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Dag Vongraven (ed.)

# Assessing vulnerability of flora and fauna in polar areas

Symposium proceedings

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# Assessing vulnerability of flora and fauna in polar areas

## Symposium proceedings

The Norwegian Polar Institute is Norway's central governmental institution for management-related research, mapping and environmental monitoring in the Arctic and the Antarctic. The Institute advises Norwegian authorities on matters concerning polar environmental management and is the official environmental management body for Norway's Antarctic territorial claims.
The Institute is a Directorate within the Ministry of Climate and Environment.

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## Preface

This report constitutes a compilation of proceedings, extended abstracts and abstracts from a symposium held at the Fram Centre in Tromsø, 3-4 November 2014. The symposium was attended by almost 60 experts from 22 different institutions and organizations in eight countries, lending their ears and eyes to 17 presentations on vulnerability of flora and fauna in polar areas. The Norwegian Polar Institute hosted the symposium as a part of the institute's long-term effort to increase its insights into and oversight over a wide theme that is of substantial importance in decision-making processes for management purposes in the polar regions. The Institute wishes to thank all contributors, and we hope that readers will get inspired by the content of these proceedings. We have included some poems for extra inspiration.

Tromsø, July 2015
Dag Vongraven

*Round and round.*
*Planet Earth is steadily rotating around its central axis.*
*24 hours a day.*

*Round and round.*
*For every 365th time Earth's rotating around itself, a journey around the sun is completed.*
*365 solar days.*

*Round and round.*
*24 hours a day.*
*365 solar days.*
*Where 23.5 degrees makes a world of difference.*

*23.5 degrees.*
*That makes all the difference at the top – and bottom – of the world.*
*23.5 degrees.*
*Setting the solar angle.*
*Tuning light and darkness.*
*Defining life.*

*And nowhere is the solar angle as defining as at the Earth's poles.*

*Spring. Summer. Fall. Winter.*
*All defined by the solar angel.*
*At the poles – a question of total darkness or everlasting light.*

*Kriss Rokkan Iversen, SALT*

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## Introduction

Dag Vongraven

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Polar environments are increasingly being impacted by human activities. As human activity increases in polar areas, the need for knowledge about how the environment responds to exposure to new and disturbing stimuli is increasing. Polar areas are among the last frontiers on the planet, representing economic potential in the form of hidden resources, e.g. minerals and petroleum, and as areas where people can venture into pristine environments.

So, how vulnerable are these environments, as a whole, and how vulnerable are the different parts of it? What is vulnerability, anyway? What data do you need to realistically assess the vulnerability of polar species and environments? And, what methods are available?

Vulnerability is a complex term, with many nuances and definitions. A generic definition has to do with how probable it is that an environmental component will change in a negative direction as a result of an impact, or more specifically, as defined by Kværner et al. 2006: “the degree of sensitivity to environmental change by external impacts”. How vulnerable a species is will also depend on how we understand the consequences of human impact on it. The table below illustrates the complexity of assessing impacts of disturbance:

| Vulnerability to disturbance depends on: | What is the source of disturbance? | Characteristics of the disturbing factor: |
|---|---|---|
| - Species | - One foot | - Loud |
| - Reproductive state | - Many feet | - Quiet |
| - Time of year | - Kayak | - Silent |
| - Macro factors | - Rowboat | - Duration |
| - Micro factors | - Zodiak | - Constant |
| - Weather | - Snow mobile | - Predictable |
| - Age | - Research vessel | - Variable/Pulasting |
| - Topography | - Coastal Express ship | - Sudden |
| - One or many | - Knowledge level | - Velocity/Speed |
| - Habituation | | |
| - Distance | | |

Does the displacement of a polar bear from its feeding site affect only this individual once or is this happening regularly across a larger area in a manner that has the potential to harm the entire population? At what distance or scale does a disturbing factor become detrimental to the environment or the species, and how resilient is the environment or species? A term intimately linked with vulnerability, resilience is defined as the ability of an environmental component to return to a “normal” state after a change, or its ability to resist change.

It follows that vulnerability is inherently difficult to assess. Both qualitative and quantitative assessments need a precise definition of a concept that is extremely multivalent, and, equally important, precise formulations of the problem at hand. In addition, quantitative assessments require data of various types, critical to the understanding of vulnerability for specific species and systems and also for understanding the consequence of human impact. This is often equivalent to long-term data of various kinds, data that are in demand most places.

Collecting data in polar areas is often logistically challenging and highly resource-demanding. Methods specifically tailored for vulnerability assessments aren't numerous. It is also critical that the chosen method matches the available data, in terms of resolution and in other ways. With a less than optimal data set, low-resolution analyses are usually better than high-resolution.

With the primary objective to help identify methods aimed at assessing vulnerability of flora and fauna in polar areas, and the data requirements of these methods, we invited a group of experts that in concert could offer an overview of appropriate methods and the required data.

The apparent width of the topics presented mirrors the multiplicity of the vulnerability concept from long-term ship-based monitoring of nesting birds in Antarctica to the response of migrating caribou in Canada to climate change – from vulnerability to oil spills in Russia, assessed through mapping of marine areas, to how benthic communities respond to trawling in the Barents Sea. The diverse themes dip the audience into the ocean of a research field that occupies more and more experts and that will grow in importance with increasing human activity, and the need to document and make decisions regarding its consequences.

*Polar resources.*
*From marine microalgae to vascular plants on land.*
*From tiny crustaceans to top predators.*
*From landscapes to seascapes – and everything in between.*

*Polar resources.*
*From individuals, species and populations.*
*To interconnected species, ecological communities and ecosystems.*
*And humans and social-economic systems.*

*Polar resources.*
*Some resistant and tolerant to pressure.*
*Some having the ability to adapt to change*
*– through resilience, adaptive capacity or plasticity.*
*Others lacking both tolerance and adaptability.*

*The sensitivity of polar resources.*
*Found in the intersections between these traits.*
*Subject of different polar pressures.*
*Depending on properties of both resources and pressures.*

*Polar pressures.*
*The factors influencing a given resource.*
*Defined by scaling of the influences, in time, space and intensity.*
*One-by-one and entangled.*

*Polar pressures.*
*From acute to accumulating.*
*From single to combined.*
*From local to global scales.*
*And back.*

*Polar pressures.*
*From footprints of a walking man to busy shipping routes.*
*From the hunt of one reindeer to commercial fisheries on pelagic fish species.*
*From sewage from a single hut*
*to persistent organic pollutants travelling with air and water.*

*Polar resources and polar pressures.*
*Sensitivity and exposure.*
*The meeting point defining vulnerability.*
*And identifying the tools for polar management.*

*Kriss Rokkan Iversen, SALT*

# Vulnerability assessments in Svalbard – "simplistic" methods to aid development of management plans for protected areas

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The Norwegian Polar Institute is a directorate under the Ministry of Climate and Environment, and one of the institute's main tasks is to act as an advisory body for management where polar environmental issues are concerned. Part of our mandate is to coordinate and provide the knowledge needed to manage the Norwegian Arctic and Antarctic environment in a sound and knowledge-based manner. This implies doing research, and conducting and coordinating monitoring that keeps track of the status and trends of the environment, how pressure from activities impact environmental values, and how these activities can be regulated.

Of the total land area in Svalbard, 65% is protected as nature reserves or national parks. There are seven national parks, all on the main island of Spitsbergen. Of these are three significantly larger than the others.

The Governor of Svalbard makes management plans for these areas, plans which are based on a wide knowledge base.

## *Data*

Data that are regularly sampled in Svalbard include seabird colonies (mainly cliff-breeding) for population monitoring, walrus haul-out sites for monitoring of population size and harbour seal haul-out sites. In some areas, data are collected on Arctic fox denning and Svalbard reindeer abundance. There is also a research database on polar bears, including four decades of satellite track data, and various other research data series. Data quality varies from sporadic registration campaigns linked to specific and finite research projects, through "near-monitoring" data series collected opportunistically, but on a regular basis, to the real protocol-based monitoring that takes place e.g. in seabird key sites.

These data have been used for vulnerability assessments in various contexts. Here we will briefly explain two examples, one in which we were tasked with delivering the knowledge base for management plans, in 2011 for the large nature reserves in eastern Svalbard, then in 2013 for the large national parks in western Svalbard. The second example is how we have assessments of the vulnerability to oil pollution for the resources we have data for, and how these have been presented in a tool to be used by decision-makers in the first hours after an accident to decide on how and where to prioritize clean-up efforts.

## *Vulnerability assessments for management plans*

A vital part of the task to present a knowledge base for the development of management plans for large areas has been to identify which areas and which species are more vulnerable to various forms of human traffic than others.

The larger dataset— occurrence of cliff-breeding birds in the breeding colonies—was chosen to identify larger areas of elevated vulnerability to human traffic. The various species were classified into categories of high, medium and low vulnerability (see Table 1). Breeding occurrence of the most vulnerable species was then aggregated on a 10x10 km grid (see Figure 1).

Table 1 Expert assessment of seabird species and their vulnerability to human disturbance from various sources (from Vongraven 2014).

| | Vulnerability for disturbance from | | |
|---|---|---|---|
| SPECIES | Air | Sea | Land |
| Little auk | 0 | 0 | 1 |
| Fulmar | 2 | 0 | 0 |
| Barnacle goose | 2 | 1 | 2 |
| Ivory gull | 1 | 0 | 0 |
| Pink-footed goose | 2 | 1 | 2 |
| Kittiwake | 2 | 0 | 1 |
| Common guillemot | 2 | 1 | 1 |
| Puffin | 0 | 0 | 0 |
| Brünnichs guillemot | 2 | 1 | 1 |
| Glaucous gull | 1 | 1 | 2 |
| King eider | 1 | 2 | 2 |
| Brent goose | 2 | 1 | 2 |
| Arctic tern | 2 | 0 | 2 |
| Sabine's gull | 2 | 0 | 2 |
| Great skua | 1 | 0 | 2 |
| Great black-backed gull | 1 | 0 | 2 |
| Black guillemot | 0 | 0 | 0 |
| Common eider | 2 | 2 | 2 |

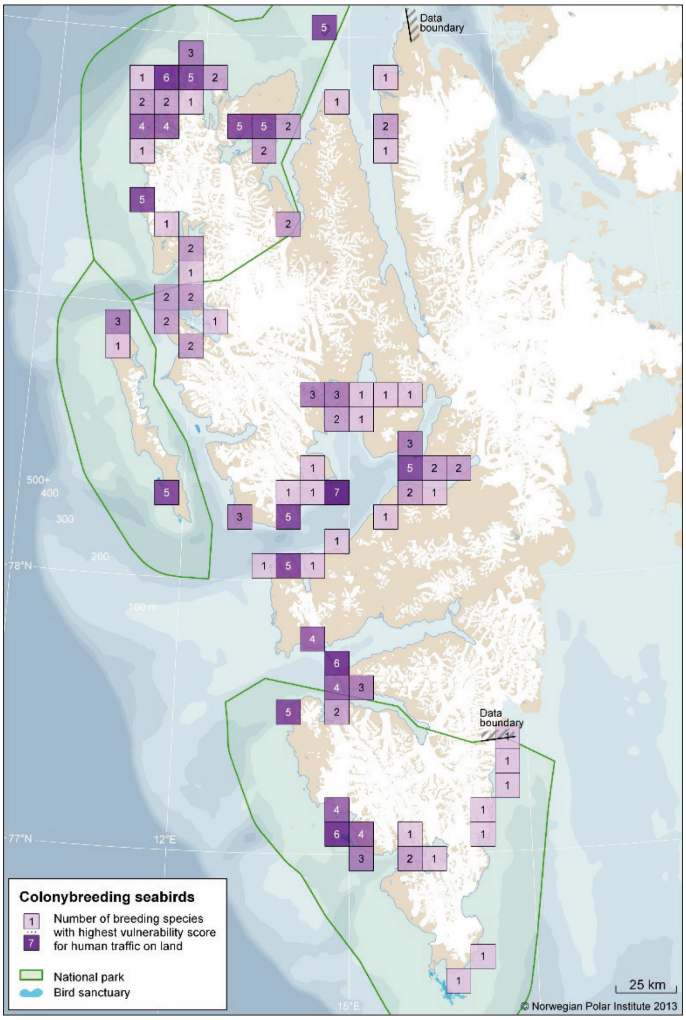


Figure 1 Aggregated number of colony-breeding seabird species with a high vulnerability to human traffic on land in western Spitsbergen (from Vongraven 2014).

We have chosen to categorize these analyses as simplistic, as there are many factors that weaken the analyses and that make it absolutely necessary to use this analyses with caution.

First of all, the data are up to a decade old. Secondly, assessments made based on data on seabird breeding are valid only in the breeding season. In Spitsbergen, data on wildlife for seasons outside spring and summer are extremely scarce.

But, the resolution of the data balances well with the simplicity of the method and the general strength of the conclusions. It is possible, based on this type of analysis, to delineate a larger area that is showing a larger occurrence and density of breeding vulnerable species. However, to investigate further, on a finer scale, one needs additional methods and additional data.

### *A tool to visualize areas and species highly vulnerable to oil pollution*

Management of the polar environment of Svalbard is challenging, and the increase in ship traffic around the archipelago emphasizes the need for updated oil spill contingency plans and an alert and responsive emergency preparedness. The need for updated tools that can aid the scaling of emergency and clean-up efforts once the accident is a reality paved the way for PRIMOS. PRIMOS is a GIS-based tool that maps the most vulnerable species and locations based on simple assessments of environmental elements and their vulnerability to acute oil fouling.

Vulnerability to oil was assessed using a three-step scale; high, medium and low vulnerability.

Seabird colonies were assessed based on an aggregated score of all species within the same colony, a score that was based on a combination of threatened status (Red List Category), species-specific vulnerability to oil, colony size and the amount of legal protection. Of the 680 colonies that were assessed, the 65 colonies with the highest scores were assigned to the highest vulnerability category, and the next 100 colonies to the medium category (see figure 2).

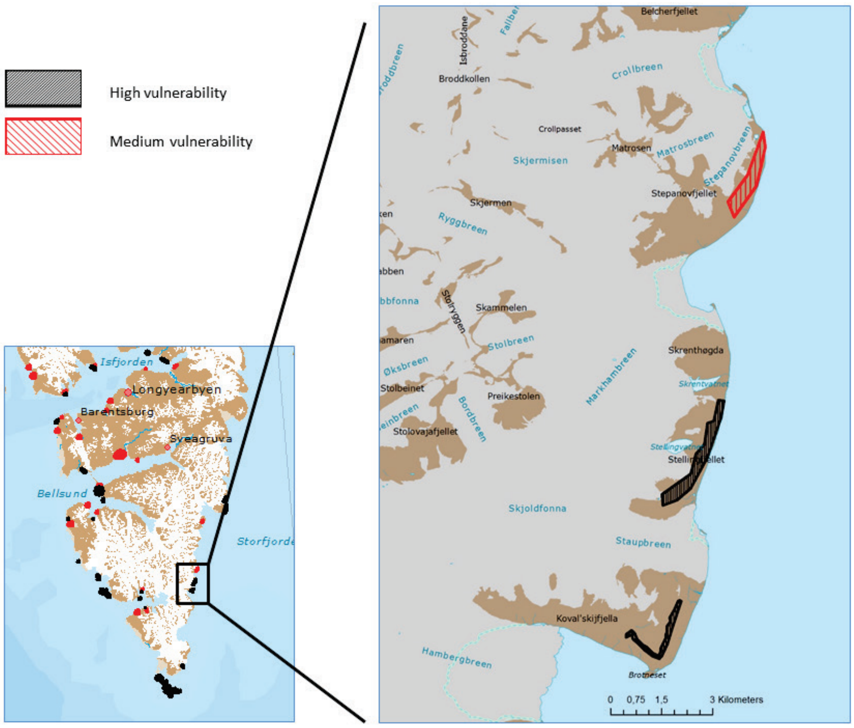


Figure 2 Seabird colonies vulnerable to acute oil pollution in the southern parts of Spitsbergen.

Other environmental components were assessed in a more qualitative manner:

- Walrus haul-out sites
- Harbour seal haul-out sites
- Anadromous Arctic charr river outlets
- Cultural heritage sites
- Coastal substrate types
- Marine benthic values
- Glacier fronts (not assessed, but mapped, as keeping oil away from ice is a priority)

The quality of the vulnerability assessments that are integrated into this tool is constantly under review. The main aim of the tool is to aid decision-makers in the first minutes and hours of an operation in deciding where to put available limited emergency response resources in play, presenting an immediate image of where the most vulnerable species and locations are.

The tool can be accessed at http://svalbardkartet.npoolar.no. Choose the operative layers "Miljo", and then "PRIMOS" (Figure 3).

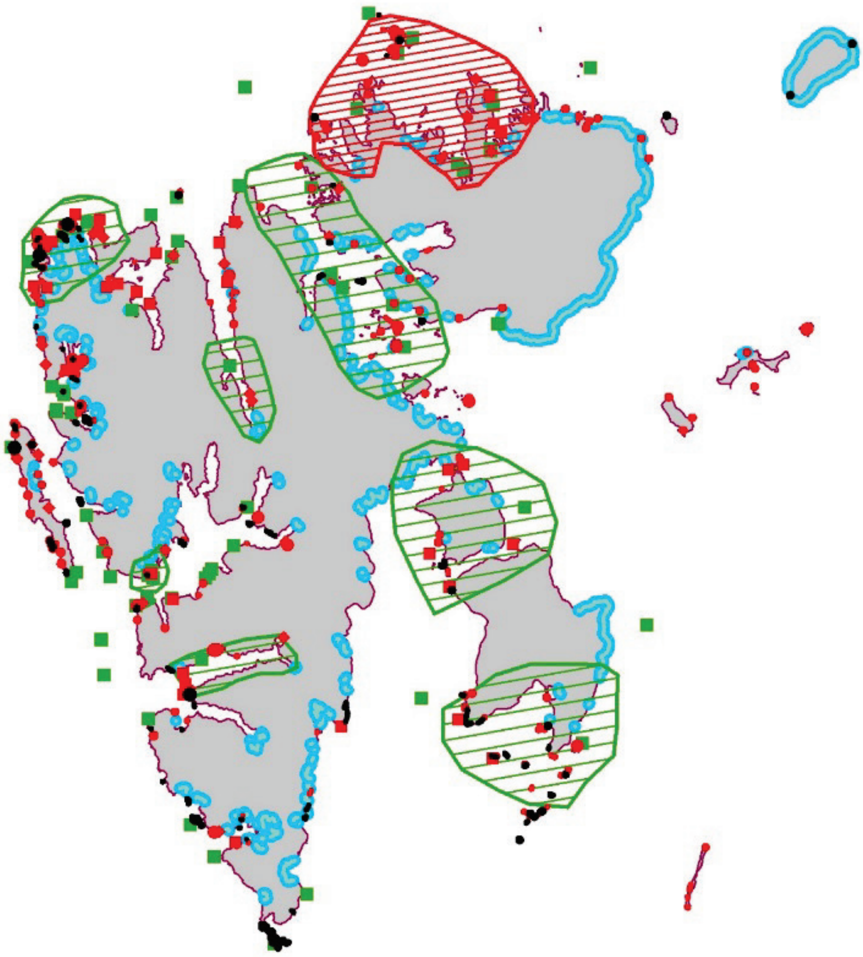

Figure 3 The PRIMOS map of the Svalbard archipelago, except Bjørnøya. Black points and polygons are High priority, green points and polygons are Medium priority, and red points and polygons are Low priority. Glacier fronts are blue.

# Appropriately managing remote places in Antarctica

Neil Gilbert

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## *Introduction*

The Antarctic Treaty, agreed in 1959, had the primary purpose of addressing disputes over territorial sovereignty in the region. As such the Treaty itself is silent on matters related to environmental management and resource use. To address matters not covered by the Treaty, the Antarctic Treaty Parties have, over time, negotiated a series of additional international agreements that together make up the Antarctic Treaty System. The most recent of these agreements is the 1991 Protocol on Environmental Protection to the Antarctic Treaty (the Protocol). The Protocol designates Antarctica as a natural reserve devoted to peace and science and sets out key principles and obligations on Parties to minimize impacts on the Antarctic environment.

The Protocol provides that all activities in the Antarctic Treaty area shall be planned and conducted so as to limit adverse impacts on the Antarctic environment and to avoid detrimental changes in the distribution, abundance or productivity of species or populations of species of fauna and flora, and to avoid further jeopardy to endangered or threatened species (Article 3).

The Protocol also requires activities in the Antarctic Treaty area to be planned and conducted on the basis of information sufficient to allow prior assessments of and informed judgments about their possible impacts on the Antarctic environment (Article 3(2)(c)).

These obligations set a high standard for the conduct of activities in the Antarctic Treaty area and require all activities to make use of the best available information on the environments in which they are to be conducted.

## *Ice-free Antarctica*

Almost all of Antarctica is permanently covered in ice and snow. Just 0.34% of the continent is ice-free (approximately 46,000 km$^2$ (Shaw *et al* 2014)). Most of these ice free areas exist at low altitudes near the coast, especially along the Peninsula. Ice free areas are also present away from the coast as nunataks and in some dry, windswept valleys such as the Dry Valleys of Victoria Land in the Ross Sea region.

Ice-free areas are where most of Antarctica's biology is concentrated. Ice-free Antarctica provides breeding grounds for birds, including penguins and sea-birds (Lynch and LaRue, 2014; Lyver *et al* 2014), as well as haul-out areas for seals (Boyd *et al*, 1998). Ice-free areas are also important locations for Antarctica's endemic moss, lichen and invertebrate communities (Casanovas *et al* 2013; Adams *et al* 2006).

## *Pressures on ice-free Antarctica*

The majority of human activities in Antarctica also take place in ice-free areas. Of the 104 facilities owned and / or operated by National Antarctic Programs in the Antarctic Treaty Area (as listed in the spreadsheet of Antarctic facilities held on the website of the Council of Managers of National Antarctic Programs, COMNAP, 2014), 79 (75%) are located on ice-free sites. The construction of national programme facilities has grown steadily since the mid-1940's (Figure 1) and new bases continue to be established (Korea, 2011; China, 2014).

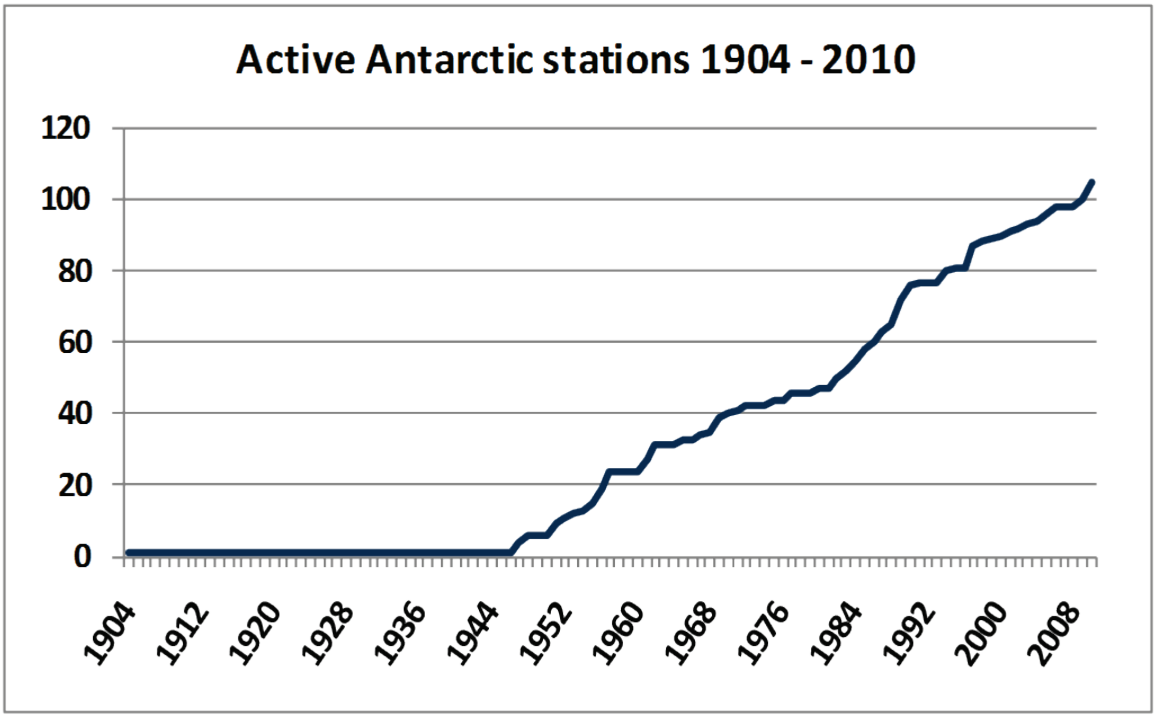


Figure 1 The number of national Antarctic stations and bases established over time. Source: COMNAP.aq.

Ice-free Antarctica is routinely used by the Antarctic tourism industry to provide a range of visitor experiences for tourists. Ship-borne tourism remains the foremost type of tourism activity in Antarctica. This "traditional" form of Antarctic tourism involves passengers embarking and disembarking at a port in a southern hemisphere country (the vast majority of which are conducted from South America (IAATO, 2014; ASOC and UNEP, 2005) with passengers remaining on-board for a period of between 10 and 14 days.

Once in Antarctic waters, landings are conducted each day during which passengers are transferred ashore, normally in small boats. Expedition staff accompany passengers ashore to act as guides as well as to ensure compliance with required standards. Such visits are typically one to three hours long depending upon factors such as the site itself, the time of day, the ships itinerary, and local weather conditions. It is common for such landings to encompass a range of experiences in any one cruise, including seeing wildlife (penguins and seabirds), scenery, historic sites and active Antarctic stations and bases. A quick assessment by the author suggests that more than 85% of the locations routinely visited by tourists are ice-free locations.

The number of passengers being landed in this way has steadily grown since the mid-1990s (Figure 2), and despite a slight reduction in numbers between 2008 and 2011, numbers appear to be increasing again.

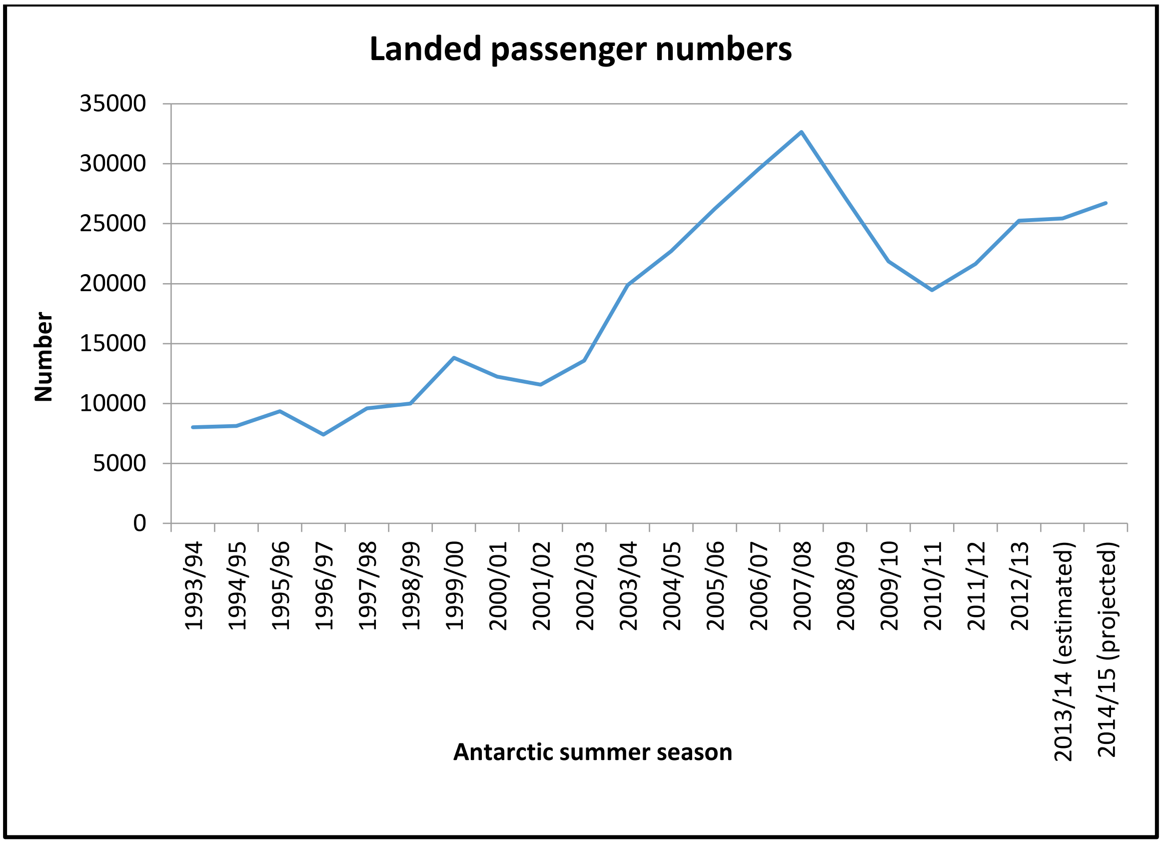


Figure 2 The number of tourists landed ashore each season between 1993/94 and 2014/15. Source: IAATO.org.

Passenger landings and marine traffic are highly concentrated at a few specific locations on the western Antarctic Peninsula. Growth in Antarctic tourism has occurred disproportionately rapidly at these sites relative to growth in visitation on the Peninsula as a whole (Naveen *et al*, 2001; Lynch *et al*, 2010).

Up to and including the 2008/09 austral summer season 73 sites were visited every season by one or more vessels, and received approximately 80% of all passenger landings. Among the top 20 most visited sites for the period 2003 to 2009, 54% of all landings occurred at just 7 sites, representing a significant focus of activity (New Zealand, 2012).

The Antarctic climate is also changing. The Antarctic Peninsula in particular is experiencing rapid climate change (Turner *et al*, 2014). Regional warming is resulting in a range of responses including: significant retreat of the majority of glaciers along the Antarctic Peninsula (Cook *et al*, 2005) and changes in the abundance and distribution of several Antarctic species (Turner *et al*, 2014, Vera 2011, Fraser *et al*, 2013). Non-native species have also become established at several ice-free locations (Chown *et al*, 2012).

### *Current and future management requirements*

These pressures on the Antarctic environment, and in particular on ice-free areas of Antarctica, continue to demand the attention of Antarctic managers and policy makers.

Some management and regulatory controls have been put in place for coastal, ice-free areas of the continent. The majority of the 72 Antarctic Specially Protected Areas (ASPAs) designated under the provisions of Annex V to the Environmental Protocol, are located close to the coast and protect a range of values located in ice-free environments (Antarctic Treaty Secretariat, 2014a). Access into ASPAs is prohibited without a permit issued by a national authorising agency.

Separately, the Treaty Parties have developed a suite of site specific guidelines for sites regularly visited by tourists (Antarctic Treaty Secretariat, 2014b). These guidelines have been developed on the basis of good site knowledge, including the data and information collected by the long-term monitoring programme undertaken by the US-based NGO *Oceanites* (Naveen and Lynch, 2013), as well as the expert site knowledge held by the tourism industry. The intent behind the guidelines is to describe and map the specific characteristics of the sites routinely visited by tourists, and to put in place management controls specific to those characteristics. Such controls include, for example, preferred access and walking routes, limitations on numbers ashore at any one time and limitations on the number of visits within a 24 hour period. A number of these guidelines have been reviewed and updated with regard to their site specific controls (UK *et al*, 2013).

However, the adequacy of the protected areas network in Antarctica has recently been examined by Shaw *et al* (2014), who suggest that the system fails to meet international standards and is unrepresentative in an Antarctic context. Further, the sites regularly visited by tourists have not been subject to any systematic assessment, nor indeed routine monitoring, to determine the appropriateness, relevance or adequacy of the existing controls.

Following a study of the environmental aspects and impacts of tourism activities, undertaken by the Committee for Environmental Protection (the environmental advisory body to the Antarctic Treaty Consultative Meeting (ATCM); New Zealand, 2012), the ATCM requested the CEP, "*as a matter of priority*, to develop an appropriate definition and method of assessing site sensitivity and to undertake a relative sensitivity analysis for at least the most heavily visited sites in Antarctica, as appropriate, including, for example, consideration of the vulnerability of visited sites to non-native species establishment, for the purpose of more rigorously assessing appropriate management needs" (ATCM, 2012).

To meet these expectations of the ATCM, work is underway to develop new approaches for analysing and quantifying site sensitivities. Aspects that are under consideration include: undertaking a broad-based survey of expert opinion to identify and quantify the 'dimensions of sensitivity'; developing tools that make use of the abundance and distribution of key species (e.g. seabirds) to determine and predict temporal and spatial change in site sensitivity, and updating biological surveys of visited sites, with a particular focus on moss, lichen and other poorly surveyed species contributing to a site's unique biological diversity (Australia, 2014. See also Foley, Lynch and Naveen in these proceedings).

It is anticipated that these new approaches and information will allow for the assessment of both inter- and intra-seasonal variation in site sensitivity, and will also provide a means for assessing the adequacy of existing controls; ensuring consistent controls are applied between sites; providing a robust means for assessing new sites being considered for visitation, and for reviewing management controls over time and with emerging or changing context (such as changes to a site as a result of responses to climate change).

In conducting this work, site sensitivity methodologies used in comparable areas, especially the Arctic (i.e. those presented and discussed at this symposium), are being considered and assessed as appropriate, in order to inform the development of the methodology for the Antarctic context.

***Summary***

The Environmental Protocol to the Antarctic Treaty sets high standards for the management of Antarctica's natural environment and the protection of its biodiversity. At a time when the environments of Antarctica are under increasing pressure from a changing climate and expanding human activity, as well as the establishment of non-native species, it is imperative that appropriate management controls are established if Antarctica's status as a natural reserve devoted to peace and scientific research is to be maintained.

One aspect of this is to establish a robust, practicable methodology for assessing the vulnerability of sites to regular visitation, so as to ensure management controls are well placed and relevant to the sensitivities of the sites in question.

Work is underway to develop such a methodology and, if successful, it is likely that this will broader application than visitor site management, including to support environmental impact assessments for research and logistical activities as well as to assist in the selection and designation of protected areas.

## Vulnerability in polar areas – Review of concepts and methods

Hagen D. [1], Systad G.H. [2], Eide N.E. [1], Vistad O.I. [3], Stien A. [4], Erikstad L. [5], Moe B. [1], Svenning M.[4] and Veiberg V[1].

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### *Introduction*

The management of polar areas is getting more challenging. There is an increase in activities in the petroleum sector, in tourism, fisheries and transport. Type, extent and intensity of pressure are changing and relevant knowledge is needed for the right management priorities and get the decisions properly rooted. More specific knowledge related to the concept of vulnerability is demanded among management authorities in polar areas. Vulnerability deals with resource capacity to cope with different pressures. A large number of effect studies have been done and a lot of data is available, however there is a lack of tools to put this knowledge into management actions. A review of the concept, within the knowledge and frame of different management systems is needed to meet this. This is a short version of a report written in Norwegian (Hagen *et al.* 2014), summarizing existing concepts.

Very different types of influence put pressure on resources in polar areas. Some function on a global scale, as climate change and long-range transboundary pollution. Others work on a local scale as land use from technical constructions or traffic, where local management authorities can have influence on the development. There is also a link between global and local influence. The influence is variable in time and space. Vulnerability concepts are often treated based on specific pressures. Traffic and land use are focused in this work.

Vulnerability and risk assessment of alien species is another important issue. Harvesting of biological resources is a third, ranging from small-scale recreational hunting up to large-scale fisheries on pelagic fish species. Petroleum related activities offshore and mining on land are other important pressures on polar areas of varying potential and risk. As an additional factor, climate changes provide altered effects of the other factors of influence.

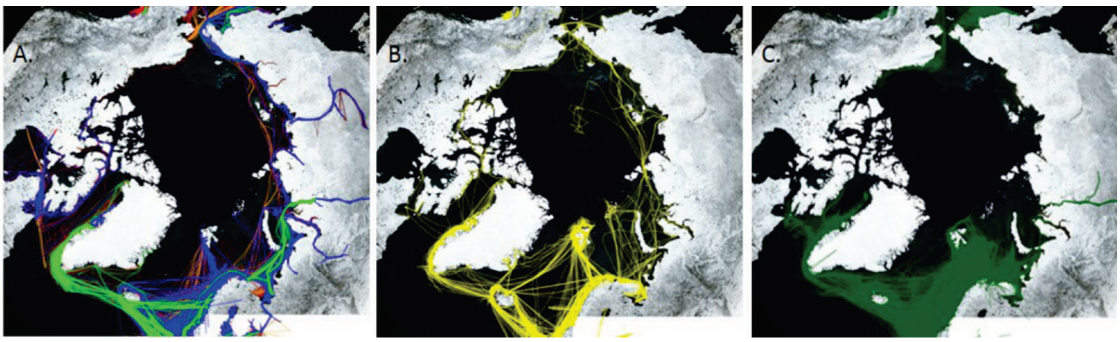


Figure 1 Ship transport in the Arctic. A - Oil/gas/chemistry tankers, bulk ships, mixed cargo, container ships and refrigerator cargo ships. B -Tourism / Passenger ships. C - Fishing vessels. Source: Norwegian Coastal Administration (http://havbase.kystverket.no)

## *Methods*

Vulnerability has been explained in a variety of ways by different scientific environments (Berkes and Folke 1998, Chapin III *et al*. 2010, Miller *et al*. 2010), and there have been large discussions and disagreements on the matter (i.e. McLaughlin and Dietz 2007, Adger 2006). We have chosen to give thorough definitions of the concepts, which is important for further analyses. The definitions of the vulnerability system and its concepts have background in, among others, Gallopin (2006) and Williams *et al*. (2008). Other important sources are Adger (2006) and Villagrán De León (2006).

Resources have varying degrees of ability to cope with changes, and some are more resistant to change (resistance, tolerance), while others have a greater ability to adapt to change (resilience, adaptive capacity, plasticity) (figure 2). This provides the sensitivity of the resource, as defined in this article (figure 2). Different resources are more or less subject to different pressures, depending on the characteristics of both the resource and pressure. For some types of pressure the vulnerability relates to the influence over time, while for others the vulnerability is related to a calculated risk or likelihood that an influence will occur. Data about effects are the basic knowledge for management authorities to draw conclusions about impact from the pressure. Therefore, as effect can be calculated and recorded, the impact is a combination of values, vulnerability and pressure.

Adaptive capacity indicates the resource's potential to adapt to changes. Important aspects that contribute to resource adaptive capacity are genetic diversity, phenotypic plasticity, plasticity in behavior and dispersal ability (e.g. Dawson *et al*. 2011). The adaptive capacity also affects the manageability of the resource. Plasticity is limited to denote the ability to change behavior. In evolutionary ecology, this entails both genetic and phenotypic plasticity. Adaptive capacity is often used as synonymous with plasticity within ecology, but holds more aspects.

Resilience is used for the ability of a resource to return to normal condition after a change without changing the character of the resource, while resistance is used for resources resistance to change through its general health. The concept of resilience can be nuanced in "engineering resilience", which is the capacity the resource have to return to a natural steady or cyclic state after an influence, while "ecological resilience" refers to the ability to maintain the resource's state under an impact (Levin and Lubchenco 2008). Ecological resilience is thus very to resistance by this definition. The term robustness is widely used, both in Norwegian, "Nordic" and English, and both in ecology and the social sciences. It is used with various meanings: as something approximately equal resistance ( Jentoft 2010, Pelling 2003), or as another word for more or less equal resilience ( Zachrisson 2009, Janssen *et al.* 2007). In this report, we will therefore primarily keep to the English concepts of resilience and resistance.

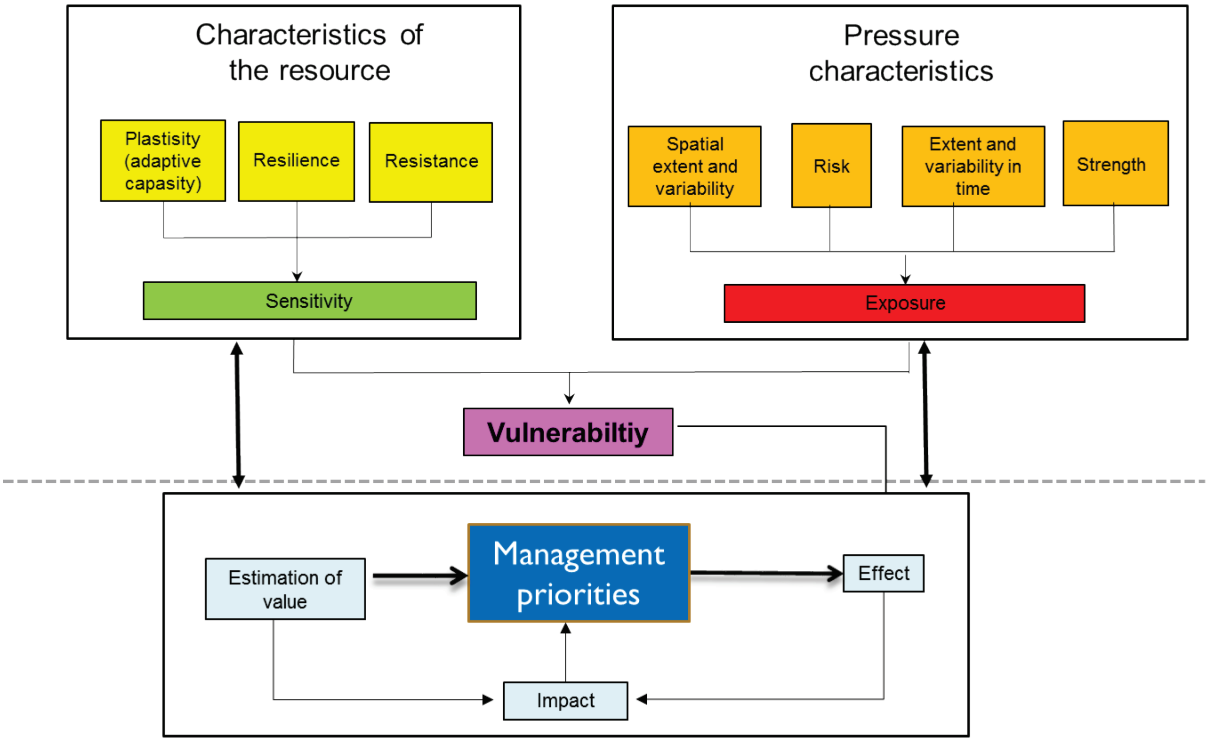


Figure 2 Vulnerability model used for defining concepts used in evaluating vulnerability and management priorities (Hagen *et al*. 2014). Other works use different interpretations and definitions for the concepts mentioned. Therefore, it is important to define the use of the concepts thoroughly.

## *Discussion*

Systems and methods to describe and assess vulnerability is needed for the implementation of vulnerability in management of polar areas. Different traditions focus on qualitative or quantitative methods, where qualitative assessments often are quicker and include expert evaluation, while quantitative methods are easier to repeat. Quantitative methods also include element of expert evaluation. Examples of vulnerability assessments based on specific influencing factors addressed in the report are assessments related to traffic and land use, vulnerability and risk assessments of alien species, considerations related to the harvesting of biological resources, and vulnerability to climate change and potential offshore oil-spill.

Using vulnerability as an approach in management have different traditions in terrestrial and limnic environments as compared to marine polar areas. One common link is that most models relate to a specific type of pressure. Vulnerability assessments for land-use, traffic, alien species and harvesting deal with real and continuous influence, and not a predicted or immediate situation. This is as opposed to marine vulnerability assessments where the influence often is a calculated probability of potential accidents (typically in petroleum industry). There seems to be a link between the type of influence and how much efforts are put into collecting data for vulnerability assessments. Potential accidents trigger off more serious and long-term knowledge building compared to a continuous influence from a diffuse or diverse group of actors. One example is traffic and trampling, done by everyone present in an area. Tourism is just one example, but also local inhabitants, scientists and other visitors do influence an area just by their presence. The presence of alien species is also related to a diffuse group of actors, and addressing “responsibility” is rather complicated.

The relationship between value**,** strategy and vulnerability is essential for the implantation of knowledge into management. In the future, the elements of uncertainty will likely get more attention, and available data is crucial for calculating the level of uncertainty between exposure and effects. As long as the calculations can be verified, it is less relevant whether this is based on qualitative or quantitative methods. Combined vulnerability as it is appears in literature and present management is quite theoretical. Moreover, in a situation of diverging and/or lacking of knowledge we will prefer separated vulnerability assessments based on specific components and pressures.

Our approach was to focus on the vulnerability issues that can be handled by local management authorities in polar areas. The real situation is that Arctic and Antarctic areas are under large changes, due to climate change, transboundary pollution of air and oceans, and increased access to the areas and this put the resources under increased pressures. This development will give new challenges to the local, regional and global management of polar areas. The tempting exploitation of these technical and economical possibilities is a high-level political issue.

It is crucial to consider the human and society as "natural" elements and the key factors in polar systems – hence references from the research literature on the development and management of so-called “social-ecological systems” (SES) essential. Most relevant measures and efforts from management authorities will inherent focus on the impact factors – i.e. people, organizations, businesses and society. Therefore, it is also required a stronger integration of natural resource and community management, as vulnerability, resilience and adaptability are critical phenomena both in social polar systems and in the polar environment (see Chapin III *et al*. 2006; Folke 2007). In a social-ecological mindset, human presence is not basically an inherent negative pressure; however man is an obvious element within the system. It must be studied and are forms of acceptable use of nature. The question is thus how research, tourism, fishing, transport etc. should be exercised, and what knowledge is needed about the actors, the activities, the conduct and (possible) effects of these. There is not one specific level of vulnerability, as this will vary between situations. Good management is based on the ability to collect and incorporate new knowledge into relevant management efforts. Adaptive management is not a fixed management model, but a systematic way of working based on an understanding that the system to be managed is probably unstable and changes will happen continuously. In order to implement effective measures it is essential to put focus on a scale and a level that management authorities can influence and handle.

# The Local Ecological Footprinting Tool (LEFT)

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## *Introduction*

Many business activities in industries such as mineral extraction and agriculture involve making changes to land use in areas where operations take place. Increasingly businesses making decisions which will affect land are attempting to mitigate potential operational and reputational risks associated with modifying natural ecosystems (Franks *et al.* 2014, Pedroni *et al.* 2013). A typical approach is to conduct a field-based environmental impact assessment in advance of beginning operations at a site. However, for many organisations, especially multinational companies, which have many large-scale globally distributed operations at various stages of project development, preliminary desk-based analyses are required in order to screen sites at a project planning stage, and to reduce the costs associated with hiring consultants to perform field-based assessments.

We have developed a tool, the Local Ecological Footprinting Tool (LEFT), which addresses these issues (URL: www.biodiversity.ox.ac.uk/left). LEFT is a decision support tool which can allow communities, businesses, governments and NGOs to make land use decisions which take account of the consequences for biodiversity and ecosystem function (Willis *et al.* 2012). Use of the tool is free of charge, and novice users are able to register an account, and specify an area of interest using a simple web-based map within a few minutes. The tool then automatically performs an analysis and sends an email to the user, typically within about 1 hour, to notify them that their analysis has completed.

The output is a custom pdf report containing a series of maps of the area of interest, together with a zip file containing spatial data which users can optionally use in a geographical information system (GIS). The tool works by using stored globally consistent environmental data layers, and automatically performs some geoprocessing operations to implement a series of published methods for analysing environmental data (Figure 1).

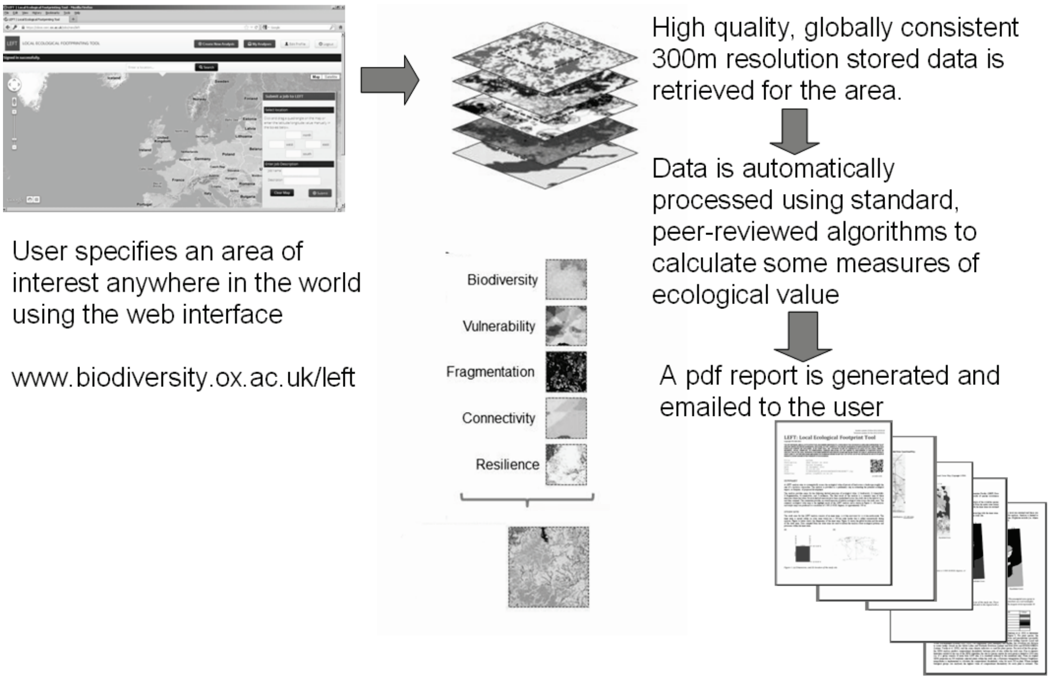


Figure 1 Schematic diagram of LEFT system

The user interface is a simple web-based slippy map (Figure 2). Users can pan and zoom the map and toggle between a satellite and topographic map view. Toponyms can be typed into a text box if the user wishes, and a gazetteer then looks up the name and centres the map. Users can use a rectangle drawing tool to draw and adjust a rectangular area of interest on the map. Alternatively the minimum and maximum north, south, east and west extents in decimal degrees of the area can be entered into four boxes to specify an area of interest. Users may also enter a name for the analysis for their own reference. There is a submit button to start the analysis running automatically.

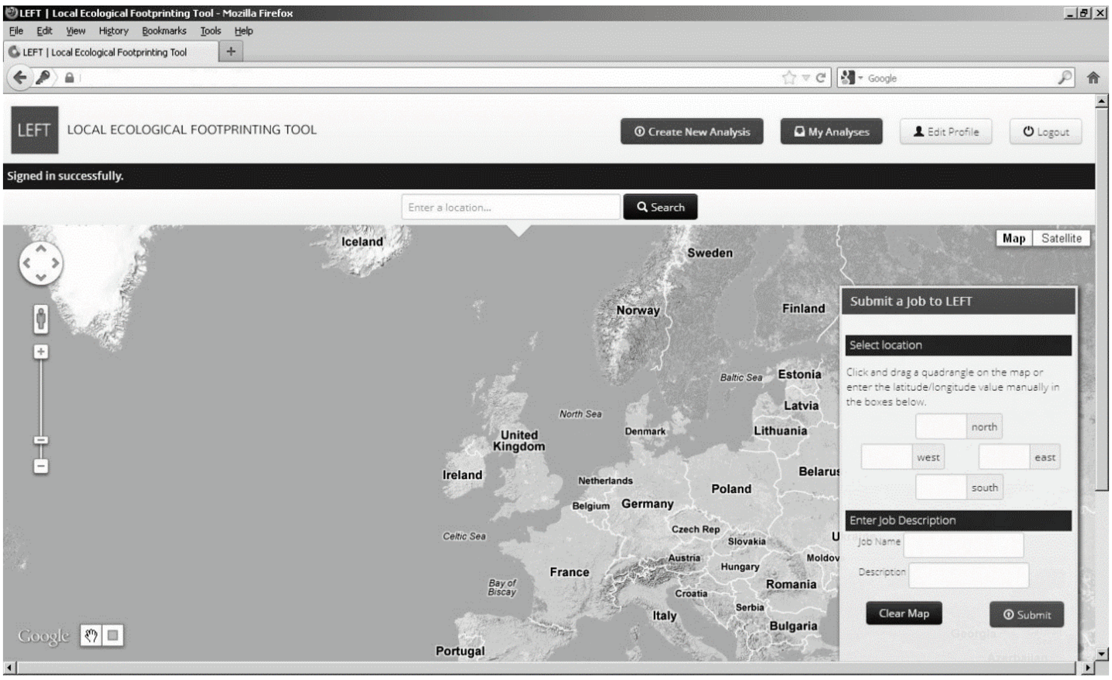


Figure 2 Screenshot of LEFT web interface.

LEFT is intended as a pre-planning tool, which can help decision makers rapidly evaluate whether a landscape contains important biodiversity features and understand the distribution of features across the landscape at fine spatial resolution. Also LEFT uses global datasets and present globally consistent analyses using published algorithms which have been subject to scientific peer-review. Additionally, the adequacy of the environmental data drawn from global datasets has been validated using large long-term, multi-taxa, landscape scale biodiversity datasets in Madagascar and Honduras in order to show that the patterns of ecological value estimated by LEFT are comparable to those which would be produced by extensive field surveys (Willis *et al*. in press).

The development of LEFT has been sponsored by Statoil, the state oil company of Norway, and Statoil staff have begun to use LEFT operationally to screen potential project sites. In this chapter we describe the datasets used in LEFT, the automatic processing algorithms implemented in LEFT, and finally include a case study of a LEFT analysis performed in a landscape in Canada in order to inform planning of oil exploitation.

## *Data used in LEFT*

All datasets used in LEFT are either in the public domain and may be redistributed without permission, or we have obtained written permission from dataset owners to distribute their data in LEFT.

Open Street Map data (URL http://openstreetmap.org) is used to provide context for LEFT analyses. The European Space Agency (ESA) Globcover 2009 land cover classification product is used as the base layer in LEFT. WWF ecoregion polygons are used to broadly characterise ecologically similar land to inform subsequent analyses (Olson 2001). The Global Biodiversity Information Facility (GBIF) database (URL http://gbif.org) is the source of biodiversity records. GBIF provides access to more than 300 million records of species occurrences worldwide. The IUCN redlist (IUCN 2009) is used to provide a list of the latin names of species which have been assessed to be globally threatened. Migratory species are taken from the global register of migratory species (GROMS; Riede el al 2011). Environmental variables are taken from Worldclim (Hijmans *et al.* 2005), Hydrosheds (Lehner and Doll 2004), the Global Lakes and Rivers Database (Lehner and Doll 2008), the Harmonized World Soil Database, and MODIS NPP (Zhao el al 2009).

## *Geoprocessing algorithms*

Data on species occurrence are obtained automatically from the Global Biodiversity Information Facility (GBIF) Data Portal (http://data.gbif.org). The WWF Ecoregion classification (Olson, Dinerstein *et al*. 2001) is then used to decide which of the available species occurrence records should be included in the following analyses. GBIF records are collected from a bounding rectangle calculated by buffering the user-specified area of interest by 300km on all sides. However only those records found within the set of WWF ecoregions that also intersect with the user's area of interest are retained for further analysis.

Of the total GBIF records retrieved, only terrestrial species that are identified to species level are retained and these are further divided into five groups (amphibians, reptiles, mammals, birds and plants) for analysis. Analysis is limited to those groups for which there are occurrence records for ten or more different species. Duplicate records (i.e. where the same species was recorded multiple times in the same location) are also removed.

In order to map beta-diversity, the final set of retained GBIF records are analysed using a generalized dissimilarity model (GDM, Ferrier, Drielsma *et al*. 2002) to determine the compositional turnover with respect to selected environmental variables. For plant species, the covariates include: annual mean temperature, annual mean precipitation, temperature and precipitation seasonality (from Worldclim, Hijmans, Cameron *et al*. 2005), % nitrogen in soil and soil water holding capacity (Land and Water Development Division, FAO, 2003). For amphibians, birds, mammals and reptiles, the covariates are: distance to water bodies (based on the Global Lakes and Wetlands Database (Lehner and Döll 2004) and Hydrosheds (Lehner, Verdin *et al*. 2008)), and the same climatic indicators as used for plant species. For each of the five groups, the GDM analysis predicts compositional dissimilarity between pairs of sites within the study area. Due to memory limitations related to the use of the GDM algorithm, the site-by-species matrix for each group is limited to 2000 sites (i.e. if a group consists of more than 2000 sites, it is randomly reduced to this maximum size). From an original GDM projection on 300 randomly selected pixels within the study site, a Delaunay triangulation (Nearest Neighbour) interpolation is implemented to calculate the compositional dissimilarity value for each 300 m pixel. Where multiple biological groups are analysed, the highest value of compositional dissimilarity for each pixel is retained. This process is iterated 10 times, and the median dissimilarity value among the 10 runs is taken.

The map of vulnerable species distribution is derived using the IUCN Red List of Threatened Species (IUCN 2012). A list of all terrestrial mammals, birds, reptiles, amphibians and plants in four threat categories: critically endangered (CR), endangered (EN), vulnerable (VU) and near threatened (NT) were extracted. For each species the list of countries making up the geographic range of the species was compiled from the individual species pages on the IUCN web site, excluding only countries in which the species is listed as vagrant or introduced. For each species a list of locality observations was obtained from GBIF and filtered by boundary polygons of the countries in the geographic range. Next, for each species we modelled the potential distribution using MaxEnt (Phillips, Anderson *et al*. 2006) and six environmental and geo-physical variables (bio1, bio4, bio12 and bio15 from Worldclim, Hijmans, Cameron *et al*. 2005; and aspect and slope). Only models with AUC >= 0.7 were retained. For each LEFT analysis, the models for those species whose native geographic range is included in the study area are projected using the same environmental variables and the projected probability values hardened to [0,1] at a cut value of 0.5. The hardened probability values are then summed across all modelled species. The resulting map represents the relative numbers of threatened species potentially present across the study area.

The extent of fragmentation in the landscape is calculated from GlobCover vegetation data (Copyright © ESA GlobCover Project, led by MEDIAS-France) by identifying the vegetation patch to which each pixel belongs and measuring the size of each patch. We reclassified the GlobCover vegetation categories into the following broad groups: closed forest, open forest, shrubland, grassland, sparse vegetation, flooded vegetation, and other. The other class includes agriculture, mosaics of agriculture and natural vegetation, urban areas, bare surfaces, water and snow/ice. Land in the class 'other' was assigned a patch size of zero.

There are two measures of connectivity included in the LEFT: the relative number of migratory species estimated to be present and identification of the landscape features that support migration. All available species range polygon shapefiles for birds, terrestrial mammals and turtles identified as migratory species in the Global Register of Migratory Species (GROMS, Riede 2004) were summed to estimate the relative number of migratory species potentially present across the study area.

Differences in resilience across the study area are indicated by the ability of vegetation to retain high productivity despite low rainfall conditions. Values of annual net primary productivity (NPP (kg m-2 yr-1), Zhao *et al*. 2009) for the year 2005 per vegetation type (determined by GlobCover, also as of 2005) were overlaid with data of the historical mean total annual precipitation (mm) over 1950-2000 (from Worldclim, Hijmans *et al*. 2005) to identify patterns across space in the level of productivity of each vegetation type given spatial variations in rainfall. Quartiles of precipitation and NPP per vegetation type are calculated and used to identify areas that maintain maximum NPP during intervals of low precipitation. Areas that fall in the 4th quartile of NPP and the 1st quartile of precipitation are assigned a value of 1. Areas that fall in the 3rd quartile of NPP and the 1st quartile of precipitation are assigned a value of 0.5. All other areas are assigned a value of zero for resilience.

A LEFT analysis generates maps of five derived measures of ecological value: 1) biodiversity, 2) vulnerability, 3) fragmentation, 4) connectivity, and 5) resilience. The final result of the analysis is a summary map of these measures where the values for each derived measure have been normalized across the study site to the interval [0, 1] and then summed. There are two distinct components to connectivity, so each of these contributes just half its value to the sum. The summation then has a maximum value of 5 and provides an overall estimate of relative ecological value across the study site.

Rivers, lakes and wetlands support migration for many species. The Global Lakes and Wetlands Database (GLWD; Lehner and Doll 2004) and Hydrosheds database (Lehner, Verdin *et al*. 2008) are used to identify these features within the study area.

All pixels identified by the GLWD as a lake, river, freshwater marsh/floodplain, swamp forest/flooded forest, coastal wetland, pan/brackish/saline wetland, bog/fen/mire, intermediate wetland/lake or wetland mosaic and the pixels immediately adjacent to these features are given a value of one. All pixels containing a polyline in the Hydrosheds 15 arc second resolution global rivers shapefile, which represents drainage channels with an upslope contributing area greater than about 100 km2, and all pixels immediately adjacent to these features were given a value of one. Finally the connectivity measures derived from GLWD and hydrosheds were added together and reclassified such that all pixels containing or adjacent to a GLWD wetland or containing or adjacent to a hydrosheds channel took a value of one and all other pixels are given a value of zero for this measure of connectivity.

## Site guidelines in Svalbard

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### *Background*

The proposal to develop Site guidelines in Svalbard origins in AECO's membership. It is considered to be a proactive tool to meets concerns related to negative impacts from cruise vessels landings in Svalbard.

AECO applied for funding from Svalbard Environmental Fund several years ago, but the first application was turned down as we aimed at eastern Svalbard and this was considered premature, seen in connection with the regulation process. The second application, limited to Spitsbergen, was granted funding and site guidelines for nine sites on the west-coast of Spitsbergen were developed in 2011. It was a premise that AECO at that point in time "stayed out" of Eastern Svalbard Nature Reserves with the project, as the ongoing regulation and management plan process was far from concluded.

The 2011-project was a success and AECO's site guidelines have been recognized by the authorities as well as other stakeholders. This was further strengthened when AECO a month ago was informed of new funding from Svalbard Environmental Protection Fund to develop site guidelines within Eastern Svalbard Nature Reserves.

AECO has based the application partly on the ongoing management plan process – and the results of this process which at this point in time are more than likely to become realities. This includes the future demand for site guidelines for five sites within Eastern Svalbard Nature Reserves: Polarstarodden, Andréeneset, Kræmerpynten, Andréetangen and Kapp Lee. The aim of the AECO application was to develop site guidelines within Eastern Svalbard nature reserves. If the management plans is passed with such a requirement for site guidelines, and AECO is not able to develop the guidelines, it will probably become a concern for each individual operator.

### *Progress*

Due to short time between the expected decision from Svalbard Environmental Fund and this summer season, AECO started to prepare a potential site guidelines project before we knew the outcome of the application. This includes contact with the project group from last year and dialogue regarding vessel hire. At this point in time the project group had committed and the vessel hire was agreed.

### *Project group*

The project group from last summer worked very well and it is a great advantage that almost everyone is able to participate this year as well. This adds to the efficiency and provides value for money in this project. The group was originally put together based on expert knowledge, background, positions and cooperation skills, and will this year include:

- Dagmar Hagen, Norwegian Institute for nature research – botanist – in charge of on-site methodology.
- Georg Bangjord, (formerly Norwegian Polar Institute, presently Norwegian Directorate of nature) – biologist, bird expert.

- Kristin Prestvold, (formerly Governor of Svalbard, presently Fylkesmannen i Sør-Trøndelag) – archaeologist.
- Ko de Korte, biologist, AECO/Oceanwide Expeditions – EL, Eastern Svalbard expert.
- Thor Larsen, (formerly NPI, presently Norwegian University of Life Sciences biology), biologist, guide, eastern Svalbard and polar bear expert.
- Jørn Henriksen, AECO-EC/Hurtigruten – EL, Eastern Svalbard expert. (not participating in site inspection) – serves as EC-contact in the project.
- Lisa Strøm, "Stockholm"/PolarQuest – EL, Charter-staff.
- Frigg Jørgensen, AECO, project leader.

### *Methodology*
As last year we will base the site inspection on the methodology developed by NINA in the project "Environmental impacts from tourism in Svalbard". This is a method where scores are used to consider vulnerability on the environment; vegetation, different species of birds and animals as well as cultural remains. The score will indicate the need for special consideration on the site.

### *Inspection*
The inspection will take place August 17 – 27 with the vessel "Stockholm". "Stockholm" has been chartered from PolarQuest.

### *Sites*
As mentioned, five sites have been pointed out in the management plan and the locations of these sites will more or less give the sailing-route in this project.

AECO's EC has discussed the "dilemma" connected to especially Lågøya and Tusenøyane. These are sites that most likely will be proposed closed in the coming hearing of the management plan. If AECO conduct a site inspection and find that site guidelines can be developed, we risk that these site guidelines will be of no use in the future. Nevertheless, the EC has decided that these sites will, if the local conditions allow for it, be included on the list of sites that will be inspected. The project group serves as experts and will be able to make an onsite professional consideration of the sites. If they find that the site can take visitation, their findings may be used as arguments in our comments to the hearing.

With this*, at least seven sites are already given*. The project group is discussing additional sites – all visits depending on local conditions when the inspection finds place and time. Other considerations will especially be location (located close to "must"-sites), level of visitation and need for guidelines. Others potential sites are: Eolusneset, Krossøya, Isflakbukta, Faksevågen, Augustabukta, Torellneset, Vibebukta, Binnebukta, Sundneset, Diskobukta and Tiholmane.

### *Finances*
AECO applied for funding of NOK 967 000 and received NOK 900 000. This gives some challenges as costs have to be reduced, but as it looks, we will be able to carry out this project within the budget.

### *Other issues*
We will need pictures from the sites. We have an ongoing dialogue with a "media representative" who can serve as photographer for AECO, as well as producing media stories from the inspection. If it does not work out we will need a photographer. This is an unpaid task.

We are in dialogue with the polar bear guards we used last year regarding a new “contract”. This too is an unpaid task.

### *Way forward*
Up until the inspection takes place the project group will make preparations by collecting and systemizing site data. This will serve as background during the inspection. The objective is to finalize as many discussions as possible during the inspection – and to finalize most of the text.

After the inspection we will need to trim the text, choose pictures and work on the maps. We will use last year’s template for the lay out. As last year we will have the final guidelines approved by the members, if possible at the Annual meeting.

### *In retrospect*
The Site Guidelines, together with AECO operational guidelines and guidelines animations are at the core of the AECO operation. Having a membership that complies to these guidelines is essential for the credibility of the organization and our vision is that their combined effect is a more sustainable expedition cruise tourism industry in the Arctic.

AECO have done a feasibility study of making site specific guidelines in Greenland – an initiative very much welcomed (and asked for) by local authorities. AECO is also involved in projects that revolve around the same in Arctic Canada.

In the Russian Arctic National Park that covers Franz Josef Land, the park authorities have made guidelines inspired by the AECO Site Guidelines. What started as a project limited to the Norwegian Arctic area of Svalbard seems to become embraced by other Arctic nations. For Expedition Cruise operators that have regular operations in many or all Arctic nations having a set of guidelines that follow the same graphic outline and is familiar to use is seen upon as an advantage. User-friendliness is instrumental.

*The polar landscapes and seascapes.*
*A polar puzzle of life and knowledge.*
*A puzzle that is now changing.*
*The whiteness fading, the vastness decreasing and the vulnerability constantly challenged.*

*The polar landscapes and seascapes.*
*A polar puzzle of life and knowledge.*
*A puzzle that is now changing.*
*To contribute to the knowledge base of how our collective actions are influencing*
*the polar puzzle, each one of you spends your time and efforts bringing pieces of knowledge to the table.*

*The polar landscapes and seascapes.*
*A polar puzzle of life and knowledge.*
*A puzzle that is now changing.*
*Every effort, every hour you dedicate yourself to your work is needed,*
*– 'cause the list of impact factors, effects and affected species is long and increasing.*

*You all find pieces of the polar puzzle.*
*Terrestrial biologists, geographers and social scientists*
*– observing local impact factors influencing individuals, species and communities.*

*You all find pieces of the polar puzzle.*
*Marine biologists, statisticians and oceanographers*
*– measuring the effects of global impact factors on selected indicator species.*

*You all find pieces of the polar puzzle.*
*Climate scientists, ecotoxicologist, philosophers and social anthropologist.*
*Worrying about the long-term effects of yesterday's and today's emissions*
*on the inhabitants of the polar regions of tomorrow.*

*Each one of you holds one piece of the polar puzzle.*
*By sharing your knowledge, engaging in the discussions,*
*taking the birds eye view on your own results,*
*you will all contribute towards putting the pieces together.*

*Kjersti Eline T. Busch and Kriss Rokkan Iversen, SALT*

## Initial approaches analyzing Antarctic site sensitivities, 1994–2011

Ron Naveen

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### *Introduction*

The Antarctic Site Inventory (ASI) is a substantive, long-term monitoring programme that includes data and information collected across all heavily visited tourism locations, sites believed to be most sensitive to potential environmental disruption, and all sites covered by site-specific visitor guidelines that Antarctic Treaty Parties have adopted. The ASI has resulted in many analyses and publications from its 20-year database (see References, below).

Since the ASI began fieldwork in November 1994, it has demonstrated an ability to reach Antarctic Peninsula visitor sites frequently and cost-effectively, relying opportunistically on commercial cruise/tour vessels, yachts, and various national research vessels. The advantages of placing researchers on this assortment of vessels include wide spatial coverage of the western and northeastern Antarctic Peninsula and a negligible "footprint" on the landscape. These well-timed visits by trained researchers have proved an effective means of characterizing sites and for collecting relevant biological data.

The ASI field season generally runs from mid-November to mid-February and comprises two components: utilizing expedition tour ships to reach a regular group of 'core sites' whose breeding penguins and seabirds are censused annually, and utilizing yachts/smaller vessels in a directed effort to reach 'remote, data gap sites' that are infrequently visited and under-surveyed. These remote areas include: the South Shetland Islands; the northwestern western Weddell Sea; the western Antarctic Peninsula between Brown Bluff and Astrolabe Island; and Marguerite Bay in the southern Peninsula.

The ASI's comprehensive, Peninsula-wide, spatial and temporal approach is unique, aimed at collecting and analyzing data that are otherwise impossible to obtain via 'single site' penguin studies or at national Antarctic research stations, and has generated an enormous body of data, information, and analyses that are readily and publicly available (http://www.oceanites.org/links/ and http://lynchlab.com/publications/).

These data and the associated analyses — particularly, the three editions of the Oceanites Site Compendium — have enabled a suite of important scientific and practical outcomes including a better understanding of climate change in the vastly warming Antarctic Peninsula environment, the development of site-specific management guidelines that Treaty Parties have adopted, and the Treaty Parties' ongoing examination of potential tourism impacts (ATCM 2012, Naveen *et al.* 2012, Naveen and Lynch 2011, Naveen 2003, Naveen *et al.* 2001, Naveen 1997, Naveen 1996).

Data collected by the ASI assist the implementation of the 1991 Protocol on Environmental Protection to the Antarctic Treaty, which, among other things, requires a priori environmental impact assessments for all activities for which advance notification is required, including tourism, and for monitoring to be done, as and when necessary, to assess and verify predicted environmental impacts. The ASI's primary objective is to identify and detect changes at the sites being monitored, and to determine whether any changes are naturally occurring or are caused by tourism or other human activities (ATCM 2012, Hofman and Jatko 2002, Abbott and Benninghoff 1990, Benninghoff and Bonner 1985, Emslie 1997, SCAR 1996).

Recently, these region-wide analyses have been assisted by the availability of high-resolution commercial satellite imagery. Lynch *et al*. (2012) and Naveen and Lynch *et al*. (2012) demonstrate the utility of such imagery for detecting penguin colonies and estimating penguin abundance. Along the Antarctic Peninsula, the project has begun to examine changing relationships between species diversity and environmental factors to assist with the management of Antarctica's floral communities.

### *Results, trends*

In 20 seasons from November 1994 through February 2014, the ASI has made 1,421 site visits and collected data at 209 Antarctic Peninsula locations. In the 2013-14 season, as well as over the 20-year history of the ASI, there have been repetitive visits to all of the visitor sites that are most heavily visited by expedition tourists, to all sites which exhibit the most species diversity and are most prone to potential environmental disturbance from human visitors (Lynch *et al.* 2008, Naveen 2003, Naveen *et al.* 2001, Naveen 1997), and to the species-diverse, environmentally sensitive tourism sites now subject to Site Guidelines for Visitors that have been adopted at recent Antarctic Treaty Consultative Meetings (ATCMs).

The ASI continues to track and document the rapid change in the relative populations of gentoo, chinstrap, and Adélie penguins throughout the western Antarctic Peninsula, with gentoo penguin populations increasing rapidly and expanding their range southward, and the other two species declining significantly.

### *Previous analyses of Antarctic Peninsula site sensitivities*

From its inception in 1994, the ASI has collected data regarding the presence or absence of nesting species of penguins and flying birds, wallows of southern elephant seals, and large patches or beds of lichens and mosses at all sites visited. Inventory researchers also record whether nests, wallows, and large floral patches/beds may be readily/easily accessed and/or trampled.

These presence/absence data were have been used to rank sites as to their species diversity, based on cumulative tallies of breeding penguins and seabirds recorded, southern elephant seals, and large patches or beds of lichens and mosses. Sites with "high" species diversity tallied 10 or more faunal species or major floral groups. Sites with "medium" species diversity tallied 5-9 faunal species or major floral groups. "Low" diversity sites tallied 0-4 faunal species or major floral groups.

In the first Oceanites Compendium (Naveen 1997), 51 sites were evaluated in terms of nine specific site sensitivities:

- High science value at the site
- High species diversity
- Particular geological and physical features
- Boundaries of extant protected areas
- Species with limited distribution, rare occurrence
- Proximity to giant petrel nests
- Easily disturbed gulls, shags, terns
- Restricted visitor space
- Easily trampled moss, lichens

In the second Oceanites Compendium (Naveen 2003), which covered 82 sites, the ASI's presence/absence data and the descriptive information for each site were used to evaluate each site's:

- Species diversity
- Proximity of visitors to fauna and flora
- Sensitivity to disruption

Five sites with high species diversity were identified, and 17 sites with medium species diversity.

Each site's potential sensitivity to disruption by visitors was also evaluated depending on: (a) the number of penguin and seabird species whose nests visitors may access easily, (b) whether or not visitors may access southern elephant seal wallows easily, and (c) whether or not visitors may access easily and possibly trample large patches or beds of lichens and mosses. Sites with five or more tallies were considered to be "highly" sensitive to potential disturbances by visitors; sites with 3-4 tallies were considered to be "moderately" sensitive; and sites with 0-2 tallies were considered to have "low" sensitivity to potential disturbances. Four highly sensitive sites and 12 moderately sensitive sites were identified.

Also examined was whether each site presented restricted visitor space, based on: (a) whether there are only very narrow or, perhaps, non-existent pathways between visitors and nesting penguins; and (b) whether high tides or other landing conditions (e.g. ice caked on shore) crowd penguins or other wildlife onto the landing beach. 12 such sites were identified.

Another analysis examined whether visitors were disproportionately "attracted" to sites that exhibited high or medium species diversity, or to sites exhibiting high or moderate sensitivity to potential environmental disruptions. Results showed that sites with high species diversity comprised only 5.9% of the 85 sites visited, but attracted 18.2% of all landings and 14.3% of all visitors. The fifteen sites with medium species diversity comprised 17.7% of sites visited, but attracted 39.4% of landings and 35.5% of all visitors. That sites with high/medium species diversity accounted for more than 50% of all Peninsula zodiac landings and visitors was highly significant statistically, and supported the view that visitors come to the Peninsula to see a diversity of wildlife.

However, because of the physical variation in landing sites, species diversity does not necessarily equate to visitors' attaining relatively close views of resident fauna and flora. Using the Inventory's presence/absence data as a base, this paper further examined whether disproportionate numbers of zodiac landings occur where visitors may attain this close proximity, relying on the sensitivity ranking of sites noted above. It was assumed that sites are more or less sensitive to potential disturbance according to the number of penguin and seabird species whose nests visitors may access easily, whether or not visitors may access southern elephant seal wallows easily, and whether or not visitors may access easily and possibly trample large patches or beds of lichens and mosses.

The four sites with high sensitivity to potential disturbances by visitors comprised 4.7% of sites visited, but attracted 11.8% of all landings and 9.6% of all visitors. The nine sites with moderate sensitivity to potential disturbances comprised 10.6% of the 85 sites visited, but attracted 15.4% of landings and 14.6% of all visitors. That sites with high/moderate sensitivity to potential visitor disturbances accounted for more than 24% of all Peninsula zodiac landings and visitors was also highly significant statistically, and supports the view that visitors come to see wildlife that is easily accessed.

This highly significant attraction was maintained, even when the 30 sites visited only once were removed from the analysis. The 17 sites with high/medium species accounted for 59.5% of the landings and 59.7% of the visitors, and the 12 sites with high/moderate sensitivity accounted for 28.1% of the landings and 29.0% of the visitors.

## *Into the future*

With the 3rd Oceanites Compendium (Naveen and Lynch 2011) covering 142 sites and the ASI now comprising 209 sites, Oceanites and colleagues at Stony Brook University have been tasked by Antarctic Treaty countries at the 37th ATCM to develop a new site sensitivity methodology that builds on these previous analyses. This effort is more particularly described in these proceedings, in Elements of a new, comprehensive framework analyzing polar site sensitivities, by C. M. Foley.

# Elements of a new, comprehensive framework analyzing polar site sensitivities

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## *Introduction*

The Antarctic is a special region due to its unique landscape and geopolitical standing. The region is managed according to the 1959 Antarctic Treaty, in a uniquely multinational setting. Through the Antarctic Treaty System, the wilderness and aesthetic value of the Antarctic have been highlighted and management actions must seek to maintain these values. Article 3 of the 1992 Environmental Protocol of the Antarctic Treaty states:

> *The protection of the Antarctic environment and dependent and associated ecosystems and the intrinsic value of Antarctica, including its wilderness and aesthetic values, and its value as an area for the conduct of scientific research, in particular research essential to understanding the global environment, shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area.*

The issue of managing human activities has been repeatedly discussed at Antarctic Treaty Consultative Meetings (ATCM) since 1966 and remains a frequently-debated issue. In 2012, the Committee on Environmental Protection (CEP), an advisory committee to the Antarctic Treaty Consultative Parties, prepared a report on the environmental impacts of tourism and other non-governmental human activities in the Antarctic. The study made eight recommendations, including:

> *Recommendation 3: An appropriate method of assessing site sensitivity should be developed and a relative sensitivity analysis undertaken for at least the most heavily visited sites in Antarctica, including, for example, consideration of the vulnerability of tourist sites to non-native species establishment, for the purpose of more rigorously assessing appropriate management needs. Site sensitivity considerations should also be included in the Environmental Impact Assessment process for tourism activities.*

This report was endorsed by treaty parties at the ATCM XXXV in 2012, and several recommendations were referred back to the CEP for further study. Notably, Recommendation 3 was highlighted “as a matter of priority” (Final Report of ATCM XXXV). In light of the pressing need for research on the assessment of environmental sensitivity, we discuss a project that is currently underway to assess visitor site sensitivity in on the Antarctic Peninsula.

## *A Framework to Consider the Science–Policy Relationship*

In a 2005 report, The Nature Conservancy developed a framework for establishing sustainable ecotourism programs, highlighting the need to develop Conservation Area Plans (CAPs). The framework described four stages to conservation design, from tourism site evaluation through the establishment of management plans and monitoring. While the Antarctic tourism industry has already existed for decades, and organizations such as the International Association of Antarctica Tour Operators (IAATO) have carefully monitored tourist activities, little quantitative research has been conducted regarding effective environmental management. The Nature Conservancy framework highlights the importance of spatial scale in ecotourism management planning. Their framework describes management considerations at a regional scale, to set priorities, and at a local scale to capture the spatial heterogeneity of visitor sites. This consideration of spatial scale is especially important in an Antarctic context, where managers must consider management at a regional scale to account for issues such as climate change, and the local scale to consider localized disturbances.

### *Expert Elicitation to Evaluate Site Sensitivity*

To develop comprehensive assessment methods, we have developed a three-part approach to assessing sensitivity (Figure 1). These interrelated components include (1) a survey of expert opinion to identify and quantitatively assess the dimensions of sensitivity; (2) leveraging remote sensing data to assess wildlife abundance; and (3) updating known knowledge gaps at visitor sites, with particular focus on moss, lichen, and other poorly studied species. While work on each of these components is currently underway, the remainder of the present discussion will focus only on the use of expert elicitation methods to assess sensitivity.

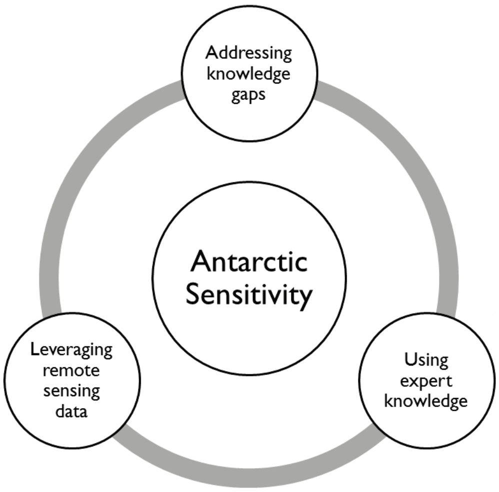


Figure 3 A comprehensive approach to evaluating Antarctic site sensitivity.

Numerous studies have identified local ecological knowledge (LEK) as an important source of information for ecological management (Merkel *et al.* 2005; Bundy and Davis 2013) and sophisticated statistical methods to incorporate this type of data into resource management models are becoming common in management frameworks (Failing *et al.* 2007; Low Choy *et al.* 2009; Martin *et al.* 2005). Local knowledge may play an especially important role in harsh environments with sporadic monitoring. In these cases, we suggest that scientists and professionals working in the region possess a great deal of knowledge which is currently underutilized. As such, we are surveying local experts to assess which visitor sites are considered the most sensitive and determine the specific factors experts feel are the most important in determining sensitivity. This method allows each respondent to define "sensitivity" according to their experiences working in a dynamic landscape and accounts for local variation within and among sites. The use of these expert elicitation methods will allow for a multivariate statistical analysis to determine the dimensions of sensitivity which are the most important in assessing individual visitor sites, including those sites not incorporated into the original survey and newly established visitor sites.

### *Polar Considerations to Assess Environmental Sensitivity*

In developing these methods to assess polar site sensitivity, we consider several important considerations. First, we recognize the interrelationship of science and policy to develop meaningful conservation and management practices. For the development of effective, science-based policy, we must recognize that our data analysis must be designed with particular questions in mind. As scientists, we are able to provide quantitative assessments of biological factors, however, the assessments undertaken by scientists in this context must be both driven by the information needs of policymakers and inform the outcome of policymaking.

The importance of spatial context in managing visitor sites in the Antarctic is also a critical consideration. Some sites, for example, possess highly restricted visitor space which implies a potentially higher human impact on a smaller are. Other sites, however, are more open and allow are likely to have a lower human impact per unit area. This spatial heterogeneity across the peninsula requires site-specific analysis to determine potential sensitivity and impact. Through the use of expert elicitation methods, we believe that these differences will be captured. Additionally, the Western Antarctic Peninsula is experiencing climate change at a particularly alarming rate, with sea ice extent declining 20% since 1950 (Curran *et al.* 2003). As sea ice declines, we may expect to see the creation of new visitor sites along the retreating edge of summer sea ice. The metrics we are establishing from our expert survey will allow for the evaluation of the sensitivity of new tourist sites based on easily measured factors.

## Linking PVA models to explore the impacts of declining polar ice on interconnected species in the arctic ecosystem

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The decline of polar ice – both pack ice and land-fast ice – has a number of direct impacts on the species that take refuge on the ice, travel over and feed from the ice, or avoid competition with subarctic species that cannot exploit resources under the ice. Some of these impacts on top level predators or rare species have been appropriately highlighted as concerns in recent years. However, the indirect impacts on the arctic ecosystem may be even larger, as the effects of changing ice conditions cascade through trophic levels. Populations of some currently abundant species may collapse to much lower numbers and, because they are key species within the arctic food chains, there will likely be secondary impacts on species that prey upon them, are preyed on by them, or compete with them.

We are testing the use of multiple Population Viability Analysis (PVA) models linked into "meta-models" (see Lacy *et al*. 2013 for a description of the general approach) to examine the inter-dependencies of ringed seals, bearded seals, and polar bears in the Barents Sea, and to project the impacts of changing ice on this part of the arctic faunal community.

The models indicate that the largest effects of climate change may be on species not currently of conservation concern, and the most critical threats to already endangered species may be the disruption of food chains. The models also show that the effects of changed climate on wildlife populations with long generation times can be delayed for several decades when the impacts hit most severely on reproductive success.

Field monitoring of demographic changes combined with models that project the consequent population dynamics will be required to reveal the long-term consequences of climate change impacts that are already underway. Where sufficient information exists about the species, the use of such metamodels might be valuable for projecting impacts of changing climate in other regions of the Arctic or extended to include other species interactions. Where data are currently too sparse to allow detailed modeling of species dynamics, preliminary models can help to identify potentially critical interdependencies that require study.

# Environmental niche modelling for polar species using MaxEnt

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## *Introduction*

Describing species distributions is essential to understanding and quantifying threats, monitoring changes, assessing protected area representation and investigating future impacts, all of which are important to evaluating vulnerability. Knowing the distribution of a species is difficult, especially in remote regions where it is not possible to comprehensively sample. Whilst it would be desirable to estimate species distributions using an explicit understanding of limiting factors, this is often not realistic within the budgets and timescales needed for creating vulnerability assessments. This creates an apparent need for easy to use tools that can be applied to numerous species and perform with a reasonable degree of accuracy, whilst requiring relatively little data.

Environmental Niche Models (ENMs), sometimes referred to as Species Distribution Models, are one such example of this (Elith and Leathwick 2009). These model species' suitable habitat using an incomplete set of occurrence records coupled with spatially explicit data layers of environmental conditions, assuming that the abiotic factors input into the model determine, or correlate with, locations where populations of the species can persist (Austin 2002; Elith and Leathwick 2009). Many input environmental conditions can be included in ENMs, but often these are not available at the detail necessary, especially at larger spatial scales. Climate data, however, is readily available worldwide at high resolution, meaning climate-driven ENMs can be built for virtually any system, though they require a greater set of assumptions and a more careful application (Araújo and Peterson 2012).

The Polar Regions are particularly well suited to the application of climate-driven ENMs. The climatic extremes present strongly impact species' distributions, with clear climatic gradients observable in communities. Palaeoclimatic investigations show that climatic changes of the past have strongly impacted polar (Bigelow *et al.* 2003; Emslie *et al.* 2007) species distributions. This means that the major assumption of ENMs, that species' occurrences correlate to environmental conditions, can be met with reasonable confidence. Detection of many species is also relatively easier in Polar Regions due to the low complexity environment, though sampling bias must still be accounted for. The use and interpretation of ENMs requires caution and a consideration of the costs of inaction in comparison with the uncertainties inherent in the modelling approach (Wiens *et al.* 2009). In the absence of other options however, they provide an invaluable first step for understanding distributions.

I investigated the applicability of ENMs in a group of Arctic breeding species, shorebirds, and used this to assess how well their current suitable habitat is represented by protected areas. Shorebirds are a group of migratory wader species predominantly of the family Charadriidae that rely on coasts and wetlands. Numerous shorebird species breed throughout the Arctic, making them a useful model group for investigating the efficacy of climate-driven ENMs in estimating distributions for a group of species. Furthermore, they are severely threatened throughout their range, especially in staging sites along the migratory route, with many experiencing dramatic declines in recent years (Kirby *et al.* 2008). It is therefore important to understand the distribution of suitable breeding habitat for shorebirds, in order to quantify threats and assess the vulnerability of these species.

## *Methods*

24 species were selected for study, based on those species that breed primarily in Arctic tundra (Table 1). Models were built using the niche modelling software MaxEnt, which uses a machine-learning algorithm to estimate a probability distribution of maximum entropy, i.e. the closest to uniform, for each species; constrained by the input environmental variables (Phillips and Dudík 2008). MaxEnt was chosen as it is designed to perform without 'absence' data and allows the user to account for sampling bias, relevant here due to large variation in sampling effort across the Arctic region. It has been shown to perform well, even with low sample sizes (Elith *et al.* 2006; Costa *et al.* 2010), but is sensitive to the tuning parameters used (Merow *et al.* 2013). Criticisms of MaxEnt largely stem from users failing to account for sampling bias, or incorrect interpretations of model output (Royle *et al.* 2012; Yackulic *et al.* 2013). It is therefore important to note that MaxEnt's output does not suggest occupied space or even a probability of occurrence, rather the presence of habitat that contains conditions similar to where the species is currently known to exist.

### Data

Occurrence records for the 24 species were gathered from four key sources: the Global Biodiversity Information Facility (GBIF), The International Breeding Conditions Survey on Arctic Birds (www.Arcticbirds.net, last accessed October 2014), The Atlas of Breeding Waders in the Russian Arctic (Lappo *et al.* 2012) and via David Boertmann for occurrences in Greenland. All records where definite breeding activity was confirmed (e.g. nest occupancy, recently hatched young) were included in the analysis, and for those where breeding status was unknown, acceptable records were those gathered between 15$^{th}$ May and 30$^{th}$ June from 1990 to now, and that fell within expert mapping of the breeding distribution (Cramp *et al.* 1983; Sibley and Monroe 1990; Del Hoyo *et al.* 1992).

The study region was Pan-Arctic with the southern limit defined by current estimated distributions of the 24 study species: between 50◦N in parts of Canada and 59◦N in parts of Russia. Projections were made for all land north of 50◦N. 19 bioclimatic variables, together with the standard deviation of elevation were used, with all data obtained from WorldClim (www.worldclim.org, last accessed October, 2014). Standard deviation of elevation was included as a predictor variable in the models because most shorebirds prefer to breed on vegetated flat tundra (Meltofte 2007) and variation in topographic heterogeneity, even for a given set of climatic conditions, is likely to have a significant influence on distribution. This was calculated by downloading the finest scale elevation grid from WorldClim, 30 arc seconds, and finding the standard deviation of these pixels within the 10 x 10km grid cells used for modelling.

### Model Parameters

A spatial grain size of 10 x 10km was used for analysis, to reflect the approximate resolution of most of the distributional records and a scale at which climate, rather than microhabitat factors, is more likely to be limiting (Mackey and Lindenmayer 2001). Although there are records of breeding shorebirds from all parts of the Arctic, the intensity of survey effort varied markedly, and this was accounted for by selecting background points (a suite of pixels used by MaxEnt with which to compare occupied pixels) only from known sampling locations. In this way the occurrence records and the background have the same sampling bias, removing its effect from model output.

Models were optimally tuned by adjusting the regularisation parameter, which alters tightness of fit (Anderson and Gonzalez Jr 2011; Radosavljevic and Anderson 2014). To choose the best regularisation parameter for each species, five-fold cross validated models were run for 12 values of the regularisation parameter at increasing intervals between 0.5 and 5, with the one resulting in highest mean AUC and lowest mean standard deviation selected. The performance of all models was evaluated using null model significance testing as described by Raes and ter Steege (2007), which estimates the probability that each model performed better than 1000 null models based on an equivalent number of occurrence points drawn at random from all surveyed locations. Distributions were also compared to expert derived range maps (Cramp *et al.* 1983; Sibley and Monroe 1990; Del Hoyo *et al.* 1992).

A threshold can be set for the model output, converting the logistic probability output that MaxEnt gives to a binary value indicating suitable or unsuitable habitat – useful for assessing protected area coverage. The threshold value was selected as that which balanced specificity and sensitivity, i.e. Type I and Type II errors in the model. Any cells with a logistic output above this value were converted to 'suitable' and any below 'unsuitable'.

**Protected areas**

Finally, protected area coverage of current distributions was analysed. Boundaries for all protected areas in the Arctic region were downloaded from www.protectedplanet.net (accessed 15th of July, 2014). Of these, UNESCO Biosphere reserves were excluded as they can include areas that have no formal protection (Coetzer *et al.* 2014). To ascertain whether the protected area network adequately represented a species, target proportions of protection were defined according to Rodrigues *et al.* (2004). Targets were set such that species with a geographic range size below 1000km$^2$ required 100% protection, those with a range size above 250,000km$^2$ required 10% protection, and species with intermediate geographic range size were logarithmically interpolated between these two thresholds. All protected area analyses used the total area of climatically suitable conditions from the thresholded MaxEnt output.

## *Results*

Models for all species performed very well, with most AUC > 0.95 and all being significantly better than null ($p < 0.001$) (Table 1). Even for species with relatively few occurrence points, current distribution models aligned closely with expert-derived range maps. Given that the models are predicting the occurrence of suitable climatic conditions, rather than the species' distributions themselves, some models inevitably showed suitable climatic conditions in areas far from the current distribution of the species being modelled. A common feature was for North American species to show some areas of high climatic suitability in parts of Russia. Often, these unoccupied but suitable areas are actually occupied by closely related sister species. Example distribution maps are shown in Figure 1.

Most species had fairly large range sizes; meaning protected area target proportions were low. Nevertheless, all species were well represented within protected areas, with all meeting their targets (Table 1).

Table 1 The 24 species used for modelling. Shows model performance metrics (AUC and Null Model p), as well as target and actual proportions of suitable climatic habitat represented by protected areas.

| Species Name | Common Name | AUC | Null Model *p* | Target Proportion of Protection | Actual Proportion of Protection |
|---|---|---|---|---|---|
| *Arenaria interpres* | Ruddy turnstone | 0.86 | <0.001 | 0.1 | 0.28 |
| *Calidris acuminata* | Sharp-tailed sandpiper | 0.99 | <0.001 | 0.1 | 0.30 |
| *Calidris alba* | Sanderling | 0.98 | <0.001 | 0.1 | 0.26 |
| *Calidris bairdii* | Baird's sandpiper | 0.98 | <0.001 | 0.1 | 0.22 |
| *Calidris canutus* | Red knot | 0.97 | <0.001 | 0.1 | 0.22 |
| *Calidris ferruginea* | Curlew sandpiper | 0.96 | <0.001 | 0.1 | 0.26 |
| *Calidris fuscicollis* | White-rumped sandpiper | 0.99 | <0.001 | 0.1 | 0.12 |
| *Calidris himantopus* | Stilt sandpiper | 0.99 | <0.001 | 0.1 | 0.14 |
| *Calidris maritima* | Purple sandpiper | 0.95 | <0.001 | 0.1 | 0.25 |
| *Calidris mauri* | Western sandpiper | 0.99 | <0.001 | 0.1 | 0.39 |
| *Calidris melanotos* | Pectoral sandpiper | 0.95 | <0.001 | 0.1 | 0.20 |
| *Calidris minuta* | Little stint | 0.94 | <0.001 | 0.1 | 0.20 |
| *Calidris ptilocnemis* | Rock sandpiper | 0.99 | <0.001 | 0.1 | 0.34 |
| *Calidris pusilla* | Semipalmated sandpiper | 0.98 | <0.001 | 0.1 | 0.17 |
| *Calidris ruficollis* | Red-necked stint | 0.97 | <0.001 | 0.1 | 0.18 |
| *Eurynorhynchus pygmeus* | Spoon-billed sandpiper | 0.99 | <0.001 | 0.1 | 0.21 |
| *Limnodromus scolopaceus* | Long-billed dowitcher | 0.96 | <0.001 | 0.1 | 0.25 |
| *Limosa haemastica* | Hudsonian godwit | 0.99 | <0.001 | 0.1 | 0.27 |
| *Numenius tahitiensis* | Bristle-thighed curlew | 1.00 | <0.001 | 0.17 | 0.46 |
| *Phalaropus fulicarius* | Red phalarope | 0.95 | <0.001 | 0.1 | 0.21 |
| *Pluvialis dominica* | American-golden plover | 0.97 | <0.001 | 0.1 | 0.15 |
| *Pluvialis fulva* | Pacific-golden plover | 0.94 | <0.001 | 0.1 | 0.19 |
| *Pluvialis squatarola* | Grey plover | 0.93 | <0.001 | 0.1 | 0.20 |
| *Tryngites subruficollis* | Buff-breasted sandpiper | 1.00 | <0.001 | 0.1 | 0.18 |

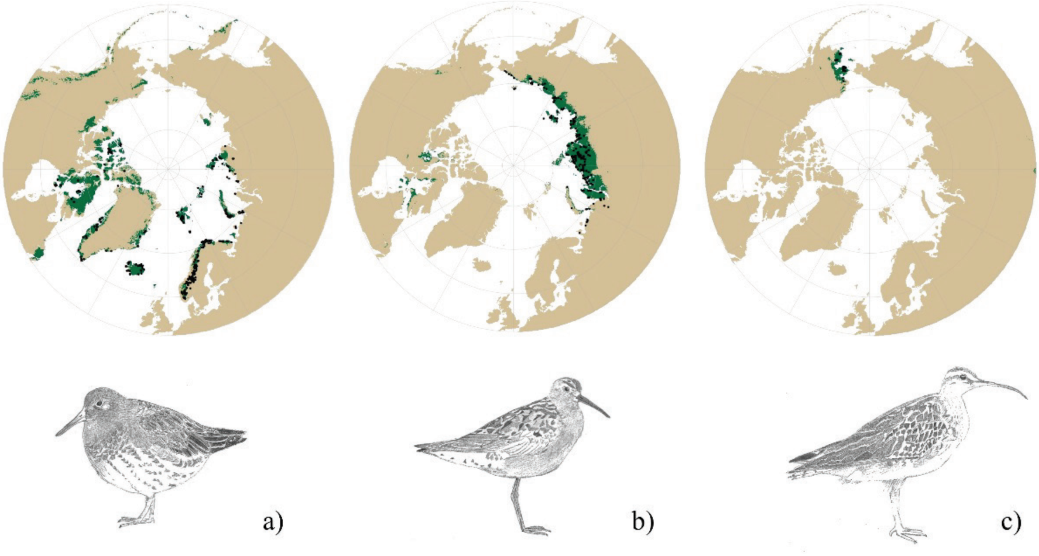


Figure 1 Example suitable climatic habitat maps for **a)** Purple sandpiper *Calidris maritima*, **b)** Curlew sandpiper, *Calidris ferruginea* and **c)** Bristle-thighed curlew, *Numenius tahitiensis*. Black dots represent occurrence points that were input to MaxEnt, and green indicates modelled suitable climatic habitat.

## *Discussion*

MaxEnt appears to have given reliable distributions of suitable climatic habitat for all species investigated. Whilst some habitat was identified outside areas of known occupancy, general trends of distributions were good, and model performance statistics confirmed this. The models were built on a broad spatial scale and do not reflect detailed microhabitat choice of species, rather a broader understanding of distribution. More importantly, they rely on the assumption that distributions are constrained by, or correlate with, abiotic factors. If, in reality, the true factors affecting distributions are biotic, such as prey and predator interactions that do not closely correlate with climatic variables, then this assumption may be violated. Therefore the models must be dealt with cautiously, especially when projecting into novel scenarios.

These distributions can be used for identification of spatially explicit threats to species, an important component of assessing vulnerability. Currently, all species appear to have adequate proportions of suitable climatic habitat represented by protected areas, an encouraging result from this analysis. Models can also be used to project future impacts to distributions, such as climate change impacts (Wauchope 2014). This requires a broader set of assumptions, but is once again a useful tool for identifying key species that are particularly at risk to a warming environment.

Whilst Environmental Niche Models and are no substitute for a detailed understanding of species physiological and biological requirements, they provide an excellent first step in understanding distributions that can be built for a number of species using publicly available data and a relatively simple method.

*Carbon.*
*The fundament for life.*
*Found in carbon dioxide, cells and diamonds.*

*Carbon.*
*The fundament for life.*
*Brought into the food chains through photosynthesis.*

*Carbon.*
*The fundament for life.*
*Harvested from carbon dioxide by plants – assisted by sunlight and water.*
*With oxygen as a valuable bi-product.*

*Polar plants.*
*The fundament for life at high latitudes.*
*Assisted by substrate and nutrients.*
*And tailor-made environmental conditions.*

*Lemmings. Ptarmigans. Reindeer.*
*And migratory birds.*
*Ermines and birds of prey.*
*Foxes and wolverines.*
*Wolves and bears.*
*Fury and feathery predators feeding on herbivores of the white polar landscapes.*

*Together a polar pyramid.*
*Build of cosmic forces, magical water molecules and valuable carbon.*
*By flora and fauna.*
*As polar ecosystems.*

*Polar darkness.*
*Midnight sun.*
*Water. Drought.*
*Flora. Fauna.*

*They all rule the polar kingdom together.*
*A majestic kingdom on the edges of Earth and life.*
*A majestic kingdom, both robust and vulnerable.*
*A majestic kingdom in an era of change.*

*Kriss Rokkan Iversen, SALT*

## Mapping tundra's most vulnerable surfaces, from field detection to satellite aided detection

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### *Introduction*

During the last decades, an increasing number of people are finding their way into different arctic and alpine regions. The traffic is mainly associated with tourism, science, or exploitation of natural resources. Using the arctic archipelago of Svalbard as an example, the number of passengers at Svalbard airport has more than doubled since 1997 (Governor of Svalbard 2012) . Large parts of the Arctic are also populated by native people who have different kinds of traditional land use, such as reindeer herding. In their traditional form, such land use is usually sustainable, and an integrated part of the local ecological systems. However, the modern world is also coming to these settlements, and higher expectations of profitability with it. To meet these new expectations, higher efficiency is needed, and motorized vehicles in the field are increasingly common in some areas.

The new situation raises several questions regarding sustainability in arctic and alpine systems. However, authorities of several countries are responding, and we see projects on monitoring impacts and assessing vulnerability being carried out several places in the Arctic. Vulnerability of arctic land surfaces is also the scope of this study, which is focused on new methods of mapping vulnerable surfaces. Land surfaces in the Arctic are in general considered as vulnerable to mechanical impact due to their low capability of regeneration. However, there is obviously some variation among different arctic surfaces both in their ability to resist mechanical impact and their ability to regenerate. A better understanding of this variability is needed in order to establish a sustainable management of arctic regions. In particular, we see great potential in improving management by correctly identifying and mapping variation in surface vulnerability.

Conventionally, the mapping and evaluation of vulnerable surfaces have been tackled by manual fieldwork. This is probably a good approach in some contexts, but there are some important limitations. Without a consistent methodology, much subjectivity is introduced in the results, and the quality and priority is highly dependent on the experience of the personnel doing the work. Vulnerability of land surfaces is a variable comprising various components, the most important probably being soil texture, hydrology, topography, flora, and vegetation. Hence, making a good judgment requires a profound understanding of the system. Manual fieldwork is also expensive, and there is a great limitation in the area one is able to cover during a field survey with reasonable funding. As a result, mapping of vulnerability is often limited to small areas, and often includes non-visited areas for which results are extrapolated, introducing considerably greater uncertainty than in visited areas.

The aim of this study was to overcome some of the limitations of the conventional mapping of vulnerability, and develop a cost efficient and less subjective method for mapping vulnerable surfaces over larger areas. We knew that most fragile and vulnerable surfaces in tundra have characteristics regarding vegetation types and bare soil fractions, which should be possible to identify in satellite images. It is also beyond doubt that the topography and the slope of the terrain greatly affect the vulnerability of land surfaces. Hence, we wanted to model what we here call the topo-spectral signature of vulnerable land surfaces.

Láhko National Park, which is a recently established protected area in an alpine area of central Norway, was chosen as the study area. An increasing number of tourists are expected in the Park, and reindeer herders on off-road vehicles also use the area. High-resolution satellite imagery and a digital elevation model were the tools for creating a topo-spectral model, based on reference areas delimited in the field. The inferred top-spectral signature of known areas with vulnerable land cover, was then used to detect similar vulnerable surfaces over the entire park and map them in high spatial detail.

## *Material and methods*

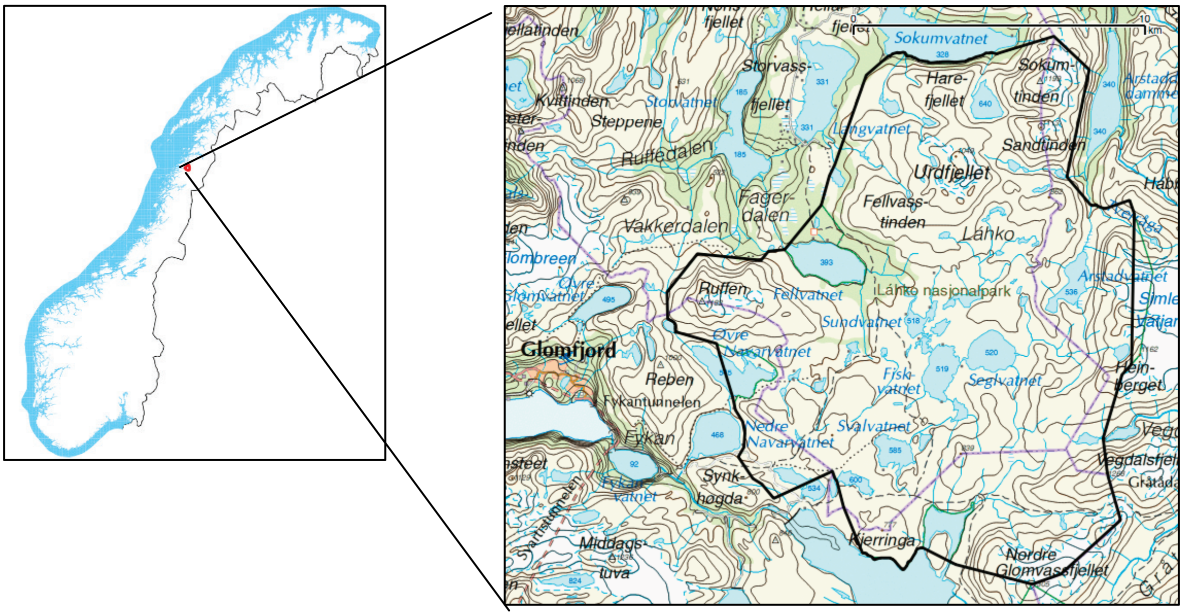


Figure 1 Map of Norway indicating the position of Láhko National Park, and a more detailed map giving an overview of the park.

Our study area, Láhko National Park is a small park (188 km$^2$) situated in central Norway, in the county of Nordland, and it is mainly a treeless alpine area. The traditionally extensive use of the area in the past is expected to intensify with the establishment of the National Park. A number of reasons are pointing in that direction; The Park is fairly easily accessible by car, and there are some attractions now getting better known. Some impressive marble outcrops account for Northern Europe's largest area of alpine karst, and the calcareous substrates are suitable for a number of rare alpine plant species, such as *Braya linearis*, *Draba lactea*, *Draba cacuminum* ssp. *angusticarpa* and *Cystopteris regelii*, which all occur in the area. Several of the Park's lakes are also becoming popular destinations for trout fishing, and the Norwegian Trekking Association has marked several new routes in the area. We are focusing on preventive mapping of vulnerable surfaces at this stage, but the expected changes in traffic also creates some interesting possibilities in relating the present results to future events in the Park.

A surface´s vulnerability to mechanical impact depends on several parameters, the most important probably being soil texture, hydrology, slope, and vegetation cover. Hagen *et al*. (2012a) discuss this in detail, but a short summary is given here. Fine-grained soils are usually less stable than gravelly soils. Wet soils are more easily altered than the equivalent dry soils. A sloping terrain is more easily disturbed because more friction is needed in order to move around on it than on a horizontal surface. Finally vegetation cover greatly influences vulnerability in several ways. Dense vegetation creates a protective layer between the soil and the disturbing agent. A lignified vegetation cover of dwarf shrubs is usually more resistant than grasses and herbs. Furthermore, the root systems of plants bind the soil together, and in doing so significantly strengthen the resistance of fine-grained soils. These variables are all working together forming a variety of vulnerability regimes.

As a starting point for modelling the vulnerable surfaces in Láhko, representative parts of the Park were surveyed in order to get an overview and delimit reference areas containing vulnerable surfaces. We found in particular surfaces with a fragmentary vegetation cover on fine-grained soil. Such surfaces usually occur on ridges, and they are also provide potential habitat for *Braya linearis*, one of the rare plant species in the area. However, late snow beds can have a fragmentary vegetation cover as well, combined with fine-grained moist soil, making it a very fragile surface easily altered by mechanical impact. The recovery potential of such systems is also poor as the production rate is very low. Bogs are also usually considered as vulnerable, as the soft surface is quite badly affected especially by vehicles, and the tracks subsequently serve as draining channels, generating a positive feedback process that erodes them even deeper. Bogs and other wet surfaces are not common in Láhko, as the marble is perforated by caves and ducts draining the water into a subterranean system. However, in the southeastern parts bogs do occur. In the present case study we modelled the occurrence of fragmentary vegetation cover on fine-grained soil as well as vegetated wet areas such as bogs and springs, throughout the Láhko National Park.

Detecting unvisited vulnerable surfaces was done in a three step procedure. The first step was combining the reference areas outlined in the field, satellite images, and digital elevation model (DEM) in a geographical information system (GIS). The satellite imagery provides reflectance characteristics and the DEM topographical features (slope, aspect) of the reference areas. The output of this initial step is the topo-spectral signature of the vulnerable surfaces represented by the reference areas, calculated by the GIS. The second step consists of determining the topo-spectral similarity between visited vulnerable sites and unvisited areas, which can be interpreted as the likelihood that a given area is vulnerable. The third and last step is finding the optimal threshold value for classifying the landscape into vulnerable or non-vulnerable areas. This is done by evaluating the performance of the model in know areas, but also a somewhat subjective process

Cloud-free satellite imagery was acquired over the Láhko National Park in July 2013 by the Worldview-2 sensor. It is one of the only sensors to combine a high spatial resolution with a high spectral resolution. It produces images of the Earth surface with a pixel size of 2 meters, enabling the detection of relatively small features of the landscape. It images the Earth not only in red, green and blue wavelengths, as do regular digital cameras, but also in yellow and three ranges of near-infrared wavelengths. This characteristics makes it possible to distinguish a variety of different land cover types in the imagery. The inclusion of different near-infrared channels in the sensor, makes it particularly suited for differentiating between vegetated land cover types, as healthy vegetation is characteristically bright in near-infrared wavelengths.

### *Results*

The topo-spectral signature of the vulnerable land surfaces was determined by comparing areas identified as such, to other areas in 10-dimensional space defined by the 8 channels of the Worldview-2 sensors, a topographic slope gradient, and a topographic aspect gradient. When considered in this way, vegetated wet areas, and fragmented vegetation cover on fine-grained soils, both are unique, having a combination of spectral and topographic characteristic that is fairly clearly distinguishable from other land surface types.

Robustness of the results was evaluated by iteratively excluding subsets of the field data from the determination of the spectro-topographic signature determination. We then assured, that even when they were excluded from this 'calibration' phase, the model correctly estimated the hold-out data subset as vulnerable.

The output of the three-step process is a readily interpretable raster layer indicating the occurrence of the vulnerable land surface types, in this case, sites with fragmentary vegetation cover on fine-grained soils, and vegetated wet areas such as bogs and springs. Depending on the context and further use of the results it is necessary to do further interpretations. In the result presented in Figure 2 we have chosen to draw lines around areas having particularly dense occurrences of vulnerable surfaces. Such delimitation is useful in managing an area such as a National Park.

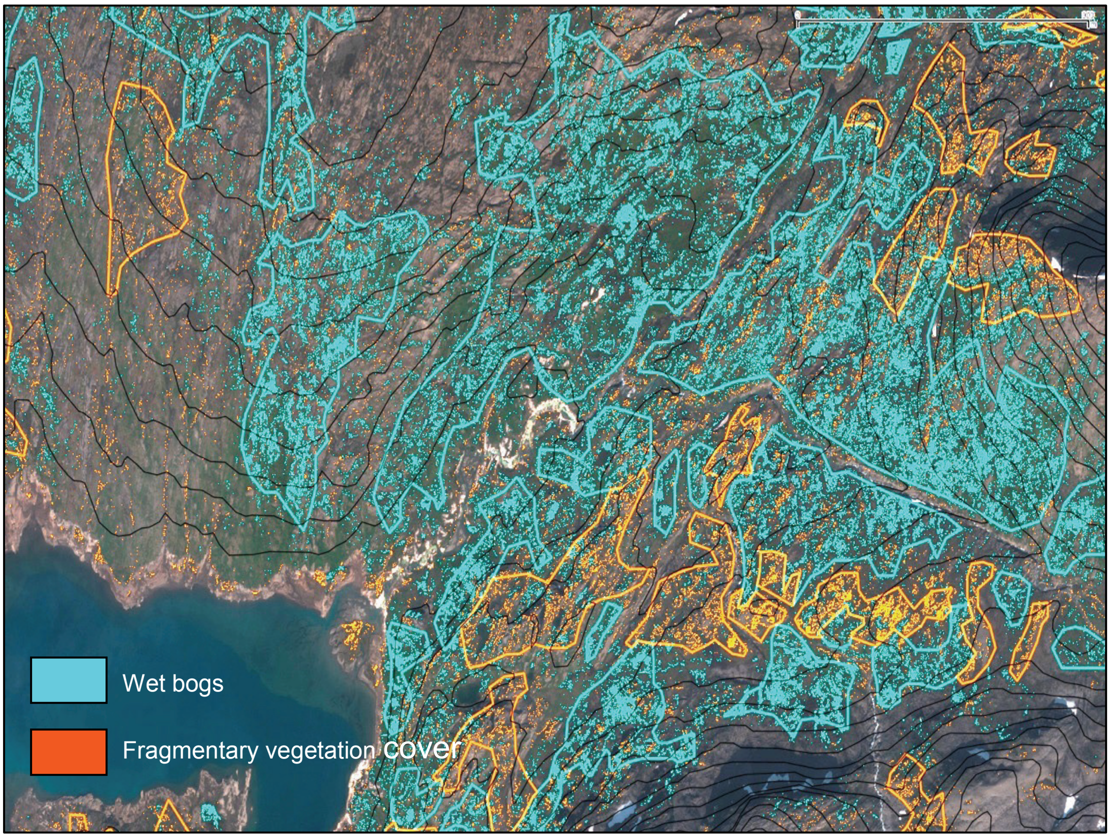


Figure 2 An area in the southeastern parts of Láhko having occurrences of the two modeled vulnerable surfaces treated in this study.

### *Conclusion and perspectives*

This work has to a large degree succeeded in detecting and mapping the distribution of vulnerable surfaces over a fairly large area and with a modest budget. The detected occurrences of the vulnerable units are plausible, and evaluation of the results in known areas indicates that the model performs well. The advantages of this method over more conventional mapping are the possibility to extend the model over large continuous areas, which could not possibly be surveyed within reasonable budgets. It is also a more objective approach of extrapolating limited field observations giving the possibility to statistically compare additional field observations to model results. Further model evaluation can also indicate areas where the map is more uncertain and further field surveys could be optimally allocated to further improve the maps.

There are, however, limitations; In high arctic systems, a short growing season and high cloudiness are strongly limiting the opportunities to obtain satellite imagery. Also low sun angles throughout the year and dramatic topography creates shadowing and other artefacts on the images. Nevertheless, we see this as a very useful method for mapping vulnerable surfaces over extensive areas in both arctic and alpine systems. Problems with clouds and shadowing are evident, but as this method is intended to be used in mapping of larger areas, and time series of images is not needed, reliable imagery will be available in most cases. When available, time series could in theory be used to track changes in landscape vulnerability. However, even in the absence of clouds, atmospheric and illumination conditions vary between satellite images acquired on different dates, as does vegetation phenology. These variations are not easily accounted for, and mean that single models to detect particularly land surface type cannot be directly transferred between satellite scenes. Further research is needed to evaluate to what extent the present method can robustly be extended for surface vulnerability change tracking.

# Monitoring human and climate change-induced plant stress in the Nordic Arctic Region and Svalbard using remote sensing and field surveys

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The Arctic is warming more rapidly than almost anywhere else, and this is resulting in equally rapid environmental change. At the same time, man-induced stress and wear and tear to the vegetation is increasing. In order to detect and monitor plant and vegetation stress, remote sensing has become a valuable tool. However, also field based methods are needed to evaluate and assess the remotely sensed data. Here, we review methods for detection and monitoring of vegetation stress and damage, with examples from recent studies.

## *Man-induced plant stress*

Increasing traffic by all-terrain vehicles (ATV) has become a problem in the Arctic. In order to assess damage from such activity, we used very high resolution imagery (spatial resolution of 1 m) acquired by satellites (Figure 1) and/or digital aerial imagery including Unmanned Aerial System (UAS) in combination with field observations (Tømmervik *et al*. 2012). These studies were conducted in northern Norway and Svalbard, and the conclusions were that high to very high resolution optical satellite imagery are well suited (Norway; overall accuracy = 85%; see Table 1) for surveying damage to the vegetation caused by ATVs. Even single tracks of small ATVs were detectable in open terrain. Fens (mires) was the habitat type most severely damaged.

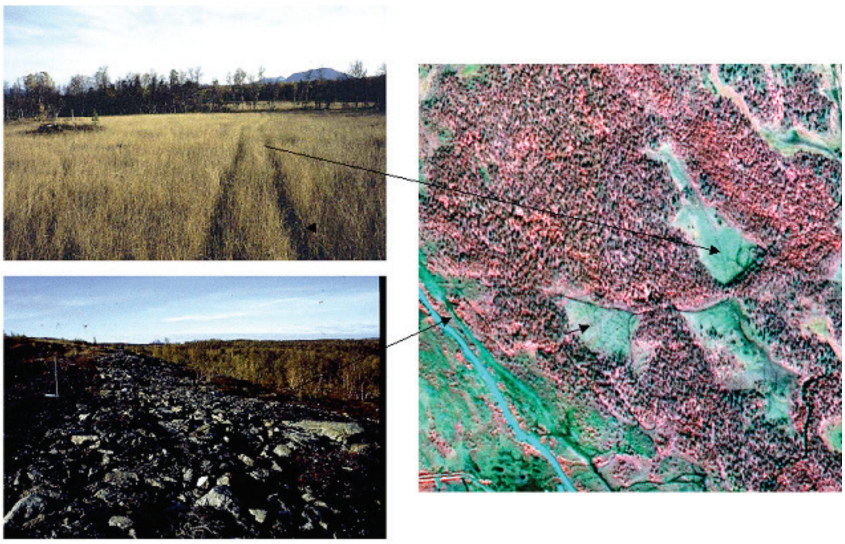

Figure 1 Single track from ATV (6-wheeled motorbike) in a fen can be observed in the high resolution imagery acquired by the IKONOS-1 satellite. Also observed is a road under construction.

Table 1 Detection accuracy of ATV tracks of major land cover types. The majority of M113 tracks are more than 25 years old.

| Type of ATV | Leopard Armoured Vehicle (tank) | CV-90 Armoured vehicle | M113 Armoured vehicle (old tracks) | Medium large ATV: BV-202 (old tracks) | Medium large ATV: BV-206 | Small ATV (bikes) | Small ATV(bikes); Single tracks | Overall accuracy |
|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % |
| **Mountain heaths** | 100 | 100 | 43 | 86 | 80 | 80 | 20 | 79 |
| **Fens (mires)** | 100 | 100 | 78 | 91 | 92 | 90 | 80 | 90 |
| **Forests** | 100 | 100 | 50 | 84 | 86 | 71 | 20 | 76 |
| **Overall accuracy** | 100 | 100 | 60 | 88 | 89 | 86 | 50 | 85 |
| **Number of sites** | **7** | **23** | **27** | **268** | **42** | **37** | **20** | **424** |

Using UAS equipped with proximal NDVI cameras on a test field in Adventdalen in Svalbard (Figure 2) showed a significant correlation between the surface *NDVI* plant community level and the UAS *NDVI* plant surface level ($R^2$ = 0.75 , $p$<0.01). This suggests that UAS is a suitable tool for assessing the environmental state of vegetation in Svalbard (Tømmervik *et al*. 2014).

Cultural heritage sites are among the main tourist attractions in Svalbard, and some sites are much visited by cruise ships – a traffic that can damage or destroy the sites. In order to assess the impact of trampling and wear by tourists we used digital aerial imagery from 1990 and 2009, UAS imagery from 2014, field plot surveys and fluorescence measurements. Preliminary analyses (unpublished) show that the principal component analysis (PCA) on the imagery was most satisfactory concerning detection of wear, but classification and change detection using NDVI indices also provided satisfactory results.


Figure 2 UAS based NDVI image taken 100m above the surface in Adventdalen, Svalbard. Ground spatial resolution is 2.5m.

### *Climate change-induced plant stress*

The release of cold temperature constraints on photosynthesis has led to increased productivity (greening) in significant parts (Fig. 3) of the region north of the Arctic Circle (Xu *et al*. 2013), but still, much of the Arctic shows stable or reduced productivity.

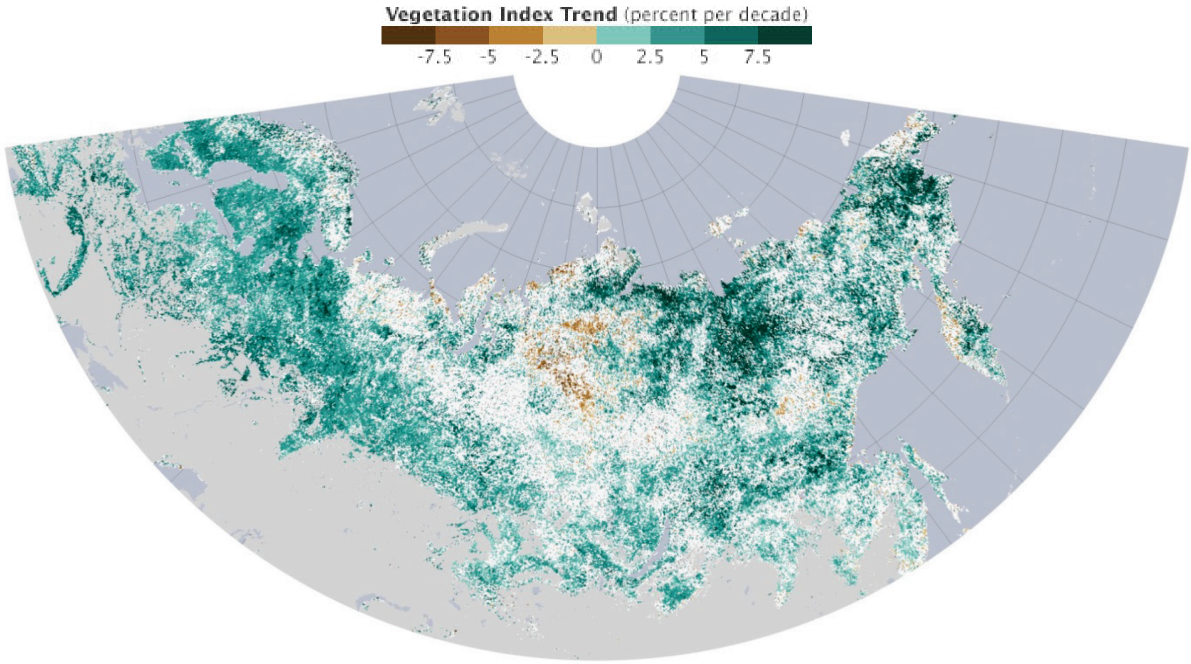


Figure 3 Productivity of the vegetation presented as vegetation index trend (percent per decade) in the period 1982-2011 based on NOAA AVHRR GIMMS NDVI3g imagery. Productivity increase (greening) is presented in green colour while decrease (browning) is presented in brown colour. Map based on the results in Xu *et al*. 2013.

In a recent paper (Bjerke *et al*. 2014), we show examples on how weather events in all seasons cause significant ecosystem damage (also called browning) in the Nordic Arctic Region (Fig. 4). We show how a combination of field-based surveys (including proximal NDVI-cameras) shortly after events and use of satellite imagery (MODIS, Landsat and SPOT) are suitable tools for assessing habitat vulnerability to the stress imposed by these events.

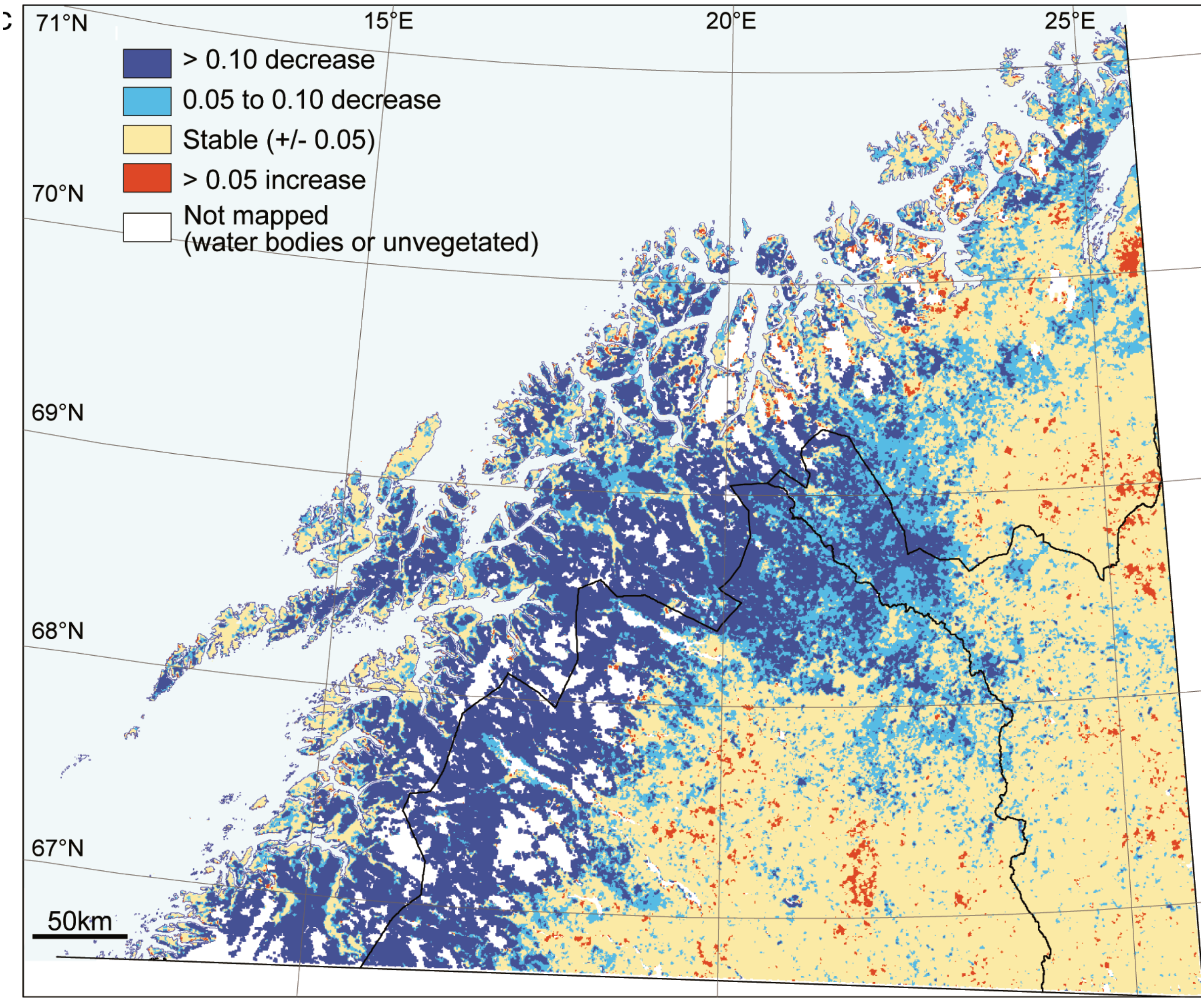


Figure 3 Change in vegetation greenness (NDVI)in the Nordic Arctic Region based on the Terra MODIS satellite imagery. The map shows areas with NDVI values in 2012 lower (blue colours) or higher (red) than the 2000–11 average. Scale shows changes in NDVI units. Source: Bjerke *et al*. 2014, ERL.

We showed that primary productivity in the region is more regulated by events than by long-term changes in mean climatological parameters. As also concluded by the IPCC group for Polar Regions, we see an urgent need to incorporate monitoring of effects of weather events in ongoing Arctic monitoring programmes in order to better understand how factors other than average summer temperature, drought and wildfires affect primary productivity (Bjerke *et al*. 2014).

## Effects of pink-footed goose grubbing on tundra vegetation: A proposal for a monitoring programme in Svalbard

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In the high-arctic archipelago of Svalbard, the pink-footed goose *(Anser brachyrhynchus)* population has increased dramatically over the last decades (Fox *et al*. 2010; Madsen *et al*. 1999; Madsen and Williams 2012). After arrival in spring (medio May) the pink-footed geese forage for 2-3 weeks on below-ground plant parts, including roots and rhizomes, using a strategy known as grubbing (Fox and Bergersen 2005; Fox *et al*. 2006). Up to 90% of the forage of the pink-footed geese consists of below-ground plant parts (Fox and Bergersen 2005; van der Wal *et al*. 2007a). The grubbing may lead to degradation of the tundra vegetation due to geese removal of plant parts and disturbance of soil properties and carbon storages (Sjogersten *et al*. 2008, 2012; Speed *et al*. 2010a; Speed *et al*. 2010b; van der Wal *et al*. 2007a). Strong top-down effects on both plant productivity and community structure have been documented (e.g. Bazely 1997; Sjogersten *et al*. 2012; Speed *et al*. 2010a; van der Wal *et al*. 2007), demonstrating that grubbing has consequences for the structure and function of tundra habitats.

The arctic tundra is characterized by low productivity and a slow recovery rate from disturbances (Speed *et al*. 2010a). Grubbing may therefore lead to long-lasting impacts on the terrestrial Svalbard ecosystem. The recovery rate of the grubbed areas generally depends on habitat type, the degree of grubbing and the weather conditions (e.g. Handa *et al*. 2002; Jefferies and Rockwell 2002; Speed *et al*. 2010a).The population increase and the corresponding range expansion (Jensen *et al*. 2008), suggest a substantial increase in the potential for disturbance of the tundra caused by goose herbivory. Such developments have underlined the need to monitor plant-herbivore interactions as an integral part of ecosystem-based monitoring of the terrestrial food web, a paradigm currently under vigorous development both nationally and internationally (Ims *et al*. 2013; Ims *et al*. 2014).

Here we presented the study design and field sampling methods suggested to monitor the goose grubbing activity in pre-breeding staging areas and at the nesting sites (Anderson *et al*. manuscript; Ims *et al*. 2013). We propose an adaptive monitoring programme consisting of two monitoring designs: 1) Goose targeted approach based on Anderson *et al*. (manuscript) and 2) landscape scale contrast approach based on Ims *et al*. (2013). These designs incorporate gradients in habitat (from wet to dry) and climate (snow cover differences) and contrasts in population abundance of geese and other tundra herbivores. Preferably, the goose targeted monitoring should be carried out at 3-year intervals to be coordinated with the reporting from the international adaptive management plan for the Svalbard population of the pink-footed goose (Madsen and Williams 2012), and the latter approach corresponding to the annual temporal scale of Ims et. (2013).

# An approach to assessing vulnerability of migratory tundra caribou in northern Canada and Alaska to a warming climate

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## *Introduction*

This paper is about vulnerability of circumarctic reindeer and caribou *Rangifer tarandus* L. to climate change. *Rangifer* are keystone species of the tundra biome (CAFF 2013) responsible for top-down forcing of plant responses to climate warming. For example, foraging by reindeer can retard an increase in shrub growth and thus increase the breeding habitat for some bird species (Zöckler *et al*. 2008).

*Rangifer* populations constitute major sources of sustenance for indigenous peoples and are also prey for top predators (Hummel and Ray 2008). Thus, assessing the vulnerability of caribou and reindeer in a changing climate and development activities within the system is important to the wider assessment of vulnerability of circumarctic people, flora and fauna.

Many factors affect abundance and distribution of caribou and wild reindeer (Tveraa *et al*. 2007; Bergerud *et al*. 2008; Gunn *et al*. 2009). These factors include natural cycles (Gunn 2003), predation, landscape changes including interacting effects of a warming climate, industrial development, hunting technology and governance (Gunn *et al*. 2009). Thus, many interactions complicate our ability to assess the relative contributions of drivers to apparent population changes associated with global change.

Recently, we have focused on assessing the cumulative effects of ecological and anthropogenic drivers on caribou productivity and population trends (Gunn *et al*. 2011, 2014; Russell 2012). However, declines of many migratory tundra caribou herds since the mid-1990s (Fig. 1) have added urgency to assess global change as well as industrial disturbance (Festa-Bianchet *et al*. 2011).

Our approach to assessing vulnerability is built on the IPCC definitions (http://www.ipcc-wg2.org/; Parry *et al*. 2007). Exposure to environmental change and the sensitivity of *Rangifer* lead to potential impact on the system that can be offset by the adaptive capacity of the *Rangifer* system. We view adaptive capacity as a buffer to potential impact as we assess vulnerability (Fig. 2).

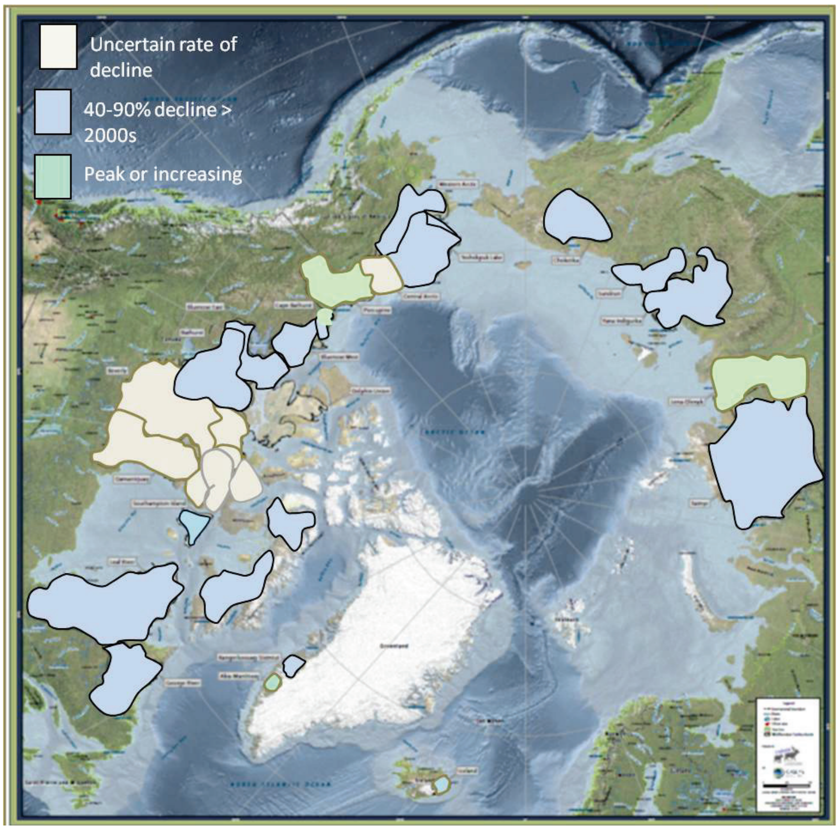


Figure 1 2014 assessment of circumarctic caribou and wild reindeer populations based on CARMA datasets.

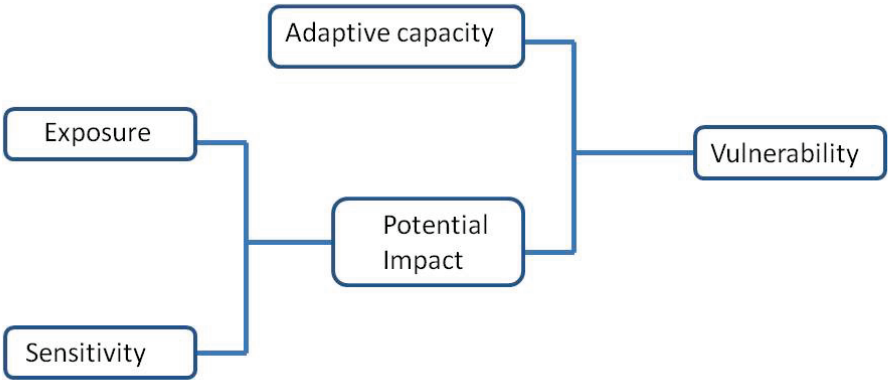


Figure 2 Schematic relations used to estimate **vulnerability** based on **exposur**e to climate change, **sensitivity** of the system and the potential to offset **potential impact** by **adaptive capacity**. Schematic based on recommendations from IPCC 2007.

## *CARMA's approach to assessing vulnerability of human/caribou systems*

Assessing vulnerability is knowledge-intensive. We realized that to describe the components of vulnerability (exposure, sensitivity and adaptive capacity) we needed a detailed understanding of nutritional ecological relationships relative to productivity and survival. To propose and test the relationships through modeling took a high degree of collaborative data sharing and working together. We developed CARMA (CircumArctic Rangifer Monitoring and Assessment) Network that since 2004 has generated data banks for the major Arctic herds in North America as well as for Russia, Norway, Iceland and Greenland (Russell *et al*. 2013a). These data banks include herd range climate data (MERRA), population size and productivity, morphometric data (body mass condition indices and health indices such as incidence of parasites and diseases).

Further, CARMA has developed new (Frid *et al*. 2014) or enhanced existing (Russell *et al*. 2005; White *et al*., IN PRESS) models that allow us to integrate our energy-protein dynamics with population demography to make an assessment of cumulative effects whether due to climate change, industrial development or management policies (Russell *et al*. 2013b; Gunn *et al*. 2014). We now have the experience and trust from working within the CARMA Network to derive a functional analysis of vulnerability of arctic caribou herds based on their exposure to climate change, and our assessment of herd-specific sensitivity and adaptive capacity.

Because we are working with caribou/human systems, we hypothesize that the offset of potential impact to the system will be both through herd and range management and through physiological and ecological strategies evolved by *Rangifer* as a species.

**1. Determining Exposure to global change drivers**

Across the circumarctic, *Rangifer* herds are exposed to the decadal continental-scale climate drivers: namely, the North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and the North Pacific Decadal Oscillation (NPDO). Effects on winter include snow depth, icing events and freeze-thaw cycles which, in turn, influence *Rangifer* survival and body condition (Griffith *et al*. 2002; Miller and Gunn 2003). In summer, duration of the growing season and temperature effects have a cascade of direct and indirect effects through nutrition. As an example, summer drought conditions can dramatically alter forage quantity and quality (digestibility, nitrogen content) and result in significant variability in cow/calf energy-protein dynamics. Monitored during the rut, lower body weight and fat reserves effect probability of pregnancy and calf survival.

From our climate database we note considerable variability in herd long-term drought conditions between 1979 and 2009. We maintain that herd-specific energy-protein strategies have evolved to allow herds to thrive under variable long-term climatic conditions within their ranges. However, with increasing evidence of climate change, especially climatic extremes, it is important to examine trends and variability among herds.

We chose three herds with similar long-term drought index averages (Taimyr, Western Arctic and George River) and note that the pattern of annual drought conditions varies considerably. The George River experiences relatively stable conditions while the Taimyr herd experienced much more variability especially in the mid-1980s. Using CARMA's climate database, we can document such herd-specific *exposure* to climate indicators.

A climate warming has increased the northern movement of both plant and animal pathogens. But changes in green-up date, in relation to winter stress can expose animals to increased parasite and other pathogens that require a strong immune system that extracts a cost to both the protein and energy balances of the animal. These effects are frequently sub-clinical but can cascade through the nutrient balance of the animal affecting productivity at a number of levels (Fig. 3).

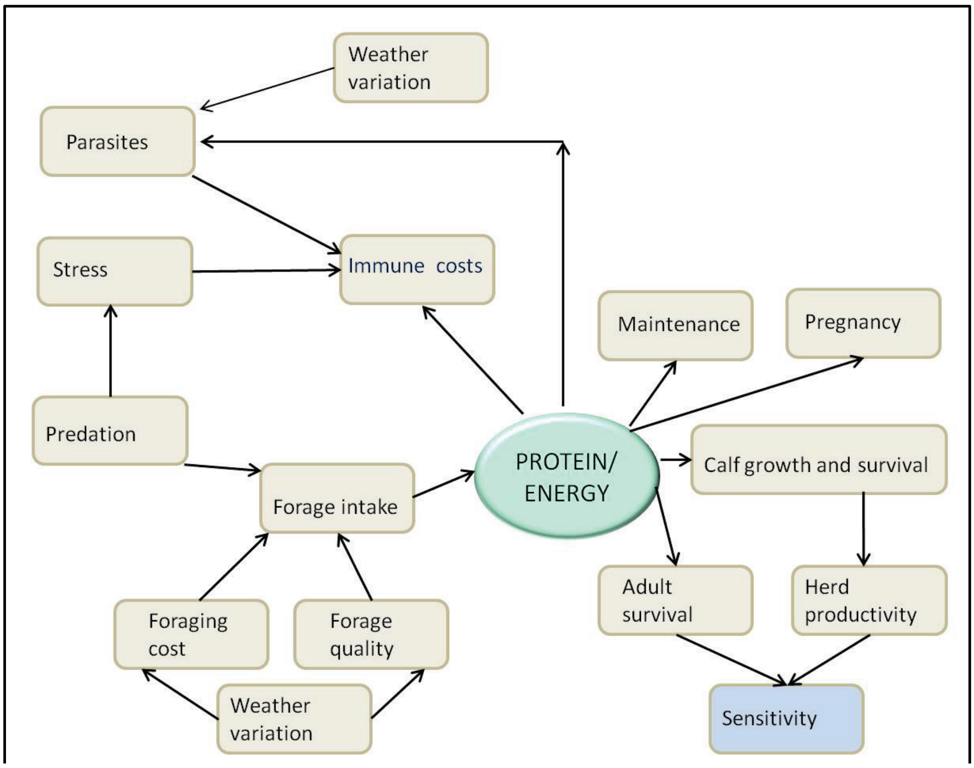


Figure 3 Interacting drivers of the caribou/reindeer energy-protein model as integrated in CARMA's model. The energy-protein model and linked population model can describe the sensitivity of the caribou to climate change.

**2. Assessing Sensitivity to change**

As a starting point, we can use the probability of pregnancy to assess sensitivity to climate change. The probability that a cow caribou will become pregnant during the rut is linked to body weight and fat reserves, usually in the form of a logistic function (Fig. 4). However, when we used CARMA's body condition database to determine the shape of the logistic curve we found it varied among herds, especially with respect to the steepness of the curve (Fig. 4).

We assume that herds with a steeper curve are more affected by changes within their respective ranges because a given decrease in body weight will result in a large impact on a cow's probability of pregnancy. Thus, by linking changes in the body condition of a cow during the rut due to climate change, with herd specific functional responses with respect to probability of pregnancy we can provide *sensitivity* metrics to vulnerability of herds to climate change.

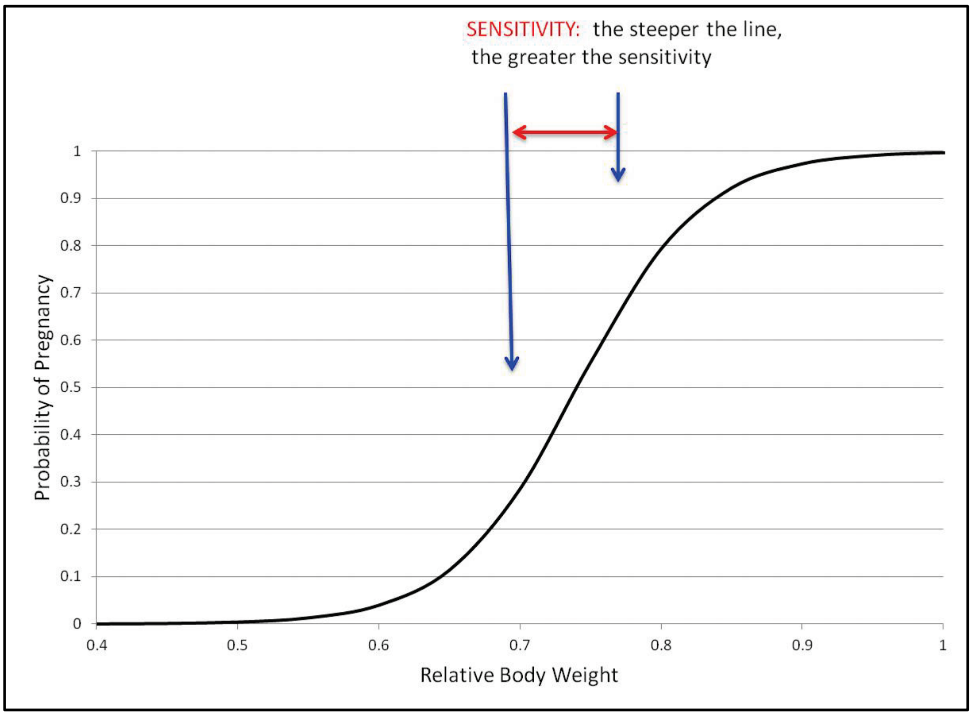


Figure 4 Steepness of the probability of pregnancy in relation to relative body weight is used to implement a **sensitivity** measure of the caribou/reindeer system.

### 3. Adaptive Capacity

We recognize both a physiological as well as a sociological contribution to adaptive capacity of a herd to buffer environmental change. Weaning strategy in caribou is an example of physiological strategy. Weaning in caribou normally occurs during the rut, however if conditions are poor caribou can wean either immediately post-calving, during the summer or in early September depending on the condition of the cow and her calf.

Further, caribou will extend lactation into the winter if it benefits the survival of the calf at the expense of the cow becoming pregnant (Russell and White 2000, Fig. 5). Such a dynamic process buffers environmental change and ensures optimum reproductive output under varying conditions.

Caribou normally undergo long-term cycles of abundance (Gunn 2003). Harvest and management of industrial disturbance can impact the timing and magnitude of the recovery period or delay the abundance peak (Kolpashikov *et al*. in press). Thus, we suggest that management policies can enhance the adaptive capacity of a herd to withstand global change within their ranges. As an example, we point to a progressive program, the Harvest Management Strategy developed for the Porcupine Caribou Herd (PCMB 2010). Developed after a recent decline and during a period when population estimates were not available, the strategy outlines a detailed list of monitoring indicators that are compiled and analyzed annually in order to assess current harvest policies.

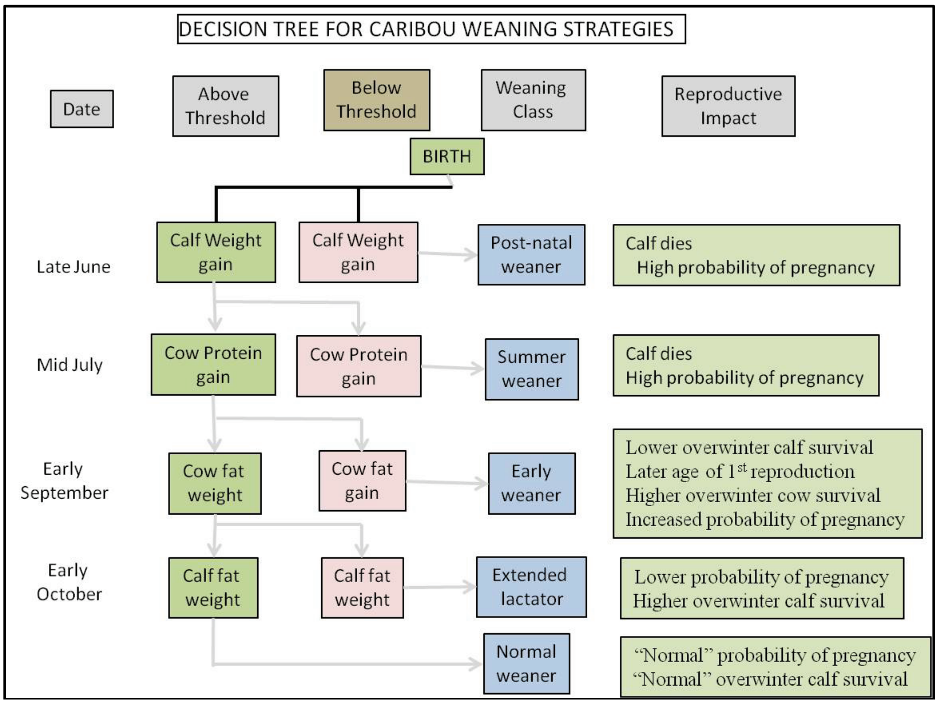


Figure 5 Proposed decision tree by which an individual weans her calf based on her body condition and that of the calf. This decision tree was derived from field data for the Porcupine caribou herd (Russell and White 2000). The cow is assumed to detect body condition of her calf through the calf's nursing behavior. We assume the decision process maximizes individual reproductive success on a long-term or lifetime basis. In each year the extent of population buffering of environmental effects can be assessed from the relative distribution of females in each of the weaning classes.

## 4. Assessing Vulnerability

CARMA's integrated modeling approach can be used to assess herd-specific vulnerability to global change. The model structure allows us to assess the vulnerability with respect to climatic exposure, herd sensitivity and adaptive capacity. Because management agencies and research studies document population herd size and trend, we frequently know the current status of herds (Fig. 1). We can assess whether population status can be used as a proxy for vulnerability of the *Rangifer* system. Independent of whether population status is the appropriate proxy for vulnerability, we need to determine the relative contributions of the measures we used to compute sensitivity, potential impact and adaptive capacity that can reinforce our modeling effort.

We are considering using a "pathway analysis" of contributions of climate, biotic and management interrelations. If we can determine the relative strength of the variables, we could then set up our multi-model system to further verify pathway mechanisms. We anticipate that such an analysis will allow us to make snapshot estimates of vulnerability of unstudied caribou/reindeer systems and will provide a more mechanistic approach to prediction of vulnerability based on outputs from regional climate change and vegetative response models.

Such an attempt for the Saami herding areas (Tyler *et al*. 2007) and those of Barents Sea region of Russia (Rees *et al*. 2007) resulted in conclusions that climate change may result in a minimal influence on tame reindeer herds, but that the adaptive capacity through either owner herd management or “political” management could more strongly influence the vulnerability of the these reindeer owner systems. Our analysis will test whether climate change may play a potentially larger role in hunting systems associated with caribou and wild reindeer populations.

*Covered by ice and snow,*
*they might at first sight look the same,*
*the polar landscapes, seascapes and everything in between.*
*White, vast and untouched.*
*However, looks can be deceiving.*

*If you ever find yourself at the South Pole,*
*you are standing in the midst of the world's fifth largest continent*
*at one of the driest places on Earth.*
*Underneath is 3000 meters of solid ice*
*covering a spot of Antarctica that barely reaches above the sea level.*

*This place – the Antarctic plateau – is one of the most inhospitable places on Earth.*
*Where temperatures range from unfathomable -80 degrees to -12 degrees Celsius.*
*Strong winds are formed by dense cold air at the central plateau*
*moving northwards in all directions,*
*falling down the steep slopes at the edge of the highland at devastating speed.*

*At this place hardly any sign of life can be observed,*
*with the exception of some rare examples of the specie* Homo sapiens.

*If you on the other hand have made it all the way to the North Pole,*
*your life as a terrestrial being is depending on a tiny fleet of ice,*
*not more than four meters thick.*
*Underneath is the Polar Ocean, with a depth of 4807 meters.*

*An ocean formerly believed to be as hostile to life as the Antarctic plateau,*
*but that is now known to be far from the truth.*
*In these waters, myriads of organisms unfold themselves in three dimensions.*
*Drifting with currents, migrating upwards and downwards in the cold water-masses.*
*Searching for prey and avoiding predators.*

*And* at *the tiny rim where land meets sea; a noisy, lively and beautiful scene displays.*
*Nowhere is land and ocean closer entangled.*
*Nowhere is the food chain shorter.*
*Nowhere is the balance of the of the Earth's climate system more important.*

*Penguins, polar bears, walrus and seals*
*all depending on the landscape above and the ocean below the sea surface.*

*Covered by ice and snow,*
*they might at first sight look the same,*
*the polar landscapes, seascapes and everything in between.*

*Kjersti Eline T. Busch, SALT*

## Species vulnerability and their use in oil spill risk assessments

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### *Introduction*

Offshore oil and gas activity always have a risk for environmental impact due to potential accidental releases of oil and gas. The Method for Environmental Risk Analysis (MIRA method) was developed during the period from 1994 – 2000 as a cooperation between the Norwegian Oil Industry Association (OLF) and offshore operators. The Method was first presented by Sørgård et. al. (1997). A common guideline for conducting ERAs by this method was available in 1999 and this guideline and method has been revised several times since, most recently in 2007 (Brude et. al. 2007). This paper presents the use of species vulnerability values in the MIRA method and also gives another example on such use from recent methodology on risk from ship traffic.

### *Offshore oil & gas methodology*

An environmental risk analysis for oil spills starts out with defining potential spill scenarios at a given offshore oil field or exploration drilling site. These spill scenarios (blowout, leakages etc.) are typically modelled statistically with an oil spill model in order to see the potential influence area where acute effects could be expected for various environmental resources and compartments (shoreline, seabirds and marine mammals and fish in the water column). These Valued Ecosystem Components (VECs) are selected on basis of the following criteria:

- VEC must be significantly present within the influence area
- VEC must be vulnerable for oil pollution
- VEC must have a high probability for exposure

In addition to the above criteria, red list species should also be considered included as the effects on such populations are more severe than others.

The VEC population distribution must be mapped at a 10x10 km spatial grid resolution with a monthly temporal resolution. Grid cell values must be in terms of population fraction in each grid cell.

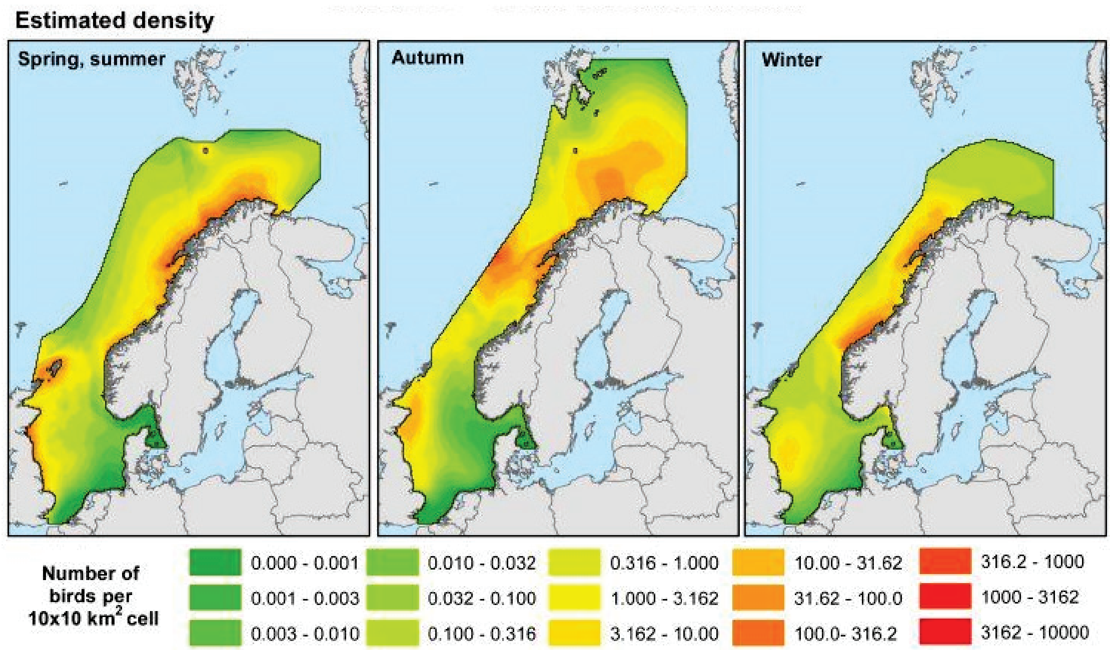


Figure 1 Example of resource distribution on Atlantic puffin (*Fratercula arctica*) used in risk calculations in the MIRA method. Source: SEAPOP (http://www.seapop.no)

For VEC populations, information is also needed on their vulnerability towards oil (value S1-S3, where S1 is low and S3 is high) both of the individual vulnerability of the species (probability of being exposed and dying from oil pollution) and on the population level (reflecting the restitution potential of the population). For VEC habitats the vulnerability value is typically a function of the type of substrate and wave exposure, reflecting the potential for re-colonization of a habitat. Determination of the vulnerability values follows principles back to Anker-Nilssen (1987) as shown in figure 1. Individual vulnerability parameters include behavioural aspects and potential to be exposed to oil and the effect of such exposure, while population vulnerability parameters address the effect on and recovery of the population from a given population loss.

| Individual vulnerability | Population vulnerability |
|---|---|
| 1 - Time in area | 10 - Degree of exposure |
| 2 - Time at sea | 11 - Population size |
| 3 - Area utilisation | 12 - Flocking tendency |
| 4 - Behaviour at sea | 13 - Frequency of immatures |
| 5 - Shore affinity | 14 - Reproductive potential |
| 6 - Possibility of reaction | 15 - Population trend |
| 7 - Flight capability | 16 - Proportion of population at risk |
| 8 - Physical fitness | 17 - Potential immigration |
| 9 - Recovery capability | |

Figure 2 Factors used by Anker-Nilssen (1987) to describe the vulnerability of a seabird to oil pollution.

The VEC distribution is linked to the oil drift fate and trajectories to calculate the potential impact. For each individual oil drift simulation, the acute population reduction (mortality) is calculated as a function of oil mass and vulnerability according to an effect key (Table 1). Acute reduction is calculated for each grid cell and summarized over all cells to give a population reduction for that oil drift simulation.

Table 1 Example of effect key for sea birds giving the acute mortality rate (in %) of a population fraction in a grid cell as a function of oil mass and individual species vulnerability ($S_1$ – $S_3$).

| Oil mass (tons) in 10 x 10 km grid cell | Effect key – acute mortality rate | | |
|---|---|---|---|
| | Individual vulnerability for VEC seabird | | |
| | $S_1$ | $S_2$ | $S_3$ |
| 1-100 | 5 % | 10 % | 20 % |
| 100-500 | 10 % | 20 % | 40 % |
| 500-1000 | 20 % | 40 % | 60 % |
| ≥1000 | 40 % | 60 % | 80 % |

When all oil drift simulations are analyzed, a distribution of various population losses is obtained and a damage key links the population loss to restitution time (in years) for the population based on empirical data from historical oil spills. Different damage keys are used for different population vulnerabilities depending on their current status and recovery potential.

Table 2 Example on damage key for sea birds and marine mammals with high population vulnerability and low restitution potential.

| Acute population reduction | Consequence category – environmental damage Theoretical restitution time in year | | | |
|---|---|---|---|---|
| | Minor <1 year | Moderate 1-3 years | Considerable 3-10 years | Serious >10 years |
| 1-5 % | 50 % | 50 % | | |
| 5-10 % | 25 % | 50 % | 25 % | |
| 10-20 % | | 25 % | 50 % | 25 % |
| 20-30 % | | | 50 % | 50 % |
| ≥ 30 % | | | | 100 % |

For VEC coastal habitats, the restitution time is estimated directly as function of accumulated oil mass stranded and the vulnerability (Table 3). The final damage categorization of habitats in a 10x10 km grid cell is weighted with the relative distribution of shoreline habitat with vulnerability $S_1$-$S_3$ in the grid cell. The results give a probability distribution of the different damage categories.

Table 3 Damage key for estimation of the probability for damage on coastal habitats with high vulnerability ($S_3$).

| | Damage category Theoretical restitution time | | | | |
|---|---|---|---|---|---|
| Vulnerability | Oil mass (tons) | Minor <1 year | Moderate 1-3 years | Considerable 3-10 years | Serious >10 years |
| High ($S_3$) | 1-100 | 20 % | 50 % | 30 % | |
| | 100-500 | 10 % | 60 % | 20 % | 10 % |
| | 500-1000 | | 20 % | 50 % | 30 % |
| | >1000 | | | 40 % | 60 % |

### ***Environmental risk from shipping methodology***

Another case example is taken from the methodology used in oil spill risk assessments for ship traffic. As this activity is not particular site specific and can happen everywhere along the coast where the traffic goes, the following steps must be taken in order to establish a quantitative risk picture:

- establish traffic pattern by use of AIS data
- quantify probabilities for different spill types and volume and establish their damage potential
- adjust the damage potential based on distribution of vulnerable environmental resources
- quantify probabilities for different environmental consequences

Example of how the actual consequence from a spill is estimated based on different vulnerability is shown in Table 4 where a change in vulnerability leads to a shift in consequence category. This actually means that the variation in consequence is equally dependent on the spill volume and the environmental vulnerability. Vulnerability data for this particular case could be derived from Havmiljo.no (2014) for Norwegian waters (see Figure 2).

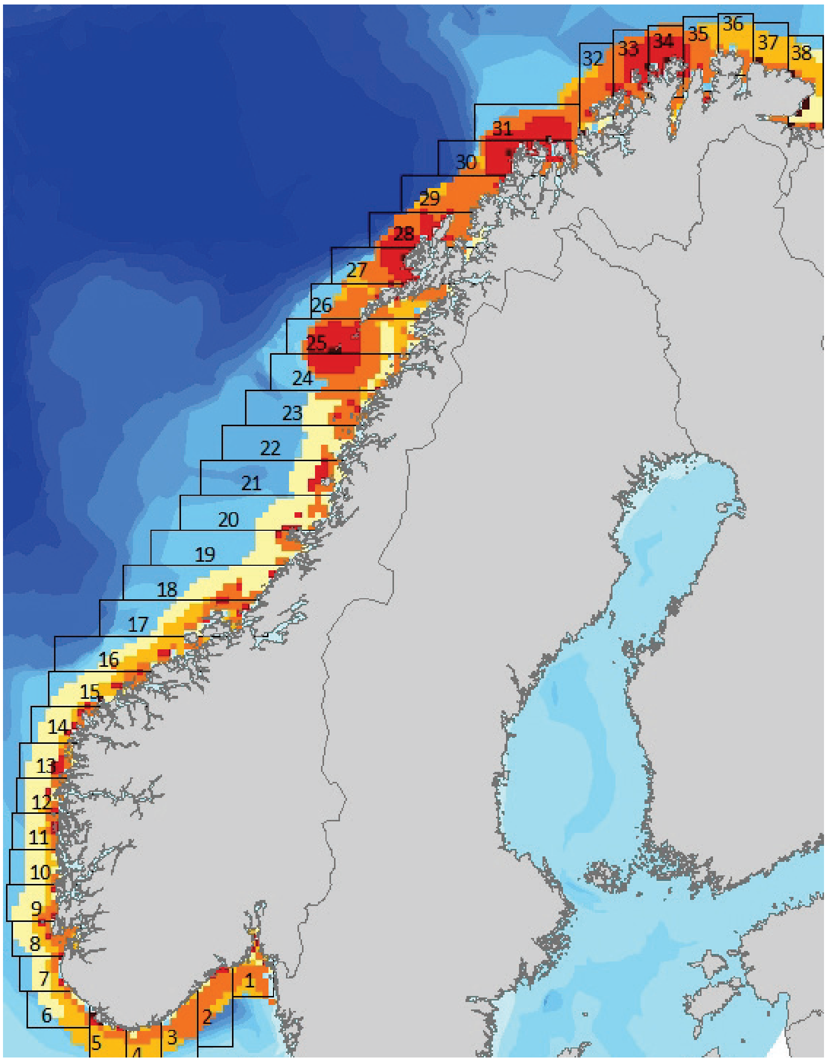


Figure 2 Environmental vulnerability towards oil spills for seabirds along the Norwegian coast in April. Darker colours indicate higher vulnerability. Source: Brude *et al.* (2011) and Havmiljø (2014).

Table 4 Categorisation of consequences for oil on the sea surface (seabirds, marine mammals and coastal habitats) for different discharge categories (product type and volume) and environmental vulnerability. The consequences are divided in classes (K1 to K6) where there is increasing environmental impact with increasing volume released. Darker colour indicates more severe consequence.

| Sea surface | Volume categories (tons) | Environmental Vulnerability and Consequences | | | |
|---|---|---|---|---|---|
| | | Low | Moderate | High | Extreme |
| Crude oil | 100-2000 | K1 | K2 | K3 | K4 |
| | 2000-20 000 | K2 | K3 | K4 | K5 |
| | 20 000-100 000 | K3 | K4 | K5 | K6 |
| | >100 000 | K4 | K5 | K6 | K6 |
| Oil products | 100-2000 | K1 | K1 | K2 | K3 |
| | 2000-20 000 | K1 | K2 | K3 | K4 |
| | 20 000-100 000 | K2 | K3 | K4 | K5 |
| | >100 000 | K3 | K4 | K5 | K6 |
| Chemicals | 100-2000 | K1 | K1 | K1 | K2 |
| | 2000-20 000 | K1 | K1 | K1 | K2 |
| | 20 000-100 000 | K1 | K1 | K2 | K3 |
| | >100 000 | K1 | K2 | K3 | K4 |
| Marine diesel | <200 | K1 | K1 | K1 | K2 |
| | 200-400 | K1 | K1 | K1 | K2 |
| | 400-1000 | K1 | K1 | K2 | K3 |
| | >1000 | K1 | K2 | K3 | K4 |
| Intermediate Fuel Oil (IFO) | <200 | K1 | K1 | K1 | K2 |
| | 200-400 | K1 | K1 | K2 | K3 |
| | 400-1000 | K1 | K2 | K3 | K4 |
| | >1000 | K2 | K3 | K4 | K5 |
| Heavy Fuel Oil (HFO) | <200 | K1 | K1 | K1 | K2 |
| | 200-400 | K1 | K1 | K2 | K3 |
| | 400-1000 | K1 | K2 | K3 | K4 |
| | >1000 | K2 | K3 | K4 | K5 |

# Mapping water area vulnerability for oil spill contingency, response and other natural protection purposes: MMBI's methodology

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## *Introduction*

The availability of maps showing the environmental vulnerability of marine coastal zones (shorelines and adjacent water areas) to oil spills is a critical element of preparedness. "Making and updating sensitivity maps are key activities in the oil spill contingency planning process. These maps convey essential information to spill responders by showing where the different coastal resources are, and by indicating environmentally sensitive areas" (IPIECA 2000, IMO/IPIECA 1994).

The methodology of mapping the vulnerability of marine and coastal waters to oil and oil products proposed herein is based on the recommendations of international organizations (IMO/IPIECA 1994, IMO/IPIECA 2010, IMO/IPIECA/OGP 2012). It also draws on approaches adopted abroad and the experience of Russian experts (Pogrebov 2010, Blinovskaâ *et al.* 2012) and institutes, including the Murmansk Marine Biological Institute (MMBI; Ŝavykin & Il'in 2010, Blinovskaya 2004).

This paper aims at presenting the science-based Russian methodology of mapping the environmental vulnerability of marine and coastal waters to oil spills, primarily in the Arctic, and the development of such maps when full data on biota are available as well as when source data are deficient.

The proposed approach also assumes sensitivity map development of ESI for the shoreline as described by NOAA (2002).

## *1. Features taken into consideration for vulnerability mapping*

The background maps used for producing summary vulnerability maps should contain the following elements: 1) valued components of biota (VCB) distribution; 2) features of special significance (FSS); 3) the location of nature protection areas (NPA).

VCB are groups of organisms with major significance for the ecosystem: algae macrophytes; other bottom organisms (zoo benthos), fish, birds (surface-feeding and diving seabirds, coastal birds) ; sea mammals (toothed whales, baleen whales, pinnipeds) and other mammals (e.g., polar bears and sea otters) that are ecologically connected with sea ; Red List species.

FSS are water areas with especially valuable ecological, social, cultural and/or economic significance. Ecologically significant areas include fish breeding and feeding grounds and key seabird and mammal habitats. Especially significant social and cultural areas include those relating to cultural heritage, areas visited by tourists and recreational areas. Economically significant areas include fishing areas, areas of significance to indigenous livelihoods, areas of trapping, areas where bottom invertebrates and other marine resources are harvested and areas of current or prospective mariculture/aquaculture, industrial facilities and installations relating to marine transport, facilities relating to power supply and the exploration for, production of, and transportation of oil.

NPAs include nature reserves, wildlife preserves, national parks and natural monuments.

The mapping area is the area in which distribution of biotic and abiotic components are considered. For each strategic and tactical map it's an area within the boundaries of each concrete map. For operational maps it's the area of individual object impact for oil spills covered by one or more operational maps.

The mapping area is the area within which all calculations and definition of vulnerable areas are performed. In our case, for the tactical map – it is the boundary of the Kola Bay (Fig. 1). For the object map the mapping area is district of Severomorsk (Fig. 2).

The definition of mapping area borders for tactical and strategic maps is essential for wide coastal areas, as it will effect the results of vulnerability assessments. In this article, this issue is not addressed.

## *2. Delimiting the timeframe for mapping*

It is necessary to set seasonal limits for area to be mapped on account of the temporal aspect of the biological components in the mapping area. The number of periods/seasons distinguished within a year is not necessarily four. Here we will discuss only seasonal maps, although when data are available maps can be developed on a monthly basis, using a similar method.

## *3. Multiscale mapping of seasonal distribution of VCB and location of FSS and NPA*

### 3.1. Mapping the distribution of biota when complete data are available

Background maps of VCB distribution are developed on the basis of data for selected seasons ($B^{gs}$) in units of measurement accepted for specific groups/subgroups/species - g/m$^2$, kg/m$^2$, ind/km$^2$… ,where g in $B^{gs}$ is the index of group/subgroup/species and *s* – index of a season. Standardization is carried out to operate in relative and uniform units of measurement for all biotic components (for 'summation' of the maps).

First standardization.

The original distributions of $\boldsymbol{B^{g_p s}/B^{g_p(l_i)s}/B^{g_p(l_i(m_j))s}}$ groups/subgroups/species are standardized to the average annual abundance of group $\boldsymbol{P^{gy}}$(average annual quantity or biomass of the group in the mappin area at a particular season):

$$\boldsymbol{B^{gs[y]} = B^{gs}/P^{gy}} \quad , \tag{1}$$

Bracketed *'y'* indicates that the data are standardized to the average annual abundance of the group.

The ration $\boldsymbol{B^{gs}}$ (e.g., in g/m$^2$) to the average annual abundance $\boldsymbol{P^{gy}}$ of the group *'g'* in the mapping area produces the part of group's average annual abundance per area unit (1/m$^2$) at a season. A similar procedure is applicable to subgroups/species. The values $\boldsymbol{B^{g_p(l_i)s[y]}/B^{g_p(l_i(m_j))s[y]}}$ – the subgroups/species are parts of average annual abundance of the group *'g'* per area unit at a season 's' ($\boldsymbol{l}$ – index of subgroups*, m* – index of species).

### 3.2. Mapping the distribution of biota with deficient data

The distribution of VCB ($B^{gs}$) is mapped for each season *'s'* not in original units of measurement but by ranks: $B^{gs}$ = 1, 2, 3 corresponding to low, average or high values of biomass or density per unit of area within the mapping area. $B^{gs}$= 0 if the groups or species are not present in the mapping area.

Literature and informed judgment regarding the abundance of the organisms in question must be drawn upon when assessing standardized seasonal coefficients:

$$A_b^{g_p s_1} : A_b^{g_p s_2} : A_b^{g_p s_3} : A_b^{g_p s_4} \text{ , (for each } 'p') \qquad (2)$$

where *p* = 1, 2, 3 … - index of *'g'* group; $s_1$, $s_2$, $s_3$, $s_4$ are seasons (not necessarily four); *b* – index refers to biota. For each $'g_p'$ group we have:

$$\sum_k A_b^{g_p s_k} = \sum_{k,i} A_b^{g_p(l_i)s_k} = \sum_{k,i,j} A_b^{g_p(l_i(m_j))s_k} = const, \text{ (for each } 'p') \qquad (3)$$

where $l_i$ – subgroups index of the *'g'* group (*i=0, 1, 2 …);* $m_j$ – species index of the $l_i$ – subgroup or g-group ($m_j$*=0, 1, 2 …*). . The sample of this type of estimation is presented by Ŝavykin & Il'in (2010).

### 3.3. Mapping the location of FSS

Distribution of the preselected FSS (not counting the biota) is indicated on maps with polygons $C^e$. All polygons $C^e$ are assigned a value of 1; other water areas are assigned the value 0.

### 3.4. Mapping the location of NPA

The list and the location of NPAs are determined regardless of the presence of the biota therein. The background maps of their distribution are developed to reflect the location of NPAs as polygons $D^f$. All polygons $D^f$ are assigned a value equal to 1; other water areas have a value of 0.

## *4. Valuation of the vulnerability coefficients and definition coefficients of protection priority*

### 4.1 Vulnerability coefficients of VCB

Vulnerability coefficients for all g groups $V_b^g$ are estimated with the following equation (Offringa & Lahr 2007):

$$V_b^g = (S^g \times E^g)/R^g \quad , \qquad (4)$$

where $S^g$ is sensitivity, $E^g$ is exposure and $R^g$ is recoverability of *'g'* group (same for each $l_i$ subgroup of *'g'* group ($g_p$) and for each $m_j$ specie of $l_i$ subgroup). The proposed approach suggests that the values of $S^g$, $E^g$ , $R^g$ having ranked (ordered) values or might be evaluated as physical quantities). For species $m_j$ or subgroups $l_i$ within $g_p$-group, the analogous expression is used to derive vulnerability coefficients for each subgroup or species within the VCB group.

$E^g$ – the exposure of different organisms (ecological group/subgroup and species) – is the probability of contact of the organisms with oil. The higher the exposure the higher the level of $E^g$. $E^g$ is assessed depending on properties of oil and its fate after a spill as well as the distribution of organisms in the water column., Exposure ($E^g$ ) is determined as the probability of contact of organisms with oil after spill. When considering the exposure of biota to medium-weight crude oil it is presumed that most of the oil will evaporate, dissolve or form a slick rather than reach the bottom. Pollution by this type of oil will impact the water column to 10-20 m below the surface, where most biota will be exposed.

$S^g$ – sensitivity of organisms – is the organism's capacity to respond to specific impacts. The higher the sensitivity, the higher the level of $S^g$. The sensitivity of groups/subgroups/species ($S^g$) may be defined through the toxicity of oil to them. Lethal and sub-lethal concentrations of medium-weight crude oil for the main types of biota a have been assessed (Ŝavykin & Il'in 2010) or these values are represented as ranks which is less preferable.

$R^g$ – recoverability of organisms – is the organism's capacity to recover the status it enjoyed prior to the impact. The recoverability rate used to assess $R^g$ depends on the life cycle of the organisms and the number of reproduction cycles per unit of time as well the duration of the life span and fertility indices. The higher recoverability rate is demonstrated by a group of organisms after the impact with a higher $R^g$ value.

### 4.2 Protection priority coefficients of FSS and NPA

For FSS, coefficients of protection priority ($V_c^e$) are determined by their significance for the ecosystem, people and trade. The value of $V_c^e$ grows with the significance of FSS to people and the functioning of ecosystem.

For NPA, coefficients of protection priority ($V_d^f$) are defined by the NPAs' conservation status established under international, national and regional conservation policies and laws.

## *5. Mapping multiscale seasonal vulnerability of VCB, FSS, NPA*

### 5.1. Mapping of biota vulnerability when source data are available in its entirety

For every season background maps of distribution of all VCB are 'summed up' (maps of distribution of $B^{gs[y]}$), multiplied by the corresponding vulnerability coefficients $V_b^g$:

$Y_b^s = \sum_p B^{g_p s[y]} \times V_b^{g_p}$ for 'relative' vulnerability maps (5),

and then maps are standardized for each season:

$Y_b^{s(s)} = Y_b^s/(maxY_b^s$ for season $s$), where $Y_b^{s(s)}$ is the 'relative' vulnerability of biota to oil in the mapping area within the range of season-specific (for season) vulnerability - from minimum (min$Y_b^{s(s)}$) to maximum value (max$Y_b^{s(s)}$);

$Y_b^{s(y)} = Y_b^s/(maxY_b^s$ for year), where $Y_b^{s(y)}$ is the 'absolute' vulnerability of biota to oil in the mapping area within the range of annual vulnerability - from minimum (min$Y_b^{s(y)}$) to maximum values (max$Y_b^{s(y)}$).

Round brackets, *'s' or 'y'* indicate that the data are standardized to the seasonal or annual maximum ($\boldsymbol{maxY_b^s}$).

After this second standardization for VCB maps we have maps of $Y_b^{s(s)}$ (for 'relative' vulnerability) and $Y_b^{s(y)}$ (for 'absolute' vulnerability) in the range min$Y_b^{s(s)}$– 1 or 100 and min$Y_b^{s(y)}$– 1 or 100.

### 5.2. Mapping biota vulnerability when data are deficient and ranked

The calculation is performed as follows:

$$Y_b^s = \sum_p A_b^{g_p s} \times B^{g_p s} \times V_b^{g_p} \quad , \qquad (7)$$

where $A_b^{g_p s}$ is the seasonal abundance ratio groups, see equation (2), which is used for accounting for the seasonal variations of group's abundance.

The levels of vulnerability of polygons for the resulting maps are standardized to the maximum value of the integral vulnerability for specific seasons ($maxY_b^s$) and brought to the range $minY_b^{s(s)}$– 1 or 100. Thus the maps of the distribution of 'relative' vulnerability of biota $Y_b^{s(s)}$ are obtained for each season.

A similar procedure is followed to obtain the maps of 'absolute' vulnerability, with the exception that standardization to the integral vulnerability is carried out not to a season but to the whole year ($\boldsymbol{maxY_b^y}$). The maps of $\boldsymbol{Y_b^{s(y)}}$ distribution are obtained also with the integral vulnerability range $\boldsymbol{minY_b^y}$ – 1 or 100. Here, as the case is with available data on biota, the maps of 'relative' vulnerability demonstrate a uniform maximum of $(\boldsymbol{maxY_b^{s(y)}})$ = 1 or 100 regardless of the season. Meanwhile the maps of 'absolute' vulnerability have the annual range of vulnerability (min$\boldsymbol{Y_b^{s(y)}}$ – $\boldsymbol{maxY_b^{s(y)} = 1 \text{ or } 100}$). Therefore not all 'absolute' vulnerability maps demonstrate minimum and maximum $(\boldsymbol{minY_b^{s(s)}}$ – $\boldsymbol{maxY_b^{s(s)}})$ of vulnerability and corresponding ranks in every season.

### 5.3. Mapping FSS protection priority

Maps of FSS locations are 'summed up' for each particular season following the multiplication of values of $C^{es}$ for polygons by the coefficients of protection priority $V_c^e$:

$$Y_c^s = \sum_e C^{es} \times V_c^e \qquad (8)$$

The index '*s*' is indicative of the season to which the values are attributed; *e* – index refers to FSS.

The resulting maps are standardized: levels of the vulnerability of obtained FSS polygons are standardized to the maximum integral vulnerability in the corresponding season (standardized to $maxY_c^s$ ) and transferred to the range from $minY_c^{s(s)}$ to 100 (the resulting map reflects the distribution of $Y_c^{s(s)}$ values). A similar procedure is followed to obtain maps of 'absolute' vulnerability, with the exception that standardization to the integral vulnerability is carried out not to a season but to the whole year (to $maxY_c^y$ if different from $maxY_c^s$). Maps demonstrating the distribution of $Y_c^y$ in the range $minY_c^y$ – 1 or 100 are obtained.

### 5.4. Mapping NPA protection priority

Maps of NPA locations are 'summed up' for each particular season following the multiplication of values of $D^f$ for polygons by the coefficients of protection priority $V_d^f$:

$$Y_d^s = \sum_{f=1}^{n} D^{fs} \times V_d^f \quad (9)$$

*where d* – index refers to NPA.

The resulting maps are standardized: levels of the vulnerability of obtained NPA polygons are standardized to the maximum integral vulnerability in the corresponding season (standardized to $maxY_d^s$) and transferred to the range from the minimum value of $minY_d^{s(s)}$ to 100 (the resulting map reflects the distribution of $Y_d^{s(s)}$ values). A similar procedure is followed to obtain maps of 'absolute' vulnerability, with the exception that ranking in the course of standardization to the integral vulnerability is carried out not to a season but to the whole year (to $maxY_d^y$ if different from $maxY_d^s$). Maps demonstrating the distribution of $Y_d^{s(y)}$ also in the range $minY_d^{s(y)}$ – 1 or 100 are obtained.

## *6. Mapping multiscale seasonal integral vulnerability*

To obtain maps of 'relative' integral vulnerability of the waters in the mapping area in a GIS application (e.g., ArcMap) the 'summing up' of 'relative' vulnerability maps for VCB, FSS and NPA is carried out:

$$Y_\Sigma^{s(s)} = k_b \times Y_b^{s(s)} + k_c \times Y_c^{s(s)} + k_d \times Y_d^{s(s)} \quad (10)$$

The range of obtained values of the vulnerability $Y_\Sigma^{s(s)}$ for each season is subdivided into three necessarily equal (!) subdivisions. The equality of the subdivisions ensures the correct estimates and comparison of the vulnerability of different water areas.

Subdivisions with maximum integral vulnerability are assigned a value of 3 and those with minimum vulnerability are ranked 1. The obtained maps of season-specific vulnerability are integrated into oil spill contingency plans. Parts ranked 3 are subject to protection priority (Figures 1, 2).

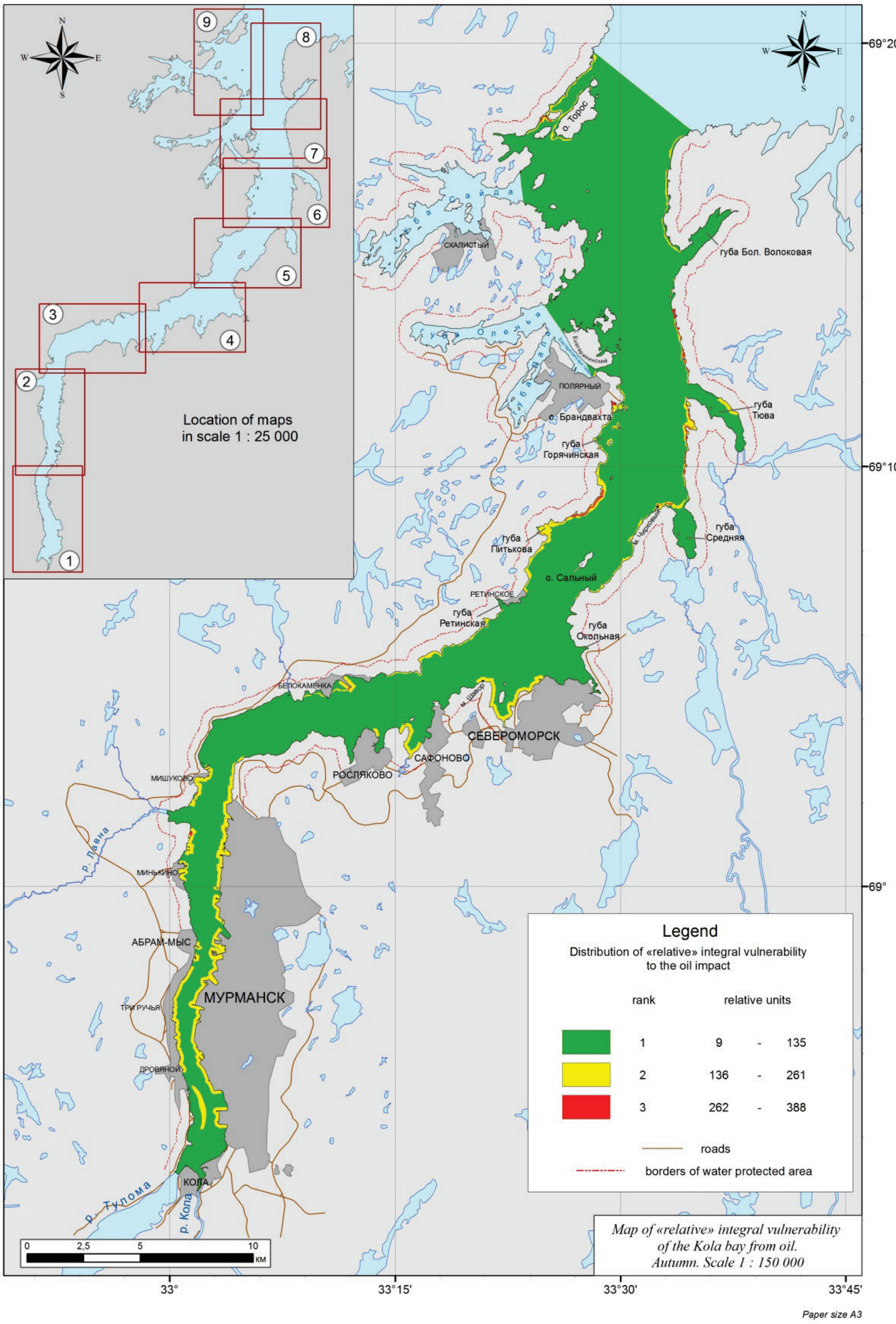


Figure 1 Map of 'relative' integral vulnerability to oil of the Kola Bay. Autumn. Scale 1: 150 000.

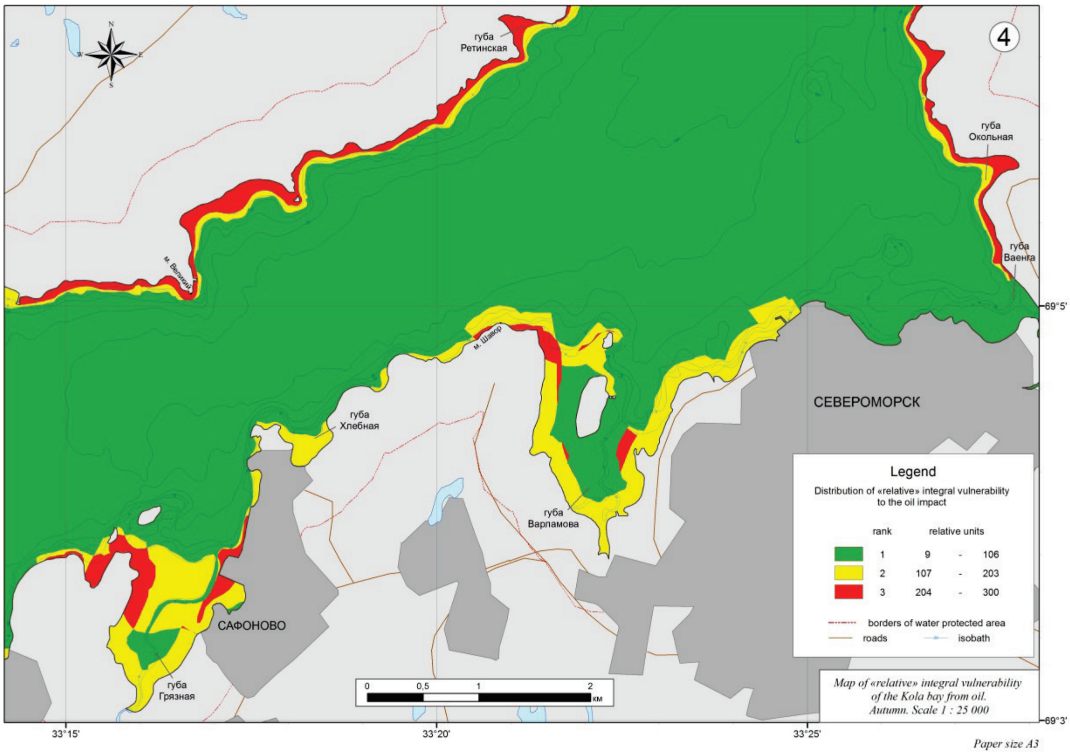


Figure 2 Map of 'relative' integral vulnerability to oil of the Kola bay. Autumn. Scale 1: 25 000.

To obtain maps of 'absolute' integral vulnerability of water areas the maps of 'absolute' vulnerability of VCB, FSS and NPA are 'summed up':

$$Y_{\Sigma}^{s(y)} = k_b \times Y_b^{s(y)} + k_c \times Y_c^{s(y)} + k_d \times Y_d^{s(y)} \quad (11)$$

The range of 'absolute' integral vulnerability for the whole year is divided into three equal (!) subdivisions and are used to create maps with three ranks, as is done for maps of 'relative' vulnerability.

Coefficients $k_b, k_c, k_d$ are selected on a case by case basis, depending on the significance of specific components of the ecosystem (VCB, FSS and NPA) for its normal functioning and the maintenance of the economy of the region. These could be, for example, the values $k_b = k_c = k_d = 1$, or when nature protection areas (NPA) are critical for the area in question, these coefficients may be assigned values of 0.25, 0.25 and 0.5.

## Barents Sea ecosystem vulnerability

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### *Introduction*

An integrated ecosystem assessment (IEA) is considered a key element in ecosystem-based management (EBM) (Levin *et al.* 2009). A fundamental challenge in developing IEAs that reliably inform EBM is to provide assessment tools that are process-oriented and address whole ecosystem properties, such as biodiversity, that closely relate to ecosystem vulnerability. The above challenge will require an integration of information on demographic characteristics, ecological interactions and ecosystem functions of component species. Whole ecosystem properties of relevance for ecosystem vulnerability have been singled out, and functional diversity and food-web structural properties play a prominent role in this context. In particular, functional diversity is expected to promote ecosystem adaptability by providing alternative ways of functioning to an ecosystem experiencing change, whereas food-web modularity will reduce ecosystem sensitivity by limiting the propagation of the effects of environmental perturbation to few species within a food-web module (Levin and Lubchenco, 2008). Trait-based approaches and food-web analysis can provide the required information on the above ecosystem properties, which, if properly integrated and communicated, will inform EBM on fundamental aspects of ecosystem vulnerability.

Trait based approaches break down information on life history, behavior and other relevant phenotypic characteristics into response traits and effect (or functional) traits. Response traits determine the vulnerability of a species to a specific environmental stressor like fishing, whereas effect traits provide information on ecosystem functions of species (Lavorel and Garnier 2002). Response traits data allow to rank species according to their vulnerability, an approach that has been particularly fruitful in the context of assessment of vulnerability to fishing (Le Quesne and Jennings 2012), and rank data can be averaged across species present in a given area or location to provide a measure of community vulnerability (Wiedmann *et al.* 2014a). Effect traits data allow to classify species according to their ecosystem functions and provide the basis for the assessment of collective properties of ecosystems such as functional diversity, which affects the adaptive capacity of ecosystems, and functional redundancy, which affects the sensitivity of ecosystems (Wiedmann *et al*. 2014b). Finally, foodweb data allow to measure species properties, such as centrality (Lai *et al*. 2012, Kortsch *et al*.), and ecosystem properties, such as foodweb modularity, that depend on the configuration of ecological interactions connecting ecosystem components.

For the Barents Sea, many of the necessary data and tools for an Ecosystem Vulnerability Assessment (EVA) approach have been made available by the NRC-funded project BarEcoRe (Barents Sea ecosystem resilience under global environmental change, 2010-2013), and have been successfully implemented in the project VULDER (2014) supported by the FRAM Centre (Ecosystem vulnerability assessment of demersal resources in the Barents Sea – Additional support to ICES WGIBAR 2014). Further developments of the approach, combined with a synthesis of results, are under way, and are intended to support areal assessment and monitoring of ecosystem vulnerability to fishery and other environmental stressors. The developed tools and approach for EVA are applicable to any ecosystem, be it marine, freshwater or terrestrial.

### *Data used in the Barents Sea Ecosystem Vulnerability Assessment*

Occurrence data needed to obtain the species composition at a given station (Wiedemann *et al*. 2014a) were collected by the Barents Sea Ecosystem Survey conducted by the Institute of Marine Research (Norway) and PINRO (Russia). Response traits and functional traits data for fish were compiled within the project BarEcoRe based on literature surveys, and reports and data available at IMR and PINRO (list of species and traits in Wiedmann *et al*. 2014a,b). Food-web data were also compiled in the context of the BarEcoRe project (Planque *et al*. 2014) and are presently being extended to obtain a highly resolved and comprehensive metaweb for the Barents Sea (Kortsch *et al*.).

### *Data analysis and mapping of results*

The sensitivity to fishing (trawling) of individual fish species was assessed based on life history characteristics (response traits) affecting demographic growth rates (Wiedemann *et al*. 2014a). The fish response traits data were analysed by ordination, and species were ranked according to their sensitivity based on their scores along a Principal Component axis associated with maturation schedules. The mean fish sensitivity score at a station was obtained by averaging the sensitivity ranks of the fish species present at that station (Wiedmann *et al*. 2014a). The fish functional diversity at individual stations was estimated based on a functional traits dendrogram and compositional data. The functional traits data were subjected to clustering to obtain a functional traits dendrogram summarizing the distance between species in functional traits space (Wiedmann *et al*. 2014b). The functional diversity at a sampling station was then estimated by calculating, based on the dendrogram, the cumulative functional traits distance between the species found at that station (Wiedmann *et al*. 2014b). The degree centrality of fish species was obtained from the Barents Sea food-web matrix (Kortsch *et al*.). The mean fish degree centrality at a station was calculated by averaging across the species found at that station (Kortsch *et al*.). The information obtained from the response traits, functional traits and food-web data was mapped based on location of sampling stations and a color coded surface (representing values obtained by kriging on a regular grid) was superimposed as an aid to visualization (Figure 1).

### *Synthesis of results and management applications*

The maps shown in Figure 1 help to illustrate how information on ecosystem vulnerability can be presented and synthesized in a way that is accessible to decision makers, and useful in an areal management perspective.

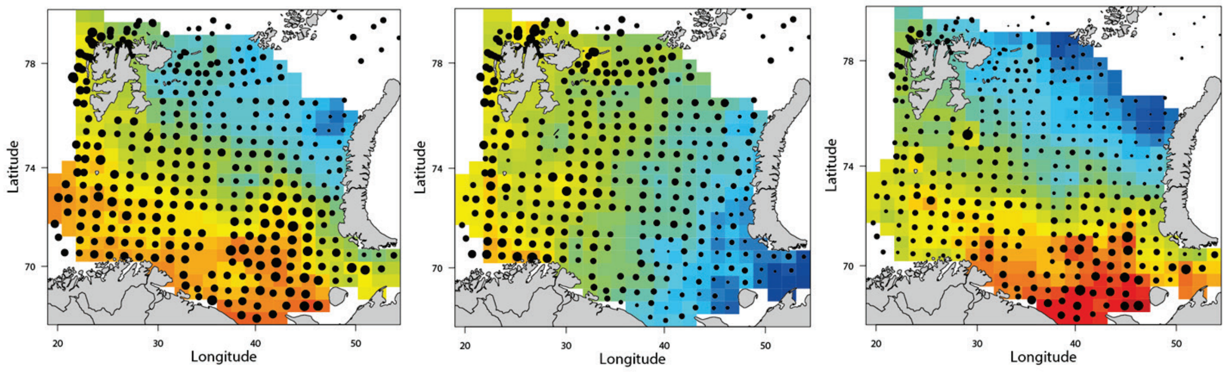


Figure 1 Barents Sea vulnerability maps (symbol size proportional to estimated values at station – high cell values in red, low cell values in blue) for mean sensitivity to fishery based on life-history traits (left panel), functional diversity (central panel), and mean degree centrality based on food-web data (right panel).

The substantial spatial variation detected for each of the three properties influencing ecosystem vulnerability stresses the importance of Ecosystem Vulnerability Assessment within the Barents Sea. To exemplify the use of the EVA maps in an areal management context, we can focus on the South-East Barents Sea, an area where fish sensitivity to trawling is high, functional diversity is low, and fish species are highly connected to other species in the food-web. As a consequence, a high fishing effort in the area would result in a likely decline of local fish populations, leading to a loss of functional diversity in an area with an already low adaptive capacity, and a widespread impact on non-target species that are connected to fish via their many feeding links.

# Mapping the vulnerability of benthic communities to trawling in the Barents Sea

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## *Introduction*

The gold standard for evaluating the vulnerability of biological communities to specific pressure requires a combination of experimental and empirical approaches, in which the response of each species to the pressure is modelled and then predicted under different pressure scenario, ideally integrating species interactions as well. In practice however, vulnerability assessments are more qualitative and pragmatic, especially when the communities under focus are hard to access or the pressures are hard to simulate or manipulate, a typical problem in many marine case studies. Many vulnerability assessments rely therefore on the ad-hoc aggregation of factors related to species morphology, behaviour, demography, habitat or conservation status (Feeley *et al.* 2007, Lees and Perez 2008, Wang *et al.* 2009, Davidson *et al.* 2012, Jeppsson and Forslund 2013, Furness *et al.* 2013, Ameca y Juarez *et al.* 2014, Bradbury *et al.* 2014). In these studies, factors are often scored between 0 and 1 and then aggregated, possibly to survey data, using ad-hoc formulas such as weighted sums of terms. Classical outputs are a ranking of species according to their degree of vulnerability, and the production of vulnerability maps when survey data are employed.

The application of these factor-mediated vulnerability assessments is convenient when knowledge and data are limited. For example, benthic communities on the continental shelf, upper slope and seamounts are submitted to trawling pressure (Clark and Tittensor 2010, Puig *et al.* 2012), but estimating capture and survival rate following a trawl for each benthic species is very challenging because of the difficulty of accessing and manipulating these organisms.

Factor-mediated vulnerability assessment was actually pioneered by Garthe and Hüppop (2004) in the seabird-windfarm context, through the development of the Wind-farm Sensitivity Index (*WSI*). It is notable that their framework has already been transposed to other types of hazards (Stelzenmüller, Ellis, and Rogers 2010; Sonntag *et al.* 2012), and that similar methods are currently being used in the context of cumulative impact assessments (Halpern *et al.* 2008, Coll *et al.* 2012, Maxwell *et al.* 2013). In this study, we applied a revised version of Garthe and Hüppop (2004)'s approach, allowing the factor-mediated examination of the vulnerability of the benthos community to trawling pressure in the Barents Sea.

## *Method*

The Barents Sea is submitted to an intense fishing activity carried out through bottom trawling (Jakobsen and Ozhigin 2011). Therefore, identifying areas where benthic communities will be most sensitive to trawling is important for the management of this marine ecosystem and the conservation of the benthic community. In 2009, an exhaustive snapshot of the Benthic community over the whole Barents Sea has been gathered through a series of 391 bottom trawl stations during the Barents Sea Ecosystem Survey (Michalsen *et al.* 2013). These trawl stations are placed according to a regular sampling grid every 50km, and cover homogeneously the whole Barents Sea continental shelf (1 600 000 km$^2$). All benthic invertebrates caught in the trawl were identified to the species level and weighted, resulting in a unique inventory of the distribution and abundance of 355 benthic species. These taxonomic categories are the result of an intense cooperation between Norwegian and Russian taxonomists on board of the survey vessels and since 2004. This process, along with the data and the benthic community structure, is extensively described in Jørgensen *et al.* (in press).

For the Benthos-trawl case study, five vulnerability factors have been chosen after thorough discussions in expert-group meetings. They reflect the morphological and ecological properties controlling the probability of being damaged by a demersal trawl haul that could be unambiguously documented for the 355 taxa of our study. The main idea behind the selection and ranking of these five factors is that large and sessile species living at the sediment surface are the most likely to be captured in a trawl haul. When captured, species with complex and fragile shells will be more likely to be damaged than species with simple morphology and hard shell.

$F_1$ classify the benthos species in three size classes, tiny (1), medium sized (2) and large (3). Tiny organisms are those that are likely to pass through the meshes of a trawl, medium sized organisms have some chances of escaping and large organisms will most probably not escape the trawl if caught.

$F_2$ relates to the position of benthos species relatively to the sediment, distinguishing infauna organisms spending most of their lives buried within the sediment (1) from epifauna organisms (3) spending their life at the sediment surface. An intermediate code (2) has been used to distinguish individuals migrating from within the sediment to the surface.

$F_3$ refers to the mobility of organisms, ranging from sessile organisms (3) that have no ways of escaping a coming trawl to fast moving/swimming organisms that have better chances to escape (1). An intermediate code (2) is used for the organisms presenting slow mobility.

$F_4$ refers to the vertical dimension of organisms that affects their probability of suffering damages when caught by a trawl. It distinguishes vertically erected organisms composed of many tiny branches (3) from ball- or flat-like organisms (1). An intermediate code (2) corresponds to some degree of vertical erection and complexity.

$F_5$ refers to the hardness of the shell of the organisms, distinguishing soft (3) from hard and calcified (1) organisms. An intermediate code (2) corresponds to some degree of natural protection.

F1, F2, F3 are primary factors, and F4, F5 are aggravation factors. All scores have been divided by 3 to be comprised between 0.33 and 1. The estimate of trawling-induced individual vulnerability $t_i$ is made using the following equation:

$$t_i = a_i^{1-\left(\frac{g_i}{g_i+\gamma}\right)}, \text{ where } \quad a \in [0,1], \ \ g \in [0,1], \ \ \gamma \in \left]0.1,1\right] \quad \text{(eq. 1)}$$

with $a_i=(F_{i1}+F_{i2}+F_{i3})/3$ ; $g_i=(F_{i4}+F_{i5})/2$ and $\gamma$=0.5.

Then, benthos vulnerability to trawling is mapped using a modified version of Leinster and Cobbold's (2012) diversity indices, in which the most vulnerable species receives more weight. Benthos vulnerability map is shown together with a map of benthos biomasses, in order to display simultaneously areas of high vulnerability and areas of high abundances.

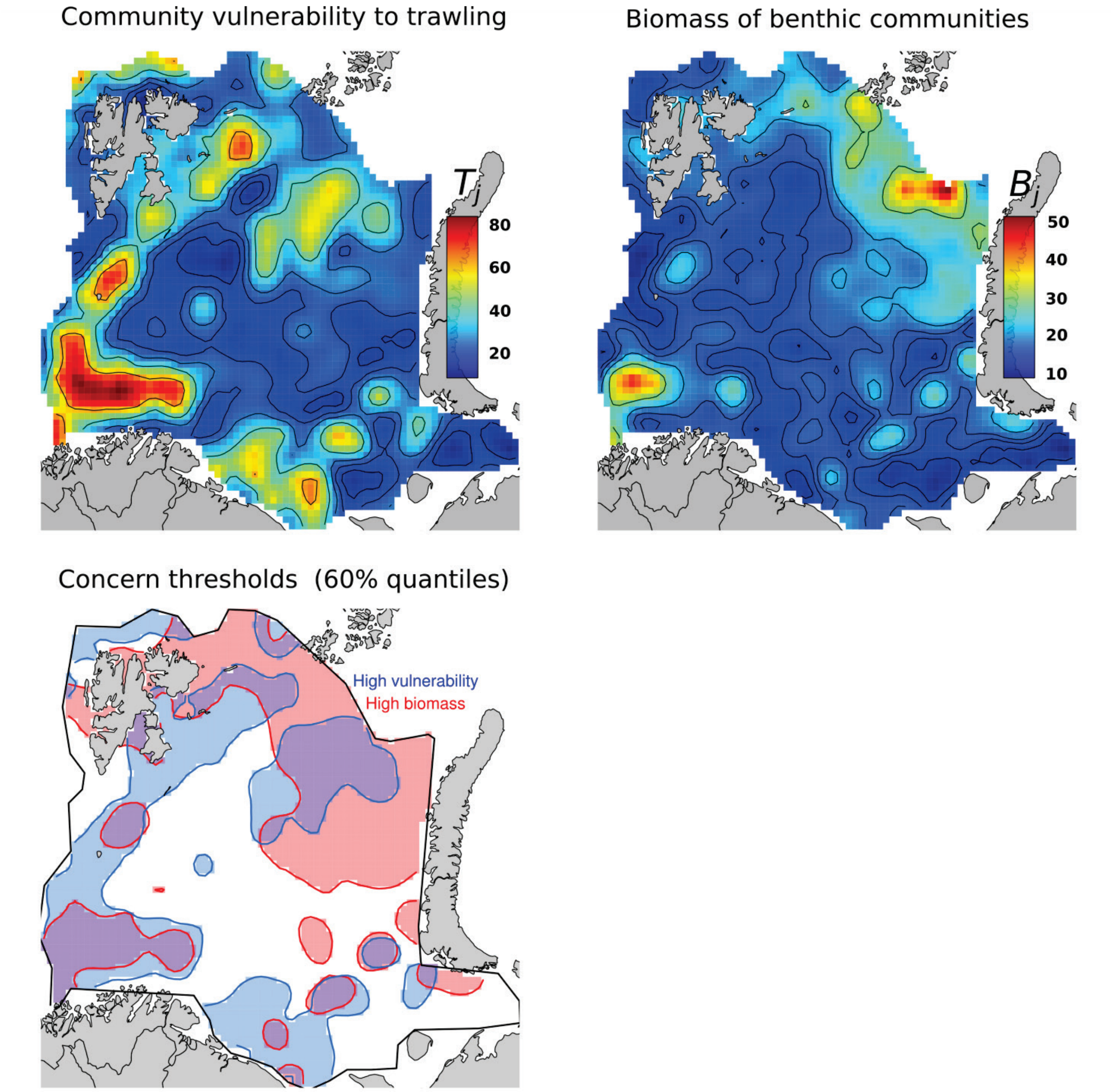


Figure 1 Diagnostic panel for the Barents Sea data (summer 2009). Note that biomass of benthic communities have been cubic-root transformed for better visualization.

## *Results and discussion*

The diagnostic panel for benthic organisms in the Barents Sea clearly highlights strong contrasts between the central Barents Sea and the surroundings area. Community vulnerable to trawling are mostly localised on the southern and western part of the Barents Sea, but also important vulnerability patches are observed in the North. Biomasses have almost a reverse pattern, being much higher in the whole northernmost areas. Two main areas where high vulnerability and high biomasses overlap can be observed in the South-West and North-East of the Barents Sea, and constitute potentially critical area for the conservation of benthic organisms.

The application of our method for benthos vulnerability shows how to use benthos survey data at regional scale, and therefore complement and extend past vulnerability assessment based on qualitative information at global scale (Clark and Tittensor 2010).

Of course, limitations in the benthos dataset need to be clearly stated. One problem is that we used community data issued from trawl by-catch, and therefore, our description of the benthic community composition is biased toward species that are actually caught. As a result, our vulnerability assessment is likely to over-emphasize vulnerable communities. This has to be kept in mind when interpreting the vulnerability maps. Alternative sampling methods less subject to this problem, such as grabs or video recording (Beazley *et al*. 2013) exist, but they have not been implemented extensively at the scale of the entire Barents Sea yet.

The high trawling vulnerability recorded on the South-western Barents Sea is partly attributable to the abundance of several sponge species in this area (Jørgensen *et al.* in press). Bottom trawling might have a severe impact on these slow-growing sponges, most likely requiring many years to re-establish themselves in a degraded area. The identification of large biomasses of highly vulnerable communities in the North-eastern part of the Barents Sea is an important result, as these areas were until now either not or only slightly impacted by the fishing activity. However, with a warming climate and the potential migration of several fish species of commercial interest (Hollowed *et al.* 2013), it is likely that some of these areas will be more and more targeted by fisheries. Therefore, the clear identification of these highly vulnerable communities can serve as guidelines for protecting some of these previously undisturbed communities from the potential impact of fisheries development.

## Assessing the red king crab vulnerability of a diesel oil spill

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There are large interests in utilisation of new areas for tourism, fishing, transport and exploration of natural resources as the ice coverage of Arctic waters decrease. The traffic is increasing and it is expected to further increase in Arctic and sub-Arctic areas. The increased shipping activity will increase the risk for accidents with leakage of oil products to the marine environment. The large majority of vessels use marine diesel as propulsion fuel.

There is a lack of knowledge of how cold-water organisms respond to diesel spil, as effect of diesel exposure has only been studied for a few species. We therefore studied the uptake, elimination (recovery) and effects of diesel exposure in red king crab (*Paralithodes camtschaticus*). The experiment mimicked a grounding scenario with releases of marine diesel in a semi exposed and shallow coastal environment. The red king crabs and their food of blue mussels (*Mytilus edulis*) and Icelandic scallops (*Chlamys islandica*) were in a laboratory experiment exposed to mechanical dispersed diesel. All three species accumulated diesel. Further, the red king crab recovered by reducing its hepatopancreas concentration of ?16PAH (poly aromatic hydrocarbon) from 22,300 µg/kg to 1,600 µg/kg wet weight during three weeks of recovery in clean water.

The most polluted red king crab group showed a tendency for elevated concentrations of the enzyme catalase. However, three weeks of recovery set this biomarker concentration back to normal levels. Three other biomarkers did not show any sign of response. A behavioural flight response among the highest exposed crabs indicated that the crab censed the diesel.

The red king crab has principally two different life forms. The first is a passive life form of egg and larvae floating with currents. As the larvae grows bigger, the young crab settles and starts actively to walk on the bottom. Our study object was the sub-adult, highly mobile form. In a real spill situation, the highest concentration of oil and its components are in the upper water layers and at shallow water. It is therefore easy for young and adult red king crabs to seek away from the water with high hydrocarbon concentrations; they can just walk into deeper water. The observed flight response indicates that young and adult red king crabs will try to avoid the water with high concentration of oil components. In addition, if they accumulate some diesel components their excreting or metabolic capacity, or presumably both, will help to clean the body. As the only biomarker response disappears after three weeks of recovery, we conclude that a diesel spill will not affect this life stage of the red king crab significantly.

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*Over thousands of years, humans found their place in the polar kingdom.*
*First as strangers, then as integrated parts of the kingdom at the edges of Earth and life.*

*Polar explorers.*
*Seeking to map the edges of the world.*
*Conquering wild polar seas and white polar landscapes.*
*Through ships, sledges and skies.*
*Through balloons, zeppelins and airplanes.*
*Through visions, courage and determination.*
*All driven by dreams and ambitions on the top and bottom of the world.*

*Polar scientists.*
*Seeking to understand the edges of the world.*
*Revealing wild polar seas and white polar landscapes.*
*Through observations and descriptions.*
*Through measurements and samples.*
*Through questions, methods and curiosity.*
*All driven by the dreams and ambitions on the top and bottom of the world.*

*Polar traders.*
*Seeking to harvest the edges of the world.*
*Utilizing wild polar seas and white polar landscapes.*
*Through fishing gears, traps and harpoons.*
*Through mining and drilling.*
*Through needs, prosperity and wealth.*
*All driven by the dreams and ambitions on the top and bottom of the world.*

*The polar human.*
*In all its forms.*
*Some visitors, others inhabitants.*
*All influenced by the rules of the polar kingdom.*
*All influencing the kingdom at the edges of Earth and life.*

*For thousands of years humans have been influenced by the polar kingdom.*
*For thousands of years humans have influenced the polar kingdom.*

*Living off the land. Living off the sea.*
*Hunting and fishing. Tracking and sailing.*
*Mining for coal, drilling for oil.*

*Leaving traces in the white polar landscapes.*
*Leaving traces in the wild polar seas.*
*For thousands of years humans have been influenced by the polar kingdom.*
*For thousands of years humans have influenced the polar kingdom.*

*Kriss Rokkan Iversen, SALT*