

# Climate Vulnerability in the Barents Sea Ecoregion: A Multi-Stressor Approach

**Karen O'Brien, Heather Tompkins, Siri Eriksen, and Pål Prestrud**

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**Tittel: Climate Vulnerability in the Barents Sea  
Ecoregion: A Multi-Stressor Approach**

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**Sammendrag:** Denne rapporten undersøker hvordan klimaendringer sammenfaller med andre stressfaktorer og kan forsterke påvirkningen på det biologiske mangfoldet i økoregionen Barentshavet. Vi undersøker økoregionens sårbarhet overfor framtidig oppvarming og overfor økning i transport av olje og gass fra vestlige deler av Russland og utvikler et foreløpig rammeverk for analyse av sammenfallende stressfaktorer. Ved hjelp av literaturgjennomgang identifiseres nøkkelprosesser og arter som bidrar til økoregionens biologiske mangfold. Eksisterende og framtidige trusler mot disse skapt av sjøtransport diskuteres. Videre presenteres mulige klimaeffekter og sårbarhet for området, samt klimascenarier basert på resultater for 2050 fra Bergen Climate Model. Potensielle skjæringspunkter mellom de to stressfaktorene og et eksempel på strukturell analyse av sammenfallende stressfaktorer legges fram. Analysen illustrerer at biologisk mangfold påvirkes av mange faktorer som i stor grad er avhengige av hverandre. Når klimaendringer virker gjensidig forsterkende med økt transportaktivitet er trusselen mot biologisk mangfold spesielt stor. Dette sammenfallet mellom stressfaktorer kan være synergistisk i tillegg til kumulativt. Derfor bør klimaendringer ses på som en forsterkende faktor heller enn bare en uavhengig tilleggsfaktor. Vi konkluderer med at sårbarhetsanalyse overfor økende transportaktiviteter ikke er en tilfredsstillende som basis for forvaltning av økoregionen med mindre denne analysen inkluderer komplekse effekter og usikkerhet generert av framtidige klimaendringer.

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**Abstract:** In this report, we examine how climate change impacts may intersect and interact with other stressors in the Barents Sea Ecoregion (BSEr). We investigate the vulnerability of the BSEr to both climate change and increased transport activity, particularly in relation to oil and gas transport from Western Russia in order to develop a preliminary framework for assessing the effects of multiple stressors. Based on a survey of existing literature, some of the key processes and species that contribute to biodiversity in the BSEr are identified and current and future threats from maritime traffic discussed. We next discuss climate change impacts and vulnerability and present some future climate scenarios based on the results for 2050 from the Bergen Climate Model. We then assess potential interactions between the two stressors and present an example of a structural analysis of multiple stressors for the BSEr. This analysis demonstrates that the various factors that affect biodiversity are interdependent. Biodiversity pressures may be created simultaneously by climate change and increasing transport activities, and that interaction between multiple stressors may be synergistic as well as cumulative. There is therefore a need to consider climate change not as merely another stressor added to other stressors in BSEr, but as a stressor that interacts with other stressors in the region. We conclude that assessments of present-day vulnerability to growing maritime traffic are insufficient as a basis for long-term management plans unless they take into account the complexity and uncertainties introduced by climate change.

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We would like to thank Lynn Rosentrater and Egil Dragsund for commenting on earlier drafts and for providing useful literature for this study.

Miners have their canaries to warn of looming dangers, and climate change researchers have their arctic ice... (Kerr, 1999, p. 1828)

## **1 Introduction**

The Barents Sea Ecoregion (BSEr) is a unique environment that forms part of the arctic ecosystem. The combination of specific biological processes, species groups and geographical features creates an ecosystem that is among the world's highest in marine biological production (Sakshaug et al. 1994; Olsen and von Quillfeldt 2003). Although the BSEr is considered pristine relative to many other areas of the world, human impacts on the environment related to fishing activity, offshore oil and gas exploration, heavy metals and organic contaminants, and the potential for radioactive pollution are becoming increasing concerns (Klungsoyr et al. 1995; AMAP 2002). Preliminary assessments show that this ecoregion is vulnerable to multiple stressors, and that management policies must take into account the interactions of these stressors if biodiversity conservation is to be effective (WWF In Press). One important stressor that cannot be ignored in conservation and management strategies is climate change and its impacts on arctic marine ecosystems.

Anthropogenic emissions of greenhouse gases have increased steadily since the onset of the industrial revolution, raising atmospheric concentrations of CO<sub>2</sub> by 30% since 1750. There is a growing consensus among scientists that these will lead to an enhanced greenhouse effect, resulting in global warming and climate change (McCarthy et al. 2001). Indeed, the global average surface temperature has increased by 0.6°C (+/- 0.2°C) over the past century, and model projections suggest that the temperature will increase further by 1.4-5.8°C over the next 100 years (Houghton et al. 2001). The impacts on the arctic region, where temperature increases are likely to be twice as high as in temperate and low latitudes, are a serious concern. Mesoscale and small-scale processes, including ice edges, polynyas, oceanographic fronts, and ice-seawater interfaces, play a major role in the primary production regime of the BSEr, and any changes in these are likely to influence both the region's biology and ecology (Alexander 1992). In particular, changes in sea ice resulting from warming temperatures are likely to have widespread impacts. According to the IPCC Third Assessment Report, "[c]hanges in sea ice will alter the seasonal distributions, geographic ranges, patterns of migration, nutritional status, reproductive success, and ultimately the abundance and balance of species" (Anisimov and Fitzharris, 2001, p. 804). Changes in ocean currents, vertical mixing, and salinity will also have impacts on the ecosystem. Although there is uncertainty surrounding the implications of climate change for biodiversity in the Barents Sea Ecoregion, many studies suggest that the entire food chain, from marine mammals to benthos, will be influenced by a changing climate (Alexander 1992; Tynan and DeMaster 1997, Soto 2002). Indeed, evidence of climate change is starting to accumulate, and many of the observed trends are consistent with modeling studies of long-term trends (Johannessen et al. 1999; Moritz et al. 2002; Shindell 2003).

In this report, we examine how climate change impacts may intersect and interact with other stressors in the BSEr, influencing the overall vulnerability of the ecosystem to human-induced pressures. We consider the impacts in three sections of the BSEr: the polar front and ice edge; the seasonally ice-covered areas; and the southern coastal areas. We focus on transportation pressures related to petroleum and gas activities to explore potential synergies with climate change impacts and to develop a preliminary framework for assessing the effects of multiple stressors. Such an approach may appear obvious, as vulnerability assessments of ecological systems have long acknowledged that multiple stressors present challenges to

developing conservation and management strategies. Yet much of the conservation literature fails to address the interactions between climate change and other stressors. Rather than “just another stressor,” climate change is likely to present enormous challenges to the conservation and resource management communities, in the near-term as well as in the future. Given the multidimensional and largely simultaneous effects of ecological interactions under climate change, “a merely linear account of effects will surely underestimate the eventual outcome overall” (Myers 1992, p. 345).

This report underscores the need to account for the cumulative and synergistic effects of climate change in ecosystem management—effects which seem to be underemphasized in contemporary debates surrounding the development of a holistic management plan for the Norwegian part of the Barents Sea Ecoregion. Climate change represents a potentially large and important additional stressor that must be incorporated into conservation and management plans now to ensure the future integrity and sustainability of this highly valued ecosystem.

### **1.1 Vulnerability Assessments**

Vulnerability is a term used to describe the likelihood of being hurt or damaged by some process or event. Within the climate change literature, the concept of vulnerability has been widely used to assess climate impacts and the distribution of these impacts. Vulnerability is generally considered to be a function of exposure, sensitivity, and adaptability (McCarthy et al. 2001). Exposure refers to the degree or magnitude of changes in climate parameters, such as temperature and precipitation. These are often referred to as the first-order effects of climate change, and they in turn generate higher order impacts, such as changes in sea ice, runoff, and salinity, which in turn may lead to changes in primary production, species composition, and so on. Sensitivity is the degree to which species or ecosystems are influenced by climate change. Some species or systems are more resilient than others, and have a higher threshold for coping with climate variability and change. Others may be highly sensitive, such that small changes will have large effects. Finally, adaptability refers to the capacity to respond to changes in climate. Some species will be able to readily adapt or migrate in response to changing conditions, while others may face barriers and constraints.

Vulnerability is both a differential and scale-dependent concept. It is differential in that some species or ecosystem processes and functions may experience greater negative impacts than others under equal exposure to a given stress. Some species or components of the BSEr may be more sensitive to climatic factors than others, and some may be able to adapt to changing climate conditions more successfully than others. Vulnerability is scale-dependent in that the vulnerability of one component or sub-region may be different from the overall vulnerability of the ecoregion (Harte et al. 1992). It is, for example, possible that the overall vulnerability of the BSEr may be greater than the cumulative vulnerability of its parts, once synergistic effects are taken into account. For example, any impacts on populations of cod, capelin or herring are likely to have widespread implications for vulnerability in the BSEr, as these are keystone species that link different levels of the food chain. To assess ecosystem vulnerability, one must identify the processes and features that are most important to the functioning of the ecosystem and then evaluate the influence of climate change. Assessing vulnerability involves identification of species or indicators that merit particular monitoring and concern, and is usually a first step in developing management strategies.

While it may be meaningful to assess vulnerability to climate change alone as a means of identifying the gravity of the problem, in reality species and systems are vulnerable to multiple stressors, of which climate change is but one. Indeed, “[t]he magnitude and consequences of climate change cannot be viewed in isolation from other anthropogenic global stresses” (Harte et al. 1992, p. 334). Similarly, conservationists and resource managers concerned with current pressures on biological systems cannot ignore the impacts of climate

change, as it is likely to invalidate many assumptions and conclusions regarding vulnerability. Climate change is unlikely to be just “one more stress” on the ecosystem, but rather it will create complex and dynamic changes in the environment that may drastically alter the baseline for evaluating vulnerability. To develop management and conservation strategies for the BSEr (or for species within this ecosystem), it is essential to consider the synergistic effects of climate change, and how they may shape vulnerability in the BSEr over the next 20 to 50 years. Fundamental changes to current management programs may be required if climate change is to be successfully addressed (Hannah et al. 2002).

A multiple stressor approach must take into account the impacts of both stresses and shocks. Stresses are considered long-term, persistent pressures, such as gradual changes in sea surface temperatures, or operational discharges from ships. A shock, in contrast, is a unique or semi-periodic perturbation that has immediate and long-term consequences for the species or system. Environmental catastrophes (e.g., oil spills) and extreme weather events (e.g., storms) are considered shocks. When assessing vulnerability, both stresses and shocks must be considered. Many species will be exposed to multiple stresses and shocks, therefore it is common in environmental impact assessments to consider “cumulative effects.”

Cumulative effects can be defined as changes to the environment that are caused by an action in combination with other past, present and future human actions (Environment Canada 2003). The magnitude and effects of multiple stresses or shocks along different “pathways” of interactions can be equal to the sum of the individual effects (additive effects) or they may strengthen or weaken each other (positive or negative synergistic effects). As an example, polar bear reproductive failures due to climate change and polar bear mortality due to hunting will have additive effects on polar bear populations. However, an increase in oil transport in combination with an increase in extreme weather events such as storms or blizzards may increase the probability of shipping accidents and the discharge of oil, while also reducing the chances of successfully responding to the oil spill. For many species, the multiple stressors of transport and climate change together represent risks greater than additive impacts on health and habitat. When a species is weakened by one stress it often becomes more vulnerable to other stresses. Climate impacts are likely to have many synergistic effects with other stresses, whereby the combined effect is more harmful than the sum of the separate effects of the stresses (Harte et al. 1992).

## **1.2 Assessing Vulnerability in the Barent Sea Ecoregion**

There have been a number of environmental assessments in different areas of the Barents Sea Ecoregion (BSEr), including an environmental and resource inventory (Føyn et al 2002), an assessment of particularly valuable areas (Olsen and von Quillfeldt 2003), and a Barents Sea Biodiversity Assessment (WWF In Press). Furthermore, Det Norsk Veritas (DNV 2003a) has recently completed a study assessing the region’s suitability to be classified as a Particularly Sensitive Sea Area (PSSA), which would open up new possibilities for protecting biodiversity (WWF 2003). A series of environmental impact assessments have also been undertaken to identify the consequences of different economic activities and external influences on the Barents Sea (Norsk Polarinstitut 2003; DNV 2003a). Although climate change is discussed as a potential threat in several of these reports (Norsk Polarinstitut 2003, WWF In Press), the impacts have not been comprehensively evaluated in the context of existing pressures, and existing pressures have not been comprehensively evaluated in the context of climate change.

Although it is widely recognized that the BSEr is under pressure from more than one stressor, there has been a general failure to address the synergistic effects of climate change and other activities on biodiversity in the region, in part because many of the effects are unknown or uncertain. Yet the impacts of climate change in the Arctic are likely to be considerable (Anisimov and Fitzharris 2001), and despite uncertainties there is a need to take them into account in developing current and future management strategies. As a preliminary

report from Norsk Polarinstitutt (2003, p. 13) points out, climate impacts will serve as the backdrop for other impacts, setting the conditions that will determine how other environmental parameters will react to other stressors.

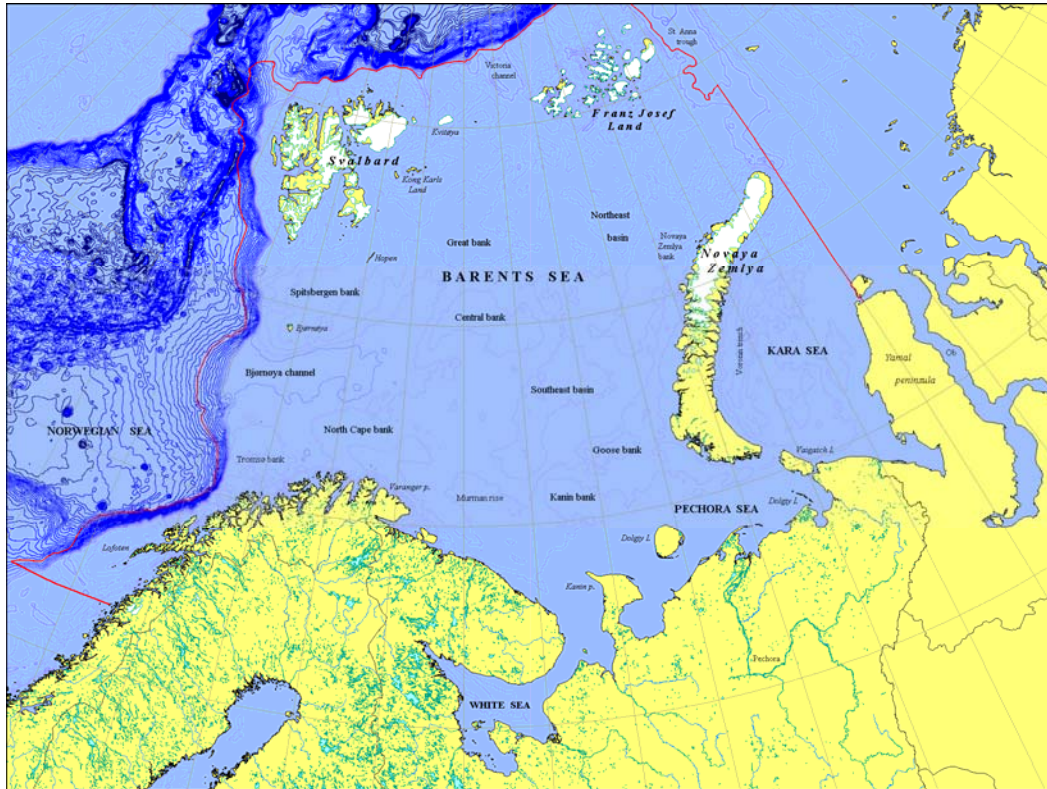
Below, we assess the vulnerability of the BSEr to both climate change and increased transport activity, particularly in relation to a projected increase in oil and gas transport from Western Russia. Although there are other stressors that could be addressed in a vulnerability assessment, these two stand out because they are likely to increase over the next 20-50 years and pose growing threats to the BSEr. This report is based on a survey of existing literature, and includes a mapping of results from a global climate model, as well as an example of what a structural analysis of multiple stressors might look like for the BSEr. Given that knowledge of the cumulative (and particularly synergistic) effects of climate change and other stressors is scant, there is a clear need to fill some knowledge gaps before “letting the stressors loose.”

In the sections that follow, we first identify some of the key processes and species that contribute to biodiversity in the BSEr, then discuss current and future threats from maritime traffic. We next discuss climate change impacts and vulnerability, and present some future climate scenarios based on the results for 2050 from the Bergen Climate Model. We then assess potential interactions between the two stressors, emphasizing a few potential synergistic effects. The results are then discussed within the context of current debates about maritime activities in the BSEr. The report concludes by emphasizing that assessments of present-day vulnerability to growing maritime traffic are insufficient as a basis for long-term management plans unless they take into account the complexity and uncertainties introduced by climate change that will continuously shape vulnerability in this region over the next decades.

## **2 Biodiversity in the Barents Sea Ecoregion**

Biodiversity can be used to describe the number, variety and variability of living organisms. The Biodiversity Convention drafted in Rio in 1992 defines biodiversity in the following way: “Biological diversity’ means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (CBD 1992). In this section we briefly discuss some of the prominent features of biodiversity within the BSEr by highlighting key processes and species groups. Some of this discussion draws upon the biodiversity assessment of the BSEr conducted by the WWF (WWF In press). This assessment examines key species groups and processes and identifies priority areas in the region that are crucial to preserving biodiversity. These priority areas take into account various factors such as ice edge dynamics, spawning grounds, seabird colonies and the spring bloom.

The BSEr consists of a relatively shallow continental shelf sea with an average depth of 230 m, covering an area of  $1.4 \cdot 10^6$  km<sup>2</sup> (Klungsoyr et al 1995) (Figure 1). It is among the most productive oceans of the world, and one of the most biologically diverse of the Arctic. In order to understand biodiversity in the BSEr one must recognize that there are integral processes and physical features in the region that are interconnected (Alexander 1992). The critical features that support the biological productivity in the BSEr include the influx of warm Atlantic water masses that create the polar front, the ice edge and polynyas. Of these, both the polar front and the ice edge have been recognized as “Particularly Valuable Areas” in the Lofoten – Barents Sea region (Olsen and von Quillfeldt 2003). These features are likely to be influenced by climate changes, particularly changes in ocean temperatures and sea ice extent.

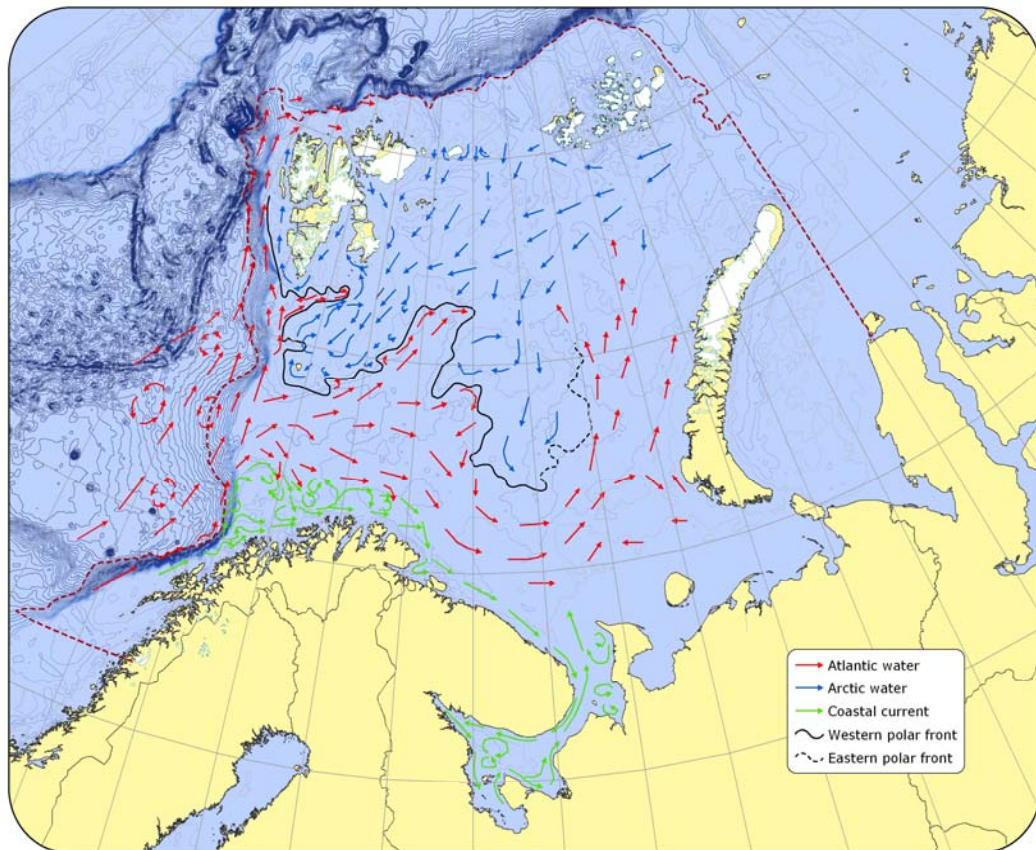


**Figure 1.** The Barents Sea Ecoregion (BSEr). Bathymetric lines are in 100 meter intervals. (Source: WWF- A biodiversity assessment of the Barents Sea Ecoregion, In press)

## 2.1 Polar front

Figure 2. Key hydrographic conditions in the Barents Sea Region. One of the factors that make the BSEr unique as a polar environment is the convergences of certain ocean currents. The Barents Sea is divided into a northern and a southern part by the polar front where relatively warm, saline Atlantic water descends under the cold but less saline arctic water (Loeng 1991) (Figure 2). The convergence of differing water masses is marked by the polar front, a hydrographic feature whose position is also influenced by the bathymetry of the relatively shallow sea floor. The polar front is more distinguishable in the western than eastern Barents Sea and is a region where nutrients are brought into the photic zone from deep waters which stimulates primary production. Productivity is highest south of the polar front due to additional mixing by wind, but it is more concentrated north of the polar front since it is limited to a smaller zone that follows the retreat of sea ice (Sakshaug and Slagstad 1992). South of the polar front several processes and in particular wind-induced mixing ensure the supply of new nutrients to the photic layer (Slagstad and Støle-Hansen 1991). In this area the spring bloom generally starts in the end of April or beginning of May and ends in the end of May or beginning of June. However, several blooms throughout the growth season lead to a high productivity ecosystem. Both model studies and observations demonstrate that the Atlantic waters south of the polar front are the most productive waters in the Barents Sea. This primary production is distributed more or less evenly over large areas in contrast to the production north of the polar front, which is concentrated into a narrow band (20 – 50 km wide) following the ice edge.





**Figure 2.** Key hydrographic conditions in the Barents Sea Region.

## 2.2 Ice edge

The ice edge is a particularly productive part of the region and has considerable influence on biodiversity. A permanent ice sheet, three to four meters thick, covers the seas north of Svalbard and Franz Josef Land. South of this area the ocean is seasonally covered by ice up to eight months of the year. The ice and the snow covering the ice are sufficiently opaque to prevent measurable growth of phytoplankton in early spring under the ice (Palmisano et al. 1986) and the nutrient supply is therefore low until the ice has melted. When this ice starts to melt in April/May, the upper twenty meters of the ocean is stabilized by the melted freshwater. The stratification of the water column is too strong to be eroded by wind and this pronounced pycnocline remains at 25 – 35 m depths for the remaining part of the growth season. Phytoplankton associated with the underside of the ice may serve as seeding stocks (Syvertsen 1991) and the phytoplankton bloom therefore develops extremely rapid when the ice melts creating a pycnocline between 10 and 25 m (Slagstad and Støle-Hansen 1991). As the ice edge retreats northward, new nutrient rich water is exposed to light. As a result, a phytoplankton bloom trails the ice edge as a band moving northwards as the ice melts. Primary productivity after the spring bloom is small and mainly regenerative (Sakshaug and Slagstad 1992) leading to a low-productivity ecosystem. During the spring bloom the production increases exponentially until nutrients are consumed and the herbivorous zooplankton has increased in number (Sakshaug et. al. 1981; Rey 1981a; Rey 1981b).

## 2.3 Polynyas

Polynyas are areas of open water in regions covered by sea ice. They may be open seasonally or throughout the year, and they serve as “outposts of enhanced activity within pack ice removed from the effects of marginal ice zones. They appear to have both biological and oceanographic significance far in excess of their size and extent...” (Alexander 1992, pp. 226-227). In fact, large polynyas and edges of the polar pack are vital to the overall biological productivity of polar oceans and to all trophic levels of the associated ecosystems (Stirling 1997). There is an overlap between these areas of productivity and the location of hydrocarbons (Stirling 1997). Their size is a function of temperature and wind—two variables that are expected to be influenced by climate change. There are two types of polynyas: linear shore leads opening at the edge of land fast ice or wind driven polynyas which open on the leeward side of islands (WWF In press). Polynyas attract large numbers of seabirds and are critical for over-wintering birds. The failure of a polynya to open can have drastic consequences, including massive mortality of birds and mammals (Alexander 1992).

## 2.4 Key Species Groups

The BSEr is characterized by simple marine food webs with short food chains that facilitate the high productivity of the region (Figure 3). These simple food webs support key species groups that are integral to the ecosystem’s structure. The functioning of the food webs depends on a balance between “bottom-up” (ie: resource availability) and “top-down” (ie: grazing, predation) processes (Legendre and Rivkin 2002). An important feature of the BSEr is that a relative few species link different trophic levels of the food chain, rendering the system as a whole vulnerable to any changes in the populations of these species. Specifically, capelin (*Mallotus villosus*), polar cod (*Boreogadus saida*), and herring (*Clupea harengus*) are keystone species linking primary production with higher trophic levels.

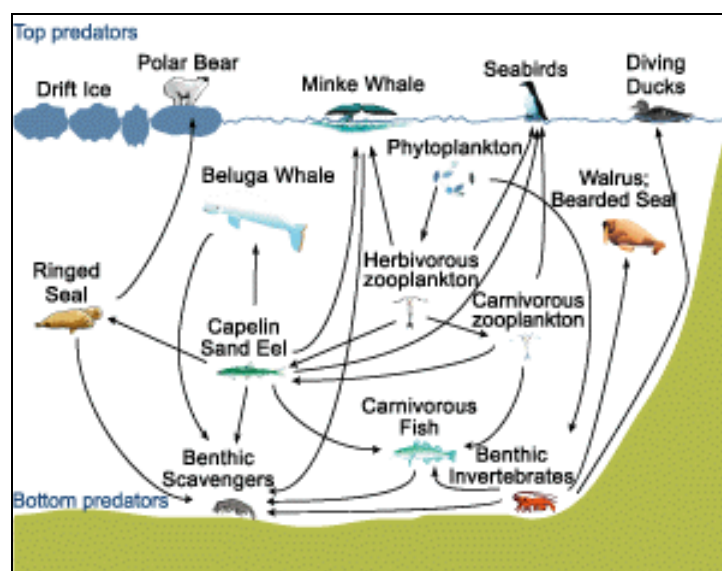


Figure 3. Arctic marine food web. (Source: Akvaplan –Niva)

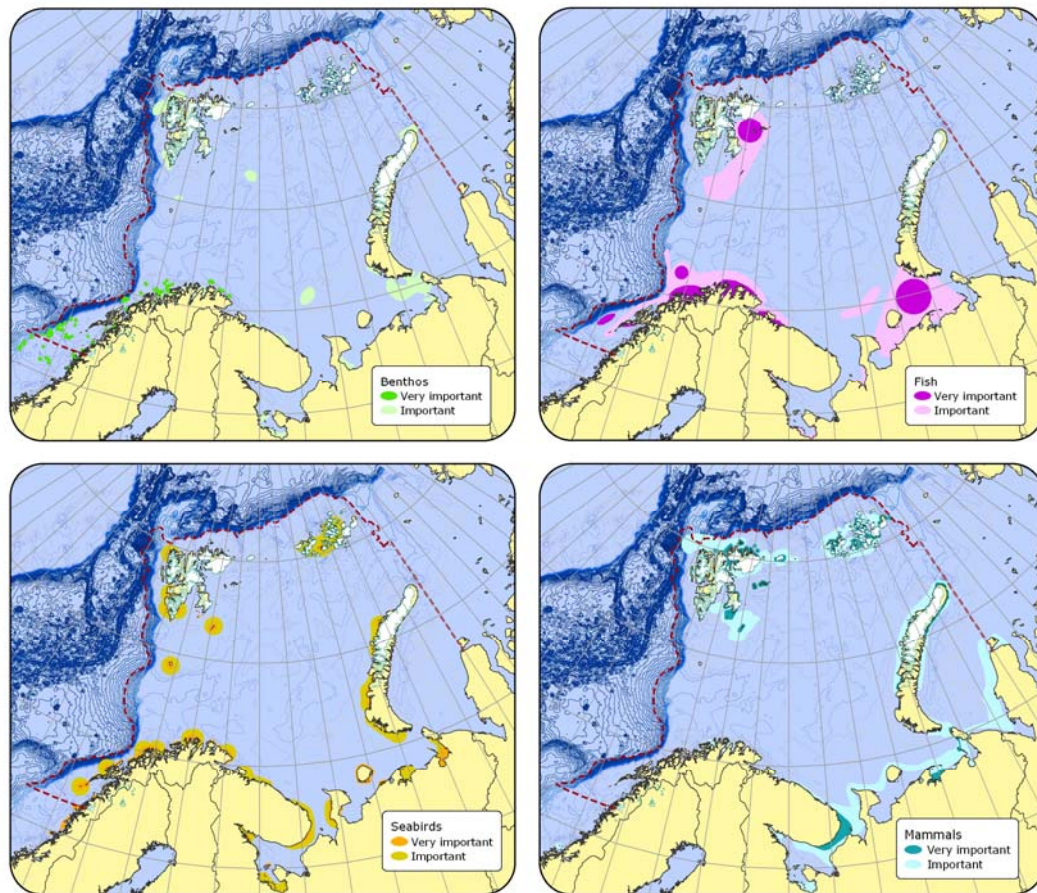
The concept of “match and mismatch” is important in the BSEr, with “match” implying that predators and prey are located in the same space at the same time, and “mismatch” implying that they are not (Cushing, 1990). As an example of “match,” the growth and survival of cod larvae depend on synchronous production of their main food sources, which are early stages of zooplankton (Stenseth et al. 2002). As an example of “mismatch,” the

collapse in the capelin stocks in 1986/87 appears to have had negative consequences for some seabirds, including the surface-feeding kittiwakes (*Rissa tridactyla*), common guillemots (*Uria aalge*) and puffins (*Fratercula arctica*) (Barrett and Krasnov 1996).

Generally, there are five marine species groups in the BSEr that are dependent upon the geophysical features described above: benthos, plankton, fish, seabirds and marine mammals.

#### 2.4.1 Benthos

Also known as benthic organisms, benthos live on or close to the bottom of the sea floor, and can include plants, invertebrates and fish. Among marine organisms in the BSEr, benthos exhibits the highest degree of species diversity, with a total of 2499 documented invertebrate species (Sirenko 1998). Species diversity for benthic organisms is correlated to four factors: 1) climate and age of the biogeographical region; 2) number of available habitats; 3) salinity, and 4) stability of the system (Direktoratet for Naturforvaltning 2001). Figure 4a illustrates benthos areas in the SEr that are either very important or important to its biodiversity (WWF-Norge 2003).



**Figure 4.** Areas of importance for key species groups in the BSEr. a) benthos; b) fish; c) seabirds; d) marine mammals. (Source: WWF - A biodiversity assessment of the Barents Sea Ecoregion)

### **2.4.2 Plankton**

Plankton are small plant and animal organisms that float or drift with currents, and are made up of two main plankton communities: phytoplankton and zooplankton. The phytoplankton bloom and the correspondingly high secondary production along the ice-edge is also called the “ice-edge effect”. The ice-edge effect occurs earlier than general spring blooms in open waters. It creates an early food base for zooplankton, fish, seabirds and mammals.

The ice edge is not always easily detectable, because the distribution of ice is not solely determined by temperature, but depends also on wind and currents. Even though the primary production in this area is lower than south of the polar front (Thingstad and Martinussen 1991; Sakshaug and Slagstad 1991) the ice edge is a high productivity ecosystem. This primary production is the food base for zooplankton, and thus fish, seabirds, and mammals, all of which concentrate at the ice edge during this period.

The ice edge dynamics are a driving force of the Barents Sea ecosystem, and the abundance of all other elements in the arctic food web are closely associated to the vigorous blooms of the primary producers in the spring. The success of the energy transfer from primary producers to the herbivorous zooplankton requires that patches of the two are well timed and similarly distributed geographically.

### **2.4.3 Fish**

The number of fish species in the BSEr is relatively poor, yet the area holds some of the largest fish stocks in the world, such as Atlantic cod, polar cod, capelin, and herring (Figure 4b). Atlantic cod (*Gadus morhua*), capelin (*Mallotus villosus*) and Atlantic herring (*Clupea harengus*) spawn along the Norwegian coast while polar cod (*Boreogadus saida*) spawn and live along the ice edge. Strong interactions exist between fish species in that species are being eaten or eating one another at different life cycles (Klungsoyer et al. 1995). Also, the size and distribution of each year class has marked effects on other components of the ecosystem. For example, Atlantic cod eat adult capelin and young herring fry while adult herring prey on capelin fry. The feeding migrations of large fish stocks are closely linked to the seasonal production of zooplankton.

### **2.4.4 Seabirds**

The BSEr is home to some of the largest colonies of seabirds in the world (Figure 4c). More than 30 species breed in the area (WWF In press), and an estimated 20 million individuals summer in the BSEr (Anker-Nilssen et al. 1999). However, four main species make up 85% of the breeding population in the region (WWF In press): Kittiwake (*Rissa tridactyla*), Brunnich’s Guillemot (*Uria lomvia*), Little Auk (*Alle alle*) and Puffin (*Fratercula arctica*). Seabird distribution is dynamic, related to the sea ice edge and prey distribution. While most birds breed on land, they feed on the BSEr’s abundant marine resources, including its large fish stocks, abundant supply of krill and other large zooplankton, and the amphipods associated with subsurface sea ice (WWF In press). The disappearance of sea ice could potentially influence seabird distributions, as the distance between breeding grounds and feeding areas on sea ice is important in terms of energetics (Kovacs 2003).

### **2.4.5 Marine mammals**

Marine mammals consist of a broad group that includes animals such as whales, polar bears, walrus and seals (Figure 4d). The population size of some of the species in the Arctic and the BSEr is low due to over-hunting in the past. Only three species are permanent Arctic residents: the white whale (*Delphinus leucas*), narwhale (*Monodon monoceros*) and bowhead whale (*Balaena mysticetus*). The BSEr is home to the walrus (*Odobenus rosmarus*) and seven species of seal. The harp seal (*Phoca groenlandica*) is the most numerous marine mammal species while the ringed (*Phoca hispida*) and bearded seal (*Erignathus barbatus*) are important to the survival of polar bears. The BSEr has important breeding and wintering sights for seals and walruses, the most important being Svalbard and Franz Josef Land and the

Pechora Sea. Polar bears are perhaps the most recognizable species in the BSEr. The Polar Bear Specialist Group determined in 2001 that there are about 2000-5000 bears in the region (IUCN 2001). The bears spend the majority of their time on sea ice, particularly the edge, foraging for prey. Their main feeding period is in the spring and summer which is critical to maintaining body condition and ensuring reproductive success. Pregnant females den in the fall while the rest of population remains active on the sea ice.

Although the BSEr is currently relatively pristine, a number of threats have been identified that could influence the status of the five key species groups. These threats are related to fishing activities, offshore oil activity, organic contaminants and trace metals, radioactive contamination, and climate change (Klungsoyr et al. 1995). These threats are described in more detail in the WWF's "A Biodiversity Assessment of the Barents Sea Ecoregion" (WWF In Press). Many of the threats are directly associated with shipping activities, which are currently expanding in the BSEr. Although transport of oil and gas through the Barents Sea represents only a small percentage of shipping in the region, this type of transport is growing far more rapidly than projected, and is expected to increase more in the future (Frantzen and Bambulyak 2003). The transport of oil and gas from Western Russia to North American and European markets is a particular concern because of the risks associated with loading methods used in the region, and with the transport of petroleum and gas itself. Loading methods include ships pumping oil directly from an oil pipe running from land along the ocean floor and smaller tankers reloading to larger 'terminal tankers' (up to 100000 dwt<sup>1</sup>), which in turn reload to tankers of about 20000 dwt that ship the oil to European market. Another threat, namely climate change, is a global scale phenomenon that could have profound impacts on the BSEr.

In our analysis, we distinguish between the polar front and ice edge; the seasonally ice-covered areas; and the southern coastal areas because these support different aspects of biodiversity in the ecoregion and are likely to face very different transportation pressures. Primary productivity is a central feature of the polar front and ice edge, with some passenger and tourism traffic likely to increase, for example. Meanwhile, the southern coastal areas support fish and mammal and bird species, and oil transport from Russia is expected to increase dramatically. The processes taking place in the three sections are described in section five of this report.

### **3 Shipping and Transportation: A growing threat to biodiversity**

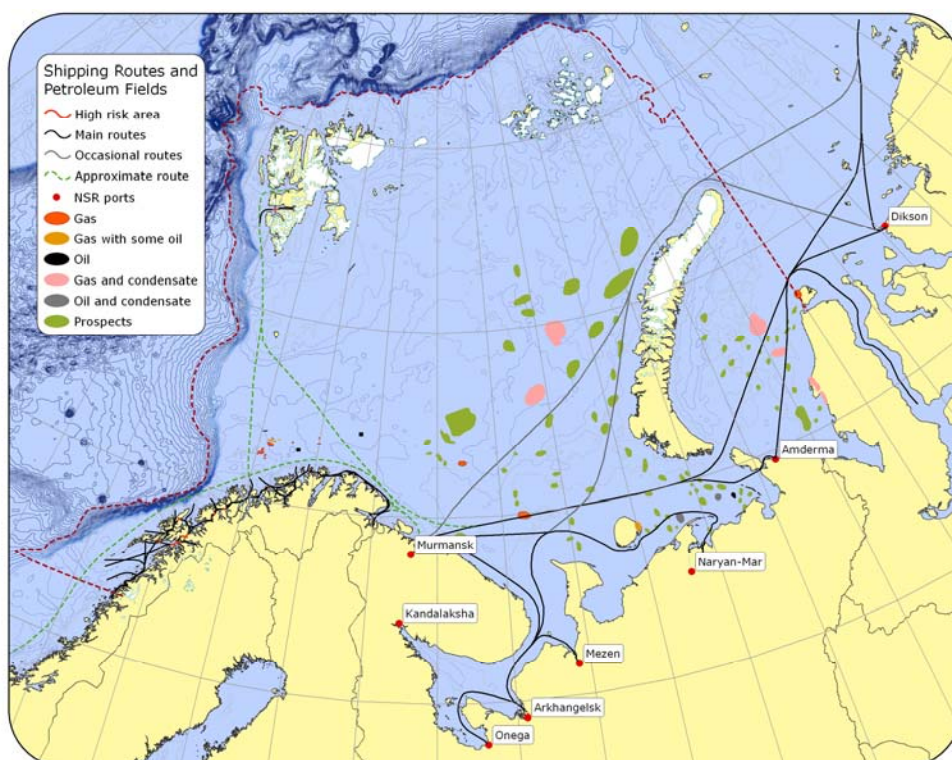
Transportation in the BSEr is developing into a major activity. Technology for navigating in shallow, ice-filled waters is improving, enabling more and larger ships to venture into the region. Simultaneously, interest in petroleum exploration and transport and tourism is growing, resulting in more and more ships passing through the Barents Sea. It is estimated that over 30,000 voyages are made across the coast of northern Norway annually, with more than half of these related to fishing operations (Kystverket 2003). International traffic in the Barents Sea and northern part of the Norwegian sea is dominated by vessels going to and from Russian ports, such as Murmansk, Arkhangels and Kandhalaksha, in connection with oil export. While seasonal variations in fishery fleet activity is connected to the distribution of fishery resources, prevailing ice conditions determine shipping activities connected to Russian oil export from the White Sea and Pechora area, as well as traffic to Svalbard (PAME 2000; DNV 2003b).

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<sup>1</sup> Dead weight tonnes, a measure of how much weight the ship can carry

Figure 5 depicts major shipping routes and petroleum fields in the BSEr. Traditionally, shipping routes will follow the easiest path, normally ice free waters that include open leads and polynyas. Traffic is usually restricted to the southern portion of the region, which is generally ice free from late spring to early autumn. A decrease in ice cover in the northern part of the region is likely to influence shipping routes. Transportation in the BSEr consists of the following types of vessels:

- transport of general cargo and bulk (wet and dry) cargo, containers
- fisheries
- tourism including whale watching, cruise vessels, passenger vessels
- research and other vessels
- transport of vessels for scrapping
- ice breakers and tugs



**Figure 5.** Shipping routes and petroleum activities in the Barents Sea Region.

Whereas fishery activities and research voyages are expected to remain stable over the foreseeable future, all other types of activity are assumed to increase (PAME 2000). Indeed, overall traffic through the BSEr is expected to increase significantly in the coming decades. A study carried out by the Transportøkonomisk Institutt (TØI) estimated that ship traffic, measured in nautical sailing miles, is expected to increase from 13.7 million in 2001 to 18.6 million in 2021 in the Norwegian waters of the Barents Sea alone (Jean-Hansen 2003, pp. 46-47). The increase in traffic may be even more dramatic when ship traffic in Russian areas of the BSEr, and the increase in international traffic connected to Russian oil export that will pass through Norwegian waters, are taken into account. The number of tankers transporting oil from Russian ports is expected to rise from 166 in 2002 to 250 in the current year, 2003. It

is assumed that by 2015, more than 650 tankers will be involved in export from Russia through the Barents sea, most of which will be larger tankers than at present (tankers larger than 100,000 dwt compared to 30,000 dwt and smaller) (DNV 2003a).

**Table 1:** Environmental Impacts of Shipping (Source: PAME 2000)

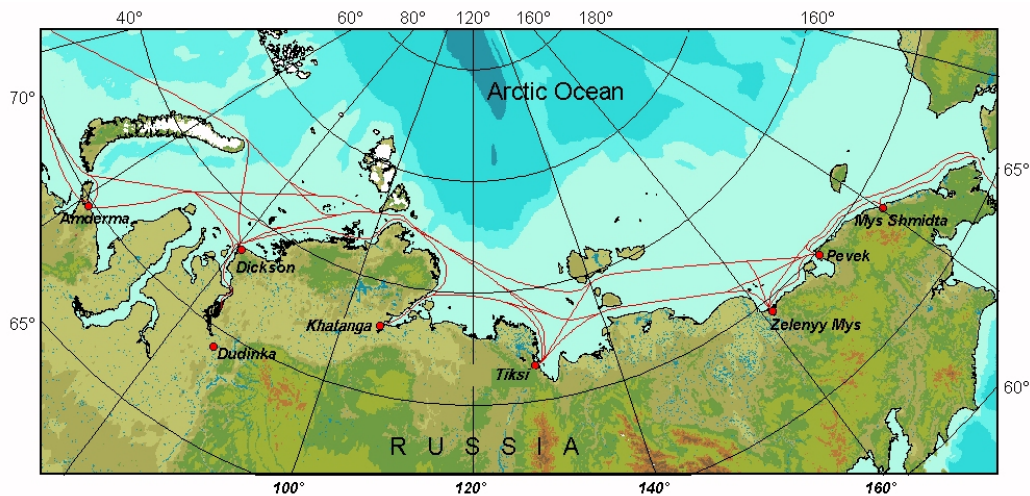
Activity/ Operation	Issues of concern
Onboard production of oily wastes, sewage and garbage.	Shortage of reception facilities. Illegal discharges to the sea. Onboard incineration. Oil reacts differently in cold water, including slow breakdown.
Discharge of ballast water of foreign origin.	Introduction of foreign species that may harm the region's biodiversity.
Release of TBT from anti-fouling paints.	TBT is a chemical that persists in the sea water and damages marine species.
Cruise/ passenger vessels	Disturbance of vulnerable ecosystems.
Loading and unloading activities.	Increased risk of discharges of oil and bilge water.
Tanker traffic	Transport of oil products with high potential impacts in accidents.
Heavy bunker oil as cargo and fuel.	Heavy bunker oil has very high impact if discharged.
Operation in areas of high ice concentration.	Increased risk of accidents hence increased risk of pollution.
Tugging / Towing	Increased risk of accidents.
Transport of radioactive material	Increased risk of accidental leakage and high risk of localized, long-range and long-term damage to region's biodiversity.

Shipping is one of the activities identified as a contributor to pollution in the Arctic (PAME 2000). Impacts and risks associated with transport activity are numerous and are influenced by factors such as geographic location, weather and hydrologic conditions. The damage costs associated with shipping are currently small in the BSEr, but are expected to grow as oil and gas transport increase (Jean-Hansen 2003). Table 1 outlines activities and operations that may negatively impact the ecosystem.

There is growing concern related to the recent increase in oil tanker traffic through the Barents Sea, particularly from Russia (Frantzen and Bambulyak 2003). Russia is already the largest user of water transport in the Arctic. One of the main transportation corridors in the region is the Northern Sea Route (NSR). This route carries the largest volume of traffic of any arctic seaway (PAME 2000). The NSR stretches from Novaya Zemlya to the Bering Strait and is marketed as being the transcontinental route between the Pacific and the Atlantic. A fleet of ice-strengthened freighters carries cargoes of several million tons annually to and from the ports of Murmansk and Vladivostok, aided by about 20 icebreakers. The NSR officially opened to international transit in 1991, but reports from the International Northern Sea Route Programme<sup>2</sup> indicate that the use of NSR for shipping on an annual basis has yet to be proven safe and stable. Another large shipping route is also being developed, called the Northern Maritime Corridor (NMC). The NMC aims to facilitate the transport of goods

<sup>2</sup> <http://www.fni.no/insrop/>. Last accessed 14. December 2003.

within the North Sea region to connect the North Sea basin with the Northern Periphery area (see Figures 6 and 7).



**Figure 6:** The Northern Sea Route. Source: INSROP home pages. <http://www.fni.no/insrop/nsrmap.jpg>. Last accessed 14. December 2003.

Much of the increase in Russian oil export is likely to affect the seasonally ice-covered areas of the Russian part of BSEr, as well as transport through the relatively ice-free Norwegian part of the Barents Sea. Until 2001, most of the oil and fuel exported from Russia through the Barents Sea was transported from oil fields on land to ports in the White Sea by train. Small tankers then transported the oil to European ports. The White Sea is shallow and this prevents transport by larger tankers. In addition, ice hampers exports during winter. In 2002-2003, oil transport increased dramatically as oil from small tankers from the White Sea was increasingly reloaded to larger tankers in Murmansk. Several export terminals were established in the White Sea and the Timan/Pechora area, and a pipeline from west Siberia to Murmansk was planned (Frantzen and Bambulyak 2003).

The oil that is exported from North-west Russia originates from the Timan/Pechora and Western Siberian Basins, the latter of which is the most important oil producing region in Russia. Oil exploration in the Timan-Pechora area and West Siberia may boost the annual production potential in this area of Russia to 110 million tons in less than 10-15 years. Production in some fields in the Pechora Sea is also expected to start in 2005-2006 (8 million tons/year). Because the capacity of pipelines to Europe and vessels from the Black Sea is limited, a large part of the increase in export is expected to take place through the Barents Sea (as well as the Baltic Sea and the Adriatic Sea). Through reloading to larger tankers in Murmansk, the export capacity in the Murmansk area alone may triple within 1-2 years. The port of Murmansk is increasing in its importance as a shipping terminal for oil and gas, transport of oil from Murmansk/Petsjenga by the Barents Sea likely to increase from 4.5 million tonnes to 22.0-35.0 metric tons in 2015 if current plans are realized (DNV 2003a). The extent to which investment and ownership should be private or through the governmental company Transneft has sparked some controversy in Russia. If the pipeline nevertheless goes ahead as planned, it may start operating in 2007 and may have a capacity of up to 100 million of oil per year (Frantzen and Bambulyak 2003). This will result in an increase in tanker traffic from Murmansk to western markets, through the BSEr. Although this type of transport remains only a small fraction of total shipping activities in the area, the potential for environmental damage is high (DNV 2003b).





**Figure 7:** Map showing the 20 regions in eight regions involved in The Northern Maritime Corridor. Source: Northern Maritime Corridor home pages. <http://www.northern.maritime.corridor.no/map.aspx>. Last accessed 14. December 2003.

The transport of oil and gas will increase even further if the Norwegian Barents Sea is opened for oil and gas activities. The total oil and gas reserves in the Norwegian part of the Barents Sea were estimated at more than 7 billion boe<sup>3</sup> of which 90% are yet to be discovered. Petroleum exploration the region has been ongoing for the last 20 years. However, it is only recently that companies have been allowed to establish operations in the BSEr. The Snøhvit field is located only 160 km from the coast of northern Norway and the major seabird colonies that exists there. A second field much closer to the coast, the Goliat oil field, is in the process of being developed and production is planned for 2004-2005. In the eastern part of the Barents Sea, 21 oil and gas fields are in the process of being opened up. This activity is likely to increase the number of transport voyages from less than 100 per year in 2005 to at least 450 per year in 2020 (DNV 2003b).

A specially commissioned report on the consequences of year-round petroleum activities for and by shipping traffic identified four types of accidents that are of greatest environmental significance: groundings, collision, structural errors, and fires/explosions (DNV 2003b). There is particular concern that an increase in ship traffic may result in an oil spill. A large oil spill could have dramatic implications for animals such as seals, polar bears and seabirds

<sup>3</sup> Barrels of oil equivalent (BOE). Gas volume that is expressed in terms of its energy equivalent in barrels of oil. 6,000 cubic feet

in the affected area. The oil can interrupt insulation causing death by freezing. Ingestion of the oil may not kill immediately but can have long-term toxicity. Fortunately, the BSEr has not experienced any major oil related accidents, but a minor spill in 1979 in the Varanger fjord in the eastern Barents Sea has been attributed with killing 10-20 thousand Brünnich's guillemots (Barret, 1979). To minimize potential accidents, a series of measures have been suggested and some have already been implemented, such as expanding Norway's territorial borders, which up until now is four nautical miles from the coastline (DNV 2003b). An expansion of territorial border to 12 nautical miles would force ships to travel a farther distance from land, and make it easier to control ships traveling along the coast (DNV 2003b). This would reduce the probability for grounding, which is the most frequent cause of large oil spills from ships.

Transport activity in the BSEr region impacts biodiversity in other ways as well. The action of icebreakers in the region can alter ice conditions in the ice pack. As the ships pass through the ice, a passage is created characterized by ice fragments of various sizes and concentration. The regeneration of the ice pack after transit depends on the time of year. Reconsolidation is quick during the winter and spring, but slow or nonexistent in the late spring and summer. Traffic may also affect the stability of ice edges, particularly during freeze-up and break-up. Edges may break or collapse earlier than normal, advancing the break up of fast ice in general. During freeze-up, traffic can delay the formation of new ice edges, preventing the development of a land fast ice cover. Therefore it is critical for icebreaker activity to be conducted carefully so as not to negatively impact species. For instance, ships should refrain from activity that is close to large concentrations of animals, such as ringed seal and walrus resting areas.

The noise from transport activity has also been found to affect certain species such as belugas, narwhals and walrus. One study found that belugas reacted to ship activity 85 km away and responded by moving 80 km further away (Finley and Green 1993). In contrast, narwhals appeared to "freeze" in response to noise and slowly disperse. In some cases narwhals have been noted to disperse along the ice edge in front of advancing ships. A study on walrus behavior in response to offshore drilling activity (Brueggeman 1993) found that walruses reacted greatest to icebreaker activity within half a kilometer and moved deeper into the pack ice.

Overall, transport activities in the BSEr are relatively low compared to other areas of European maritime areas. However, increased transport of oil and gas from Northwest Russia, combined with increased interest in petroleum reserves in the region, will contribute to greater maritime activity and an increase in the potential risks involved. Many operational or accidental spills that do occur in the region are not reported, implying that the potential scope of impacts may be underestimated. The largest impact and most long-term influence on the region's biodiversity may in fact be chronic low level exposure to contaminants, such as oily wastes from operational discharges (PAME 2000).

## **4 Climate Change Vulnerability in the Barents Sea Ecoregion**

There is strong evidence that the earth has been undergoing a warming that can be attributed to human causes. In the arctic region, evidence of warming has largely been linked to sea ice. Overall, sea ice extent decreased by approximately 3% per decade between 1978 and 1996 (Parkinson et al. 1999). Multi-year ice has been declining at a rate of 7% per decade during the last 20 years and a 15-20% decrease in summer extent of arctic sea ice has occurred over the last 30 years (Johannessen et al. 1999). IPCC has stated with very high confidence that 20<sup>th</sup> century warming over arctic land areas has increased on average by 5 degrees celcius and that there has been a slight warming over sea ice in the 1961-1990 period (Houghton et al. 2001). High interannual variability in sea ice thickness has been found to be influenced by

changes in the amount of summer melt, which is likely to increase with climate change (Laxon et al. 2003). The IPCC Third Assessment Report concludes that the Arctic is extremely vulnerable to projected climate change, and that major physical, ecological, sociological, and economic impacts are expected (Anisimov and Fitzharris 2001). As the result of a variety of positive feedback mechanisms, the Arctic is likely to respond rapidly and more severely than any other area on Earth, with consequent effects on sea ice, permafrost, and hydrology.

Climate change will have both direct and indirect effects on species and ecosystems. The presence of indirect effects in particular presents new conservation challenges and exacerbates current conservation problems (Harte et al. 1992). In most traditional analyses of the biotic consequences of climate change, the results from general circulation models (GCMs) are used to estimate future temperatures and precipitation levels based on different assumptions about future greenhouse gas emissions. The present-day distribution of species is then correlated with the same climate variables, and the ability of the species to persist in their present location is assessed given the climate change scenario. Adaptation options, including migration, are then assessed, along with conservation implications. One problem with this approach is that it “assumes that the factors governing the distribution of plants and animals are the direct climate variables whose values the GCMs predicts.” Furthermore, “it presumes that other anthropogenic stresses do not interact with the stress of climate warming” (Harte et al. 1992, p. 325).

#### **4.1 Model projections for the Barents Sea Ecoregion**

General circulation models can provide coarse projections of future climate change under different scenarios of greenhouse gas emissions. Although subject to large uncertainties, these models provide a glimpse of what may be expected in the future. As a basis for assessing the specific impacts on biodiversity, however, the GCM model results are imperfect because of their coarse spatial and temporal resolutions (Harte et al. 1992). For example, projected average monthly temperature or precipitation changes provide little information to ecologists working in specific habitats. Equally important, GCM scenarios currently do not provide adequate information about extreme events, which are often important in generating climate impacts. Nor do they provide information on the rate of climate change, which is critical to the potential adaptation of species and ecosystems to new climatic conditions.

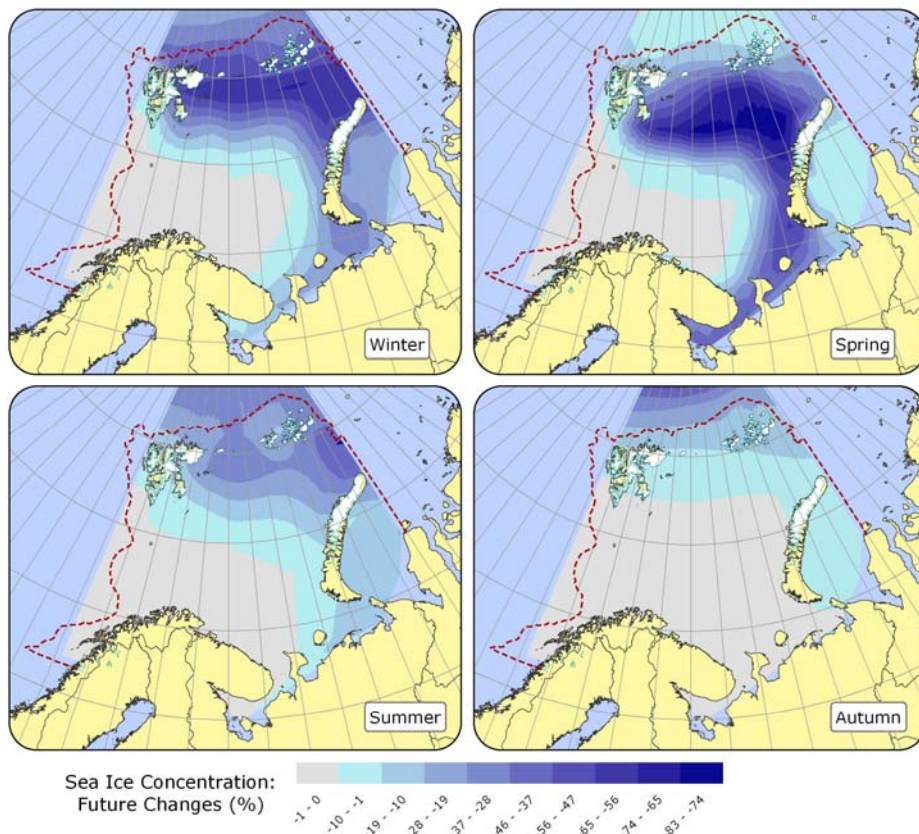
GCM results do, however, provide internally consistent projections of the large- or meso-scale circulation changes that can influence features such as sea ice, which in turn affects biodiversity. From this information, ecologists and biologists can consider the direct physiological consequences and interspecific connections related to climate change and its synergies with other stressors. Below, we present one scenario of climate change, based on a Norwegian model that specifically addresses sea ice changes.

The Bergen Coupled Model (BCM) is a fully coupled atmosphere-sea ice-ocean general circulation model. One of the main advantages of this model over others is its ability to adequately handle sea ice changes. The model has been run using for the IPCC intermediate B2 emissions scenario, which assumes “a world in which the emphasis is on local solutions to economic, social, and environmental sustainability” (Nakicenovic and Swart 2000). Our focus will be on the 2050 period which is based on average seasonal data for the period 2040-2059 and with an increase of 1% CO<sub>2</sub> per year starting from present-day climate state (A. Sorteberg, pers. comm.) The differences between the 2050 1%-CO<sub>2</sub> increase run and a control run (based on the same period but with constant CO<sub>2</sub> concentrations at approximately 1995 levels) has been calculated for four parameters:

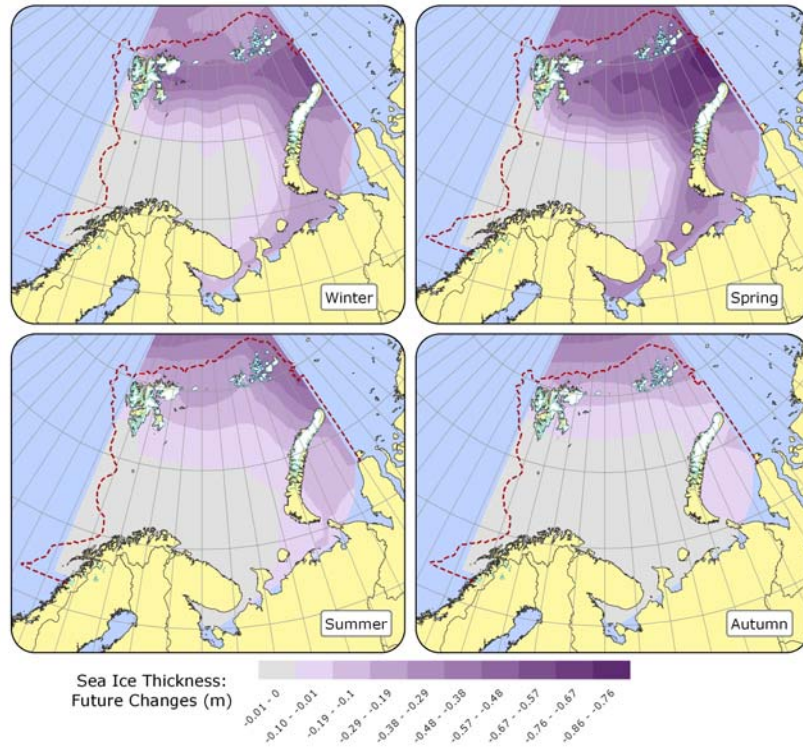
- Sea ice concentration (% coverage)
- Sea ice thickness (meters)

- Sea surface temperature (SST) (degrees Celcius)
- Sea surface salinity (SSS)

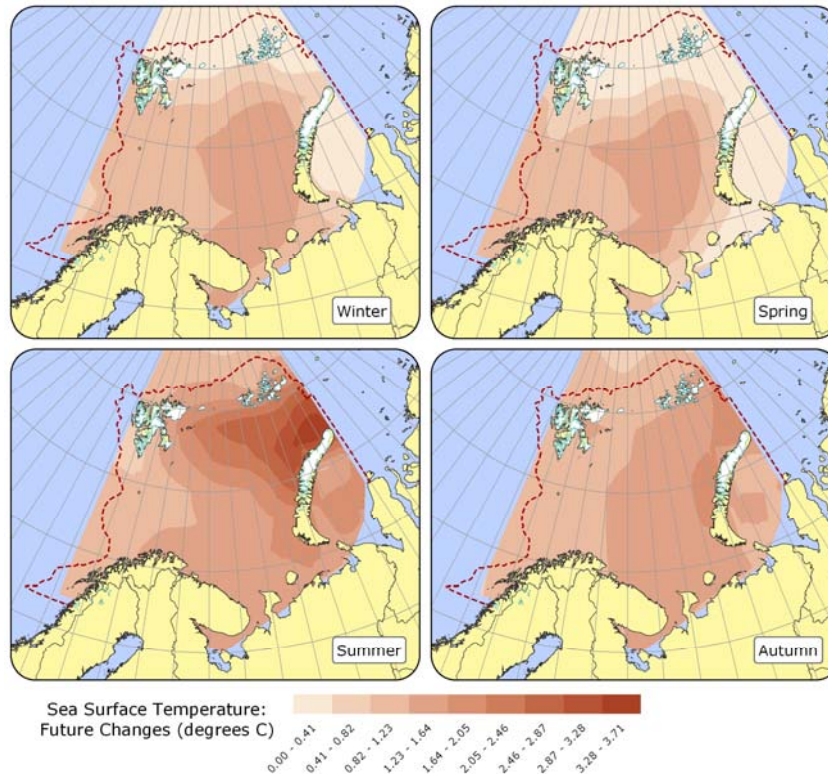
These four parameters have been chosen because they are critical indicators for climate change in the region and are known to influence the region's biodiversity. Deeper sea temperatures are also very important to productivity in the BSEr, but most climate models do not include detailed results for ocean layers. Climate data was only provided for the extent of the BSEr, as shown in Figures 8 through 11.



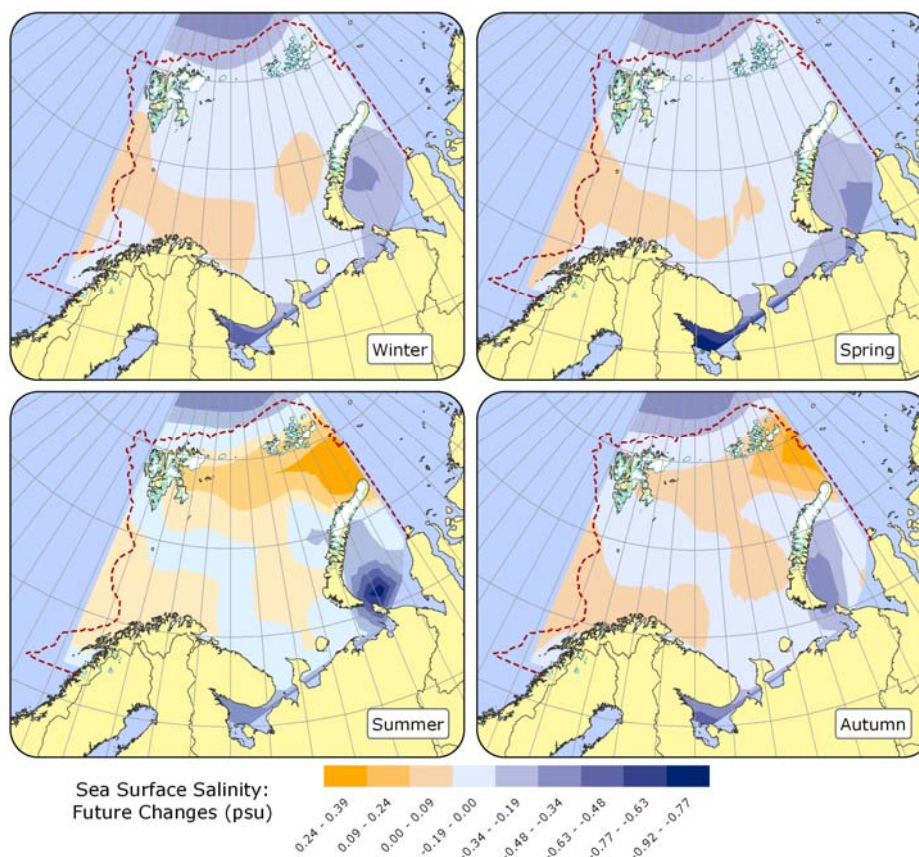
**Figure 8.** Changes in sea ice concentration from the BCM (for winter, spring, summer and autumn).



**Figure 9.** Changes in sea ice thickness from the BCM for winter, spring, summer and autumn (control run versus 2050).



**Figure 10.** Changes in temperature from BCM for winter, spring, summer and autumn (control run versus 2050).



**Figure 11.** Changes in sea surface salinity (2050) as projected by the Bergen Climate Model.

The BCM results indicate that there will be substantial changes in the region over the next 50 years (Furevik et al. 2002). Table 2 provides an overview of potential changes. One of the most significant changes is in sea ice concentration (or percent coverage of sea ice). While the southern portion of the BSEr may remain ice free year round, the model projects a significant decrease in sea ice concentration in the northern Barents Sea, where up to 83 % of normal ice cover may be lost by 2050. Decreases in ice concentration are the most pronounced in the winter and spring (Figure 8), which are key periods for this ecoregion. In addition to a decrease in sea ice cover, there will also be thinning of the ice, in some case over  $\frac{3}{4}$  of a meter. The decrease in sea ice thickness (Figure 9) is perhaps not as dramatic as the loss in sea ice concentration, but the two are linked. The pattern of losses between the two parameters is similar for each season; with greater and more extensive losses in the winter and spring.

Significant increases in sea surface temperature (SST) are also projected (Figure 10). The largest increase occurs in the summer, with a maximum increase of 3.71° C of the northern coast of Novaya Zemlya. In the winter and spring, the warming is strongest in the central part of the region extending westwards. In the summer and fall, however, the warming is strongest in the eastern part of the region. Projected changes in sea surface salinity are small, but there are indications that some areas will become more saline while others become fresher (Figure 11).

Extreme weather in the BSEr is a significant concern, with fog, strong winds and snowstorms having particularly significant effects. GCMs are currently unable to adequately project changes in extreme events. The mechanisms that drive extreme events are not fully

understood, resulting in non-uniform modelling results. Nevertheless, speculated changes in extreme events may have direct and indirect consequences for biodiversity through changes in population dynamics and through impacts on human activities.

Despite the high year-round relative humidity in the region, the occurrence of fog is small during winter. This is partly due to the low availability of condensation particles (INSROP, 1998). However one could assume that encroaching development along the coast of the region and an increase in maritime traffic could provide more condensation particles and increase fog occurrence and strength. In summer, fog is more common and can be brought on by only a small decrease in temperature. Coastal areas and islands in the western portion of the BSEr tend to experience the strongest fog in the summer when warm currents meet cold arctic air masses (INSROP, 1998).

In the case of snowstorms the period of occurrence is usually October through May along the coastal region, and slightly longer in the north. The mean annual number of days with snowstorms ranges from 100-120 (INSROP, 1998). Unfortunately, there are no concrete results that project changes in snowstorms in the region, but a general consensus holds that the magnitude and frequency of storms will increase with global warming. Strong winds are another important extreme event in the region but most models project no substantial changes. Wind is an important factor affecting ice conditions, since wind drift of ice prevails in the arctic seas. Winds can be classified as “pushing-off” and “pushing-to” winds, according to their influence on drift ice. Pushing-off winds favour better ice conditions (i.e., they weaken or remove pressure in ice) while pushing-to winds have the opposite effect.

## **4.2 Climate Change Impacts**

Climate change may have widespread impacts on the biodiversity of the BSEr. The response of the ecosystem to climate change depends greatly on the fate of the sea ice and changes in ocean temperatures and currents. However, many other aspects of the physical environment may also change, and the impacts are likely to be both complex and diverse.

One of the main concerns is how a warming may affect the productivity of the region. Both changes in sea ice and ocean temperatures are likely to influence productivity, through two potential scenarios: on the one hand, primary productivity may increase due to an increase in open water, better vertical mixing and increased light availability which would benefit phytoplankton. On the other hand, primary productivity may decrease due to the weakening of the polar front, the reduction of sea ice and the associated ice algae species that have an important role as well (Alexander 1992; Klungsøyr et al, 1995). It has been estimated that 30% of primary production in the Barents Sea comes from sub-ice algae (Hegseth, 1994). The spring bloom may be smaller under warmer conditions, and will follow the retreating ice-edge; the onset of the spring bloom may occur much farther north and be limited to a smaller zone compared to its present distribution.

Ice-associated species may be threatened by climate change. Some species may be forced to migrate northwards following the retreating ice-edge. The ice edge serves as the main feeding area for capelin, thus they are likely to follow it. Polar cod, which spawn and live along the ice edge, would also have to migrate, or adapt to new conditions. Capelin, arctic cod and herring constitute important trophic levels in the food chain, thus changes to these populations could have widespread effects. Seals, such as the ringed seal, which breed and raise their young on or near the ice edge, would experience a loss of habitat. Polar bears, which hunt seals from the ice edge would have to move further north in search of prey. The earlier spring ice break-up and later fall freeze-up could have drastic consequences for polar bears. They would be forced off the ice earlier in the spring or left to deal with an unstable ice edge, leading to a general reduction in body condition. Female bears may have to go longer distances in pursuit of food leaving cubs unattended and vulnerable (Stirling et al. 1999). Walrus and whales, which rely on sea ice of a relative thickness that they can break

through to create breathing holes, would benefit from a thinner ice sheet, but walrus would then encounter the problem of finding adequate sea ice to support their weight.

The retreat of sea ice will threaten the existence of polynyas. These areas of high productivity are known for attracting large numbers of sea birds and marine mammals. In the Barents Sea, well known polynyas occur in Storfjorden and Hinlopen on the eastern part of Svalbard and southwest of Frans Josefs Land. The importance of these polynyas for the biodiversity and productivity of the Barents Sea is not known. The loss of polynyas has traditionally been a result of the open water not appearing or closure by surrounding ice. With climate change, however, the loss would most likely be attributed to the lack of sea ice that helps to define polynyas. It is unknown how this disappearance of polynyas will affect the region's biodiversity.

Changes in ocean temperatures may affect species ranges and productivity. The relationship between ocean temperatures and productivity of phytoplankton, zooplankton and fish stocks is well established. In the Barents Sea, for example, increases in ocean temperature in some years have been shown to improve recruitment and increase the growth of capelin, cod and herring (Brander 1995, Planque and Fredou 1999, Ottersen and Loeng 2000, Ottersen and Stenseth 2001). Persisting higher ocean temperatures may, however, result in a poleward change of the range of many species (Nakken and Raknes, 1987; Ottersen et al. 1998). Cold water zooplankton and fish stocks could be forced further north and be replaced by more temperate species when temperatures increase. This displacement may have negative impacts on seabirds and marine mammals which are used to feeding on specific prey. Fish and seabirds may alter their range in an attempt to locate suitable prey or adapt to a different food source. This could result in recruitment failure. Generally, seabirds feed only 100 km from their breeding sites but this range may be extended. Zooplankton abundance has been shown to be a factor of sea surface temperature with colder waters increasing total biomass.

The IPCC TAR identifies some potential social benefits from climate change, including new opportunities for shipping across the Arctic Ocean, lower operational costs for the oil and gas industry, lower heating costs, and easier access for tourism (Anisimov and Fitzharris 2001). From an economic perspective, some of these changes may be viewed positively. However, from a biodiversity perspective, such changes may put increasing pressure on the BSEr.

It is important to emphasize that climate change will not occur in isolation; other stressors are likely to contribute to both cumulative and synergistic effect. More important, synergistically driven ecological changes "may not be linear and gradual in their eventual outcome but rather nonlinear and sudden in occurrence" (Myers 1992, p. 347). There is a need to improve upon current understanding of these potential outcomes. In the next section, we consider the impacts of climate change from a multistressor perspective, showing that the consequences of increased transport in the BSEr are likely to interact with climate change, posing even greater threats to biodiversity.



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**Table 2: Potential Climate Change from the Bergen Climate Model**

<b>Seasonal change (averaged over 2040-2059)</b>				
<b>Parameter</b>	<b>Winter</b>	<b>Spring</b>	<b>Summer</b>	<b>Autumn</b>
<b>Sea ice concentration (SIC)</b>	<p>General decrease in SIC.</p> <p>Interesting anvil pattern of SIC loss in the region.</p> <p>Strongest decrease in north and eastern BSEr (up to 83% loss).</p> <p>Negligible decrease in southwestern BSEr.</p>	<p>General decrease in SIC.</p> <p>Interesting anvil pattern of SIC loss in the region.</p> <p>Strongest decrease in north and eastern BSEr (up to 83% loss).</p> <p>Negligible decrease in southwestern BSEr.</p> <p>Low loss of ice in north and south eastern BSEr.</p>	<p>General decrease in SIC.</p> <p>Highest loss in sea ice located in north western BSEr off Novaya Zemlya (up to 46% loss).</p> <p>Negligible decrease in south western BSEr.</p>	<p>Decrease in SIC in east (up to 10% loss) and in the north (up to 28% loss).</p> <p>Negligible decrease in most of the BSEr.</p>
<b>Sea ice thickness</b>	<p>Largest decrease centered along the northeast border of the BSEr (up to half a meter decrease).</p> <p>Decrease extended along the eastern border to the south coast.</p>	<p>Largest decrease for all seasons (up to 0.84 m), concentrated along north-east border extending towards Svalbard as well as the south coast.</p>	<p>Less pronounced than in other seasons, mainly concentrated in the far north (up to 0.48 m) and along the eastern edge of the region (approx. 0.19-0.29 m decrease)</p>	<p>Less pronounced than in other seasons, mainly concentrated in the far north.</p> <p>Average decrease up to 0.10 m.</p>
<b>Sea surface temperature</b>	<p>Increase in SST throughout the BSEr.</p> <p>Largest warming (up to 1.64° C) in center of the region.</p>	<p>Increase in SST throughout the BSEr.</p> <p>Largest warming (up to 1.64° C) occurs in center of the region.</p>	<p>Largest warming of all the seasons (up to 3.71° C).</p> <p>Greatest warming located off north-western coast of Novaya Zemlya</p>	<p>Increase in SST throughout the BSEr.</p> <p>Greatest warming located in eastern portion of the region (up to 1.64° C).</p>
<b>Sea surface salinity</b>	<p>Increase in salinity up to 0.09 psu extending from the western edge of the BSEr and off the west coast of Novaya Zemlya.</p> <p>Elsewhere, general freshening that is strongest along the southern coast (decrease up to 0.63 psu), in the far north and off the east coast of Novaya Zemlya.</p>	<p>Increase in salinity up to 0.09 psu extending from the western edge of the BSEr and off the west coast of Novaya Zemlya.</p> <p>Elsewhere, general freshening that is the strongest along the southern coast (decrease up to 0.77 psu), in the far north and off the east coast of Novaya Zemlya.</p>	<p>Largest increases in salinity (up to 0.39 psu).</p> <p>Strongest increase centered between Franz Josef Land and Novaya Zemlya.</p> <p>Elsewhere, a center of freshening located in the Kara sea (decrease up to 0.77 psu) and along the southern coast.</p>	<p>Less pronounced increase in salinity than in summer.</p> <p>Large increase in salinity (up to 0.39 psu) Franz Josef Land and Novaya Zemlya.</p> <p>Less pronounced freshening located in the Kara sea (decrease up to 0.48 psu). Freshening along southern coast and in far north.</p>
<p><i>Winter</i> – December-January-February; <i>Spring</i>: March-April-May; <i>Summer</i>: June-July-August; <i>Autumn</i>: September-October-November</p>				

## **5 Multiple Stressors in the Barents Sea Ecoregion**

A combination of multiple stressors can redefine the vulnerability of biodiversity in the BSEr in new and unpredictable ways. As discussed in the introduction to this report, the intersection of two or more stressors is likely to compound the effects of each stressor alone. Below, we consider how direct and indirect effects of climate change and transport may interact in the BSEr. We then illustrate one method that can be used to assess these interactions in a more comprehensive and systematic manner.

There is little doubt that climate change will have direct effects on species and ecosystem functions. However, climate change will also indirectly influence other activities, such as fishing, tourism, oil and gas exploration, and transport, and it may condition the responses of species to these human activities. Many of the linkages between the two stressors are under-researched and hence somewhat speculative. Nevertheless, by integrating climate change into the transport vulnerability analysis for the BSEr, a new view of the region's vulnerability can be constructed that can be explored through further research on synergistic interactions. This new view can aid in creating a more comprehensive conservation policy for the region. Below, we consider some of the potential interactions that may have important implications for biodiversity in three distinct subregions of the BSEr; the polar front and ice edge; seasonally ice-covered areas; and the generally ice-free southern coastal zone.

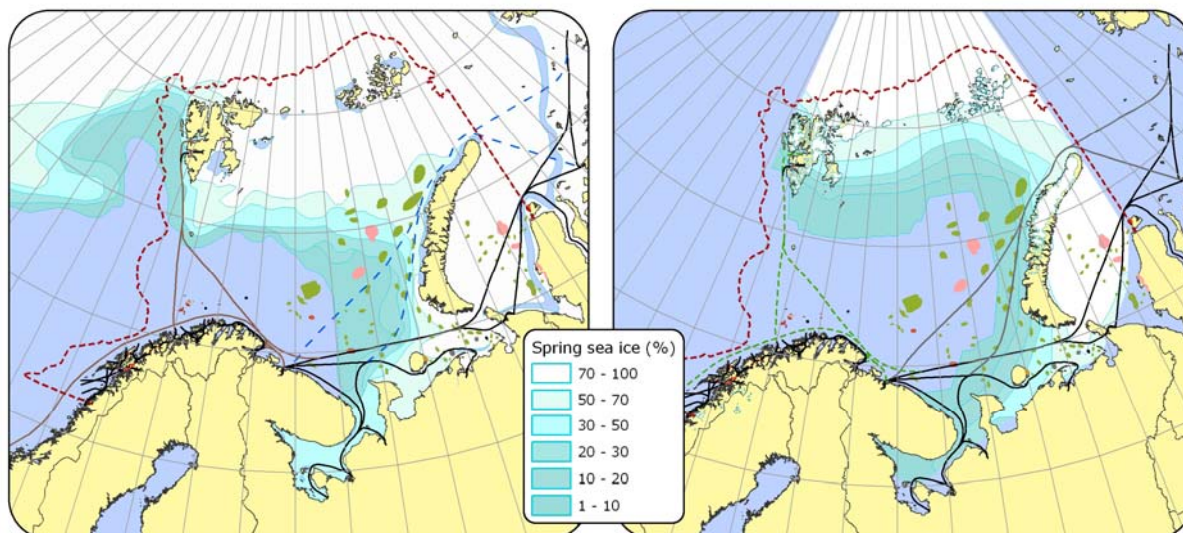
### **5.1 The Polar Front and Ice Edge**

In this area, transportation is expected to increase, due to the growth in tourism and passenger vessel traffic to Svalbard. Much of the transport related to oil export from Russia to Europe currently takes place in areas closer to the coast in areas south of the polar front and the ice edge and may therefore not affect the biological production related to the polar front and the ice edge to a great extent. Any increase in international transport towards the east (NSR), in particular any routes passing north of Novaya Zemlya, could affect areas of high productivity at the polar front, however.

Climate change is expected to lead to a retreat northwards of the ice edge, forcing species such as polar cod and capelin to migrate northwards or adapt to new conditions. Significant increases in sea surface temperature are also projected, possibly affecting species ranges and productivity. The eastern parts, in particular the northern coast of Novaya Zemlya, are likely to experience the largest warming in summer. While open water, better vertical mixing and increased light availability benefit phytoplankton and lead to increased primary productivity, weakening of the movement of the polar front and the reduction of sea ice and the associated ice algae species may lead to a decrease in primary productivity. The onset of the spring bloom may occur much farther north and be limited to a smaller zone compared to its present distribution. Seals and polar bears may experience a shift northwards or a loss of habitat altogether.

Polar cod may not only face a loss of habitat; reproduction success may also be affected if increased transport activity and climate change occur in the region. Polar cod occur in large schools of millions of fish and dominate the eastern portion of the BSEr (WWF In press). This species is an important source of food for other fish, seabirds and mammals. Figure 12 illustrates the changes in sea ice concentration and the impact it may have on polar cod larvae regions, and shows that marginal ice zones that polar cod prefer may be lost in the next 50 years. Polar cod spend most of their life-span along the sea ice edge, in particular, the larvae are known to concentrate off the coast of Novaya Zemlya and Svalbard. In the case of the Novaya Zemlya region, a reduction in sea ice is likely to occur in areas with high polar cod larvae concentrations as well as a high number of petroleum fields. There are prospect oil

fields from Novaya Zemlya westwards (see Figure 5) in areas where the eastern parts of the polar front is currently located (see Figure 2). In addition to climatic impacts, therefore, transportation and petroleum activities may also influence polar cod populations, even if the level of activity may be larger in other areas of the BSEr. It has been shown that chemicals produced from petroleum activity (oil industry), specifically produced water, are capable of disrupting hormonal processes in cod (Meier et al, 2002). Alkylphenols in produced water can reduce estrogen levels in female fish, delaying spawning. Male fish may experience lower testosterone levels resulting in a lower sperm count.



**Figure 12.** Current (a) and future (b) spring sea ice extent for the BSEr. Note the location of key species groups such as the ringed seal and polar cod.

## **5.2 Seasonally Ice-covered Areas**

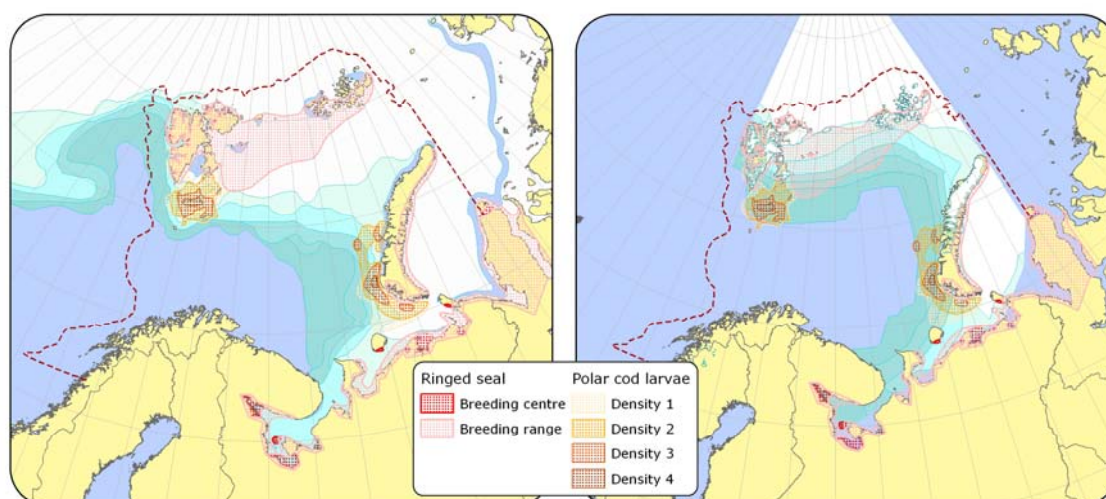
The southern areas of the BSEr, near the Russian coast, are seasonally ice-covered. The ice edge, described above, also moves seasonally. Some of the areas described here coincide with the discussion in the previous section, therefore. In the southernmost areas, transportation related to Russian oil exports is expected to increase dramatically. Both the size and number of tankers is increasing with shipments of oil exports from West Siberia and Timan-Pechora through ports along the coast, in particular in the White Sea and through Murmansk. Transport through ice-infested areas represents a risk of accidents and spills; in addition, the transfer of oil from small tankers to big tankers are a potential source of pollution. Such pollution may in particular affect birds and mammals that live in the coastal areas and on the ice.

Climate change is expected to lead to the southern areas being ice free for longer periods of the year. Decrease in ice extent and higher air temperatures are likely to alter the habitats of species dependent on the ice and the coastal areas, such as seals and birds. The effects of increased ocean temperatures on fish and primary productivity are not well established; however, these areas are possibly less valuable in this regard compared to areas connected to the ice edge and polar front further north. The northern areas of the BSEr, usually covered in ice year round, are likely to experience a retreat and thinning of ice, as described in the section above. Polynyas occurring in Storfjorden and Hinlopen on the eastern part of Svalbard and southwest of Frans Josefs Land are likely to be affected by decrease in sea ice extent, and any biodiversity connected to these polynyas affected.

The change in sea ice extent and thickness is one of the most obvious ways in which climate change will influence transport activity. Presently, sea ice extent is a limiting factor in transport activity in the BSEr, determining the seasonal extent of traffic in the southern areas as well as the northwards extent. A decrease in sea ice extent will have a marked influence on winter transportation and petroleum activities in this region by enabling increased transportation from the north, where ice cover has permitted little or no shipping activity in the winter. The Northern Sea Route, which was officially opened to commercial traffic in 1991, has not opened the region to large-scale traffic as many expected because of economical, logistical, and technical issues (PAME 2000). Also, ice-breakers have been used extensively during the winter along the coastline. It is expected that transport activities will increase during the winter throughout the region, especially along the coastline. Areas that were once thought of as too dangerous to navigate will now experience traffic. As well, heavier traffic throughout the region may take place due to the reduction in the use of icebreakers in now-ice free waters.

Ice-retreat due to climate change would also open up areas for petroleum exploration and extraction. Figure 13 depicts current spring sea ice cover versus future (2050) spring sea ice cover in the Barents Sea. It appears from this figure that many petroleum areas will eventually be located in ice-free waters in the spring, facilitating industrial activities. This situation is especially pertinent on the west coast of Novaya Zemlya where fields that were previously located in areas with greater than 50% sea ice cover are likely to have less than 30% cover in 2050.

Ringed seals are a critical species for the BSEr. The large population of ring seals and their role as one of the main consumers of polar cod means that the species constitutes a large biomass and serves as a top predator in the food chain. These mammals rely on the ice edge as a birthing, resting and hunting platform. Ringed seals are also the main food source for polar bears, directly affecting one of the region's key predators. Ringed seals are known to breed mainly along the coast and on sea ice (Figure 13). However, a reduction in sea ice extent will reduce the breeding range of the ringed seal in the north.



**Figure 13.** Current (a) and future (b) spring sea ice extent for the BSEr. Note the location of shipping routes and petroleum fields.

The northern BSEr is an important wintering site for many species due to the occurrence of a large polynya. Yet at the same time it has potentially valuable petroleum fields, and may increasingly be opened up to transportation if sea ice diminishes (Figure 12). Such activity may affect biodiversity, although the receding of the ice northwards may also remove polynyas and wintering sites from those opened up to and exploration and related transport. The intensification in maritime traffic and increased accessibility to petroleum fields associated with the reduction in sea ice extent could have both negative and positive effects on the biodiversity of the region. Although a reduction in sea ice may reduce the risk of accidents such as oil spills, a higher frequency of voyages will increase the risk. And although a warmer climate may make the clean up of oil pollution easier and more efficient, increased traffic may contribute to larger amounts of operational discharge. In the long run, this may have an overall negative impact on the region's biodiversity. The higher density of traffic may also have negative impacts on the welfare of some species, especially in areas that have seen little or no traffic previously. For example, the potential opening up of the region to heavier traffic and petroleum exploration could have significantly negative effects on the beluga population. The noise associated with such activity may force the whales to move their wintering locations further north in search of less noise disturbance and more ice cover.

### **5.3 Southern Coastal Areas**

In this area, transportation is expected to increase. In the westernmost areas, sea ice does not limit transportation; there is little ice cover in the Norwegian part of the Barents sea, for example. However, the increase in transport from Russia due to a combination of climate change induced expansion of transportation season and the growing oil export from Murmansk, White Sea and other coastal ports will lead to increased transport along the coast to European ports. There are increasing concerns about the effects that this increased transportation, and possible increased frequency of accidents and oil spills, may have on the biodiversity along the coast. In particular, bird species living in the coastal zone may be affected by oil spills.

Climate change is expected to alter the biodiversity and species composition, although little is known about the character of these changes. Mackerel is one species that has already expanded northwards along the Norwegian coast, for example (Blindheim et al. 2001). Mammal and bird species found in the coastal zone may be affected both by climate change and increased transportation; these interactions are not yet well understood, however.

An additional major concern for the BSEr that illustrates the influence of multiple stressors is the occurrence of introduced species. The release of foreign ballast water is a source of introduction of new species in a region. Sources of introduced species in other areas include aquaculture and species carried on the ship hull. Introduced species may displace or eliminate native species or disrupt species interactions (WWF In press). Climate change is likely to alter the conditions of the region, potentially making it more hospitable to foreign species. In addition, the heavier traffic increases the risk of introduction of species through the release of ballast water when a ship loads its cargo. The dramatic increase in the population size and distribution of the red king crab (*Paralithodes camtschaticus*), which was introduced to the Barents Sea from the Kamchatka Peninsula in the 1960s, has posed challenges for ecosystem management because, as with climate change, the long-term ecological impacts are unknown. This invasive species feeds on a wide range of prey, but because of the large quantities of food it consumes relative to its body size, serious depletions of some benthic species are possible. Furthermore it may be a competitor of bottom-feeding fishes (WWF 2002). Changing climate conditions combined with species introduced through increased transport activities increases the risk of similar situations occurring in the future.

As one can see from the few examples listed above, the Barents Sea is under the influence of many stressors, not all of which are listed here. However, it has been shown that the

stressor of climate change and transportation do not act independently of one another on the region's biodiversity. These stressors both influence the region separately as well as concurrently, creating a more nuanced picture of vulnerability in the region. Therefore, it is advisable that one considers more than one stressor in the region when determining its vulnerability and constructing a conservation management plan.

#### **5.4 Structural analysis of multiple stressors**

One way to assess cumulative effects of multiple stressors is through structural analyses and interaction matrices. In this section, we describe a preliminary attempt at applying structural analysis and constructing an interaction matrix for the BSEr. The testing of this approach yields information regarding the usefulness of the matrix in enhancing our understanding of multiple stressors in the BSEr as well as recommendations for how the method can be improved for use in the BSEr context.

Structural analysis pinpoints key elements in a system and highlights the relationships between these elements, offering a way to see through the complexity of the impacts of climate change (Martin and Lefebvre 1993). The most relevant variables are identified, and the role of each is analyzed in terms of driving power, which is a measure of its ability to influence the whole system, and its dependency, a measure of its ability to be influenced by other variables (Martin and Lefebvre 1993). Similarly, interaction matrices tabulate the relationship between two quantities to identify the potentially strongest cause-effect relationships. Such matrices are often used to identify the likelihood of whether an action may affect a certain environmental component, or to present the ranking of various effects on different ecosystem components (Environment Canada 2003).

The matrix in Table 3 illustrates how the structural analysis method described above can be adapted to investigate the effects of multiple stressors affecting the BESr. The matrix serves as a useful illustration of dependencies and vulnerability rather than an absolute and precise description of relationships between factors. Relationships were identified using examples based on literature reviewed in earlier sections of this report. The matrix was then filled in through a preliminary group discussion exercise by the authors. A more comprehensive and detailed structural analysis could be carried out through a workshop with key experts in the fields of climate change, transportation, and the biology and ecology of the BSEr. Such a workshop could, for example, be carried forward building on the method of the Adaptive Environmental Assessment and Management for Svalbard.

Elements were selected on the basis of our discussion of how interactions between climate change and transport affect the BSEr. Climate change and transport activities are the two main driving forces investigated in the matrix. Other factors that are determined by these two forces, such as the extent of sea ice and sea surface temperature, receive a score in their column cells (dependency). These factors in turn drive other factors, such as reproduction and habitat and thus receive a driving power score. Scores are only registered for the most proximate determining factor in a causal chain. In the matrix, habitat is therefore described as dependent on sea ice extent, rather than climate change directly. Some of the relations may nevertheless operate through two steps. For example, storms may bring up new nutrients to the surface, thus affecting population. The row sums in the right hand column indicate the driving power of the force or factor, while the bottom row sums shows the dependency of the various elements. Relevant variables are combined into factors; for example, ecological processes include trophic level and biogeochemical cycles for the purpose of this analysis. Species composition includes the aspect of spread of invasive species.

Sea ice extent was the factor that emerged with the highest driving power (12), with ocean currents and temperature receiving the second highest score (9). The score does not distinguish between important and less important influences, however. Sea ice extent affects a high number of factors; but it only affects population in restricted areas (area where sea ice

extent changes, not in the open water or permanent ice areas). Ocean currents and temperature is more fundamental to the system, affecting populations in larger areas. The range in driving power could possibly be addressed in the matrix by weighting the strength of relationship using a range of values (for example 0, 0.1, 0.2 .... 0.9, 1.0) rather than the current dichotomous valuing (0 or 1). Additionally, an improved analysis could consider the feasibility of including positive and negative values to reflect whether a factor would affect another, such as population size, negatively or positively. Environmental disasters is the factor with the highest driving power among the transportation factors, possibly affecting all the listed biological/ecological factors, as well as operational discharge/pollution and noise and disturbance related to clean-up exercises.

The matrix illustrates synergies in driving forces. For example, climate change related factors affect biodiversity directly; in addition, climate change affects biodiversity indirectly by potentially enhancing future levels of transportation activity. In addition, climate change makes the threat posed by transport much bigger. Climate change makes conditions favourable for alien species; an increase in transportation activities may facilitate their introduction through, for example, releases of ballast water containing alien species, the end result being altered species composition. Such synergies are reflected in the high column sum (dependency). The shaded areas of the matrix reflect the outcome for biodiversity. The combination of climate change and transport will have widespread biological effects, in particular on population size, species composition and ecological processes. It should be noted that transportation activity is determined in large part by factors other than climate change, such as developments in the oil sector in Russia. Further research is needed on many of these relationships, and in particular the interactions illustrated in the matrix.

The matrix demonstrates how the various factors that affect biodiversity in the BESr are interdependent. The elements that have a high dependency sum are likely to be more vulnerable to multiple stressors; however, it is equally, if not more, important to consider the character of stressors affecting an element, such as ecosystem functioning, than the actual dependency sum. Nor should the matrix be considered a final representation of dependencies. The exercise of attributing and assessing dependencies, and the way interactions are affected, may be one of the most useful aspects of this method.

The matrix is two dimensional and only a limited number of elements can be included. A matrix of this kind may not easily handle complexities of long causal chains. Effects on biodiversity are inferred from the elements listed that affect it, such as habitat, population size, species composition and ecological processes. For more sophisticated analysis, a matrix could include refined indicators of biodiversity, such as particular species of interest, or the different elements of population size (births, deaths, net immigration). Elements in the matrix may be affected both in terms of exposure, sensitivity and adaptability, the three aspects of vulnerability. Reduction in ecosystem functioning, for example, may reduce the adaptive capacity of species population to migrate in response to climate change induced altered habitats. The matrix is better able to demonstrate sources of exposure or stress than changes in sensitivity and adaptability, however.

## **6 Conclusions: Implications for Conservation and Management**

This report has pointed out the importance of assessing vulnerability to multiple stressors in the BSEr, including the potential impacts of climate change, which may have widespread consequences for biodiversity. Although there is great uncertainty about the specific future impacts of climate change, there is nevertheless sufficient knowledge and understanding to justify concern for the future integrity of the BSEr. Specific responses and adaptation measures are difficult to identify, but a few courses of action appear to be prudent. Two

approaches that have been recommended as strategies for increasing the resilience of species and ecosystems include habitat protection and the reduction of non-climate stressors (Rosentrater and Ogden 2003). In the case of the BSEr, habitat protection might be best achieved through the granting of status as a Particularly Sensitive Sea Area (PSSA) (DNV 2003a). The protection of keystone species such as cod, capelin, and herring would also strengthen resilience, as the status of their populations is critical to the entire trophic system.

In terms of reducing non-climate stressors, a number of measures can be taken to accommodate increasing transport of oil and gas resources through the BSEr. A series of measures have been identified (DNV 2003b), including increases in quality standards of ships operating in the BSEr, Stringent enforcement of discharge regulations, reduced access to vulnerable locations, surveillance and monitoring of shipping activities, including wider spacing of ships, and an extension of the jurisdictional boundary for Norway to 12 nautical miles (DNV 2003b, Rosentrater and Ogden 2003).

Holling et al. (1998) call for a rethinking of resource management science in a world of uncertainty and surprise, and they promote a systems approach and adaptive management. As pointed out by Rosentrater and Ogden (2003), there is an immediate need for resource managers to begin testing the viability and effectiveness of resilience-increasing management actions. There is also a great need for further research on the cumulative and synergistic impacts of multiple stressors. In particular, the potential synergistic effects between climate change and other stressors have been under-researched. Indeed, writing about synergisms and climate change more than a decade ago, Myers (1992, p. 346) argued for the need “[to] stimulate thinking in an emerging subject area that is critical to conservation biology.” Clearly much research remains to be done in this field. This study illustrates that biodiversity pressures may be created simultaneously by climate change and increasing transport activities, and that interaction between multiple stressors may be synergistic as well as cumulative. There is therefore a need to consider climate change not as merely another stress added to other stresses in BSEr, but as a stressor that interacts with other stressor in the region.



**Table 3. Structural analysis exemplified: Interaction matrix for the BSE**

		Climate Change						Transportation activity (incl. transfer and production)				Biological and ecological factors				<i>Row sum (driving power)</i>
		Sea ice extent	Salinity	Ocean currents and temperature	Storms/blizzards	Coastal fog	Air temperatures	Operational discharge/pollution	Environmental disaster/oil spills	Noise and disturbance	Ballast water release	Habitat	Population size	Species composition	Ecological processes	
<b>Climate Change</b>	Sea ice extent		1	1		1	1	1	1	1	1	1	1	1	1	12
	Salinity			1								1	1	1	4	
	Ocean currents and temp.	1	1			1	1		1		1	1	1	1	9	
	Storms/blizzards							1	1			1			3	
	Coastal fog								1						1	
	Air temperatures	1	1	1		1						1	1	1	7	
<b>Transportation activity *</b>	Operational discharge/pollution										1	1	1	1	4	
	Env. disaster/oil spills							1		1		1	1	1	6	
	Noise and disturbance										1	1	(1)		2	
	Ballast water release												1	1	2	
<b>Biological and ecological</b>	Habitat											1	1	1	3	
	Population size												1	1	2	
	Species composition											1		1	2	
	Ecological processes											1	1		2	
	<i>Column sum (dependency)</i>	2	3	0	3	3	2	3	4	2	1	5	11	10	10	

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