1996	68,793	207,941	-	276,734	21,402	8.4%
1997	52,478	217,359	-	269,837	-6,897	-2.5%
1998	53,434	227,780	-	281,214	11,377	4.2%
1999	52,645	184,533	-	237,178	-44,036	-15.7%
2000	76,169	219,564	-	295,733	58,555	24.7%
2001	74,145	218,903	-	293,048	-2,685	-0.9%
2002	103,095	202,721	-	305,816	12,768	4.4%
2003	116,359	207,811	-	324,170	18,354	6.0%
2004	137,413	264,546	-	401,959	77,789	24.0%
2005	165,311	225,993	-	391,304	-10,655	-2.7%
2006	114,518	166,924	-	281,442	-109,862	-28.1%
2007	87,561	184,666	15	272,242	-9,200	-3.3%
2008	101,390	258,696	-	360,086	87,844	32.3%
2009	128,652	192,546	-	321,198	-38,888	-10.8%
2010	102,454	206,241	-	308,695	-12,503	-3.9%
2011	32,234	171,270	-	203,504	-105,191	-34.1%
2012	104,783	177,063	-	281,846	78,342	38.5%
2013	129,037	264,067	-	393,104	111,258	39.5%
2014	125,169	271,984	-	397,153	4,049	1.0%
2015	149,947	356,998	-	506,945	109,792	27.6%
2016	167,933	350,259	-	518,192	11,247	2.2%
2017	156,472	384,152	-	540,624	22,432	4.3%
2018	110,320	340,906	-	451,226	- 89,398	-16.5%

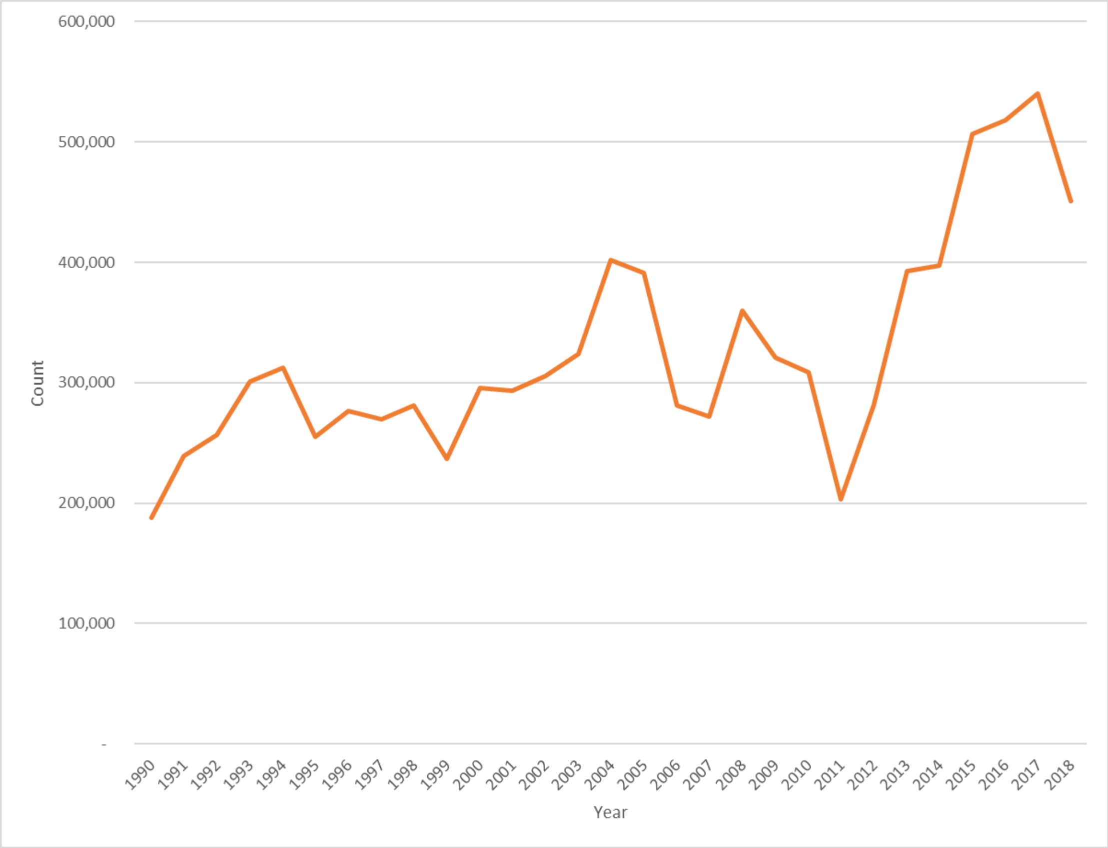

Figure 7: Estimated population size of pink-footed geese (IGC annual survey data, 1990-2018)

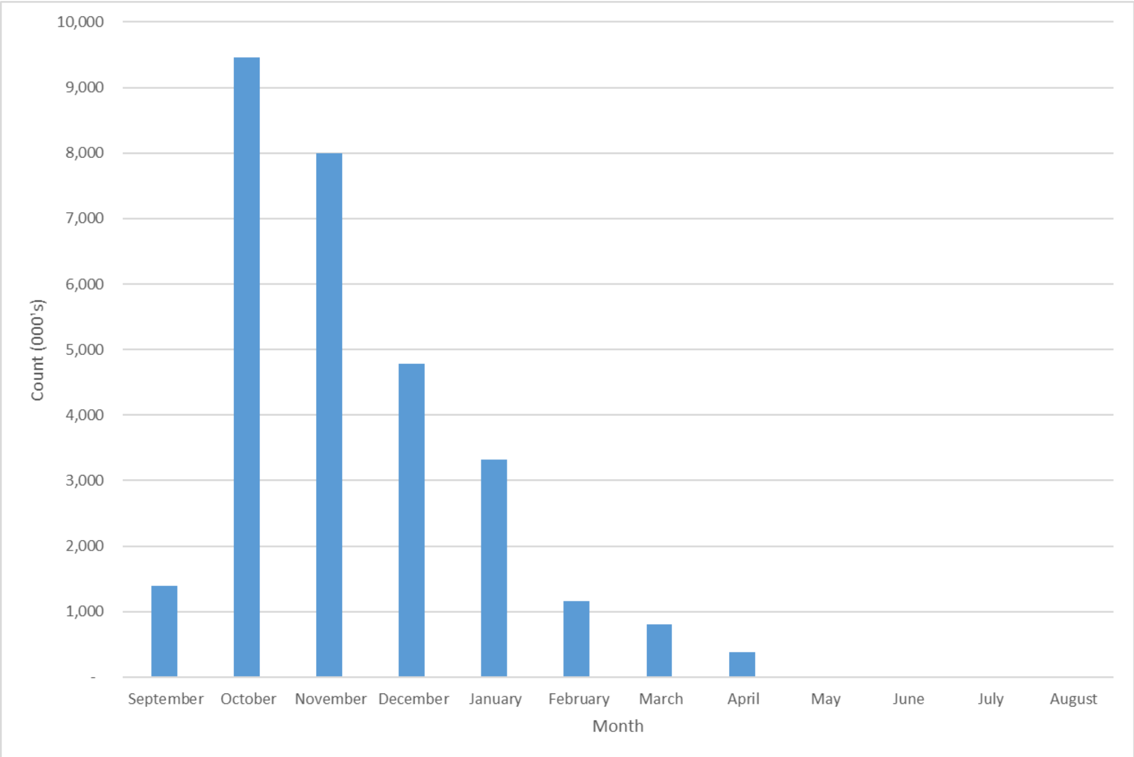

Figure 8: Total estimated population size of pink-footed geese, by month, for all years (IGC annual survey data,1990-2018)

2.5.5 Changes in the number of sites where pink-footed geese were recorded

Initial analysis of the distribution of count sites across the UK, based on the annual IGC surveys conducted between 1990 and 2018, for sites where there were positive counts in October, reveal a modest increase in the number of new sites where pink-footed geese were recorded (Table 4). In the earliest period, 1990-1993, positive counts were recorded in a total 118 sites during the month of October, of which the vast majority, 101, were in Scotland. By 2018 the number of sites with positive counts had risen to a total of 129, an increase of 11 sites over the total period. In England, the number of new sites recording the presence of pink-footed geese increased between 1990 and 2018, from an initial 17 sites to a total of 39, whilst the number of sites in Scotland showed a decline from the initial 101 recorded to 90. Only a single site recorded counts in Wales during the period 2004-2008, with no other October counts recorded in Wales in any other period.

Table 4: Number of sites where pink-footed geese were present and counted during the ICG October survey

Period	No. of sites in Scotland	No. of sites in England	No. of sites in Wales	Total No. of sites
1990-1993	101	17	0	118
1994-1998	86	18	0	104
1999-2003	93	29	0	122
2004-2008	88	33	1	122
2009-2013	87	35	0	122
2014-2018	90	39	0	129

A comparison of the spatial distribution of these sites between periods is shown (Figure 5), over which period increased in the number of sites in the North West of England, in particular Lancashire, and also North Norfolk are apparent.

Whilst the number of sites between 1990 and 2018 has increased only relatively modestly, up 11.8%, the population of overwintering pink-footed geese was seen to substantially rise by 96.0%. The recording of increased populations has therefore largely been recorded at existing sites, where annual abundance has steadily risen. Sites which support 1% or more of the international population estimate (i.e., 2,250 birds) are deemed to be of international importance (Rose & Scott, 1997). The number of sites supporting 2,250 birds or more rose from 20, in the period 1990-1993, to 44 in the period 2014-2018, representing a rise of 120% (Table 5). Similar rises were also recorded in the number of sites recording 1,000 birds or more, up 106%, and smaller sites recording 500 birds or more, up 111%, with also the smallest sites holding 100 or more individuals, up 84%.

Table 5: A comparison of the relative site abundance and number of sites recording abundance thresholds by 5-year period.

Mean Range (5 Year) *	Mean (October)	No. Sites	No. Sites >2250	No. Sites >1000	No. Sites >500	No. Sites >100
1990-1993*	246,216	118	20	32	37	56
1994-1998	279,184	104	19	28	35	57
1999-2003	291,189	116	26	37	43	65
2004-2008	341,407	122	32	44	51	66
2009-2013	301,669	122	29	47	64	88
2014-2018	482,828	132	44	66	78	103

Changes in temporal abundance and distribution are shown in (Figure 9), in which the 5-year maximum abundance by site is plotted for each period, 1990-2018. Examination of the data reveals growth in abundance in Norfolk, with a rise of compound annual growth rate of 6.6% between 1990 and 2018, and an estimated population of 59,500 individuals in 2018.

2.5.6 Temporal changes in spatial abundance

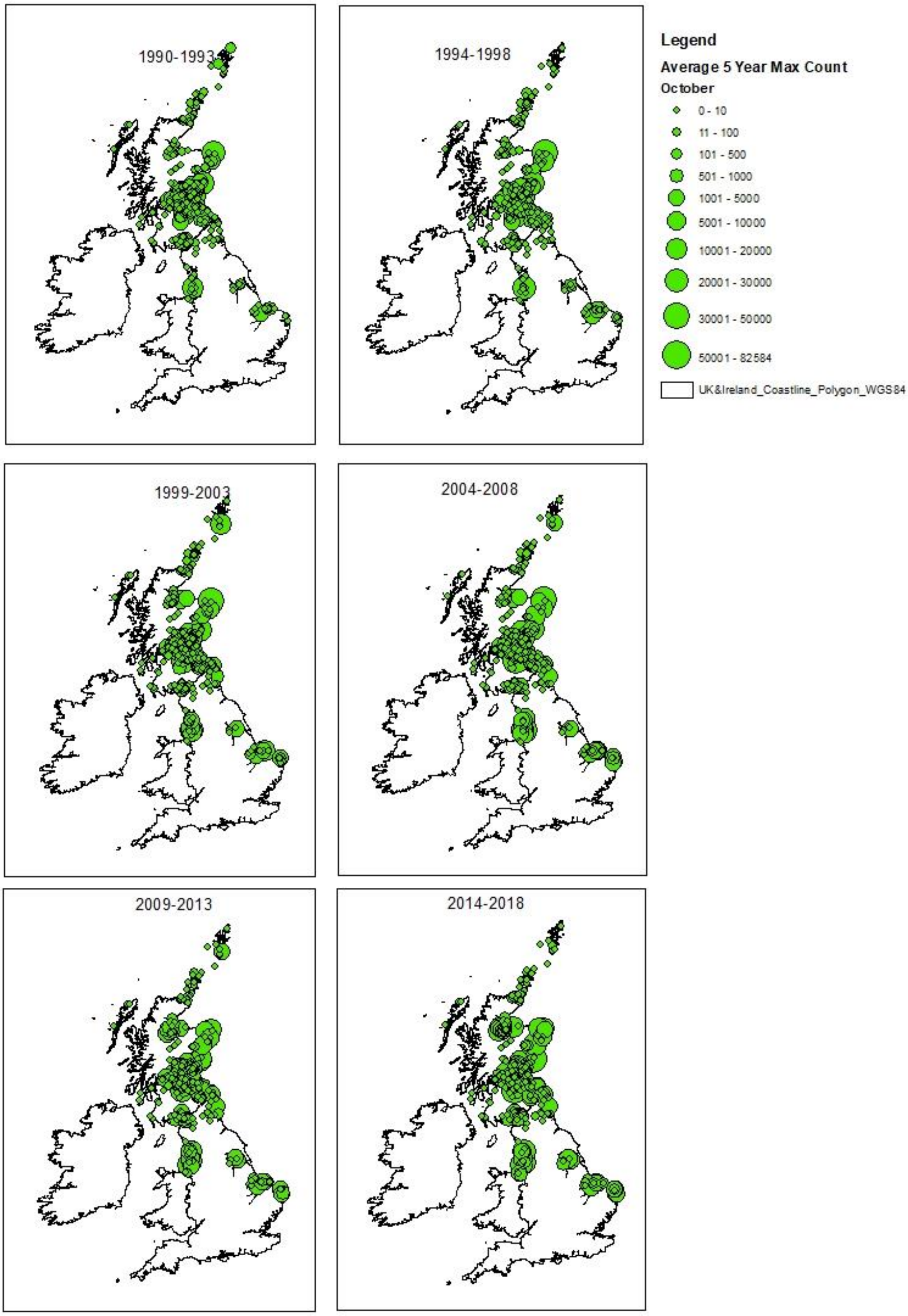

Figure 9: UK distribution and abundance of pink-footed geese, 1990-2018 (October 5 year mean count estimate for all sites)

2.5.7 Variations in abundance between sites

Whilst there are 479 sites in total recording the presence of pink-footed geese during any monthly count across the UK, the total number of sites recording the presence of the geese for the annual IGC October counts is 307. The lower number of sites recording positive counts in the month of October represents the relative concentration of the birds at key sites, early on in the winter months, following their arrival in the UK. Analysis of the maximum count by site for all months across all 479 sites shows a significant tail in distribution with the bottom 119 sites only accounting for 5% of the total population recorded. There is a clear pattern of relatively few sites having high counts and many with moderate or low counts. For the October IGC counts a relatively low number of sites, account for a relatively high percentage of the overall population estimate. The site with the highest abundance is Montrose Basin, where 5.3% of the total estimated population has been counted. The top 20 sites, ranked by abundance, account for 50% of the total estimated population and the top 70 sites, 80% of the estimated population. This distribution is clearly evident in (Figure 10).

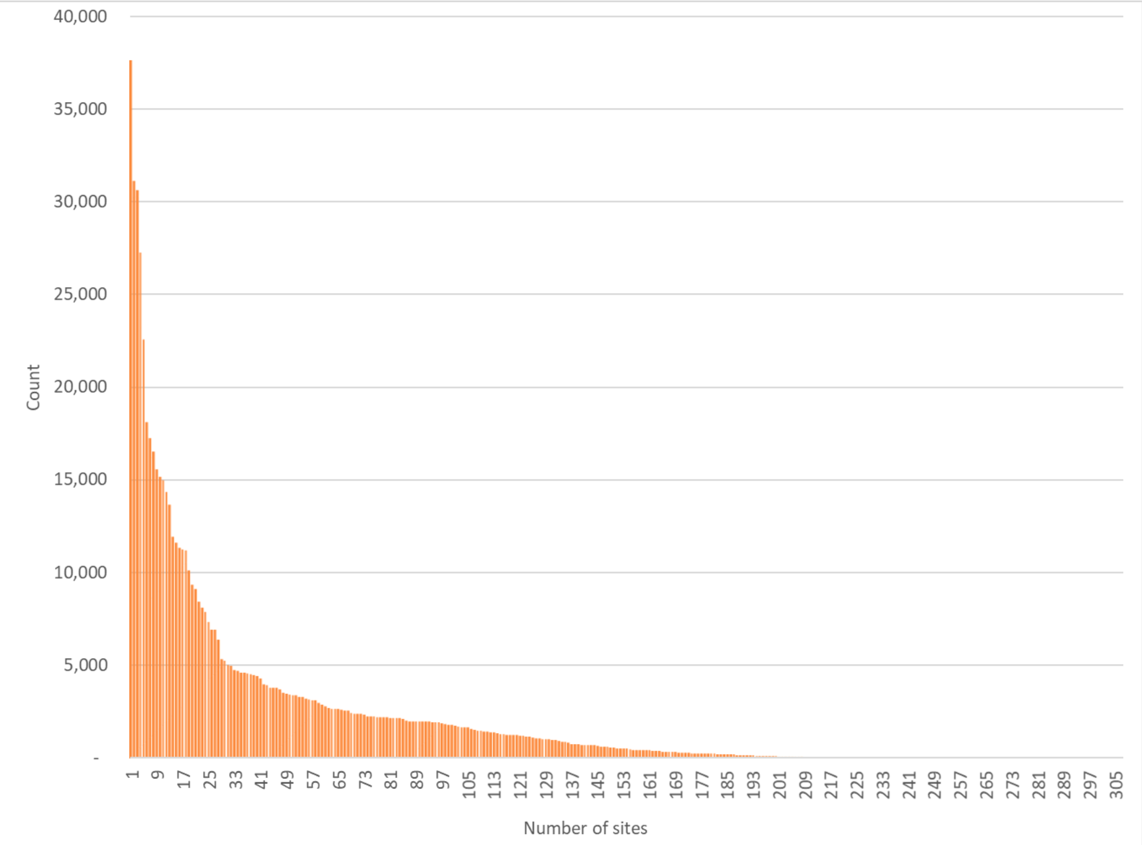

Figure 10: Distribution of abundance by individual survey site (using the maximum annual October count by survey site, for all years, 1990-2018) and ranked in descending value

Changes in annual abundance can be reviewed by site (Table 6). Whilst some sites, e.g., Montrose Basin, show a clear pattern of increasing abundance throughout the total period, 1990-2018, patterns for other sites are less obvious.   In particular, where there are multiple sites within close proximity, e.g., Holkham/Wells (site 563), Wells (site 483) and Holkham Bay (site 482), the fluctuations in individual site abundance are more marked and likely to be affected by between year variations in individual site use and local movements around the date of the IGC count, rather than illustrate long term trends for the individual site itself.

To better illustrate both the abundance but also changes in abundance for key sites, the annual average abundance is mapped for a total of 75 sites where the average population has been deemed significant and supporting 1% or more of the UK population size, i.e., above 2,250 individual birds.   The average site abundance, 1990-2018 is first shown in (Figure 11). This re-enforces the fact that a number of sites in Scotland, notably on the east coast in areas such as the Moray Firth, Loch of Strathbeg near Fraserburgh, Aberdeenshire and the Firth of Forth, are among those that continue to host the highest abundance of geese. In addition, the importance of Lancashire, North Norfolk and to an extent the Humber Estuary are visible within England. However, there are long term changes in the abundance at the key sites is further visible in (Figure 12). In particular increases in abundance are evident in nearly all sites across England. In Scotland, whilst still supporting some of the highest overall abundances of geese across all sites, individually some of the myriad of sites around the Firth of Forth are showing signs of longer-term decline in abundance, in place of seemingly greater presence at coastal sites, e.g., Montrose Basin, Loch of Skene in Aberdeenshire and Findhorn Bay in south east Scotland.

Table 6: Change in abundance by site, by period (1990-2018), for the Top 25 UK sites

Site	Country	Mean count 1990-1993	Mean count 1994-1998	Mean count 1999-2003	Mean count 2004-2008	Mean count 2009-2013	Mean count 2014-2018	Average annual count 1990-2018
Montrose Basin	Scotland	26,553	21,680	20,936	26,968	22,030	82,584	37,585
Loch of Strathbeg	Scotland	28,300	40,425	35,756	41,269	18,560	15,498	31,098
West Water Reservoir	Scotland	19,459	25,434	27,892	43,591	21,090	37,688	30,582
South Lancashire Mosses (Geese)	England	11,203	26,122	23,196	31,341	13,958	-	27,258
Dupplin Lochs	Scotland	35,725	36,470	15,780	3	466	-	22,583
Goswick Sands	England	-	-	-	-	3,628	-	18,140
Sandwick	Scotland	-	-	12,460	3,240	1,560	-	17,260
Pilling to Cockerham	England	-	-	4,372	2,440	13,876	22,343	16,551
WWT Martin Mere	England	-	-	10,300	8,909	10,590	23,090	15,556
Loch Leven	Scotland	19,938	15,329	14,087	13,822	13,275	9,530	15,184
Holkham/Wells	England	-	-	-	3,000	-	-	15,000
Lune Estuary	England	-	-	-	8,610	-	-	14,350
Carsebreck And Rhynd Lochs	Scotland	5,725	12,892	10,826	10,940	18,540	20,040	13,662
Gosford Ponds	Scotland	3,746	7,572	14,514	15,494	10,330	8,305	11,928
Marshside 1	England	-	-	-	-	-	4,658	11,645
Winter Loch, St Fergus Gas Terminal	Scotland	-	-	-	-	-	2,272	11,360
Alt Estuary	England	-	-	487	1,367	10,827	16,604	11,264
Meikle Loch Slains	Scotland	3,053	15,412	5,880	11,532	9,318	8,424	11,231
Middlemuir (New Pitsligo Moss)	Scotland	-	-	-	1,600	9,500	11,164	10,120
Hule Moss	England	6,316	13,839	9,568	5,840	4,894	8,490	9,353
Wells	England	-	-	11,720	7,263	2,763	3,777	9,115
Beauly Firth Consolidated	Scotland	120	25	22	16	6,889	18,300	8,449
Findhorn Bay	Scotland	11	41	7,990	7,828	3,660	13,080	8,152
Loch of Skene	Scotland	1	255	2,416	10,591	7,225	20,535	7,899
Ribble Estuary	England	-	-	5,240	5,115	6,100	5,631	7,362

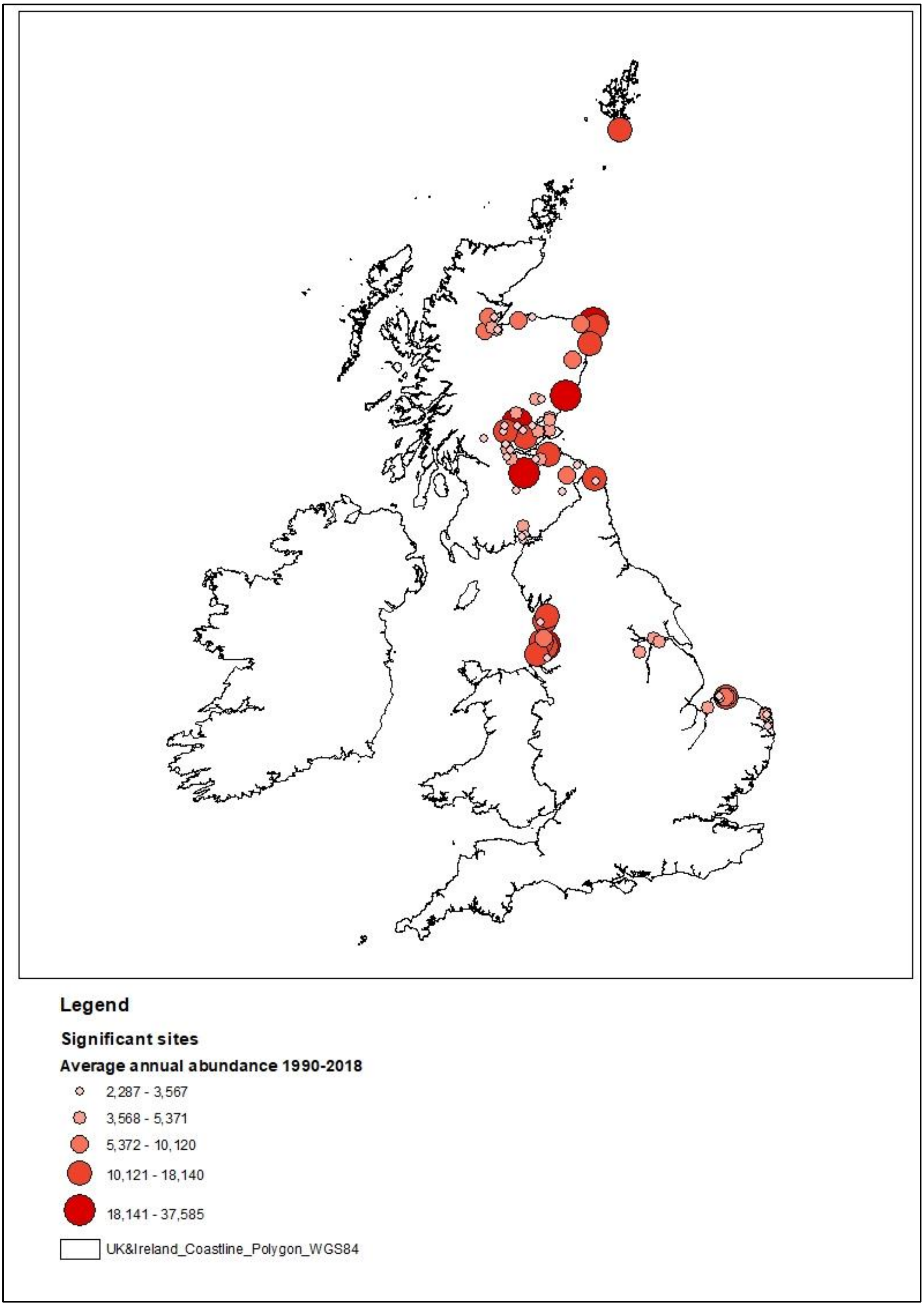

Figure 11: Average annual abundance recorded, 1990-2018 for sites where >2,250 individual birds have been recorded

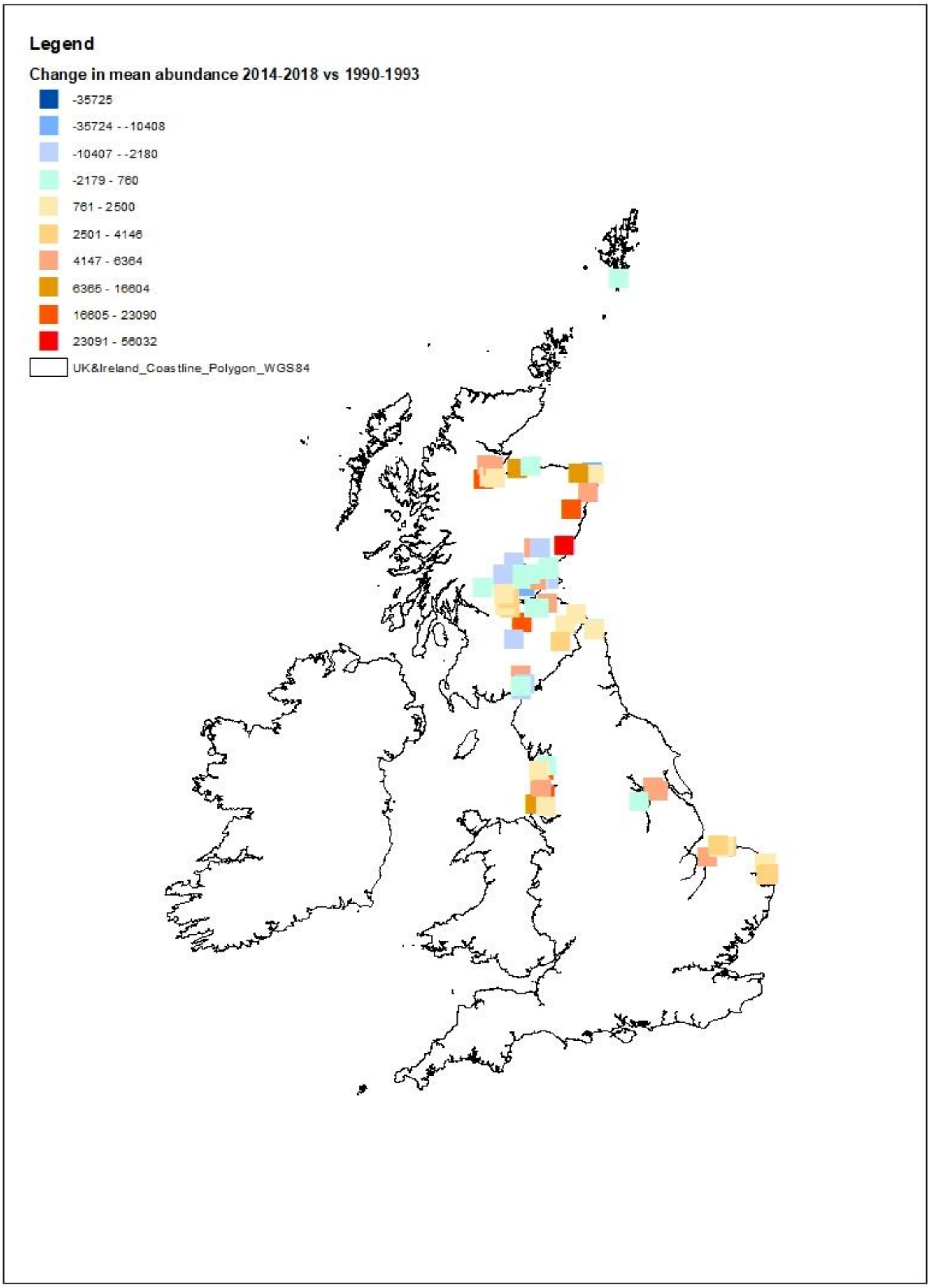

Figure 12: A comparison in temporal changes in mean annual abundance, by site, between 2014-2018 and 1990-1993.

2.6 Discussion

2.6.1 Population size

There is strong evidence of a sustained and significant population growth of pink-footed geese both since records began in the early 1960's, but continued and calculated to be 3.1% compounded annually between 1990-2018, based on the annual IGC counts which are considered to provide an accurate assessment of the species abundance (Frederiksen et al., 2004). A number of other factors give further confidence in the population estimates, including; the conspicuous size and nature of pink-footed geese aiding there detection and visual counting by comparison with smaller bird species, e.g., waders on an estuary, or than of species with large ranges and distribution e.g., many passerines, giving rise to a greater probability of detection (Ralph et al., 1995). In addition, whilst foraging in large agricultural fields systematic counting is feasible, especially for trained and familiar observers (Bibby et al., 2000). Equally too their large size and relatively slow flight provide good opportunities to count multiple skeins in the sky, coming to and leaving roosts. A high degree of roost site fidelity has also been proven, which coupled with the knowledge that roosts are predominantly on coastal locations, greatly increases the likelihood of observing the majority of pink-footed geese present (Giroux, 1991). Observational count is unlikely to can be 100% accurate (Dytham, 2011). However, the count methodologies employed when combined with their consistency in application can be considered to provide accurate trends in population size and are also those most commonly used and advocated for monitoring bird populations (Sauer & Droege, 1990; Gilbert et al., 1998; Bibby et al., 2000; Sutherland et al., 2004). A key assumption in the monitoring of the geese at key sites, is that annually the number of sites and the presence of the geese are detected and that detection probability is high. A combination of the use of regional co-ordinators, conspicuous nature and tendency of the geese, which are both themselves relatively large and audible, coupled with increased use and detection of birds from BTO Bird Track data is likely to greatly increase the annual detection probability, especially by comparison with more evasive species (Pollock et al., 2004). However, even greater confidence and accuracy in the species population size could be achieved through the use of randomised spatial sampling techniques and has been recognised by the WWT as a potential for further developments likely to increase the detection probability of geese at new sites (Mitchell, 2004; Brides, 2013).

2.6.2 Population distribution

Despite a significant growth in population size, pink-footed geese have not significantly increased their wintering range in the UK or adopted significant numbers of new sites. This is evident from the presence of pink-footed geese in relatively large numbers (>500 individuals) at a relatively limited number of key sites between 1990-2018 (Mitchell, 2004), where despite the recorded population nearly doubling, +96.0%, the number of new sites at which they were recorded grew by only 11.8%.

It would have been reasonable to predict that during an expansion in population size that pink-footed geese would expand their geographic range, potentially southwards, but there is no significant evidence to support this. Instead, the North Norfolk overwintering populations of pink-footed geese have remained the most southerly populations of geese throughout the study period, where the species has been recorded in abundances of >500 individuals, with only much lower numbers recorded further south in Kent (Brides, 2013). However, whilst Scotland remains the most favoured destination for the geese, supporting 90 of the 129 sites surveyed in 2018, there has been a shift in bias and use of sites within England. Most notably a growth in numbers of individual birds and in sites has been recorded in Lancashire and North Norfolk, with a more than doubling of significant sites between 1990-2018 from 17 to 39. The analysis of the distribution of sites across Britain reveals in part a change in distribution from Scotland to England but reveals no overall trend or change in the most southerly latitude where the species is recorded. It would be reasonable to conclude therefore that pink-footed geese are not currently constrained by the foraging resources available to them within their existing UK wintering range, despite continued increases in population size and densities recorded at existing sites.

2.6.3 Limitations of the IGC October data

It is important to recognise that there are limitations in assessing the spatial distribution of pink-footed geese based on the IGC data due to the fixed annual timing and one-off nature of the annual counts, conducted in October. The October counts have proved to be the most reliable for counting the largest counts, since the counts are conducted at a time when the geese are both all believed to have arrived at UK wintering grounds, yet have not fully dispersed across the UK. However, the October count is relatively early during the species overwintering stay, and as such it is likely that the data has a northerly bias to it and is not fully representative of the total UK wintering distribution throughout the entire winter. This is likely to be as a result of recording the geese only relatively recently after their arrival in the UK with initial arrivals occurring during September. Counts if conducted in January are likely to present a different pattern of distribution versus those recorded in October, with greater numbers of geese likely to be recorded further south and exploiting different food resources, e.g., sugar beet being harvested in Norfolk during December and January. In part these movements and distribution have been reported since the 1950's, including a conspicuous migration to Norfolk in mid-winter from November onwards, and then subsequently a northerly migration of the same birds from the end of January (Fox et al., 1994). However, these movements are not captured by the IGC data, due to the focus of effort on the annual October count and the IGC data should be considered as only providing an initial snapshot of the distribution of the geese in the early part of the winter. To further evaluate changes in the UK wintering distribution of pink-footed geese would require count data for all months that would also reveal any changes occurring between months and possibly attributed or correlated with other variables, e.g., changing availability of agricultural crops, including the timing and harvest of root crops, the emergence of spring cereals, natural grassland and potentially also climatic variables.

Whilst it is therefore not possible to examine the abundance of pink-footed geese at all sites, over the duration of each winter, at some sites, primarily at sites within NNR's, SPA's or Wildlife Trusts, counts are undertaken throughout the winter and IGC data is present for each month at each site. The review of count data for Norfolk in 2018 is a good example of how monthly count estimates vary, with peak estimates totalling 44,423 individuals in October, 75,558 in November and 93,368 in December i.e., showing a gradual rise month on month through to December. The growth in numbers wintering in north-Norfolk has been well documented, and largely attributed to the undisturbed feeding on widely available residual sugar beet tops which have no commercial value (Gill et al., 1997). However, since not all sites, throughout the UK, are counted each month, it is not possible to chart or plot changes in distribution over the wintering period.

2.6.4 Key factors influencing population growth

The rise in pink-footed geese numbers have in part been the result of their adaptability and ability to forage energy rich agricultural resources and move away from a reliance on traditional natural grasslands (Fox et al., 2005). Whilst these positive influences enable the species to benefit during the months they spend overwintering in the UK, they too are benefiting from changes on their breeding grounds in Iceland, where they spend an almost equal part of the year (Kery et al., 2006; Madsen et al., 2007; Jensen et al., 2008).

An expansion of the breeding range and adoption of new breeding areas has also affected annual productivity. In the immediate year or two following expansion into a new breeding area, productivity is initially lower, with younger adults learning to exploit the area. However, following an initial lull in productivity and adoption of new areas productivity has been recorded as soon rising again (Fox et al., 1989a). Therefore pink-footed geese are at present both likely to expand their breeding range and capacity, and long term also maintain productivity.

The annual survival of pink-footed geese has also been correlated to winter climate change, with warmer winters and earlier springs enhancing survival (Kery et al., 2006). Further climatic changes are affecting the snow cover, timing and availability of both suitable ground breeding locations and the availability of food, with warmer conditions again increasing breeding attempts and productivity (Madsen et al., 2007). Favourable changes in climatic conditions during the summer months are also significant in determining annual mortality, since the summer months represent the lowest survival probability of any period (Madsen et al., 2002). Predictions for the distribution of pink-footed geese nesting under a warmer climate scenario, in Svalbard, predict further growth in population sizes, due to predicted increases in the size of suitable nesting areas resulting from global warming (Jensen et al., 2008). Declines in mortality might also be influenced in part by changes in the hunting practices or 'harvesting of the geese' with fewer being shot and hunting activity no longer suppressing populations to the same extent. In certain areas in Iceland pink-footed geese were locally eradicated through hunting, however such extreme local harvesting or hunting has ceased (Fox et al., 1989a; Fox et al., 1989b). The on-going hunting of grey geese species still continues and has the potential to impact on population size, dependent upon the level of successful hunting undertaken (Frederiksen et al., 2004).

Pink-footed geese are not the only species to benefit from more favourable climatic conditions on the breeding grounds and also seeing a rise in population size. Barnacle geese too have risen in estimated population size, bringing into question whether there is now interspecies competition for resources, particularly on the breeding grounds (Madsen & Mortensen, 1987). Whilst breeding predominantly in Iceland, and in limited numbers in East Greenland, East Greenland is used as a moulting area for non-breeding pink-footed geese and also Barnacle Geese, where both species arrive in late June, moulting into July (Mitchell, 2004). These non-breeding birds are thought to migrate to East Greenland to avoid, in part, the grazing pressure and densities of breeding adults in Iceland, which are yet unable to fly and take advantage of the emerging vegetation growth in East Greenland (Fox et al., 1989a). The two species exhibit little overlap, seldomly mixing or occupying the same habitats with different niche preferences for foraging resources and even geographic landscape features. Pink-footed geese favour and use wide rivers and lakes whilst the Barnacle Geese favour and use smaller rivers and lakes in the proximity of low hills (Fox & Bergersen, 2005). The increased abundance of both species has though resulted in changes in foraging behaviour and profitability. Both species will, when separate, feed on sedges and grasses, but when in close proximity, the smaller Barnacle Geese, increasingly feed on sub-optimal mosses, and as a species suffer from the presence of pink-footed geese (Madsen & Mortensen, 1987). Therefore, in marginal habitats and where increasingly forced closer together and competing for resources, the slightly larger pink-footed goose, will out compete Barnacle Geese, a factor impacting the potential population size of Barnacle Geese but not necessarily pink-footed geese.

Outside of the breeding season, evidence suggests that pink-footed geese and Barnacle Geese do not directly compete for food resources, due to different dietary preferences (Fox & Bergersen, 2005). Pink-footed geese diet during pre-breeding, based on studies in Svalbard, showed that the geese fed mostly (93%) by excavating below-ground parts of plants, whereas the Barnacle Geese fed almost exclusively (97%) on above-ground plant material, such as moss. Hence there is little feeding overlap in diet and feeding ecology between the two species, during pre-breeding.

Iceland has undergone changes in land-use, with the conversion of landscapes into man-made surfaces, at a rate faster than elsewhere in Europe. Nearly 97% of wetlands present in Southern Iceland have been partially or entirely drained (Jóhannesdóttir et al., 2014). Iceland is of global importance for migratory wader populations because of expanses of suitable open habitats, a sparse human population and fairly low-intensity agriculture. The impacts of land use change are greater for wader species versus geese species, since the habitat loss that has occurred has been largely in coastal area, where waders have more commonly bred (Jóhannesdóttir et al., 2014). The large central areas, where pink-footed geese breed, have not been affected by the land use changes and are therefore not a limiting factor on productivity and population size (Madsen & Mortensen, 1987; Jensen et al., 2008).

2.6.5 Predicting future population size

In 1969, the UK wintering population of pink-footed geese was estimated at 64,920, and the future population discussed as likely to either stabilise around 70,000 or potentially decline in the future (Boyd & Ogilvie, 1969). Not long after making the initial predictions, Ogilvie (1969), derived further predictions, based on more extended observations between 1969-1975 of the estimated populations to make predictions for the following five years, 1976-1980 (Ogilvie & Boyd, 1976). A prediction of 91,800 for 1980, proved to be much closer to the annual IGC survey data and estimated population of 95,410 for that year. It was acknowledged that simple straight-line regression was simplistic in approach, especially when projecting forecasts based on only a few years data. Equally too, a deterministic approach, assumed factors affecting population size would continue to act and interact as they had done historically (Ogilvie & Boyd, 1976).

Further studies modelled future population levels of pink-footed geese, using estimates of the species productivity and annual mortality rates (Fox Et al.., 1989a). Whilst these were acknowledged as also being relatively simplistic in approach, with the results regarded with extreme caution, increases in annual increments in abundance of 4% were predicted, culminating in a predicted population of 235,000 by the year 1995. These predictions were closer to the estimated population size recorded as part of the IGC annual surveys. Whilst a population of 235,000 was not estimated in 1995 (the IGC count for 1995 was 200,343) the predicted figure was very close to the count estimate a year later in 1996, of 235,559 individuals (Figure 7). Rises in the population were attributed to increases in productivity, measured as the percentage of young birds within wintering flocks, and also increasingly associated with breeding range expansion within Iceland. In Iceland it was noted that geese were not only returning to areas where they had previously been heavily hunted, but also had begun successfully breeding in new areas, reducing density dependant influences on productivity (Fox et al., 1989a).

Due to rising populations of pink-footed geese, including also the Svalbard population, which winter in North Europe, focus has been on the modelling and likely rise in conflict of the population with agriculture. The wintering distributions of Northern Europe, were modelled through to the year 2050, using generalized linear models (Wisz et al., 2008). The study, recognised the importance of the geese's preference for feeding at suitable sites, relatively near to the coast (within 20km), on land with suitable elevation and a degree of habitat closure. Across the countries of Northern Europe, Belgium, Holland, Germany and Denmark where the Svalbard population over winter, models of land use change, resulting from either global economic influences or regional and environmental policies were predicted. They concluded that an ever-increasing population would be forced into more concentrated areas of suitable agriculture landscape, which would also give rise to conflict with commercial interests. Again, the focus of discussion, has more recently centred on 'The unexpected international implications of successful goose conservation', (Fox & Madsen, 2017). Because of the significant agriculturally rich landscape available within the wintering range of pink-footed geese and historical existence below carrying capacity. It was also concluded that there were few indications of factors that would limit the population size, or immediate growth of the populations in the near future, albeit no absolute predictions of future numbers were made.

2.6.6 The need for wider understanding of pink-footed geese movement

Populations of pink-footed geese have been shown to be rising and are at record levels, yet the species is still classified as one of conservation concern within the UK BOCC, due to its confined global range. Growth in the population is giving rise only to nominal increases in wintering range, but significant rise in concentrations at key sites and areas. These key sites are within relative proximity to coastal roost sites, with daily foraging occurring on agricultural land (Wisz, 2008). Whilst seemingly widely available, the suitability of individual fields and crops and their selection by the geese for foraging is dependent upon their size, aspect, likelihood of disturbance and also to the harvesting timing and regime of each crop and even each field (Gill, 1996). Given the species now dependence on agricultural crops as a food resource, the population size of the geese is now likely intertwined with the availability of crops. This availability may change in the future due to agricultural policy, agricultural practices or even changes in land use.

Accurately predicting the future population size, distribution and trends of pink-footed geese is difficult due to the number of factors affecting the population at any one time and not being distinguishable as individual differences and highlighted by others as requiring further research (Madsen & Cracknell, 1999).

Chapter 3 : Examining the winter foraging ranges of pink-footed geese in North Norfolk

3.1 Introduction

3.1.1 Current knowledge of pink-footed geese winter foraging ranges

Historic knowledge of pink-footed geese movements has been limited to traditional color marking techniques, and the collation of in-field observed recoveries (Fox Et al.., 1994; Mitchell, 2004). During the 1990's advancements in technology enabled individual birds to be tracked using radio-tracking (Giroux, 1991; Giroux & Patterson, 1995). The possibility to remotely track and record the continuous movements of both individual and larger samples of birds was not possible until the advent of recent GPS technology, which have facilitated dramatic advancement in the ability to understand animal movements, ecology and behaviour (Bridge Et al.., 2011; López-López, 2016). The analysis of Global Positioning System (GPS) telemetry data has been identified as being able to provide insight into population distributions, resources utilised and general patterns of space use (Horne, 2007).

In order to assess whether the potential loss of agricultural land, and the food resources it offers for overwintering pink-footed geese in the UK, may impact the species population size, it is important to understand, and as accurately as possible, define the species use of the landscape. This includes the need to determine the species daily foraging ranges, to evaluate the area typically used for foraging, but also an evaluation of the daily distances travelled, in order to help evaluate also the daily energetic expenditure and therefore energetic food resource requirements.

Historic records of the movements of pink-footed geese were derived using color marking darvic leg-rings or neck collars, incorporating a unique 3-letter engraved code. Significant samples of 14,000 pulli were ringed in Iceland, using standard BTO metal leg rings, and a further 14,000 adult pink-footed geese caught in Britain, during the 1950's, and later a further 2,300 adults caught, from 1987, at sites including Martin Mere, Loch Leven (Fox Et al.., 1989b; Mitchell, 2004). Records of ringing recoveries from these efforts provided knowledge of movements within Britain that quantified the timing of passage through Scotland and Iceland and led to better understanding of population dynamics (Fox Et al.., 1994). However, color marking as a technique has limitations in being able to detect patterns of fine scale daily movements, due to the reliance on being able to locate, observe and re-locate each bird (Bairlein, 2003). These limitations are illustrated by the low number of re-sightings gained during this study of geese fitted with standard neck collars. From the initial sample of 48 pink-footed geese caught in January 2018 fitted with standard neck collars, and not GPS tags, 26 individuals were re-sighted with records reported to the WWT and shared with the author and ringing team. However, these re-sightings predominantly only included between 1 and 3 re-sighting records for each bird, across several months, and from which only 9 individuals were re-sighted outside of Norfolk, with typically only one re-sighting each. This paucity of re-sighting data does not allow detailed analysis of daily movements and range to be undertaken.

Even with highly committed teams of field workers, there are limitations to the results possible from visual observers. A long-term observational study, conducted in Perthshire, utilised historical WWT count data and in-field observations, between 1966-1970 (Newton et al., 1973). In the Perthshire study effort was undertaken to map the presence of a total population, estimated at 58,000 individuals. The results found that only 1% of the study population foraged beyond 20km, with foraging being more commonly undertaken within 5km of the roost, 66% of the time, between 5-10km, 19% of the time and between 10-20km 14% of the time. The study offered the first real insight into pink-footed geese daily movements, and is a useful benchmark as to the foraging ranges of the species. However, the study could not guarantee identifying, tracking and recording individual birds' movements continuously throughout their daily range, with individual birds often going undetected for significant periods of time and not being relocated amongst large flocks using visual observations alone. Equally observational studies cannot assess the flight distances undertaken throughout the day of individual birds, since it is impractical to continually locate and follow individuals through visual observations alone. Greater knowledge of these movements is therefore sought.

Advancements in technology enabled a more recent study in north-east Scotland, which used radio telemetry, to examine the roost fidelity of a sample of 10 pink-footed geese, over two winters (Giroux, 1991). The study showed that the geese used on average 3.4 different roost sites during any one winter. Practically though, the telemetry study did not reveal more about the individual birds' wider movements. The radio transmitters were able to relocate individual birds, but not able to record the intervening movements, with fieldwork located and focussed on the monitoring of roost sites. Despite the immense field effort employed, including 500 nights of visits, not all roosts were visited each night, or all nights during the winter surveyed, with a 67% coverage of combined nights and sites. Therefore, whilst we now know more about the species likely fidelity to roosts, knowledge of their ranges and daily foraging distances was still absent.

A second study, of radio transmitted geese in north-east Scotland, did reveal further insights into the geese's foraging ranges and preferences, with a recorded foraging range of between 21-69km^2 reported (Giroux & Patterson, 1995). The study also reported patterns of foraging predominantly within 10km of the roost site, and more commonly within 5km, with the geese exhibiting a high fidelity towards feeding, in large flock sizes on cereal stubble and potatoes. This study, for the first time provided quantified evidence of both foraging ranges and daily distances travelled, of pink-footed geese in the UK. Radio telemetry, by comparison with more recent GPS technology is a labour-intensive way of tracking individual birds, and has the disadvantage that in practice often only a single bird is located, tracked and followed at any one time. This was the case in the north east Scotland study (Giroux & Patterson, 1995), with a single individual being randomly selected on each day of observation. Therefore, without multiple observers, each equipped with radio tracking devices, and working 24 hours a day, 7 days a week, tracking results, and thus a practical study sample size are limited by the resources available. GPS technology overcomes these limitations, which with no need for in-field observations or tracking, and with no practical limits, greater sample sizes, simultaneously recording and providing data, can be achieved. However, there are still trade-offs and limitations associated with GPS technology, whose units vary in size, fitting technique, cost and capability (Fiedler, 2009; Mitchell Et al.., 2019).

The previously detailed studies have provided insight and evidence into the movements, foraging ranges and daily distances travelled by pink-footed geese in the UK (Newton Et al.., 1973; Giroux, 1991; Giroux & Patterson, 1995). However, to examine and quantify these movements in greater detail, a continual tracking of both individual birds and a larger sample size is desirable to improve the confidence levels and ability to apply findings in statutory conservation models, used for the purpose of undertaking impact assessments on the population of the species.

3.1.2 Aims and objectives

This chapter aims to examine and describe both the annual migratory movements and timings of individuals tagged and recorded moving between wintering and breeding grounds and also the more detailed daily movements and behaviour of the same individuals examined during their wintering stay in North Norfolk. More specifically the study focusses on the North Norfolk overwintering population of the species and utilise GPS / GSM tracking data collated from two samples of pink-footed geese, caught in the study area during January and December 2018, with the key objectives of:

i) Quantify the wintering range used by each individual, within North Norfolk, undertaking a comparative analysis of any differences between the two cohort samples and two winters of the study.

ii) Estimating the daily distances travelled by each individual, within North Norfolk, to derive minimum, mean and maximum distances recorded, and undertake a comparative analysis of any differences between the two cohort samples and two winters of the study.

In addition, analysis of the tagging data provides an overview of the annual movements of the birds tagged, across the UK, but also to and from their breeding grounds in Iceland and East Greenland, with the objective of:

iii) Providing greater context and understanding of the annual movements, timing and passage of the study sample throughout the recorded period for each bird.

Furthermore, Arc GIS analysis of the North Norfolk crop coverage quantifies the availability of sugar beet crop in the county, with the objective of:

iv) Providing context and initial analysis of the carrying capacity this crop provides for populations of pink-footed geese, in conjunction with knowledge of the daily energetic requirements of the geese.

3.2 Methodology

3.2.1 Selecting the study site

North Norfolk was selected as a study area for the targeted capture, tagging and monitoring of pink-footed geese. Pink-footed geese are a qualifying SPA feature species of the area and North Norfolk Coast, with 32,900 individuals recorded at a single site, Lodge Marsh near Wells in 2010/11 (England, 2007), and 68,560 individuals estimated across the county in 1996 (Gill Et al.., 1997).

Consideration was given to alternative or additional catch sites in East Yorkshire, at sites around the Humber and the Yorkshire Wolds, where geese are recorded in large numbers (Short, 2017). However following reconnaissance of potential catch sites, the area was deemed too challenging to attempt cannon net catches with any reasonable degree of confidence in success.

The observation in North Norfolk of over-wintering pink-footed geese during 2016 / 2017 fieldwork, undertaken to conduct baseline ornithological assessments for Hornsea Project 3 on-shore cabling route, recorded the geese reliably feeding for periods of several days or more in individual fields. These locations were deemed to offer the best chance of undertaking successful cannon net catches, with the geese observed moving onto recently harvested fields of sugar beet tops each day shortly after dawn.

Figure 13: Sugar beet tops left following harvest of fields near Weybourne, January 2018.

3.2.2 Initial attempts to catch geese at Weybourne, and undertaking the first successful catches at Holt, January 2018

In December 2017 plans were made to target catches for mid-January, coinciding with the planned harvesting of sugar beet. However, in late December snowfall saturated fields, including high value cereal crops adjacent to the target sugar beet fields. The sugar beet crop was harvested earlier than planned to attract and divert geese from standing in and damaging the winter cereal crops, resulting in the harvested remains being consumed earlier than had been anticipated. An attempt to attract the geese back into these same fields, on the planned catch dates, was made by spreading chopped sugar beet within the catch area (Figure 14), and nets set in the target area (Figure 15). However, this did not attract the return of the geese to the target area.

Figure 14: Spreading of chipped sugar beet, as potential bait, across the target catch area (Photographs by Matthew Stone).


Figure 15: Placement of dummy cannon nets alongside the target catch area (Photographs by Matthew Stone).

Pink-footed geese were located on other recently harvested sugar beet fields, just outside Holt, where following further reconnaissance, the first successful catch was undertaken on morning of Tuesday 16th 2018. Following this catch, and as a likely consequence of the associated disturbance the geese did not return until Thursday 18th January, when a second catch was successfully undertaken.

3.2.3 Undertaking catches at Burnham Market, December 2018

In November 2018, pink-footed geese were recorded in good numbers in and around Holkham NNR, where suitable catch sites were monitored with the aid of much local support, and where two successful catches were undertaken outside Burnham Market on the 1st December 2018. Artificial decoy geese, comprising a party of six birds, and the use of chopped sugar beet, gathered and spread conspicuously in the catch area, were both determined to have been successful in attracting geese into the target catch area (Figure 16).

Figure 16: A party of six pink-footed Geese decoys placed in the target catch area, December 2018.

3.2.4 Selection criteria and capability of the selected tagging devices

The fitting of telemetry devices to wild birds is governed by the BTO and the Special Methods Technical Panel (SPTP), to whom a full application must be submitted and approved prior to fitting any tag. A key requirement is that any tag is kept to a minimum weight, and in the case of neck collars to a maximum of 1% of the average geese's body weight, which for pink-footed geese is 2.8kg, necessitating a maximum tag design and weight of 28g, fully assembled. The size and weight of a tag directly influences its' capability, with a series of trade-offs and decisions required as to the demands placed therefore on it, as regards its' battery life, frequency of fixes and frequency of download (Mitchell Et al.., 2019).

3.2.5 Determining the tagging fix schedule

In conjunction with the chosen tag provider, Pathtrack UK, an optimal scheduling programme was derived and deployed that utilised the tags finite battery capabilities. These schedules, once deployed could not be changed remotely. The scheduling included the use of two separate fix frequency schedules, effectively one for migration, where the maximum level of fixes could be obtained, and a second schedule, used during the summer and winter periods, where a comparatively low level of fixes could be used to further verify an individual's movement, status and also to provide further opportunities for analysis. In the first winter of deployment, the 9 tags fitted in January 2018, were deployed with a schedule that targeted a migratory fix of every 30 minutes (between the 16th February and 15th April, and also the 16th

September and 15th November), and outside that period, i.e., whilst breeding in Iceland in the summer or wintering in the UK, a fix schedule of every 8 hours (between 16th April and 15th September, and also the 16th November and 15th February) (Table 7).

A corresponding schedule of data downloads was also derived, during which the tags would attempt to transmit the recorded GPS data utilising the GSM network and mobile data masts. The schedule set attempted downloads of data every 21 days, excluding during the migratory periods, when the available battery was used solely for recording fixes. For a download to be successful the bird must be relatively close, and within a few kilometres, of a mobile mast, when the transmission is attempted. If not successful, transmissions are attempted a second time each schedule with 3 days. GSM coverage for Iceland is relatively good around coastal areas, and in particular the south coast a front on which the birds are known to arrive each spring (Figure 17).

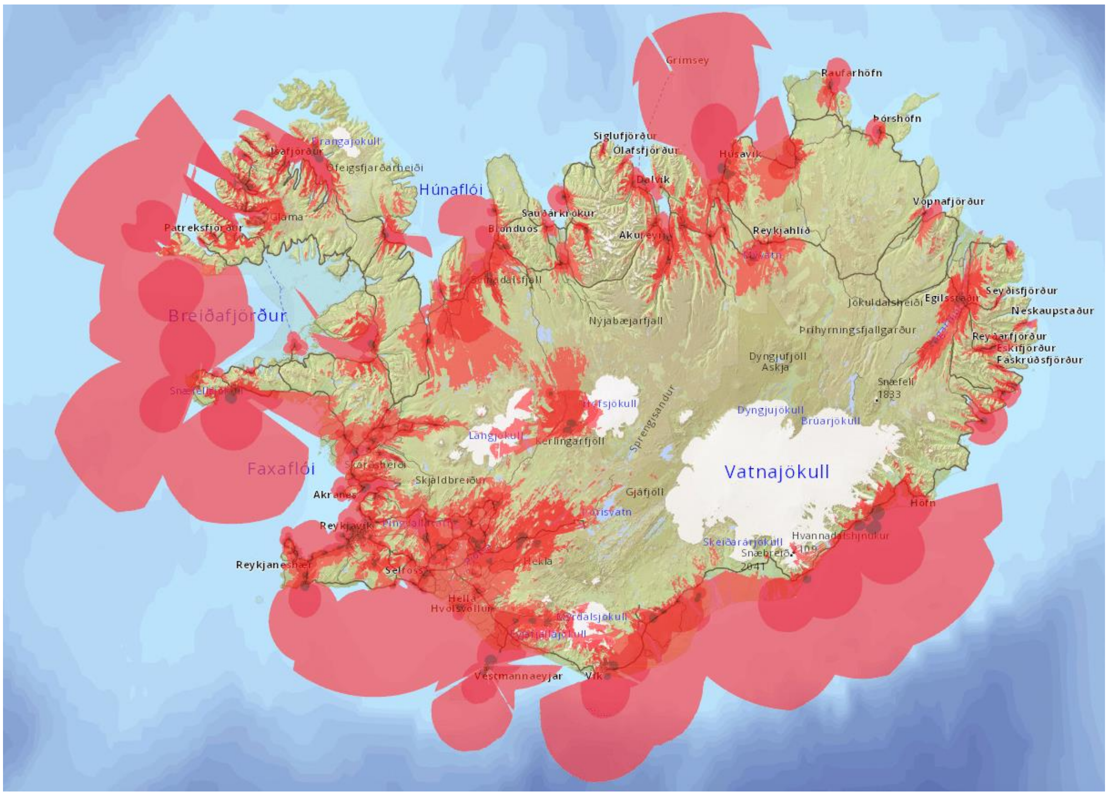

Figure 17: Mobile GSM coverage in Iceland (Map reproduced from: https://www.lavacarrental.is/information-iceland/how-is-the-mobile-and-data-connection-in-iceland).

Following the remote monitoring of tag performance and battery life of tags fitted in catch 1, January 2018, improvements in the tagging fix frequency were incorporated and scheduled into the tags fitted in catch 2, December 2018. Fix frequency was increased to every 15 minutes during migratory periods and to 2 hours during non-migratory periods, including the overwintering period in the UK (Table 7).

Table 7: Tagging fix schedules deployed, catch 1 and catch 2

Schedule	Schedule period	Activity	Catch 1 (Jan 2018) Fix Frequency	Catch 2 (Dec 2018) Fix frequency
Schedule A (migratory)	16th Feb to 15th Apr &	Spring migration	Every 30 min	Every 15 min
	16th Sep to 15th Nov	Autumn migration	Every 30 min	Every 15 min
Schedule B (non-migratory)	16th Apr to 15th Sep &	Summer	Every 8 hours	Every 2 hrs
	16th Nov to 15th Feb	Wintering	Every 8 hours	Every 2 hrs

3.2.6 BTO Licensing and University of Hull Ethical Approval of Research

All aspects of the catching, tagging, ringing and color marking of pink-footed geese was approved by the BTO and under the specific A permit license conditions of Robin M. Ward, license number 4265, along with other named individuals holding the relevant permits and licenses relevant to their involvement and roles within the catches undertaken.

In addition, the undertaking of all associated fieldwork was approved by the University of Hull Ethical Research Committee, reference: FEC_2019_162.

3.2.7 Processing caught birds and selecting individuals to tag

Following the safe extraction of geese from the nets, individual geese were placed into sacks, and moved to a safe area before being processed. Each individual was aged based on moult, weighed and the key biometrics of wing length and bill measurement recorded (Figure 18). In addition, all birds caught were fitted with a unique BTO metal leg ring. Based on weight, each bird was then either fitted with a standard plastic neck collar, with unique letter combination, or identified as being of a suitable weight for fitting with a GPS/GSM neck collar (Figure 19). All individuals fitted with a GPS/GSM neck collar were also colour marked by fitting a unique leg colour ring.

Figure 18: Processing the catch and the measurement of key biometrics (Photographs by Mikal Ball)

Figure 19: Fitting of standard BTO metal rings and colour marking leg rings and neck collars (Photographs by Mikal Ball)

3.2.8 Deployment of the GPS / GSM neck collar tags

The GPS/GSM tags were designed to weigh a maximum of 1% of the average pink-footed geese body weight (Figure 20). Adult pink-footed goose weight ranges from 2.22kg – 3.40kg, i.e., an average of 2.81kg (Robinson, 2005). It must be noted that the weight derived from the BTO database is derived from a low sample of birds (n=54). The tags designed by Pathtrack, and subsequently approved by the BTO Special Methods Technical Panel weighed a maximum of 28g, fully assembled.

Prior to the catch a predetermined plan was devised to attempt to tag both juvenile and adult birds, since the natural mortality figures were relatively similar, 0.829 for adults and 0.775 for juveniles (BTO, 2018). The plan was to also try and identify, whilst still in the net, family groups of birds, with the aim of being able to spread the allocation of tags across different families, if possible. This predetermined plan aimed to improve the insight into the species movement by studying individuals from different families and ages.

Since the tags were designed to be 1% of the reported average weight of the geese it was anticipated that in any catch up to 50% of individuals could in theory be fitted with a tag, if desired, and be of sufficient weight to meet the 1% criteria.

In practice the average weight of birds across all catches (n=58) was 2.16kg, some 650g lower than the average anticipated weight, with a wide range from as low as 1.05kg to a maximum of 3.0kg.

The low weight of the birds caught may in part be attributable to the fact that all birds were caught early in the morning and prior to feeding. It is possible that if caught after feeding the birds may have weighed some 200-300g more. The birds were also caught in mid-January and possibly at a low point in their annual weight cycle.

As a result, the number of tags fitted to individual birds was lower than anticipated. From a total catch of 58 individuals, only nine individuals were fitted with tags, based on identifying them as having a suitable weight. The nine individuals represented 15% of the total catch.

Figure 20: Fitting of a solar panelled GPS / GSM tag (Photographs by Mikal Ball)

3.2.9 Release of captured birds

Once processed each individual bird was placed in a small tent close to the processing area, and allowed to settle following being captured and handled. All birds were then released together to optimise the chance of natural groups being able to return to the main flock (Figure 21).

Figure 21: Holding and release of individually processed birds in groups and families (Photographs by Mikal Ball).

3.2.10 Additional catch attempts

Further attempts to catch more birds and fit additional tags were made over the weekend of the 27th and 28th January 2018, near Langham. However, these catches were unsuccessful due to the birds either not feeding in the target and set catch area, or due to local disturbance.

3.2.11 Home Range analysis and use of step analysis to calculate daily distances travelled

In this analysis a Brownian Bridge Movement Model (BBMM) has been used to create a continuous-time stochastic model of movement in which the probability of being in an area is conditioned on starting and ending locations, the elapsed time between those points, and the mobility or speed of movement. The analysis is aimed at capturing 'normal' movement and activities, which in the case of pink-footed geese wintering in North Norfolk, is confined either to roosting, foraging or loafing and travelling between areas to undertake these activities. In applying the BBMM and using a fixed-point Kernel density model, it is possible to predict the probability of each individual bird being within an area during a specified period of time. In the analysis conducted and presented in the Home Range results 3.3.12, two probabilities are utilised. These are a 50% and 90% chance of probability, and defined areas, in which the bird's movements are likely to be defined, acknowledging that an occasional, but less typical movement may lie out with these presented boundaries.

In order to calculate the total distance travelled each day, by each bird, step analysis of the distance between each recorded fix point and longitudinal / latitudinal GPS waypoint was totalled and aggregated for each day. This approach is relatively simplistic, and the results are dependant in part on the number of fixes achieved per day, in-between each of which any movement is unknown.

3.3 Results

3.3.1 Summary of the total annual tagging data and movements recorded

A total of 98 pink-footed geese were caught during the study, from which all the available 18 GPS tags were fitted (Table 8). A total of nine GPS tags were fitted to birds caught in the first winter (January 2018) across two catches on different dates and a further nine GPS tags fitted to birds caught during the second winter (December 2018).

Table 8: Summary of successful catches undertaken and the birds caught and tagged in each catch.

Date	Catch site	No. of pink-footed geese caught	No. of birds fitted with GPS / GSM tag
16th January 2018	High Kelling, Holt	26	5
18th January 2018	High Kelling, Holt	32	4
1st December 2018	Burnham Market	40	9
Total		**98**	**18**

Attempts to monitor all tagged birds were made through to the late autumn of 2019, when it was anticipated individual birds would be returning to the UK from Iceland, and within mobile GSM coverage that was required to download recorded tracking data.

The duration of recorded, and successfully transmitted data, varied considerably by bird and tag, varying from 20 days recorded data to 483 days data, and with individual birds last fixes varying from being in Norfolk, to Scotland or Iceland (Table 9). A total of six birds from each of the two samples of nine birds caught, were successfully recorded and tracked throughout their remaining wintering stay in the UK and onwards to Iceland. The movements of a total of four individuals from a total sample size of 18 tagged birds successfully recorded movements from the UK to breeding grounds in Iceland and subsequently also a return to the UK the following year. Tag failure, in respect of failing battery life is thought to have resulted in the limitation of further data collation, as a potential result of placing a high fix frequency demand on the tags during the migratory period. Two tagged birds, whose movements were not recorded or downloaded via GSM, were physically spotted in North Norfolk in the autumn following their capture and fitting of tags in the prior winter.

Table 9: Summary of total tagging data duration and last fix position by bird.

Catch	Date Fitted	Tag No.	First Fix	Last Fix	No. Days Data	Migrated to Iceland	Returned to UK	Last fix position
Catch 1	16/01/18	**14984**	16/01/2018	14/05/2019	483	Y	Y	Norfolk (Yr. 2)
Catch 1	16/01/18	**14999**	16/01/2018	05/09/2018	232	Y	Y	Norfolk (Yr. 2)
Catch 1	16/01/18	**15501**	16/01/2018	21/05/2018	125	Y	?	Iceland
Catch 1	16/01/18	**15502**	16/01/2018	05/09/2018	232	Y	?	Iceland
Catch 1	16/01/18	**15504**	16/01/2018	15/08/2018	211	Y	?	Iceland
Catch 1	18/01/18	**15506**	18/01/2018	07/02/2018	20	?	Y	Norfolk (Yr. 2)
Catch 1	18/01/18	**15514**	18/01/2018	08/02/2018	21	?	?	Cumbria
Catch 1	18/01/18	**15515**	19/01/2018	09/06/2018	141	?	?	Lanarkshire
Catch 1	18/01/18	**15516**	21/01/2018	29/04/2018	98	Y	?	Iceland
Catch 2	01/12/18	**15500**	01/12/2018	20/07/2019	231	Y	?	Iceland
Catch 2	01/12/18	**15507**	01/12/2018	02/02/2019	63	?	?	Norfolk
Catch 2	01/12/18	**15517**	01/12/2018	16/02/2019	77	?	?	Norfolk
Catch 2	01/12/18	**15518**	02/12/2018	17/04/2019	137	Y	?	Iceland
Catch 2	01/12/18	**15519**	01/12/2018	17/09/2019	290	Y	Y	Northumberland
Catch 2	01/12/18	**15520**	01/12/2018	01/05/2019	151	Y	?	Iceland
Catch 2	01/12/18	**15521**	01/12/2018	09/06/2019	190	Y	?	Iceland
Catch 2	01/12/18	**15524**	01/12/2018	25/03/2019	114	?	?	Lanarkshire
Catch 2	01/12/18	**15227**	10/12/2018	22/04/2019	133	Y	?	Iceland

The full spatial scale of each birds’ movements across their entire annual range are shown in (Figure 22), indicating locations and movements of the tagged birds’ migratory routes, staging and wintering throughout the UK as well as their flight paths to Iceland and in one case, also to East Greenland.

Whilst the map includes recorded movement in Norfolk, across the UK and to the high Arctic, the data captured for each individual does not represent this wide scale movement for all birds, with differing limits on the data collated by individual. The total duration of movement recorded by individual bird varies significantly, and ranges from 63 to 483 days (Table 9).

The longest duration of tagging data recorded is for Tag 14984. This individual was caught in January 2018, and was successfully tracked and recorded migrating to Iceland in the spring, moving to East Greenland, and subsequently returning to the UK in the following autumn. This same individual was also recorded returning once again to Iceland in the spring of 2019, and in total was tracked for 483 days.

All 18 birds tagged were successfully recorded moving around and wintering in Norfolk. However only 12 of the 18 birds were subsequently recorded migrating to Iceland, including 6 each from both Catch 1 in January 2018 and Catch 2 in December 2018. Only one bird from each of these cohorts was subsequently recorded returning to the UK from the tagging data (Tags 14984 and 15519). The long-term movements of Tag 14984 are described above, with Tag 15519 being last recorded in Northumbria in September 2019. However, two further individuals (Tags 14999 and 15506) whilst not transmitting recorded tagging data, revealing their movements, have subsequently been visibly re-sighted by observers in Norfolk, with the colour marking codes of the leg rings being noted and reported.

Therefore whilst 12 of the birds tagged were recorded moving to Iceland, 6 individuals were either last recorded in Norfolk or elsewhere in the UK. Two of these individuals, Tags 15507 and 15517, were only ever recorded in Norfolk in the weeks following being tagged, recording 63- and 77-days data respectively. The remaining four individuals were recorded leaving Norfolk, with two last being recorded in Lanarkshire (Tags 15515 and 15524), one being recorded in Cumbria (Tag 15514) and one being recorded in Lancashire, on the Ribble Estuary (Tag 15506). This last individual (Tag 15506), was subsequently re-sighted in Norfolk the following autumn, but without its GPS/GSM neck collar, giving concern over the reliability of the fixings of the collars. This re-sighting was reported prior to Catch 2, prompting an interim review of the neck collar fixing, but not in sufficient time to complete any full re-design, moulding change and re-approval by the BTO SMTP. However, in Catch 2 a much more liberal application of adhesives and fixings were used in the attachment of each tag to the adjoining neck collar band and within the seated lugs of the housing, by comparison with more pre-cautionary applications of adhesive in Catch 1. Given this bird was though observed in Norfolk during the autumn of 2019, following its’ tagging the prior winter, it does indicate the individual will have successfully migrated to and from Iceland in that year bringing the total number of individuals completing the migration to Iceland to a minimum of 13, versus the 12 reported from the tagging data.

The recorded movements of two GPS neck collared birds, from the initial fitting of tags to the first sample catch, January 2018, indicated a possible loss to shooting. Following detailed analysis, and for one bird / tag, visits to the last known area of movement, no subsequent recovery was made or firm conclusions reached (see Appendix 3). Indeed, four color marked birds from the first January catch, fitted with standard neck collars, were reported as ringing recoveries, following being shot. Three of these were shot in Iceland and one in Northumberland (see Appendix 4).

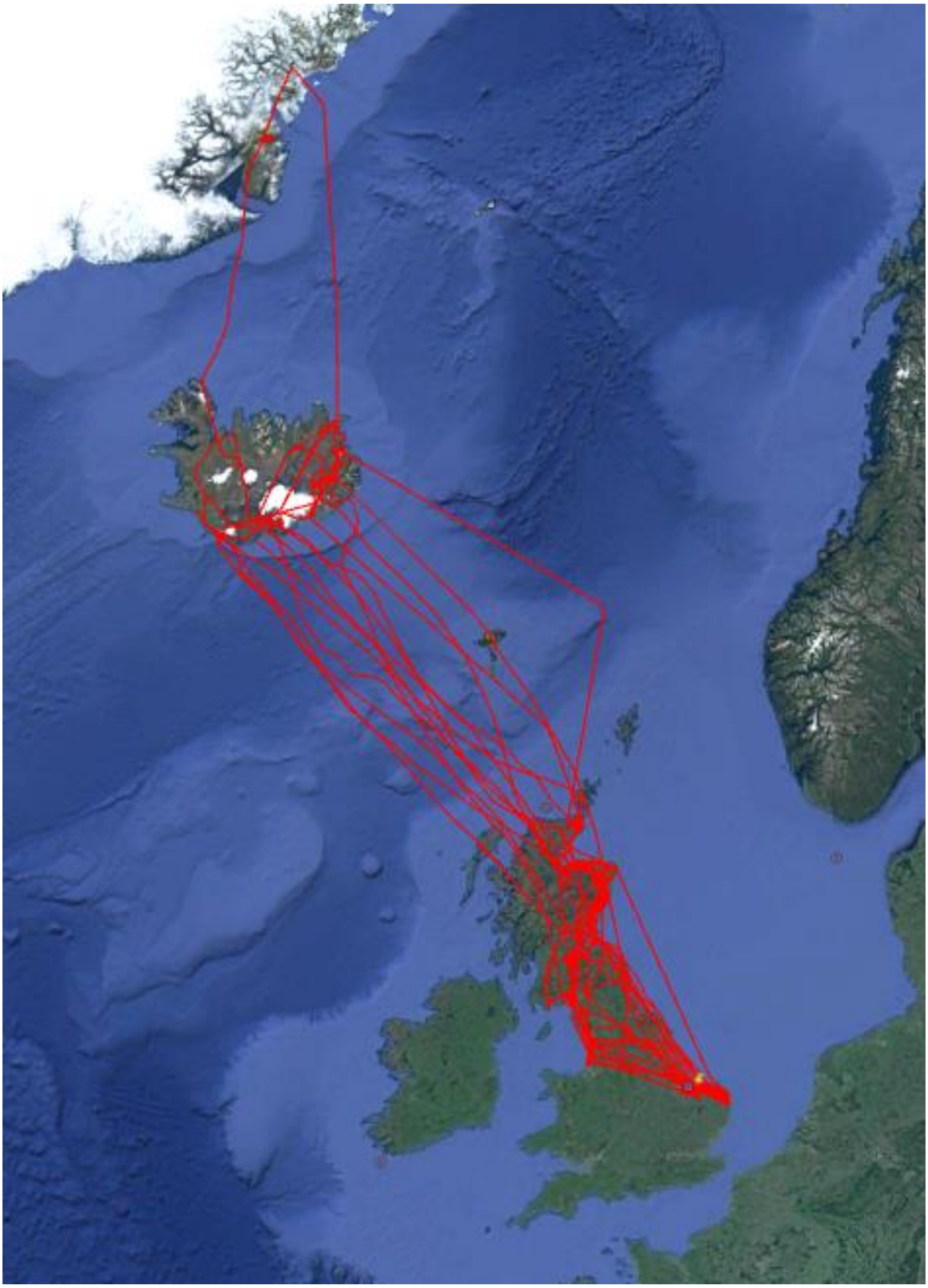

Figure 22: The widescale movements of nine individual pink-footed geese recorded between January 2018 and September 2019, all initially tagged in North Norfolk at High Kelling, Holt in January 2018 (catch 1), illustrating the migratory staging and corridors used through the UK and a variety of arrival locations and choice of breeding areas selected in Iceland and Greenland.

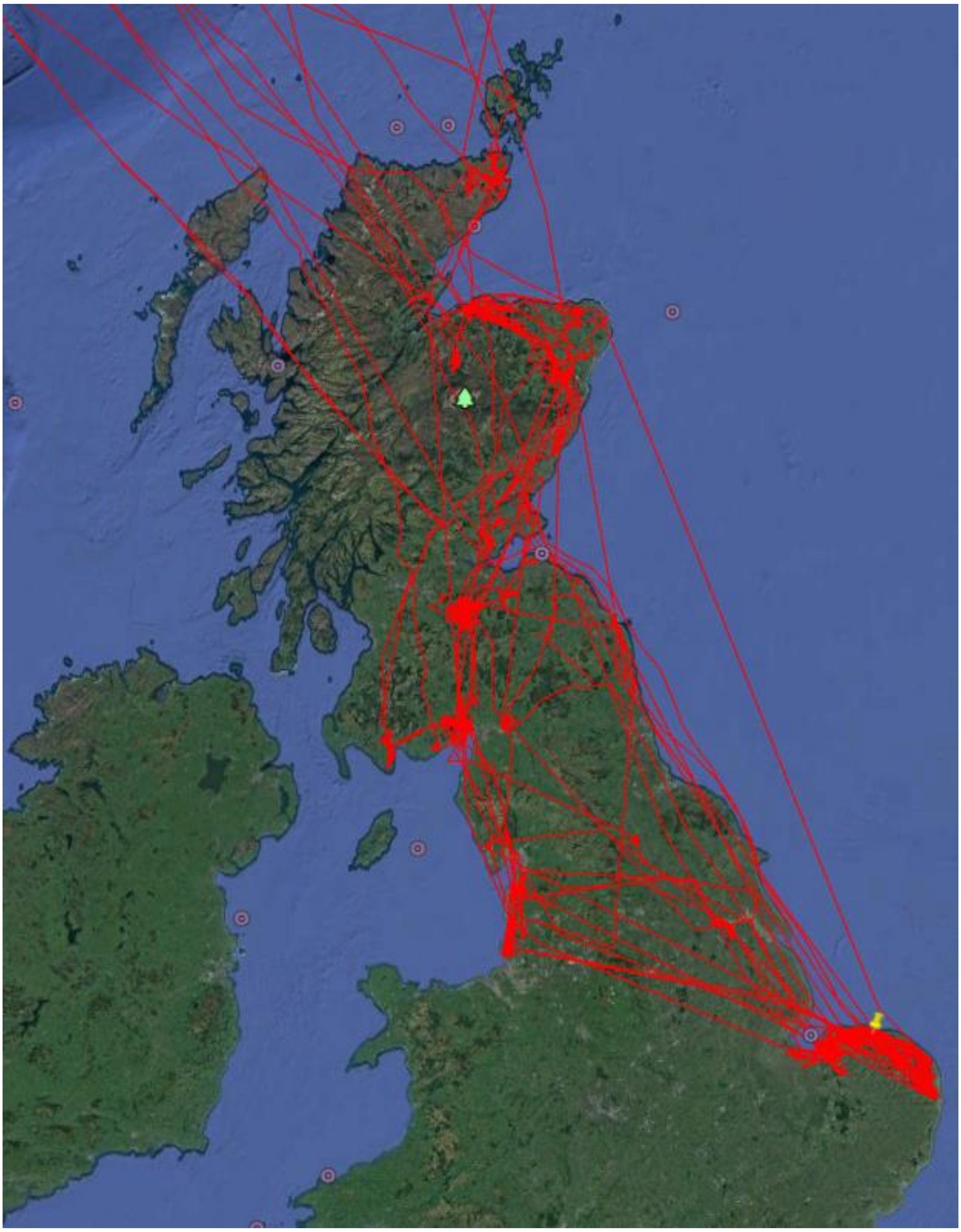

Figure 23: Detail of the movements across the UK of nine individual pink-footed geese recorded between January 2018 and September 2019, all initially tagged in North Norfolk at High Kelling, Holt in January 2018 (catch 1), illustrating alternate flyways, migratory routes and staging strategies of individuals.

3.3.2 Summary of the total number of fixes and data collated by movement phase

In total some 56,155 positional fixes were recorded across the entire annual duration and periods in which the 18 fitted GPS / GSM tags have successfully transmitted data for, generating a significant data set. The majority of these fixes are collated during migration, when the fix frequency is every 15 minutes and is capturing in part the birds final staging in the UK, migratory flight and short periods either side of these windows, depending on the individual movements and dates of each bird in relation to the recording schedules (Table 10).

A total of 8,936 fixes were also recorded of movements in Iceland, with a similar number, 8,260 fixes being recorded during the winter and within North Norfolk. The number of fixes collated varies between the two winters significantly, due to an improvement in the fix schedule during the second winter (an increase from 3 per day to 12 per day, between Catch 1 and Catch 2) and the timing of undertaking the catches and duration thereafter the geese were in the study area (Catch 1 being undertaken in January 2018 and Catch 2 being undertaken in December 2018, providing around an additional month of data).

Table 10: Summary of the number of fixes collated by key period (wintering, staging, migrating and breeding) per catch sample.

Birds from Catch	Geographic Area	Period	Year(s)	Core activity	No. of fixes
Catch 1	Norfolk	January to February	2018	Winter foraging	709
Catch 2	Norfolk	December to February	2018 / 2019	Winter foraging	7,551
Catch 1	UK (outside Norfolk)	February to September	2018	Spring staging / migration	2,177
Catch 1 & 2	UK (outside Norfolk)	February to September	2018 / 2019	Spring staging / migration	34,588
Catch 1	UK (outside Norfolk)	September to November	2018	Autumn staging / migration	2,104
Catch 1 & 2	UK (outside Norfolk)	September to November	2019	Autumn staging / migration	90
Catch 1 & 2	High arctic	April to September	2018 / 2019	Summer / breeding	8,936

3.3.3 Summary of the Norfolk wintering data and movements recorded, catch 1

Wintering tagging data were successfully collated for all 9 birds caught in Catch period 1, January 2018, capturing movement of the birds in North Norfolk. On average 18 days data were collated per tag, since the tag recorded its first fix, until the individual bird left Norfolk (Table 11). The number of day's data collated per individual varied between 9 days and 30 days, with the first bird (tag 15506) leaving Norfolk on the 27th January 2018, having being marked and tagged on the 18th January. The last bird to leave Norfolk, and head north, left on the 15th February (tag 14984). A peak of departures occurred in early February, with five of the nine birds tagged, leaving on either the 3rd or 4th February 2018. All birds caught in catch 1, therefore recorded data in North Norfolk at a fix rate of every 8 hours, all leaving just before the faster migration schedule began. In total 162 days data were collated, at an average fix of every 8 hours, generating 486 fixes in total. The average departure date for birds in Catch 1 was the 4th February, 2018.

A summary of the individual movements of the birds tagged in Catch 1 and their wintering movements is shown in (Figure 24). Initial analysis of these movements shows that 7 of the 9 individuals tagged predominantly spent their time roosting and foraging within North Norfolk, between the Wash and Sherringham, with favoured roosts at Scolt Head, Holkham and Cley.

Two individuals though moved east with one residing at Brayden Marshes (Tag 14984), and another (Tag 15501), briefly visiting the Broads directly to the west of Great Yarmouth, and around the river Bure.

3.3.4 Summary of the Norfolk wintering data and movements recorded, catch 2

Wintering tagging data were successfully also collated for all 9 birds caught in Catch period 2, December 2018. Since the birds caught in Catch 2 were caught earlier in the season than those in the prior January 2018 catches (Catch 1), the number of wintering days data were significantly higher. On average, 58.3 days data were recorded of the bird's movement in North Norfolk before they left the county and began moving north again. Again, the number of day's data collated by tag varied greatly as a result of the variation in timing of individuals leaving Norfolk. The first bird (tag 15520) actually left Norfolk before Christmas on the 13th December 2018, and was one of two birds to begin northerly movements ahead of 2019, flying north to Dumfriesshire, before on-wards to Iceland. By contrast the last bird(s) (tags, 15500, 15518 and 15524) to leave Norfolk left on the 22nd February, with three individuals departing on that date, some nine weeks after the first bird had left the county. These birds recorded a total of 83 days tagging data and movement between deployment and leaving. With a faster schedule being programmed for birds tagged in Catch 2, a much bigger data set and number of fixes was obtained. A total of 506 days data, recording at 2 hourly intervals was recorded, resulting in a potential 6,072 fixes. This was further supplemented by data collated at an even higher fix rate, of 15 minutes, due to three individuals remaining in Norfolk beyond the winter schedule and recording data for 6 days each on the faster 15-minute migratory schedule. The average departure data for birds in Catch 2 was the 29th January, 2019.

Each individual birds' movements within North Norfolk, of birds tagged in Catch 2, is shown in (Figure 25) and reveals a much greater range of movement than recorded in the prior winter and Catch 1. Eight out of the 10 birds tracked during this period (including Tag 14984 tracked over both winters) moved east, away from North Norfolk, for at least part of their wintering movement. These individuals, in part, frequenting Brayden Marshes and the Marshes of the broads for substantial periods of time. Only two of the Individuals tracked during the winter of 2018/2019 (Tag 15524 and Tag 15527), remained solely within North Norfolk, both largely frequenting the salt marshes of the Wash, west of Wolferton. These initial findings are a stark contrast to those of the prior winter and Catch 1, indicating a potential change in habitat and foraging selection, and also use of traditional natural grazing areas versus arable land use.

Table 11: Summary of tagging data collated for North Norfolk, catch 1 and catch 2

						Catch 1		Catch 2	
Catch	Date Fitted	Tag No.	First Fix	Left Norfolk / Last fix	Total No. Days Data	No. Days @ 8 hrs	No. Days @ 30 min	No. Days @ 2 hrs	No. Days @ 15 min
Catch 1	16/01/18	14984	16/01/18	22/02/18	**37**	37	0	n/a	n/a
Catch 1	16/01/18	14999	16/01/18	07/02/18	**22**	22	0	n/a	n/a
Catch 1	16/01/18	15501	16/01/18	03/02/18	**18**	18	0	n/a	n/a
Catch 1	16/01/18	15502	16/01/18	03/02/18	**18**	18	0	n/a	n/a
Catch 1	16/01/18	15504	16/01/18	03/02/18	**18**	18	0	n/a	n/a
Catch 1	18/01/18	15506	18/01/18	27/01/18	**9**	9	0	n/a	n/a
Catch 1	18/01/18	15514	18/01/18	04/02/18	**17**	17	0	n/a	n/a
Catch 1	18/01/18	15515	19/01/18	04/02/18	**16**	16	0	n/a	n/a
Catch 1	18/01/18	15516	21/01/18	04/02/18	**14**	14	0	n/a	n/a
Catch 2	01/12/18	15500	01/12/18	22/02/19	**83**	n/a	n/a	77	6
Catch 3	01/12/18	15507	01/12/18	02/02/19	**63**	n/a	n/a	63	0
Catch 4	01/12/18	15517	01/12/18	16/02/19	**77**	n/a	n/a	77	0
Catch 5	01/12/18	15518	02/12/18	22/02/19	**83**	n/a	n/a	76	6
Catch 6	01/12/18	15519	01/12/18	19/01/19	**49**	n/a	n/a	49	0
Catch 7	01/12/18	15520	01/12/18	13/12/18	**12**	n/a	n/a	12	0
Catch 8	01/12/18	15521	01/12/18	31/01/19	**61**	n/a	n/a	61	0
Catch 9	01/12/18	15524	01/12/18	22/02/19	**83**	n/a	n/a	77	6
Catch 10	01/12/18	15227	10/12/18	24/12/18	**14**	n/a	n/a	14	0
Catch 1	Total				**169**	169	0	-	-
Catch 2	Total				**525**	-	-	506	18
Catch 1	Average				18.0	18.0	0.0	n/a	n/a
Catch 2	Average				58.3	n/a	n/a	56.2	2.0

3.3.5 Analysis of the North Norfolk wintering range

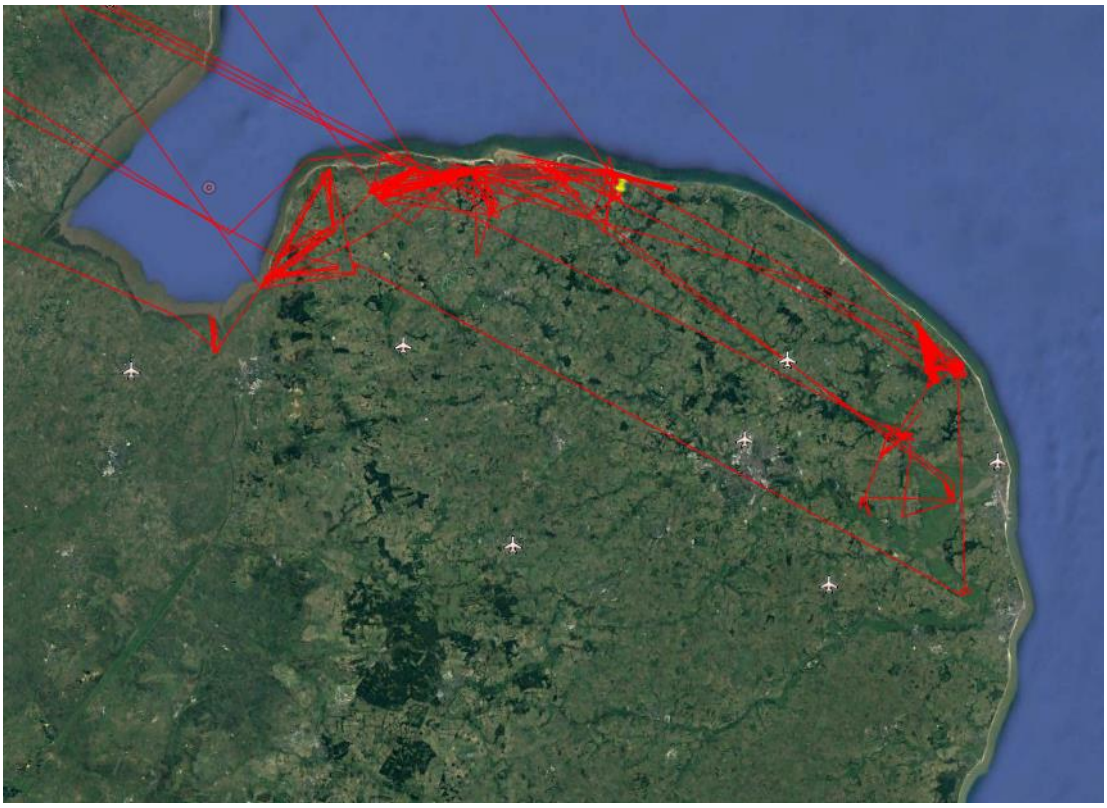

Figure 24: Wintering movement of the nine birds caught in Catch 1, High Kelling, Holt (January 2018 to February 2018).

Figure 25: Wintering movements of the nine birds caught in Catch 2, Burnham Market (December 2018 to February 2019).

3.3.6 Study area wintering movements: Individual track summary, catch 1

Individual tracking movements are shown in (Figure 26) for each of the birds caught in Catch 1, January 2018. Their wintering movements, including throughout the year(s), across the UK, and where recorded, passage to Iceland and Greenland are described in further detail in Appendix 1.

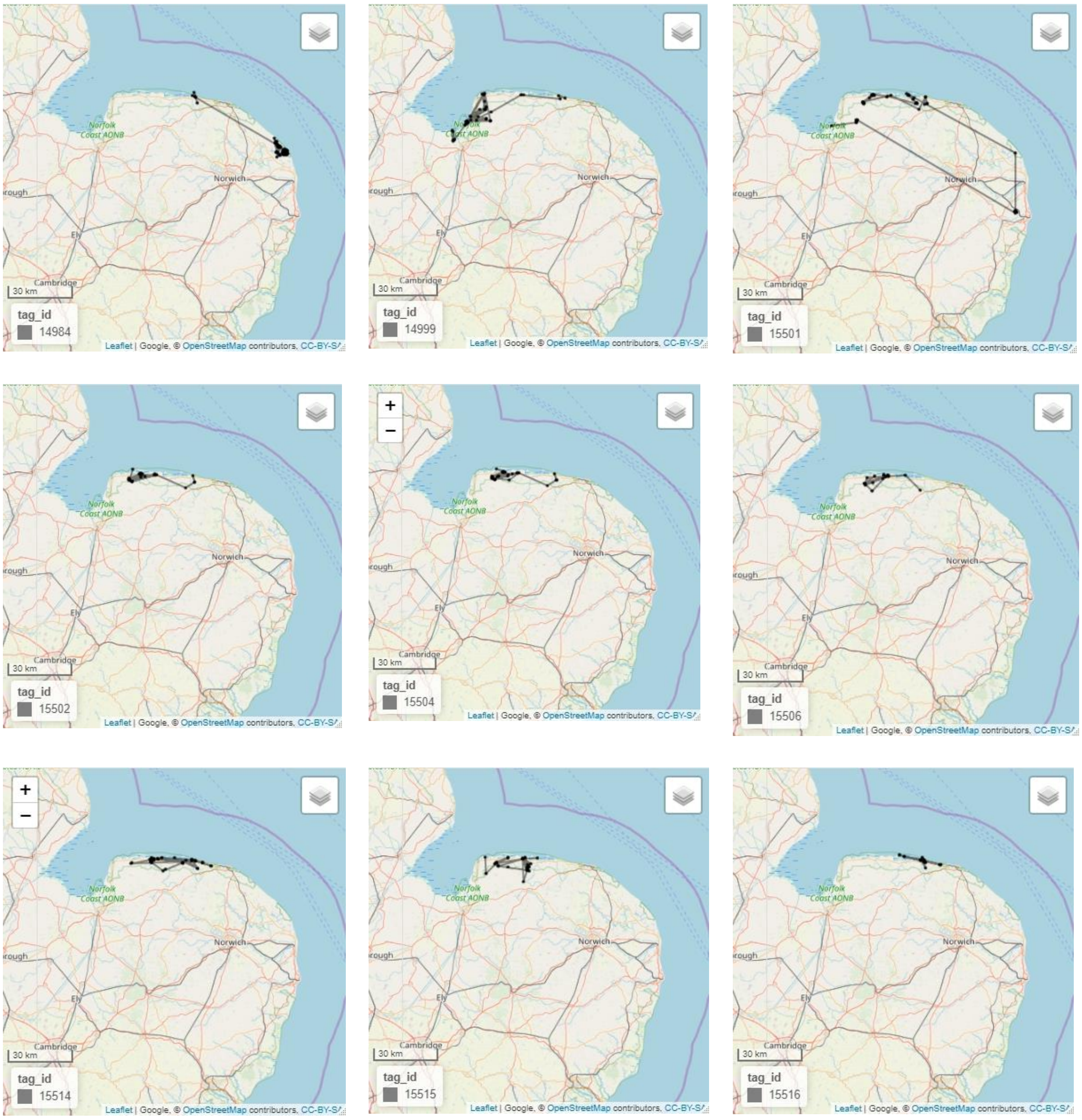

Figure 26: Individual tag track summary for birds caught in Catch 1 (January 2018 to February 2018).

3.3.7 Study area wintering movements: Individual track summary, catch 2

Individual tracking movements are shown in (Figure 27), for each of the birds caught in Catch 2, December 2018. Their wintering movements, including throughout the year(s), across the UK, and where recorded, passage to Iceland is described in detail in Appendix 2.

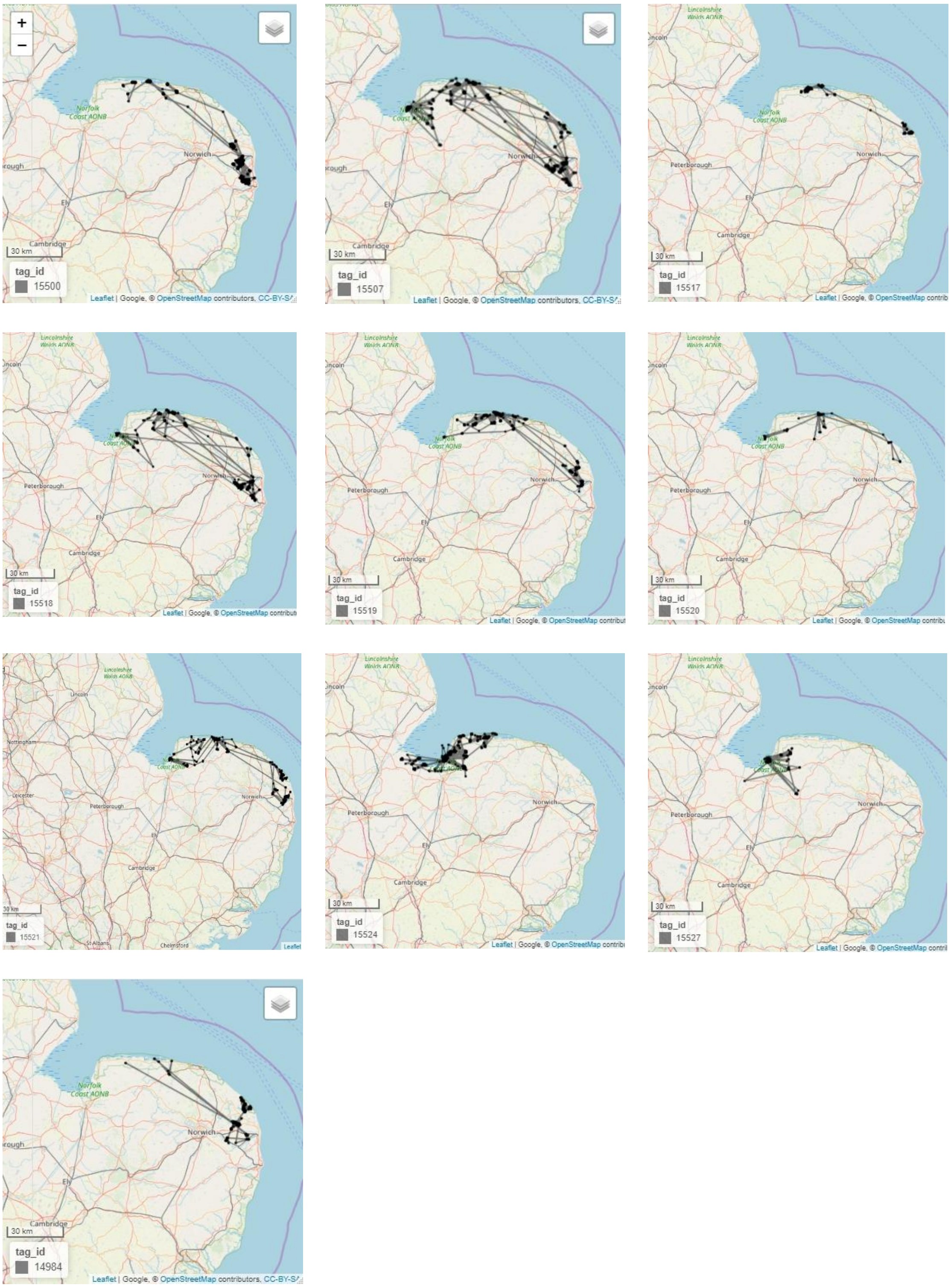

Figure 27: Individual tag track summary for birds caught in Catch 2 (December 2018 to February 2019), including Tag 14984 caught in Catch 1, but tracked over 2 winters.

3.3.8 Review of the habitat available in the study area

It is evident from observational data that pink-footed geese favour the harvested bi-product of sugar beet farming to meet their daily energetic requirements, and that the size of the population that a wintering area can support will in part be dependent upon the amount and availability of food in that area (Gill Et al.., 1996b). It is therefore of merit to review the agricultural crop type use across the UK, but specifically within Norfolk and the study area.

In 2018 the Utilised Agricultural Area (UAA) was 17.4 million hectares, covering 71% of the land in the UK (DEFRA, 2018). Of this area, permanent grassland accounts for the greatest coverage with 10.0 million hectares, whilst the utilised arable croppable area totalled 4.67 million hectares. Active use of arable land is dominated by the growing of cereal crops, primarily wheat and barley, and utilises a total of 3.10 million hectares across the UK, i.e., 66% of all arable land. Nationally sugar beet utilised 114,000 hectares in 2018, representing 2.4% of the total arable crop coverage. The 2018 coverage of sugar beet is slightly higher than the 5 years mean coverage of 103,000 hectares, between 2014 and 2018.

By contrast, in the county of Norfolk, sugar beet is grown in much higher density with the total coverage being 37,294 hectares in 2018 (Stone, 2020) and is shown in (Table 12). The county of Norfolk therefore accounted for around one third, 32.7% of all sugar beet coverage in 2018. The growing sugar beet in the county represented 6.8% of the total arable crops grown in the county, and is markedly greater than the nationally recorded 2.4% across the UK.

Sugar beet is grown widely across the county of Norfolk, and in all areas. The densities grown in North Norfolk are relatively higher, than in central Norfolk, where major cities and towns are located, i.e., Norwich, Fakenham and Kings Lyn. Densities grown are also higher than in south Norfolk, where there are large areas of heathland, the Brecks and the Thetford National Forrest. The distribution of fields used for growing sugar beet in 2018 are shown in (Figure 28).

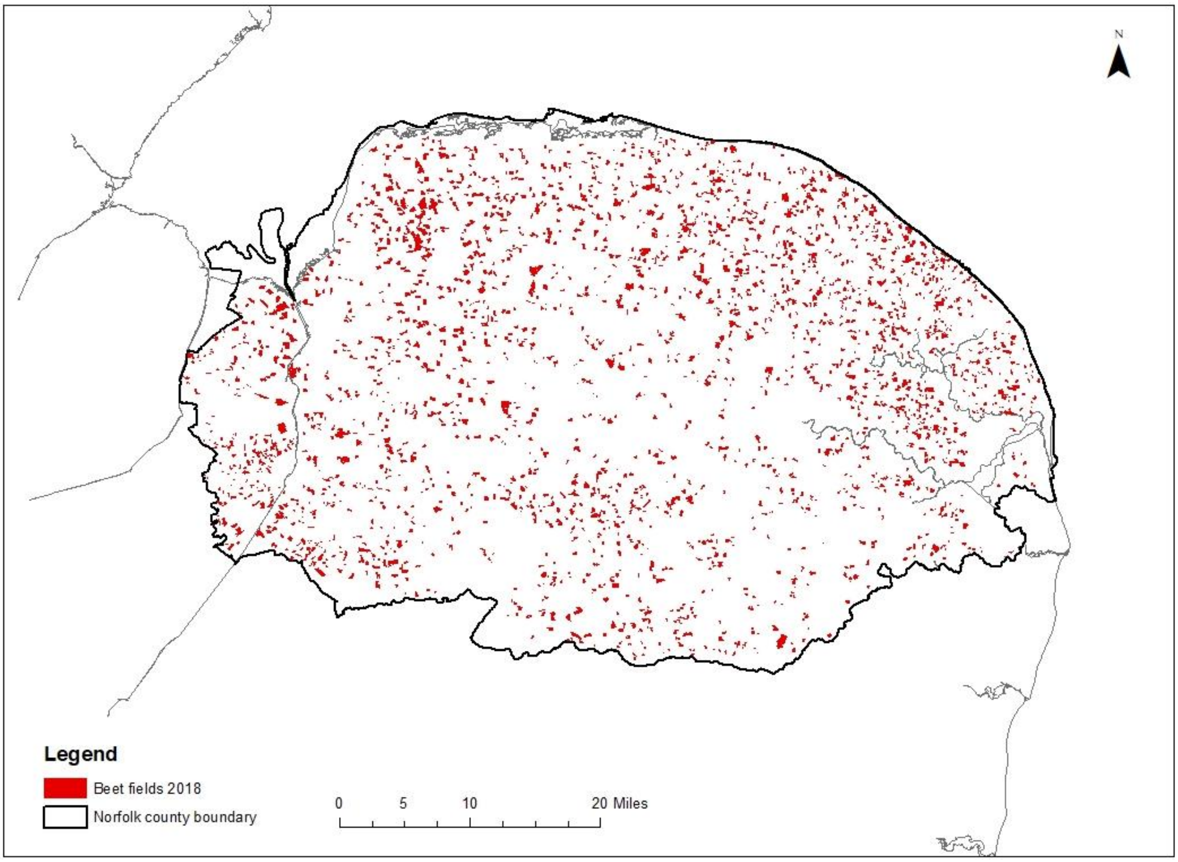

Figure 28: Norfolk county; beet field crop coverage 2018

Table 12: Norfolk county crop cover 2018

Crop type	Hectares	Percentage of total crop cover
Winter Wheat	98,534	17.9%
Grass	81,138	14.7%
Winter Barley	45,196	8.2%
Beet	37,294	6.8%
Oilseed rape	32,981	6.0%
Other crops	24,777	4.5%
Spring Wheat	23,878	4.3%
Potatoes	14,136	2.6%
Spring Barley	12,138	2.2%
Beans	8,813	1.6%
Maize	8,743	1.6%
Total crops	387,628	70.4%
Norfolk county size	550,835	

3.3.9 Home range analysis

The home range of the sample of birds tagged in year 1 depicts a relatively concentrated and defined area of range, both at a KBBM 50 and KBBM 90 scale, with movements largely confined to the North Norfolk coast and within relative proximity of the coast (Figure 29). The mean home range size for this sample, year 1, is 20.4 km^2 and 100.8 km^2 at KBBM density scales of 50 and 90 respectively (Table 13).

By contrast, the home range mapping of the sample of birds tagged in year 2 depicts a much larger area of range, both at KBBM 50 and KBBM 90 scales, with both much greater movements and distance travelled in-land, but also much greater use of the east coast and Norfolk broad's area (Figure 31). The mean home range size for this sample, year 2, is 46.2 km^2 and 372.3 km^2 at KBBM density scales of 50 and 90 respectively (Table 14).

The differences in home range size are substantial, and reflect the much wider movements recorded in year 2, with seven of the ten birds tracked that winter moved at some point to the east coast, versus year 1, where only two of the nine birds tracked made such movements (Figure 26 and Figure 27). The between year variance in KBBM 50 scale density, depicts a range that is more than double, 126%, in year 2 than year 1. This variance is even more marked at KBBM 90 scale density, where a 269% increase in range is recorded in year 2 versus year 1.

In year 1, the individual movements and home ranges mapped, depict movement and use of roosts and land along the North Norfolk coast, synonymous with the presence of pink-footed geese and long-established reserves, including the roosts at Holkham, Cley and Wells. The variance in ranges used between individuals varies considerably for this sample. Tag 14984, which recorded movement for the longest duration, 37 days, amongst the sample for this first winter actually recorded the shortest movement range. The minimum range, recorded by tag 14984 was confined to an area of 4.8 km^2 at KBBM 50 scale and 6.6 km^2 at KBBM 90 scale. By contrast the maximum range, was recorded by tag 14999, over 22 days, recording a range of 40.1 km^2 at KBBM 50 scale and 174.7 km^2 at KBBM 90 scale (Table 13).

In year 2, the individual movements and home ranges mapped, depict movement along the North Norfolk coast, but also much further inland, including areas around Docking. Movements are also recorded around the North Norfolk broads, west of Great Yarmouth and slightly further to the north, around Hickling Broad. The minimum range recorded was by tag 15517, over a substantial period of 77 days, which recorded a range of 7.1 km^2 and 60.1 km^2 for KBBM scales 50 and 90 respectively. The maximum range recorded was by tag 15518, which also recorded movement for a substantial period totalling 83 days, and recorded a range of 43.3 km^2 and 792.8 km^2 for KBBM scales 50 and 90 respectively (Table 14).

One of the most interesting comparisons is the difference in home range for bird and tag 14984, between years, especially since this is the only bird to have been successfully tagged and having transmitted data for both year 1 and year 2 winters. As shown in the year 1 analysis, tag 14984 actually had the smallest home range of 4.8 km^2 at KBBM 50 scale and 6.6 km^2 at KBBM 90 scale, with movements confined solely to the area of Hickling Broad. In the following year, this range was much greater. Data recorded for year 2, showed use of a home range totalling 69.2 km^2 and 318.2 km^2 for KBBM scales 50 and 90 respectively, and also in the east of the study area, again around Hickling Broad, but also to the south and the wider Broads. A return to the same area, year on year, is a possible indicator of site fidelity and learnt behaviour, in the knowledge that the area is a profitable one, albeit without a greater sample size, evidence of site fidelity is limited.

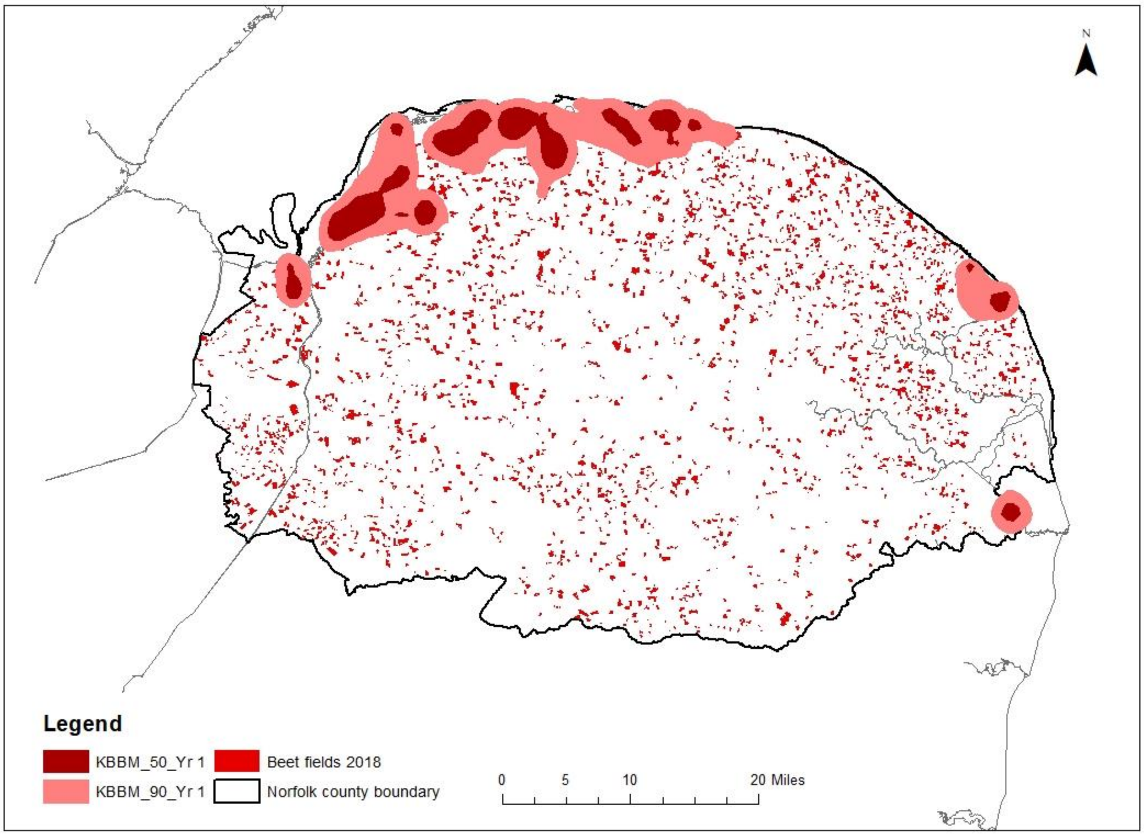

Figure 29: Summary of the North Norfolk wintering home ranges recorded of the nine birds tagged in Catch 1, January 2018 at High Kelling, Holt, depicting movements during the 1st winter until departure from the county and including the 2018 sugar beet crop coverage for the county.

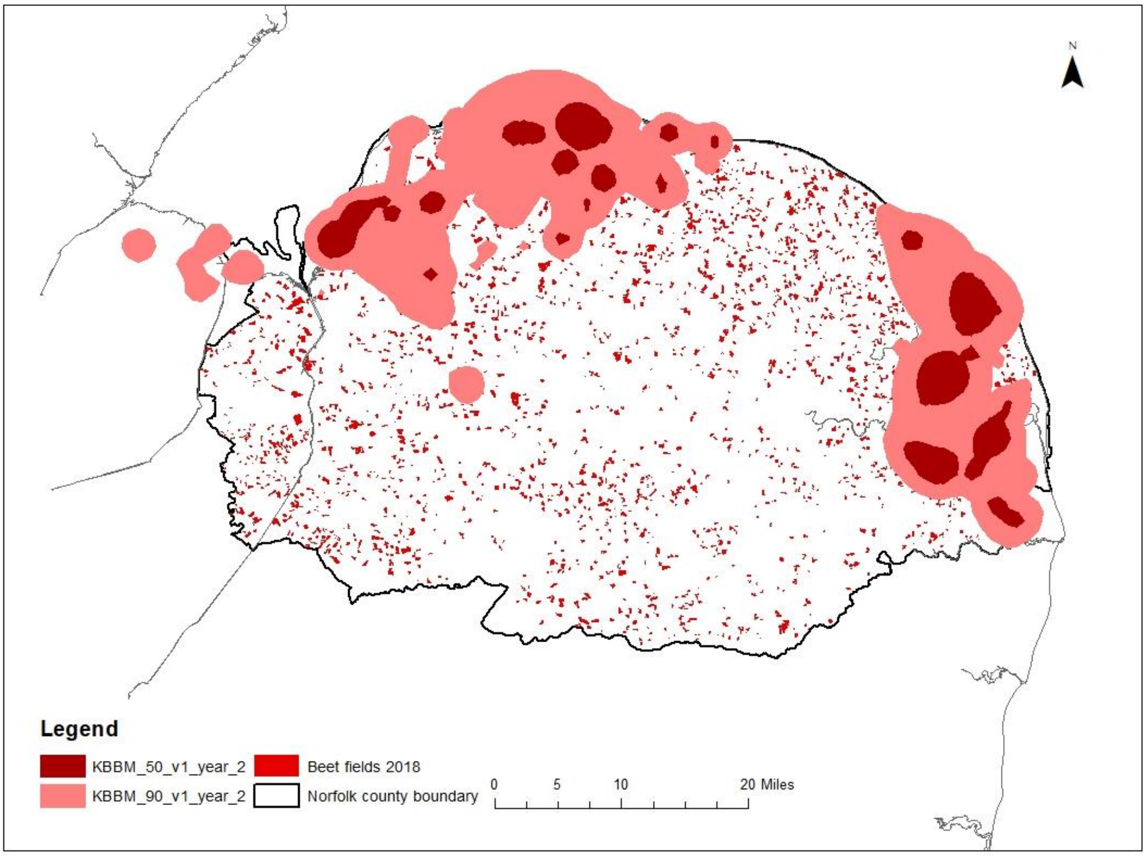

Figure 30: Summary of the North Norfolk wintering home ranges recorded of the nine birds tagged in Catch 2, December 2018 at Burnham Market, depicting movements during the 2nd winter of the study and until individual birds’ departure from the county and including the 2018 sugar beet crop coverage for the county.

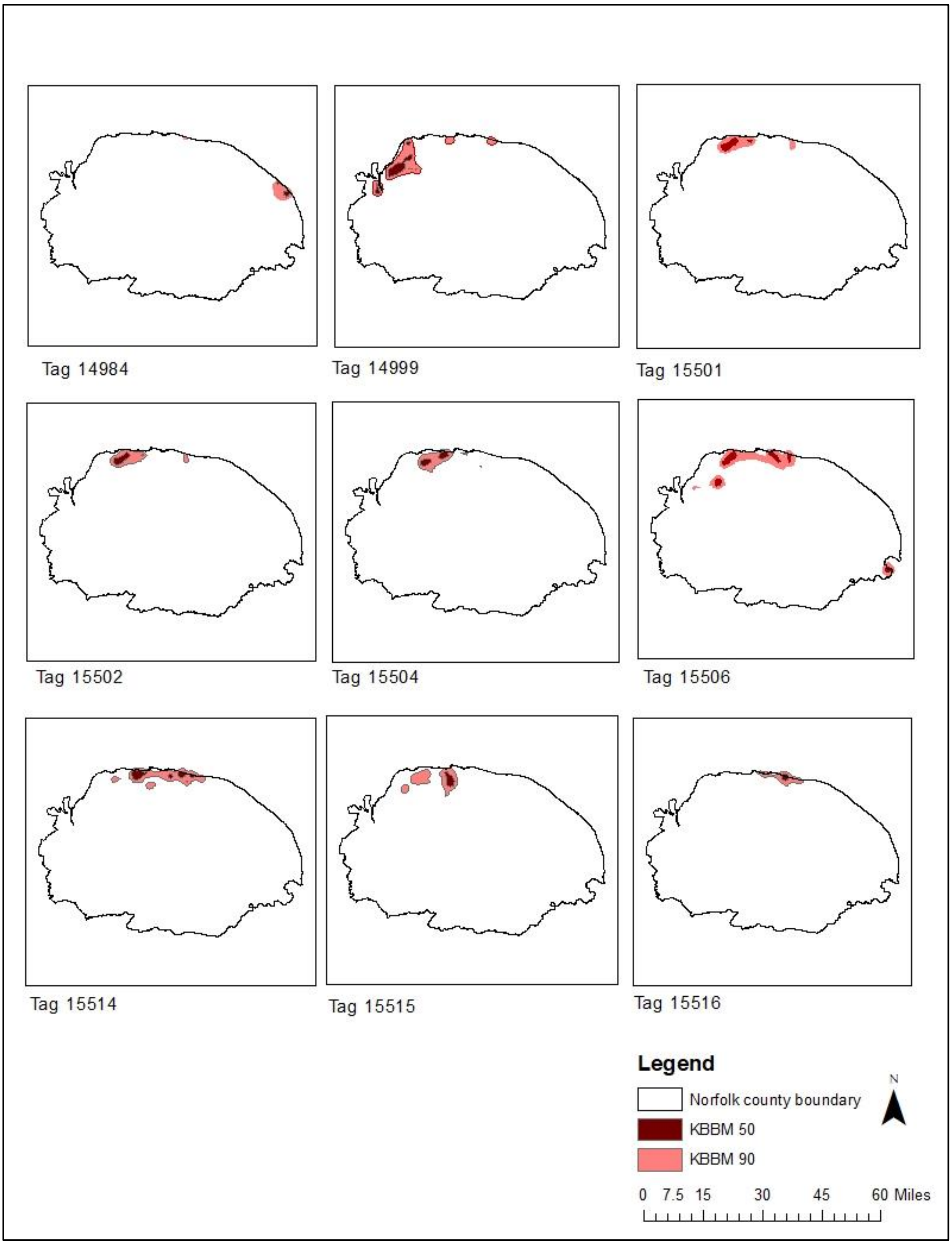

Figure 31: Individual North Norfolk wintering home ranges recorded of the nine birds tagged in Catch 1, January 2018 at High Kelling, Holt, depicting movements during the 1st winter of the study until individually leaving the county.

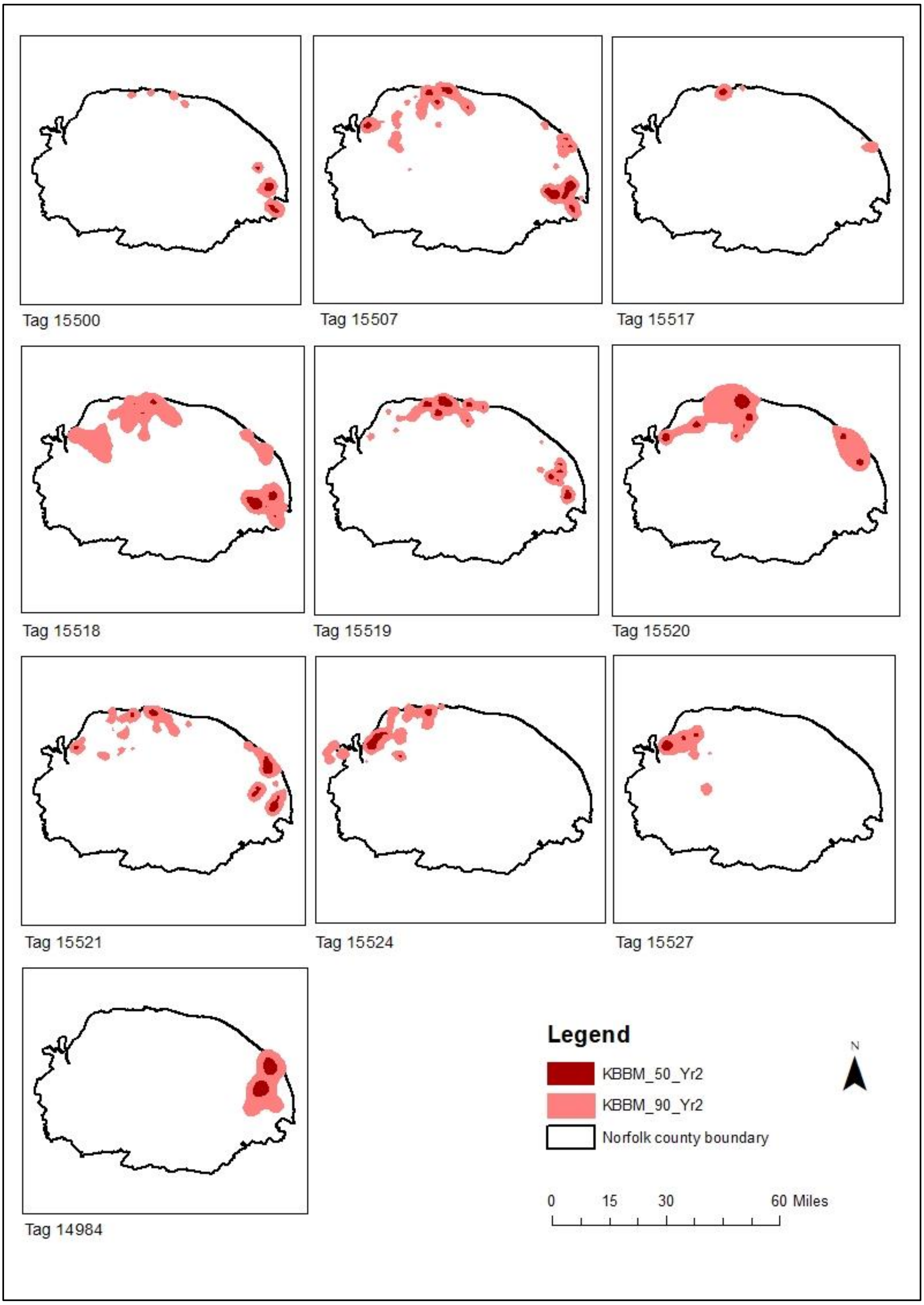

Figure 32: Individual North Norfolk wintering home ranges recorded of the nine birds tagged in Catch 2, December 2018 at Burnham Market, depicting movements recorded during the 2nd winter of the study individually leaving the county. This figure also includes the movements of an individual bird Tag 14984, which was tagged in Catch 1, January 2018 and successfully tracked over both winters.

Table 13: Summary of home ranges, in both Km^2 and ha, for Kernel densities 90 and 50, for geese tagged in Year 1.

Tag ID	No. days data	Km^2 KBBM 90	Ha KBBM 90	Km^2 KBBM 50	Ha KBBM 50
14984	37	6.6	662	4.8	484
14999	22	174.7	17,473	40.1	4,009
15501	18	201.4	20,140	37.8	3,783
15502	18	78.1	7,814	18.5	1,853.4
15504	18	76.5	7,652	17.6	1,757
15506	9	79.4	7,939	17.8	1,783
15514	17	139.8	13,979	25.3	2,530
15515	16	98.6	9,858	14.9	1,486
15516	14	51.8	5,176	6.6	662
Mean	18.8	100.8	10,077	20.4	2,039

Table 14: Summary of home ranges, in both Km^2 and ha, for Kernel densities 90 and 50, for geese tagged in Year 2.

Tag ID	No. days data	Km^2 KBBM 90	Ha KBBM 90	Km^2 KBBM 50	Ha KBBM 50
14984	68	318.2	31,824	69.2	6,915
15500	83	144.5	14,447	21.8	2,178
15507	63	501.2	50,125	78.3	7,829
15517	77	60.1	6,010	7.1	705
15518	83	792.8	79,275	43.3	4,335
15519	49	353.0	35,295	59.8	5,978
15520	12	639.3	63,934	64.4	6,441
15521	61	420.4	42,040	59.4	5,942
15524	83	314.4	31,444	36.4	3,637
15527	14	179.2	17,923	22.8	2,282
Mean	59.3	372.3	37231.6	46.2	4624.3

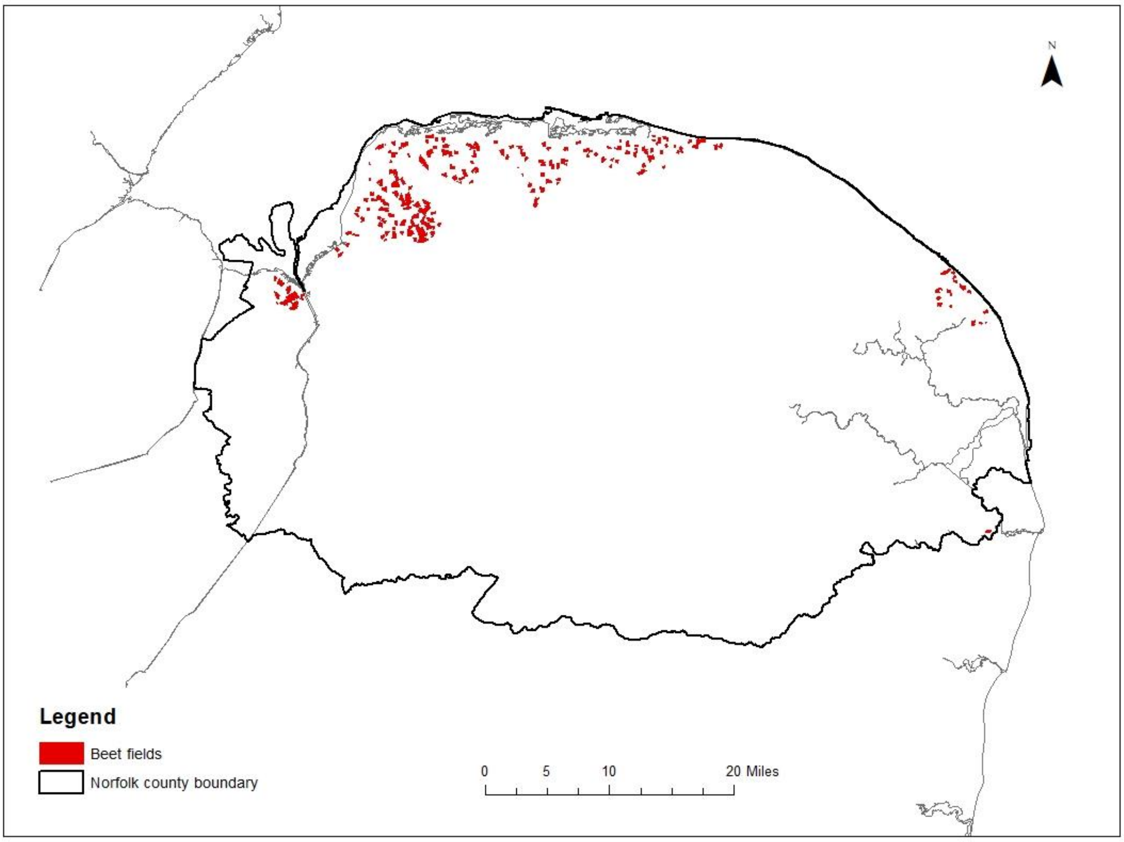

Figure 33: Sugar beet fields within the home range (KBBM 90) for Year 1 sample.

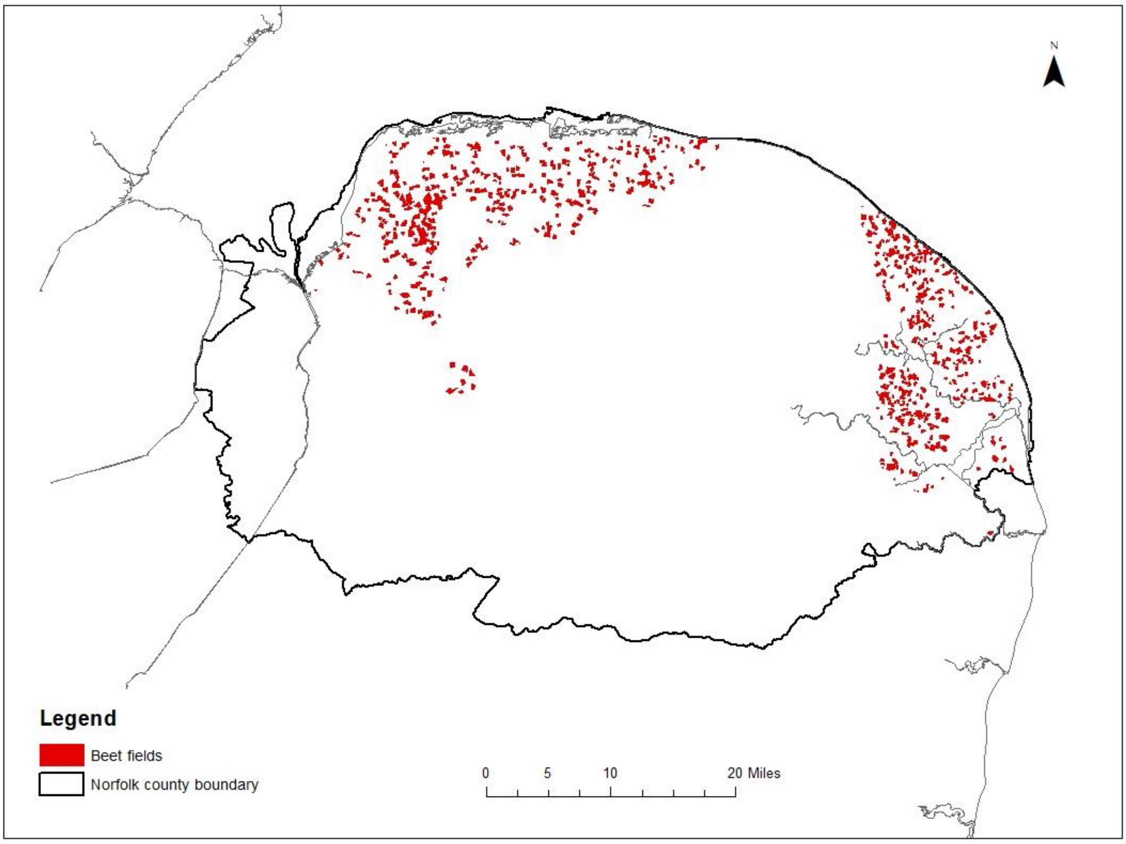

Figure 34: Sugar beet fields within the home range (KBBM 90) for Year 2 sample.

3.3.10 Daily movements

Analysis of the daily distance travelled by individual birds shows a significant difference between years, and birds caught in catch 1 (Table 15), who's data were collated during the first winter, and birds caught in catch 2 (Table 16), who's data were collated over the second winter of the study. This is in keeping with the findings and analysis of the home range sizes, which also show differences between years, and greater range in winter 2, presented in section 3.3.12.

The average of the mean daily distance travelled by each bird in catch 1 was 12.0 km (Table 15), compared to an average mean daily distance of 20.2 km for catch 2 (Table 16), an increase of 68.3% between years. The minimum distance travelled per individual bird was similar between the two samples, or catch cohorts, with both catches being around 2 km at 1.9 km and 2.2 km for catch 1 and catch 2 respectively. The significance of this difference was calculated using a paired-samples t-test examining the minimum mean distance travelled between years for each cohort of birds tagged, i.e., between the winters of 2017-2018 and 2018. This calculation derived no significant difference between the two cohorts with the 2017-2018 minimum mean daily distance travelled being (M=1.90; SD=1.81) and the 2018-2019 minimum mean daily distance travelled being (M=2.20; SD=3.02), conditions (t=0.83 d.f.= 16, p=0.21). A low minimum daily distance travelled may result from either an individual remaining at roost, during a period and day of bad weather, or potentially from movement not being captured due to the tagging data frequency.

The maximum distance travelled per individual bird though to a greater extent reflects the longer distances travelled during the 2nd winter and catch 2 birds versus catch 1 and the 1st winter. The average of the mean daily maximum distance travelled in catch 1, was 34.2 km and over twice this distance, 76.2 km in catch 2, during the subsequent winter. This is a result of the longer distances covered and in particular movement during the 2nd winter of the majority of the birds from North Norfolk to the Broads, and movements described in 3.3.7 Study area wintering movements: Individual track summary, catch 2.

A like for like comparison of the time period, mid-January to mid-February, allows a direct comparison of each sample and between year variations to be made (Figure 37 and Figure 38). The analysis reveals that during the same period, 15th January, for all birds recorded in the study area until each bird left North Norfolk the average daily distance travelled was almost identical. In catch 1 and therefore the first winter the average daily mean distance travelled was 12.0 km. By comparison, for the same dates, the average daily mean distance travelled in catch 2 and the 2nd winter of the study, from mid-January onwards was 11.7 km.

This direct comparison therefore points to the additional movement and longer distances travelled being recorded taking place during the early winter, i.e., from the catch date on the 1st of December, through to mid-January. These longer distances travelled are evident in the first period of recording and (Figure 36). Both data sets, i.e., both years, where comparable show evidence of either one or two birds making a longer trip, exceeding 60 km, which we know from the mapped movements are to the east and Broads, but these are the exception.

Prior to mid-January, the recorded movements of the birds caught in catch 2, i.e., from the 1st December 2018 through until the 15th January 2019, showed that their average daily movements and distance travelled were around double that recorded post the 15th January, with an average daily distance of 23.2 km travelled versus 11.7 km travelled.

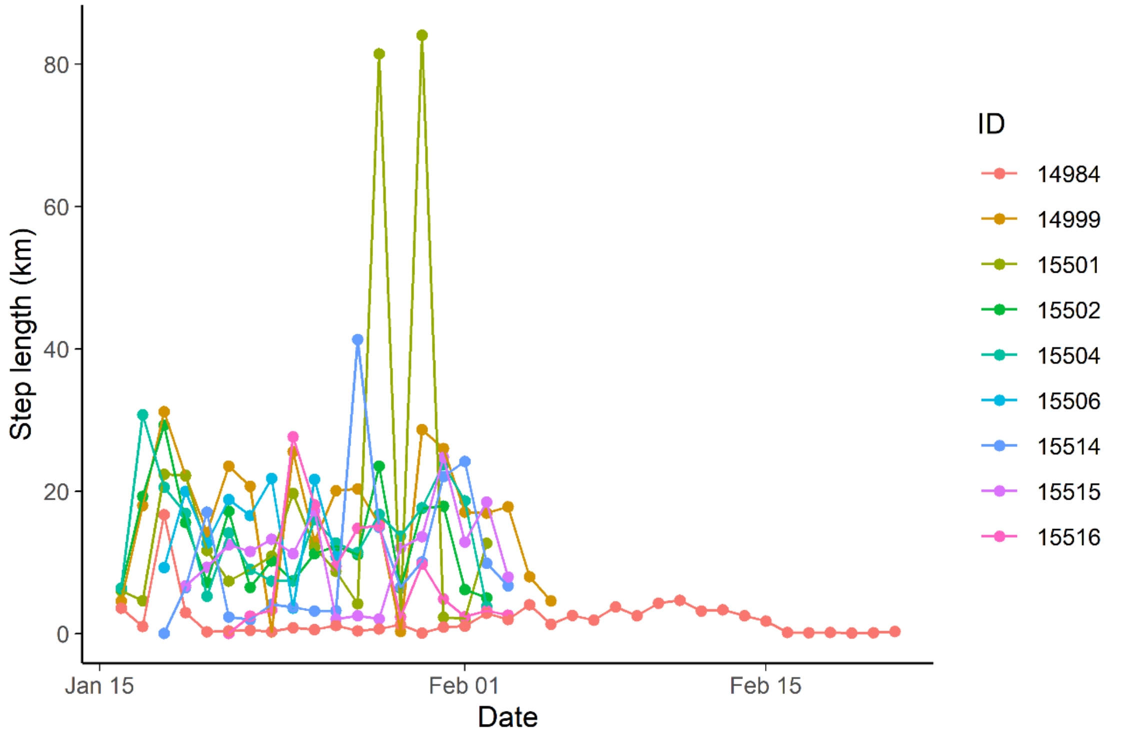

Figure 35: Daily distance travelled, by bird, for all birds caught in January 2018, catch 1

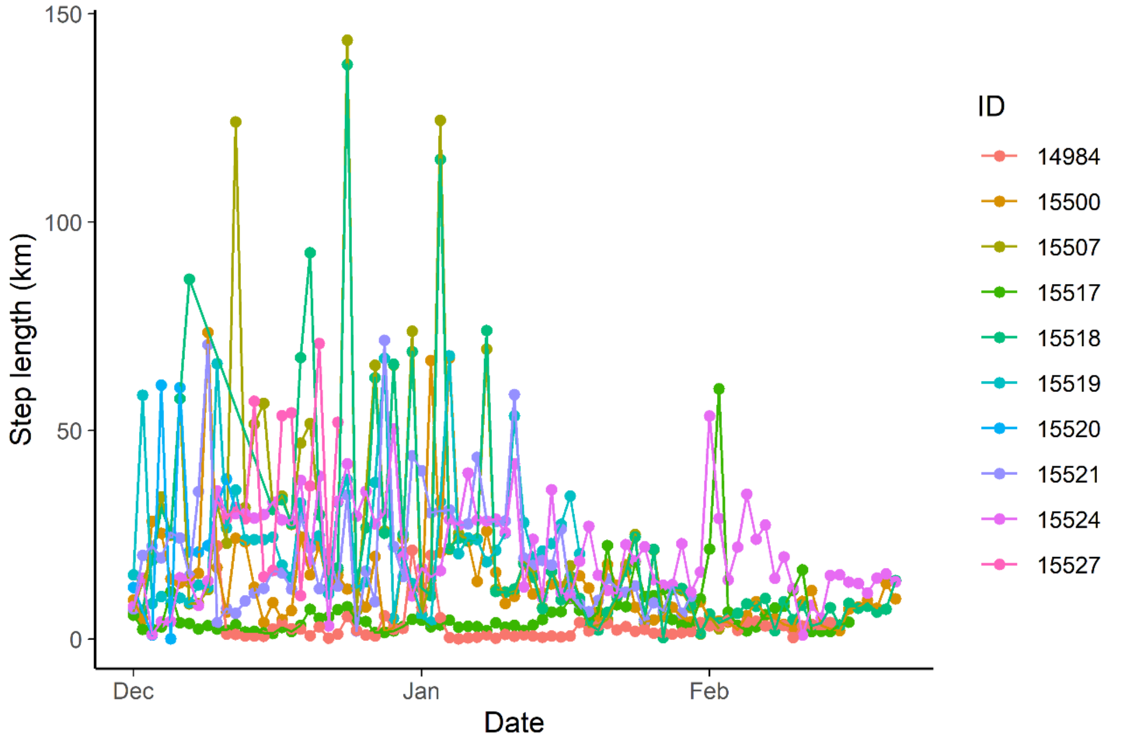

Figure 36: Daily distance travelled, by bird, for all birds caught in December 2018, catch 2

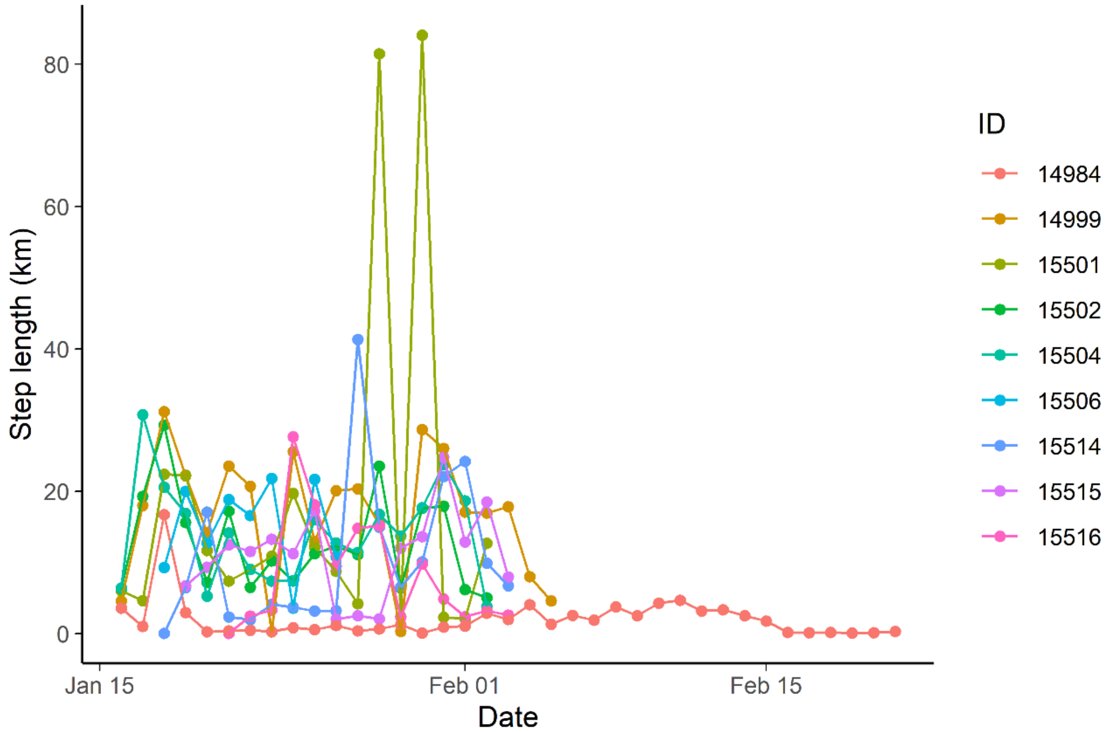

Figure 37: Daily distance travelled, by bird, since January 15th 2018, for birds caught in catch 1

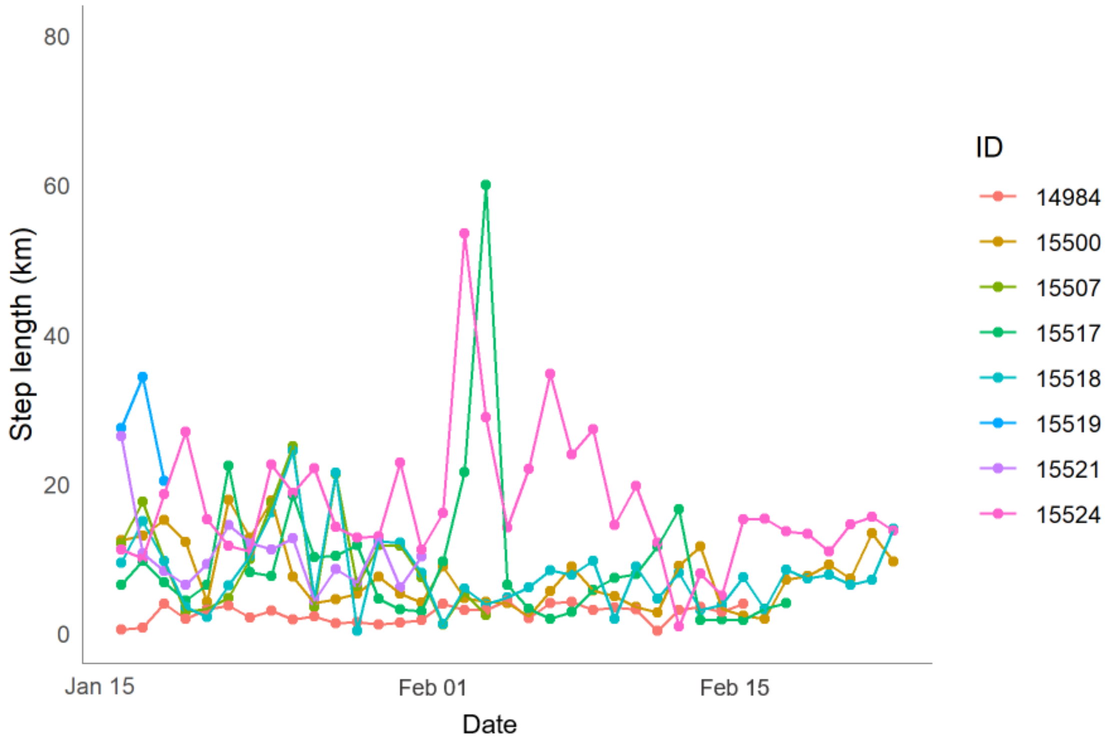

Figure 38: Daily distance travelled, by bird, since January 15th 2019, for birds caught in catch 2

Table 15: Summary of daily distance travelled by bird, catch 1

Tag ID	No. days data	Min distance travelled (Km)	Max distance travelled (Km)	Mean distance travelled (Km)	Mode distance travelled (Km)
14984	37	0.1	16.7	2.0	3.6
14999	22	0.3	31.2	16.6	4.6
15501	18	2.1	84.1	18.0	6.0
15502	18	5.1	29.3	12.8	6.3
15504	18	3.8	30.8	14.0	6.4
15506	9	3.6	21.8	15.0	9.3
15514	17	0.0	41.3	10.5	0.03
15515	16	2.1	24.8	11.1	6.7
15516	14	0.1	27.7	8.3	0.04
Average	18.8	**1.9**	**34.2**	**12.0**	**4.8**

Table 16: Summary of daily distance travelled by bird, catch 2

Tag ID	No. days data	Min distance travelled (Km)	Max distance travelled (Km)	Mean distance travelled (Km)	Mode distance travelled (Km)
14984	68	0.1	22.4	3.0	22.3
15500	83	1.7	73.6	13.3	9.3
15507	63	1.2	143.6	27.7	6.6
15517	77	1.3	60.0	6.0	5.7
15518	83	0.3	137.8	22.4	6.9
15519	49	4.0	68.0	24.6	15.4
15520	12	0.0	60.9	27.3	12.3
15521	61	1.9	71.7	20.6	7.2
15524	83	1.0	53.5	21.1	7.8
15527	14	10.4	70.9	36.0	33.1
Average	59.3	**2.2**	**76.2**	**20.2**	**12.7**

3.4 Discussion

3.4.1 The significance of home range size and knowledge of daily movements

Knowledge of the home range size and daily movements of pink-footed geese tracked during the study in North Norfolk have helped define more accurately than previous studies the species spatial use of the landscape during winter in the UK. GPS technology, and the focus of the study, has enabled suitable data to be collated that quantifies the foraging ranges of pink-footed geese and can contribute towards evaluations of the potential loss of land in environmental assessments. However, there are also other variables that need to be both understood and quantified to complete a comprehensive impact assessment of potential agricultural land loss and the associated loss of suitable foraging resources to be evaluated in relation to the species population size. These include knowledge of the species daily energetic costs and therefore requirements, in part which will include the knowledge of the energetic cost associated with flight for which quantified data in this study detailing the species movements, ranges and daily distances travelled can contribute towards. Similarly, the food resources available within observed ranges can be estimated by assessing the crop coverage within the ranges recorded. Further evidence is reviewed here to help synthesise the knowledge available, including reviewing annual yields in sugar beet, alongside evidence and modelling of energetic requirements, albeit Individual Based Modelling (IBM) techniques are beyond the scope of this study.

3.4.2 Energetics; the cost of flight for pink-footed geese

By further understanding the daily energetic requirements of geese, and their activities, including those incurred during flight, it is possible to interpret the findings of foraging range and daily movements, in context of both the animal's energetic expenditure and needs (Fieberg & Börger, 2012). A review of the knowledge available as regards the daily energetic requirements of pink-footed geese, coupled with analysis of their foraging ranges and also an estimation of the food resources available, in particular sugar beet crop remains, is useful in providing some estimation of the carrying capacity of foraging ranges recorded.

The energy costs of flight for pink-footed geese are high, by comparison with the energy costs of foraging or of resting. The cost of flight, for pink-footed geese is 363.1 kJ hr^{1}, compared to 57.2 kJ hr^{1} of foraging and 53.8 kJ hr^{1} expended during resting (Madsen, 2006). The Daily Energy Expenditure (DEE) for pink-footed geese has been calculated as between 1,057 kJ and 1,076 kJ (Therkildsen, 2000). These values though are considered to be the bare minimum required to meet daily energetic requirements and do not account for the requirements to meet body conditioning and the build-up or storing of body fats. Observational studies of the geese feeding have estimated the actual recorded daily consumption energetic values to be higher than those estimated to be required to meet minimum requirements. The same studies support evidence of greater resource requirements, in particular studies of the comparative energetic values of spring cereal crop versus grassland recorded daily energy values consumed to be between 1,267 kJ and 2,824 kJ, with the higher value associated with cereal crops and the lower value with traditional grassland (Madsen, 1985). Further calculations have estimate that for pink-footed geese the maximum energy assimilation possible, based on body mass and calculations presented by Kirkwood, is 3,595 kJ per day (WWT, 2018 and Kirkwood, 1983). Whilst these results and estimates vary significantly in range, they provide useful values to begin understanding the energetic needs in context of the food resources available.

Further knowledge of the energetic costs associated with flights can also be synthesised from a variety of studies and combined with knowledge gained from this study. Pink-footed geese have previously been shown to forage within 20km of their roost site, as a maximum, 99% of the time, albeit more commonly the distance travelled is less than 10km (Newton Et al.., 1973). We also know that pink-footed geese are estimated to fly at 48km per hour (Duriez Et al.., 2009). Therefore, it is possible to calculate the amount of time it takes to travel at an assumed daily maximum of their range, i.e., 20km at 48km per hour will take an estimated 25 minutes. This allows the energetic flight cost of the distance covered to also be calculated, equating to 150.5 kJ for a 20km flight, which if repeated twice daily, i.e., on an outward and return foraging trip from a fixed roost stie would equate to 301 kJ energetic requirement. This initial estimate, of a total energetic flight cost of 301 KJ, for an individual pink-footed goose represents between 8.4% and 28.5% of the total Daily Energetic Requirements (DEE), applying the lowest and highest estimates of daily energetic requirements (1,057 kJ and 3,595 kJ) presented. To meet this energetic cost, feeding on harvested sugar beet remains would require a pink-footed goose to consume 29.8 grams of sugar beet (dry mass), based on an energetic value of 10.1 KJ g^{-1} dry mass for sugar beet (301 kJ / 10.1 kJ), (WWT, 2018).

Initial estimates therefore can be made as to the amount of food resource required by the geese. However, these estimates are based on only knowledge of the dry mass of sugar beet and there is little evidence to understand what this would equate to as a wet weight, or whether this energetic value is provided solely from the harvested beet root or differs from the energetic value provided from the waste remains available post-harvest of the tops and shoots of harvested sugar beet. Understanding these values and those actually available as a foraging resource are required to more accurately estimate the energetic values of resources available and put into context relative measures derived from published yields per hectare of sugar beet harvesting. However, no knowledge within the literature associated with pink-footed geese or searches of agricultural references provided further data to allow a more accurate assessment and estimate to be undertaken.

Although specific knowledge of the energetic value of harvested sugar beet remains does not exist, one source of data based on agricultural studies did examined the use of sugar beet tops as a potential food resource or silage constituent for which the moisture levels of the tops were calculated as 86.9% (Salo, 1978). This allows an attempt to therefore convert knowledge of the dry mass of sugar beet energetic requirements into a total wet mass, which can in turn be used to contextualise the amount of sugar beet required in context of known harvested yields. By assuming a DEE of 1,076 kJ, an energy value of 10.1 kJ/g, a moisture level of 86.9% and assimilation rate of 0.90% (WWT, 2018), the daily wet food intake has been calculated to be 911g, equivalent to around one third of the mean average body weight for an individual adult pink-footed goose (BTO, 2020).

Equation:

$$Daily\ Food\ Intake\ (wet\ g) = \frac{Daily\ Energy\ Expenditure\ (kJ)}{Energy\ in\ Food\ (kJ\ per\ g)\ x\ (1 - Moisture)\ x\ Assimilation\ Efficiency}$$

Calculation:

$$Daily\ Food\ Intake\ (wet\ g) = \frac{1{,}076\ (kJ)}{10.1\ (kJ\ per\ g)\ x\ (1 - 0.87)\ x\ 0.90}$$

Result: Daily Food Intake (wet g) = 911 g

A value of 911g, equating to around a third of an individual pink-footed goose's body weight seems to be a viable estimate, but to help further validate and compare this result, it is possible to examine other energetic studies on geese species. Studies of White-fronted geese (*Anser albifrons*), have estimated that individual birds will consume between 650 g and 800g of fresh food per day, representing over 25% of their body weight (Owen, 1972). White-fronted geese are very similar in size to pink-footed geese, being only a fraction smaller, according to recorded wing-length comparisons (412mm for White-fronted geese and 434mm for pink-footed geese), albeit insufficient data exists to compare their weights (BTO, 2020). It is though reasonable to assume that their daily energetic requirements and physical size and biology are similar enough to make close comparisons, and therefore an estimate of the weight of daily food consumed equating to around one third of an individual's own body weight seems to be a reasonable estimation and of value to further exploring food resource availability versus needs.

3.4.3 The energetic value of agricultural crops versus natural food resources

Agricultural crops are known to both provide high energetic and nutritional value but are also efficient food resources to consume, require little handling by comparison with traditional food resources (Madsen, 1985). The energetic costs associated with flight are known to be the most expensive energetic costs for pink-footed geese (Madsen & Klaassen, 2006) despite efficiencies in energy expenditure being achieved in flight through flying in V shaped formations (Cutts & Speakman, 1994). Therefore flying, including to and from roosts and foraging areas places high energetic demands on individual birds (Masden Et al.., 2010; Johnson Et al.., 2014). Despite these costs pink-footed geese will undertake flights to forage on agricultural crops to exploit relatively high energy rich resources (Fox, 2005), and the benefits of feeding on both palatable and resource rich crops have long been observed and recognised (Reed, 1976). However, these energetic costs can be increased if both individual birds and flocks are disturbed and have to take flight more frequently (Bélanger & Bédard, 1990).

Evidence shows that the Svalbard population of pink-footed geese have both expanded their range and population size by exploiting nutrient rich winter wheat, which has a high protein content that remains constant throughout the winter and enables the geese to sustain themselves even during colder conditions (Therkildsen, 2000). Winter wheat, by comparison with traditional grasses, can provides almost three times as much protein during winter months (Fox, 2017). Interestingly in the context of the potential conflict between foraging geese and agriculture the consumption of wheat by geese during the early stages of the crop's growth has been shown to not effect crop yield, despite appearing damaged (Flegler, 1987).

Variations in the energetic content of agricultural crops have been shown to exist, ranging from 10.1 KJ g-1 dry mass for sugar beet to a maximum of 15.9 KJ g-1 dry mass for stubble fields and residual grain, followed by 15.1 KJ g-1 dry mass of winter-sewn crops. Both potato and carrot crops offer 14.2 KJ g-1 dry mass energy (WWT, 2018). However, foraging geese do not necessarily select the food resource with the highest energetic value as shown by studies in North Norfolk, where pink-footed geese were shown to favour the harvested remains of sugar beet versus other food resources, despite the relatively lower energetic value to the winter-sewn crops also grown in the area. This habitat choice was extensively studied by J A Gill, during the early 1990's (Gill, 1994 and Gill, 1996), examining why pink-footed geese favoured harvested sugar beet fields. Whilst in the county cereal crops were the most abundant crop type, they provide little winter food resource with stubble fields of spring cereal ploughed in throughout the winter and winter cereal crops only beginning to emerge during the end of geese's wintering stay. Potato and carrot crops are sewn in much lower quantities. Sugar beet crops, during the study, between 1990-1993 accounted for 13% of the fields, two-thirds of which were harvested in November and the remaining third in January onwards. Yet, despite this lower density of crop availability, harvested sugar beet was shown to be the consistent favourite habitat or crop type selected for foraging. Since the residual bio-mass of sugar beet tops has no commercial value there is little or no objection and therefore active discouragement to disturb the geese feeding on it. By comparison, cereal crops are of much higher commercial value, and geese showing an interest and attempting to forage in such crops are actively moved on through scaring, shooting and repetitive disturbance. This is likely to have led to and influenced long term habitat selection and behaviour, albeit is also re-enforced each year through active management. Pink-footed geese selection of food resources is therefore shown to be more complicated than simply selecting the highest energetic value of resource available and has been shown to also be influenced by a much broader range of factors, including proximity to roads, likely disturbance and individual field size (Gill, 1994; Gill, 1996).

Another factor to consider is that whilst different agricultural crops offer varied levels of energetic value, nutrition and fibre, they are not necessarily all available, and in all areas, throughout the UK winter. Returning in early autumn the geese are able to exploit spilt grain on stubble fields, and as observed in Scotland, then subsequently the harvested remains of potato crops in mid-winter, followed by growing cereals in the spring (Newton, 1973). Similarly, in Lancashire, geese feed on stubble fields in early autumn, moving onto the harvested remains of both potato and carrot crops, before also utilising winter cereal and pasture in early spring (Bell, 1988). By comparison in North Norfolk, the use and feeding on harvested sugar beet is most dominant (Gill, 1994). These patterns of use are the result of the timing of availability of each resource, with stubble and grain being available in early autumn, but subsequently ploughed in, and the harvesting of potatoes and root crops occurring in mid-winter, typically following the first frosts. Subsequently the growth of winter cereals can be utilised in late winter, along with grasslands and pasture in early spring.

Pink-footed geese, along with other migratory geese species, require food resources during the winter to maintain body fat. However, these requirements change during late winter and early spring, when body conditioning is more important, prior to and preparing for long distance migratory journeys (Tinkler, 2009). These changing energetic requirements and the changing availability of food resources, as described, are major determinants in driving behaviour and the distribution of the geese during the UK wintering period. As with many migratory species, there are a variety of spring migration strategies adopted by different individuals, families or parties (Van de Kam, 2004). Some may choose to leave the UK early, making substantial flights, whilst others stage their return northwards (Madsen, 2001). Evidence of varied staging strategies are evident from the sample of birds in this study and are presented in section 3.3.1. Adopting a variety of strategies across any species helps reduce the overall dependency on any single strategy, since each have their own advantages and risks, e.g., arriving too early on breeding grounds to find food resources covered by unseasonably high snow cover, versus the opportunity to be on the breeding grounds first and select the most premium breeding site (Duriez, 2009).

The studied habitat selection of migratory pink-footed geese in northern Europe, during stopover, also raises a further key factor influencing habitat selection, and that is of disturbance. During the stopover, the geese will often favour large fields where the predation risk is typically lower, but the nutritional value of the food resource selected are not necessarily the highest available, with the geese making a trade-off between fast re-fuelling and disturbance/predator avoidance (Chudzińska, 2015). The impact of disturbance was a key factor studied in the habitat selection favoured by pink-footed geese during the early 1990's (Gill, 1994 and Gill, 1996), along with the constraints determining winter site use (Gill, 1996). These studies revealed the sensitivity of the geese to feeding in areas where disturbance was high, including proximity to roads, areas in which shooting was undertaken, but also a preference for selecting larger fields, higher in elevation and where sight lines, and hence reduced exposure to predators and danger, were optimal with fewer hedgerows or woodland. The sensitivity to hunting and shooting has further been demonstrated and examined in northern Europe, where attempts to create more attractive areas, or refuges have been undertaken (Casas, 2009). A direct correlation between three variables, proximity to roads, hunting and an open landscape were also concluded to affect the use of foraging areas by pink-footed geese and where if each factor was unfavourable the geese were more likely to take flight, increasing their energetic requirements (Madsen, 1985). Similar studies on Brent geese estimated that disturbance whilst feeding on grass pasture was the cause of 68.9% of all flights taken by the geese and the larger the flock size was, the more prone the geese were to disturbance (Riddington Et al.., 1996).

The energetic demands for pink-footed geese are determined and influenced by a number of factors. It is too simplistic to say that the geese will fly to the nearest and most energy rich food resource each day. Their behaviour has been shown to be affected by a combination of a number of factors, including the timing of harvests, physical features of fields and a proneness or sensitivity to human disturbance. Each of these factors exert additional energetic costs for the birds, increasing the distances they need to travel and potentially too the amount of time they have to move, through disturbance, between areas.

3.4.4 Annual yields of sugar beet

To attempt to contextualise the amount of harvested sugar beet available in any winter for pink-footed geese a review of the annual harvesting yields was undertaken for which British Sugar reported that a total of 8.9 million tonnes of sugar beet was harvested across the winter of 2017/2018 (Day, 2018). This represented a yield of 83.4 tonnes per hectare, which was also a new record in 2018 and higher than the previous record of 79.8 tonnes, as a result of increased efficiencies in harvesting and production, that had delivered increases in yields totalling 25% over the last ten years.

With Norfolk's beet coverage totalling 37,294 hectares, the total yield, based on the average UK yield achieved that year per hectare, can be calculated to be just in excess of 3.1 million tonnes.

Whilst wintering in Norfolk, sugar beet is not the only food resource available for the geese, it has been shown to be clearly favoured, with the geese only spending between 10 and 20% of their time on foraging on winter-sown cereals fields in North Norfolk (Gill, 1994). Cereal crops are much higher in commercial value than sugar beet, generating several times the income per tonne, albeit cannot be grown continuously in the same fields year to year, hence sugar beet is planted in part as a rotational crop.

In Norfolk, during undertaking field work and counts near Weybourne, geese were recorded foraging on large coastal fields, but also frequenting neighbouring fields of winter wheat. To avoid damage of the crops, in a particularly wet December (2017), sugar beet fields were harvested earlier than planned to act as diversionary food resource and to successfully encourage the geese to leave the wheat fields in favour of more profitable sugar beet fields. Elsewhere, where geese were beginning to use wheat fields to gather, in between feeding on adjacent sugar beet fields, farmers actively used scaring tactics to discourage the geese, including the firing of rockets and gas scaring guns. Further knowledge of these movements, not captured by the fix frequencies of the tags deployed in this study, are required to evaluate the cumulative flight distances, including those resulting from disturbance.

3.4.5 The impact of harvesting regimes and harvesting methods

Despite the fact that significant volumes of sugar beet are harvested annually in Norfolk (3.1m tonnes in 2017/2018), pink-footed geese rely on foraging on the bi-product of the harvest, and the remaining waste. The amount of food resource this provides for the geese can vary depending on harvesting machines used, with previous researched comparing the differences of two harvesting methods; the use of armer-harvesters, which lifted entire roots before chopping off the crown, versus flailing harvesters that cut the crowns off from the roots whilst still in the ground, before lifting them (Gill Et al.., 1996b). Armer harvesters were shown to leave significantly more bio-mass in the field versus flailing harvesters. However, the differences did not appear to greatly influence whether the geese selected fields to subsequently forage in or offer any significant relationship between the bio-mass available and the number of days spent foraging. Gill concluded that individual sugar beet fields once harvested were able to support over 2,000 goose/days' worth of profitable foraging per hectare.

Based on the above conclusions, and calculated hectares of sugar beet in Norfolk, totalling 37,294ha, as a county Norfolk has the propensity to support almost 75m individual goose days of foraging (37,294ha*2,000 individual goose days). If each goose spends an estimated 60 days in Norfolk, solely foraging on sugar beet, this would equate to providing suitable foraging for 1.24m individuals (74.58m individual days / 60 days foraging). Between 1990 and 2018, data provided from the WWT IGC counts recorded a mean maximum of 49,437 individuals and a maximum of 78,046 individuals in 2004. This suggests that the available food resource to pink-footed geese, in the form of harvested sugar beet, is not an immediate limiting factor in their wintering number, since their peak number in the county would only utilise around 6% of the food resource available (78,046 individuals/1.24m days available).

However, it is evident from the tracking data that pink-footed geese do not utilise the whole county of Norfolk for foraging, and therefore the above calculations represent an extreme of the food resource available. In fact, in 2018, the fields planted with sugar beet, and within the home ranges measured, totalled 6,489 ha, the equivalent of 17.4% of the total coverage of sugar beet in the county. These fields, totalling 798 in number, are shown in (Figure 34). In 2019 the fields planted with sugar beet, and within the home ranges measured, totalled 25,297 ha, the equivalent of these fields, totalling 3,553 in number, are shown in (Figure 35). If the lower of these two annual home ranges, totalling 6,489 ha is used, the area could potentially provide suitable foraging for 216,300 geese (based on 2,000 goose days per ha, each using any given resource for up to 60 days, i.e., December to January, 6,489*2,000 / 60).

This does though only represent a theoretical maximum population size in relation to resource availability, assuming all fields would be utilised regardless of their size, aspect or proximity to roads, but which are recognised as factors influencing habitat choice by the geese (Gill, 1996). Equally, it is likely that any harvested remains of sugar beet would not remain palatable for the entire winter, possibly degrading in quality following exposure to rain and frosts.

3.4.6 An alternative calculation of the food resources available

It is possible to use a combination of the published yields (83.4 tonnes of sugar beet / ha), the calculated gross hectares available within the home ranges of sugar beet fields (6,489 ha for catch 1 sample), and calculated residual bio masses of sugar beet remains following harvest (111g / gm^2, for flail harvesters and 235 gm^2 for armer harvesters) (Gill, 1994) to calculate an alternative maximum density of geese feasible in the home range area. Such an estimate would aim to be a reasonable best estimate, applying the findings and knowledge reviewed.

If a daily gross weight of 911g of sugar beet remains are required per individual bird, then each bird will require a minimum of 8.2 m^2 to meet its daily energetic requirements (911g/111g). Resultingly each hectare could theoretically support 1,218 goose days (10,000 m^2/8.2 m^2). This estimate is somewhat lower than the 2,000 goose days per hectare presented (Gill Et al.., 1996b). The estimate does though assume a relatively high rate of gross food resource being available, 911g, which may actually in practice be less, by as much as 50% less. The estimate also assumes the lower of the two residual biomasses of sugar beet remains being available from the two harvesting methods, flailing and armer harvesters, with provide 111gm^2 and 235 gm^2 of food resource respectively. Therefore, at the other extreme a hectare may theoretically support a total of 5,164 goose days, if these alternate factors were applied. Equally though, both calculations assume that the entire food resource in any given field or hectare is fully utilised. This would include every m^2, adjacent to hedgerows, field boundaries and as proven less favoured or safe areas in which the geese feed. Through field observations, and previous studies, we known that the geese will not fully utilise all resource on offer, due to their weariness and a combination of these factors (Gill, 1996; Gill Et al.., 2001).

3.4.7 Between year changes in climatic conditions and rainfall

A theory as to why the between year variation in both the ranges and distances travelled by birds in catch 1 versus catch 2, whereby greater movements are recorded in catch 2 is that the birds moved as a response to different climatic conditions. In particular it is hypothesised that higher rainfall may have impacted on the timing of beet harvests and availability of beet tops for foraging resources. This theory was discussed, pers. comm D Lyles, with a local landowner, who suggested that movements away from North Norfolk and to the Broads, occur when sugar beet harvests have been delayed, due to unsuitable harvesting conditions, forcing the geese to travel and find suitable food resources elsewhere. The movements recorded of the birds in catch 2 to the Broads suggest such an attractiveness, but may also be dependent on the amount of rainfall and corresponding water levels to provide suitable safe roosting habitat with proximity to other food resources, including nearby sugar beet. During a heavy winter with high rainfall potato crops can be difficult to fully harvest or harvest efficiently with many potentially being left exposed but unharvested and available as a food resource.

A paired-samples t-test was conducted to determine the significance of the difference in winter rainfall, comparing the mean monthly rainfall recorded between years for the winters of 2017-2018 and 2018-2019 over the months of September to March. There was no significant difference between the 2017-2018 monthly rainfall (M=61.1; SD=25.12) and the 2018-2019 monthly rainfall (M=41.4; SD=12.53), conditions (t=1.93 d.f.= 6, p=0.10).

An examination of the historical meteorological data and monthly rainfall reveals the highest level of monthly rainfall in December 2017 (106.3mm) (Figure 39). This heavy rain was experienced during fieldwork and preparations for an initial catch with the rain directly impacting the planned timings of catches. The high rainfall resulted in winter cereal fields adjacent to the target sugar beet fields for catches at Weybourne becoming heavily saturated and crops being damaged when geese were present in large numbers (>3,000 individuals) as a result of the geese paddling in them. To avoid damage of winter cereal crops the local farm manager at Weybourne lifted sugar beet ahead of schedule during late December ahead of the planned January harvest and in doing so made available sugar beet tops which acted successfully as a diversionary food resource tempting the geese away from the more profitable and commercially sensitive spring cereal crops. Rainfall remained relatively heavy over the winter months, January to March, 2018, by comparison with the same months in 2019. In both winters all remaining sugar beet would have been lifted during this period, providing a food resource in both periods, and correlating to periods of similar mean daily distances travelled.

In the 2nd winter, and October 2018, rainfall was much higher than the prior year, with 58.0 mm versus 23.5 mm of rainfall in 2017. This may have resulted in increased water levels within the Norfolk Broads, and improved the attractiveness of this area, and accounted for the wider ranges and longer distances covered by birds from catch 2 in the second winter.

Truly understanding the individual motivations and decisions made by the geese is a seemingly endless challenge. Hypothesising that water levels in the broads, combined with changes in harvesting regimes and timings in North Norfolk seem reasonable and plausible causes, or motivation, for the geese to relocate between foraging areas. However, these observed movements and potential causes also illustrate the complexities of modelling numerous variables, many of which are in a state of flux, especially environmental factors but also the impact they have on harvest timings and habitat.

Within this study it was impractical to carry out fieldwork to attempt to record the actual timing and harvesting of several hundred individual fields across either the foraging ranges of the birds, calculated to be in excess of 4,600 ha in year 2 or sections of the county which in total include over 37,000 ha of sugar beet crop and thousands of individual fields. Knowledge of which fields the geese were using throughout the study was also not available until the GPS tracking data had been received and analysed, which due to the timing and schedules of downloads, aimed at preserving battery life to record migratory movements, meant that data was often not received until months after the movements occurred. A combination of impractically being able to monitor and record individual fields harvesting dates and an inability to correlate individual birds' movements to specific fields due to the timing of data was a limiting factor in further analysis within this study, but possibly an opportunity for further studies.

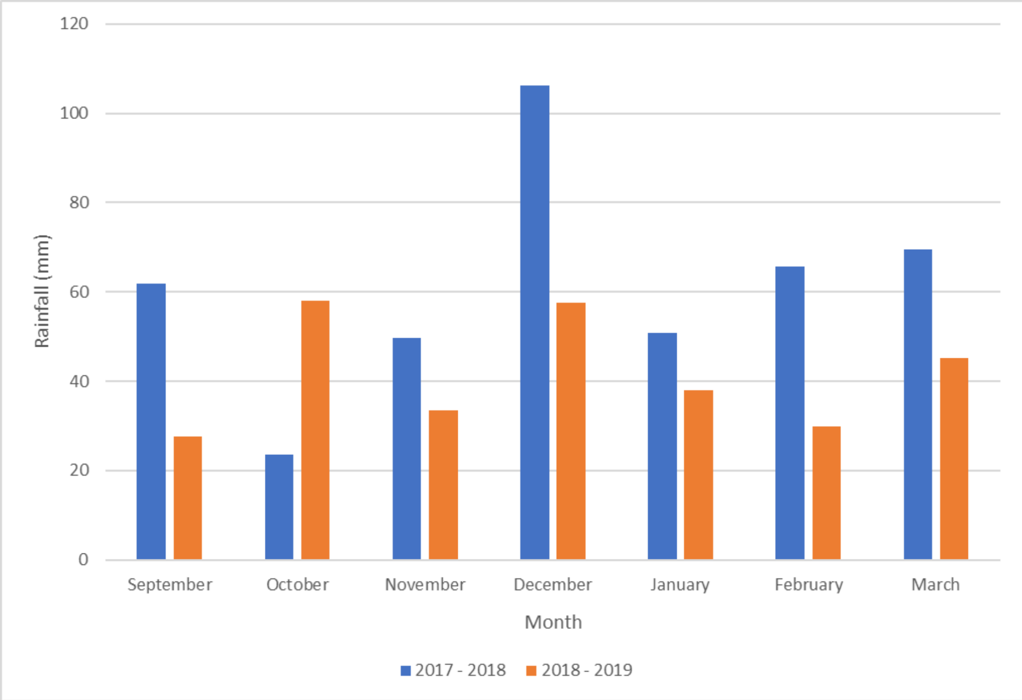

Figure 39: Monthly rainfall (mm) recorded in Lowestoft for the winters of 2017/2018 and 2018/2019 (Met Office, 2020).

3.4.8 Sample size considerations

The fitting of a total of 18 tags to two samples of pink-footed geese is relatively small in consideration of both the total UK population and the wintering population, estimated at 68,560 or more for North Norfolk (Gill, 1997). However, determinants of the feasible size of a target sample include the costs associated with acquiring suitable tags, with individual tags costing in the region of c. £1,000 per tag, plus the operational costs of mounting and organising large catch teams. Furthermore, the sample size permissible to tag is dictated and governed by the BTO Special Methods Panel, who must approve all tagging schemes, and for which numbers tagged in excess of those in this sample are rare. Finally, the catching of pink-footed geese, away from protected reserves and roosts, is notoriously challenging, and the effort substantial in both selecting suitable sites, but mounting and installing cannon nett equipment is laboriously difficult too, requiring the presence of large experienced teams. Each of these factors influenced both the target and final sample sizes achieved, however pink-footed geese are known to move in large flocks and family groups and therefore the movements of individually tagged birds are likely to be a good proxy of the over wintering population in the study area.

Ideally a series of small samples, perhaps of 3-4 birds would have been made from multiple catches at multiple locations, selected from individual catches of 30 or more geese, to which tags would be fitted. Using a stratified sampling approach, as described, would aid the confidence level in the statistical interpretation of the results, in respect of the data representing those of the total population. However, even fitting a single tag to an individual bird, can reveal much about and represent the movements of thousands of individuals within a population (Stockwell & Peterson, 2002). Small sample sizes have revealed valuable data in other tagging studies, aimed at understanding further the movement of specific species, including those of Herring Gulls (*Larus argentatus*), n=2 (Rock et al., 2016), Northern Gannet (Langston et al., 2013), n=32, and Taiga Been Geese (*Anser fabalis fabalis*), n=10 (Mitchell et al., 2016), with the study by Mitchell able to describe both home range size and migratory routes. Practically, in the field, given the time and efforts required and need to utilise large and willing teams, the feasibility of being able to follow any ideal sampling regime, were outweighed by the reality of simply being able to catch any birds, a challenge that has eluded previous studies. Prior to the first catch, it was anticipated that 30 or more birds may be caught in a single fire, or catch, from which selected individuals would be tagged. Since the geese often operate and feed in family groups, one aim was to ensure that only a single bird be tagged from any given family, on the basis that maybe three or four family groups may be caught, along with other unpaired individuals. Whilst efforts were made to attempt to 'bag' birds caught in close proximity and to follow this protocol, in practice from the birds caught the birds weight became the biggest determinant of whether it was tagged. It was anticipated that the average weight of an individual would be 2.81 kg, according to BTO records, which was a determinant of the tag design and weight and a conditional minimum for tagging any individual. However, from the sample catches the average weight was 2.16 kg, i.e., considerably lower and some 650g less than the average anticipated. This resulted in the ability to only deploy tags on the largest, and limited number, of the catch, and primarily on adults (which were not able to be reliably sexed in the field).

Chapter 4 : Final discussion and conclusions

4.1 Population size

The UK wintering population size of pink-footed geese has been shown to now be in excess of half a million individuals (Frost et al., 2019) and to have experienced sustained and significant growth calculated in this study to be equivalent to 3.1% annual compound growth between 1990-2018. Whilst a number of factors have been shown to benefit pink-footed geese and to have contributed to this growth, including climatic change, less snow cover on Icelandic breeding grounds and greater productivity (Fox et al., 1989a; Kery et al., 2006; Madsen et al., 2007; Jensen et al., 2008) one of the main causes of population growth is the adoption of agricultural crops as a food resource, since these have been shown to be both abundant, nutritional and of comparative high energetic value (Reed, 1976; Therkildsen & Madsen, 2000; Fox et al., 2005; Fox & Bergersen, 2005; Tinkler et al., 2009). These changes have also benefitted other avian herbivore species, such as the Icelandic population of Whooper Swan (*Cygnus cygnus*), which like the pink-footed goose breeds in Iceland and winters primarily in Britain and Ireland (Cranswick et al., 2002). Both this similarity, and others, shared between Whooper Swan and pink-footed geese are useful for comparing changes in an avian herbivore species breeding in Iceland and wintering in the UK. This comparison is aided by the fact that like pink-footed geese, Whooper Swans have also been studied in the UK since the 1960's (Boyd & Eltringham, 1962) and consistently by the WWT (Robinson JA, 2004). Whilst the geographic range of Whooper swan is greater than that of pink-footed geese, with a total population estimate of 34,004 individuals and growing significantly across its range, 155% since 1995 (Hall et al., 2012; Hall et al., 2016), the Icelandic UK population of Whooper Swan is not as considerable a size as that of pink-footed geese, totalling and estimated 20,645 individuals following the January 2000 UK census count (Cranswick et al., 2002). However, like the pink-footed goose the population Icelandic Whooper Swans wintering in the UK have experienced significant long-term growth, equivalent to 210% over the last 25 years (Frost et al., 2019). The growth of the UK Whooper Swan population has also largely been attributed to the benefits of feeding on agricultural cropped land versus natural vegetation and has been observed occurring since the 1970's (Cadbury, 1975; Owen & Cadbury, 1975). Whooper Swans reliance on cropped arable land for foraging resources is not as great as pink-footed geese with the species still relying on the importance of natural and improved pasture, where they spend over 80% of their time feeding, often on improved or flooded pasture adjacent to permanent inland waters (Robinson JA, 2004). Similar to pink-footed geese, Whooper Swans are subject to anthropogenic mortality, despite being legally protected throughout their range with an estimated 13% of the population shot each year (Newth et al., 2011), albeit this level of hunting has not stemmed a continued increase in the total population size.

Since Whooper Swans spend less than 15% of their time foraging on arable land during winter (Rees et al., 1997) their presence is less likely to result in agricultural conflict than other species (Robinson JA, 2004). A rise in pink-footed geese populations that are more heavily dependent on agricultural crops and their harvested remains is though more likely to bring the species into increased conflict with farmers (Fox & Madsen, 2017). Rises in population levels of pink-footed geese in Northern Europe has given rise to attempts to manage numbers through the creation of diversionary habitats (Koffijberg et al., 2017) and in the UK, warranted the Scottish Executive to undertake a wider review and an examination of the need to manage the differing interests of conservation and commercial land use (Bainbridge, 2017). The call for more balanced goose populations in relation to their ecological impact and ecosystem services is a concern shared worldwide (Buij et al., 2017). The rising numbers have also given increased concern to aviation safety and the possible collision risk (Bradbeer et al., 2017). However, the management or sustained harvesting levels required to manage geese populations in the UK have been identified to be too significant to be politically palatable, especially since each species is also offered legal protection, with one estimate suggesting that around 40,000 pink-footed geese would need to be shot annually to limit the future population growth (Cope et al., 2005). Despite these pressures, for conservation it is still important to consider what predictions can be made around the future population size of geese species. This includes the future population size of pink-footed geese, which given that they are now also largely dependable on agricultural food resources are therefore also potentially vulnerable to any changes in agricultural practice and policy that may deprive them of those resources (Tombre et al., 2005).

Predicting future population sizes is complex and requires a greater understanding of the species population dynamics (Madsen & Cracknell, 1999) and an understanding of whether future climatic changes will continue to influence the species breeding range, productivity and survival rates (Jensen et al., 2008).

4.2 Population distribution

An examination and mapping of the temporal distribution of wintering pink-footed geese across the UK between 1990 and 2018 showed that whilst the population size increased significantly during this period the temporal distribution remained relatively constant. The number of new sites at which internationally important numbers were recorded, >2,250, (Rose & Scott, 1997) increased only marginally from 118 to 129 between 1990 and 2018.

Predominantly, rather than expanding in range across the UK, or exhibiting a southerly range shift, the increased numbers of pink-footed geese were recorded at existing sites with the number of sites recording higher abundances of international importance more than doubling and concentrations of these higher abundancies being estimated at a total of 75 sites. These 75 sites accounted for 80% of all the pink-footed geese estimated during the IGC annual counts. To an extent, it is important to acknowledge that these abundance and distribution patterns are in part limited by the timing of the IGC count data collated in the month of October and are unlikely to reflect the full temporal wintering distribution in the absence of monthly winter counts being conducted. Monthly counts, whilst ideal for exploring correlations in the changes of spatial and temporal distributions in relation to changes in land use and crop availability would require significant resource to co-ordinate and undertake. However, should such data become available it would facilitate analysis including the application of Spatial Distribution Models (SDM) that can incorporate ecological theory with migratory and population dynamics and further ecological factors to examine distribution changes (Guisan & Thuiller, 2005).

Again, as regards the spatial distribution of pink-footed geese, there are useful comparisons to be made with those of UK wintering Icelandic Whooper Swans. The increasing population of Whooper Swans have been estimated to be increasing in number and concentrations at existing sites with 44% of the British estimated population recorded at 20 SPA sites (Stroud, 2001). The largest populations of Whooper Swan are recorded at the Wildfowl and Wetland Trusts centres of Caerlaverock (Dumfries and Galloway), Martin Mere (Lancashire) and Welney (Cambridgeshire), with over a 1,000 individuals being recorded at each site (Robinson JA, 2004), albeit the supplementary feeding of the swans at these sites is likely to contribute to the individuals presence in such numbers. Whilst Whooper Swans favour freshwater sites and in surrounding areas from these sites they too have proved to be highly mobile (Rees et al., 1997) and predicted not to be significantly impacted by losses of food resources in those areas (Wood et al., 2021). Further modelling of warming climatic change and scenarios also suggests that the current network of SPAs in the UK is likely to remain sufficient for the species currently listed as qualifying features (Johnston et al., 2013). Both rises in the population size of pink-footed geese in the UK and limited evidence of range expansion therefore can be considered reasonable evidence that the geese are not yet constrained by the food resources accessible from those sites. However, to satisfactorily reach such conclusions requires further evidence and knowledge of both the foraging ranges and food resources available.

4.3 Population wintering foraging ranges and movements

The advent and use of GPS tracking technology has provided the opportunity to collate, study and analyse a great wealth of ecological data in relation to an individual bird's movements and migratory behaviour (Fiedler, 2009; López-López, 2016). The capture, and fitting of GPS / GSM neck collar tags, to a total of 18 individual pink-footed geese, caught across two cohort samples, both in North Norfolk, has enabled evidence of the species wintering foraging ranges to be calculated. The ranges recorded and estimated to be 100.8 km^2 at 90% KBBM probability, in catch 1 from birds caught in January 2018 are greater than the estimates previously derived by Giroux, of between 21km^2 and 69km^2, based on observations and radio tracking of single individuals in Perthshire, Scotland (Giroux & Patterson, 1995). Albeit the foraging ranges recorded from birds in catch 2, caught in December 2018 are within the previous estimates derived by Giroux, since they were calculated to be 46.2 km^2 at 90% KBBM. The results of this study, whilst demonstrating a high degree of individual variability do provide the greatest evidence of the foraging ranges of pink-footed geese collated to date due to the studies greater sample size, *n*=18, and ability to track all individuals continuously using GPS tracking technology versus smaller samples, *n*=10 and limited radio tracking in previous studies (Giroux, 1991; Giroux & Patterson, 1995).

The between years variability in the ranges observed and movements recorded illustrate individual birds' willingness and ability to range extensively to presumably seek out suitable foraging resources, with ranges recorded in the second winter of the study extending to 372.3 km^2, at 50% KBBM probability. Between year variances were examined undertaking a statistical analysis of the temporal movements on a like for like time basis, between years, to ensure that they were not the result of improvements in the tagging capabilities achieved where greater level of fixes were achieved of birds in catch 2. Individual variations in the foraging ranges were also noted and show that individual birds are able to forage, presumably successfully, within both relatively small areas (7.6 km^2 minimum, 50% KBBM, Tag 15517 catch 1, tracked for 77 days) recorded, but also utilise larger foraging areas (43.3 km^2 minimum, 50% KBBM, Tag 15518, tracked for 83 days). Further exploration of the data and mapping of foraging ranges also demonstrates how individuals are capable of utilising much greater ranges (795.8 km2, maximum, 90% KBBM, Tag 15518, tracked for 83 days), and both their ability and willingness to relocate to different foraging areas.

The fact that the majority of individual birds tracked (7 out of 9) from catch 2, during December 2018, relocated during the month to either the North Norfolk broad, Great Yarmouth area or Hickling Broads, a substantial distance, >80km, from their original point of capture near Burnham Market, suggests also further evidence of a mobile species. This mobility is likely to result from individuals seeking out both suitable and available food resources outside their favoured areas, e.g., moving from North Norfolk to the Norfolk Broads, a distance of over 80km, likely due to between year variations in the timing of harvests and meteorological influences.

The mean daily flight distances recorded by individual pink-footed geese largely concur with historic studies (Newton & Campbell, 1973; Giroux & Patterson, 1995), with the mean daily distance travelled being 12.0 km (catch 1) and 20 km (catch 2). Given these distances will include movement and a flight away from the roost, and also a return to roost, then in effect the minimum distance travelled each day will be half of these figures, i.e., between 6 km and 10 km. This is consistent with estimates of foraging ranges being predominantly <10 km from the roost (85% of the time) and nearly always <20km (99% of the time) (Newton et al.., 1973). The finding is also consistent with Giroux's study where patterns of foraging were reported as predominantly within 10km of the roost site, and more commonly within 5km (Giroux & Patterson, 1995). For all birds tagged, there was a demonstrable fidelity and use of coastal roost sites, predominantly at well-known locations within the North Norfolk SPA, which is consistent with previous radio tracking studies of the species in Scotland (Giroux, 1991).

By comparison with both historical studies, the GPS tagging and tracking of individual birds in this study provides greater evidence of the foraging ranges and daily movements of pink-footed geese that can be further applied in IBM modelling and assessments of the species in relation to potential land-loss. Such modelling though requires further understanding of the species energetics.

4.4 Energetic modelling

A limited attempt to understand the energetic costs and energetic resources available to pink-footed geese, derived from the daily distances travelled by individual birds and the food resources available to them within the study area were made but require more detailed data and IBM modelling to satisfactorily complete.

The energetic costs of flight were considered for an observed daily flight distance of 20 km (average mean daily distance travelled for individuals in catch 2), which totalled 25 minutes and which equated to an estimated energetic cost of 301kj, or 23.7% of the 1,267kj daily energetic requirements considered necessary for pink-footed goose. Whilst the mean daily distances travelled were recorded, they are subject to limitations in the sampling frequency and need to obtain sufficient tagging fixes capable of capturing all movements and flights undertaken by individual birds. In particular potential series of shorter movements, resulting from disturbance or the geese moving between foraging areas are likely to have not been recorded due to insufficient tagging fix frequency in this study and maximum interval of two hours being achieved. Equally it is important to recognise the energetic costs associated with these shorter flights and repetitive take-offs are likely to be comparatively higher than those associated with one longer flight, and are likely to therefore be a further underestimate of the total energetic costs estimated (Johnson et al., 2014).

An initial examination of the crop coverage for North Norfolk, and in particular the coverage of sugar beet, suggests there is sufficient gross availability of the crop to support a continued increase in numbers of pink-footed geese. A staggering 3.1m tonnes of sugar beet, excluding the bi-product or waste tops which are not quantified, are harvested across the county, of which around 17.4% is harvested within the defined home ranges of pink-footed geese caught in year 1 of the study (Day, 2018). A crude estimation suggests that within this home range area such coverage could support 216,300 pink-footed geese for a period of sixty days. Of course, this calculation would require the geese to be able to exploit all the resources available, both utilising every field, but also every m^2 of the field. It also assumes that these resources would all be available throughout the sixty-day period, or at least a constant rolling availability of the harvested sugar beet remains on the field tops. An assumption is also made that all the food resources available would be selected and consumed and that no allowance for preferences such as the selection of sugar beet remains based on size, and resulting handling time and profitability occur.

In practice, we know that pink-footed geese exhibit clear habitat choice preferences, and that not all fields would be selected, in particular smaller fields prone to disturbance, or adjacent to woodland, busy roads or other perceived threats (Madsen, 1985; Bélanger & Bédard, 1990; Gill, 1996; Gill et al., 2001). It would be possible to further examine and review the individual size of each field and its proximity to a number of these variables, and so evaluate and determine the number of fields likely to be used, versus fields unlikely to be selected. A more realistic appraisal of individual fields suitability and further analysis of this is beyond the scope of this study, but would be of merit. However, it is equally important to recognise that the geese have been shown to be both able and willing to move significant distances each day to find suitable food resources, in particular illustrated by the early wintering movements recorded by pink-footed geese caught in year 2. This may suggest that actually an ever-increasing population within North Norfolk would be willing to fly further to find and exploit available food resources. Such movements would require flights further inland and further away from coastal roosts, both of which have been observed during analysis of the geese caught in year 2. Equally harvested sugar beet is not the only food resource available in North Norfolk. Although sugar beet has been favoured by the geese, there are both natural food resources available, such as grazing marshland in the Broads, and also other crops, such as potatoes and carrots, albeit both have less crop coverage. Analysis and a review of the wider movements throughout the UK also illustrates both the ability and willingness of pink-footed geese to move between large areas, and even return to areas previously visited, e.g., moving across country east to west and then returning east, or flying to the borders in Scotland, only to move south again into England. The ability of the geese to undertake these movements, in relatively little time, demonstrates their physiological capability, indicative of their adaptability in seeking out and exploiting resources available across a much wider landscape. A detailed IBM study of Whooper Swan, Mute Swan and Bewick's Swan in relation to the loss or changes in food resourced and competition suggests that for these species predicted changes in the UK winter food resources are not likely to limit their population size (Wood et al., 2021) and that the species had considerable capacity to buffer against losses of food resources. Given both the mobility and adaptability of pink-footed geese to seek out varying food resources it is reasonable to predict that their population size too would be limited by anything in the UK other than substantial agricultural land use change.

4.5 The significance of the findings for conservation

The findings in this study have the potential to influence the monitoring requirements and assessment of pink-footed geese by Statutory Nature Conservation Bodies (SNCBs), including Natural England, for whom the assessment of the potential impacts any anthropogenic activities may have on the population size is a legal requirement (Phillips, 2015). The significance of the findings challenges to an extent the current assumptions around the species foraging ranges and the use of a 30km impact risk zone and area radiating from Specially Protected Areas (SPAs), such as the North Norfolk Coast SPA. Currently any development resulting in a change of land-use that would result in the loss of agricultural land deemed as functionally-linked to an SPA (De Chazal & Rounsevell, 2009; Chapman & Tyldesley, 2016) and within an impact risk zone requires the undertaking a Habitats Regulation Assessment (HRA) cand statutory consultation. The premise of this assessment is the assessment is that the geese are dependable on the food resources available within the defined area. However, the movements of pink-footed geese in this study have shown the species to be varied, with individual birds likely responding to local food resource availability and willing to travel and repeatedly move far greater distances than the pre-cautionary 30km defined for assessment within an impact risk area. Whilst the mean foraging ranges recorded were within the defined impact risk area (12km in catch 1 and 20.2km in catch 2), the maximum distances recorded were much greater (34.2km in catch 1 and 76.2km in catch 2), and individual birds were recorded, particularly from catch 2 moving from North Norfolk to the Broads and back throughout their wintering stay. If the evidence of these wider movements and seemingly willingness to re-locate, multiple times throughout any winter to seek alternate foraging resources, were incorporated into modelling associated with an assessment of the species then the need for statutory consultation may be lessened or re-defined.

Another consideration for SNCBs is the potential for any changes in the UK wintering distribution of pink-footed geese arising from longer term agricultural changes, e.g., a change in the harvesting practices of sugar-beet in North Norfolk, and or a decline in sugar-beet growing as a crop, could result in a reduced use and numbers of pink-footed geese wintering in North. In North Norfolk this is a key consideration for Natural England, but would equally apply to other SNCBs throughout the geese's wintering range, Nature Scotland. This is because pink-footed geese and their numbers are protected at individual SPA sites rather than necessarily throughout their wintering range. E.g., none-breeding pink-footed geese are a qualifying species of the North Norfolk Coast SPA, identified and listed as a feature species when the site was classified in 1989, Natural England (2021), Designated Sites View https://designatedsites.naturalengland.org.uk. The published site conservation objectives for the North Norfolk Coast SPA include the need to maintain or restore the populations of each of the qualifying features, including those of pink-footed geese and these objectives are bound by law under the EU Birds Directive within the Habitat Regulations. Therefore, if there were to be significant future changes in the UK wintering distribution of pink-footed geese that may result in the lower presence of their numbers at individual SPAs, SNCBs may be considered to be not meeting their conservation objectives, even if the total population size remained stable or even continued to increase. It is therefore argued that a consideration of any potential changes in UK wintering distribution relating to other factors, e.g., change in agriculture is of value for SNCBs in their on-going assessment and understanding of the species, aside from the development of both on-shore and off-shore wind, which have presented new potential risks to the species population, that have required such assessment (Langston & Pullan, 2004; Percival, 2005; Hüppop et al., 2006; Houghton, 2009; Furness et al., 2013).

4.6 Recommendations and priorities for further research

The successful capture of pink-footed geese in North Norfolk during this study, away from protected reserves and roost sites, is a great achievement a first for the county, despite other historical attempts. The tagging of pink-footed geese in this study was also the first study to involve GPS tagging of individuals believed to be associated with migratory movements along the east coast of the UK and the analysis of the movements of 18 individuals has revealed much about the species annual migration pattern but specifically has quantified the species daily movements, flight distances undertaken and foraging ranges. However, there are a number of both refinements to this study and evidence gaps that exist in our knowledge of the geese that would benefit from further research. Following is an attempt to specify these in a priority order deemed to be of greatest value to the ongoing assessment of the conservation value of pink-footed geese.

4.6.1 Assessment of changes in agricultural practices and food resource availability

Within North Norfolk it is evident that different harvesting practices for sugar-beet are being employed to deliver ever greater harvest yields (Gill et al., 1996; Kenter et al., 2006; Day, 2018). In addition, changing harvesting regimes, i.e., the sowing of different crops in varying agricultural coverages and the subsequent timing of their harvest and use of the land all have the potential to affect the food resources available to pink-footed geese. In particular a rise in the trend of sowing winter cereal crops (Cerkal et al., 2001) may be reducing the duration any harvested sugar beet remains are actually available as a food resource before being ploughed in. This gives rise to concerns as regarding the food resource availability of sugar beet in North Norfolk in relation to how much sugar beet is being sown, how much of that resource is actually being left post-harvest and for how long that resource is actually available. Further quantification of these changes is required to undertake more comprehensive modelling of the impacts in relation to the species population size and on-going conservation (Börger et al., 2006b; Fox & Abraham, 2017).

To understand these impacts further and to be able to quantify any resulting changes it is considered important to assess:

- i) Annual changes and trends in the crop type coverage, in particular that of sugar beet.
- ii) The extent to which modern harvesting practices versus more traditional techniques are being utilised to harvest sugar beet and are likely to change in the future.
- iii) The relative residual bio-mass available following the harvesting of sugar beet using differing harvesting practices.
- iv) Quantification of the energetic value of any residual sugar beet bio-mass, based on evidence of the plant parts consumed by the geese versus the energetic value of the root crop.

v) An assessment of the duration any harvested sugar beet remains are available as a food resource before being ploughed in, i.e., before other crops are sown or the fields are ploughed versus historically being left until spring.

4.6.2 Greater knowledge of daily flight duration and associated energetic costs

The tagging of 18 individual pink-footed geese and recording of their movements over two winters has provided new insights and valuable quantifiable data that can contribute to on-going assessment and conservation of the species. However, the tag's deployed in this study had limitations in their capabilities, and like much of technology, have subsequently been superseded by telemetry devices with far greater capabilities, include those capable of tracking and estimating both flight speed and flight heights and deployed on wildfowl (Green et al., 2019) or those deployed on large gulls to study fine scale temporal movements (Thaxter et al., 2019). It is therefore recommended that future studies utilise tags capable of recording positional fix frequencies with greater frequency and also ideally incorporating accelerometers to aid study and assessment of the bird's behaviour, in particular whether they are foraging or loafing. These advances will greatly improve the accuracy in the total daily distances travelled and total likely energetic costs of flight, which combined with knowledge of greater knowledge of the energetic food resources both available and consumed will allow robust Individual Based Models to be built and run, similar to those built to assess changes in Berwick's Swan populations in relation to changing food availability (Wood et al., 2021).

Specifically, the tags deployed in this study were able to capture movements on a relatively limited schedule (8-hour interval, catch 1, and 2-hour interval, catch 2). However, to truly capture all significant movements undertaken by individual geese, and to correlate these to habitats and also the bird's activities, individual birds would benefit from the fitting of tags with fix schedules able to capture movement in increments of minutes, rather than hours. Due to the rapid development of tag design and capability, tags suitable for fitting to geese now are capable of recording such movements and also incorporating the ability to geo-fence study areas. A greater fix frequency would enable a more accurate recording of the total flight distances undertaken each day, capturing smaller movements, possibly arising from disturbance, and therefore record more accurately estimations of the energy expenditure costs and resulting energy needs from flying activities. Consideration should also be given to the use of GPS geofencing techniques that can optimise the amount of data collated within a defined study area by only collecting high fix frequency data when an individual animal is within a defined geofenced area and thereby optimising the use of finite battery powers efficiently (Sheppard et al., 2015) and recommended for studies contributing towards Environmental Impact Assessments (Largey et al.).

To understand whether an individual is foraging, loafing or at roost, it would be of scientific value to incorporate accelerometer functionality into any device deployed which would be capable of capturing movements, interpreted and associated with core behaviours and activities. The use of accelerometers has successfully been used to monitor Greenland white-fronted geese, and compare feeding and migration strategies between two cohorts of the population, one wintering in Ireland and the other in Scotland (Weegman et al., 2017) and also Brent geese (Dokter et al., 2018). Incorporation of accelerometers does add weight to GPS tagging units, resulting with a trade-off with other functionality, including battery life and fix frequency, albeit is increasingly likely to be able to be successfully incorporated as tag designs improve (Mitchell et al., 2019). The combined gains in both fix frequency and the understanding and recording of core behaviour would also enable greater and more complex modelling range analysis to be undertaken (Börger et al., 2006a; Mills et al., 2006; Fischer et al., 2013).

In addition to fitting telemetry devices with greater capability it would be of benefit to increase the sample size of future studies, and to ideally capture and tag birds from different sample populations. Whilst funds existed to potentially source and deploy up to 50 tags, the approval and pre-cautionary licensing by the BTO SMTP, limited the deployment of tags to 18 units until further evidence could be provided of their safety. The fitting of GPS tags to greater sample sizes would also allow a more thorough sampling regime of the target population, and also enable more stratified sampling of birds from potentially different sub-populations, caught in different locations; family parties; adults and juveniles (Börger et al., 2006a). This would require greater fieldwork, in-field monitoring, planning of catches and the willingness and availability of licensed individuals and ringing teams to attempt multiple catches.

4.6.3 Assessment of the winter foraging ranges outside of North Norfolk

Whilst this study focussed on the wintering movements of pink-footed geese during their stay in North Norfolk, it is evident from the tagging movements recorded that individual birds have differing migration strategies, including different timings of migration and different staging throughout the UK. The wider movements of pink-footed geese also include the utilisation of differing areas and differing food resources, e.g., the feeding on autumn stubble, other root crops and grasslands. This study has discussed the potential impacts of changes in agricultural practices primarily related to sugar beet growing and harvesting in North Norfolk, but would be of equal value to also study the wintering movements, daily distances travelled and both the energetic value and availability of other food resources throughout the UK wintering range. This would be particularly relevant if one or more of the food resources currently selected were to become less abundant and available in much lower quantities, e.g., reduced crop coverage of sugar beet in North Norfolk, and / or reduced harvested remains, which are likely to put pressure on the population to seek alternate food resources. Therefore, it is considered of value to assess the widescale UK crop coverage and any long-term trends or changes occurring in connection to those specifically occurring in North Norfolk.

4.6.4 Greater understanding of factors affecting the species population dynamics

A number of factors have been identified as contributing to the species population growth, including changes on the breeding grounds and declines in hunting (Kery et al., 2006; Madsen et al., 2007; Jensen et al., 2008; Clausen et al., 2017). However, it has been identified that there is no comprehensive understanding of the population processes that have contributed to these increases, especially those occurring during breeding in Iceland and Greenland and including an assessment of breeding success, and monitoring of movements and mortality patterns (Madsen & Cracknell, 1999). Increased use of telemetry and marking will aid gathering further evidence along with potentially the use of other remote sensing technologies, e.g., the long-term monitoring of changes in high arctic snow cover, habitat change, and the exposure of suitable nesting areas can be more readily assessed through the use of advancements in remote sensing techniques, the use of aerial imagery, satellite and LIDAR (Robinson et al., 1993; Gottschalk et al., 2005). Whilst these technologies are not as exciting for the field researcher as being able to fly over large river systems in Iceland by helicopter, and coral and catch fledged and flightless goslings, they offer great capability in being able to quantify ongoing changes affecting breeding range (Madsen et al., 1992; Mehlum, 1998). More broadly greater knowledge and evidence is required as to the ecology of pink-footed geese, their annual productivity, survival and mortality. A species review conducted by the WWT also concludes that more detailed regular information on breeding success (number of pairs attempting to breed and brood size at or around fledging) would aid refinement of population models (Mitchell, 2004), albeit it is also recognised that the logistical difficulties of collecting such data are, however, significant. Lastly, as regards population dynamics and ecology many of the factors discussed also need to be considered for other species competing for the same resources, especially those on the breeding grounds in order to assess future limitations to growth.

4.7 A species of conservation concern?

Despite the significant and sustained growth in population pink-footed geese remain a species of conservation concern, with amber status in the UK, due their confined global range and concentration of wintering numbers (Eaton et al., 2015). As such pink-footed geese remain on the 'watch' list for SNCBs, and are an ongoing consideration in evaluating proposed developments, such as off-shore wind-farms and on-shore developments, in particular changes in land use.

The rise in abundance, presented by Fox and Madsen, who describe how the population has risen from 'threatened species to super-abundance' (Fox & Madsen, 2017) raises questions as to the merit of their conservation status, or certainly the focus placed on them. Stroud, summarises the issue well, saying 'The hard truth for conservationists is that the current laissez-faire approach to these increasing populations is becoming ever more difficult to justify – ecologically, economically and politically' and that 'there is a very real risk that continued uncontrolled growth of goose populations will trigger irrational and spontaneous political responses – to the detriment of wider conservation objectives' (Stroud et al., 2016), with details of attempts in Northern Europe to actively manage the population of Svalbard pink-footed geese to between 50-70,000 in number presented.

In North Norfolk pink-footed geese are synonymous with the wintering landscape where their movements are part of a true wildlife spectacle and occur in a part of the world where eco-tourism associated with the saltmarshes and coastline are depicted by professional artists and amateur fieldworkers (McCallum, 2001; 2009). Locally there are many farmers who equally see value in their role of supporting and providing food and who will actively consider both the planting and harvesting regime of suitable crops in a way that supports a species they too adore (*pers*. comms Paul Middleton and David Lyles). Whether this same fondness will continue to exist if the population continues to rise, remains to be seen. Equally too pink-footed geese are distributed throughout the UK in many areas where there is not the same level of local passion and eco-tourism.

4.8 Overall conclusion

Evidence of sustained population growth of pink-footed geese is compelling. Growth has resulted from increases in productivity, through the species ability to expand its breeding success in Iceland, reduced hunting mortality, and increased survival through the adaptability of foraging on abundant agricultural crops during the winter. It appears, that the adaptability of pink-footed geese, which through study of their movements, are shown to be highly mobile, that the immediate continued growth in population is not materially limited by the availability of abundant agricultural crops, in the UK. Despite the challenges of foraging in adverse weather, and seasons where the availability and abundance of food resources are influenced by the timing of harvests of favoured crops, the geese are shown to be highly adaptable. Growth in the population size has not resulted in material wintering range expansion, or the adoption of new sites, but has largely resulted in increased numbers of geese at existing individual sites. Analysis of their movements has shown that while they are able to successfully operate in small winter foraging ranges, they are equally able to adapt and move when required, considerable distances, to seek and exploit alternate resources. These movements are also recorded and illustrated outside of the immediate study areas, with individuals moving both cross country and on occasion returning south from initial northerly staging. As a result, given the size of the agricultural crop cover in the UK, and the adaptability of the geese, the loss of local agricultural crops would need to be very significant to have negative impacts on the population size. The use of the results of the defined foraging ranges and daily distances travelled should enable further modelling of any potential impacts on the species population, used when analysing local populations in areas under consideration for development and change in land use. Refinements in the modelling accuracy and predictions would benefit from a greater understanding of other variables, including; changes to harvest regimes; analysis of the quantity of available edible bio-mass available. Equally too, IBM modelling accuracy would benefit from even richer data collation and deployment of the latest tagging technologies, in particular in respect of further analysing the number of daily flights and duration, given their high energetic costs. The continued need and statutory obligations required to monitor potential impacts on the species population are likely to help grow our knowledge of the species, through continued support and funding of studies by energy providers and others. The balance between conservation and the pressures of increased population growth though may result in future challenges and even defining ideal and sustainable population sizes, if population growth places excess pressure on commercial interests. However, for now, the return each autumn of the geese remains one of the great visual spectacles of the natural world, and is welcomed in anticipation by so many who enjoy the geese's presence, including farmers, conservationists and others alike.

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Appendices

Appendix 1: Summary of the movements recorded of each bird tagged in January 2018

Tag 14984

Having successfully been tagged at Holt on the 16th January 2018, Tag 14999 moved to Cley Fresh Marshes, north of the catch site on the same day. Its' stay in North Norfolk was short-lived, moving on the 18th January 46km east to Hickling Broad, from where it foraged daily no further than 6km from two selected roost sites. The bird remained in the broads, until the 22nd February when it flew North West, passing via the Wash and leaving Norfolk, having spent a total of 37 days in the study area since capture and being tagged.

After leaving Norfolk the bird flew North, primarily over land to Dunbar in Scotland, and then to Aberdeenshire the same day, on the 23rd February. It resided in Aberdeenshire until the 2nd April, when its movements recorded passage over Troup Head and the Moray Firth onto Sinclair's Bay, near Wick. Three weeks later, on the 25th April the bird left Scotland and the UK, arriving in southern Iceland covering an estimated flight distance of 930km. The bird remained in Iceland for almost a month, before leaving on the 22nd May 2018, flying further north to East Greenland, and a further 820km in distance. Tag 14984 is the only individual recorded completing passage and movement to East Greenland, an area associated with non-breeding foraging. The bird returned to Iceland on the 16th September, almost four months later, and was recorded subsequently also leaving Iceland ten days later, leaving for the UK on the 26th September. After further staging in Northern Scotland the bird successfully returned to Norfolk on the 9th December 2019. Tag 14984 was the most successful tag as regards recording movements for the longest duration and a total of 483 days, and uniquely recording movement in North Norfolk during both the winter of 2017/2018 and 2018/2019.

Tag 14999

Having successfully been tagged at Holt on the 16th January 2018, Tag 14999 was first recorded on the coastal marshes to the north of the catch site at Salthouse later the same day, moving then to roost at the Cley Marshes WWT reserve. The following day the bird moved west to Holkham NNR and then the subsequent day moved further to the east and coastal saltmarshes near Wolferton. The bird remained in this area for a total of 15 days, up until the 2nd February. During this period the bird moved onto a variety of fields, ranging between 5km and 15km to the east and north east, from its roost. On the 3rd February the bird moved further south west within the wash, near Admiralty Point, again roosting on the coast and utilising fields for foraging to the south and within a 5km radius of the roost site. On the 7th February the bird left the Wash and flew to the Ribble Estuary on the west coast.   A total of 22 days positional data was recorded whilst in the study area.

The bird subsequently flew to Iceland, following moving north through the UK, via Dumfriesshire, Midlothian and finally north Lewis on the 15th April, reaching Iceland the following day on the 16th April. The birds last recorded fix was on the 4th September 2018 in north east Iceland. However, the bird was re-sighted, from its leg colour ring, in Snettisham n Norfolk on the 26th November 2019, seemingly paired with another neck colour banded collared bird, marked XAC.

Tag 15501

Having successfully been tagged at Holt on the 16th January 2018, Tag 15501 was first recorded in fields 3km directly south of Cley, on the same day, with the bird moving onto Cley WWT reserve to roost for two nights, and foraging in arable fields by day. The bird spent the subsequent 10 days rooting first at Overy marshes and then Stiffkey marshes, and foraging predominantly within 6km of the individual roosts in fields. On the 28th January the bird made a significant movement east, flying some 55km to the broads and Martham broad near Winterton, and then a further 26km south the same day to the broads west of Great Yarmouth. The bird resided here for two days, before again moving back North West, in a journey of 83km to an area of arable fields 2km south east of Fring. After two days in the immediate area, the bird flew west to the coast and Wash from where it immediately left Norfolk on the 3rd February 2018. A total of 18 days positional data was recorded whilst in the study area.

The bird subsequently flew to Iceland, following moving north to Reeds Island on the Humber, then to the Solway Firth near Gretna, Lossiemouth in north east Scotland and finally further north east still to Loch Hempriggs, just south of Wick. On the 10th April the bird left the UK, arriving in south east Iceland the same day. The birds last recorded fix was on the 20th May, 2018, further west, but still in south east Iceland.

Tag 15502

Having successfully been tagged at Holt on the 16th January 2018, Tag 15502 was first recorded in fields 3km directly south of Cley, on the same day, with the bird moving onto Cley WWT reserve to roost for two nights, and foraging in arable fields by day. The initial movements of Tag 15502 were the same as those of Tag 15501, with the individuals potentially belonging to the same family group. The bird moved west the following day to Holkham, and then 6km west to Overy Marshes, Burnham, spending a total of 15 days in the area. Initial foraging ranges extended up to 12km in distance from the roost at Holkham, and thereafter whilst using the same foraging area from the more adjacent roost at Overy Marshes only extended to within a 5km radius of the roost. On the 3rd of February 2018 the bird left Norfolk and the study area. A total of 18 days positional data was recorded whilst in the study area.

The bird subsequently flew to Iceland, following moving cross country to the west and Merseyside, before staging near the river Wyre in Lancashire and then for a prolonged period around the estuary near Wigtown in Galloway. Further time was spent in the lowlands of Strathearn, south west of Perth, before passing over the Isle of Skye on the 15th April and reaching south west Iceland later the same day. The birds last recorded fix was on the 5th September 2018 in north east Iceland.

Tag 15504

The movements of Tag 15504 are almost identical to those of Tag 15502, including the wintering movements, roosting and field use in Norfolk, and the entire staging to Iceland. As per Tag 15502, Tag 15504 spent a total of 18 days within the study area.

Both birds arrived in Iceland together on the 15th April, recording the same flight route and moved to the same breeding ground area in north east Iceland, where again the range of movements were largely mirrored. The last positional fix recorded was on the 15th August 2018, in north east Iceland.

Tag 15506

Having successfully been tagged at Holt on the 18th January 2018, Tag 15506 was first recorded at Warham Salt Marshes, near Wells-Next-The-Sea, and known roost site. The following day the bird flew 17km west and was recorded in fields south of Brancaster. The bird stayed in the area only briefly, moving between roost sites at Overy Marshes and a small sample of three fields south of Brancaster, over a period of 8 days. A total of 9 days positional data was recorded whilst in the study area.

The bird left Norfolk on the 27th January 2018, flying successfully almost 350km to Northumberland the same day, near Holy Island. The following day the bird then began moving in a southerly direction, making a southerly trip of 235km by the 1st February to Digley reservoir, near Holmfirth in West Yorkshire. From here the bird moved again directly to the Ribble in Lancashire and west coast and then river Wyre near Fleetwood, where its' last positional fix recorded and successfully transmitted was taken on the 7th February. The bird was though seen again, the following winter, in Norfolk during December 2018, however without its neck collar, for which it is surmised the fixings somehow became undone, resulting in the tag being lost.

Tag 15514

Having successfully been tagged at Holt on the 18th January 2018, Tag 15514 was first recorded near the coast at Salthouse Marshes, where the bird roosted overnight. The following day the bird moved 5km west to Blakeney Marshes, from where it foraged for two days 5km inland on arable fields. It subsequently moved west again along the coast, roosting in and around Overy Marshes, and primarily foraging within arable fields 2km to the south of the roost site. On the 4th February, the bird left Norfolk, having being recorded in the study area for a period of 17 days.

The bird, having left Norfolk, flew directly North West to Haverigg Pool in Barrow in Furness, some 310km away. Four days later, on the 8th February, the last fix for Tag 15514 was recorded nearby on Duddon Sands. No subsequent fixes were transmitted for this individual.

Tag 15515

Having successfully been tagged at Holt on the 18th January 2018, Tag 15515 was first recorded the following day at Warham Marshes, near Wells-Next-The-Sea. On the 20th February, the bird moved to Holkham NNR, and foraged daily to the south on arable fields between 4km and 6km from the roost, with a single movement 10km south on the 25th February. Subsequently the bird moved west to Norton Marsh, near Burnham Deepdale and foraging for a couple of days to the south west, some 6km in land on arable fields, and roosting a further night at Holme next to the Sea. On the 4th February, the bird left Norfolk, having being recorded in the study area for a period of 16 days.

Following leaving Norfolk, the bird flew 252km North West to Cockerham Sands, near Fleetwood, where it spent 12 days roosting and foraging before heading further north. After a few days in Dumfriesshire, the bird moved to Lanarkshire. The last fix from Tag 15515 was received on the 9th June, in Lanarkshire, where it is surmised the bird died, based on an interpretation of local movements and knowledge that it had not successfully completed its spring migration. These movements are discussed in more detail in section 0.

Tag 15516

Having successfully been tagged at Holt on the 18th January 2018, Tag 15516 was first recorded three days later on the marshes at Salthouse, near Cley. In the following days, foraging trips included movements east to coastal fields between Weybourne and Sherringham, around 8km from the roost, and then to the west, some 11km west to Warham Marshes. The bird then left Norfolk on the 4th February, having being recorded in the study area for a period of 14 days.

After leaving Norfolk the bird was recorded moving north, 320km to Northumberland and the River Coquet, and then to the Northumberland Coast and Budle Bay near Holy Island. On the 21st February the bird again moved further north, to Granthouse, roosting on nearby moorland, and then to north east Scotland and Ellen where it resided for a month, before flying North West and leaving Scotland and Findhorn bay on the on the 15th April. The bird was then recorded in Iceland on the following day. However, movements of the bird soon stopped, with the last successful fix being transmitted on the 28th April, on the coast of southern Iceland. These movements, and potential loss to shooting, are discussed in more detail in section 0.

Appendix 2: Summary of the movements recorded of each bird tagged in December 2018

Tag 15500

Having successfully been tagged near Burnham Market on the 1st December 2018, Tag 15500 was first recorded at the tagging site, prior to release. It then moved to Overy Marshes at Holkham, briefly roosting, before moving slightly east to Warham Salt Marshes. On the 9th December the bird moved south east to the broads, 80km from the catch site, favouring three key sites, Upton Marshes, Hickling Broad and Upton Marshes on the river Bure. The bird then left Norfolk on the 22nd February 2019, having being recorded for 83 days in the study area.

After leaving Norfolk the bird began its northerly migration along the east coast, flying off-shore as far north as the Forth of Tay, and then overland to North West Scotland and to near Fraserburgh in a flight of around 650km in distance. After reaching the Orkney Islands on the 28th February, the bird left a few days later on the 9th April and reached south west Iceland later the same day. Once in Iceland the bird moved to around the west, before flying into a more central location and breeding grounds. Tag 15500 last recorded fix was on the 20th July 2019, in central Iceland.

Tag 15507

Having successfully been tagged near Burnham Market on the 1st December 2018, Tag 15507 was first recorded at the tagging site, prior to release. The bird then moved to Holkham NNR to roost, predominantly foraging under 10km from a variety of roost sites at the reserve in subsequent days, before moving slightly east to Wareham Marshes. On the 6th January the bird began moving more widely, moving to Hickling Broad, 55km to the south east, then further south in the broads to Breydon Water for a brief stay. On the 12th January the bird again moved widely, now towards the Wash and Wolferton, some 80km to the west. Subsequently the bird returned to sites previously frequented on the North Norfolk coast, and again to Hickling Broad, before more extensively residing again at Breydon Water. The bird was not recorded leaving Norfolk, albeit recorded a total of 63 days in the study area.

The birds last recorded fix was at Cantley Marshes RSPB reserve, on the 2nd February 2019. No further movements were successfully transmitted thereafter.

Tag 15517

Having successfully been tagged near Burnham Market on the 1st December 2018, Tag 15507 was first recorded at the tagging site, prior to release. The bird then moved to the nearby

Morston Salt Marshes, less than 5km away, where it roosted for a pro-longed period and foraged locally, before moving slightly east to Warham Salt Marshes on the 21st December. On the 2nd February the bird moved 60km further south east to Martham Broad near Winterton, and subsequently the nearby Hornsea Mere at Breydon Marshes. The bird was not recorded leaving Norfolk, albeit recorded a total of 77 days in the study area.

The birds last recorded fix was at Breydon Marshes RSPB reserve, on the 16th February 2019. No further movements were successfully transmitted thereafter.

Tag 15518

Having successfully been tagged near Burnham Market on the 1st December 2018, Tag 15518 was first recorded the following day in nearby fields around South Creake. The bird then utilised both Overy and Wells marshes for roost sites, and foraged within 15km of the roost, visiting fields to the north of Fakenham at the furthest distance from coastal roosts. On the 6th December the bird moved much further east and moved to Hornsea Mere, before moving again on the 16th December back across Norfolk 80km to the Wash. Further wide scale movement was exhibited with a return to Holkham, followed by a move east again to the broads and Breydon Water on the 24th December. In early January the bird moved back to the North Norfolk coast, but soon again returned to the broads, returning 64km from Cley to spend time across three key sites in the broads between the 8th January and until leaving Norfolk on the 22nd February, having being recorded for 83 days in the study area.

After leaving Norfolk the bird began its northerly migration along the east coast, flying predominantly off-shore, with some movement in-land and up to the Firth of Forth and Kinross. On the 1st April the bird then flew further north to Inverness shire, before leaving Scotland and arriving in Iceland on the 5th April 2019. The bird was recorded moving to south west Iceland, with the last transmitted fix being recorded on the 17th April 2019.

Tag 15519

Having successfully been tagged near Burnham Market on the 1st December 2018, Tag 15519 was first recorded at Warham Marshes at Wells-Next-The-Sea, from where it soon moved some 55km to the east and Hickling Broad. Further movements included localised travel to Breydon Water in the Broads, a return to North Norfolk and Warham Marshes, repeat longer distance movement to the broads and again a return to North Norfolk. Whilst at a roost site, foraging ranges extended up to 17km, e.g. between Warham Marshes and the large coastal fields at Weybourne. On the 12th January, the bird moved briefly to the west and to the Wash, before moving again to North Norfolk and Cley Marshes and ranging across the North Norfolk coast. On the 19th January the bird left Norfolk, having been recorded in the study area for a total of 49 days.

After leaving Norfolk the bird flew 116km North West to Whitton Island, on the inner Humber Estuary. The bird then moved west, to Barrow in Furness, but subsequently returned to the Humber, before moving again West to the Ribble, north to Pilling Sands, then back to the Ribble, before staging 435km further North in the Cromarty Forth. The bird then flew to Iceland on the 22nd April 2019, moving to breeding areas in the east. The bird was successfully recorded leaving Iceland and returning the following autumn on the 13th September, via the Faroe Islands and on to Sutton in Ashfield in Northumberland. The last recorded positional fix for Tag 15519 was at Darden Lough reservoir in Northumberland on the 17th September 2019.

Tag 15520

Having successfully been tagged near Burnham Market on the 1st December 2018, Tag 15520 was first recorded at was first recorded at Warham Marshes at Wells-Next-The-Sea, from where it subsequently moved east to Hickling Broad, similar to bird and Tag 15519. After a brief stay in the broads, the bird moved back 55km to the North Norfolk coast on the 6th December. Here it ranged locally, within 15km of roosts at Wareham Marshes, to fields directly to the south, before heading to the Wash on the 11th December. After two days foraging locally from a roost in the Wash, the bird left Norfolk on the 13th December 2018, only 12 days after first being tagged.

The bird's early migration north included passage over the middle Humber and Barrow on Humber, through to Nosterfield in the eastern dales of Yorkshire, where it resided for 11 days. Subsequent movement recorded passage to the west coast and Solway Firth, before heading further north to Lanarkshire and a return to the Solway Firth again. The bird left the UK, flying over North West Scotland on the 12th April 2019 and reaching Iceland on the far south east corner. From here it moved to central northern breeding grounds. The last positional fix for Tag 15520 was successfully recorded and transmitted on the 1st May 2019 in Iceland.

Tag 15521

Having successfully been tagged near Burnham Market on the 1st December 2018, Tag 15521 moved locally to the marshes of Holkham NNR. Over the next 9 days the bird utilised roost sites at Holkham and Wareham Marshes, and ranged up to 20km each day to the furthest fields, before moving east on the 10th December to the broads around Breydon Water. The bird subsequently returned both to North Norfolk coast and back to the broads again on the 11th January, where it resided in the area around Hickling broad before returning to the North

Norfolk coast and leaving Norfolk on the 31st January 2019. During its time roosting at Hickling Broad, daily forages extended up to 12km from the roost, albeit were more typically recorded within a range of 5km to 8km from the roost. The bird was recorded in the study area for a total of 61 days.

Following leaving Norfolk, the bird moved North West via the Peak District and south Lancashire and up to Grange Over Sands. After 23 days the bird moved again further north to Fife, leaving on the 5th April and arriving in southern Iceland the following day. After arriving the bird moved to North East Iceland, from where its last transmitted positional fix was recorded on the 9th June 2019.

Tag 15524

Having successfully been tagged near Burnham Market on the 1st December 2018, Tag 15524 moved immediately north to Scolt Head, one of the main known North Norfolk roost sites. After two days the bird moved slightly east to the nearby marshes of Holkham NNR and foraged in local fields, up to 7km south of the roost. On the 10th December the bird moved to the Wash, and a new roost some 28km to the west, where it spent time roosting and foraging at three sites around the Wash, until the 15th January, when it briefly returned to the North Norfolk coast. On the 22nd February, the bird left Norfolk, having spent a total of 83 days in the study area.

After leaving Norfolk the bird moved north overland to Northumberland, before flying west to the Solway Firth. The bird left the Solway Firth five days later on the 27th February, moving to Lanarkshire in southern Scotland. Tag 15524 was last recorded in Lanarkshire on the 25th March 2019.

Tag 15527

Having successfully been tagged near Burnham Market on the 1st December 2018, Tag 15527 was not subsequently recorded until the 10th December, residing within the Wash, near Wolferton. The roost at Wolferton was used throughout the birds stay in Norfolk, from where it initially ranged east in-land at a maximum distance of 15km, and then subsequently further south to an area some 25km from the roost. The bird left Norfolk the same month, on the 24th December, after spending 14 days in the study area following being caught and tagged.

After leaving Norfolk the bird flew north, overland, to Whitton Island on the Humber, from where it then moved to the west coast and Pilling Sands, east of Fleetwood. It subsequently moved south to Formby Bank, near Crosby in Lancashire, before flying north to Fife on the 20th

February, and then to Grantown-on-Spey, leaving Scotland and the UK on the 14th April, and arriving in southern Iceland the same day. The bird moved north across Iceland, residing in the north east, from where the last successful positional fix was recorded just over a week from first reaching Iceland on the 22nd April 2019.

Tag 14984

Having successfully been tagged near Holt on the 1st December 2018, Tag 14984 was recorded not only during the winter of 2017/2018, but also subsequently moving to Iceland, East Greenland and returning to the UK the following autumn. Uniquely, over a duration of 483 days, its movements are recorded over two winters, with the movements of the first winter already discussed in section 3.3.6.

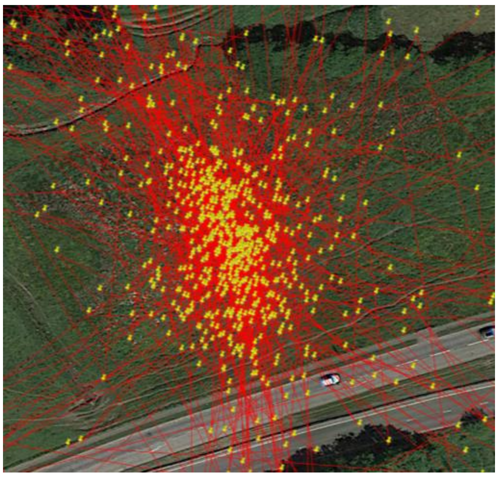
Movements of Tag 14984 during the second winter of 2018/2019 initially show the bird arriving in North Norfolk at Scolt Head on the 10th December 2018, and then heading directly to the broads and the marshes of Breydon Water. Movement and roosting in the broads continued until the 31st December when the bird moved briefly back to the North Norfolk coast and Wareham Marshes. However, after a brief stay the bird moved back again to the broads within 24 hours, residing first at Upton Marshes, then on the 18th January at Hickling Broad, before leaving Norfolk from the Broads on the 14th February 2019. Daily forages from roosts in the Broads largely ranged from between 2km and 6km in distance from the roost.

After leaving Norfolk on the 15th February 2019, the bird flew 535km north to Loch of Strathbeg, staging its wintering movements there before moving to Wick in north east Scotland. Tag 14984 left Scotland and the UK on the 20th April 2019, returning again to Iceland, albeit arriving in North East Iceland versus arriving in Southern Iceland the previous spring. The last successful positional fix was recorded in Iceland on the 14th May 2019.

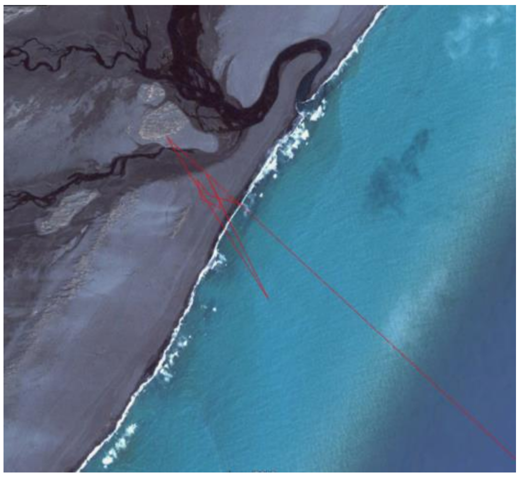
Appendix 3: Attempts to understand the fate of individual birds whose tracked movements suddenly ceased

Attempts to understand the fate of birds whose tracks had suddenly stopped were undertaken in 2018, with efforts made to recover the bird, and tag, and to ascertain whether the bird had died of natural causes, had been shot or to potentially eliminate tag failure as a cause in the cessation of movement.

Tag 15515, was recorded moving from Norfolk to Lanarkshire in Southern Scotland on the 22nd February 2018. The bird was unusually still present on the 9th June, 2018 in an area of South Lanarkshire and field of grazed marshland (OS Grid Reference NS864585), with these movements reported and evident from data downloads on the 4th July, 2018, around a month after the last recorded fix. Fixes for the last three weeks of recorded data, from mid-May to the last fix in early June, were confined to an area approximately 150m^2 and one field (Figure 40). Whilst the positional fixes were spread within this area, these variances in mapped positions were deemed likely to be a result of the number of variable GPS satellite fixes achieved during each registered fix and mapped position, rather than representing fine scale movement of the bird. An initial search of the area was undertaken by the landowner, within days of the reported tagging data, following contact and provision of a series of aerial maps to aid the search. During this search no bird could be located. Given the merit of conducting further searches, and gaining evidence for intended subsequent BTO tagging applications and annual reporting requirements, the author conducted further searches in mid-July. Despite methodically mapping the area and using a GPS to complete cross-sectional transects through the field and search area, frustratingly no bird, or tag, could be located. The fate of this bird is therefore unknown.



Tag 15515 (Last fix 09/06/2018, Lanarkshire)



Tag 15516 (Last fix 29/04/2018, Iceland)

Figure 40: The last positional fixes and movements of Tags 15516 and 15516

Appendix 4: Potential and reported losses from shooting

To date a total of four birds caught across the two catches have been reported as shot, and recovered, with the ringing details submitted by hunters. All four individuals were part of the total 98 birds caught during ringing operations, but not fitted with a GPS / GSM neck collar, but in place only standard neck collars and BTO metal leg rings (Figure 19). Three of the four shot birds were shot in Iceland during late September and early October 2018, in coastal areas, favoured for shooting as the birds move through or spend time in around migratory departure periods. The other individual shot, was shot in Morpeth, in the UK, on the 10th November 2018. These four reported shootings represent 6.9% of the initial sample population, and are not dissimilar in number to those expected to be shot annually, with an average 8% being reported as likely to be shot by Natural England in their Anthropogenic mortality review (England, 2015).

No GPS/GSM tagged birds have been reported shot and recovered, albeit statistically one or two would be expected to be shot, based on an annual anthropogenic mortality of 8% and a total sample of 18 individuals across the two winters. However, the movements of one individual (Tag 15516) are indicative of a bird that may have been either shot on arrival in Iceland following its northerly spring migration, or alternatively died shortly after arrival of exhaustion from its journey. Having arrived on the south west coast of Iceland the bird moved in-land 350m, undertaking a few short journeys in the immediate vicinity, before flying off-shore a similar distance and then last being recorded on the shoreline (Figure 40). The area the bird was last recorded in is known to be an area in which hunting and shooting take place, and the movements of the bird are potentially of a bird that has been shot, or winged, and died shortly thereafter, but not necessarily recovered. Due to the remote location and cost of associated with getting to the area, no attempt was made to search for the bird at its last known location, and its ultimate fate is unknown.