Nordic Council of Ministers

Signs of Climate Change in Nordic Nature

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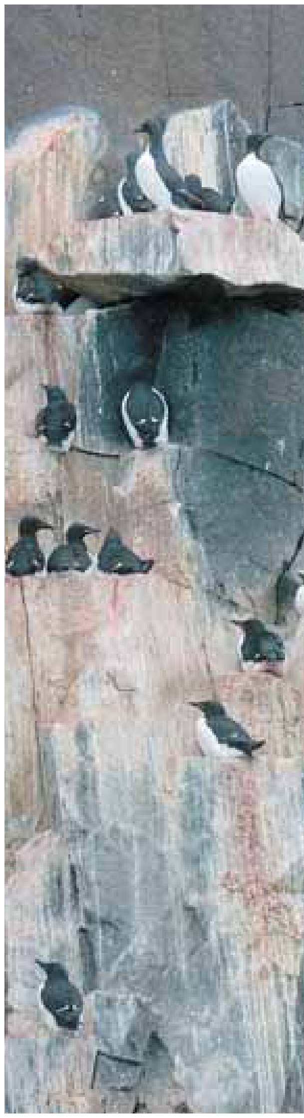

Photo: Biopix.

Photo: Maria Mikkelsen

Preface

The aim of this report is to highlight the extent of climate change effects in Nordic nature. It is based on findings and results from Nordic monitoring programmes and, when adequate, additional data sources from European research institutes.

The present report responds to the recommendation given previously to develop a set of indicators that would enable the Nordic countries to measure and evaluate climate change effects on nature (TemaNord 2005:572). Moreover, the Nordic Council of Ministers' Environmental Action Plan 2005-2008 stresses that efforts should be put towards "the development of monitoring methods and indicators that will make it possible to follow the effects of climate change on biological diversity".

The project group behind this report consists of researchers and representatives of environmental agencies and research institutes in the Nordic region:

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- Høgni Debes, Laboratory of Fishes, The Faroe Islands
- Hans Erik Svart, Danish Forest and Nature Agency, Denmark

The project group would like to thank the many Nordic experts, who were so very helpful in providing data, information sources and advice, especially Annika Hofgaard, Bergur Olsen, Erik Born, Erling Ólafsson, Fernando Ugarte, Käthe Rose Jensen, Leif Aarvik, Margrét Hallsdóttir, Nina Eide, Steinar Sandøy, Tero Härkönen and Ævar Petersen. We would also like to thank the Danish Agency for Spatial and Environmental Planning for housing and administering the project. In addition, many thanks to Britta Munter for designing and doing the lay-out of the report, Pia Andersen for her assistance in organising meetings and Troels Rolf for making the project's website.

Maria Mikkelsen, Birkerød, July 7 2009.

Summary

Not only is the Earth's climate changing, our natural world is also being affected by the impact of rising temperatures and changes in climatic conditions. In order to track such climate-related changes in Nordic ecosystems, we have identified a number of climate change sensitive indicators. We present a catalogue of 14 indicators that demonstrates the impact of climate change on terrestrial, marine and freshwater ecosystems in the different biogeographical zones of the Nordic region.

The indicators have been identified using a systematic and quality, criteria based approach to discern and select the most relevant indicators. It is important to stress that by selecting a set of indicators rather than individual indicators, it is then possible to evaluate more general trends and not solely separate developments. The amount and quality of data vary between the selected indicators; monitoring data on population size and range of the polar bear, for example, are scarce, whereas data on the pollen season are extensive.

Each indicator is evaluated using a number of quality criteria, including sensitivity to climate change, policy relevance and methodology. Although the indicator framework presented here has been developed to describe climate change indicators in the Nordic region, the approach may be applicable to other regions as well.

In the project, we show that climate change is not only affecting a few individual species or habitats in the Nordic region, but that instead a number of changes are occurring concurrently and on multiple scales. Important indicators of climate change include: pollen and growing seasons beginning earlier; fish stocks shifting northwards; bird populations adapting to a changing climate; sensitive natural phenomena such as palsa mires declining in distribution; and polar bears being threatened by ever earlier ice-breakup.

Photo: Bo Normander

Dansk resumé

Ikke alene er klimaet under forandring, men som følge deraf påvirkes også vort naturgrundlag. For at gøre det muligt at følge konsekvenserne af de klimatiske ændringer i den nordiske natur har vi i denne rapport identificeret en række klimasensitive indikatorer. Vi præsenterer hér et katalog af 14 indikatorer, som viser påvirkningen af klimaforandringen i terrestriske, marine og limniske økosystemer.

Indikatorerne er blevet identificeret gennem en systematisk gennemgang på baggrund af nogle udvalgte kriterier for at finde frem til de mest velegnede indikatorer. Ved at udvælge et sæt af indikatorer frem for enkelte indikatorer vil det være muligt at følge mere generelle tendenser frem for individuelle udviklingsforløb. Mængden og kvaliteten af data varierer en del mellem de udvalgte indikatorer, f.eks. er datamængden for populationsstørrelsen og udbredelsen af isbjørnen i den nordiske region begrænset, hvor datagrundlaget for pollensæsonen er anseligt.

Hver enkelt indikator er som nævnt blevet evalueret på baggrund af en række kvalitetskriterier, herunder sensitivitet overfor klimaændringer, politisk relevans og metode. På trods af at dette sæt af indikatorer er udviklet for indikatorer i Norden, kan den hér anvendte metode og de kriterier vi har lagt til grund for udvælgelsen af indikatorer i dette projekt meget vel bruges i øvrige regioner i verden.

I det nærværende projekt viser vi, at klimaforandringen ikke kun rammer enkelt arter eller habitattyper i Norden, men at påvirkningen er generel og rammer på alle niveauer. Særligt vigtige indikatorer er: den tidligere start af pollensæsonen, fiskepopulationernes ændrede udbredelse mod nord, fuglenes ændrede adfærdsmønstre, palsa mosernes reducerede størrelse og udbredelse, samt isbjørnenes svækkelse på grund af den til stadighed tidligere optøning af havis.

Photo: Maria Mikkelsen

Climate change effects...

It is widely recognised that climate change is already a fact, with changes occurring in global temperature, precipitation and snow melting; furthermore observations of effects on natural eco-systems are becoming more and more widespread (IPCC 2007). Plants, butterflies and birds are expanding ever northwards (Hickling & al. 2006), the growing season starts earlier and ends later (Menzel & al. 2006), trees flower earlier, and there is an observable advancement of phenological events in birds and insects like clutch initiation and emergence dates (e.g. Høye & al. 2007).

The global increase in temperature - observed since the mid-nineteenth century – is an average of 0.6 °C (IPPC 2007). However, the temperature increase in the Northern Hemisphere is higher, and in the Nordic countries, the average temperature increase for the same period is above 1°C. For example, in Denmark, Greenland and the Faroe Islands a temperature increase of 1.5°C was measured between 1870 and 2007 (Fig.1).

Average temperatures in the Nordic countries are expected to continue to increase as global emissions of greenhouse gases (GHG) rise. It is widely recognised that anthropogenic emissions of greenhouse gasses such as carbon dioxide (CO_2) and methane (NH_4) are leading to climate change (IPCC 2007). In the Nordic countries, the total emissions of greenhouse gases, however, have slightly decreased from 1990 to 2006 by a measure of 1% (Fig. 2).

Early focus on the emissions of greenhouse gases

Climate change has been a central issue in environmental monitoring ever since the United Nations (UN) Kyoto Protocol entered into force in 1994 (e.g. EEA 2008). The main effort has been put towards monitoring the emission of greenhouse gases in order to evaluate the effectiveness of emission reduction measures. Comparatively less effort has been expended on studying the effects of climate change on ecosystems. As climate change effects on nature are reported increasingly more often, the emerging trend suggests that climate change effects will become more pronounced in the future (EEA 2008). Monitoring these effects is of vital importance (Nordic Council of Ministers 2005), and today there are only a few monitoring systems in place.

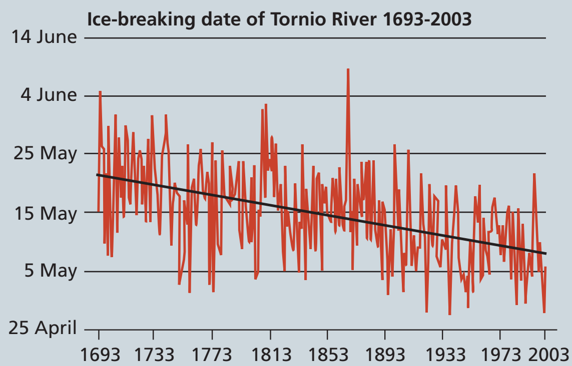
Monitoring of climate change effects on nature

During the last decade, several initiatives have been undertaken at the national as well as the international levels to develop monitoring systems that measure the impact of climate change on nature. For example, the United Nations agreement in 2002 that states that the rate of decline in biodiversity must be significantly reduced by 2010 has led to the development of new monitoring and reporting systems, e.g. Streamlining European 2010 Biodiversity Indicators (SEBI 2010). Also, systems set up to measure progress in the area of sustainable development include the monitoring of effects on nature. Most monitoring systems use indicators as tools to measure and communicate developments; the SEBI 2010 set of biodiversity indicators also includes climate change relevant indicators. Several national initiatives have focused on developing climate change indicators that are more broad than just emission indicators and include suggestions for depicting climate change effects on nature as well (Donelly & al. 2004; Buse & al. 2001; Brunvoll & al. 1999; Framstad & Kålås 2001). These initiatives show strong need for more knowledge concerning the complex causal link between climate change parameters and effects on nature. There is also a need for greater availability of longterm data sets to monitor the effects.

Despite the fact that climate change is happening on the global scale, changes at the regional or local level may show variability. Consequently, identifying effect indicators on a geographical scale capable of representing similarities in eco-system functioning, may provide a means of evaluating larger trends in development than those confined to national borders.

Tornio River

Because of its importance for local populations around the world, the ice-breaking date of big rivers has been registered for centuries. In Finland, the ice-breaking date of the Tornio River has been registered since 1693. The breaking of the ice has advanced by around 12 days from May 20 in 1693 to around May 8 in 2003. Ice plays an important role, not only for the people who must cross the river and who depend on fishing or sailing, but it is also important for the organisms living in the river.



indicators and monitoring

A representative set of indicators

In this report, we present 14 indicators of climate change effects in Nordic nature. Each of these indicators is used to quantify observed (or expected) changes in nature, e.g. range shifts in fish stocks of the North Sea or phenology changes in moths. The set of indicators aims to measure climate change impact by the selection of representative climate change sensitive species or traits in the terrestrial, marine, and freshwater ecosystems. Most of the indicators are impact indicators signalling that a societal response to climate change effects on nature will be determined by developments related to these indicators.

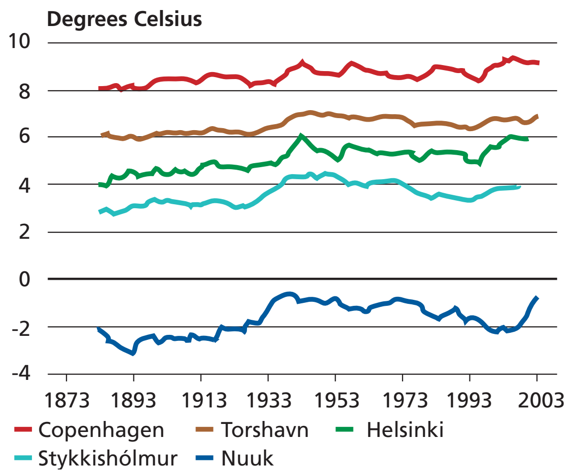


Fig. 1

Temperature trends for selected stations in Finland, Iceland, Denmark, Greenland and the Faroe Islands over 100 years (Nordic key indicators 2006, Nord 2006:003)

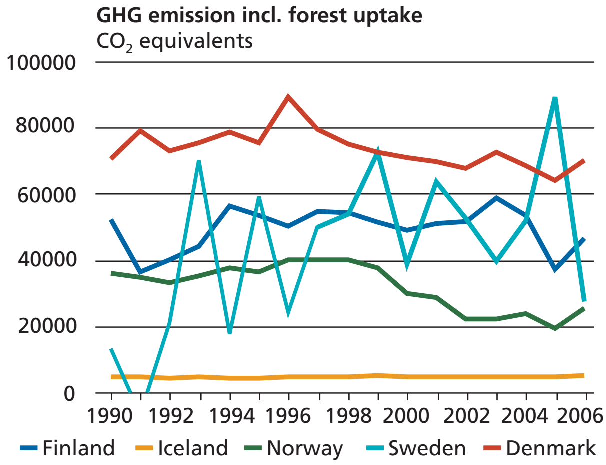


Fig. 2

Emission of greenhouse gases in the Nordic countries from 1990 to 2006. Emissions in Nordic countries have decreased slightly by 1% during this period. (http://unfccc.int/di/DetailedByParty.do)

Photo: Bo Normander

Growing season

Photo: Britta Munter

> "The growing season in Fennoscandia has extended by up to four weeks in the period 1982 to 1999. Moreover, an advancement of the beginning of the growing season by up to two weeks has been observed for the period from 1982 to 2006. All are signs the experts consider a likely response to climate change."

A clear signal

In the whole of the southern part of the Nordic countries, the spring starts considerably earlier now than in 1982 (NORUT; Høgda & al. 2001) (Fig. 1). The most significant change is in the southern part of the region, with changes of up to two weeks. At the same time, the fall is delayed by one to three weeks for the whole of the area, apart from the most continental section of northern Scandinavia. In the mountains, there are a few places with a shortening of the season and – as a result of thicker snow cover due to an increase in winter precipitation – a longer period of snow cover (Menzel & Fabian 1999) (Fig. 2). In general, the results show a pattern relating to vegetation zones (north to south) and vegetation belts (altitude). The length of the growing season and the timing of spring have a great impact on primary-production, the composition of the plant communities and the range of plant species (Norby & Luo 2004).

Photo: Maria Mikkelsen

The most significant change in growing season is observed in the southern part of the Nordic region.

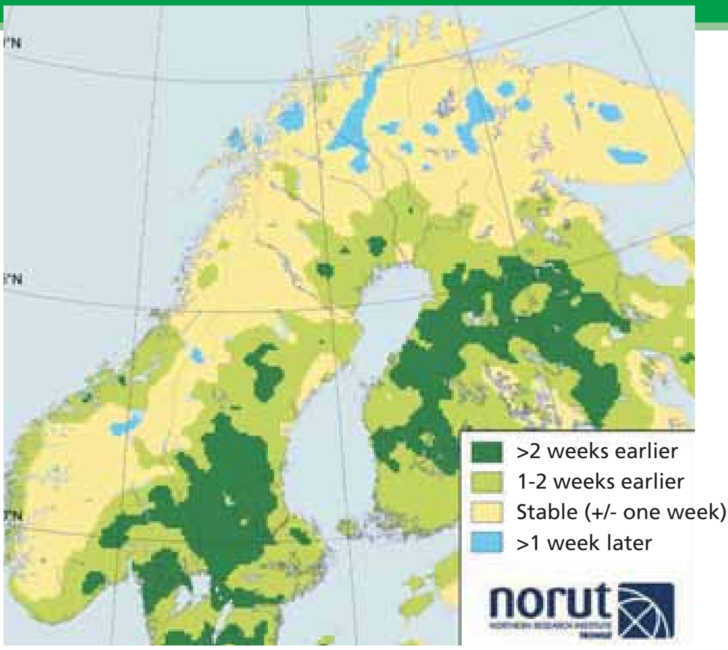


Fig. 1
The onset of the growing season has advanced in the period 1982 – 2006. Corresponding data for Iceland, Greenland and the Faroe Islands are not available (NORUT).

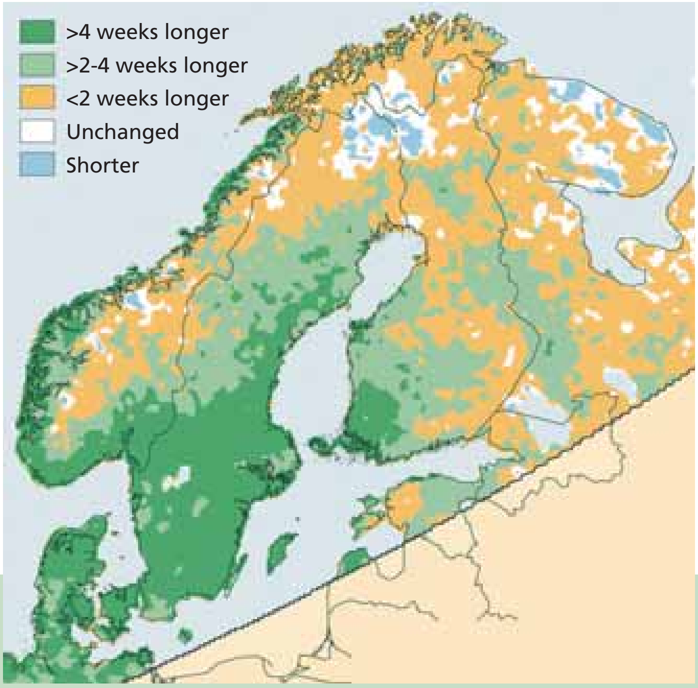


Fig. 2
The map shows the prolonging of the growing season for the period 1982 – 1999 by four weeks. Corresponding data for Iceland, Greenland and the Faroe Islands are not available (NORUT).

Quality criteria	Growing season
1. Representative for the Nordic region	Yes, monitored in all countries
2. Sensitive to climate change	Yes
3. Policy relevant	Indirectly, major socio-economic importance, e.g. changes in agricultural crop yields
4. Easily understood	Yes
5. Relevant for ecosystems	Yes, direct influence on ecosystem development
6. Scientifically agreed methodology	Partly, the growing season is monitored by different methods in Fennoscandia
7. Quantitative	Yes
8. Timeseries available	Yes
9. Country comparison possible	Yes

Methodology

The Normalized Difference Vegetation Index (NDVI) is a simple numerical indicator that can be used to analyze remote sensing measurements – typically but not necessarily from a space platform – and assesses whether or not the target being observed contains live green vegetation (Compton & al. 2001). A high NDVI is indicative of vigorous photosynthetic activity. This is used to register the onset and end of the growing season. The Global Inventory Modelling and Monitoring System (GIMMS) group and the NDVI dataset were used to investigate the climate change impact on the length of the growing season in Fennoscandia, Denmark and the Kola Peninsula from 1981 to 1998 (Fung 1997).

Birch pollen season

Photo: Maria Mikkelsen

> **Throughout the Nordic region an advancement of the tree pollen season has been observed during the last three decades in addition to the increase in the amount of pollen within each season. Experts consider these changes to be a result of climate change. As birch is a common tree species for the Nordic countries, it can become a valuable indicator for climate changes across the region.**

Birch pollen

Birch (*Betula spp.*) is the most common deciduous tree native to the Nordic countries and in areas where vast birch forests exist, the wind-dispersed birch pollen can be a harmful allergen (Hallsdóttir 1999; Karlsen & al. 2009). Pollen allergy is becoming an increasing problem: a definitive explanation for this does not yet exist, but the so-called unhealthy "western lifestyle" has been posited along with the increasing amount of pollen in the air (Rasmussen 2002; Linnenberg & al. 1999). The flowering of birch plants results in the release of a large number of pollen grains into the air. The pollen of birch becomes windborne after being released from flower stamens in search of the pistil of another flower and can be carried for great distances (Skjøth & al. 2008).

Pollen season

Research has shown that the starting date of the pollen season is closely related to temperatures of the pre-season (Spieksma & al. 1995; Hallsdóttir 1999; Emberlin & al. 2002; Rasmussen 2002). Researchers have pointed out that predicted future increases in temperature will probably affect both the flowering of plants and the dispersion of pollen into the air. However, other meteorological parameters such as precipitation, cloud cover, wind and humidity may also affect the birch pollen season. It must be noted though, that the starting date has been defined in several ways and therefore must be considered carefully when results from different areas are compared (Rasmussen 2002).

The amount of wind-dispersed pollen in the air has been monitored for the past 20 – 30 years in Finland, Norway, Sweden, Denmark and Iceland (http://www.polleninfo.org/). The data shows that for many tree species, including birch, the pollen season now starts ever earlier. The birch pollen season in Denmark, Norway and Iceland starts 10 to 26 days earlier today than it did two decades back (Fig. 1). For example in Copenhagen, the season started 12 days earlier in 1998 in comparison to 1979 (Rasmussen 2002). Correspondingly, the amount of birch pollen has increased during the period 1985 to 2007 (Fig. 2). In Copenhagen, the amount, or annual total of birch pollen increased by more than 230% from 1979 to 1998 (Rasmussen 2002).

Prediction

In order to estimate the start date of the pollen season, different approaches have been taken. Models to estimate the start-date in Denmark have been based on Growing Degree Hours and give reliable predictions overall (Rasmussen 2002). Others have found correlations between the start date and the accumulated thermal sum or mean temperature over a certain time period (Spieksma & al. 1995; Hallsdóttir 1999). More recently, satellite data along with birch pollen counts have been used to predict the onset of the birch pollen season in Norway (Karlsen & al. 2009).

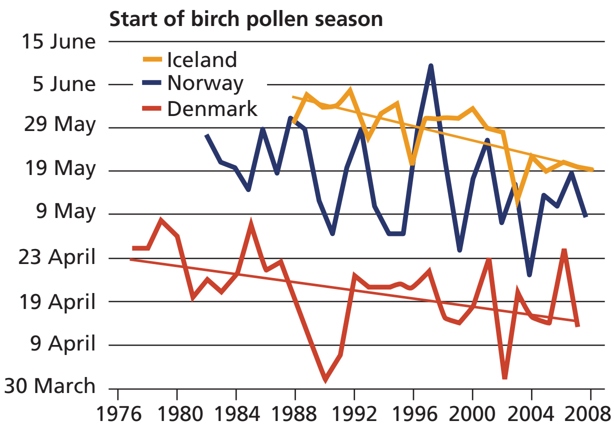


Fig. 1
Pollen season start-date for birch in Denmark (Danish Meteorological Institute) and Iceland (Hallsdóttir, pers. com.) and Norway (Ramfjord, pers. com.).

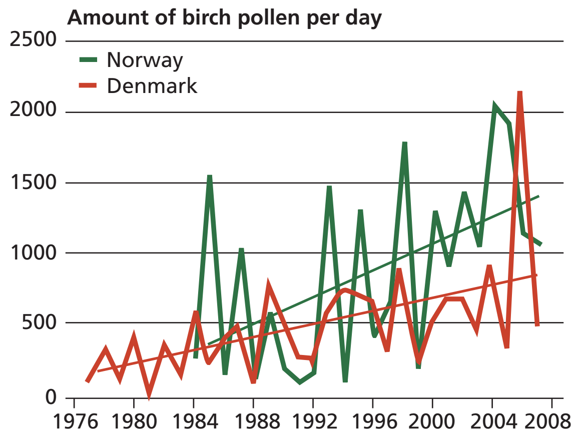


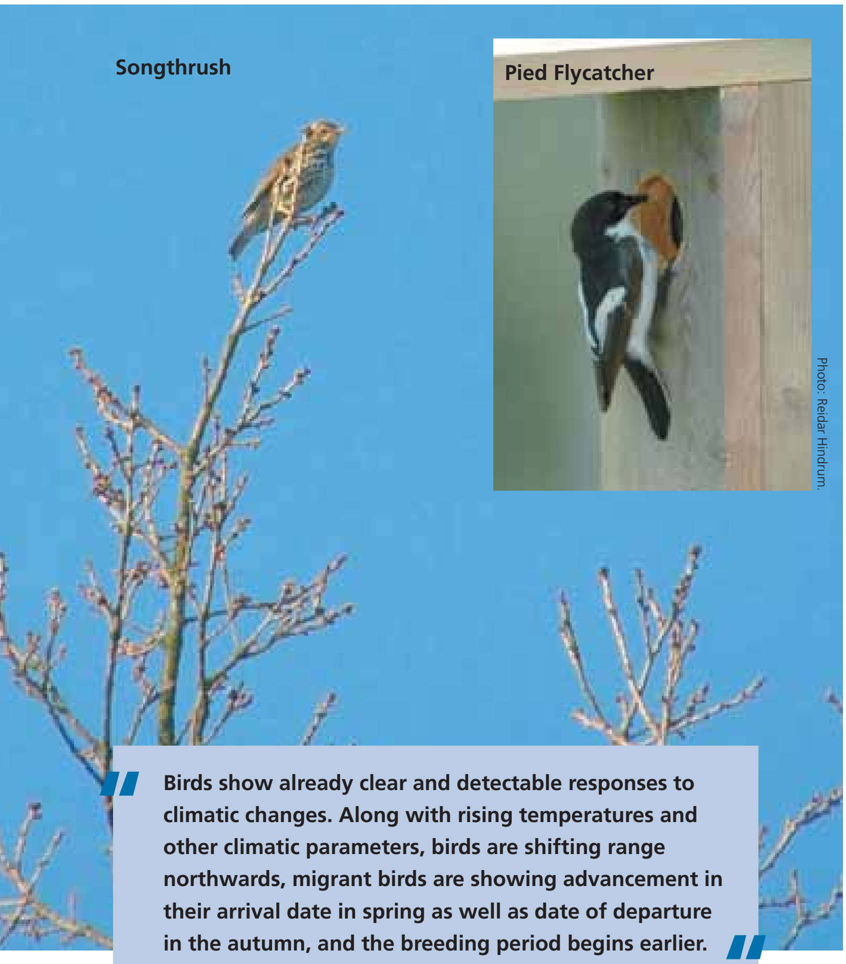
Fig. 2
Annual amount of birch pollen in Norway (Karlsen & al. 2009) and Denmark (Danish Meteorological Institute).

Quality criteria	Birch pollen season
1. Representative for Nordic region	Yes, monitored in a number of cities in all Nordic countries (not yet relevant for the Arctic region)
2. Responsive to climate change	Yes, the length of pollen season is directly linked to temperature
3. Policy relevant	Yes, usually used in relation to allergy warnings, but the link to climate change needs to be acknowledged
4. Easily understood	Partly, pollen statistics is widely known and used, but the link to climate change is less known and understood
5. Relevant for eco-systems	Partly, pollen is an indirect measure of the state of certain species (e.g. trees)
6. Scientifically agreed	Yes, methodology is well established and follow international standards
7. Quantitative	Yes
8. Time series available	Yes, pollen counts have been carried out yearly in the Nordic countries for the past 20 to 30 years
9. Country comparison possible	Yes

Methodology

The start of the pollen season has been defined in various ways throughout the literature. Typically, the start-date is defined as the day when the pollen count passes a certain threshold of a daily or accumulated amount, or alternatively as the day when a certain percentage of the total catch for a season has been recorded. These definitions provide information about when pollen is in the air, but not the time of actual flowering or when the pollen has fully matured on the plants (Emberlin 2002). Pollen grains are sampled in pollen traps, which are placed in a number of large cities within the Nordic countries. The amount of pollen is quantified as the number of grains of pollen per cubic meter of air. In the Nordic countries, pollen records go back to the 1970s (http://www.polleninfo.org/), with the exception of Greenland where records are available only for the period 1997-1999 (Porsbjerg & al. 2003).

Migrant birds



Songthrush

Pied Flycatcher

Photo: Reidar Hindrum.

Photo: Christina Mikkelsen.

> **"Birds show already clear and detectable responses to climatic changes. Along with rising temperatures and other climatic parameters, birds are shifting range northwards, migrant birds are showing advancement in their arrival date in spring as well as date of departure in the autumn, and the breeding period begins earlier."**

Timing of arrival

Climate change is seen to have a large impact on the phenology of migrant birds (Tøttrup & al. 2006). The timing of migratory bird arrivals has globally, as well as in the Nordic region, changed as a direct response to global warming. The number of migrating birds varies with latitude; less than 10% of birds around the equator migrate, whereas as many as 80 % of the birds living north of the polar circle migrate south (CMS report). The timing of migration is changing with the changing climate. Several studies suggest that birds are reaching their breeding grounds progressively earlier as the temperatures become warmer (Vähätalo & al. 2004; Tøttrup & al. 2006; Forchammer & al. 2002).

Birds shift range in Finland

In a Finnish study, 140 bird species were evaluated to determine possible changes in range margins (Brommer 2004). A shift in range implies that the southern distribution diminishes, while the northern part expands. In the study, 116 southerly bird species and 34 northerly species were analysed over a 12 year period (1974 – 1979 to 1983-1986). All birds showed a significant northward shift in range. As the shift was general for all birds studied and therefore not species-specific (as the effect of a landscape change would be), the experts therefore connected this shift in range to climate change. Corresponding UK studies (e.g. Gregory & al. 2007) showed a range margin shift, which was half the size of the Finnish study. This might indicate that the northern, high latitude species are more sensitive to changes in temperature than their more southern European counterparts (Forchammer & al. 2002).

Migrant birds not only arrive earlier in spring….

At temperate and higher latitudes, many birds have adapted to colder winters by evolutionary processes and/or by migrating to regions with more optimal temperatures and food resources during the cold season. They then return to their breeding grounds when temperatures are more ideal. The timing of migration is regulated endogenously, i.e. hormonally, which in turn, is under the control of the daylight (photoperiodic) cycles. However, external factors like spring temperatures, wind conditions, ice and snow cover and the North Atlantic Oscillation (NAO) also contribute to influence phenology (Tøttrup & al. 2006). The NAO determines inter-annual fluctuation rates in winter temperatures in the Northern Atlantic region and is correlated with global as well as regional temperature fluctuations (Forchammer & al. 2002). Thus, the timing of spring arrival and autumn migration is regulated by conditions in the wintering region throughout the entire migratory route as well as within the breeding grounds. Studies of migrant birds in northern Europe have shown that migrant birds are not only advancing the timing of their spring arrival but also the timing of their autumn migration. The timing of autumn migration has been shown to depend on the start of breeding, which is determined by year to year fluctuations of spring temperatures (Tøttrup & al. 2006).

In a Swedish study, a time series from 1952 to 2002 was analyzed for signs of change with possible connections to climate change (Stervander 2005). The study showed a correlation with climate in the form of the NAO: birds arrived earlier, ranging between 2.5 days to 0.7 days every 10 years, especially after mild and humid winters. Studies from Finland correspond with the findings in Sweden (Vähätalo & al. 2004). The Finnish studies showed that the majority of the 81 migratory bird species arrived earlier after a positive NAO, indicating a warm and humid winter in Northern Europe. Both of the above studies indicate a strong adaptability and elasticity (spring arrival to climatic change without time delay).
Correlating data from bird migration or phenology with the NAO index might seem unimportant when assessing the effect of climate change on birds; however, it shows the strong effect of climate on birds regardless of the specifics of the driver.

.. but also leave earlier in autumn

As documented above there is ample knowledge concerning the changes in the timing of birds' spring migration, whereas less is known about the timing of their autumn departure. There is however, a Danish study of 22 species' time of departure for the period 1976 to 1997, showing clear indications of autumn migration phenology. The short distance migrants, with a migration distance of 1,500 to 2,500 km, showed earlier departure times for the majority of the given species (Fig. 1).

Effects on egg-laying date

In Norway, the egg laying date for the pied flycatcher (*Ficedula hypoleuca*) was monitored from 1992 to 2007. During this period, a relationship between the egg laying date and the temperature was revealed. Pied flycatchers strive to nest and lay their eggs as early as possible in order to give their young enough time to mature before the autumn migration. The ecological effects of this advancement are not quite clear (Framstad 2008). The result of egg laying date tracking temperature/climate change has also been observed in many other places and is supported by a number of international studies (Forchammer 1998; Stenseth 2002; Winkler & al. 2002).

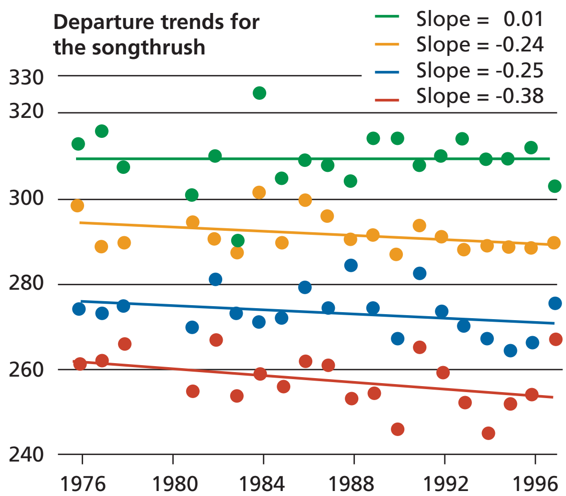


Fig. 1
Illustration showing population departure trend for the period 1976 to 1997 for the songthrush (*Turdus philomelos*). Lines are regression lines describing the change in departure for 95% (red circles), 50% (blue circles), 5% of the total population remaining to be trapped (yellow circles) and the last individual (green circles) (Tøttrup & al. 2006).

Photo: Peter Brandt.

The Robin – another migrant bird reacting to climate change.

Quality criteria	Migrant birds	Methodology
1. Representative for the Nordic region	Yes, migrant birds are monitored in the whole region	The selected indicator shows historical shifts in the geographical range and phenology of birds. The indicator is constructed on the basis of bird trapping in the Nordic countries performed by an extensive number of volunteers.
2. Sensitive to climate change	Yes, birds are highly mobile and can react very quickly changes in their environment, e.g. temperature. Other factors such as change in land use also has an impact on migration of birds	
3. Policy relevant	Yes, birds are under national and international protection e.g. the EU Birds Directive (SPA)	
4. Easily understood	Yes	
5. Relevance for ecosystems	Yes	
6. Scientifically agreed methodology	Yes	
7. Quantitative	Yes	
8. Timeseries available	Partly, bird population sizes are monitored yearly, but their phenology (e.g. migration timing) is not monitored on a regular basis	
9. Country comparison possible	Not yet	

Moths and butterflies

> Some insects have through the last decades shown a northern shift in range. Whereas some butterfly species show 5-10 days advancement in the flying time and a production of a second or even third generation through one season. All these signs may be an indication of response to climate change.

Photo: Erling Ólafsson.

Photo: Erling Ólafsson.

General assessment

Climate change as expressed by rising temperatures is documented to have a large impact on the range and phenology of some butterfly species (Parmesan et al. 1999). Already, several responses to climate changes have been observed among insects as butterflies and moths in the southern part of the Nordic countries, in Iceland and in the Faroe Islands.

Moths and butterflies shift range

In the Nordic countries there are obvious indications that butterflies and moths are responding to the climate change. In a study of 114.000 moths collected by light traps through a 12 year period from 1994 to 2006 an increasing number of moths species from the Middle European area have settled in Denmark and are now expanding their range considerably (Stadel Nielsen 2008) (Fig. 1). The species in question have some common traits. They are characterized by being unspecialized butterflies that live in quite common habitats as butterflies as well as in their larvae stadia. The experts consider this shift in range and expansion as sign of climate change. The corresponding pattern of southern or southeastern butterfly species shifting range is also observed in Norway especially through the last 20 years with species coming in from the south (Arvik, L. pers. com.).

For a number of species a change was found in the phenology of the butterflies when comparing the flight time between the two periods 1994-1999 and 2000-2006 (Stadel Nielsen, 2008). The greater part of the analyzed species showed considerable changes. The flight time of the butterflies was quite commonly advanced in time for 5 to 10 days. This advancement has given time for the production of a second or in some cases even a third generation of butterflies before the season was over. Correspondingly a similar pattern has been observed in Finland where a number of moths produce a second or a third generation during one season (Pöyry & al. 2008).

In Iceland moths have been monitored since 1995 and similar trends have been witnessed. Some species advance their flying time in early season and there are examples of a second generation individuals of the early flyers in the autumn, which are certainly not able to produce further. The same holds for a dipteran tipulid species (*Tipula rufina*), there is also indications of southern species becoming more numerous and extending their range towards north. Moreover new species have successfully colonized the country during this time (E. Olafsson, pers. com.).

The noctuid moth *Melanchra pisi* is an example of a southern and formerly rather scarse species that is advancing in flying time, gradually becoming more common and at the same time extending its range in Iceland.

Do butterflies respond even faster than birds to climate change?

In a newly published report the possibilities of building a European Butterfly Climate Change Indicator were investigated (Van Swaay & al. 2008). By using a so called Community Temperature Index (CTI) which shows the butterfly communities composition in relation to temperature, where an increased CTI implies an increasing part of a given community being composed by warm affiliated species. This method has been used on birds also (Devictor & al. 2008). Comparing the two groups of animals show that butterflies seemingly respond faster to climate change than birds. Possibly due to their cold-blooded nature which bounds them more to temperature regimes than the warm-blooded birds (Van Swaay & al. 2008).

Mountain refuges for butterflies

Butterflies thus seem to be excellent indicators of climate change effect on nature being mobile with short time of generation. Experts have recently finished a research modeling project on the effects of climate change on the distribution of around 100 butterfly species. Traditionally butterflies in the Mediterranean and the northern most regions are considered to be most vulnerable to climate change, but the study show that also species of lowlands and coastal regions of the north will suffer from the effects of climate change. As pointed out earlier species can react to changes by shifting range or adapting and in mountainous regions that provide many varied habitats and microclimates over small geographical areas offers good possibilities for survival (http://mmm.multiedition.fi/syke/envelope/envelope6).

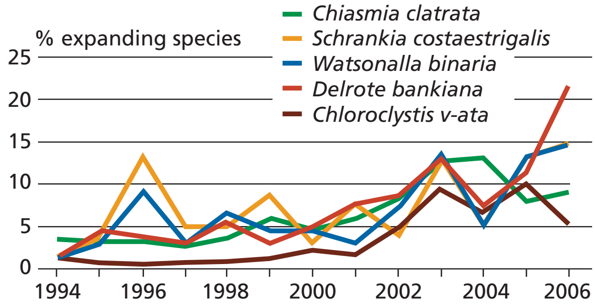


Fig. 1

Expanding species in Denmark with breeding populations in 1994 (Stadel Nielsen 2008).

Quality criteria	Moths and butterflies	Methodology
1. Representative for the Nordic region	Yes	The selected indicators show historical shifts in the geographical range and phenology of butterflies. The indicator is constructed on the basis of mercury light traps and an abundant amount of statistics for individual butterfly species. The indicators conform to most of the quality criteria listed.
2. Sensitive to climate change	Yes, butterflies have a short life-cycle, which means that their numbers react quickly to changes in their environment, including temperature. However, there is a demand for being alert towards the bias of land use changes	
3. Policy relevant	Yes, several species are red listed (endangered) and included in the EU Habitats Directive	
4. Easily understood	Yes	
5. Relevant for ecosystems	Yes, important part of the food web and responsible for pollination of plants	
6. Scientifically agreed methodology	Yes	
7. Quantitative	Yes	
8. Timeseries available	Partly, butterfly monitoring schemes exist in an increasing number of countries in Europe. In the Nordic region only Finland is active but Sweden, Norway and Denmark are expected to increase the monitoring efforts	
9. Country comparison possible	Not yet, data lack for some countries	

Tree line

"Studies show a topographical change of the tree line that is considered a direct effect of increasing temperatures in the Nordic countries. The tree line as an indicator of climate change is relevant also because of its accessibility and visibility."

Two types

There are two major types of tree lines: latitudinal and altitudinal. The latitudinal distribution is mainly characterized by a species' northern distribution limit. There are observations that individual species have moved their distribution limit northwards by 50-300 km (Kullman 2008). Both tree line types are determined by climatic conditions, mainly temperature, but factors as e.g. wind exposure, grazing pressure, and moisture may also play an important role.

Shift upwards

Extensive data series from Sweden have documented an upward shift in elevation/altitudinal shift (Kullman 2001). In other countries similar indications exist, e.g. recent research indicates that the tree line of mountain birch has shifted upwards over the last few decades in Iceland as well (Wöll 2008). This shift is considered to be an indicator of the effects of climate change. The tree line response is relevant as a climate change indicator as it has been shown to be in accordance with the changing climate. The difference between older and more current data gives a quantitative expression of climate change effects at different altitudinal levels and under different local climate patterns. Knowledge about the response of different tree species underpins the use of the tree line as a climate change effect indicator to better understand how and where this indicator should be monitored. (e.g. Truong & al. 2007; Callaghan 2002; Kullman 2008).

There is, as of yet, few systematic programs for alpine tree line monitoring. National forest inventories (NFI) in the Nordic countries do not, by definition, include treeless alpine heath (Fig. 1). For latitudinal changes of tree lines, NFIs may serve as a viable data source. However, NFIs are performed on a coarse scale and such programs are not designed for detecting sparse objects, and thus may not work as an early warning indicator. Another approach is to use remote sensing for assessing changes in the alpine tree line. There are several reports of successful monitoring when remote sensing data are used (e.g. Hill & al. 2007; Stow & al. 2004). Although many studies support the hypothesis that the spreading of trees is driven by the climate, some studies have shown that change in land use, such as cessation of human impact, may also cause a change in the tree line zone (Holtmeier 2005).

Photo: Maria Mikkelsen

Fig.1
The Swedish forest inventory network. The empty parts in the northwest are treeless alpine communities, which make forest inventory impossible.

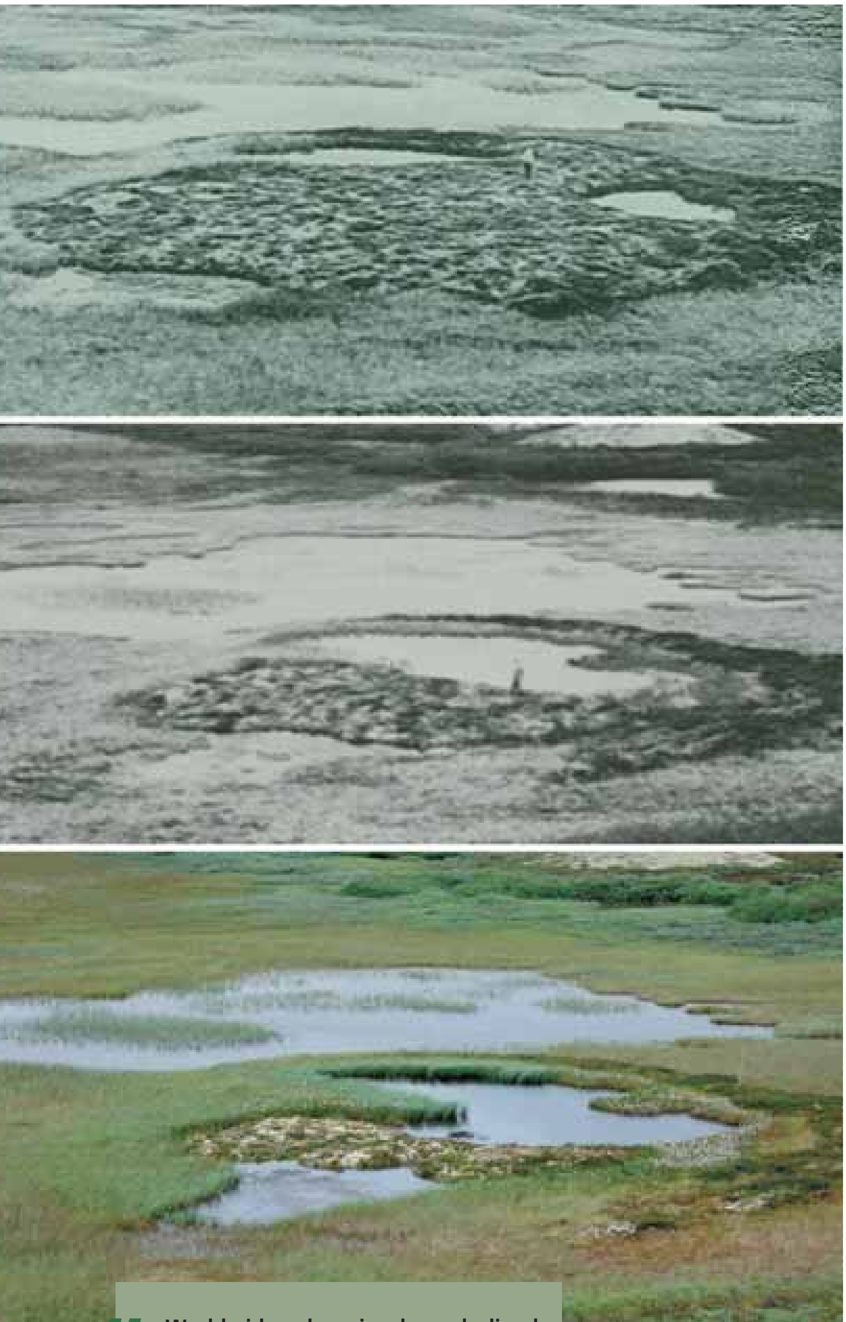
Quality criteria	Tree line
1. Representative for the Nordic region	Yes, for the alpine region
2. Sensitive to climate change	Yes, tree and forest lines are determined by local climatic conditions
3. Policy relevant	Indirectly, as indicator of socioeconomic impact on forestry
4. Easily understood	Yes
5. Relevant for ecosystems	Very relevant for alpine heath communities that may be turned into forests
6. Scientifically agreed	Yes, the treeline is a well defined term, however several methological approaches are used
7. Quantitative	Yes
8. Time series available	In a few cases, e.g. in Sweden
9. Country comparison possible	Yes

Methodology

The tree line is defined as the upper limit for trees which are at least 2 m in height and of a certain species at a certain spot. A closely-related concept is the forest line, which is defined as the highest altitude capable of supporting a continuous forest cover. Above the tree line we find the treeless alpine heath. Contrary to the forest line, the tree line has been shown to react swiftly to changes in climate, with distinct and significant signals. Moreover, the tree line has shown to be relatively less disturbed by non-climatic parameters (i.e. inter- and intra-specific competition, human disturbance and grassing) than has the forest line. The tree line can however be locally affected by short term weather extremes in the form of strong winds combined with frost, which can result in the breakage of stems and the lowering of the tree line. Extreme weather events are, on the other hand, predicted to be an effect of climate change (IPCC 2007), and should be considered an important factor when discussing tree line shifts.

The tree line indicator combines several biotic and abiotic variables into both altitudinal and latitudinal distribution patterns for the specific tree species. The alpine tree line can be monitored by field work or remote-sensing based on systematic observations. One such initiative is a baseline network of more than 200 sites in the southern Swedish Scandes (Kullman 2001). A larger scale international initiative is also run by IPY (International Polar Year), whose core project, PPS Arctic, uses a common protocol for studies and the detection of changes in the tree line zone (http://ppsarctic.nina.no). National forest monitoring programs (NFI) may have a possibility of detecting changes in latitudinal distributional patterns. A new, promising but not yet fully implemented or evaluated method of detecting the tree line and its temporal trends is areal laser scanning, which creates the possibility of detecting individual trees but not saplings (A. Hofgaard, pers. com.).

Palsa mires



Reduction in a pals in Haugtjørnin, Douk observed over 31 years from 1974-1996-2005 (J. H. Sollid).

> **"Worldwide palsa mires have declined during the last century and today they continue to decline including in the Nordic region. Experts consider the decline a likely response to climate change."**

Palsa mires and permafrost

Palsa mires are found throughout the northern hemisphere, specifically along the outer limit of the permafrost zone. The Nordic distribution of palsa mires includes areas of northern Norway, Finland, Sweden and Iceland (Fig. 1 - 2) (Sollid & Sørbel 1998; Thorhallsdottir 1997). Palsa mires are characterized by mosaic complexes with areas of permanently frozen hummocks as well as peat areas without permanent frost and ponds. The marginal locations of the palsa mires make them sensitive to climatic fluctuations (Seppälä 1998).

It has been hypothesized that a further climatic warming and/or precipitation increase would result in the melting of most palsas at marginal sites, within a few decades. Norway has established a palsa monitoring programme (e.g. Hofgaard 2004). There is however a general lack of organized or methodologically consequent project monitoring of palsa peat land dynamics elsewhere in Fennoscandina and the North Atlantic islands (Hofgaard 2003). Palsas form heterogenous landscape elements holding a great biodiversity, especially for birds, but also for other species groups (Luoto & al. 2004). Palsa mires are also listed in the EU Habitats Directive wherein they are recognised as highly valuable for nature conservation purposes.

Growth and decay

Palsa mires are dynamic structures with their own natural growth and decay cycles, i.e. the decline and decay of the palsa structures are natural dynamics of this system as well as the embryonic building-up of new palsas. The palsa cycle starts when the snow cover is locally so thin that a local ice lens can develop with the associated rise of the bog surface. This reinforces the freezing of the palsas and corresponding upheaval. At this point a break of the palsa surface follows as part of the natural process of palsa dynamics (Seppälä 1988). However, if there is a general degradation within an area without any rebuilding, it may reflect a more general change in the environment or climatic conditions (Zuidhoff 2005). This destruction of the palsa structure may also derive from human activity that interferes with hydrological conditions and vegetation structures of the peat lands, e.g. grassing pressure, use of vehicles especially during summertime and drainage activities. Thus, any given degradation of palsa must be analyzed and interepreted according to the aforementioned factors before the connection to climate change may become clear.

Palsa mires in the Nordic countries

Case studies in the northern hemisphere show that - as is the case for many biological features – there is no clear and fixed prerequsite for the excistence of the palsa mire (Parvianen & Luoto 2007). The palsa mires in the Nordic countries occur from 70 to 1,400 meter above sea level, with a mean annual temperature of just below 0°C and mostly with a climate of continental character. The large variations in temperature and precipitation requirements point to a sensitive inter-seasonal balance between temperature and precipitation, causing fairly large differences in climatic restrictions for palsa boundaries. However, it has been stated that palsas in Scandinavia does not maintain themselves where average annual temperature is over -1°C (Zuidhoff 2002).

Fig. 1
Distribution of palsa mires in Fennoscandia (Sollid & Sørbel 1998)

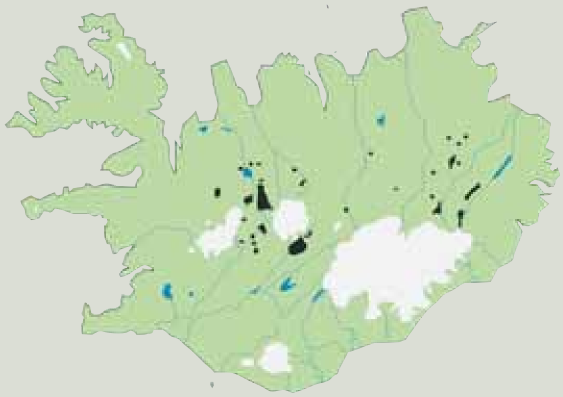


Fig. 2
Distribution of the main palsa areas in Iceland in black (based on Thorhallsdottir 1997).

Quality criteria	Palsa mires
1. Representative of Nordic region	Yes, palsa mires are found in all Nordic countries the (except Denmark with no permafrost)
2. Sensitive to climate change	Yes, palsa mires depend on a permanently frozen core
3. Policy relevant	Yes, listed as priority habitat type by the EU
4. Easily understood	Yes
5. Relevance for ecosystems	Yes, palsa mires are biologically heterogenous environments with a unique species diversity (e.g. birds)
6. Scientifically agreed methodology	No, lack of well established methodology
7. Quantitative	Possible, based on air photos and field studies
8. Timeseries available	Not yet, some limited timeseries for local areas exist
9. Country comparison possible	Partly

Methodology

The palsa mires are currently showing historical shifts in range and structure. The indicator is constructed on the basis of air photos, field studies and information from weather stations that monitor snow depth, precipitation, wind and temperature. A Norwegian study suggests using a specific monitoring programme (Hofgaard 2003) that includes temperature registration, habitat classification, morphology, vegetation structure and human impact/land use. In Norway such palsa mire monitoring programme has been started up in five local a reas (http://www.dirnat.no/content.ap?thisid=500038759&language=0. The use of satelite photos in the registration of palsa mires is currently beeing tested with some promising results (A. Hofgaard pers. com.).

Snow bed communities

Photo: Annika Hofgaard.

> **Snow bed plant communities develop in some alpine habitats of the Nordic countries as well as in other alpine regions in the world. They hold species with unique climatic requirements. These plant communities are vulnerable to warmer climates and may therefore be a sensitive indicator of climate change.**

Unique plant communities may suffer from warming

Some alpine habitats in the Nordic countries have evolved under a climatic regime that results in late melting snow beds in some spots. Snow beds are formed in topographic depressions that accumulate large amounts of snow during winter, and where the final snowmelt is delayed until late into the growing season. These spots have favoured the development of a unique plant community. Some plant species thus prefer snow bed habitats, while a few are actually restricted to these habitats. Snow bed communities are found worldwide in areas with high amounts of snow, especially where the topography favours wind redistribution of snow. As the late melting snow beds offer a temporal refuge from competition, some species, such as *Sibbaldia procumbens* and *Oxyria digyna*, are confined to these habitats (Björk & Molau 2007). The snow beds thus promote a unique component of alpine biodiversity.

Schob & al. (2009) have shown that snow bed specialist species will suffer as a consequence of earlier snowmelt. A Norwegian study found significant increases for a number of plant species when open-top chambers were used to simulate a warmer climate at a specific snow bed location (Sandvik & al. 2004). In a future warmer climate, the snow bed specialists will probably be replaced by species that today can not establish themselves in snow bed sites. However, a Japanese study showed that only the earliest melting snow beds were affected by a warmer climate, while late melting snow beds remained unaffected despite increasing temperatures (Kudo & Hirao 2006).

The timing of snowmelt is key

The timing of the snowmelt is a crucial factor in determining the phenology of plant species. For insect-pollinated plant species, a delayed flowering may result in a decreased seed set, caused by a shortage of pollina-

Typical Scandinavian snowbed community species the snowbed willow (*Salix herbacea*).

Photo: Annika Hofgaard.

Example of snow bed, where the late melting snow is a prerequisite for a number of plant species escaping competition by their late emergence and thereby forming a unique alpine plant community that is threatened in a warmer climate.

tors due to autumn frost that could potentially kill the pollinating insects. Another important effect of changed duration of snow cover is nutrient cycling. Nitrogen mineralization in deep snow zones occurs mainly in winter, whereas nitrogen mineralization in ambient snow zones occurs mainly in spring (Borner & al. 2008).

Quality criteria	Snow bed plant communities	Methodology
1. Representative for the Nordic region	Yes, for the alpine/arctic region	Snow bed plant communities need to be monitored by manual field work. Soil and air temperatures are preferably recorded using automatic loggers. Persistence of snow beds could be monitored by remote sensing (air and satellite photos), as the snow at these spots persists for a long time after the thaw period of the surrounding landscape has completed.
2. Sensitive to climate change	Yes, snow beds are directly linked to temperature	
3. Policy relevant	Yes, if the snow beds disappear, alpine plant diversity may suffer	
4. Easily understood	Yes, mountain walking is popular and disappearance of snow beds is conspicuous	
5. Relevant to nature	Yes, snow beds host alpine plant communities and ecosystems that have developed by escaping competition from other species	
6. Scientifically agreed methodology	No, need further development	
7. Quantitative	Not yet	
8. Time series available	No, this is a new approach to monitoring of alpine vegetation	
9. Country comparison possible	Not yet	

Arctic fox

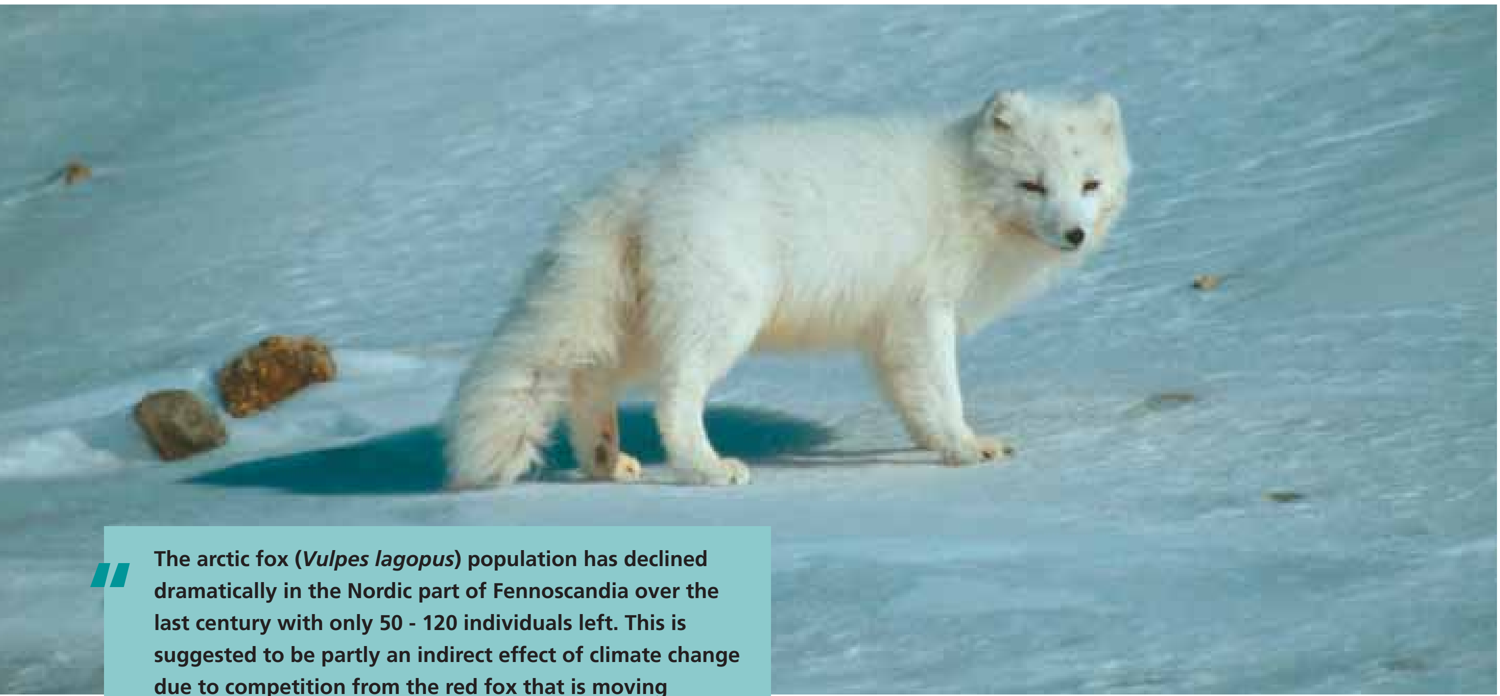


Photo: Marie Lier/Naturplan.

> **The arctic fox (*Vulpes lagopus*) population has declined dramatically in the Nordic part of Fennoscandia over the last century with only 50 - 120 individuals left. This is suggested to be partly an indirect effect of climate change due to competition from the red fox that is moving northwards. On the North Atlantic Island, where the red fox is not present, the arctic fox population has increased.**

Decline in Fennoscandia in spite of protection

The fluctuations in numbers (Fig. 1-2) have been very large as the arctic fox in Fennoscandia (Norway, Sweden and Finland) normally tracks the fluctuations of rodent populations (Kausrod & al. 2008; Kaikusalo & Angerbjørn 1995; Fuglei & Ims 2008). However, despite more than 80 years of protection, the declining trend is still clear. One hypothesis is that climate change is part of the explanation (Fuglei & Ims 2008; Kausrod & al. 2008).

Competition with the red fox

The arctic fox has undergone a drastic decline in population since the beginning of the 20th century in the Nordic part of Fennoscandia. Until that time, the arctic fox was a common species in the mountainous region with the population tracking the cyclical variations in the numbers of rodents. For a number of years, the population included up to several thousand individuals in Sweden, while the whole of the Fennoscandia region now contains between 50 - 120 individuals (Kaikusalo & Angerbjørn 2007; Angerbjørn & al. 2007). In spite of being protected by law since the beginning of the 20th century in all three Fennoscandian countries, there has been no sign of recovery in the population. The population decrease in Fennoscandia has been dramatic, and a corresponding decrease is observable all over the Northern Hemispheres mainland, including Canada and Russia (CCME 2003), suggesting a circumpolar change.

One of the hypotheses used to explain the continuous reduction in arctic fox numbers is connected to the indirect effects of climate change and increase in overall productivity. The range of the arctic fox may be restricted southwards by the bigger and more dominant rival the red fox (*Vulpes vulpes*). The red fox is also moving northwards, tracking the rising temperatures of the Northern Hemisphere especially in spring and summer temperatures (Frafjord & al. 1989. It is believed that the arctic fox mainly survives in areas where the continuous food supply is not high enough for the red fox (Angerbjørn & al. 2007). An expansion of the red fox range could lead to a corresponding reduction in the potential habitat of the arctic fox. The retreat of the arctic fox in Fennoscandia could also be linked to the fading rodent (lemming) cycles that are observable in northern regions at a circumpolar scale, and are possibly also linked to global warming and climate change. Long-term monitoring data presented by Kausrud & al. (2008) show a strong relationship between the fading lemming/rodent cycles and snow hardness (meaning the number of crusts) and the shorter duration of complete snow cover.

Populations on islands

Looking at other areas within the range of the arctic fox in Nordic countries such as Svalbard, Iceland and Greenland, the same decrease is not seen. These populations are considered viable, even if solid data on the population dynamics are in some cases somewhat limited. Data from Iceland show that the population of the arctic fox has been increasing (Fig. 3), and in 2003 the population was estimated to include at least 7,500 individuals (Hersteinsson 2006). There are no indications that global warming is affecting this population. The reasons for the different patterns in Iceland and Fennoscandia may be the stable food supply in Iceland and the absence of the red fox here and on other North Atlantic islands (Fuglei & Ims 2008).

Protection

The arctic fox is a "priority species" according to the EC Habitat Directive. At the present population size in mainland Europe, even a small change in demographic parameters or pure "accidents" can affect the risk of extinction dramatically. Even though the arctic fox has been fully protected in Norway, Sweden and Finland for almost a century the situation for the mainland population is now critical.

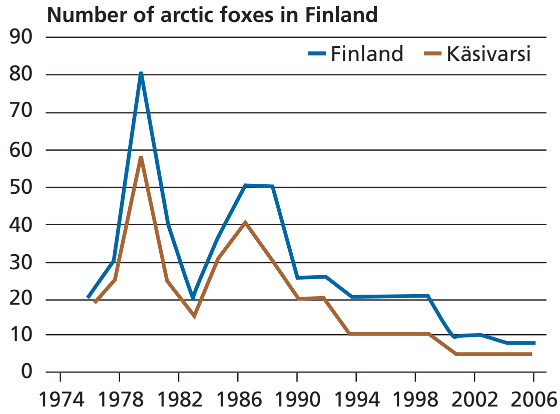


Fig. 2
Numbers of adult arctic foxes in Finland, illustrating a decline in population of the inland foxes (SEFALO).

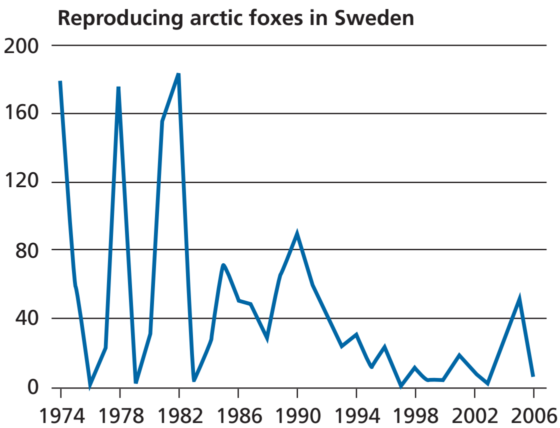


Fig. 1
Arctic foxes in Sweden, illustrating a decline in population of the inland foxes (SEFALO).

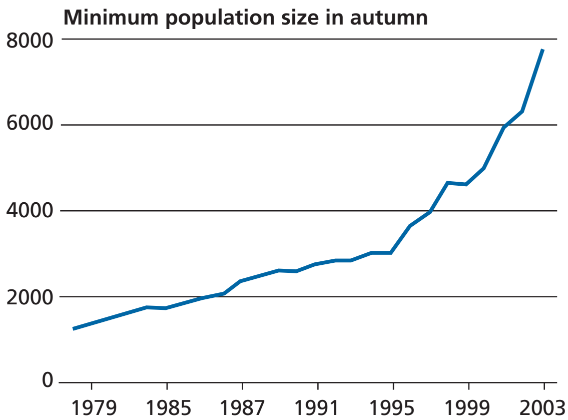


Fig. 3
Calculated minimum size of the Icelandic arctic fox population 1978-2003 (Hersteinsson 2006).

Quality criteria	Arctic fox	Methodology
1. Representative for the Nordic region	Yes, covers the arctic region	The monitoring of arctic fox populations varies over time and geographic region. Earlier data come from the registration of ear tags from hunted foxes, to actual monitoring of dens and individual animals in connection with conservation work. The new data from Fennoscandia are derived from national studies and the Finnish-Swedish-Norwegian projects on the arctic fox populations, SEFALO and SEFALO+ and are based on observations and field studies.
2. Sensitive to climate change	Yes, in particular in areas where competition from the red fox occurs. However, populations of arctic fox are also influenced by hunting	
3. Policy relevant	Yes, arctic fox is a priority species in the EU Habitat Directive and classified as an endangered species. Hunting is regulated in the region	
4. Easily understood	Yes	
5. Relevant to nature and ecosystems	Yes	
6. Scientifically agreed methodology	Yes	
7. Quantitative	Yes	
8. Time series available	Yes, to some extent. EU finances some continuous monitoring of the arctic fox	
9. Country comparison possible	Yes	

Polar bear


Photo: Stein Erik Sørstrøm.

"The polar bear is a top predator of the arctic marine food chain and closely connected to the arctic sea ice, which makes it especially vulnerable to a warming climate and thus a relevant indicator of climate change effects on nature. However, data to support this hypothesis remains scarce."

Polar bears and sea ice

Polar bears (*Ursus maritimus*) depend on sea ice for survival. Climate warming has caused significant declines in total cover and thickness of sea ice over the last decades in the Arctic and progressively earlier break-up in some areas (Fig. 1). With basis on an analysis of a number of parameters such as population size, migration patterns, feeding habits and sensitivity to changes in the sea ice, the polar bear is among the marine mammal species most sensitive to climate change (Laidre & al. 2008). Globally, it is likely that polar bears will be lost from many areas where they are common today, and the remaining populations will become more fragmented and isolated. By the end of the 21st century, areas north of the Canadian Archipelago and northernmost Greenland will have the greatest likelihood of sustaining viable, albeit smaller, polar bear populations (Stirling & Parkinson 2006).

Polar bears have a circumpolar distribution and are confined to arctic and sub arctic ice-covered seas, especially in areas where there is an annual ice cover over the continental shelves. These areas are highly productive; they form a good feeding ground for the ringed and bearded seals, both of which are main food sources for the polar bear. The essential time of year for polar bears to fill up their body reserves is during spring when they feed heavily on ringed seal pups. Studies from the western Hudson Bay in Canada have shown that the average total body mass of adult female bears has decreased from about 300 kg to about 225 kg during 1980 to 2004 (Fig. 2). This tendency is correlated with a progressively earlier spring ice break-up in the area. The spring break-up now occurs approx. three weeks earlier than in the beginning of the 1980s. It has been inferred that if the total body mass of an adult female polar bear falls below ca. 190 kg she will no longer be able to reproduce successfully. Hence, if the trend observed in south-western Hudson Bay continues the female polar bears may reach this critical body mass in a few years (Stirling & Parkinson 2006).

Female polar bears show a fidelity to special denning areas; and it is important for females to be able to reach these areas in autumn either by swimming or by walking on ice. In autumn, there is large annual variation in ice extent and the distance between ice edge and den sites. A study at Hopen Island in Svalbard showed a negative correlation between the number of dens and the date of freeze-up (Derocher & al. unpublished). In 1999, the freeze-up did not happen until close to Christmas. That year, the bears were not able to reach Hopen and consequently there were no dens on this island.

If temperatures in the Northern Hemisphere continue to rise, the open-water period with reduced hunting possibilities for the polar bear will continue to prolong and polar bears will be increasingly food-stressed (probably leading to a significant decline in their numbers) (Learmonth & al. 2006).

Protection and monitoring

The polar bear is protected in all five polar bear nations by the Agreement on the Conservation of Polar Bears and Their Habitat (1973). The polar bear species is divided into 19 more or less isolated sub populations, for which different management schemes exist. The size of some of the sub-populations is well known but several are of a less well-known size (Stirling 2002; Aars & al. in prep.). Hunting is still legal in Greenland, Canada and the USA and is regulated by quota systems. Indeed, 16 of the recognised 19 sub populations are hunted, while the three populations that exist in Norway and Russia are fully protected.

There is a need for more knowledge on the size and trends in numbers of the different populations in order to assess the potential long-term climate change effects in the Arctic system. Data on the polar bears' body weight, condition, reproduction, survival and other population parameters – as the 35-year plus studies in the Hudson Bay – are relevant in this context (Stirling & Derocher 2007).

Photo: Maria Mikkelsen.

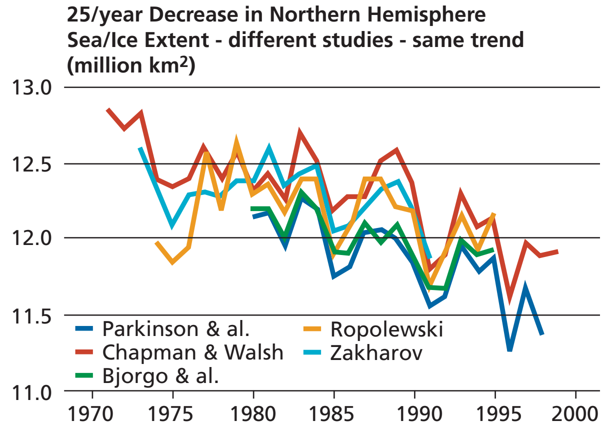


Fig. 1

25-year decrease in Northern Hemisphere sea-ice extent (Vinnikov &. al. 1999).

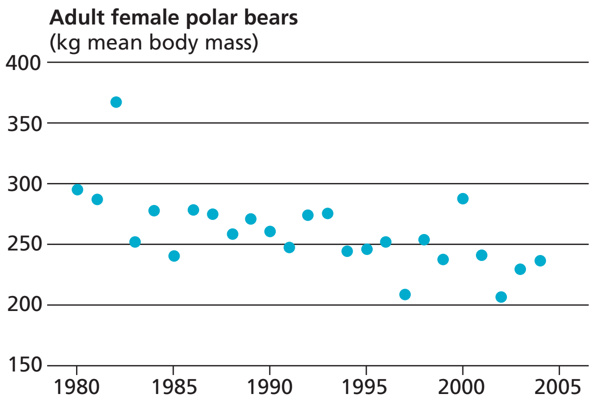


Fig. 2

Body fat index for adult female polar bears from 1980 to 2004 (Stirling & Parkinson 2006).

Quality criteria	Polar bear
1. Representative for the Nordic region	Yes, for the Arctic region
2. Sensitive to climate change	Yes, if the polar bear does not adapt and adjust its food choices and hunting methods, dependent for a great part of the year to year sea ice
3. Policy relevant	Yes, a threatened and protected species, also politically significant because of its public visibility and popularity
4. Easily understood	Yes
5. Relevance for ecosystems	Yes, top predator of Arctic food web
6. Scientifically agreed methodology	Yes, population counts
7. Quantitative	Yes
8. Time series available	No, not monitored on a regular basis
9. Country comparison possible	Yes

Methodology

The polar bear has been monitored in various ways in the Nordic region. On Svalbard, more than 1,000 polar bears have been captured and marked over the last 40 years. Data from this large-scale, capture-recapture experiment are the most important source of knowledge about the survival and reproductive habits of this species in the Svalbard area (http://npweb.npolar.no; Wiig 1998). During the 1990´s Greenland in cooperation with Canada conducted an extensive satellite telemetry study that led to identification of three sub-populations – Kane Basin, Baffin Bay and Davis Strait – that are shared by these two countries. A large scale mark-recapture study in Kane Basin and Baffin Bay resulted in estimates of population sizes. Furthermore, Greenland in cooperation with Norway has conducted several satellite telemetry studies in East Greenland leading to determination of population delineation and habitat use. Moreover, hunting statistics are used as population size indicators, as is counting from aeroplanes in polar bear assessments as well as following of tagged bears by satellite.

Marine invasive species

> Alien species like the Pacific oyster (*Crassostrea gigas*), the slipper limpet (*Crepidula fornicate*) and the American comb jelly (*Mnemiopsis leidyi*) have invaded the Nordic marine waters and now survive wintertime and reproduce successfully. Experts consider this development a likely response to climate change.

American comb jelly

Does a changing climate favour invasive species?

With climate change resulting in imbalanced ecosystems, we will meet an increasing number of invasive alien species; now as well as in the future (Dukes & Mooney 1999). Animals, plants or other living organisms that are introduced deliberately or unintentionally to places outside of their natural habitat are called "introduced" or "alien" species. If these species often become established they will reproduce and spread causing damage to native biodiversity and ecosystems, at which stage they are termed "invasive alien species" (Krajik 2005; Weidema 2000).

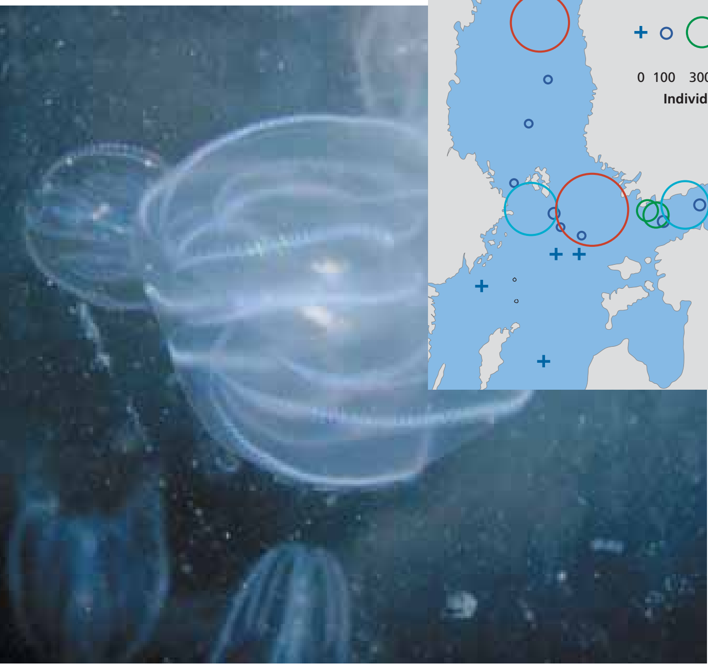
Along with the increasing transport of people and goods around the world, follows the spreading of an increasing number of species, which may become invasive and have significant socio-economic and biodiversity consequences. Invasive alien species are often characterized by being generalists with rapid dispersals (Dukes & Mooney 1999). Although the biology of invasions is a complicated process, there is a general pattern that climate change – with increasing CO_2 concentration, altered disturbance regimes, extreme weather and changed precipitation patterns – results in rendering many ecosystems off-balance, thereby optimizing the possibilities for newcomers to establish themselves (Byers 2002). Earlier, alien species were in most cases hindered from becoming invasive by cold winter or summer temperatures and only survived in small areas like warm water outflows e.g. from power plants (K. R. Jensen pers. com.). With rising temperatures, this natural limitation diminishes and so follows a rise in the number of invasive species (Krajik 2005).

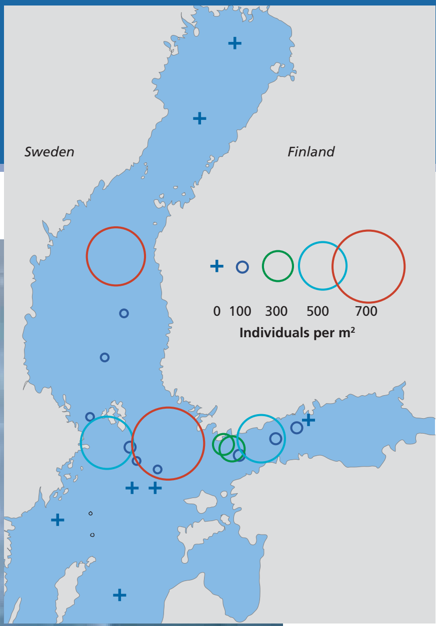
The "2005 State of the Environment" report from the European Environment Agency (EEA 2005) indicates that Europe's marine and coastal ecosystems are undergoing structural changes due to climate change. This results in the loss of key species, large concentrations of planktonic species replacing others and a spread of marine invasive species.

Old inhabitants' sudden invasions

The Nordic countries have seen a number of examples of alien species coming from warmer waters in recent years (Fig. 2). There are examples of organisms that have lived in our environment for many years but have only recently started acting invasively. One such species is the Pacific oyster (*Crassostrea gigas*), native to coastal and estuarine Japanese waters and introduced in the Netherlands in 1964 for aquaculture, and later to Germany and the island of Sylt in the Wadden Sea. Until 2004/2005 the small larvae that drifted with the current and settled in the Danish part of the Wadden Sea had not been able to survive until reproduction age. But since 2005 the Pacific oyster has been able to reproduce in Danish waters and is now found in Norwegian coastal waters as well (GISD, Global Invasive Species Database) (Fig. 3).

Another example of a marine invasive species in Nordic waters is the American comb jelly (*Mnemiopsis leidyi*), native to the Atlantic coast in temperate and subtropical waters of South and North America (Mayer 1912). The comb jelly was first seen in the southern Baltic Sea in October/November 2006 and has since then been found in the rest of the Baltic Sea (Tendal & al. 2007), sightings of which include numerous eggs and larvae indicating effective reproduction (Fig. 1). The jelly fish is now classified as invasive or potentially invasive in





Photos: Hans Ulrik Riisgård.

Fig. 1
The occurrence and abundance of the American comb jelly in the northern Baltic Sea August –September 2007 (HELCOM; Lehtiemi).

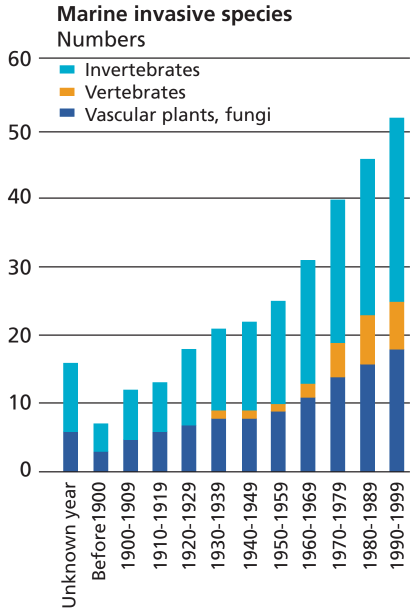


Fig. 2
Accumulated number of introduced species in the Nordic countries until 1999, analysed by the marine ecosystem (TemaNord 2006: 002).

Denmark, Sweden and Finland. Recently, it has been found that, at least in the upper part of the Baltic Sea, another species, *Mertensia sp*. may have been confused with the American comb jelly and taken for *Mnemiopsis* (Östersjöportalen 2009).

Fig. 3
Marine invasive or potentially invasive species in Nordic waters or on their way from warmer waters (K. R. Jensen pers. com.)

	Finland	Sweden	Norway	Denmark
Pacific Oyster – *Crassostrea gigas*		2007	1979	1980
American comb jelly – *Mnemiopsis leidyi*	2006	2006	2000	2005
Slipper limpet – *Crepidula fornicate*		1934	1958	1934
Snail – *Ocenebra erinacea*				

Quality criteria	Marine invasive species
1. Representative for the Nordic region	Partly, covers mainly coastal waters (North Sea, Baltic Sea)
2. Sensitive to climate change	Yes, sensitive to sea temperature
3. Policy relevant	Yes, marine invasive species may have great ecosystem and socio-economic impacts
4. Easily understood	Yes
5. Relevant to nature and ecosystems	Yes, as invasive species are characterised by negative consequences for the native biodiversity
6. Scientifically agreed methodology	Yes
7. Quantitative	Yes
8. Time series available	Partly, monitoring networks cooperate on observing marine invasive species. However, it is mainly a qualitative assessment (i.e. year of introduction)
9. Country comparison possible	Not yet

Methodology

Both on the regional and international level there is great focus on invasive species. Hence, a significant number of international conventions and agreements address this problem in order to prevent their introduction and eradicate those alien species that may threaten ecosystems. In the SEBI 2010 indicator set, invasive species are one of the indicators used, and thus the EU countries are encouraged to report data on a European basis. Moreover, there are a number of networks that coordinate monitoring data on a regional basis. These include the European Network on Invasive Species (NOBANIS) and on the global scene the GISD.

Zooplankton

Calanus finmarchichus

Photo: Torkel Gissel Nielsen.

> **Zooplankton species in the North Atlantic Ocean have expanded their range more than 1,100 km northwards over the last 50 years. Concurrent with the expansion northwards of these warm-water copepods, the cool-water copepod assemblages have retracted to higher latitudes. Increasing sea water temperatures and stronger north-flowing currents are possible causal factors.**

Extensive data series document zooplankton movement

The available data indicate that zooplankton exhibit range shifts in response to global warming that are among the fastest and largest of any marine or terrestrial group (Planque & Taylor 1998). The clearest examples are found in the Northeast Atlantic Ocean where the Continuous Plankton Recorder Survey has been in operation since 1946 (Richardson & al. 2008; Richardson & Schoneman 2004). The range of warmwater zooplankton has expanded more than 1,100 km northwards over the past 50 years (Fig. 1; Beaugrand & al. 2002). The distribution of two individual copepod species in the Northeast Atlantic Ocean has also been studied in relation to ocean warming. *Centropages chierchiae and Temora stylifera* have both moved their northern distribution limits from the vicinity of the Iberian Peninsula in the 1970s and 1980s to the English Channel in the 1990s.

Concurrent with the northwards expansion of warm-water copepods, the cool-water assemblage has retracted to higher latitudes (Beaugrand & al. 2002). Although these translocations have been associated with regional warming of sea water of up to 1°C, they may also be partially explained by stronger north-flowing currents on the European shelf edge. These shifts in distribution have had dramatic impacts on the food web of the North Sea (Beaugrand & al. 2003). The cool-water copepod assemblage has a high biomass and is dominated by relatively large species, especially *Calanus finmarchicus*. Because this assemblage has retracted north as waters have warmed, *C. finmarchicus* has been replaced in the North Sea by *Calanus helgolandicus*, a dominant member of the warm-water species (Fig. 2). This warm-water associated zooplankton typically has a lower biomass, with probable consequences for the predators of the zooplankton species.

Invisible distinction with major consequences

Despite the almost indistinguishable nature of these *Calanus* congeners, the two species do have contrasting seasonal cycles: *C. finmarchicus* abundance peaks in spring, whereas *C. helgolandicus* abundance peaks in autumn. This is critical for many reasons e.g. because the Atlantic cod (*Gadus morhua*), traditionally a major fishery species in the North Sea, spawn in spring, and cod larvae require a diet of zooplankton eggs and larvae. Since the late 1980s, *C. finmarchicus* has been virtually absent and there is very low zooplankton biomass in the North Sea during spring and summer, resulting in plummeting cod recruitment (Beaugrand & al. 2003).

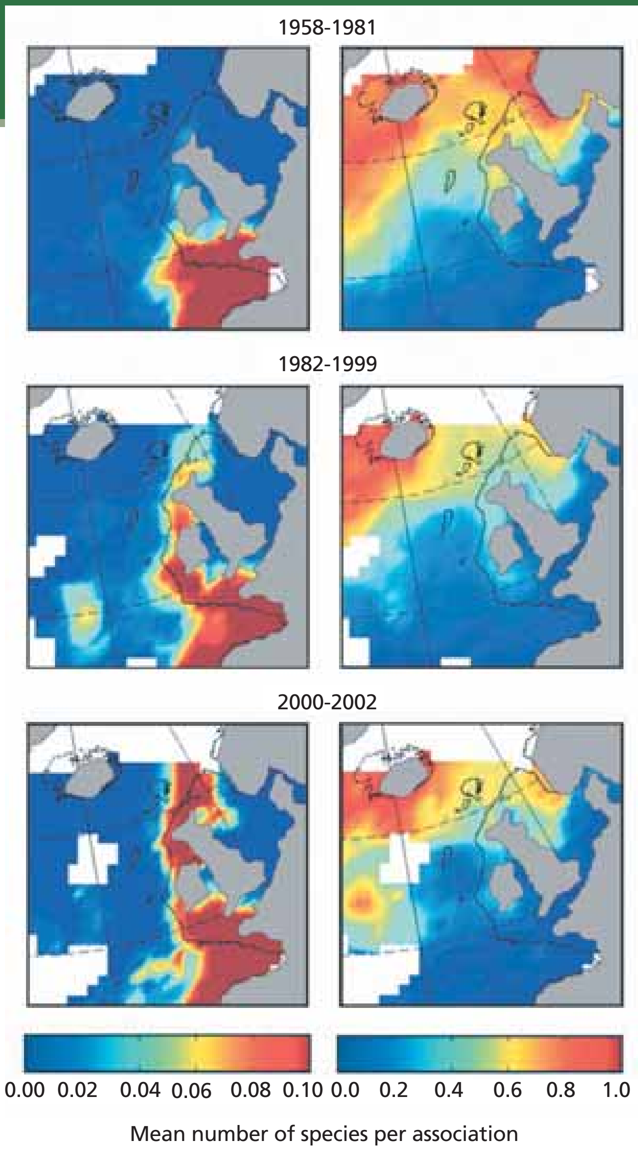


Fig. 1

Illustrations of the northerly shift of the warm temperate copepod assemblage (containing *Calanus helgolandicus*) - left - into the North Sea and the retraction of the subarctic copepod assemblages (containing *Calanus finmarchicus*) - right – to higher latitudes (Beaugrand 2002).

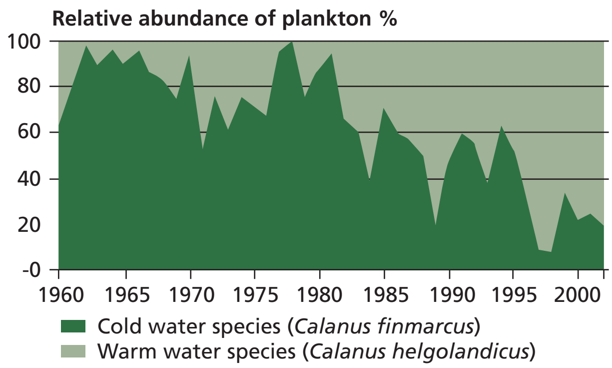


Fig. 2

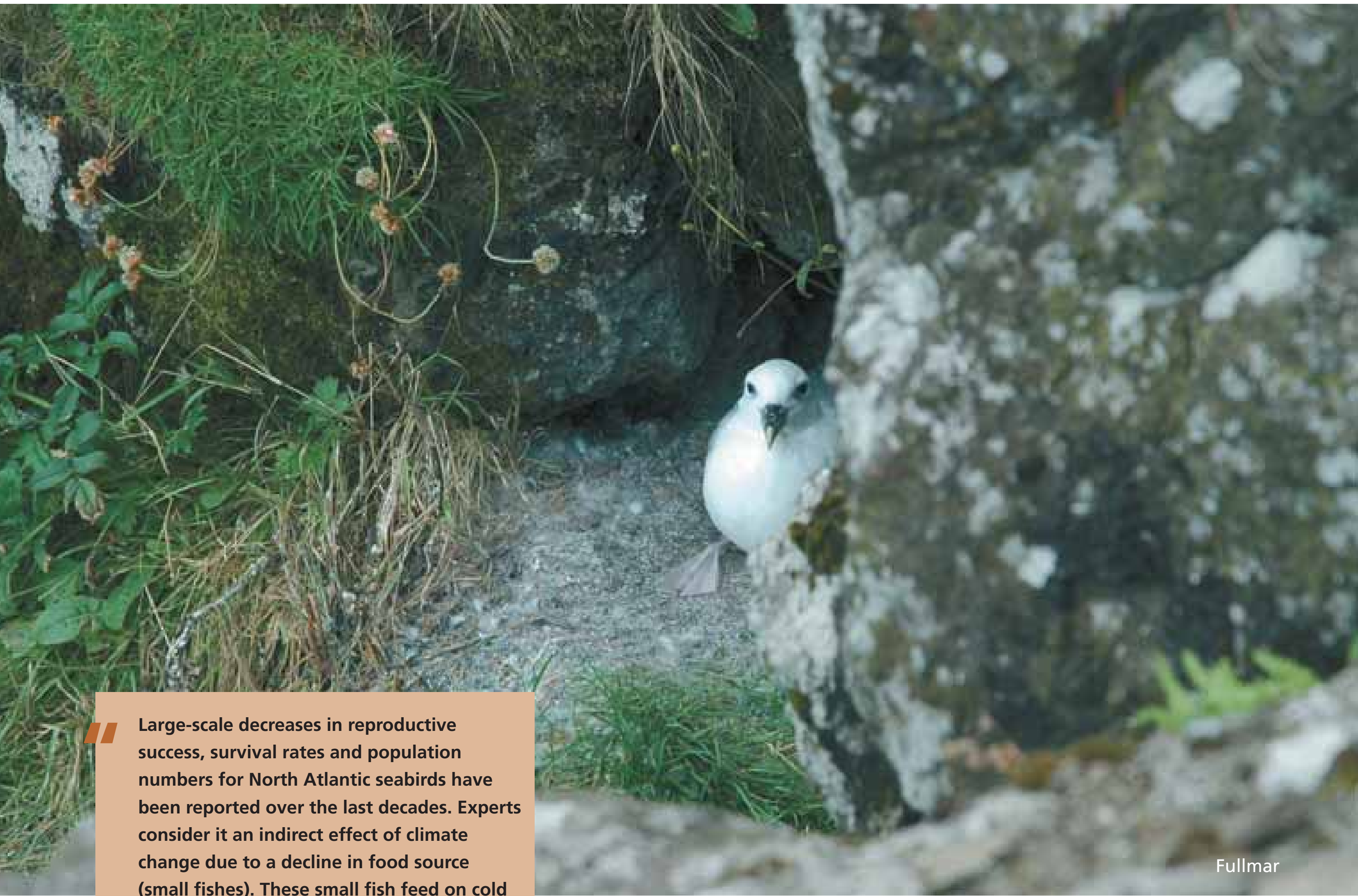
Relative abundance of two species of copepods in the Central North Sea (EEA signals 2004).

Quality criteria	Zooplankton
1. Representative for the Nordic region	Yes, the North Atlantic Ocean
2. Sensitive to climate change	Yes, responsive to changes in sea temperature
3. Policy relevant	Yes, zooplankton is a main food resource for many fish species, including species of commercial interest
4. Easily understood	Partly, zooplankton is not well known in the general public, but when explained the link between zooplankton, sea temperature and climate change may well be understood
5. Relevant for ecosystems	Yes, zooplankton is a very important constituent of the oceanic food web
6. Scientifically agreed methodology	Yes, methodology is well established and zooplankton estimates follow international standards. However, the link between climate change and zooplankton is less documented
7. Quantitative	Yes
8. Time series available	Yes, zooplankton estimates have been carried out yearly in the Nordic region since the 1960s
9. Country comparison possible	No

Methodology

A number of research projects on zooplankton in the oceans have been based on The Continuous Plankton Recorder (CPR). Researchers for this project have collected monthly samples from across the North Atlantic Ocean and the North Sea, since 1946. Samples are collected by a high speed recorder (about 20 km/h), which is towed behind voluntary merchant ships at a standard depth of about 7 m. Plankton is retained by a continuously moving band of silk, which has an average mesh size of 270 µm (Beaugrand & al. 2000b). In the laboratory, silks are unwound and plankton is counted according to a standardised methodology described for the first time in 1960 (Hays & Warner 1993).

North Atlantic seabirds



Fullmar

Photo: Maria Mikkelsen.

"Large-scale decreases in reproductive success, survival rates and population numbers for North Atlantic seabirds have been reported over the last decades. Experts consider it an indirect effect of climate change due to a decline in food source (small fishes). These small fish feed on cold water zooplankton that is decreasing, probably due to an increase in sea water temperatures."

Mismatch as an explanation of the decrease?

A key factor determining breeding success of seabirds, such as common murre (*Uria aalge*), kittiwakes (*Rissa* spp.) and arctic tern (*Sterna paradisaea*), is the co-occurrence of food requirements for offspring and food availability (Christensen-Dalsgaard & al. 2008). This renders the seabirds most vulnerable to food limitations during the breeding season. There are also geographical constraints on the match between food availability and breeding sites; birds can only benefit from food sources located close to the nest as they regularly have to feed their chicks. The relationship between food availability and breeding success is, however, more complicated than this, and it is necessary to know the biology of seabirds in order to fully understand and explain the dramatic decrease observed over the last decades (Fig. 1-2).

From zooplankton to seabirds

Concurrently with the decrease in seabird populations a significant reduction in sand eel (*Ammodytes spp.*) fishery has been observed (Fig. 3); sand eel is the primary food source for many seabirds (Grosbois 2005). The decrease in the sand eel fishery has, according to many experts, been linked to a regime shift in two North Atlantic zooplankton species; i.e. the cold water species, *C. finmarchichus*, is being replaced by the warm water zooplankton, *C. helgolandicus* (Beaugrand & al. 2002). In the North Atlantic, this shift has been linked to climate change (please consult the zooplankton indicator for more information).

Another important factor for seabird survival is food quality, especially the fat content of the food resource, which is crucial for the chicks' growth (Harris 2005). School fishes such as capelin (*Mallotus villosus*), sand eel and small herring (*Clupea harrengus*) all have a considerable fat content that renders them suitable as seabird food. Most seabirds forage by diving after the food and are excellent divers. However, species like the blacklegged

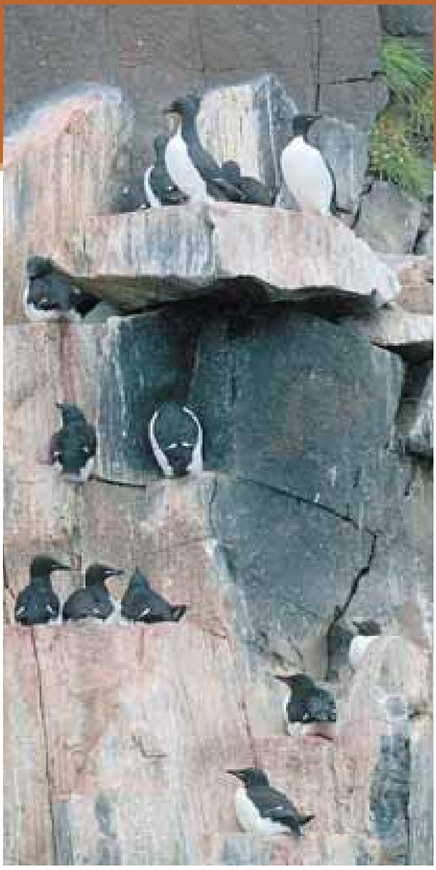
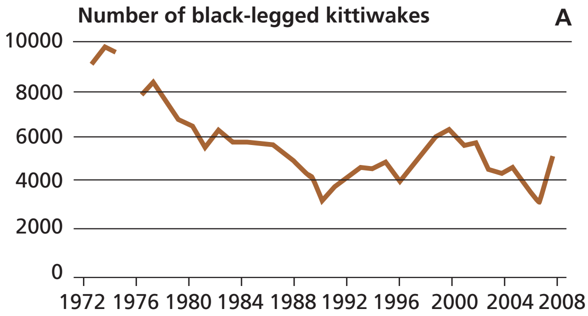


Photo: Biopix.

Common murre show sensitivity towards food availability during breeding season.



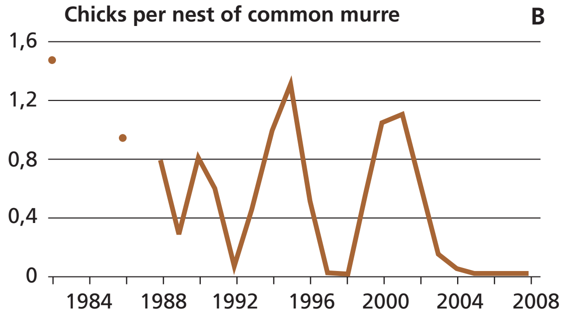


Fig. 1 and 2
Illustrations of the number of black-legged kittiwakes (**A**) and number of chicks per nest of common murre (**B**) in the Faroe Islands, Skúvoy (B. Olsen, pers. com.).

kittiwake (*Rissa tridactyla*) and arctic tern (*Sterna paradisaea*) can only get fish near the surface. This makes these two species especially vulnerable to food limitations (Suuanå & Fossheim 2008). A study of seabirds in Iceland for the period from the 1980s to 2005 shows, for example, a longterm decrease in the population of the thick-billed murre (*Uria lomvia*) and fulmar (*Fulmarus glacialis*), a decline considered to be caused by largescale changes in food supply (Gardarsson 2006).

Thus, food availability and quality is directly linked to seabird survival and reproductive success.

A patchwork of reasons

The reason behind the decrease in both seabird populations and some fish stocks is most likely due to a patchwork of factors, with overfishing and climate change being significant contributors (Frederiksen 2004).

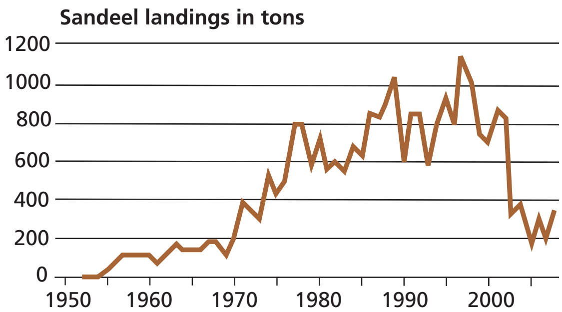


Fig. 3
Sand eel landed from the North Sea 1950-2008 (National Institute of Aquatic Resources, Denmark).

Quality criteria	North Atlantic seabirds	Methodology
1. Representative for the Nordic region	Yes	The data on different seabirds derive from fieldwork done at the breeding grounds on islands around the North Sea and the North Atlantic Ocean. Data are sampled for different time depending on the monitoring periods available, and cover one to three decades.
2. Sensitive to climate change	Yes, indirectly by change of food supply, i.e. small cold water fish influenced by change in water temperature	
3. Policy relevant	Partly	
4. Easily understood	Partly, the link to climate change may be difficult to perceive	
5. Relevant for ecosystems	Yes, seabirds form specific ecosystems on cliffs and connect the two ecosystems land and water	
6. Scientifically agreed methodology	Yes, population counts	
7. Quantitative	Yes	
8. Time series available	Partly, for some birds in some areas	
9. Country comparison possible	No	

Marine fish

Photo: Maria Mikkelsen.

Fish species, including cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), have shifted north towards cooler waters in response to rises in temperature in the marine areas of the Nordic region. Climatic changes are expected to have major impacts on fishes range, reproduction etc.

Fish stocks shift ranges in the North Sea

Climate change forces changes in marine water temperatures and salinity and is expected to have a large impact on the marine fish communities. Already, several responses to climate changes have been observed among fish stocks in the Nordic marine environment. In a study of the North Sea, it was found that a range of fish species have shifted their distribution northwards in response to a 1°C rise in sea temperature over the past 25 years (Perry & al. 2005) (Fig. 1 and 2). The Atlantic cod population has moved 120 km north and the haddock 105 km north. Researchers found that 21 species had shifted distribution in line with the rise in sea temperature, and 18 species had moved much further north (Perry & al. 2005). The impact of fishery may also play a role for the observed shifts in range but temperature change is believed to be the main factor. Shifting species include both exploited and non-exploited fish species. Many of the species studied not only moved northwards but also moved to deeper waters as they shifted north. This may also indicate an attraction for cooler water. Correspondingly, more southern species, such as scald fish (*Arnoglossus laterna*) and bib (*Gadus luscus*), have encroached North Sea waters and established themselves there (Perry & al. 2005).

In another study, climatic variability – expressed as the variation in the North Atlantic Oscillation index – is found to be consistently the most important parameter when explaining variation in assemblage composition, abundance and growth of juvenile marine fish during estuarine residency (Attrill & Power 2002). Hence, increases in the population of southern species, such as sea bass (*Heranidae* sp.) and sprat (*Sprattus sprattus*), are associated with warmer years, while several common Atlantic fish species, such as different flatfish species and herring (*Clupea harengus*), are associated with colder years (Attrill & Power 2002).

Further temperature rises are likely to have profound knock-out effects for fisheries. If the North Sea continues to warm as expected, at least two types of commercial fishes, blue whiting (*Micromesistius poutassou*) and red fishes (*Sebastes marimus*), may retract completely by 2050 (Perry & al. 2005).

Cod on the move

As described above, the Atlantic cod populations of the North Sea have moved 120 km north. Consistently, other researchers have found that a large decline in North Sea young-of-the-year cod abundances was partly attributable to elevated sea temperatures (O'Brien & al. 2000). However, because of the abundance and geographical distribution of cod, they may encounter even more dramatic changes in the near future. In a model-based study, the expected responses of cod stocks throughout the North Atlantic to future temperature changes were examined (Drinkwater 2005). Stocks in the Celtic and Irish Seas are expected to disappear under predicted temperature changes by the year 2100, while those in the southern North Sea and Georges Bank are projected to decline. Cod will likely spread northwards along the coasts of Greenland and Labrador, occupy larger areas of the Barents Sea, and may even extend onto some of the continental shelves of the Arctic Ocean (Drinkwater 2005). Hence, climate change will have a negative impact on cod fisheries in the more southern part of the North Atlantic and a positive impact in the more northern part.

Higher temperatures and lower salinity in the Baltic Sea

Air temperatures in the Baltic Sea basin have already risen over the past century, increasing by approximately 1°C in the northern areas and by 0.7 °C in the southern areas (BACC 2008). Consistent with this increase in temperature, other variables also show changes, such as an increase of winter runoff and shorter ice seasons. It is plausible that at least part of the recent warming in the Baltic Sea basin is related to the steadily increasing atmospheric concentrations of greenhouse gases (BACC 2008). A tendency towards lower salinity has been observed in both the Bothnian Sea and Western Baltic Sea and is expected throughout the Baltic Sea (HELCOM 2008). This is a consequence of higher river runoff into the Baltic Sea, in part caused by increasing precipitation in large areas of the Baltic region (BACC 2008).

Higher water temperatures and lower salinity are expected to have a large impact on the fish communities of the Baltic Sea. The former is already reflected in an increased recruitment of warm water dwelling species like perch and roach (HELCOM 2008). During the past two decades, the Baltic cod stock has declined from a historic high (in the early 1980s) to a historic low (HELCOM 2007). Besides high pressure from fishing, climate change is another factor that has affected the cod stocks negatively. The climate-induced increase of river runoff has caused higher cod egg mortality as eggs of Baltic cod develop only if the salinity is not too low (HELCOM 2007). In contrast to this decline in cod stock, sprat is on the increase, most likely due to the falling salinity (HELCOM 2007).

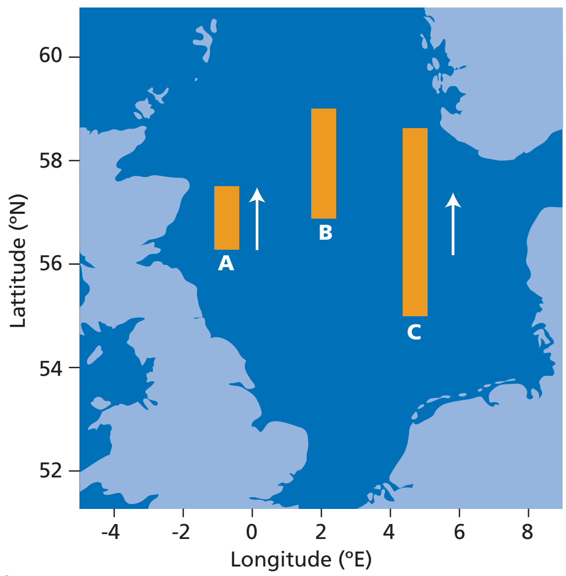


Fig.1
Examples of North Sea fish species that have shifted north with climatic warming, including (A) cod, (B) anglerfish, and (C) snake blenny. Bars on the map illustrate shift ranges of mean latitudes for the period 1978 to 2001 (Perry & al. 2005).

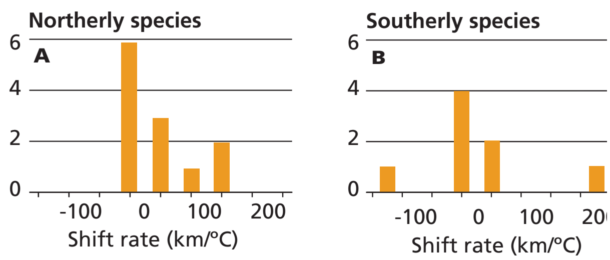


Fig. 2
Rates of shift for 20 North Sea fish species with climate change for the period 1978 to 2001. **(A)** is for northerly species and **(B)** for southerly fish species (Perry & al. 2005).

Quality criteria	Marine fish	Methodology
1. Representative for the Nordic region	Yes, covers all seas but data mainly exist for the North Sea and the Baltic Sea	The selected indicators show historical and expected shifts in the geographical range of marine fish stocks. The indicator is constructed on the basis of fishery data and an abundant amount of statistics for individual fish species and harvest locations.
2. Sensitive to	Yes, responsive to sea temperature and salinity. However, climate change may be difficult to separate the link to climate change from other factors such as fishery and environmental pollution	
3. Policy relevant	Indirectly by distribution of fish species, in particular species of commercial interest	
4. Easily understood	Yes	
5. Relevant for ecosystems	Yes, fish species are important part of the oceanic food web	
6. Scientifically agreed	Yes, methodology is well established, based on abundant methodology data on fish stocks and fishery	
7. Quantitative	Yes	
8. Time series available	Partly, fishery data are updated yearly but changes in distribution range of fish species are not calculated on a regular basis	
9. Country comparison possible	No	

Freshwater ecosystems

Photo: Maria Mikkelsen.

"Climate change is assumed to affect fresh water ecosystems in many ways. However changes in biological parameters that link to climate change are not yet clear and should therefore be further studied to develop a biological climate change effect indicator. Changes in ice-breakup dates are directly linked to air temperature, and occur simultaneously over a large geographical area. Earlier ice-breakup dates are observed in Nordic regions above an annual mean temperature of 3 °C. Experts also suggest water colour as a possible, but not unambiguous fresh water indicator."

A combination of biological parameters

A general lack of knowledge about climate change indicators in fresh water systems and temperature-sensitive single species makes it necessary to use more than one single species as climate change indicator. In addition, alpine ecosystems are often species poor (Aagaard & al. 2004) and are consequently also poor in indicator species. Therefore, using a combination of biological parameters representing aquatic communities and hydro-physical parameters would be a more robust approach, and it is important to choose a system/set of indicators known to be sensitive to climate change. During the last few years, multimetric indices have been developed and used in all Nordic countries for assessing water quality (e.g. Dahl & Johnson 2004). However, there are two very general indicators that combine the plethora of fresh water parameters affected by a climatic change: ice-breakup and water colour.

Date for ice-breakup

is one of the best indicators of climate change effect on inland waters (Duguay & al. 2006; Weyhenmeyer 2008). Changes in ice-breakup dates are directly related to air temperature, and the changes occur simultaneously over a large geographical area, bringing greater generality and predictive power to the indicator. An earlier ice-break up prolongs the ice free period and the duration of the summer stratification. It also leads to earlier phytoplankton growth, which may cause a change in the phytoplankton community leading to a higher probability of cyanobacteria blooms with subsequent oxygen depletion in the deep cold water zones (Findlay & al. 2001). This affects both the zooplankton community and the benthic fauna. Oxygen depletion in deeper zones threatens the summer refuge for coldwater-adapted fish species. Earlier ice-breakup has been observed in e.g. Sweden. Lakes located in areas with annual mean temperatures above 3 °C is exhibiting earlier ice-breakup times in 1990 compared to 30 to 40 years ago (Fig. 1; Weyhenmeyer & al. 2005). The higher the mean annual temperature, the greater the shift. Lakes in areas with a mean annual temperature of less than 3 °C, showed no temporal trend in ice-break up during the same 30-year period.

Water colour

is another variable related to a number of ecosystem processes, which responds differently to a changed climate (Evans & al. 2005). Warmer winters will cause higher levels of run-off, coupled with increasing Total Organic Carbon (TOC) concentrations in recipient waters. The water colour is also related to sulphur deposition. The level of sulphuric deposition is not related to climate, but models (Löfgren 2003) and experiments (Wright & Jenkins 2002) have shown that a milder climate will increase the amount of humus released. Darker water may change the light conditions which may have an effect on phytoplankton growth and subsequently oxygen concentrations in the deeper zones. However, the complex chemistry and causes of the variation in water colour makes this variable a plausible, but not ideal indicator for climate change (Worrall & al. 2004). Climatic effects on fresh water is dealt with in detail by the EU-project Eurolimpacs and results are presented at www.climate-and-freshwater.info.

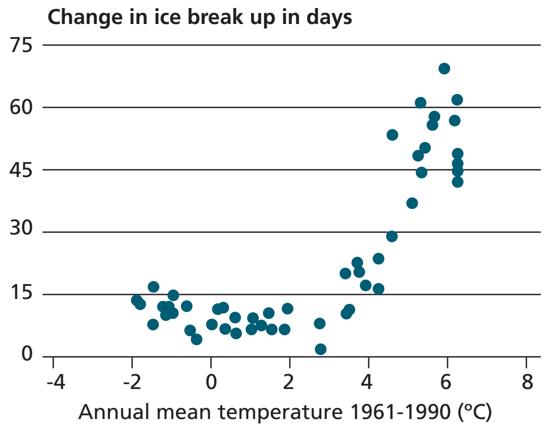


Fig. 1
Relationship between mean annual temperature and change in ice-breakup for 79 Swedish reference lakes (G. Weyhenmeyer, Swedish University of Agricultural Sciences).

***Baetis rhodani*, a case study**

The mayfly *Baetis rhodani* is a very common species found in running water in lowland areas (Aagaard & al. 2004). At a high alpine site, only a few individuals were found before 2002 and for most of these years beforehand, the species was absent for many samples. In 2003, the species colonized the site and *B. rhodani* was seen to be very abundant for the following four years. This is believed to be an effect of higher temperatures during the summer seasons after 2003, suggesting that the monitoring of temperature-sensitive fauna in freshwater may be a valid indicator of climate. However, with only one single study location, we can only say that the data coincide with the increasing temperature, but not that it is a general effect of a milder climate. It may also be a natural population development after a successful founding event.

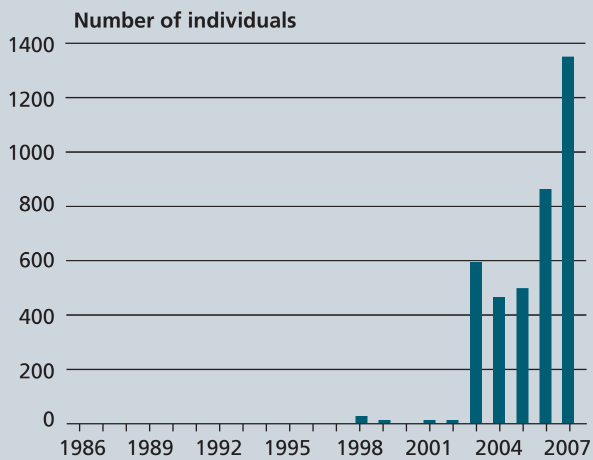
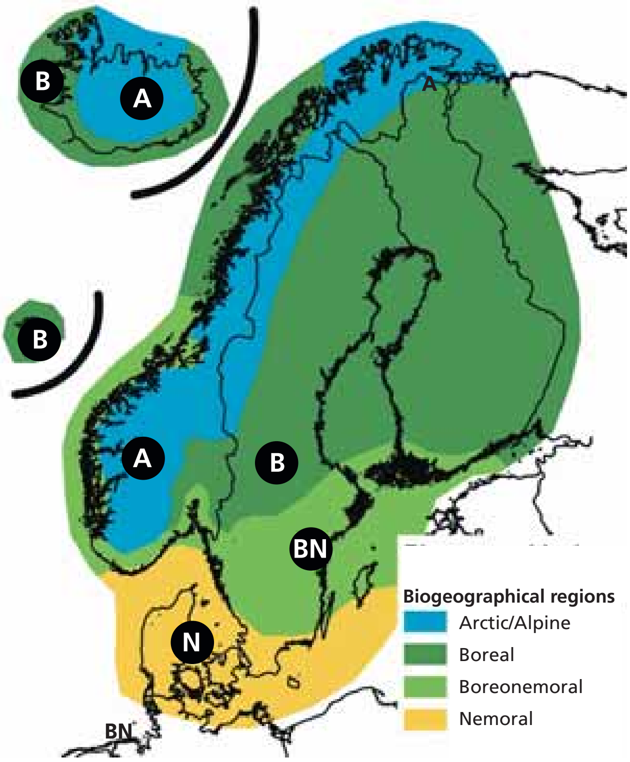


Fig. 2
Number of individuals of *Baetis rhodani* at Vidjedalsbekken, Atna River, Norway, 1200 m.a.s.l. (Terje Bongard, unpubl.).

Quality criteria	Ice-breakup	Water colour	*Baetis rhodani*	Methodology
1. Representative for the Nordic region	Yes	Yes	Not yet	Most chemical fresh water indicators rely on frequent field sampling at least once a month. Biological indicators such as diatoms, benthic fauna and phytoplankton are often sampled once a year. Physical parameters can be monitored by automatic loggers, e.g. temperature runoff etc. icing and ice-breakup can be monitored by the use of remote sensing.
2. Sensitive to climate change	Yes	Yes	Yes	
3. Policy relevant	Yes	Yes	Yes	
4. Easily understood	Very	Yes	Yes	
5. Relevant to nature and ecosystems	Yes	Yes	Yes	
6. Scientifically agreed methodology	Yes	Yes	Yes	
7. Quantitative	Yes	Yes	Yes	
8. Timeseries available	Yes	Yes	Yes	
9. Country comparison possible	Yes	Yes	Yes	

Indicator concepts, framework

The indicators presented in this report depict trends in climate change effects on nature in the Nordic countries, including marine, freshwaters and terrestrial habitats. Since national borders do not set the best limits for grouping Nordic nature types, a regional approach using bio-geographical zones of the Nordic countries is used in this report, as shown in Fig. 1. The Nordic countries can be divided into four bio-geographical zones: the Arctic/alpine, boreal, boreonemoral and nemoral zones. There are alpine regions mainly in the Scandinavian Mountains. The other zones are found in parallel belts running east-west. The Arctic regions are in the north, including Svalbard, Iceland and Greenland. The very southern coastline of Greenland shows boreal characteristics. The boreal zone consists of coniferous forests, while Denmark and the southernmost tip of Sweden lie in the nemoral zone, where deciduous forests naturally predominate. The most vulnerable regions to climate change are the Arctic, mountain areas and coastal zones (IPPC 2007).



A The arctic/alpine zones constitute areas above and north of the climatic tree border.

B The boreal zones are dominated by coniferous forests and experiences several months of temperatures well below 0 °C.

BN The boreonemoral region is a transition zone between the nemoral and boreal zones, with an increasing degree of deciduous trees running southwards.

N The nemoral region is characterised by deciduous trees, and a considerable milder climate than that of the boreal zone.

Fig.1
Bio-geographical regions in the Nordic countries. Greenland and Svalbard (not shown on the map) belong to the arctic, except for the very southern coastline of Greenland, which shows boreal characteristics (Normander & al. 2009)

The set of indicators presented in this report has been chosen despite many constraints in data quality and availability. The indicator set is to be seen as the first Nordic assessment of where and how climate change impacts have occurred and may be detected in the Nordic nature The indicators will also respond to other pressures and the observed effects may result from multiple pressures, including climate change. The selected indicators are however also sensitive to climate change and this sensitivity is preferably being demonstrated by a close correlation to climatic parameters. Each indicator should respond to climate change such that it produces a long-term trend in response to changes in temperature, and not simply respond to seasonal changes in weather.

Conceptual framework

The set of indicators have been selected within the framework of the DPSIR model (**D**riving forces, **P**ressures, **S**tate, **I**mpact, **R**esponses) (NERI, 1995; Schulze and Colby, 1996). This model conceptually links human-induced activities to pressures on the environment by connecting environmental state to ecological impact and finally societal response in order to mitigate any negative effects from human activities. This model has been widely adopted in policy analysis and environmental reporting (NERI 2001, EEA 2003, Jensen & al., 2005).

The DPSIR model used in the context of developing the given Nordic indicators for climate change is illustrated in Fig. 2. The model shows the causal link between the main greenhouse gas producing societal activities (Driving forces), the resulting greenhouse gas emissions (Pressures) and related changes in global temperature and other climatic factors (State) that have an impact on the Nordic nature (Impact), to the political responses (Response), such as the agreement on emission reduction targets of greenhouse gases and measures to reach the targets. Energy production and transport are the main contributors to emission of greenhouse gases: However other activities such as agriculture and forestry also contribute to climate change.

In this project we have focused mainly on impact indicators, since impact indicators are of great importance as basis for determining to what extent the political system should take action to reduce the impacts of climate change.

and criteria

Driving force


Photo: Highlights.

Fossil fuel Consumption, CO_2


Photo: Britta Munter.

Traffic CO_2

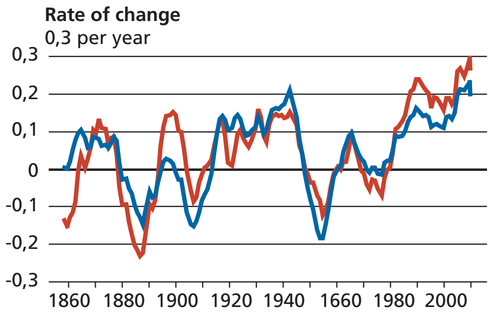

Photo: Britta Munter.

Cattle crop, CH_4, N_2O


Photo: Britta Munter.

Deforestation and peat land destruction, CO_2

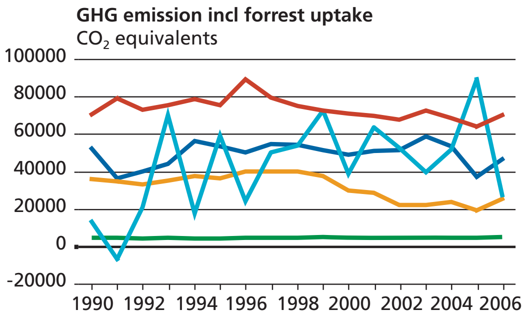
Pressure



Emission of greenhouse gases in the Nordic countries from 1990 to 2006. The emission in the Nordic countries has decreased slightly by 1% during the period (Global warming index).

- Rate of change per decade (land only)
- Rate of change per decade (land and sea

State



Temperature change - Over the past 150 years, mean temperature has increased by almost 0.8 °C globally and by about 1 °C in Europe. Eleven of the last twelve years (1995–2006) rank among the 12 warmest years since the instrumental recording of global surface temperature first began in 1850.

- Finland
- Iceland
- Norway
- Sweden
- Denmark

Impact - indicators


Photo: Erling Ólafsson.

e.g. Moths

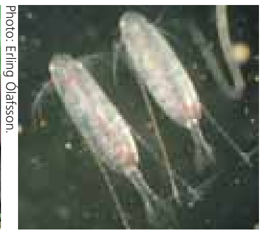


Photo: Torkel Gissel Nielsen.

Zooplankton


Photo: Henrik Eira.

Arctic fox

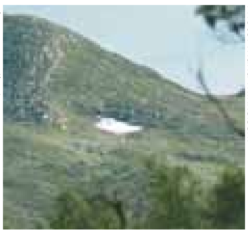


Photo: Maria Mikkelsen.

Tree line


Photo: Britta Munter.

Growing season

Response

Response Policy Initiatives as e.g. international agreements like the Kyoto Protocol, political support to research on alternative energyforms as wind, water and solar power, subsides to the development of alternative forms of transportation etc. and the conservation of carbon sinks like forests and peatlands.

Fig. 2

The DPSIR model as applied to develop Nordic nature indicators for climate change.
(Revised from: EEA, 2008. Impacts of Europe's changing climate - 2008 indicator-based assessment. http://www.eea.europa.eu/publications/eea_report_2008_4).

Indicator criteria

The Organisation for Economic Co-operation and Development (OECD, 1993) has identified a number of general criteria for the selection of indicators, including criteria for policy relevance, analytical soundness, measurability and ease of interpretation. Recently, Nordic researchers have identified a list of quality criteria that are relevant when selecting and evaluating indicators for biodiversity (Normander & al. 2009). Based on these studies, a list of 9 quality criteria was identified in this project as listed in Table 1.

In the process of selecting relevant and reliable indicators, we have tested each indicator against the 9 quality criteria. Recognising that presently each indicator may not be able to meet all of the 9 criteria, the selected indicators do nevertheless meet many of these. However, it is recognised that thoroughly and completely developing a set of indicators still would involve successive stages of improvements regarding both data collection and clarification of the link between climate change and changes in effects on the Nordic nature. Furthermore it is also recognised that it is necessary to establish an indicator data treatment and reporting system. In table 1 quality criteria no. one to five describes criteria related to policy relevance and ease of interpretation. Quality criteria no. six to nine are concerned with methodological aspects such as analytical soundness and measurability.

The indicator data are identified and collected by screening of a number of data sources, including scientific literature, environmental reports in the Nordic countries, and through personal contacts in order to identify unpublished national monitoring data.

Table 1: Quality criteria for indicator selection

Quality criteria	Explanation
1. Representative for the Nordic region	Includes a large enough or representative area of the Nordic region. Defines environment class (marine, terrestrial or freshwater) and bio-geographical zone (arctic/alpine, boreal, boreonemoral or nemoral).
2. Sensitive to climate change	Measured qualities are more sensitive to climate change than their environment (i.e. early warning). Buffered from natural fluctuations and other factors (e.g. environmental pollution) that are not caused by climate change.
3. Policy relevant	Linked to politically set targets and agreements. Enables assessing progress towards targets.
4. Easily understood	Possible to display clear messages (with eye-catching graphics) that can be understood in a broader audience.
5. Relevant for ecosystems	Measures changes in nature that are of importance to the functioning and/or stability of ecosystems.
6. Scientifically agreed methodology	Based on scientifically sound methodologies acknowledged by the scientific community.
7. Quantitative	Based on real quantitative observations and statistically sound data collection methods.
8. Time series available	Shows temporal trends and can be updated routinely, e.g. annually
9. Country comparison possible	Enables comparison (e.g. benchmarking of countries).

Glaucous gull

Photo: Bo Normander.

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Not only is the climate changing, our natural world is already being affected by the increase in temperature, change in precipitation and wind pattern etc. already seen. In order to track these changes, as they occur across the Nordic region, we have identified a variety of climate change signs for the Nordic nature. We present for the first time a catalogue of 14 signs that shows the impact on several ecosystems including terrestrial, marine- and fresh-water. The signs have been identified using a systematic and criteria based approach that is applicable to a variety of other regions as well.

In the project we show that climate change is not only affecting a few individual species or habitats in the Nordic region, but that a number of changes occur concurrently and at many scales. Important signs of climate change include; pollen and growing seasons begin earlier; fish stocks shift northwards; some bird populations decrease in numbers and other adapt by a change in migration rhythm; sensitive nature types such as palsa mires are declining in distribution, and polar bears are threatened by earlier ice-breakup.

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