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Waterbirds around the world

A global overview of the conservation, management and research of the world's waterbird flyways

Edited by G.C. Boere, C.A. Galbraith and D.A. Stroud

Assisted by L.K. Bridge, I. Colquhoun, D.A. Scott,
D.B.A. Thompson and L.G. Underhill

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Cover photography: Whooper Swans *Cygnus cygnus* arriving at Martin Mere, England. Photo: Paul Marshall.
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Developing an integrated approach to understanding the effects of climate change and other environmental alterations at a flyway level

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ABSTRACT

The environmental consequences of global climate change are predicted to have their greatest effect at high latitudes and have great potential to impact fragile tundra ecosystems. The Arctic tundra is a vast biodiversity resource and provides breeding areas for many migratory geese. Importantly, tundra ecosystems also currently act as a global carbon "sink", buffering carbon emissions from human activities. In January 2003, a new three-year project was implemented to understand and model the interrelationships between goose population dynamics, conservation, European land use/agriculture and climate change. A range of potential future climate and land-use scenarios will be applied to the models and combined with information from field experiments on grazing and climate change in the Arctic. This paper describes the content of the research programme as well as issues in relation to engaging stakeholders with the project.

INTRODUCTION

Changes to European landscapes

Socio-economic, agricultural and demographic changes have imposed modifications on the European landscape to such a degree that habitats over most of the region have been altered in some way, degraded, or removed entirely. Although many of these changes have resulted in negative impacts for European fauna and flora, some species have benefited, and indeed increased their distribution and abundance to a point where they come into "conflict" with human interests (Patterson 1991, Cope *et al.* 2003). In addition to the direct impacts of change on different elements of the European landscape, human activities involving the burning of fossil fuels during the last two hundred years have now altered climate and weather patterns beyond pre-industrial "background" levels (Jones *et al.* 1998, Huang *et al.* 2000, IPCC 2001, Jones & Mann 2004). Many of these environmental alterations have not been in the form of large "step" changes, but have often been slow, insidious, ongoing, patchy, and spread over wide spatial extents. These characteristics complicate efforts to detect and measure the changes as they happen, and to predict future patterns of change. They also make it difficult for appropriate authorities to develop strategies to halt and reverse the impacts of such change (O'Connell & Yallop 2002, Caro *et al.* 2004).

Changes to European migratory goose populations

The relatively large size and aggregative behaviour of geese, coupled with a large number of skilled volunteer observers across Europe, have made it possible to measure general changes in goose populations, i.e. overall abundance, distribution, and use of key sites (for a review, see Madsen *et al.* 1999). Long-term and large-scale capture-recapture efforts (e.g. ringing) have also produced data that can be used to model the trajectory of goose populations by analysing the demographic factors of survival, fecundity, dispersal and recruitment (e.g. Alisaiskas 2002, Cope *et al.* 2003, Frederiksen *et al.* 2004). However, quantifying general changes in goose abundance and knowing their population trajectory does not necessarily provide an understanding of the causes of the changes in measured demographic parameters, or facilitate the development of holistic approaches to conservation strategies (i.e. those encompassing the widest possible range of biotic, abiotic and human factors that operate at an ecosystem or landscape level).

Holistic research: the "ecosystem approach"

The term "ecosystem" came to prominence in the 1930s, but had been in use as a general concept since the 1860s (Botkin 1990). The view of populations connected through interactions with their proximate biotic and abiotic environment developed into a paradigm where ecological groupings were viewed within reasonably closed and self-regulating systems. Ecologists later expanded these ideas within a framework of "systems analysis" which provided a methodology to understand very complex systems and feedback loops (Odum 1953). However, the "ecosystem approach" (Hartig *et al.* 1998, Wang 2004) has a number of conceptual problems. O'Neill (2001) highlighted three key issues: (1) the selection of elements to be included within a named ecosystem is often subjective and based on *a priori* knowledge; (2) ecosystem research foci are often selected subjectively and based on favoured or "easy target" ecosystem elements; and (3) human activities are invariably seen merely as "external" disturbances to ecosystems.

In relation to ecosystem management, a further critical assessment was made by O'Connell (2003) who identified five assumptions underlying actions to protect ecosystems and manage them on a sustainable basis:

a) There is adequate inventory and monitoring to provide appropriate information for action;
b) That change in the ecosystem can first be detected and then measured;
c) That it is possible to identify the underlying causes of change;

d) There is the ability to predict the likely consequences of change in all parts of a system; and
e) There is knowledge of remedial action to halt or reverse the detected and measured change.

In most cases, these assumptions will not be met, and there is a great deal of fundamental research needed to address this situation.

The "flyway" concept

Migratory birds also raise additional difficulties for the ecosystem approach. Migration results in species moving between and within a variety of "systems", and this presents problems when trying to understand the full range of their environmental interactions and population drivers. To address some of these problems, the idea of avian "flyways" was developed. Conceptually, a flyway can be thought of as possessing ecosystem-like qualities (i.e. many interacting biotic and abiotic elements interacting within a relatively closed and self-sustaining system). But for practical applications, a flyway can also be defined simply as the network of sites (and routes) required to fulfil the annual life cycle of individuals within a migratory population. As well as providing a useful research framework for migratory species, the flyway concept also facilitates transboundary conservation measures and monitoring (Boere 2003).

Integrated flyway studies

An increasing number of migratory bird studies are being been made at the conceptual level of flyways, i.e. they consider life-history events at the breeding, non-breeding and migration sites (Francis *et al*. 1992, Hoffman *et al*. 2002, Hötker *et al*. 1998, Malcolm & ReVelle 2002, Otis 2004). However, although covering appropriate spatial scales, many of these studies still focus on only one or a small number of life history factors occurring at this scale, e.g. survival, habitat requirements, hunting levels, phenology, etc. Data limitations and research costs mean that few studies have been able to take a more holistic "whole system" approach integrating the large number of different biotic and abiotic elements impacting both species and landscapes within a flyway. The potential benefit of an integrated approach is to go beyond quantitative description, and to generate an understanding of the relative importance of different processes within a flyway system and how these interact at different spatial and temporal scales. In turn, this provides a means to forecast the likely impacts of change on individual system elements, and explore system responses under a combination of different environmental change scenarios. The central components of a framework for flyway level research is shown in Fig. 1.

COMPONENTS OF ARCTIC BREEDING GOOSE FLYWAYS

Eight species of geese breed on Arctic tundra habitats in the European Arctic (mostly beyond 65°N) and migrate to wintering grounds in climatically temperate zones (generally between 40°N and 60°N). The study described in this paper refers to a Northern Hemisphere flyway where two goose populations utilize tundra systems on the Svalbard archipelago for breeding and then migrate (via a number of stopover sites) to wintering areas on estuarine and agricultural habitats in north-western Europe. The two goose populations (described in detail below) have very different breeding site requirements and feeding ecology, and have spatially separated wintering areas.

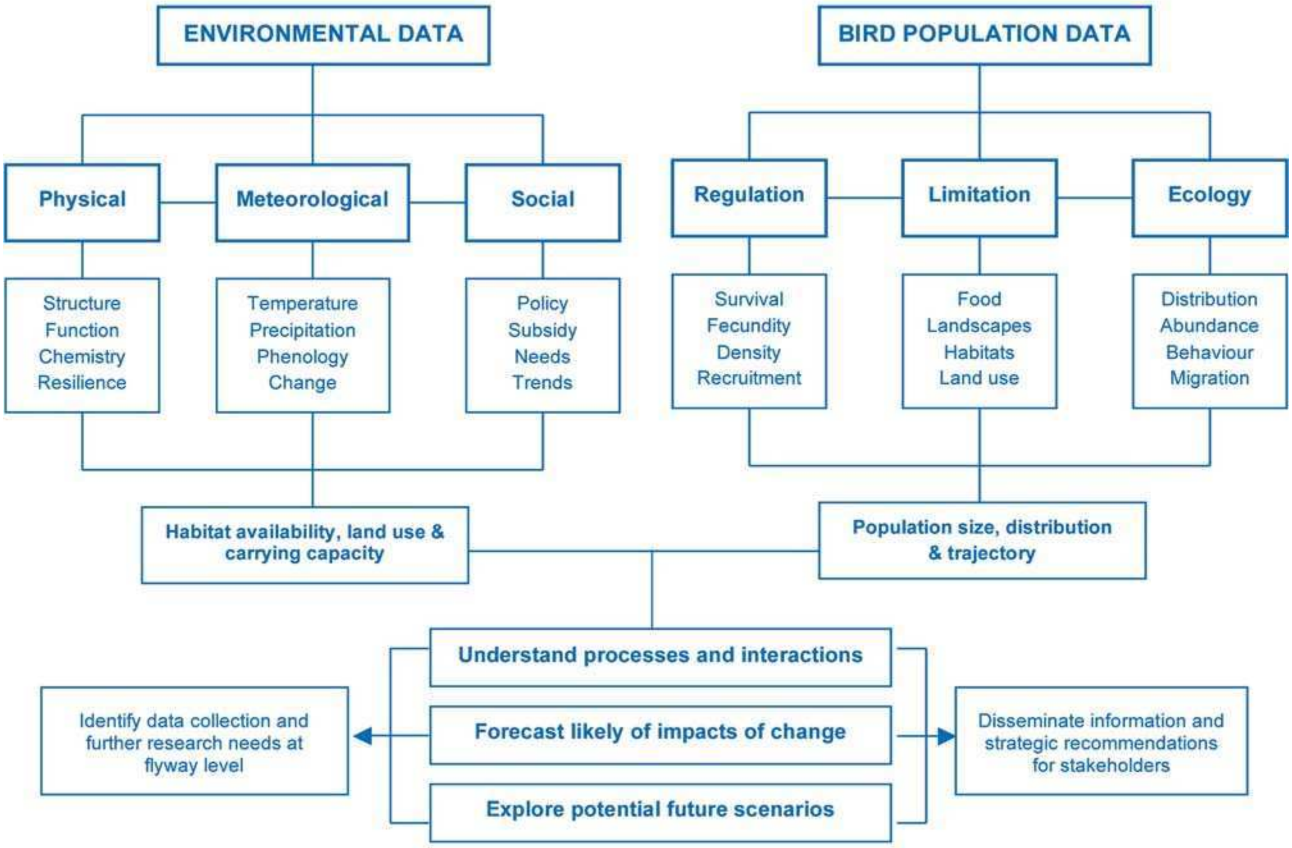

Fig. 1. Information needs and analytical outcomes of a flyway-level, integrated research approach.

Structural and functional characteristics of tundra

Globally, tundra habitats cover approximately 9% of the world's surface (Clausen 1996), with Arctic tundra occupying a circumpolar area of nearly six million sq. km. Tundra is characterized by low biotic diversity, short and simple vegetation structure, and shallow root systems. Many of the 1 700 species of plants recorded in the Arctic region can photosynthesize at low temperatures and light intensities, and most are wind-adapted and robust to soil perturbation (Epstein *et al.* 2004). Tundra soils are generally thin, generated slowly, seasonally thawed, and lie on a layer of permanently frozen subsoil (permafrost) consisting mostly of gravel and finer material. This vertical profile results in poor drainage, and where water saturates the upper surface, bogs and ponds are often present. Rainfall varies considerably within the Arctic region, but average yearly precipitation (including melting snow) is often less than 25 cm.

This combination of physical, chemical and climatic factors results in environmental conditions where atmospheric carbon dioxide is sequestered by tundra habitats, which have been estimated to contain up to 30% of the world's soil carbon stocks (Gilmanov & Oechel 1995, Waelbroeck *et al.* 1997, McGuire *et al.* 2002). This makes tundra systems particularly important in terms of global carbon balance. Tundra plant communities which are grazed by geese are often dominated by graminoids and bryophytes. However, elevated temperatures and over-grazing by geese cause a shift towards increased graminoid and decreased bryophyte dominance, and result in warming and drying of the soil, faster nutrient cycling, and increased carbon efflux. Another key characteristic of tundra ecosystems is their low nutrient status, particularly in relation to nitrogen. Increases in the rate of nutrient cycling may result from both soil warming and grazing. This is known to alter species composition and increase productivity of both terrestrial and aquatic tundra communities. In addition, increased nitrogen availability decreases the carbon : nitrogen ratio of plant tissue, thus increasing the rate at which it will decompose and hence the carbon efflux from the system (Fahnstock *et al.* 1999, Brooks *et al.* 2005). The responses of habitats to elevated temperatures can be characterized by their sensitivity, adaptability and vulnerability. "Sensitivity" defines the thresholds of climate change that result in altered composition, structure and functioning of an ecosystem. "Adaptability" is the degree to which systems can adjust in response to altered environmental conditions. "Vulnerability" defines the extent to which climate change may damage or harm a system, i.e. is related to both sensitivity and adaptability. Empirical evidence suggests that tundra habitats show high sensitivity, low adaptability and high vulnerability (Forbes *et al.* 2001, Chapin *et al.* 2004).

Svalbard tundra

The Svalbard archipelago (78°30'N, 18°00'E) consists of nine main islands with an area of just over 62 000 sq. km. The islands are mountainous (up to 1 700 m), with glaciers and snowfields covering more than 60% of the land surface in high summer and 100% in winter. The relatively milder western areas comprise a large number of steep-sided fjords with tundra habitats in the lower drainage basins and river beds.

Arctic climates and climate change

The Arctic experiences both polar maritime (i.e. influenced by oceanic factors) and continental (i.e. influenced by terrestrial land masses) climates. Weather patterns are characterized by high spatial variability, and although the region receives a large amount of solar energy in summer, the high reflectivity (albedo) of snow and ice surfaces keeps absorption of solar energy low. Heat gained during long summer days can therefore be relatively small. Maritime climate conditions prevail in coastal Alaska, Iceland, northern Norway and adjoining parts of Russia. Winters are often cold and stormy; summers are cloudy but mild with a mean temperature of about 10°C. Annual precipitation is generally between 60 cm and 125 cm, and there are normally at least six months of snow cover. At lower latitudes, "continental" climates result in much more severe winters, although precipitation is lower. Permanently frozen ground (permafrost) is widespread and, in summer, only the top one to two metres of ground thaws. This results in a poorly drained "active layer" that often remains waterlogged and on which tundra habitats can develop.

Since the end of the nineteenth century, the average temperature of the earth's surface has risen by 0.6°C, and sea levels have risen by between 10 cm and 20 cm. By 2100, temperatures are predicted to increase further by between 1.4 and 5.8 degrees, with an additional sea level rise of 9 to 88 cm. The 1990s were the warmest decade of the last millennium, and 1998 the warmest year. Mean air temperatures in the Arctic have increased by about 5°C over the last 100 years, and the extent of sea ice has decreased by 14% since the 1970s. These increases in temperature represent larger changes than any century-long trend in the last ten thousand years (Weaver & Green 1998). By the year 2100, winter temperatures in many parts of the Arctic are predicted to rise by 40% more than the global average change.

Arctic migratory geese

The Arctic region provides vast areas of relatively disturbance-free wilderness in which animals can breed. There are plentiful food resources (although relatively limited in variety) and, at higher latitudes, up to 24 hours of daylight in which to feed offspring. Approximately 430 bird species breed in the Arctic (Zöckler 1998), of which 130 are migratory waterbirds (Wetlands International 2002). There are 15 species of "true" geese within the genera *Anser* and *Branta*, and 12 of these breed both in the Arctic and elsewhere, with eight breeding exclusively in the Arctic region. Thirty-four subspecies are represented in the region (with 24 exclusive to the Arctic), comprising 67 populations of which 50 breed in the Arctic. The latter group has been estimated to total more than eight million individuals, representing 67% of the total world population of the genera *Anser* and *Branta* (Madsen *et al.* 1996).

All Arctic breeding populations of geese migrate to lower latitudes during the non-breeding season. Many species migrate on a narrow geographical front, with fixed routes and a small number of stopover sites at which the birds rest, socialize and replenish body fat reserves (Choudhury *et al.* 1996, Madsen *et al.* 2002, Prop *et al.* 2003). Traditionally, wintering birds made use of coastal and estuarine habitats, particularly coastal marshes. In these areas, large numbers of birds have been hunted by humans, and by the middle of the twentieth century the population of many species had been reduced to levels that were a fraction of their previous "natural" state (Madsen 1991, Pettifor *et al.* 2000). During the latter half of the century, changes in agricultural practices resulted in new, plentiful and seasonally reliable food sources for wintering geese (van Eerden *et al.* 1996,

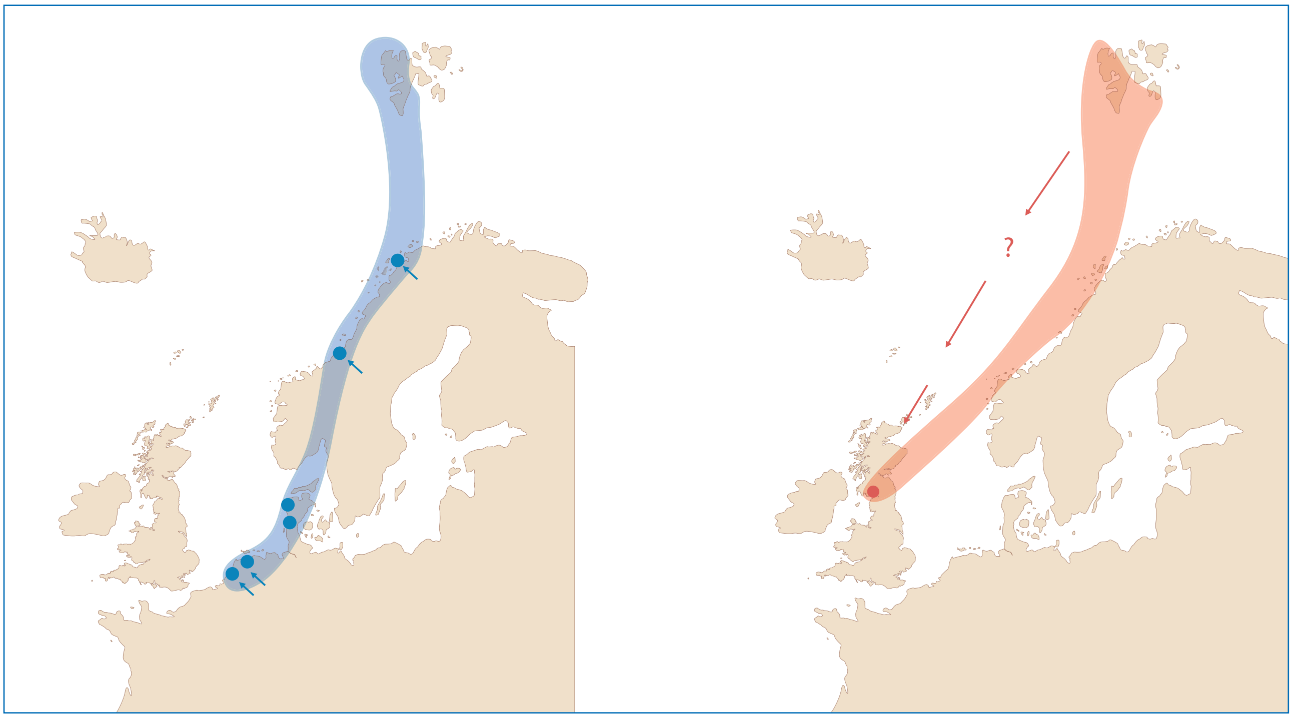

Fig. 2. Principal breeding, migration and wintering areas of Svalbard Barnacle Geese *Branta leucopsis* (red) and Pink-footed Geese *Anser brachyrhynchus* (blue).

Therkildsen & Madsen 2000). This, coupled with improved legislative protection and positive site management regimes (e.g. refuge areas and cold-weather hunting bans), resulted in a change in the fortunes of many goose populations, many of which are increasing or stable (Wetlands International 2002).

Svalbard geese

Geese breeding on the Svalbard archipelago are recognized as distinct "populations", i.e. are groups that do not experience significant immigration or emigration (Wetlands International 2002). The Svalbard Barnacle Geese *Branta leucopsis* breed colonially, mainly in the west of the archipelago. They often (but not exclusively) utilize steep rocky areas, and many colonies are on islands (Mitchell *et al*. 1998). Most of the population overwinters on the Scottish side of the Solway Firth in the UK (Fig. 2), although changes have been occurring in the timing and spatial extent of the population's wintering distribution. It is likely that the population constituted as few as 300 individuals in 1948, and came close to extinction (Pettifor *et al*. 1998). As a result of conservation measures in the mid-1950s and a switch to feeding on agricultural habitats, there was a gradual increase in the population during the last half of the twentieth century. The population is currently estimated to be nearly 28 000 birds. Although density dependence in productivity and survival has been found on the breeding grounds, it does not appear to regulate the population as a whole. At present the population is growing (Fig. 3a), presumably because birds are still colonizing new breeding habitat (Black 1998, Trinder *et al*. 2005). There is no evidence that the population has reached the carrying capacity of either the summer or winter ranges. If breeding is being regulated by population density, then further increases in population size may be small. Aggregation into relatively confined breeding and wintering areas makes this population vulnerable to stochastic events, such as adverse conditions on the breeding grounds, disease or adverse conditions during migration. The most sensitive demographic factor is adult survival (Tombre *et al*. 1998, Schmutz *et al*. 1997), and Trinder *et al*. (2005) suggest that the loss of as few as 350 individuals annually produces a median equilibrium population at its current size of nearly 28 000, with the likelihood of long-term population decline increasing markedly if additional annual losses exceeded 1 000.

While Barnacle Geese are restricted to nesting on cliffs or islands that offer protection from Arctic Foxes *Alopex lagopus*, Svalbard Pink-footed Geese *Anser brachyrhynchus* nest more widely in loose colonies on the open tundra, being capable of defending the nest from fox attacks. The species breeds in the western part of Svalbard, whereas in the eastern part, the summer season is too short to execute both nesting and brood-rearing. The population migrates via stopover sites in Norway to wintering grounds in Denmark, The Netherlands and Belgium (Fig. 2). The population increased from 12 000-20 000 in the mid-1960s to 40 000-50 000 by 2003 (Fig. 3b). The rapid increase in the 1970s was probably due to improved survival caused by relaxation of winter shooting pressure (Ebbinge *et al*. 1984), but changes in winter food supplies towards agricultural crops may also have played a role in the more recent increase (Fox *et al*. 2005). Today, the species is still subject to hunting in Svalbard, Norway and Denmark, but hunting mortality does not seem to be a factor controlling population size (Madsen *et al*. 2002).

Although not included in the present study, Brent Geese *Branta bernicla* also breed on Svalbard. The Brent Goose has a circumpolar breeding distribution with a range extending from Greenland to Svalbard and northern Russia, continuing through Alaska to the Canadian Arctic Archipelago. There are three subspecies. One of these, the Light-bellied Brent Goose *B. b. hrota*, occurs generally in the western Arctic (Canada to Svalbard and Franz Joseph Land), and has three distinct popula-

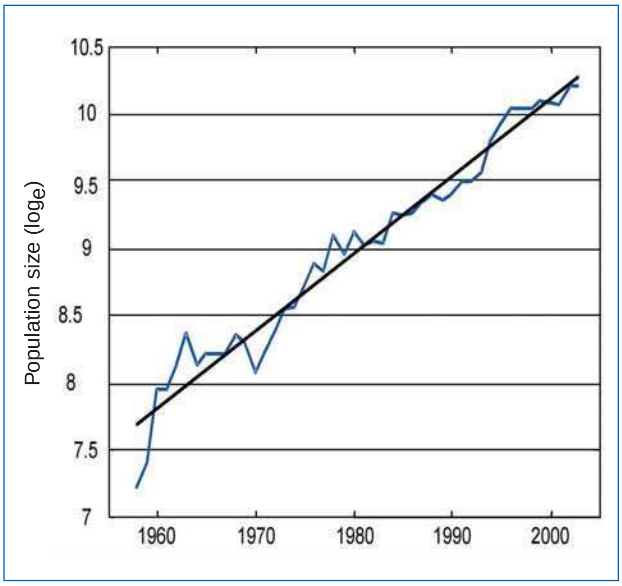

Fig. 3a. Svalbard Barnacle Goose *Branta leucopsis* (log$_e$) population size: 1957 to 2004.

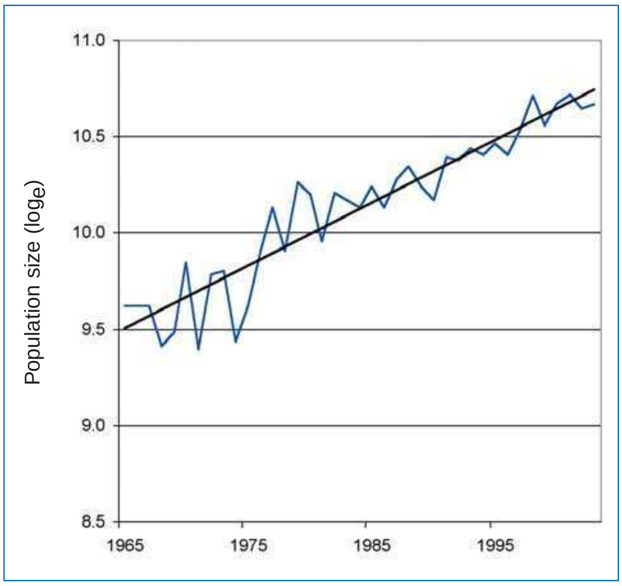

Fig. 3b. Svalbard Pink-footed Goose *Anser brachyrhynchus* (log$_e$) population size: 1965 to 2003.

tions breeding in Canada, Greenland and Svalbard. The population on Svalbard currently numbers only about 5 000 individuals. It is probable that the population was previously around 50 000 individuals during the early twentieth century, but had declined to 2 000 individuals by the 1970s (Scott & Rose 1996), with a more recent recovery to about 6 600 (Denny *et al.* 2004). This decline, in common with other Brent Goose populations, has been attributed to a disease-related die-off in their favoured food resource (eel grass *zostera*), combined with shooting and disturbance. Despite currently being protected throughout its range, the Svalbard Light-bellied Brent Goose population remains depressed and is one of the most vulnerable goose populations in the world. Suggested explanations for this slow recovery include competition with the expanding Barnacle Goose population on Svalbard, and predation there by Polar Bears *Ursus maritimus* and Arctic Foxes (Madsen *et al.* 1989, 1992).

Herbivory by geese

Grazing by geese and other herbivores can have a large effect on tundra systems (Cooch *et al.* 1991, Jano *et al.* 1998). The selective removal of biomass can alter vegetation composition and the amount and quality of litter produced. Goose grazing can also alter the nitrogen cycle (when goose droppings function as a source of nitrogen), and hence increase the productivity of their forage. It is clear that increases in the populations of geese grazing on tundra will have implications for the carbon and nitrogen balance of the system. Geese have also direct and indirect effects on Arctic freshwater ecosystems, by altering nitrogen and phosphorous regimes in lakes and ponds. For very nutrient-poor sites, faecal droppings provide a valuable input for the systems, while coastal ponds may be severely eutrophied by increased loading of nutrients. Nitrogen and phosphorous are key determinants of productivity, biodiversity, ecosystem processes and food-web dynamics in these freshwater systems (Antoniades *et al.* 2003, Graneli *et al.* 2004).

Goose migration sites

Barnacle Geese spend approximately one month on their traditional spring staging areas in Helgeland in mid-Norway (Gullestad *et al.* 1984, Black *et al.* 1991, Prop & Black 1998). In recent years, the outer islands in Helgeland have been depopulated, and Barnacle Geese have spread into new areas in the north and east (Black *et al.* 1991, Prop *et al.* 1998, Shimmings 1998). In these areas, they feed on sown pastures and heavily managed and fertilized swards (Black *et al.* 1991). Today, the geese therefore stage in either traditional maritime habitats (e.g. outer islands), or newly-exploited agricultural habitats on inland islands. In recent years, Barnacle Geese also stage in Vesterålen in northern Norway (Shimmings 2003, Tombre *et al.* 2004). Here they overlap with Svalbard Pink-footed Geese, feeding mainly on farmland close to the coast. Most of the farmland is cultivated grassland used for sheep and cattle grazing and hay. Along the coastline, some areas of salt-marsh and seashore vegetation remain, although most are overgrown through the lack of summer grazing by livestock.

The Svalbard population of Pink-footed Geese has spring staging areas in mid-Norway and Vesterålen in northern Norway. Here the population aggregates during April and May, foraging on a combination of pastures and spring-sown cereals (mid-Norway only). In recent years, conflicts between farming interests and Pink-footed Geese have given rise to organized scaring of geese from pastures in Vesterålen, which has resulted in geese departing earlier to the breeding grounds without accumulating essential nutrient stores (Madsen & Klaassen 2006) which are a prerequisite for successful breeding as well as survival (Fox *et al* 2005, J. Madsen & M. Klaassen, unpubl. data). A spring migration dynamic model predicts that an abrupt intensification of the scaring campaign, which is currently being considered in both staging areas in Norway, will have dramatic impacts on the population due to the scale of the campaign and the limited possibilities that the geese will have to gain sufficient experience and, hence, adapt to the scaring regime (Klaassen *et al.* 2006).

Goose wintering grounds, land use and climate

Up to the 1960s, Europe was a net importer of many food items, and most agricultural production was achieved by low intensity, high labour methods. As agriculture mechanized and intensified during the immediate post-war period and the European

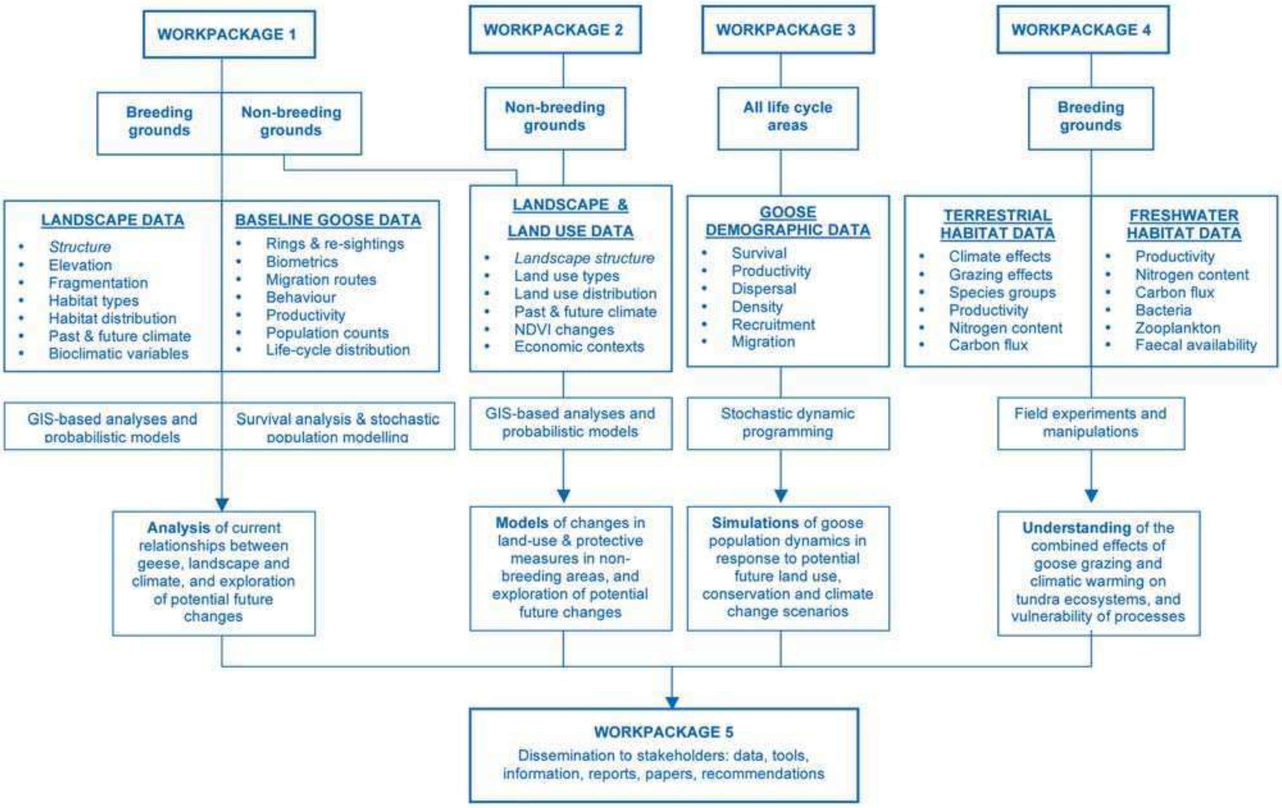

Fig. 4. Flyway area, data, methods and outputs of the five FRAGILE work packages.

economy became more service-oriented, the proportion of the labour force working on the land dropped from more than 20% in the 1950s to 5% today. However, more than ten million Europeans still work in the agricultural sector and more than 40% of the land area is dedicated to food production. Agricultural intensification in the European Union has been facilitated by the development of the Common Agricultural Policy (CAP) in the 1960s, which had the effect of favourably regulating internal and external agricultural markets. During the 1980s, the prohibitive costs associated with maintaining the CAP and a number of trade disputes with other countries prompted the EU to adopt a series of policy reforms in 1992. The "MacSharry reforms" led to reductions in domestic intervention prices, the introduction of compensatory payments, and the implementation of compulsory land "set aside" provisions (Patterson 1997, Matthews 1996, Dauberg 2003). These reforms were further developed and extended through Agenda 2000. The EU has recently expanded its area to include ten central and eastern European countries. Further CAP reforms are, therefore, necessary and are currently being developed and implemented.

These important changes in agricultural policy have been accompanied by the additional drivers of rapidly shifting consumer food preferences, and changes in crop phenology resulting from new "cold hardy" plant varieties that can be sown in winter (Commission of the European Communities 2003). This dynamic and often radically changing system has meant huge changes in what is grown, where it is grown, how it is grown, and when it is grown. In the past, Svalbard geese have spent the winter months on a mixture of naturally occurring salt-marsh (merse) and other coastal and estuarine habitats. Most Svalbard Barnacle Geese spend the winter on the Scottish side of the Solway Firth, whilst Pink-footed Geese winter principally in Denmark, The Netherlands and Belgium. Both populations now spend a considerable proportion of the winter feeding on agricultural fields, pastures and polders (Pink-footed Geese: Fox *et al.* 2005). This alteration in habitat preference has been a result of the geese exploiting new opportunities presented by changes in agricultural production methods and timing, as well as declines in the quality and extent of "natural" habitats.

Several studies have now attempted to analyse future changes in land use and agriculture through the use of scenario development techniques (for a review see Alcamo *et al.* in press). How human societies, technology and the climate will evolve in the future is simply unknown, and prediction of changes in these drivers is simply not possible. In the face of such large uncertainties, scenario development is an important research and decision support tool that can assist in the exploration of alternative futures. Scenarios of changes in the agriculture sector have now explored the role of socio-economic, policy, technology and climate change on future land use and agricultural production strategies (e.g. Alcamo *et al.* in press, Abildtrup *et al.* 2006, Ewert *et al.* in press, Rounsevell *et al.* in press). Whilst each scenario has its own particular assumptions and interpretations, a general trend from many scenarios is of declining agricultural land-use areas. Some scenarios also suggest an increase in extensive land management practices either in combination with declining areas, or as an adaptation to the pressures that cause the area changes. Whilst such trends do not constitute a prediction, they suggest very strongly that future agricultural landscapes will be very different from the present. One of the major areas of concern for goose population dynamics is that grassland areas may decline significantly in some regions of Europe. This will result from continued technological development and the reduced demand for livestock products, but also depends entirely on the ways in which policy makers will or will not respond to such developments. Currently, large areas of agricultural grassland in Europe are protected through measures such as the Less Favoured Areas scheme (LFAs). Thus, the future of goose over-wintering sites may depend as much on future European rural development policy as on, for example, the direct effects of climate change. Most authors seem to agree that climate change will, in practice, have a much less important effect on agriculture in north-west Europe than socio-economic, technological and policy change (Rounsevell *et al*. 2006). There is still an open question, however, about what will happen to the areas of land that are no longer used for agriculture. Further development in the cultivation of bioenergy crops (such as biofuels, short-rotation coppice or *Myscanthus*) seems plausible, but the "abandonment" of agricultural land in some areas seems likely. These types of land-use changes will have important implications for goose overwintering areas.

DEVELOPING AN "INTEGRATED" APPROACH

European framework research

Every four years, the European Commission sets out a "framework" of the priorities for research, technological development and demonstration activities to be commissioned during a particular time period. Framework 5 (1998 to 2002) included an area of work on "Global Change, Climate and Biodiversity", with a sub-action on "Ecosystem vulnerability". The aim was to "develop the scientific, technological and socio-economic basis and tools necessary for the study and understanding of changes in the environment". In 2002, a partnership of twelve organizations and universities across Europe put together a successful bid for funding under Framework 5. The research team combined the requisite skills, experience, knowledge and long-term data needed to attempt a holistic flyway level study. The study was called: "FRagility of Arctic Goose habitats: Impacts of conservation, Land use and climate changE" (FRAGILE).

Project drivers

The development of the project was precipitated by five observations:

- The effects of global climate change will be most acute at high latitudes;
- The distribution and abundance of many tundra breeding geese have been increasing for 40 years;
- Arctic tundra ecosystems can be functionally damaged if over-grazed by geese;
- Severe alterations to tundra result in system switches, i.e. from carbon sink to source; and
- Interactions between geese and agricultural interests in north-west Europe have increased as geese have exploited new agricultural areas during the wintering period.

These observations and the potential impacts arising from them have been recognized (and studied) within individual fields of expertise for some time. But scientists, conservationists, competent agencies, and stakeholder groups recognized a large gap in our knowledge in terms of the interactions and combined effects of these factors at large spatial extents (flyway level). Developing strategies, legal instruments and management regimes to address potential impacts requires outputs that: (a) quantify the current ecosystem/flyway state, and then (b) allow a range of potential future states to be explored on the basis of different socio-economic and climate scenarios. The FRAGILE project was therefore designed to integrate the five driver elements (above) and answer questions within four main areas:

- *Goose populations*: what have been the primary demographic parameters driving population changes?
- *Tundra landscapes*: how are tundra habitats distributed in relation to landscape and climatic factors, and how are geese spatio-temporally distributed within and between available habitats?
- *European land use*: how is European land use influenced by landscape, policy, socio-economic factors and climate?
- *Tundra ecosystems*: how do climate and grazing by geese influence tundra ecosystem function?

These areas form the main themes of the FRAGILE project. In their own right, each will generate a range of extremely useful data, information and analyses. However, the central rationale of the project is to integrate the four elements to provide:

- An understanding of the environmental and climatic drivers of observed changes in goose population parameters. This will allow an exploration of how the distribution and abundance of goose populations might change given a range of future socio-economic, land use and climate scenarios; and
- An understanding of which tundra ecosystem processes are most vulnerable to the combined effects of goose grazing pressure and climatic warming, and an ability to determine thresholds for ecosystem degradation.

Using the above framework, the overall project aim is therefore to provide a mechanistic and explorative basis for understanding the relationships between goose populations, habitats and land use. The three major contexts to this research framework are climate change, European socio-economic and agricultural policies, and international conservation instruments.

Stakeholder engagement

The project will produce a range of outputs in the form of data, information, models, analyses, exploration tools, reports, scientific papers, etc. An explicit element of the FRAGILE approach has been to engage stakeholders and potential end-users of these outputs. A stakeholder group was established at the start of the project, and a workshop held. This served to inform the group of proposed methods and outputs, and provided an opportunity to discuss and incorporate stakeholder perspectives. A post-project stakeholder workshop will also be convened.

Methods, data sources and integration

The project is divided into a series of discrete "work packages", representing different skill, knowledge and data groupings within the FRAGILE research team. Fig. 4 shows the data requirements, generic methods and analytical outputs of the five work packages. The vast amount of data and information used within the work packages was accessed from five generic sources:

- *Monitoring data*: counts of birds and productivity assessments at key sites, largely provided through volunteer-based monitoring schemes and records from individual fieldworkers;

- *Ringing and re-sighting data*: records of individually marked birds, again largely sustained by volunteer-based activities and records from key fieldworkers;
- *Remote sensing data*: Landscape and climate data in the form of satellite images, and data from satellite tracking devices attached to migrating geese;
- *Publicly accessible data*: Climate, land use and many other types of data available on the internet or on request from specific institutions; and
- *Empirical field data*: behavioural observations, experimental plots and habitat ground-truthing.

Fig. 5 schematically represents the integration of outputs from the different work elements.

How can outputs from flyway studies be utilized?

Outputs from integrated research of this nature have a variety of direct and indirect uses. Through pro-active dissemination to appropriate agencies, FRAGILE data, information, models, simulation tools and recommendations will be used to support policy and legislative instruments within the Svalbard-Northwest Europe flyway (and possibly beyond). The major relevant instruments are shown in Table 1. Most of these instruments were created in such a way as to respond directly to what was, at the time, perceived to be the main environmental problem, i.e. habitat loss. Whilst habitat loss and degradation remain major environmental issues, climate change may speed up these processes, render them irreversible in many areas, or create a new suite of issues not adequately addressed by the obligations and actions of established legislative instruments (Boere 2003). For example, UNEP/CMS (2002) identified that climate change will impact migratory species by (1) changing physiological responses, (2) altering the timing of life-cycle events, (3) changing the physical location, extent and condition of breeding, staging and wintering areas, and (4) altering atmospheric and oceanic circulation thus impacting elements such as food resources. Whilst it would be impossible to alter current international conventions in the light of these new factors, it is vital that information on all impacts of climate change are made available to competent agencies involved in their implementation. This is a major role of integrated projects such as FRAGILE and the exploratory tools they can produce. The ability to explore potential population and behavioural outcomes in response to a range of future scenarios also provides an invaluable tool in formulating and improving local, national and flyway level goose management policies (Kruse *et al*. 2004).

In addition to outputs such as data, models, simulation tools, etc., projects that attempt to analyse and integrate such a wide gamut of data also provide other indirect strategic benefits. For example, the FRAGILE project has highlighted the importance of financial support for volunteer-based monitoring activities (often seen as a poor cousin to “hard science”). Long-term, repeated measure, large-scale monitoring and ringing data are central pillars to flyway research, although our analyses have also identified a number of shortcomings in these data where improvements and modifications could be made. These will be fed back to relevant organizations and individuals and reported in later papers. The project has also provided useful lessons in relation to the actual process of attempting such a large integrated flyway research programme (considered in more detail below), and in identifying future research needs.

DISCUSSION

At the time of writing, the FRAGILE project still has a year left to run, and our results, data, models and other outputs will be published elsewhere. The aim of this paper is to provide a working example of: (1) how an integrated and flyway level project can be constructed; (2) the types of data required; (3) the types of outputs that can be produced; and (4) how the outputs

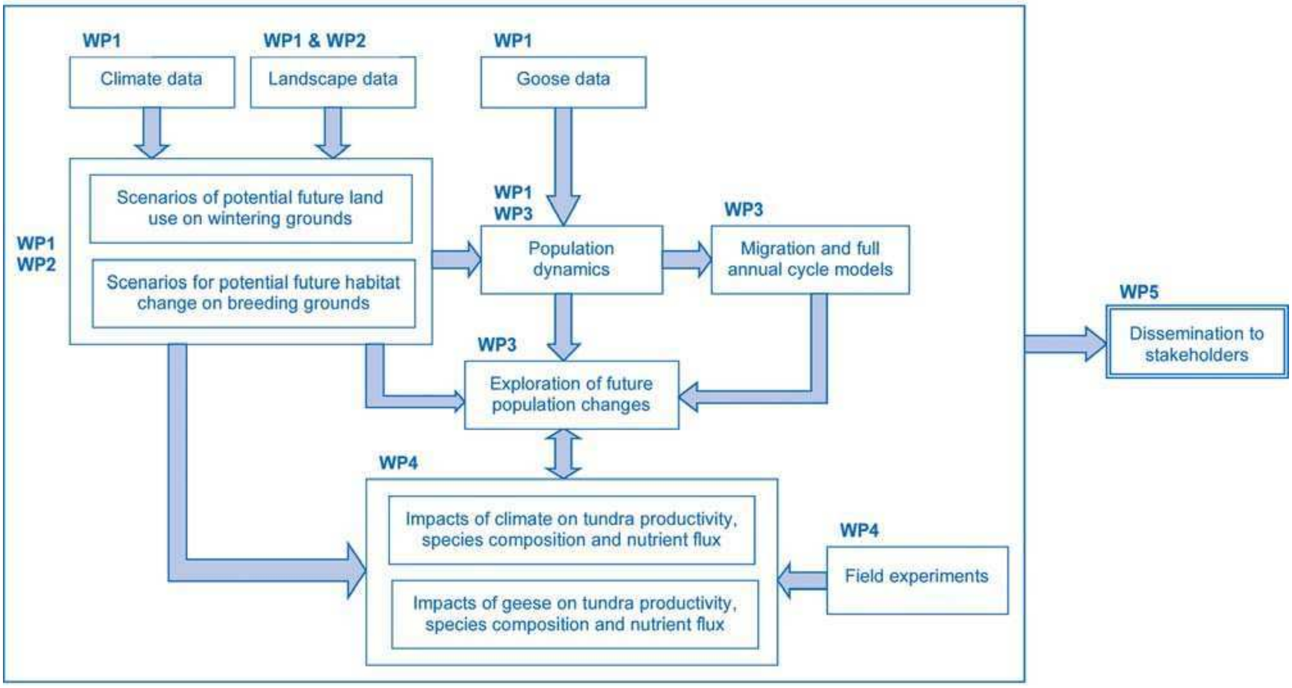

Fig. 5. Integration of the five FRAGILE work packages (WP1-5).

Table 1. **Key legislative instruments where FRAGILE outputs can be used.**

Legislative instrument	Relevant articles	Relevant actions
Council Directive on the conservation of wild birds	Articles 2, 3.1, 3.2, 4.1b, 4.1c, 4.1d, 4.2, 4.3, 4.4, 7.4, 10.1, 10.2, 12.	Deterioration of habitats within and outside SPAs; protection of habitats for migratory species; information needed to ensure sustainable use of quarry species; encouraging research on bird population dynamics; national reporting.
Council Directive on the conservation of natural habitats and of wild fauna and flora	Articles 2.1, 2.2, 2.3, 3, 4, 6.1, 6.2, 10, 11, 12.1d, 17, 18.1, 18.2.	Protection of goose wintering areas; research needs for protecting habitats; inventory of important sites; development of management plans; prevention of deterioration of breeding habitats; national reporting.
Framework Convention on Climate Change	Articles 5a-b, 6, 9, 12 Decision 5/CP.1 Recommendation 9/CP.3 Kyoto Protocol.	Methodologies and tools to evaluate climate change impacts and adaptation; transference of scientific knowledge; quantification of C and N fluxes; assessment of ecosystems as carbon sources/sinks.
Ramsar Convention on Wetlands	Articles 3.2, 4.4. Operational objectives 2.5, 2.7, 3.1, 3.2, 5, 6.	Prevention of ecological change of wetlands; encourage research and data exchange; environmental impact assessment; management including local people; develop education and public awareness of wetland habitats and issues.
Convention on Biological Diversity	Articles 7a-d, 12a-c, 13a-b, 17.1, 17.2, 25.	Identification of processes and categories of human activities likely to have adverse effects on habitats and species; encourage research and training; raise public awareness; exchange of scientific and technological information; national reporting.
Convention on the Conservation of Migratory Species of Wild Animals	Articles 2.3a, 3.4a, 5.5b-f.	Promotion of research into migratory species; conservation of habitats for migratory species; develop management plans; research ecology and population dynamics of migratory species; exchange information; maintain networks of suitable sites; AEWA Action Plan.
Convention on the Conservation of European Wildlife and Natural Habitats	Articles 2, 4.3, 4.4, 5, 10.1, 11b, 14. SC recommendation 3/84.	Maintenance of tundra habitats and species; establishment of peatland inventories. Norway has agreed to include Svalbard under this convention (except with reference to the Arctic Fox *Alopex lagopus*).
European Landscape Convention	Articles 5, 6a-c, 7, 8, 9.	Promotion of landscape protection; information on landscapes and transformation threats; raising public awareness; trans-frontier co-operation.
Pan-European Biological and Landscape Diversity Strategy	Action themes 1.1, 1.4, 3.1, 3.2, 4.1, 7.1, 7.2, 7.5.	European ecological network sites in goose wintering areas; Action 7.5 focuses on regions with emphasis on tundra in northern Europe.
Council Directive on reporting	Transfer of information from Member States to European Commission.	Results will be submitted for national reporting under Birds & Habitats Directives, FCCC, CBD, CMS, Berne, Ramsar.

can be used for conservation and sustainable resource management. We also hope that lessons can be learnt from some of the problems encountered during the implementation of the research.

The varied nature and sheer volume of the data required are two major problems with undertaking a research programme at ecosystem level. Many of the data are in "raw" format (from field observations) and need to be collated, managed, manipulated and interrogated. This raises a range of issues in terms of quality assessment and control, and where "sampling" data are used, information about sampling effort is required. Where long-term species data are employed, there can be significant changes in the number and quality of observers within the temporal extent of the data, as well as changes in the spatial extent of the data. The analytical methods for analysing presence/absence data and changes in species/habitat distributions also need careful consideration and methodological development in relation to the types of data available to the study (Fielding & Bell 1997, Brito *et al*. 1999, Thuiller *et al*. 2003, Wisz 2004). Even the range and spatial scale of information from satellites have changed radically in the last ten years. At the opposite end of the scale, where field-based data are newly acquired, three years of research funding may not be an adequate time-scale for observation. It is also true that for research into some ecosystems, data at any spatial or temporal scale simply will not be available.

Using an enormous amount of varied environmental data from a range of sources also requires a broad array of appropriate data management and analytical skills within the collaborating research groups. This and other factors inevitably make the costs of research at this scale a significant aspect of attempts to fund such work. It will therefore be important to learn and disseminate lessons from the FRAGILE project, as well as to develop rapid assessment techniques in parallel with more detailed research programmes (Boere 2003). One of the other major lessons is that true integration of outputs needs to be carefully considered. It is very easy to implement a study where different elements are being researched independently and are merely under the same project title, but quite a different matter to ensure that outputs and results (not just data) from one group are actually being utilized within the conceptual framework of the research in another collaborating group.

One of the most important features of the FRAGILE project has been the avoidance of references to making "predictions".

A prediction implies a single discernible trajectory or end point for the processes being studied. For many elements of the project, this would have been at best irrelevant, and at worst enormously misleading. Instead, the project is seeking to present species, habitat and system responses under a range of potential future scenarios of climatic, environmental and socio-economic change. Whilst in some quarters this tool-based and explorative approach might be perceived as not producing "concrete" results, it is in fact of far greater application to the intended stakeholder groups.

An explorative approach also recognizes that potential changes in habitat-species associations under new scenarios of climate change will present a number of difficult issues in relation to developing appropriate conservation and management strategies. At the present time, most strategies, conventions, action plans and management policies are fundamentally centred on "current" and narrowly defined ecosystem assemblages. However, differential species' responses to climate change will almost certainly lead to structural and phenological realignment between species comprising an ecosystem, thus making it likely that some current definitions (e.g. those within the current EC Habitats Directive) will cease to exist (Visser *et al*. 1998, Carpenter & Turner 2000). This is also another reason why integrating field experimentation (e.g. the FRAGILE manipulations on Svalbard) is so important in evaluating the combined impacts of climate change on the structure and function of systems, and empirically testing causal links suggested by analyses of numbers from monitoring, etc. Far more research of this nature (i.e. exploring re-combination and structuring at an ecosystem level) is urgently needed.

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Integrated population monitoring, such as that which has been undertaken for the population of Greenland White-fronted Geese *Anser albifrons flavirostris* over 20 years, provides the best chance of understanding the nature and consequences of climate change impacts on waterbirds. Photo: Alyn Walsh.