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Rolf A. Ims, Inger G. Alsos, Eva Fuglei,
Åshild Ø. Pedersen and Nigel G. Yoccoz

An assessment of MOSJ – The state of the terrestrial environment in Svalbard

MOSJ Miljøovervåking Svalbard og Jan Mayen

NORSK POLARINSTITUTT / NORWEGIAN POLAR INSTITUTE, FRAMSENTERET / FRAM CENTRE, NO-9296 TROMSØ, NORGE/NORWAY, www.npolar.no

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Norwegian Polar Institute
Fram Centre, NO 9296 Tromsø, Norway

Authors:
Rolf A. Ims, Department of Arctic and Marine Biology, University of Tromsø – The Arctic University of Norway
Inger G. Alsos, Tromsø Museum, University of Tromsø – The Arctic University of Norway
Eva Fuglei, Norwegian Polar Institute, Tromsø
Åshild Ø. Pedersen, Norwegian Polar Institute, Tromsø
Nigel G. Yoccoz, Department of Arctic and Marine Biology, University of Tromsø – The Arctic University of Norway

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Norwegian Polar Institute, Fram Centre, NO-9296 Tromsø
Norsk Polarinstitutt, Framsenteret, 9296 Tromsø
www.npolar.no post@npolar.no

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Executive summary

The present report is mandated to provide

(1) an *ecosystem state assessment* of terrestrial Svalbard based on quality-assured science, emphasizing the pressure impacts of climate change, invasive or increasing species, harvesting, pollution and traffic,

(2) an *evaluation of MOSJ* with respect to its aims of facilitating ecosystem state assessment, ecosystem management and achievements of national key goals for the environment, and

(3) *recommendations* on how MOSJ could be improved to better fulfill its aims.

Ecosystem state assessment

The pressures likely to cause major state changes in the terrestrial ecosystems in Svalbard are first and foremost the rapid climate changes in the Arctic region. Trends in biologically relevant climate variables show that Svalbard is presently on the verge of "a novel climate" characterized by winters without very low temperatures (< -20°C) and summers with extended growth seasons (>5°C). Accordingly, above ground biomass of tundra plants has been reported to increase, in turn contributing to the increase of some populations of Svalbard reindeer. However, short-term population declines due to episodes of rain-of-snow events (ROS) presently drive most of the inter-annual dynamics of reindeer and all other whole-year resident terrestrial vertebrates in Svalbard.

These research findings have contributed substantially to a better understanding of recent climate impacts on High-arctic ecosystems. However, the lack of historical analogues of the vast climate changes projected to take place over the next decades in combination with invasive/increasing species and expanding human traffic and activities, make reliable projections of future states of the ecosystem almost impossible to derive. A host of introduced species is already in place in Svalbard, but still restricted to the immdiate vicinity of human settlements. Presently, the largest risks caused by increasing species are the destructive impacts of native geese on the vegetation. The increase in goose abundance is mainly due to management outside the Arctic.

Among the locally manageable environmental pressures in Svalbard, wildlife harvesting appears to be presently well regulated and sustainable at present, but needs to be regularly re-assessed as other stressors, in particular climate change, increases. Similarly, although disturbance impacts of increased traffic presently are mostly local, future impact assessments need to estimate interactions between traffic, spread of invasive species and climate change. Red-listed species are presently not prioritized by MOSJ or other monitoring activities in Svalbard. Thus the information about recent changes of rare species in Svalbard is too limited to be assessed robustly.

Evaluation of MOSJ

By only providing population time series of three animal species from a restricted area in western Spitsbergen, MOSJ terrestrial is presently unable to fulfill its aims of being an integrated monitoring system for the terrestrial environment of Svalbard and Jan Mayen. Major deficiencies are due to the monitoring system not including fundamental components of the terrestrial ecosystem (e.g. vegetation) and state variables adequately representing influential environmental pressures (e.g. biologically relevant attributes of the climate). Consequently, by its incomplete scope MOSJ is not equipped to document the presence, the magnitude and the causes of ecosystem state changes in an era when such changes are expected to have unprecedented pervasive impacts on arctic biodiversity and ecosystem functions. To the extent the authors of the present report have been able to make reasonable assessments of the present state of the terrestrial ecosystems in Svalbard, it is owing to essential information provided by scientific studies not included in MOSJ.

Recommendations

In order to facilitate the nation's expressed high ambitions of showcasing Svalbard as one of the best managed wilderness areas in the world, MOSJ needs to be radically upgraded by means of a set of new long-term thematic programmes that specifically target environmental pressure–response processes according to internationally recognized protocols for ecosystem-based monitoring and management. COAT – Climate-Ecological Observatory for Arctic Tundra, for which a comprehensive science plan just has been developed and quality-assured by the Fram Centre, is recommended to become the major thematic programme targeting the enormous management and scientific challenges facing the vast and fast future climate changes in the terrestrial parts of the Norwegian Arctic.

It is also recommended that three thematic programmes are developed to complement COAT in order to target invasive species, red-listed species and the effects of increased traffic. Each of the thematic programmes should be responsible for monitoring, analyses and reporting according to internationally recognized principles of adaptive monitoring. MOSJ is then recommended to take a heuristic role in terms of integrating information across monitoring programmes and thereby provide an operative interface between environmental science, management and policy making.

Arctic fox (*Vulpes lagopus*). Photo: Eva Fuglei, Norwegian Polar Institute

Purple saxifrage (*Saxifraga oppositifolia*). Photo: Anders Skoglund, Norwegian Polar Institute

1 Introduction

1.1 MOSJ: Aims and means

A full account of the background, aims and means of MOSJ is given in Sander (2006) in the first MOSJ assessment in 2003. Sander (2006) discusses mindfully the adherence of MOSJ to internationally recognized standards of environmental monitoring at the time, especially with reference to the challenges that ought to be met for MOSJ to attain its stated aims. As an introduction to the present assessment of the terrestrial environment in Svalbard (hereafter termed "MOSJ Terrestrial") we paraphrase and discuss the points made by Sander (2006), which both relate to recent national and international developments in environmental monitoring (Section 1.2) and to the mandate of the present assessment (Section 1.3).

The key aims of MOSJ are to constitute a monitoring and assessment system that relates to:

(1) Norway's goals for "the state of the environment" both expressed as strategic goals and "key figures" for Svalbard and Jan Mayen,

(2) day-to-day knowledge needs of local environmental management in Svalbard and Jan Mayen, and

(3) Norway's international obligations with regard to the nation's commitments in international conventions and as participants in international bodies.

With regard to (1) we note that the expressed strategic objectives are very high: "Svalbard [..] shall [..] be protected against major developments and environmental pressures" and "shall be one of the best managed wilderness areas in the world". With regard to (2) we note that MOSJ terrestrial ought to facilitate a well-functioning interphase with the management authorities (i.e. Governor of Svalbard, Norwegian Environment Agency and Ministry of Climate and Environment). With regard to (3) we note that MOSJ ought to maintain a well-functioning interphase with relevant processes and working groups of the Arctic Council. Finally, we also note that an overarching goal of MOSJ is to facilitate robust establishment of cause–effect relations between pressures and state of the environment in order to be useful for management authorities and other stakeholders.

MOSJ is not in itself a monitoring programme, but rather a system that regularly collects, integrates, assesses and communicates empirical information about the state of the environment in Svalbard. In context of MOSJ Terrestrial the information is to be obtained from "thematic monitoring programmes". These thematic programmes are either mandated tasks performed by the Norwegian Polar Institute or miscellaneous projects performed by other research institutions. MOSJ is an indicator-based monitoring system in the sense that what is deemed relevant of the available data from the thematic programmes is integrated in a set of selected indicators. Based on these indicators the state of the environment is deduced by regular assessments and communicated to stakeholders at local, national and international levels. Some of the stakeholders may commission information about certain aspects of the state of the environment (Figure 1); i.e. the "key figures" defined by national white papers. However, as clearly acknowledged by Sander (2006) scientific research should play a central role in defining what is best to monitor. To assure high quality of the monitoring programmes, data analyses, interpretation assessments, science-based methods and protocols should be applied throughout the scheme presented in Figure 1.

What also becomes evident in Figure 1 is that the very foundation of MOSJ, and hence the value of all its tasks, is fully dependent on the contents and quality of the "thematic monitoring programmes". We note that Sander (2006) expresses concerns regarding whether the scope and state of the thematic monitoring programmes are adequate for providing sufficient and robust information for assessments of the state of the environment in Svalbard and Jan Mayen. This is in particular because many of the thematic programmes are based on independent and uncoordinated research projects with different aims and with unreliable financing in the long term.

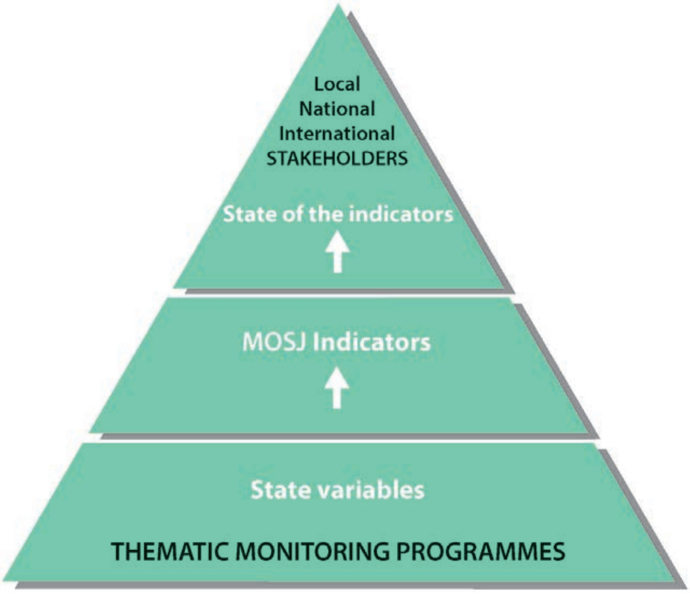

Figure 1
A schematic representation of the role of MOSJ as a link that facilitates flow of empirical information between thematic monitoring programs that acquire data on various environmental state variables, through selected MOSJ indicators derived from the state variables, and the ultimate assessment of the state of the environment as required by relevant stakeholders at different levels.

Finally we highlight the following additional points raised by Sander (2006) that we find relevant for our assessment:

- The processes of making environmental assessments will evolve over time. We note that this will depend on the development of environmental monitoring and assessment as disciplines within the environmental sciences and in policy-making.
- Local/regional assessments are not only in need of temporal baselines to establish time-trends. They will also benefit from being placed in a geographic circumpolar context – e.g. spatial comparisons across gradients or other geographic heterogeneities. In this context we note that monitoring activities and assessments within the Arctic Council ought to be particularly relevant for MOSJ.
- State-of-the-art sampling designs and quantitative analyses are required in order to make robust assessments of the changes in the state of the environment and in the establishment of cause and effect relations.
- Although "good monitoring must be funded on research", Sander (2006) points out that conflicts between the two activities (monitoring and research) are due to "right-to-data conflicts" and "resistance to open access" and different modes of publishing and dissemination. As we will discuss in Section 1.2 these conflicts will become much less apparent if long-term research, monitoring and environmental management converge as proposed in the new paradigm of adaptive monitoring/management (Lindenmayer and Likens 2009).
- As "new knowledge about important relationships will continuously be generated and new priorities will be made in environmental policy the [monitoring] system has to be dynamic". By this passage Sander (2006) in facts anticipates the paradigm of adaptive monitoring (see section 1.2).

- Linking models and monitoring should be an activity for the future within the MOSJ framework.
- In a national context MOSJ should be considered as a pilot project in terms of developing “integrated environmental monitoring”. In line with the high ambitions for managing the wilderness in Svalbard (see above), implementing a state-of-the-art environmental monitoring system for Svalbard could serve as a “show-case” both nationally and internationally.

1.2 Environmental monitoring: Recent developments

Long-term monitoring is instrumental for environmental management and policy making in order to (1) establish how various anthropogenic pressures impact the environment and (2) to assess the effectiveness of management actions intended to alleviate or mitigate such pressures whenever policies deem such actions possible and desirable. However, from originally being an activity initiated and governed by environmental management bodies and policy makers (mandated environmental monitoring; cf. Lindenmayer and Likens 2009), environmental monitoring has recently become in focus in the scientific literature, especially concerning biodiversity and ecosystems. This recent focus has laid the foundation for ecological monitoring to become a distinct scientific discipline.

The new focus on ecological monitoring has its roots in critical commentaries and reviews of how monitoring programmes are operated worldwide. These critiques have identified severe flaws in the ambition, design and organization of monitoring programmes that make them ineffective, or all together inadequate, relative to their stated aims (Yoccoz et al. 2001; Legg and Nagy 2006; Nichols and Williams 2006; Lindenmayer and Likens 2009; Edwards et al. 2010; Lindenmayer and Likens 2010a, b; Peters 2010; Lindenmayer and Likens 2011; Yoccoz 2012). When monitoring programmes fail to serve their intended purpose they most often do so with respect to one or more of the following five generic issues:

(1) The lack of clearly defined goals and targets for the monitoring, i.e. why, what and how to monitor.

(2) The lack of clearly defined questions or predictions derived from explicit hypotheses or conceptual models that outline the natural functioning of the monitoring targets and how they are expected to change with respect to the action of influential pressures.

(3) Inadequate monitoring designs (sampling protocols) and thereby inadequate data for detection of changes and quantifying cause–effect relations.

(4) Inadequate quality insurance as reporting and assessments of results are not being based on peer review processes.

(5) Malfunctioning or absence of communication and collaboration between environmental scientist, managers and policy makers.

Regarding what are biological targets of environmental monitoring, there are three main perspectives/approaches that can be identified. Programmes that focus on biodiversity typically target rare, vulnerable or threatened species (a “red list perspective”). On the other hand ecosystem-based monitoring targets components (set of species or functional species groups), processes and functions in the ecosystem that are crucial for overall ecosystem integrity, stability and resilience. Finally, indicator-based monitoring usually targets single species and/or pressure variables that are supposed to indicate the state of the biodiversity or ecosystems. MOSJ is a monitoring system that by its means is indicator-based, but according to its expressed aims is mainly in line with an ecosystem based approach as “key species for ecology” is to be prioritized (Sander 2006). Conversely, according to Sander (2006) MOSJ is not destined to prioritize species based on rarity or endemism alone, probably on grounds that rare species most often do not have an important role in the ecosystem. As rare species typically are found in rare habitats, and ecosystem-based monitoring typically is performed in dominant habitats, it is complicated to find compromises between ecosystem-based and redlist-based monitoring approaches. Furthermore, knowledge on the ecological requirements of rare arctic species (often non-flowering plant species, invertebrates, micro-organisms) is mostly poor (Talbot et al. 1999, Kålås et al. 2010), which further complicates devising targeted monitoring designs. However, using ecosystem-based monitoring approach to target hotspots of biodiversity (Elvebakk 2005a), could enhance the success of managing rare species.

There has been a long-standing debate about the relative merits of different approaches to monitoring (e.g. Simberloff 1998; Lindenmayer and Likens 2009, 2010b).The indicator-based approach has its main merits in being much simpler and less costly than the other approaches. However, the approach is entirely dependent on the existence of spatio-temporally invariant links between the selected indicators and the state of the ecosystem and/or between “key species” serving as umbrellas for rare/endemic species. These requirements are hardly ever verified and cannot even be expected to be met in the case of arctic ecosystems for which key properties are only transient owing to rapid environmental change (i.e. “what an indicator indicates tomorrow is likely to be different from what it indicates today”). On the other hand, ecosystem-based monitoring that invokes a larger set of state variables and with a focus on their dynamic linkages rather than assumed steady states, is more appropriate for detecting the sort of emergent process relations, thresholds and ecological surprises (Lindenmayer et al. 2010) that in the near future are likely to occur due to novel climates (e.g. Williams et al. 2007) and ecosystems (e.g. Macias-Fauria et al. 2012).

For these reasons the approach of ecosystem-based monitoring and management has been embraced by many science communities, management bodies and policy makers worldwide. This also includes the CAFF/Arctic Council and its new Circumpolar Biodiversity Monitoring Program (CBMP) (Christensen et al. 2013) and the Arctic Biodiversity Assessment (Meltofte 2013). The challenge is, however, to put into practice the good intention and grand ambitions when establishing ecosystem-based monitoring. It will require a stronger scientific underpinning in terms of ecosystem models that guide the design and the operation of the programme. Moreover, it will require stronger governance of operation of the monitoring system in all its tasks where scientist, managers, policy makers and other relevant stakeholders are involved.

The paradigm of adaptive monitoring of Lindenmayer and Likens (2009, 2010b, 2011) provides the most developed scheme (“a gold standard”) for implementing the ecosystem-based approach to monitoring and management (Figure 2). This scheme includes both the essential elements of hypothetico-deductive science and adaptive ecosystem management (Walters 1986) and moreover provides explicit protocols for the reporting of results, involvement of stakeholders and adjustments to new monitoring technologies. The framework of adaptive monitoring completely rules out the old-fashioned distinction between monitoring and scientific research.

In the terrestrial circumpolar Arctic, ecosystem-based monitoring (EBM) has been implemented in Alaska (low-Arctic Toolik Lake) through the US National Ecological Observatory Network (NEON) (Schimel et al. 2011) and the US Long-term Ecological Research (LTER) Program (for details, see http://arc-lter.ecosystems.mbl.edu). In Greenland EBM has been implemented in the monitoring systems in high-arctic Zackenberg (ZERO) and low-arctic Nuuk (NERO) (Jensen and Rasch 2011a, b). Norway has recently enhanced its arctic ambitions as to become “an outstanding manager of the environment" (Utenriksdepartementet 2009) and by the establishment of the Fram Centre in Tromsø (2010). The mandated goal of the Fram Centre is to become "an internationally leading centre for research on climate and the environment" (Utenriksdepartementet 2009). The Fram Centre's "Terrestrial Flagship" has recognized the instrumental importance of EBM for fulfilling these high ambitions, and has taken two initiatives in that respect. The research school AMINOR (Advanced Environmental Research in the North; www.aminor.org) was established in 2012 with the task to train PhD candidates and update environmental scientists on new developments regarding the integration of research, monitoring and management of arctic environments. The EBM framework is central within AMINOR.

The second initiative is COAT (Climate-Ecological Observatory for Arctic Tundra). Presently, COAT represents a comprehensive science-plan for a monitoring programme to be implemented in the Norwegian sector of the terrestrial Arctic; i.e. low-arctic tundra in Finnmark and high-arctic tundra in Svalbard. The COAT science plan has been developed by a crew of 23 researchers from the Fram Centre's terrestrial flagship, the Meteorological Institute in Oslo and Aarhus University, Denmark. A draft of the plan was subjected to a thorough review by an international panel of experts in 2012, which deemed it excellent, and the final plan has recently been published (Ims et al. 2013). COAT is an ecosystem-based monitoring programme that applies food web theory to identify monitoring targets, state variables and their causal links by means of conceptual modeling. Selected monitoring targets are key components of the food web liable to respond to environmental pressures (in particular climate change) and management actions (e.g. harvesting). Many of the monitoring targets represent both ecosystem services and targets for conservation. COAT will apply adaptive protocols to continuously update knowledge, models and methods, and will have an active interphase with management and stakeholders (as outlined in Figure 2).

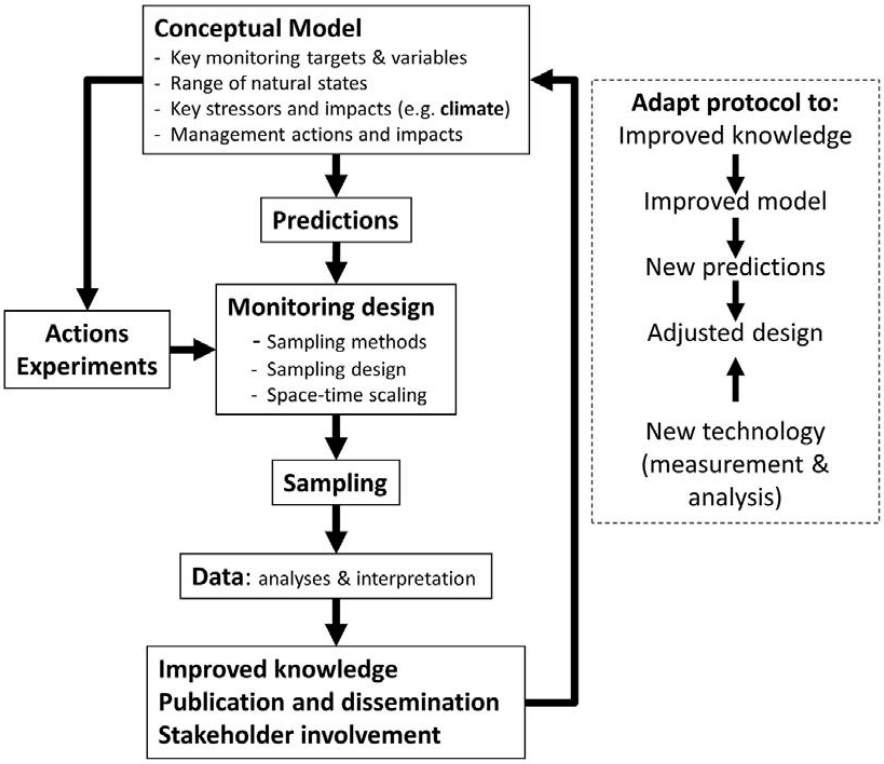

Figure 2
The scheme of adaptive ecosystem-based monitoring (from Ims et al. 2013 based on Lindenmayer and Likens 2009).

1.3 Mandate

The assessment committee of MOSJ Terrestrial has been asked to:

(1) Describe the state and trends in central components of the terrestrial environment in Svalbard and Jan Mayen. When trends are present they should be related to causal factors. This implies that a distinction between impacts of anthropogenic pressures (climate change, pollution, harvesting and traffic) and natural fluctuations in the environment must be made. Moreover, assessments of likely state changes (i.e. predictions) in context of expected future environmental change are requested, both with respect to climate change and developments of human activities (industries and infrastructure).

(2) Evaluate whether national goals for the terrestrial environment in Svalbard and Jan Mayen are fulfilled. To give advice on actions that could help to achieve these goals.

(3) Give advice on changes in the specific means of MOSJ Terrestrial (i.e. the set of MOSJ indicators as well as the organization and performance of the overall monitoring system) in order to better fulfill the expressed goals of MOSJ. The committee may also give advice on mapping and research that can improve the knowledge about the state of the terrestrial environment on Svalbard and moreover to give advice on environmental policies for Svalbard and Jan Mayen.

The mandate given for the assessment reflects that an ecosytem-based perspective should be adopted, for instance, by emphasizing that the assessment should, wherever relevant, evaluate how different components of the ecosystem could interact and how changes could cascade through the system. An ecosystem perspective on the terrestrial environment is also provided by the document "Description of ecosystem on Svalbard and Jan Mayen" and in most of the selection criteria for the MOSJ indicators.

Materials available for the present assessment are information provided in the web pages of MOSJ and various reports written specifically for MOSJ-related purposes. The web pages provide the list indicators of "MOSJ Terrestrial" and the criteria used for selecting them. Time series data of MOSJ indicators and metadata describing how indicator data has been sampled are also provided on the web pages. The assessment committee has also been asked to invoke in other relevant information about the terrestrial ecosystem on Svalbard that is beyond the selected MOSJ indicators. This is in line with Sander's (2006) outline of the organization of MOSJ (Figure 1), which emphasizes that MOSJ is also reliant on inputs from other "thematic programmes" than those providing data and variables for the core indicators of MOSJ Terrestrial. Indeed, there is a wealth of recent scientific publications that concern the MOSJ indicators as well as other central state-variables in the terrestrial ecosystem in Svalbard. To our benefit basically all of this information has just been synthesized and reviewed in the COAT science plan (Ims et al. 2013).

The presented assessment has also been mandated to include processes outside the assessment area (Svalbard and Jan Mayen) when such processes are deemed relevant for our purpose. This point is highly relevant and timely as the Arctic Council/CAFF, through the Arctic Biodiversity Assessment (Meltofte 2013), has just completed a comprehensive circumpolar assessment of terrestrial arctic ecosystems (Ims and Ehrich 2013). The circumpolar ABA assessment has the same scope as the present regional assessment for

Svalbard and Jan Mayen. Thus we will use the new ABA assessment (Meltofte 2013), as well as the earlier assessments of Symon et al. 2005 and Symon (2011) to place the assessment of MOSJ within an international circumpolar context.

Finally, in line with what internationally has become a quality-assurance requirement in environmental assessments (e.g. ABA), our assessment of MOSJ Terrestrial will mainly be syntheses of already quality-assured analyses and interpretations published in the peer-reviewed scientific literature. However, this restriction will not imply any loss of information as the peer-reviewed literature has quite exhaustively exploited the data forming the basis for the MOSJ indicators as well as extensive data from other components of the terrestrial ecosystem in Svalbard.

In this report we proceed in section 2 with a brief description of the terrestrial ecosystem in Svalbard and Jan Mayen – emphasizing what are the key components of the food webs (section 2.1), how these component are likely to be impacted by various pressures (section 2.2) and how MOSJ targets both pressures and impacts by means of prioritized indicators (section 2.3). In section 3 we make our assessment of the state of the environment in Svalbard – first in terms of levels, variability and trends in pressures (section 3.1) and then, next, by assessing how ecosystem state is impacted by the pressures (section 3.2). Here we make a distinction between which inferences can be made based on MOSJ indicators and which inferences rely on research that is not prioritized in MOSJ. We point out what are important deficiencies and knowledge gaps. We conclude our assessment of by discussing how the state of the terrestrial environment in Svalbard relates to national goals and key figures (section 4.1). Finally summarize what are main current shortcomings of MOSJ and provide recommendation on how MOSJ should be developed to better fulfill its aims in the future (section 4.2).

2 Background: Ecosystem, monitoring and assessment approaches

2.1 The terrestrial ecosystem in Svalbard and Jan Mayen

2.1.1 Geographic, climatic and biogeographic settings

2.1.1.1 Svalbard

The archipelago of Svalbard (62 700 km^2; 74-81°N, 15-30°E) harbours one of the northernmost terrestrial ecosystems of the world. The archipelago consists of numerous islands, with the largest being Spitsbergen (37 700 km^2). The North Atlantic Current has a strong effect on Svalbard's climate. While the sea north and east of Svalbard in general is ice-covered for at least eight months of the year, the warm North Atlantic Current keeps the west coast of Svalbard ice-free for most of the winter. Still the climate is arctic, and permafrost is found in all non-glaciated areas. Long-term meteorological records are mainly available from the west coast of Spitsbergen where the annual average temperature was -6.7°C for the period 1961-1990 (Longyearbyen Airport). Precipitation is low (on average 190-525 mm annually), and tends to decrease from the outer parts of the fjords on the west coast (~500 mm annually) to the inner eastern parts of these fjords (~200 mm annually) (Førland 2009).

Svalbard covers three bioclimatic tundra zones; A (Arctic polar desert), B (Northern arctic tundra) and C (Middle arctic tundra) (CAVM Team 2003; Elvebakk 2005b). In the most productive parts of Spitsbergen a topography dominated by mountains separated by deep broad valleys generates steep altitudinal gradients, and associated steep gradients in vegetation structure. Large areas with relatively high primary production are found in the bottom of the valleys, while a sparse vegetation cover of arctic polar desert type is commonly found at altitudes above 200 m. At an average July temperature of 6 °C, the vegetation in the most productive valleys is dominated by prostrate dwarf shrubs (*Salix polaris* and *Dryas octopetala*), grasses and sedges, forbs and mosses. Local variation in bedrock and topography creates considerable gradients and spatial contrasts in local climate, nutrient levels, moisture and snow depositions that cause a small scale spatial mosaic of vegetation types in terms of structural complexity and primary productivity. In addition, extensive permafrost and freeze – thaw processes in the active soil layer cause unstable soils in many areas. Productive wet marsh vegetation is often present in wet areas in the bottom of the valleys, while heath vegetation, dominated by *Luzula sp*., covers a large part of the drier areas. In addition, productive patches dominated by graminoids (e.g. *Poa sp*.) are found in moderate snow beds, and may appear up the sides of the valleys until arctic polar desert vegetation takes over at higher altitudes (Elvebakk 1994, 1997; van der Wal et al. 2000). Elvebakk (2005b) made a vegetation map using circumpolar based typologies, and he identified the following vegetation types which are rare on a cicumpolar scale and concentrated in Svalbard: high arctic *Potentilla pulchella* steppes, high arctic acidic fens, high arctic alkaline *Poa alpina* snow beds, *Deschampsia alpina* mires, moss tundra below birds cliffs, polar desert tundras and acidic polar desert on granite.

The plant biodiversity of Svalbard is similar to other arctic archipelagoes of similar climate and size (Alsos et al. 2009). However, the number of redlisted and introduced species is high for vascular plants. Whether there are similar high numbers for the other components of arctic vegetation is not known. For vascular plants crossing experiments have shown that there are reproduction barriers between individuals from Svalbard and other arctic regions (Grundt et al. 2006), and genetic studies show clear differentiation between Svalbard populations and populations from e.g. Scandinavia, Russia and Greenland (Alsos et al. 2007).

2.1.1.2 Jan Mayen

Jan Mayen is a 377 km^2 (57 km long and 3-15 km wide) volcanic island located in the North Atlantic (70-71°N, 7-9°W). Large parts of the coastline are covered by steep bird cliffs and the worlds' northernmost active and glaciated volcano, Mt. Beerenberg (2277 m a.s.l), is located on the northern side of the island. The climate of Jan Mayen is arctic and oceanic with -0.6°C as mean annual temperature for the period 1921-2010 while the mean annual precipitation is 628 mm (Kapfer et al. 2012). Mean temperature for July for 1960-1990 was 4.2°C (Jan Mayen Radio).

The vegetation in Jan Mayen belongs to the bioclimatic Middle – Low arctic tundra sub-zones (C-E; Elvebakk 1985; Elvebakk and Spjelkavik 1995; Gabrielsen et al. 1997). Poorly developed soil, lava fields, rapid drainage and exposure to frequent strong winds limit the growth of vascular plants on Jan Mayen (Russell and Wellington 1940; Virtanen and Oksanen 1995). Important vegetation components of equivalent bioclimatic sub-zones elsewhere in the Arctic, such as various shrubs and graminoids, are scarce or entirely missing. The vegetation is dominated by short growing herbs, lichens and mosses (Kapfer et al. 2012).

2.1.2. Outlines of the terrestrial food webs

There are two main ecosystem-based perspectives which can be applied when studying of state changes of terrestrial arctic ecosystems (Ims and Ehrich 2013). In one perspective, functional properties of the ecosystem is focused, such as recycling and flows of elements and energy, measured at the level of broad compartments of the system. The other perspective is based on a food web approach, where the ecological interactions (trophic, competitive or mutualistic) between species or functional species groups are in focus.

While both perspectives obviously have merits, the food web approach is most relevant in context of MOSJ. The food web has been used as framework for describing tundra ecosystems all the way back to Charles Elton's pioneering work on Svalbard (see Pimm 1982 for a review), and more recent work (e.g. Krebs et al. 2003; Aunapuu et al. 2008; Legagneux et al. 2012, 2014) has provided strong theoretical and empirical foundations for the development of conceptual pressure–impact models (cf. Ims et al. 2013). Moreover, humans often affect ecosystems through their involvements in food webs (Strong and Frank 2010), so the food web approach is very applicable in context of management and conservation. Finally, recent reviews (Post et al. 2009) and modelling (Legagneaux et al. 2012, 2014) have shown that the food web approach is very useful for detecting and predicting the many profound indirect impacts of climate change, which presently is considered to be the overwhelmingly most important pressure on arctic ecosystems (Meltofte 2013). We also note that the selection criteria used for prioritizing indicators in MOSJ is also most compatible with a food web perspective to ecosystem-based monitoring and assessments.

Compared to many other tundra ecosystems, even in equivalent bioclimatic subzones, the Svalbard food web has relatively low complexity (Figure 3), with some typical arctic keystone species and food chains missing. The isolated geographical positioning of the archipelago, possibly together with certain attributes of the climate, are main reasons for this. The key herbivore species present are one ungulate (the endemic Svalbard reindeer), one species of ptarmigan (the endemic Svalbard rock ptarmigan) and two species of migrating geese (the pink-footed and the barnacle goose). The predator/scavenger guild is also depauperate with the main species being the arctic fox and the glaucous gull, species that also make extensive use of marine food sources (Figure 3). Indeed, marine subsidies (both in terms of nutrient and energy) to the terrestrial ecosystems are more profound in the coastal areas of Svalbard than in many other high-arctic regions (Ims and Ehrich 2013).

Migrating passerines (e.g. snow bunting) and shore birds (e.g. purple sandpipers) add to the species diversity and abundance of prey in the summer season (Kovacs and Lydersen 2006). Contrary to what is found in most tundra food webs (Ims and Fuglei 2005), small mammalian herbivores (rodents and hares) and specialist predators are functionally absent in Svalbard (Strøm and Bangjord 2004). Only a local population of sibling vole is spatially restricted to the area around a sea-bird colony in Grumant, Nordenskiöld Land peninsula (Henttonen et al. 2001). Nevertheless this rodent population maintains an important zoonotic parasite (*Echinococcus multilocularis*; EM) in western Spitsbergen (Fuglei et al. 2008; see below).

There are no overwintering resident mammalian or avian species on Jan Mayen and the biodiversity and abundances at higher levels in the food web are very low (Figure 4). There are no vertebrate herbivores breeding, at least in notable numbers, whereas several species of geese are observed during migration (Gabrielsen et al. 1997) (Figure 4). Among the highest trophic levels (predators) there are some populations of migrant insectivore birds breeding (passerines and shore birds) and some marine birds (skuas and large gulls) that may potentially act as predators on terrestrial birds and insects (Figure 4). The arctic fox was for a long time present in good numbers on the island, but intensive harvesting in the beginning of the 1900s resulted in its eradication (Barr 1991).

Except for Kapfer et al.'s (2012) recent resampling of some old vegetation survey plots there are no monitoring data or other recent ecological studies available for the terrestrial ecosystem in Jan Mayen. Hence, Jan Mayen will not be dealt with further in our assessment of MOSJ Terrestrial.

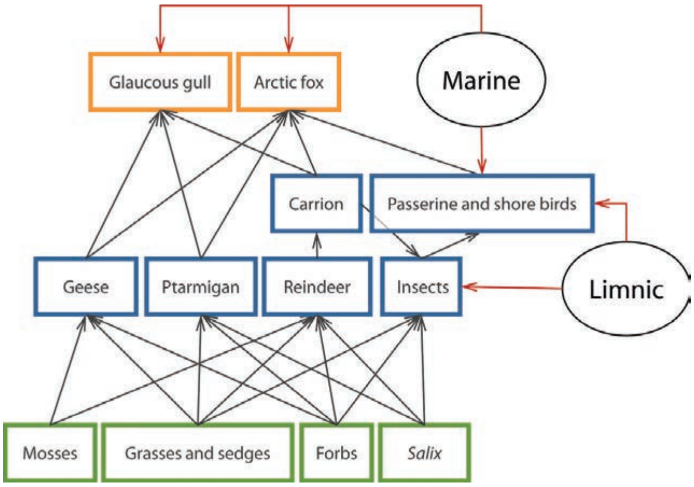

Figure 3
Key components (species or functional species groups) and trophic flows (arrows) of the plant-based terrestrial food web for Svalbard with important inputs (subsidies) from limnic and marine ecosystems (from Ims et al. 2013).

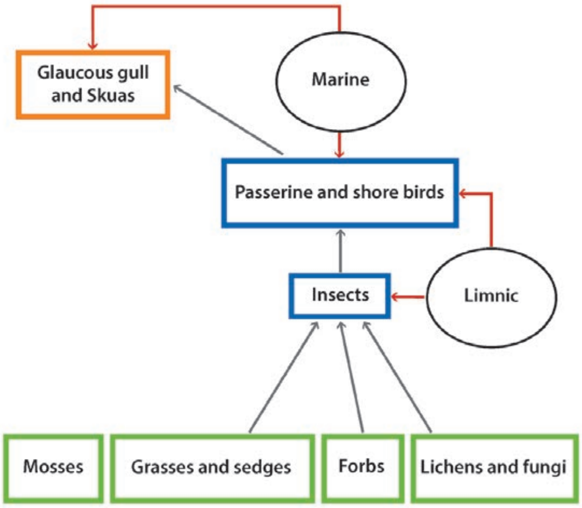

Figure 4
The main components (functional species groups), trophic flows and external subsidies (marine and limnic) of the terrestrial food web for Jan Mayen.

2.2 Pressure–impact models of the Svalbard terrestrial food web

Based on a comprehensive review of the scientific literature on the functioning of, and the known pressure–impacts on, terrestrial arctic ecosystems in general and the Svalbard ecosystem in particular, the COAT science plan identifies four monitoring modules considered essential for assessments of the future state of the Svalbard terrestrial food web. For each of these four modules a conceptual model is developed that outlines a set of monitoring targets in terms of key species or functional species groups in the food web (Figure 3) and their key environmental processes relations (Figure 5).

Specifically, each model outlines (1) key ecological interactions (trophic or competitive) between monitoring targets, (2) the most likely pathways for impacts of climate change and (3) the options and pathways for management to alleviate or mitigate negative pressure impacts. The focus on climate impact pathways pressures is in line with ABA (Meltofte 2013; Ims and Ehrich 2013), which concluded that climate change represent the single most comprehensive and urgent pressure on arctic environments. However, also other (more local) pressures can be regionally important. In the COAT models these local pressures are represented by the management–impact pathways (Figure 5), because local pressures

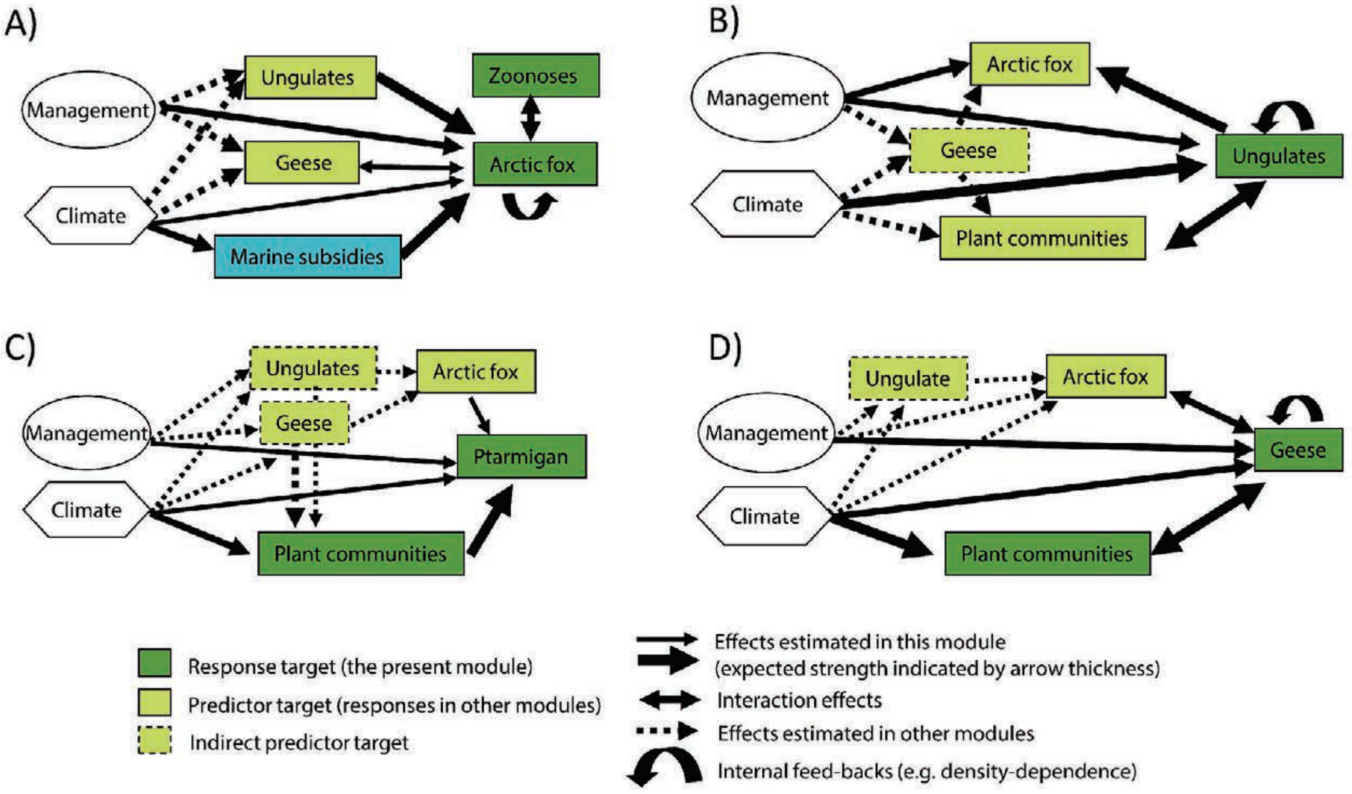

Figure 5
The conceptual models representing the four Svalbard monitoring modules of the science plan for COAT Climate-Ecological Observatory for Arctic Tundra (Ims et al. 2013). Each model specifies climate and management impact pathways on prioritized monitoring targets. A. Arctic fox module, B. Ungulate module, C. Ptarmigan module and D. Goose module.

such as harvesting, development of infrastructure and increased traffic in principle can be dealt with by appropriate local management actions. Indeed, a criterion for prioritizing monitoring targets in COAT is that they could be subjected to management actions. Other none-exclusive criteria for selecting targets were: key functions in the food web, high climate sensitivity, high importance as conservation targets or objects for comparative scientific analysis in an international (circumpolar) context.

The key attributes and motivations behind the conceptual models outlined in Figure 5 are the following:

The *arctic fox model* (Figure 5A) targets (1) the arctic fox because it is the functionally most important predator within the terrestrial food web that moreover links the terrestrial food web to subsidies from the marine food web and (2) arctic fox parasites and diseases that represent dangerous zoonones (rabies, toxoplasmosis and EM) for people. Management options and local pressures are harvesting and traffic. In an international context the arctic fox is placed on the IUCN "Climate flagship species list" to highlight "climate change disruptive effects on interactions between species". Potentially important climate impact paths, according to the conceptual model, are change of herbivore population dynamics (reindeer, geese and ptarmigan) and changing sea ice extent. An issue is also that the arctic fox is the terrestrial species most subjected to bioaccumulation of long-distance born pollutants.

The *ungulate model* (Figure 5B) targets the Svalbard reindeer. Several recent studies have revealed a strong direct sensitivity of the Svalbard reindeer to climate (Hansen et al. 2011; Hansen et al. 2013) that needs to be monitored in a climate change perspective. The reindeer has also a key role in plant community dynamics (see van der Wal et al. 2001; van der Wal et al. 2004) and a strong influence on the population dynamics of the arctic fox (Eide et al. 2012; see section 3.3). In a national conservation context the Svalbard reindeer is an endemic subspecies. In a circumpolar context, reindeer and caribou are almost omnipresent in arctic tundra, although declining in many parts (Vors and Boyce 2009), where they represent the most important provisional terrestrial ecosystem service to local people. Hence, knowledge of the state of Svalbard reindeer, and how it is impacted by climate change and management of local pressures (e.g. harvesting) is important for comparative purposes in a circumpolar setting.

The *ptarmigan model* (Figure 5C) targets (1) the Svalbard rock ptarmigan and (2) plant communities that contain the main forage plants for this herbivorous bird. The key climate-impact pathway is predicted to be indirectly mediated by phenological changes in its food plants, which thus provides a Svalbard case for the internationally recognized issue of emerging trophic mismatches owing to climate change (e.g. Høye et al. 2013). Management issues are mainly due to recreational harvesting. In a conservation perspective the Svalbard ptarmigan is an endemic sub-species.

The *goose model* (Figure 5D) targets (1) the two goose species (pink-footed and barnacle goose) and (2) the plant communities these goose species interact with. Arctic geese are internationally renowned for their high impact on certain arctic plant communities, their important interactions with the arctic fox that determines their breeding success, as well as the many issues that relate to the management of long-distant migrants which involve stakeholders in several countries with potentially conflicting interests. In addition, goose grazing may pose a threat to redlisted species, as e.g. high grazing pressure has been observed at the hot springs in Bockfjorden, the only site in Svalbard were *Sibbaldia probcumbens*, *Botrichium lunaria*, *Carex capillari*s, and *Puccinellia cf. pallibinii* grow and three further redlisted vascular plant species are found (Alsos et al. 2011).

Each of these four models is in the COAT plan further detailed by sets of state variables that will be sampled either according to intensive (seasonal – annual intervals) or extensive (5-year intervals) monitoring designs (Ims et al. 2013). The COAT plan also outlines how the conceptual models are to be translated into statistical models (state-space structural equation models) that will allow for a Bayesian updating of analytical results according to the same intervals as the sampling.

2.3 Indicators of MOSJ Terrestrial

The following priority criteria for selecting MOSJ Indicators are described below according to Sander (2006):

- High priority with respect to the stated national goals and "key figures" for the state of the environment as well as the needs the Governor of Svalbard has in day-to-day management.
- Indicators that describe the level of human-induced pressures and their impacts on components of the ecosystem.
- Processes that are assumed to be sensitive to climate in the MOSJ region and indicators that give clear signals of climate change.
- Species that are particularly influential in arctic ecosystems (key species) or representative for several species (indicator species).
- Rarity has been given lower priority than both human-induced pressures and key species for ecology. Hence, Red List species are not included.
- Different types of ecosystems must be included.
- The methods must be documented and standardized.
- International recommendations, particularly from the working groups of the Arctic Councils (AMAP; pollution and CAFF; biodiversity and ecosystem processes and functions).
- Cost efficiency.

The selected indicators in MOSJ can be categorized as Pressure indicators and Ecological State indicators, where the pressures indicators (termed "Climate" and "Influence indicators" in the MOSJ web pages) are expected to exert impact on the ecological state indicators (termed "themes that reflect state" in the MOSJ web pages). According to the terminology used in MOSJ (cf. Sander 2006) indicators are measured by one or several parameters, which is equivalent with the term state variables used in Section 2.2. In the following we prefer to use the latter term as a parameter conventionally denote a coefficient of a statistical model.

A

Figure 6
Sites and areas where pressure and ecological state indicators are subjected to field sampling in Svalbard.

Map A: Pressure indicators (variables) from site measurements of climate (C; air temperature and precipitation), below ground temperature/permafrost (GT), pollutants in air (Po), beach litter (BL) and traffic (T)

Figure 6 (continued)
Map B: Approximate areas for which yearly bag statistics of arctic fox, rock ptarmigan and reindeer harvesting are gathered, which quantify the harvesting pressure indicators.

In the sections below we describe briefly those MOSJ indicators we find the most relevant for the present assessment. Figure 6 shows maps of the areas and sites where the variables underlying the pressure and ecological state indicators are sampled in Svalbard. These maps show that monitoring of the terrestrial environment in Svalbard is geographically aggregated within a few areas along the west coast of Spitsbergen. Thus large geographic regions and major environmental gradients (e.g. in term of climate) are not represented in MOSJ Terrestrial.

2.3.1 Pressure indicators

2.3.1.1 Climate

Five climate variables, assumed to be relevant to the state of the terrestrial ecosystem, are included in MOSJ:

- Air temperature
- Precipitation

Figure 6 (continued)
Map C: Areas and sites where ecological state indicators for arctic fox (den surveys), rock ptarmigan (point transect sampling), reindeer (total population count surveys) and vegetation are subject to field sampling. Vegetation state variables are obtained from permanent plot measurements of thermo-hilic plants abundances (TP), intensive sampling of plant communities (IP), cover estimate of plant communities disturbed by traffic (DP) and site measurement of plant phenology (PP).

- Below ground temperature of permafrost at depths between 15m and 40m
- Duration of snow cover
- Plant growing season: Start, end and length

Air temperature and precipitation are based on the measurements made at the meteorological stations run by the Norwegian Meteorological Institute (Nordli et al. 2014); Bjørnøya (1910-), Hopen (1944-), Longyearbyen (in Longyearbyen: 1911-1977, at the airport: 1975-), Svea (1978-, no measurement of precipitation after 2003) and Ny-Ålesund (1951-) (Figure 6A). The measurements of ground temperature are based on a borehole located 20 km from Longyearbyen (in Adventdalen; Janssonhaugen; Figure 6A) and may have relevance for cryoturbation processes in the soil and conditions for plant growth (but see 3.1.1.2). Presence of snow cover is measured daily at the meteorological stations Svalbard Lufthavn, Svea, Ny-Ålesund and Jan Mayen, which give duration of snow cover (number of days with snow during the year). Start, end and length of growth season, which also could be regarded as an ecological state variable, is mostly based on satellite data (in particular the Normalized Difference Vegetation Index = NDVI) and the start of the time series depends on the sensor (Karlsen et al. 2009). Field measurement of plant phenology in terms of timing of flowering (start of growing season) and autumn yellowing (end of growing season) of *Salix polaris* in Adventdalen and Ny Ålesund were initiated in 2009 (Karlsen et al. 2009).

2.3.1.2 Harvesting

Three harvesting indicators (hunting and trapping), measured as number of harvested individuals (bag), are reported for three species in MOSJ:

- Arctic fox
- Svalbard rock ptarmigan
- Svalbard reindeer

The trapping season for the arctic fox lasts from 1 November to 15 March. A trapping licence and a mandatory harvesting report to the Governor of Svalbard from each trapper is required (http://www.sysselmannen.no/en/Residents/Hunting-and-Fishing/) and the total number of arctic foxes trapped is reported annually to MOSJ. The harvest is carried out by a few trappers who overwinter in isolated stations and by residents of the larger settlements where recreational harvesting is conducted. The majority of the trapping takes place at Nordenskiöld Land, but the locations for the overwintering trappers have varied through the years (see Figure 6B for trapping stations Mushamna, Austfjordnes, Kapp Wijk, Farmhamna and Kapp Schollin) as well as the number of trapping areas for the recreational trappers. Today a total of 25 trapping areas are available for recreational trapping south of Ny-Ålesund (2 areas) and on Nordenskiöld Land (23 areas) (Figure 6B). The Governor of Svalbard organizes the annual application and assignment of the trapping areas before the trapping starts. Two types of traps are allowed and each trap is controlled and approved by the Governor of Svalbard. Three traps can be used in each trapping area.

The hunting season for the Svalbard rock ptarmigan lasts from September 10 to December 23. A hunting license is required and is available for both residents and visitors to Svalbard. Bag limit is 10 ptarmigans per day for residents and five ptarmigans per season for visitors. The Governor of Svalbard requires mandatory reporting of hunting data and the total numbers of ptarmigan shot are reported annually to MOSJ. There are no geographical restrictions on the Svalbard rock ptarmigan hunt, except for in the hunting free areas around Longyearbyen, but the majority of the off-take is in Nordenskiöld Land, in the Isfjorden area and in the trapping areas of the trapping stations (Figure 6B).

Hunting for ptarmigans in Adventdalen. Photo: Øystein Overrein, Norwegian Polar Institute

The Svalbard reindeer is harvested in six hunting units (land area of 815 km^2 < 250 m altitude) on Nordenskiöld Land through recreational hunting by local residents from August 15 to September 20 (Figure 6B). The number and spatial distribution of hunting licenses is under the control of the Governor of Svalbard and most applicants receive a license. The annual bag is quota controlled, based on annual population counts, and comprises around 2.5-5 % of the total autumn population in the area. The Svalbard reindeer is harvested in a way to mimic the natural population variability, thus the quota on calves vary among years. The total number of hunted animals (category; adults and calves) is reported annually to MOSJ.

2.3.1.3 Pollution

Three pollution indicators, assumed to be relevant to the state of the terrestrial ecosystem, are described in MOSJ:

- Nitrogen and sulphur components in air
- Persistent organic pollutants (POPs) in air
- Beach litter

Nitrogen and sulphur components are measured as nitric acid and nitrate (sum NO3) in air (1990-2011) and sulphate (SO4) in air (1980-2011) at the Zeppelin Station in Ny-Ålesund by NILU. For nitrogen and sulphur components it is to be noted that much of the tundra vegetation in the Arctic is nitrogen limited (Callaghan et al. 2004a), thus external influx of nitrate is expected to be particularly influential.

A set of Persistent Organic Pollutants (POPs) in air is also collected by NILU at the Zeppelin station in Ny-Ålesund (1999-2011). POPs are considered harmful to biota due to their persistence and bioaccumulation in the food chain (Wilson & Symon 2004). They accumulate in the food chains so that the relatively long food chains in the marine environment could be expected to accumulate higher levels than in the relatively shorter food chains in the terrestrial ecosystem. The status of potentially eco-toxic pollutants in Svalbard has recently been reviewed in Gabrielsen et al. (2012) and in our assessment we only briefly discuss this issue in context of the arctic fox. Being placed at the top of the food chain, the arctic fox is expected to be exposed to the highest levels of organochlorine pollutants among all terrestrial species in Svalbard. The arctic fox is also feeding from the marine ecosystem, which accentuates its potential for being affected by POPs and in particular PCBs (Fuglei et al. 2007).

Beach has been litter registered annually by the Governor of Svalbard over stretches of 200 m at three beaches in Brucebukta, Breibogen and Isflakbukta in Svalbard since 2001. The registrations at Breibogen and Isflakbukta were treminated in 2010. From 2011 beach litter is also monitored after OSPAR's methods at two beaches, Brucebukta and Luftskipodden in Svalbard (Figure 6A). The total amount is reported to MOSJ. The ecological consequences of beach litter is probably much more severe in the marine than in the terrestrial environment because it occurs more dispersed in the oceans and in the littoral zone than on land and is more likely to be transmitted in the marine food chains. The most evident effect on terrestrial biota is when litter from especially fishing gear (wires, pieces of trawls) gets entangled in reindeer antlers and cause mortality.

Tourism in Ny-Ålesund. Photo: Geir Wing Gabrielsen, Norwegian Polar Institute

2.3.1.4 Traffic

Nature based tourism is the main economic exploitation of the terrestrial ecosystem in Svalbard (Overrein 2010). Additionally, Svalbard has become an important arena for arctic environmental research. Four traffic indicators represented by five variables are described in MOSJ:

1. Cruise tourism
- Number of people going ashore away from the settlements and Isfjorden
- Number of places where people go ashore away from the settlements and Isfjorden

2. Individual travellers
- Number of people in areas where prior notification is mandatory

3. Overnight stops in Longyearbyen
- Number of overnight stays in public accommodation

4. Snowmobiles
- Number of snowmobiles

The indicator variables are collected annually from the official travel statistics for Svalbard (for an example see Sysselmannen 2014. Indicator 1 and 2 cover the entire Svalbard where cruises and individual travellers traverse. Indicator 3 is based on data from Longyearbyen and indicator 4 is based on the total number of snow mobiles present in the entire archipelago.

2.3.2 Ecological state indicators

Most of the ecological state indicators in MOSJ have been prioritized on grounds that are expressed for the selection of "monitoring targets" in the COAT science plan (see Section 2.2 above). Thus selection criteria for the indicators are in the following only described for indicators that are not represented by monitoring targets and state variables in Section 2.2. Some indicators are mentioned in the MOSJ web pages without any data or expressed plans/protocols for data acquisition (geese, introduced species) or with some initial sampling with the ambition to become a part of the MOSJ system (vegetation indicators). Only the latter will be briefly described below. Based on other thematic programmes we are, however, able to make an assessment also of introduced species and vegetation.

2.3.2.1 Arctic fox

The MOSJ state variable for the arctic fox indicator is den occupancy (the proportion of known dens with cubs), which is surveyed in two areas in West Spitsbergen (Figure 6C) through the monitoring programme of the Norwegian Polar Institute (NPI). Six to nine dens located over approximately 220 km^2 in Kongsfjorden/Brøggerhalvøya have been surveyed since 1993 (Fuglei et al. 2003). In Sassendalen/Adventdalen up to 32 dens, over approximately 900 km^2, have been surveyed over two time periods, 1982 – 1989 and from 1997 and onward (Prestrud 1992; Eide et al. 2012). Arctic foxes are strongly dependent on good denning sites and breed in underground dens in sand or under boulders, in screes or in crevices in bedrock (Prestrud 1992; Tannerfeldt et al. 2003). The dens may be used repeatedly over long time periods (centuries) and den surveys are therefore a widely used method for obtaining population estimates (Macpherson 1969; Angerbjörn et al. 1995; Tannerfeldt et al. 2003). All the known arctic fox dens in Svalbard are registered in a GIS-database.

2.3.2.2 Svalbard reindeer

The MOSJ state variable for the Svalbard reindeer is the annual population size (Tyler 1986; Aanes et al. 2000; Solberg et al. 2012) surveyed in three regions in West Spitsbergen (Figure 6C; [Adventdalen, 1979 – present; summer season by NPI], Brøgger Peninsula [1978 – present; winter season by NPI] and Reindalen [1979 – present; summer season by NINA]).

2.3.2.3 Svalbard rock ptarmigan

The MOSJ state variable for the Svalbard rock ptarmigan is the annual density of territorial males in spring surveyed by point-transects sampling since 2000 through a monitoring programme by NPI (Pedersen et al. 2012). The monitoring area on Nordenskiöld Land is approximately 1200 km^2 and includes Hanaskogdalen, Adventdalen with side valleys, DeGeerdalen, Eskerdalen and Sassendalen (Figure 6C).

Dwarf birch (*Betula nana*) is a thermophilic species. Photo: Stein Ø. Nilsen, Norwegian Polar Institute

2.3.2.4 Thermophilic plant species

The response of arctic vegetation to climate change is expected to be highest for species at their climatic limit and a thematic programme to monitor such thermophilic plants has been initiated in Colesdalen in 2008 and 2009 (Figure 6C; Arnesen et al. 2012).The programme includes annual measurements of the density of five thermophilic species (the long-lived perennials *Betula nana*, *Vaccinium uliginosum*, *Empetrum nigrum* and *Campanula rotundifolia* and the annual *Euphrasia wettsteinii*), the assumed most important competitors *Salix polaris* and *Dryas octopetala* as well as soil temperature. In addition, the total vegetation including cryptogams was planned to be monitored every five years. No monitoring has been conducted since 2012 and the future of the programme appears to be uncertain.

2.3.2.5 Intensive plant community monitoring

Intensive plant community monitoring in Endalen (Figure 6C) was subjectively established in 2009 to estimate the cover of all species in common plant communities (vascular plants and cryptogams) within the middle arctic tundra zone (Aarrestad et al. 2010). The main aims were to assess the effects of climate change and increased input of pollutants. Soil temperature was measured and soil samples were collected and analysed for moisture, bulk density, and chemical composition. Measurements are intended to be conducted at 5-years intervals (Aarrestad et al. 2010), next time in 2014. Hence, no time series data on plant community dynamics are yet available in MOSJ, but we will be able to make an assessment based on other thematic programmes.

2.3.2.6 Vegetation subjected to heavy human traffic

Certain areas in Svalbard, in particular along the coastline, are subjected to heavy traffic which affects the vegetation (wear). Four vegetation plots were established in the summer of 2009 in each of four heavily visited sites along the west coast of Spitsbergen (Figure 6C). Traffic pressure variables are available for each of the sites. The following state variables are collected at each location using a transect design: Cover of components of the functional plants, scores of wear of these groups and other components of the ground surface (Hagen et al. 2010). Repeated surveys are planned at 5-year intervals (i.e. the next in 2014), hence, no data will be available for the present assessment.

3 Assessment

3.1 Pressures

3.1.1 Climate

3.1.1.1 Air temperature and precipitation

In MOSJ (climate/atmosphere/indicators) the data on temperature (T) and precipitation (P) are presented as smoothed trends of yearly means (with a 10-year filter), which are efficient when it comes to showing the main component of changes in mean annual temperatures at a given temporal scale, but hide important aspects of climate variability with regard to ecosystem responses such as the seasonal changes and annual variability (Yoccoz and Ims 1999). For T, the different phases (relatively high T around the 1930s, decrease until 1950-1970, and increase after the 1970s) are described, while for P, despite the heterogeneity among stations, a general increase is observed.

Førland et al. (2012) have analysed these data in more detail, splitting the time period 1912-2011 into different slices and investigating seasonal changes. In particular, the recent decades (1975-2011) have seen an increase of winter (December-February) T of 0.8 to 1°C/decade, whereas summer temperatures have increased by 0.3 to 0.5°C/decade. Changes in precipitation were larger in winter than summer (for example Ny-Ålesund had a 15%/decade increase for winter precipitation in the period 1975-2011, whereas summer precipitation decreased by 5%/decade). Very little is also written on the consistency of changes observed at the different meteorological stations on Spitsbergen, and how well these changes reflect changes for the rest of the archipelago. One should also be aware that data on precipitation are not very reliable (Førland and Hanssen-Bauer 2000), because of the difficulties involved in measuring solid precipitation. The very varied topography of Svalbard may also result

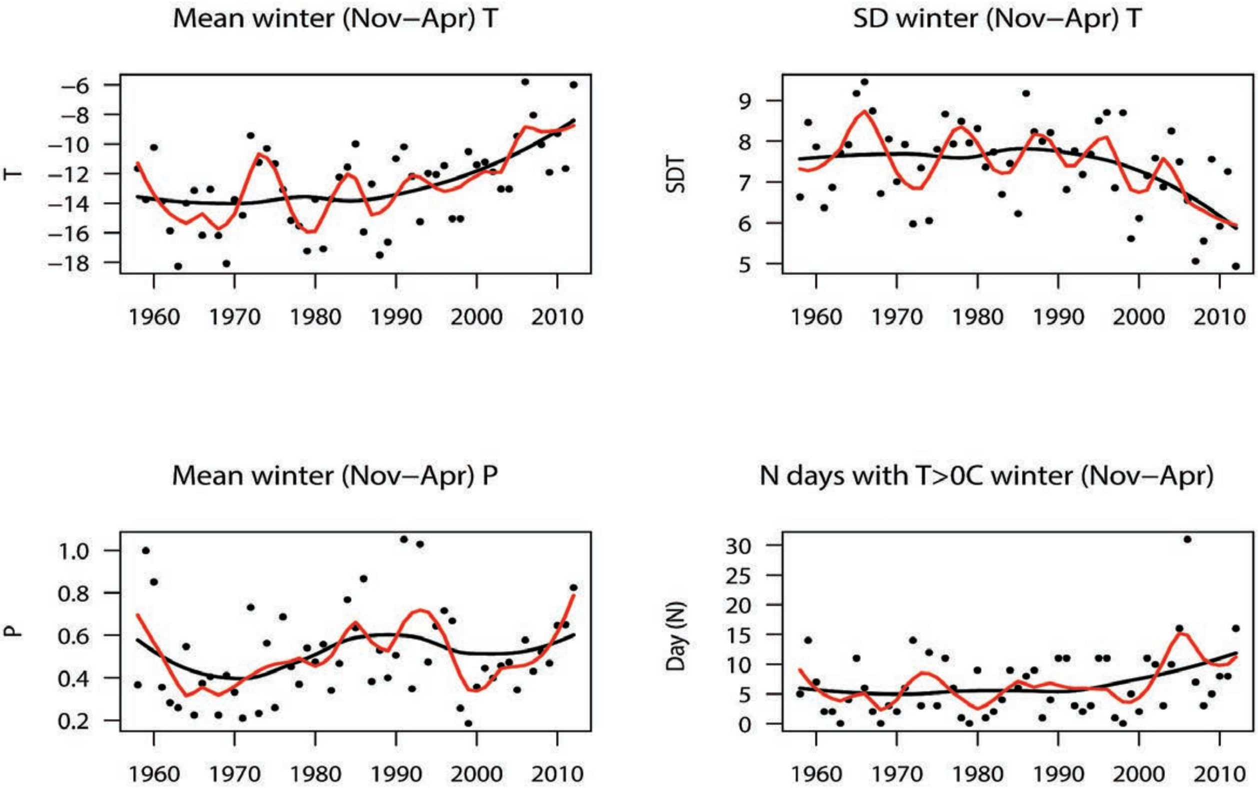

Figure 7
Changes in mean and variability (SD) in winter (November to April) temperatures (T) and precipitation (P) at Longyearbyen weather station. The number of days with above zero temperatures is also shown as it is relevant for cryosphere related processes. Dots show yearly values, whereas red (resp. black) lines are a local regression model fitted using ¼ (resp ¾) of the observations to define the neighbourhood of each datapoint (loess function in R). Large annual (dots), short-term (ca 5 to 10 years; red curves) and long-term changes (black curves), are shown and may have different impacts on ecosystems. Note the recent decrease in daily temperature variability.

in large spatial variability of precipitation and local uncoupling with large-scale atmospheric patterns (e.g. Daly et al. 2010).

Given the importance of temperature and precipitation variability and extreme events for terrestrial ecosystems in Svalbard (e.g. Stien et al. 2012b; Hansen et al. 2013) and elsewhere in the High Arctic (Callaghan et al. 2004a, b, c; Ims and Ehrich 2013) there is a need for describing trends in this variability for winter and summer seasons separately, both seasons being biologically defined.

For the winter season (November to April) both the trends and annual variability are important (Figure 7), since organisms and ecological processes respond to the ambient temperatures and not necessarily to the trends. It is also important to develop state variables linked to thresholds such as T below or above 0°C (Figure 7), occurrence and intensity of “rain on snow” events, for example defined by days with precipitation and temperature above 0°C, and amount of precipitation on such days (Stien et al. 2010a; Stien et al. 2012a, Hansen et al. 2011, 2013). There has been an increase in mean T and decrease in variability (measured as the standard deviation of daily T) since the 1990s, whereas precipitation does not show a clear trend. The number of days with T above 0°C has been very stable except for some recent increase and extreme values around 2005.

Cold extremes may also be important for instance with regard to cold tolerance of organisms (Callaghan et al. 2004b). The frequency of days with different temperatures during the winter have changed in the recent decades (Figure 8) with a larger change in occurrence of cold days (e.g. T < -20°C) than in days above freezing temperature. Thus contrary to what could be expected (e.g. Hansen et al. 2011; Huntingford et al. 2013) the variability in temperature has decreased, mainly because very cold days are becoming rare. If very cold days represent limiting factors for some plants or invertebrates, this has the potential to affect distributions.

For the summer season (i.e. June-August) we describe annual changes in temperature and precipitation, and a variable describing the extent of the growth season, as the degree-days above thresholds that are relevant for northern plants (5°C; Figure 9). The absolute change in mean summer temperatures (ca 1.5 °C in the three decades after 1980) is smaller than changes in average winter T (close to 5°C over the same period; Figure 7), but since the variability is much smaller in summer than in winter (SD=2.5°C compared to 8-10°C in winter), it means that both summer and winter will experience “new climates” (cf. Beaumont et al. 2011; Mora et al. 2013) at approximately the same rate if current trends continue. Precipitations peaked in the 1990s. Degree-days above 5°C have nearly doubled (from 75 in the 1980s to 150 in the mid-2000s) – thus a very large recent increase of potentially profound importance for growth of plants.

3.1.1.2 Temperature of permafrost at depths between 15m and 40m

The data in MOSJ are presented as smoothed trends. In this case, given the very strong inertia of permafrost temperatures at the depths considered (15 to 40m), it is unlikely that the annual variability is high. As for the meteorological data, nothing is written about spatial variability (e.g. contrast between more oceanic sites such as Ny-Ålesund with deeper snow compared to continental sites such as Janssonhaugen). Permafrost has been extensively studied in Svalbard (Humlum et al. 2003) and could represent an interesting source of information for understanding e.g. recent changes in climate or past vegetation patterns (Willerslev et al. 2014). It is, however, of limited value for understanding current climate impacts on ecosystem processes (because short-term variability is removed), except in terms of landscape changes (thaw slumps and landslides), an important concern in many areas of the Arctic (e.g. Symon 2011; Lantuit et al. 2013).

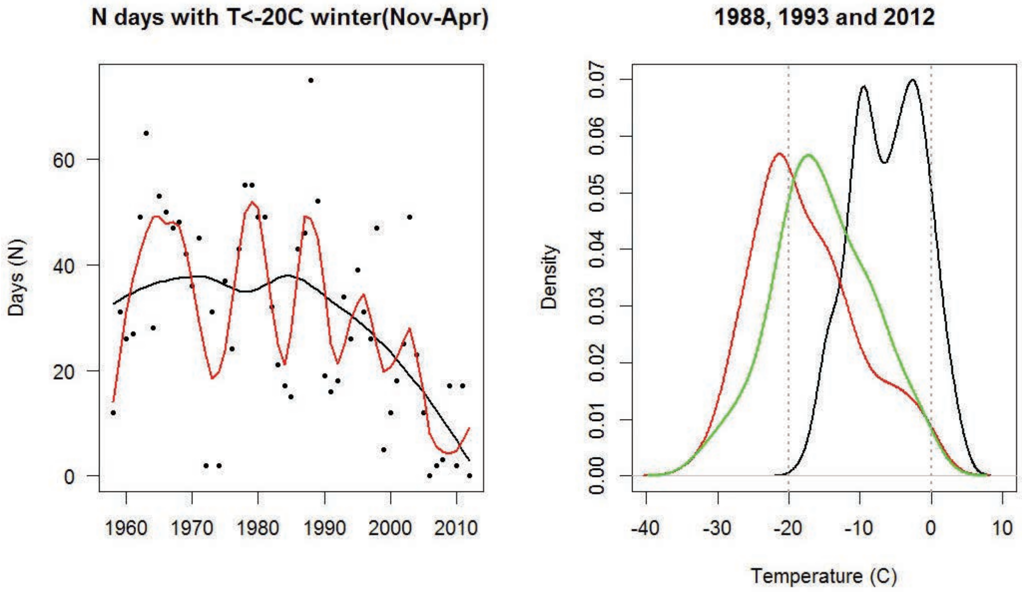

Figure 8
Changes in number of extreme cold days (T < -20°C) and changes in distributions of T for three contrasted years (cold: 1988, red; average: 1993, green; warm: 2012, black) at Longyearbyen weather station. Two thresholds (-20°C and 0°C) are indicated, showing that different patterns could be observed: changes in the occurrence of cold days without change in the occurrence of days with T>0 (1988 vs. 1993), and much larger changes in cold temperatures than in warm temperatures resulting in a large decrease in daily temperature variability. Local regression models for obtaining trend lines in the left panel are described in the legend to Figure 7, while the kernel density estimates of frequency (density) of different winter temperatures use the bandwidth selection method of Sheather and Jones (1991; function density in R).

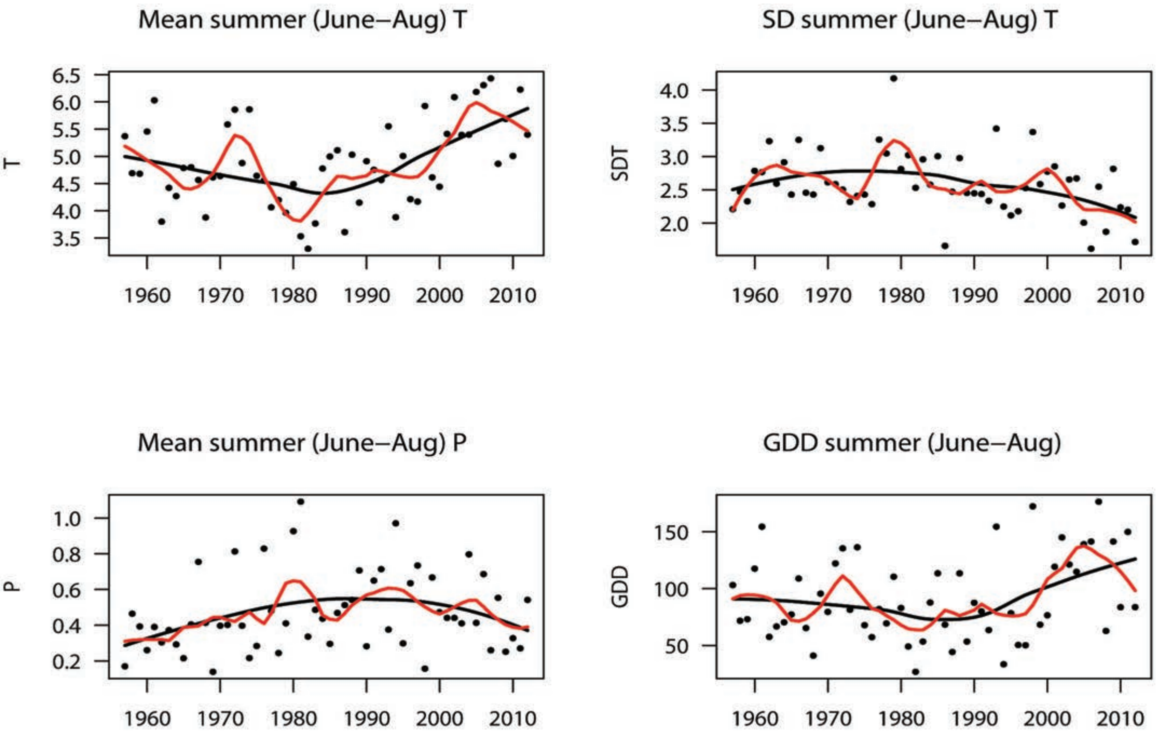

Figure 9
Changes in mean and standard deviation (SD) of summer (June-August) temperature (T), mean precipitation (P) and summer sum of temperatures above 5°C (GDD) at Longyearbyen weather station. See Figure 7 for description of methods used obtaining the trend lines.

3.1.1.3 Duration of snow cover

The MOSJ indicator is the number of days with snow on the ground from four meteorological stations. Changes over the recent decades are not consistent among weather stations (large decrease in Svea, much less in Longyearbyen; data for Ny-Ålesund are too incomplete to estimate any trends). Nothing is described on snow depth (arguably a variable which is difficult to measure meaningfully in Svalbard because of strong winds; Førland et al. 2012) and snow properties, but information from some other studies are available. Snow climate type (Sturm et al. 1995) on Spitsbergen has recently been described as rather unique in an Arctic perspective. Eckerstoffer and Christiansen (2011a) called it "High Arctic maritime snow climate", with the following characteristics: "very thin and cold snowpack, a basal layer of depth hoar with wind slabs and ice layers on top".

While much of the recent focus on snow properties in Svalbard has been on avalanches (Eckerstorfer and Christiansen 2011b; Eckerstorfer and Christiansen 2011c) and much of the research done on snow in other cold regions focus on these natural hazards (Haegeli and McClung 2007), the specific characteristics of the snowpack in Svalbard are relevant for terrestrial ecosystems, particularly the presence (or absence) of depth hoar, and ice layers either on the ground or in the snow pack and on the top. It is surprising that there is no systematic monitoring of snowpack characteristics, both because of the direct impact but also because "a description of the snow climate as it is today is important" (Eckerstoffer and Christiansen 2011a), and the current knowledge is based on data collected over a very restricted area (close to Longyearbyen) over a short period (2007-2009). However, data on snow-pack characteristics have been collected annually in other thematic studies since 2000 across three areas close to Ny-Ålesund (Kaffiøyra, Sarsøyra and Brøggerhalvøya; see Kohler and Aanes 2004 and Hansen et al. 2011 for use of data).

The occurrence of ice layers is of particular relevance for terrestrial ecosystems (see Section 3.2). On the Brøgger Pensinsula and surrounding areas NPI annually collects (since 2000) measures of ground ice, ice layers in the snow and snow depth (see Kohler and Aanes 2004; Hansen et al. 2011). Two recent studies have investigated the use of satellite data to map the occurrence of ice layers over large areas (Yamal Peninsula, Bartch et al. 2010; Alaska: Wilson et al. 2013). It would be interesting to evaluate such methods based on remote sensing tools for Svalbard as stressed early by Winther et al. (2003). With regard to MODIS data, other techniques that not rely on arbitral thresholds, have been successfully applied to monitor vegetation dynamics at high latitudes (Beck et al. 2006; 2007). Such techniques may also disentangle the impact of changes in snow cover vs. changes in plant phenology and may be less vulnerable to missing data as they integrate observations over the whole summer season.

3.1.1.4 Start, end and length of the growing season

MODIS and ASAR satellite data were used to derive values for NDVI and snow cover for Svalbard, for the period 2000-2009. NDVI was used to estimate the dates for the start and end of the growing season, with different threshold values for the Isfjord area (0.4) and other parts of Svalbard, such as Reinsdyrflya, Edgeøya (0.2). These values seem to be based on the background values for these areas, but are not well calibrated since few field measurements are currently integrated with the remote sensing data.

The short time series of NDVI in MOSJ for assessing the start of the vegetative season have not been subjected to any quality-assured analyses and it is unclear if temporal patterns represent mainly changes in snow cover. The two types of information (NDVI and snow) are shown as maps but their relationships are not quantitatively analysed, despite the well-known relationships between the start of the growing season and the disappearance of snow (Wipf et al. 2009). This is equally true for the end of the growing season. However, in the latter case, data are often missing (2 years out of 10) because of cloud cover. Given the expected increase in cloud cover (Liu et al. 2012), one could also wonder if monitoring vegetation using this kind of satellite information will be reliable in the future and if other sensors, not as dependent on cloud cover, should be used. In MOSJ these state variables are planned to be collected at 5-year intervals, which is a temporal scale not corresponding to those of most biological processes.

Over large (circumpolar) spatial scales in arctic and boreal terrestrial biomes analyses of low resolution data (AVHRR NDVI) show dramatic changes in vegetation seasonality over the last three decades (Xu et al. 2013). However, with a pixel size of 8x8 km the data were not useful for making growth season estimates for topographically diverse areas as Svalbard with much spatial heterogeneity (non-vegetated areas, glaciers, etc.). Work is presently in progress to overcome these difficulties in a project supported by the Research Council of Norway (Hans Tømmervik, pers. comm.).

3.1.2 Harvesting

There are distinct inter-annual variations in the number of harvested individuals (bags) in the three game species included in MOSJ (Figure 10). This variability reflects to some extent the size of the harvestable population, but also variation in harvesting effort (number of hunters, time spent per individual hunter) and efficiency (e.g. as determined by weather and trapability). For these reasons trends in bags may not be indicative of the trends in population size.

The total off-take per year of arctic foxes (bag) varies between 40 and 300 foxes. The abrupt increase in the number of foxes harvested in the trapping season 2008-09 was due to a very effective trapper who started to harvest in an area where the trapping load had been low for many years.

The Svalbard rock ptarmigan is the numerically most important harvestable species in Svalbard both in terms of off-take per year and the number of participating hunters. Since 1997 the off-take has varied annually between 500 and 2300 individuals. Since the hunt for the Svalbard reindeer was re-opened in 1983 for scientific purposes (1989 for local residents) the total number of shot animals has ranged from 102 to 237 (range calves [7-66]; range adults [81-173]). For the reindeer there is a trend for an increased harvest that reflects the increase in the size of harvestable population (see section 3.2.2).

3.1.3 Pollution

For the two air pollutants with the potential for affecting plant growth though acidification (sulphure component) and eutrophication (nitrogen components) MOSJ reports for the period 1990-2011 that sulphure components have had a decreasing trend while nitrogen components have had no trends. Neither levels nor trends in these pollutants suggest that they need to be taken into account as important current pressures on the state of the terrestrial ecosystem.

For beach litter the rather short time series show substantial geographic differences (i.e. between the monitoring sites) as well as large inter-annual variability that suggests that long time series are needed for detecting trends.

3.1.4 Traffic

Traffic in Svalbard has increased during the last decades as indicated by all the five indicator variables in MOSJ. However, the current indicators are to a limited degree suitable to show changes in the actual traffic and how the traffic is distributed geographically. It is also unclear how the indicators quantify the actual pressure on various components of the ecosystem (but see 2.3.2.6).

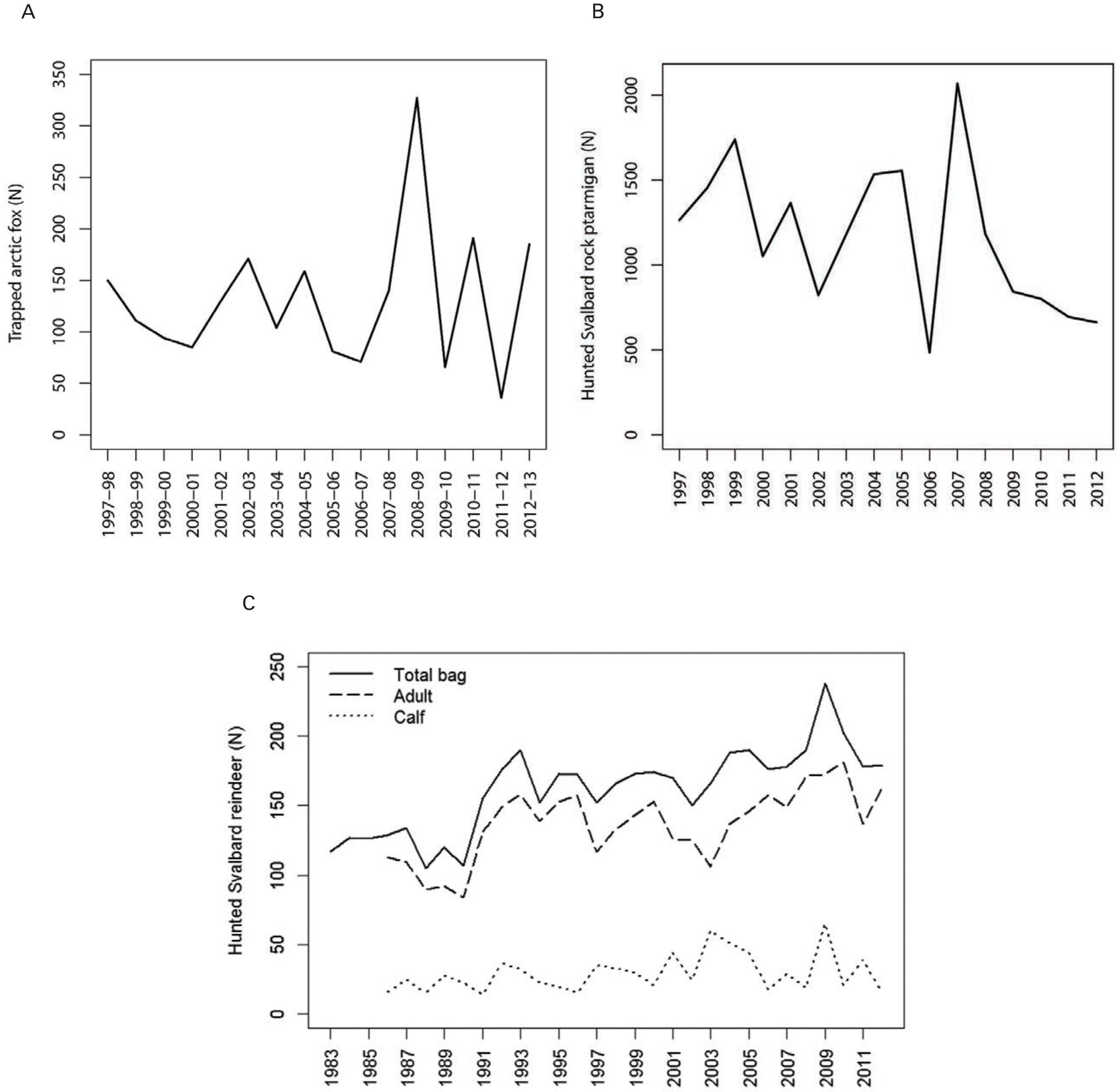

Figure 10
Bags (=number of individuals harvested per year) for the three harvestable indicator species in MOSJ.

3.2 Ecological state

3.2.1 Arctic fox

The arctic fox is almost omnipresent in Svalbard. No population estimates exist for the archipelago as a whole, but the abundance in one of the monitoring areas, Adventdalen/Sassendalen, has been estimated to 1-1.5 fox per 10 km^2 (Prestrud 1992; Eide et al. 2001). Arctic foxes were not seen on Bjørnøya for many years, but they were recently naturally reintroduced over the sea ice in year 2003 and are now reproducing annually. Through the SEAPOP programme the dens are surveyed annually and den occupancy of breeding pairs, pup production and impact on cliff-nesting seabirds are assessed (H. Strøm unpubl.). However, these Bjørnøya data do not enter into MOSJ.

3.2.1.1 MOSJ indicators

In MOSJ the Arctic fox is represented by one state variable – annual den occupancy (proportion of known dens with breeding pairs) from two monitoring areas in West Spitsbergen; Brøggerhalvøya/Kongsfjorden (BK) and Adventdalen/Sassendalen (AS) (Figure 6C).

Den occupancy rates in the six to nine surveyed dens in the BK area (Figure 11A) reveal large variations ranging from 0-100% occupancy during 1993-2012. Some of this variation was suggested to be related to an eruption and a subsequent crash in the reindeer population (Aanes et al. 2003) in the winter of 1993-1994 which first provided the fox with abundant carcasses followed by a period with low reindeer numbers and scarcity of carcasses (Fuglei et al. 2003). However, the relatively low number of surveyed dens in BK makes the occupancy rates subject to a great deal of sampling stochasticity.

Den occupancy rates in the 32 surveyed dens in the AS monitoring area (Figure 11B) reveal variations ranging from 10 to 40 % during 1997-2012. The inter-annual variation in den occupancy was related to the number of reindeer carcasses (Eide et al. 2012), which is the most important terrestrial food for the arctic fox in Svalbard. Making a distinction between dens in coastal areas close to sea-bird colonies and dens inside the more resource poor valleys, Eide et al. (2012) found a generally higher den occupancy rate in the coastal than the inland dens.

The pollutant levels in arctic foxes are represented by PCBs (sum of 7 PCB congeners) in fat and liver in MOSJ. The PCB levels found in arctic fox in Svalbard is high and may be above the threshold levels for adverse effects (Gabrielsen et al. 2012). However, there are no analyses that relate these pollutant levels to the ecological state of the arctic fox populations in Svalbard.

3.2.1.2 Other thematic programmes and studies

The state of the arctic fox population in Svalbard has been analysed in terms of a set of other state variables that are not reported to MOSJ. Litter size of arctic foxes in Svalbard is registered in context with the den surveys in both monitoring areas. These litter size data have been analysed for the AS area. Here the annual mean litter sizes vary from 4 to 7.5 cubs (Eide et al. 2012). There was a tendency for larger litters in coastal dens than in the dens inside the valleys, which was related to geographic differences in food resource availability along a coast-inland gradient (Eide et al. 2012). However, litter size was found to be a variable that was less sensitive to spatial and temporal variation in resource levels compared to den occupancy (Eide et al. 2012).

The annual den occupancy rates combined with litter size data were recently converted to population size estimates for the AS monitoring area (Hansen et al. 2013). Based on time series of these estimates Hansen et al. (2013) found a significant 1-year time lag between local declines in the reindeer population in Adventdalen and subsequent declines in the fox population (Figure 12). This lag likely results from scarcity of reindeer carcasses the year after a decline in the reindeer population.

Demographic and genetic structure are two population state variables that are derived from analyses of harvested foxes. These variables have recently been assessed in context with harvesting pressure (Fuglei et al. 2013). A significant effect of trapping was found on the age and gender composition (demography) of the population (Fuglei et al. 2013). The proportion of young foxes rose as a consequence of hunting. The most serious effect was that the proportion of older ("prime age") females in the population was lower in the hunted population compared to a non-hunted population, which may have negative consequences for the growth potential of the population. There was no clear effect of hunting on the population genetic structure (Fuglei et al. 2013). However, there was a greater degree of genetic variation among males than among females in the years immediately following harvesting. This indicates that it is primarily the immigration of young males that rebuilds population numbers after harvesting.

Although arctic foxes have been intensively trapped for many years in the AS monitoring areas (see Section 2.3.1.2), there is so far no consistent declining trend in population size (Figure 12). Thus it seems that despite the impact of harvesting on the demographic structure, the growth potential of the local population may be sufficient to prevent a decrease or that local population size is maintained through immigration. Results on population genetics support the latter explanation as there is a substantial influx of migrating arctic foxes from Russia after lemming years (Norén et al. 2012). Because such migration waves are dependent on the presence of sea-ice (Geffen et al. 2007), the on-going decline in sea ice extent may interfere with what is sustainable future harvest levels of foxes in Svalbard. The sea ice is supposedly also an important feeding habitat for the arctic fox in the winter, but so far there are no analyses made to allow for an assessment of the impact of sea ice change on other arctic fox population state variables than population genetic structure. Such analyses need sea ice data with more adequate spatial extent and resolution than what is presently available through MOSJ.

Prevalence of diseases and parasites are potentially important state variables relating to the health of the arctic fox as well as zoonoses representing risk factors for other wildlife (reindeer) and humans. Prevalence of toxoplasmosis, rabies and EM may be derived from samples of the harvested foxes, or dead foxes that are found accidentally, but at present there is no regular monitoring. Some restricted surveys have shown that toxoplasmosis is highly prevalent (43%) in arctic foxes and sometimes cause mortality in juvenile foxes (Sørensen et al. 2005; Prestrud et al. 2007). The most likely reservoir of the toxoplasmosis is migrating geese (Prestrud et al.

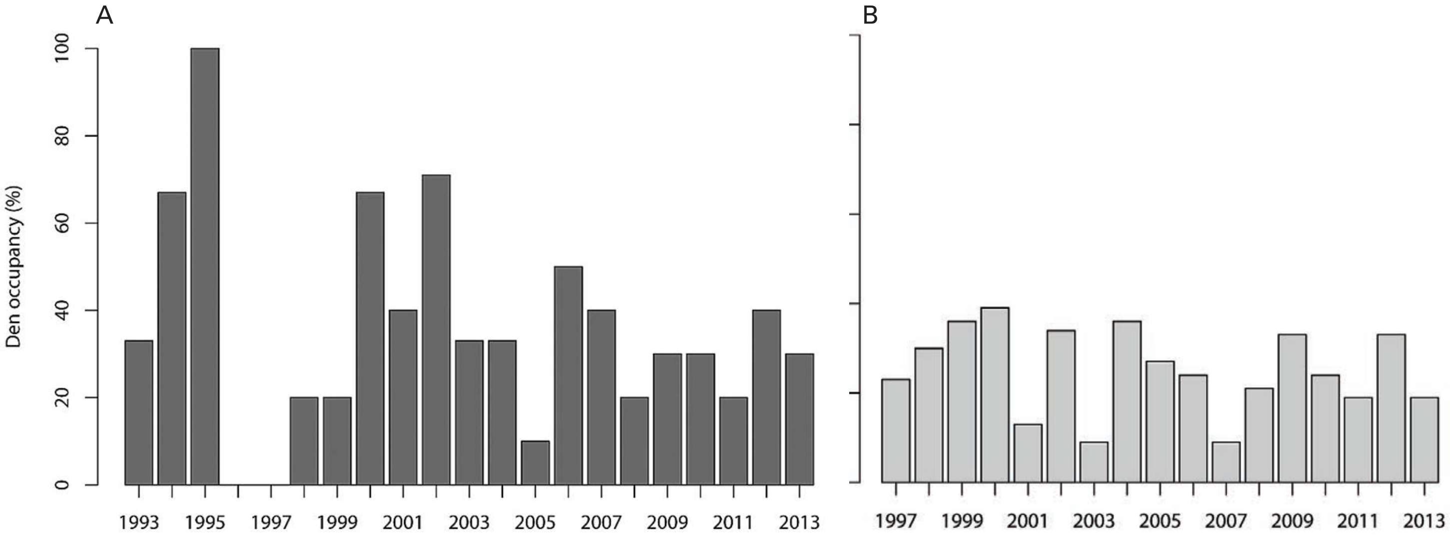

Figure 11
Den occupancy rate (percentage of known dens with cubs) in A) Brøggerhalvøya/Kongsfjorden (n=6-9 dens) and B) Advendalen/Sassendalen (n=32 dens). Note that the years 1996 and 1997 had zero occupancy Brøggerhalvøya/Kongsfjorden.

Arctic fox (*Vulpes lagopus*). Photo: Eva Fuglei, Norwegian Polar Institute

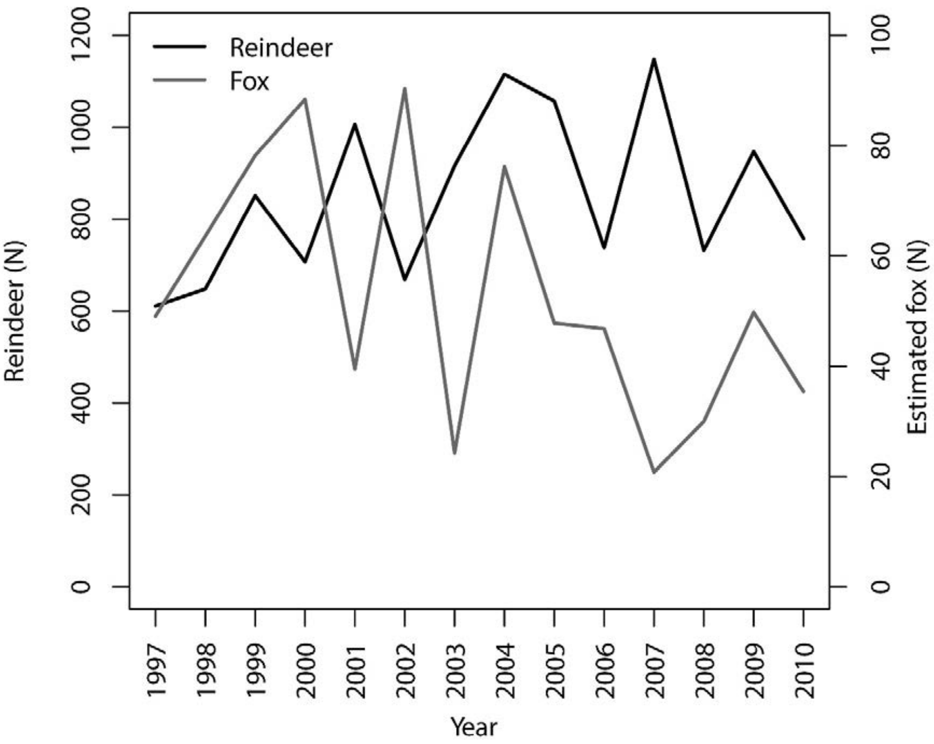

Figure 12
Time series of population size for the Arctic fox population in the Adventdalen/Sassendalen area combined with the Adventdalen time series of Svalbard reindeer (from Hansen et al. 2013).

2007). The spatial pattern of the prevalence of EM in arctic fox in Svalbard is tightly related to the area with the introduced intermediate host (sibling voles) in the Grumant area in Isfjorden (Fuglei et al. 2008; Stien et al. 2010b) and was found to be up to 60% in fox scats (Fuglei et al. 2008). Arctic foxes are the main reservoir of rabies in the Arctic. In Svalbard the first rabies outbreak was registered in 1980, with a second outbreak in 2011. Between the two outbreaks the prevalence was low (0.3%) indicating that rabies is not epizootic in Svalbard (Mørk et al. 2011), but is introduced over the sea ice by immigrating pulses of arctic foxes from Arctic Russia (Norén et al. 2011).

The level of POPs, in particular with reference to PCB levels in arctic foxes from Svalbard, has been analysed in several studies and with long time series for some tissues. Compared to other geographic areas of the Arctic the levels are high in Svalbard, in particular, for those foxes that mainly feed on marine foods (Fuglei et al. 2007). The PCB levels appear to be declining in the Arctic fox, as in other exposed species because of the diminishing transport of these contaminants into the Arctic region (Gabrielsen et al. 2012).

3.2.1.3 Conclusion

At present the arctic fox is an abundant species with significant year-to-year variation in population size in the monitoring areas, although without any obvious long-term trends. The state variable – den occupancy – accounts for most of the variation in population dynamics of the arctic fox in Svalbard, which recent studies have shown to be mainly driven by availability of reindeer carrion and thus reindeer population dynamics. A stabilizing factor for the arctic fox population in Svalbard is the consistently abundant resource subsidies provided by seabird colonies and thereby the generally high den occupancy of the coastal dens. Thus, apparent higher variability in the BK monitoring area may be attributed to less/lower access to seabirds and a smaller local reindeer population. However, more sampling stochasticity due to the smaller number of surveyed dens in BK must also be taken into account. Regarding the strong trophic bottom-up effects on the arctic fox of food resource dynamics now robustly demonstrated from West Spitsbergen, the future fate of arctic fox population in Svalbard will be much reliant on trends and variation in reindeer and sea birds. These trends and variations in the resource base of the arctic fox will in turn be dependent on climate change impacts (see 3.2.2, Marine MOSJ evaluation). The role of other marine subsidies such as seals which depends on the extent of sea ice is presently unknown. Also the future development of the population of geese may be influential.

Harvesting pressure, which is locally high, exerts significant impacts on the demographic and genetic structure of the arctic fox population. However, there is no evidence that harvesting presently is an influential factor for population size. This conclusion may change if climate change diminishes the availability of food resources both from the terrestrial and marine food webs, and if decreasing sea ice extents reduce the rate of immigrant foxes to Svalbard. The arctic fox's present use of sea ice, both for resident animals and as routes for long-distance dispersers, would be useful information.

Although PCB levels are high their impacts on the arctic fox population are unknown in particular in combination with other stressors. Also the impact of local traffic has not been studied, although the traffic levels are increasing. Finally the role of parasites and diseases (which temporally and spatially may reach high prevalence) is unknown, due to lack of monitoring, both in terms of health impacts of arctic foxes and as risk factors for other wildlife and humans. The role and impacts of zoonoses, for which the arctic fox is the main vector, are likely to change due to altered distributions and population dynamics of intermediate hosts and changes in the immigration rates of arctic foxes originating from other arctic regions.

Svalbard reindeer. Photo: Silje-Kristin Jensen, Norwegian Polar Institute

3.2.2 Svalbard reindeer

3.2.2.1 MOSJ indicators

The Svalbard reindeer is anticipated to inhabit all non-glaciated areas on the archipelago. No current total population size estimate is available. After being protected in 1925, due to depletion from hunting, the reindeer has expanded to new areas and re-colonized former ranges (Lønø 1959). Presently it is unknown if the reindeer has colonized its entire potential range on the archipelago. Svalbard reindeer population counts have been performed in three study regions since 1978/1979. The population data, based on total counts (Tyler 1986; Aanes et al. 2000) and transect counts (Solberg et al. 2001; Solberg et al. 2012), describe the year-to-year variability (annual growth rates) and eventually more long-term changes in the reindeer populations in the different study locations.

In MOSJ the Svalbard reindeer is represented by one state variable, total number of reindeer (i.e. population size), from three study locations in West Spitsbergen; Adventdalen (1979-), Reindalen (1979-) and Brøgger Peninsula (1978-). The population sizes of reindeer in Adventdalen (including side valleys to Passhytta/Eskerdalen) are characterized by an increasing trend over the entire monitoring period. The population appeared to increase less from 1979 to mid-1990s and faster from then on till today. In contrast the population size of reindeer in Reindalen (including Semmeldalen, Colesdalen and Fardalen) is characterized by a negative trend in the beginning of the monitoring period, coinciding with opening of quota harvest in 1983, and by an increasing trend from the late 1990s till today. Both the Adventdalen and Reindalen monitoring populations are characterized by large annual variations in size, ranging from 400 up to 1200 individuals (Øritsland and Alendal 1986; Stien et al. 2012b). For the last 10-15 years the yearly variations in the two populations appear to be correlated (i.e. spatially synchronous; Aanes et al. 2003; Stien et al. 2012a).

In the Brøgger Peninsula the original reindeer population was over-harvested and entirely eradicated in the late 19th century (Wollebæk 1926; Lønø 1959). Fifteen reindeer were re-introduced on the peninsula in 1978 as an ecological experiment, part of UNESCO's "Man and Biosphere" project (Aanes et al. 2000). The population grew almost exponentially (i.e. population irruption) and reached 360 individuals in April 1993 (Figure 13). The following winter 1993-1994 the population crashed due to severe ground ice and depleted forage resources (Hansen et al. 2007), which resulted in high mortality rates and migration to locations south of the Brøgger Peninsula (i.e. Sarsøyra and later Kaffiøyra; monitored by NPI, but not in MOSJ) (Aanes et al. 2000; Hansen et al. 2010). After the population crash the population has fluctuated around lower numbers (85-205 individuals) in winter.

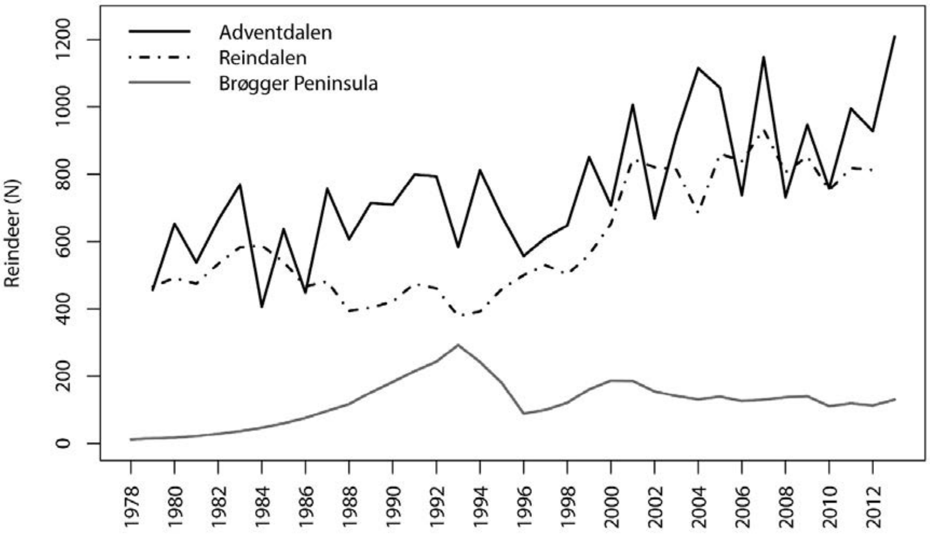

Figure 13
Population size of Svalbard reindeer in Adventdalen (annual 1979-2013) based on total counts, in Reindalen (3 year average; 1979-2013) based on transect counts and in Brøgger Peninsula (3 year average; 1978-2013) based on total counts.

The MOSJ population monitoring data have contributed to solid knowledge about the Svalbard reindeer population dynamics. Key findings are that the population dynamics in the Svalbard reindeer are mainly shaped by variation in intra-specific competition for food (i.e. direct density dependent growth) in combination with climatic variability (Reimers 1977; Aanes et al. 2000; Solberg et al. 2001; Aanes et al. 2002; Aanes et al. 2003; Kohler and Aanes 2004; Hansen et al. 2007; Tyler et al. 2008; Hansen et al. 2011; Hansen et al. 2013). However, keys to establish these cause–effect relations have been inclusion of other state variables than those made available through MOSJ (see below).

3.2.2.2 Other thematic programmes and studies

Although the time series of population counts alone have provided important information about the dynamics of the Svalbard reindeer the crucial links between population change and environmental variables shown in Figure 5b come from additional research not presented in MOSJ. Winter total counts for Sarsøyra and Kaffiøyra (i.e. areas where reindeer migrated to after the population crash in 1993/1994; Aanes et al. 2000; Hansen et al. 2010) and summer total counts for Brøgger Peninsula, Sarsøyra and Kaffiøyra from 2000 and onward provide important complements to the MOSJ data set in time and space. In Reindalen a long-term individual based mark–recapture study has been conducted since 1994 (see Albon et al. 2002; Stien et al. 2002 for a description of the study) and has among others provided data on pregnancy rates and impact of parasite loads.

A number of studies show that reindeer population fluctuations are linked to climatic variability both in winter and summer (plant growth season). In winter “rain-on-snow” events cause ground ice locking grazing pastures. Reduced winter food availability results in increased mortality (Reimers 1982, 1983), reduced calf production (Solberg et al. 2001; Albon et al. 2002; Stien et al. 2012b) and range displacement (Stien et al. 2010a). Studies, using the number of carcasses as a proxy for mortality rates in the monitoring areas, have shown a strong negative effect of winter rain (obtained from eklima.met.no) and subsequent ground ice (i.e. annual measurements from Brøgger Pensinsula since 2000).

Traffic could potentially exert an extra stressor that could impact winter mortality and fecundity. So far traffic disturbance studies have addressed behavioural and physiological responses (Reimers 1993; Tyler and Mercer 1997; Colman et al. 2001). Studies on effects of snow mobiles on Svalbard reindeer show that reindeer tend to habituate to snow-mobile traffic where there has been high volume of traffic over many years. Deliberate provocation of reindeer in Adventdalen in April has shown that a single disturbance by snow mobile resulted in flight (on average 160 m after disturbance on 80 m), but only on average 0.4 % reduction of grazing time (Tyler 1991). However, the responses depend on individuals, group sizes and areas. The time and energy costs associated with the disturbance are small. Studies in Adventdalen have shown that reindeer in July experience weaker responses to disturbances by human on foot than to snowmobiles in April (Colman et al. 2001). A study by Reimers et al. (2011) found higher vigilance, fright and flight responses in reindeer to humans on foot on Edgeøya as compared to four areas in Nordenskiöld Land. Males were less vigilant than lactating or barren females and vigilance decreased with increasing size of the groups. In Adventdalen, close to the largest human settlement in Svalbard, alert, flight initiation and escape distances were shorter than in the other study areas. This supports reindeer habituation towards humans.

Research on effects of aircraft disturbance has clearly shown the most pronounced effects. Females with calves are more sensitive than other life stages and show a panic reaction (Miller and Gunn 1979, 1981). None of the current traffic indicators in MOSJ are able to elucidate causal relationships between traffic and demographic state variables, which would be necessary for assessing impacts on population development.

In the Arctic, even a slight increase in summer temperature increases the green biomass available for tundra herbivores (van der Wal and Hessen 2009). In Adventdalen, Hansen et al. (2013) found a positive effect of summer temperature on the reindeer population growth rate. However, the outcome of effects of winter versus summer climatic variability on individuals and populations is not yet fully understood, but seems to vary among the regions, e.g. the Adventdalen populations increases (Hansen et al. 2013) while the Brøgger Peninsula population decreases (Hansen et al. 2011). Presently, an international NFR-funded research project (REINCLIM; 2012-2015) focuses on elucidating the relative role of summer versus winter climate change. In this context the long-term individual based mark–recapture study from Reindalen and adjacent valleys (1994-) will be essential (see Albon et al. 2002; Stien et al. 2002 for a description of the study).

3.2.2.3 Conclusion

At present the Svalbard reindeer is an abundant species with rather profound annual population fluctuations and some diverging population trends in the monitoring areas. The populations in Adventdalen and Reindalen increase, in contrast to the population in Brøgger Pensinsula that has decreased and fluctuates around lower numbers. The MOSJ state variable, total population size of reindeer, captures the annual variation and population development over the decades of monitoring. However, the state variables derived from other thematic monitoring programmes have been necessary for elucidating causal relations underlying these variations and trends.

The annual variation in Svalbard reindeer population dynamics is mainly shaped by direct density-dependence, i.e. year-to-year variation in intra-specific competition for food, in combination with climatic variability in both the winter and the summer season. The key climatic driver is the occurrence of “rain-on-snow” events that cause higher mortality and reduced reproduction which in combination sometimes bring about population crashes. In this context one needs to distinguish the year to year variability (variance) mainly explained by winter climate and increasing trends and variability in plant biomass driven by summer climate. Inclusion of relevant time series measuring spatial and temporal extent of ground ice and snow cover/snow pack properties (see Kohler and Aanes 2004; Hansen et al. 2011) as well as relevant vegetation variables in MOSJ will strengthen the ability to establish causal relationships.

Also inclusion of data on number of carcasses and reproduction is likely to improve the understanding of the system. The effects on individuals and population development of increased summer temperatures and extended growth seasons are yet not fully understood. To better be able to elucidate such causal relations we suggest to strengthen the summer monitoring (i.e. reproductive rates and forage resources; see Hansen et al. 2007) in Brøgger Peninsula as well as monitoring of foraging resources of the two monitored populations on Nordenskiöld Land (see the reindeer module in Ims et al. 2013). Inclusion of study locations (e.g. Sarsøyra and Kaffiøyra) that reindeer re-colonized after the population crash in 1993/94 is also recommended. The MOSJ indicator variables “duration of snow cover” and “start, end and length of the growing season” (see 3.1.1.) represent important predictors in analysis of summer season impacts on reindeer population dynamics also in terms of possible phenological mismatches/matches that have been found to be prevalent in reindeer in other places in the Arctic (Post et al. 2009; Ims and Ehrich 2013). However, the 5-year temporal scale of some of the planned vegetation monitoring in MOSJ does not match the temporal scale of reindeer population dynamics.

There is no evidence that harvest under the current practise has long-term effects on the population size (Stien et al. 2012), however, the direct yearly impact on population growth and dynamics is not known. Also, it is likely that reindeer harvesting has ecological impacts. Firstly, the harvesting removes a substantial amount of secondary production (meat biomass) from the ecosystem that otherwise would have been available to scavengers; in particular the arctic fox. Secondly, the slaughter remains from hunting left on the tundra in the autumn every year yields a different temporal dynamics of carrion resource than the natural pattern of seasonal and annual reindeer mortality.

The impact of traffic from humans on foot and snowmobile in terms of behavioural and physiological responses appears to be limited (see Overrein 2002 for a summary) and is presently not likely to be a significant pressure that affects population level state variables. However, if the traffic increases in conjunction with other stressors, its contribution to a cumulative impact needs to be considered.

3.2.3 Svalbard rock ptarmigan

The subspecies Svalbard rock ptarmigan is endemic to Svalbard and Franz Josef Land and is the only terrestrial bird residing in the Svalbard archipelago throughout the year (Løvenskiold 1963). The species are common across the entire Svalbard except for the most north-easterly parts of the archipelago. They are rare or completely absent on Bjørnøya (Pedersen et al. 2005). No population estimate exists for the whole of the Svalbard archipelago.

Svalbard rock ptarmigans (*Lagopus muta hyperborea*). Photo: Nicholas Lecomte

3.2.3.1 MOSJ indicators

In MOSJ the Svalbard rock ptarmigan is represented by one state variable – annual spring population density of territorial males from the Adventdalen/Sassendalen area (AS) (Figure 6C).

Figure 14. Estimated population densities (± 95% confidence intervals) of territorial Svalbard rock ptarmigan males per km^2 for high and medium quality habitat in Adventdalen/Sassendalen (2000-2013) (cf. Pedersen et al. 2012).

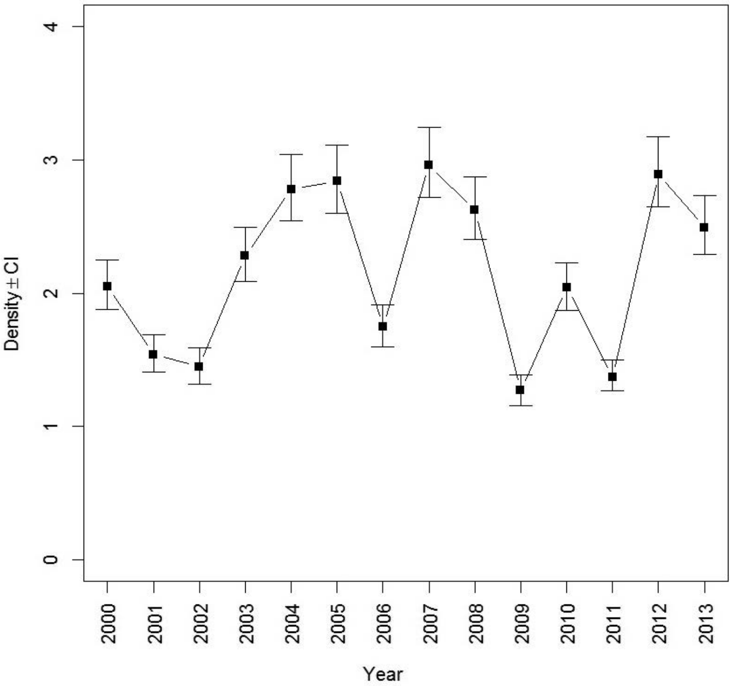

Figure 14
Estimated population densities (± 95% confidence intervals) of territorial Svalbard rock ptarmigan males per km^2 for high and medium quality habitat in Adventdalen/Sassendalen (2000-2013) (cf. Pedersen et al. 2012b).

The population density in the AS monitoring area (Figure 14) is generally low (up to three males per km^2) and the 14-year time series suggests that there is little temporal variability in the density of the breading population compared to other ptarmigan populations (Pedersen et al. 2012). Since long time-series are needed for statistical inference on population dynamic patterns, the monitoring data set is still too short to conclude whether the dynamics are cyclic as they are in many other ptarmigan populations (Moss and Watson 2001; Pedersen et al. 2012). However, population cycles are often associated with much more extreme fluctuations in population density than what is observed in the Svalbard rock ptarmigan. The limited access to suitable habitats for establishing territories is suggested to be a limiting factor for the breeding population (Pedersen et al. 2012).

Year-to-year variation in bag size (Figure 10b) was analysed by Hansen et al. (2013). Rain-on-snow events in winter were significantly associated by annual declines in the Svalbard rock ptarmigan population.

3.2.3.2 Other thematic programmes and studies

Based on site occupancy data from the population monitoring, habitat models have been parameterized so as to provide predictions on distribution of suitable breeding habitats of the Svalbard rock ptarmigan on large parts of Spitsbergen. The habitat model consisted of four statistical significant predictor variables 1) the habitat type “dense dryas heats” on a local scale, 2) altitude, 3) slope and 4) a “heat load index” (i.e. proxy for onset of snow-melt) on a landscape scale. Areas containing 1) the habitat type “dense dryas heats” and 3) slope had the highest probability of presence of territorial males in spring (Pedersen et al. 2007; Pedersen et al. 2012). The best habitats are found in narrow bands in the alpine landscape, in the upper part of the mountain slopes in south to west facing localities with good ground cover of “dense dryas heats”. Only about 3% of the land areas on Spitsbergen are predicted to have suitable breeding habitats (Pedersen et al. 2012).

Breeding and floater proportions of the total population are state variables that recently have been derived from analyses of an old unpublished data set from the Ny-Ålesund area. These variables have been compiled and analysed pertaining to how ptarmigan populations respond demographically (age, gender and body weight) to hunting mortality and the extent to which breeding densities change after harvest. The removal of ptarmigan in spring had no effects on the breeding density the next spring which indicates that there was a surplus of ptarmigans that could be harvested, at least in the years and the location of that study (Pedersen et al. 2013). Still, there is a lack of knowledge about the proportion of the Svalbard rock ptarmigan that can be sustainably harvested each year.

Winter migration and genetic diversity are two state variables important for understanding whether the birds migrate seasonally within Svalbard and to what extent local birds are harvested on. A satellite telemetry pilot study indicated that the Svalbard rock ptarmigan remain in the breeding area from spring until the start of the hunting season (September 10) (Fuglei and Pedersen 2011). However, some moved later in the autumn, September/early October, and the longest movements covered a distance of more than 100 km (Fuglei and Pedersen 2011). The results also showed that “local” birds were harvested in the early part of the hunting season, while migrating ptarmigans likely were affected later in the hunting season (Fuglei and Pedersen 2011). Samples provided for genetic analysis from the harvesting has showed that this sub-species have low genetic diversity and appears to be isolated (Sahlman et al. 2009; see also Alsos et al. 2009).

No long-time series on pollutants exist for the Svalbard rock ptarmigan. Only one study has measured the levels of persistent organic chlorines (POP, 1993-94). The levels of POPs were low and within the same range as rock ptarmigan and willow ptarmigan from Canada (Severinsen and Skaare 1997). Two studies have measured levels of heavy metals, the first in 1993-94 and the second in 1999-2000, and both documented low levels of accumulated heavy metals (Severinsen and Skaare 1997; Eikrem 2002). The levels were almost the same or lower than in willow ptarmigan on mainland Norway (Kålås and Lierhagen 1992; Pedersen and Hylland 1995; Kålås 2003) and willow ptarmigan from Canada (Langlois and Langis 1995).

Impact of traffic (disturbances from humans) has been studied in terms of effects on heart rate and behaviour in incubating Svalbard rock ptarmigan hens (Gabrielsen et al. 1985).The hens showed less marked fear behavior (i.e. did not fly away from the nest or played ill) to disturbances compared to willow ptarmigan (Gabrielsen et al. 1985). However, sustained disturbances resulted in use of extra energy which could lead to stop in incubation, and reduced body condition of the hen influencing chick production (Gabrielsen 1987).

3.2.3.3 Conclusion

The Svalbard rock ptarmigan is presently found at low breeding population densities in a minor fraction of the terrestrial areas in Svalbard. Still the results from the shooting experiment from Brøggerhalvøya indicate that populations of the Svalbard rock ptarmigan can be surprisingly resilient to harvesting. Moreover, the time series of statistical estimates of breeding density from one of the area in Svalbard most subject to hunting (Adventdalen/Sassendalen) shows that the population there is currently stable. However, the future development of the Svalbard rock ptarmigan and the impact of harvesting ought to be monitored closely. The ptarmigan’s restricted habitat distribution and food choice in the breeding season makes it particularly vulnerable to climate change. Indeed the prevailing population fluctuations of Svalbard rock ptarmigan is ruled by climatic variability in winter. The review of literature of climate impacts on tetranoid birds conducted in context of COAT, concluded that the Svalbard rock ptarmigan is likely to be particularly vulnerable to trophic mismatches (Ims et al. 2013). Because such phenological mismatches is one of the most likely threshold/tipping point effects of climatic warming in the terrestrial Arctic (Post et al. 2009, Høye et al. 2013), the Svalbard rock ptarmigan and its food plants ought to have high priority as a monitoring target.

3.2.4 Geese

Of the three migratory goose species that breed in Svalbard, the barnacle goose, the pink-footed goose and the light-bellied brent goose, the two first species are abundant with a wide geographic distribution while the latter is less abundant and has a more restricted distribution (http://goosemap.nina.no/).

Pink-footed geese (*Anser brachyrhynchus*). Photo: Christiane Hübner, Norwegian Polar Institute

3.2.4.1 MOSJ indicators

Geese are not represented by any state variables in MOSJ.

3.2.4.2 Other thematic programmes and studies

The population size of most of the temperate-wintering, arctic-breeding goose populations in Europe are increasing (Madsen et al. 1999; Fox et al. 2010). In Svalbard the pink-footed goose population has increased from 15 000 individuals in 1965 to around

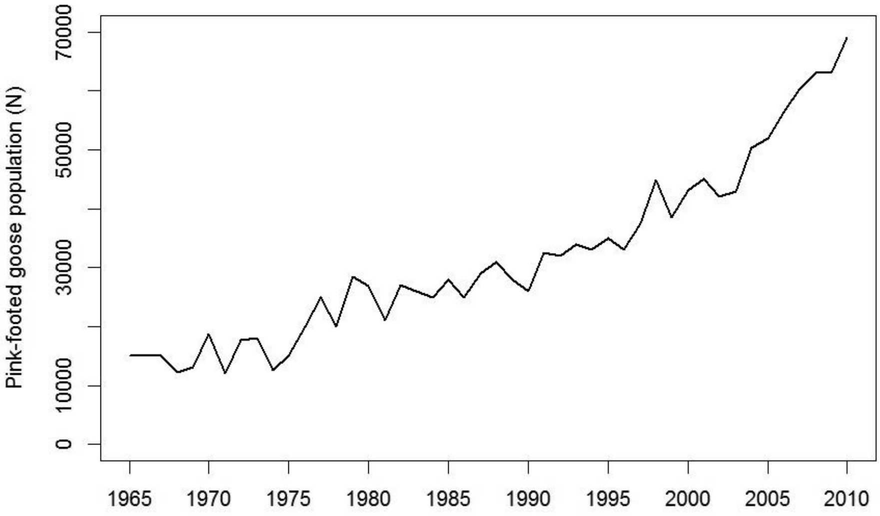

Figure 15
Development of the population size of the pink-footed goose in Svalbard (1965-2010). Numbers refer to autumn/winter surveys in the over-wintering areas. From Madsen and Williams (2012).

80 000 at present (Madsen and Williams 2012; Ims et al. 2013) (Figure 15), and the barnacle geese increased from c. 5000 to 35 000 (Griffin and Mackley 2004; Wildfowl and Wetlands Trust, www.wwt.org.uk). These increases have been caused by a combination of conservation efforts, intensified agricultural practices and a warming climate (Fox et al. 2005; Kery et al. 2006; Bauer et al. 2008a, b).

The brent goose is classified as "near threatened" in the Svalbard red-list. Their population size has increased in number over the last four decades from ca. 3000 to a stable number of around 9000 (Fox et al. 2010, Ims et al. 2013). Studies on factors that may regulate goose populations in Svalbard indicate that competition for limited food plants (Prop 2004; Black et al. 2007) and predation (Loonen et al. 1998; Tombre et al. 1998; Hübner et al. 2002; Madsen et al. 2007) may be important. In particular increased predation by polar bears on island-breeding populations of barnacle and brent geese appears to have become acute several places (Ims et al. 2013).

The web page "GOOSEMAP: Site-specific information for geese occurring on Svalbard", funded by the Svalbard Environmental Protection Fund, summarizes current knowledge on the distribution of the three goose species that breed in Svalbard. Maps are provided through the web page (http://goosemap.nina.no/) to illustrate site-specific information (aggregated in 2.5x2.5 km grids), including core breeding and moulting sites.

3.2.4.3 Conclusion

The rapidly increasing population of geese, in particularly the pink-footed goose, represents currently the most significant among the known changes of the state of the Svalbard terrestrial ecosystem. Considering the strong impact arctic geese can have on processes and functions in tundra ecosystems (Ims and Ehrich 2013, see section 3.2.5) inclusion of geese state variables in the MOSJ system is therefore a necessity. Geese are amenable to management actions at local, national and international scales and may hence be a good object for adaptive monitoring and management.

At present, no specific management plan exists for the three goose species breeding in Svalbard. Harvest levels of the pink-footed goose in Svalbard are presently low, but local management needs to be harmonized with international legislation. For the pink-footed goose, an international flyway plan is in the process of implementation under the Africa-Eurasian Waterbird Agreement under the Bonn Convention. One of the objectives is to avoid further degradation of vulnerable tundra vegetation in Svalbard by increasing the hunting pressure to stabilize the population size at around 60 000 individuals (Madsen and Williams 2012). One management action in Svalbard could be to make incentives to increase harvest.

3.2.5 Vegetation

No assessment of ecosystem state can be made without good information about the primary producers; i.e. the green plants in terrestrial food webs. International assessments of biodiversity and the general state of terrestrial arctic ecosystems therefore emphasize information about changes in vegetation and analyses that identify their causes and consequences (Symon et al. 2005; Symon 2011; Callaghan et al. 2011c; Ims and Ehrich 2013). Specifically, in a climate warming perspective there is presently a huge interest in the response of arctic vegetation as a determinant of the fate of arctic biodiversity and ecosystem functions, some of which may have global repercussions through their feedback on the climate system. Among the "hot issues" emphasized in up-coming Arctic Biodiversity Assessment with relevance to the High-Arctic are (Ims and Ehrich 2013):The increase in vascular plants, in particular shrubs, on the expense of arctic cryptogams (mosses and lichens).

- The high-arctic subzone A (CAVM Team 2003), which presently covers about 2% of the non-glaciated terrestrial Arctic, should be considered as endangered as only an increase of 1-2°C will permit the introduction of dwarf shrubs, sedges and other temperature limited species.
- The strong regulatory impact of herbivory that may change the trajectories of vegetation in the future depending on management or climate-induced changes in populations of key herbivores.
- The strong impact of change in soil hydrology and disturbance patterns resulting from changes in the cryosphere (snow, ground ice and permafrost).

3.2.5.1 MOSJ indicators

There are no MOSJ indicators with time series data available for the present assessment. New initiatives to monitor vegetation within MOSJ with different motivations are described in sections 2.3.2.4-2.3.2.6.

3.2.5.2 Other thematic programmes and studies

The vegetation in Svalbard has been subjected to numerous research projects, most often of short-term nature with different aims. Many studies have shown a pervasive impact on the two key herbivores in Svalbard – the geese and the Svalbard reindeer (van der Wal et al. 2001; Cooper and Wookey 2003; van der Wal et al. 2004; Van der Wal and Brooker 2004; Hansen et al. 2007). Both herbivores are able to bring about major state shifts of the vegetation depending on the mode of herbivory (e.g. reindeer grazing vs. goose grubbing) and vegetation/substrate type (wet lands vs. heaths) and there are examples of shifts into a more productive state from moss to grass dominated tundra vegetation state (van der Wal 2006) where herbivores consume a large fraction of plant primary production and recycle nutrients (van der Wal and Hessen 2009), temporary less productive state with suppression of important forage species (Hansen et al. 2007) as well as destruction of vegetation (Pedersen et al. 2013ab). These results show the necessity of linking future vegetation dynamics to the population developments of these herbivores.

Svalbard poppy (*Papaver dahlianum*). Photo Thor S Larsen, Norwegian Poolar Institute

Direct responses to climate variables have mostly been explored by experimental manipulations of temperature (e.g. the long-term ITEX programme (Elmendorf et al. 2012a, b) or by manipulation of the duration of the snow period (Cooper et al. 2011). In light of the strong top-down control of herbivores of the Svalbard vegetation, experimental manipulations that do not control for presence/absence of herbivores (e.g. by the use of temperature chambers) must be interpreted with caution.

Data from long-term, continuous monitoring series with precise annual measurements of biomass of all important functional groups (i.e. growth forms) in permanent plots and across several habitats have only been reported from one site (during 12 years in Semmeldalen, West Spitsbergen; van der Wal and Hessen 2009). This unique time series of precise biomass measurements according to a rigorous habitat stratified sampling design has shown an astonishing tight response of all plant functional groups across habitats to inter-annual variability in weather during the growth season. The strong dependence between measurements of above ground plant growth and current year weather cautions against making inferences about long-term trends in vegetation based simplly on pairwise comparisons between years. For instance, a study of vegetation near Brucebyen, Adolfbukta in 2008 (Prach et al. 2008) found no change in vegetation since 1936-1937 that could be attributed to climate change. In contrast, Kapfer et al (2013) found changes in vegetation composition at two of three sites studied 50-85 years after the first study. Recent studies of seed germination (Müller et al. 2011, Alsos et al. 2013) indicated about six times higher germination rates than observed in 1969.

Arctic biodiversity hotspot complexes are proposed as sites for studying and monitoring effects of climate change on arctic biodiversity (Elvebakk 2005a). These areas are also literally hot spots in terms of extraordinary warm climate, resulting in presence of thermophilic species not found in the surroundings (Ims and Ehrich 2013). Together with the adjacent areas with cold climates, these hot spots represent locations with extraordinary strong bioclimatic gradients. Monitoring these complexes may facilitate meso-scale approaches for sampling high-quality field data, which are important for interpretation of remote sensing data as well as basic data for modelling efforts. Further it may facilitate integration of population data in a bioclimatic context. Moreover, arctic hotspot sites can be expected to act as future migration centres for isolated populations exposed to climatic warming. Four such sites are identified in Svalbard (Elvebakk 2005a). Further, as the hotspots also include aggregations of redlisted species, targeting such sites facilitate a combination of redlist-based and ecosystem-based monitoring perspectives.

3.2.5.3 Conclusion

The temporal dynamics of the vegetation in Svalbard is presently to a large extent jointly determined by the population dynamics of reindeer and geese and variability in climate. However, these inferences are still restricted to studies in only a few sites and bioclimatic zones; e.g. monitoring in the sensitive bioclimatic vegetation subzone A is presently lacking. Moreover, the conclusions based on the present knowledge can to a limited degree be used to predict future vegetation states both due to uncertainties in vegetation responses to new climates and new herbivore population dynamics patterns. The pervasive role of plants in terrestrial food web dynamics implies that the future state of the terrestrial ecosystem in Svalbard cannot be assessed unless a substantially expanded monitoring of vegetation is included as a prominent component in MOSJ. The present knowledge about the importance of different functional groups of plants and habitats in food web dynamics can guide which groups and habitats that ought to be specifically targeted in long-term monitoring (Section 2.2, Ims et al. 2013). Among the existing research/monitoring activities that relate to the effect of climate impacts on vegetation, the monitoring that has given rise to the unique 12-year time series from Semmeldalen has provided the best insights and should thus be given the highest priority and secure funding for the future. To fulfil the ambitions of ecosystem-based monitoring of link plant community responses to food web processes the proposed monitoring design for herbivore related vegetation strata and plant functional groups of COAT (Ims et al. 2013) ought to be implemented.

3.2.6 Introduced species

A low frequency of human-mediated dispersal (i.e. introductions) may, until recently, have contributed to maintaining the integrity of high-arctic ecosystems. There are yet hardly any reported cases of species introductions that can be said to have significantly altered the state of any high-arctic terrestrial ecosystem (Ims and Ehrich 2013; Lassuy and Lewis 2013). Generally, the hostile climate in the High Arctic presently provides suitable living conditions for only a restricted set of potential invader species from the south. Moreover, according to Lassuy and Lewis (2013) mechanisms that may contribute to reduced non-native plant species invasion at high latitudes are:

- Increasing proportion of widespread species at higher latitudes (i.e. less regional endemism translates into fewer species that could show up as new).
- Some arctic habitats were recently disturbed by glaciations and are colonized by highly ruderal species already.
- Movement of propagules in the circumpolar region appears to be facilitated by ice, winds and currents.
- Densities of people, roads and substrate disturbance decrease with increasing latitude.

However, this does not mean the Arctic is not susceptible to invasion. Climate warming and increased human use are likely to increase that susceptibility (Lassuy and Lewis 2013).

Svalbard is among the best mapped Arctic regions in terms of biodiversity with baselines extending many decades back in time for some taxa (Elvebakk and Prestrud 1996; Prestrud et al. 2004; Alsos et al. 2009). As a consequence, the number of introduced plant species, which is assumed to be stable, is higher in Svalbard than any other arctic region (Elven et al. 2011). The solid baselines in terms of species inventories and mapped distribution make Svalbard an extraordinary useful observatory for species introductions in the High Arctic.

3.2.6.1 MOSJ indicators

The sibling vole is the only introduced species mentioned in the web pages of MOSJ. A population time series of sibling voles from its present core area in Fuglefjella, Isfjorden, was previously among the MOSJ indicators, but was removed when the monitoring of this species was discontinued in 2006.

3.2.6.2 Other thematic programmes and studies

At the present there is no systematic monitoring that specifically targets introduced species in Svalbard, but knowledge of the present state is available based on occasional inventories of flora and fauna. The flora of Svalbard was extensively investigated during the 20th century, (e.g. Resvoll-Holmsen 1927; Hadač 1944; Rønning 1972; Elvebakk 1989). However, with some exceptions (Høeg and Lid 1929; Hadač 1941; Sunding 1961), introduced species were only sporadically recorded and no attempt has been made to summarize all introduced vascular plant species in Svalbard since 1941 (Hadač 1941). In 1988, Liška and Soldán (2004) surveyed the surrounds of Barentsburg and Pyramiden for introduced species. Revisits at these two settlements in 2008-2011 have been conducted by Alsos et al., (unpublished) and analyses are now in progress to establish the dynamics (i.e. persistence, extinction, new colonization and phenological changes) within the assemblage of the introduced vascular plant species. Ware et al. (2012) recently quantified the extent of seed dispersal of plants mediated by footwear of people arriving by air to Svalbard and the germination potential of these seeds. The estimated seed load per year by this vector alone was around 270 000 of which the majority was non-native to Svalbard. In total 26% of the seed germinated under simulated Svalbard conditions.

As there is a high overlap between sites with redlisted species and sites were people go ashore (http://svalbardflora.net/), there is a risk that introduced species may pose a threat to rare native species.

A check-list for terrestrial invertebrates in Svalbard has been developed by Coulson (2007) forming an excellent baseline for establishing introductions of new species. Coulson et al. (2013) presented the first records of terrestrial invertebrate introductions outside the human dwelling in Svalbard (in Barentsburg). The records consisted of new soil-dwelling species for Svalbard (n=11) that were most likely introduced with greenhouse soils. It was concluded that none of these species were likely to spread to typical tundra soils, with the exception of one species that could potentially inhabit nutrient enriched soils under bird cliffs (Coulson et al. 2013).

A risk assessment for 78 introduced species of vascular plants and one mammal was recently done (Gederaas et al. 2012). Eleven taxa of vascular plants had well-established populations and may potentially be naturalized in the near future: *Achillea millefolium*, *Alchemilla subcrenata*, *Anthriscus sylvestris*, *Barbarea vulgaris*, *Deschampsia cespitosa* ssp. *cespitosa*, *Poa annua*, *Ranunculus acris* ssp. *acris*, *Rumex acetosa* ssp. *acetosa*, *Stellaria media*, *Taraxacum* sect. *Ruderalia*, and *Tripleurospermum maritimum*. Of these, cow parsley *Anthriscus sylvestris* was evaluated as being of high risk due to the potential for further spread to bird cliffs, where it thrives well. It tends to form dominating stands, and it may therefore out-compete native vascular plants. The governor of Svalbard took action during summer in 2013 and eradicated all visible specimens of *A. sylvestris*, which so far only has been recorded in Barentsburg.

3.2.6.3 Conclusion

Several non-native plants and animals have already been introduced and have established persistent populations in Svalbard. Their distributions are however presently restricted to local sites close to previous and existing human settlements. Although Svalbard has more records of introduced species than comparable high arctic regions, the present situation in Svalbard conforms with the general state-of-affairs concerning introduced species in terrestrial arctic ecosystems (Ims and Ehrich 2013): There are no cases of extensive spread of exotic species with pervasive impact of ecosystem state similar to what has been documented for several temperate, trophic and sub-antarctic island ecosystems worldwide.

However, in scenarios of climate warming already extant non-native species may rapidly extend their geographic distribution and impact communities of native species. In Svalbard bird-cliff communities can be predicted to be hot spots for such species invasions. The Russian sibling vole – the most renowned species introduction in Svalbard owing to its induction of a secondary introduction of a dangerous zoonosis (EM) – is already established in one of the most climatically benign and nutrient rich bird-cliff habitats in Svalbard. Hence, if monitoring specifically dedicated to detect introductions and spread of high-risk non-native species is to be carried out, such bird-cliff communities are among those to be targeted and prioritized in Svalbard. Also the three sites with the highest influx of propagules – Barentsburg, Longyearbyen, and Pyramiden – should regularly be monitored. Beyond these sites the ecosystem-based monitoring (e.g. applied to major tundra habitats as proposed for COAT) will be able to detect spread of novel species into the more extensively distributed tundra communities in West Spitsbergen. This also included the effects of microbial plant and animal pathogens, with potentially severe ecosystem impacts (Ims and Ehrich 2013), but which is not included in the present risk assessments for non-native species in Svalbard (Gederaas et al. 2012).

3.2.7 Ecosystem processes

Ecosystem-based approaches to research and management have emerged from the recognition that responses even in single species to drivers of change are often mediated by indirect pathways in the ecosystem. These pathways must be identified and understood in order to predict changes and to devise rational management. Based on a review of recent empirical findings in the extensive scientific literature on terrestrial ecosystems, the Arctic Biodiversity Assessment (Meltofte 2013) has just reached the following main conclusions that have reinforced the arguments for applying ecosystem-based monitoring, especially in the context of climate change (Ims and Ehrich 2013):

- Impacts of drivers of change are indirect both in the abiotic and biotic domain of the ecosystem.
- In the abiotic domain, climate exerts some of its most profound impact through second-order disturbances in the cryosphere.
- In the biotic domain, pervasive driver-impacts are mediated through bottom-up and top-down cascades in the trophic web.

3.2.7.1 MOSJ indicators

The indicator approach of MOSJ, focusing on a few separate state variables and their trends, does not capture the essence of ecosystem-based monitoring – namely the focus on the dynamic links between state variables that represent key processes in the ecosystem that often may be extended into causal chain-relations and indirect effects.

3.2.7.2 Other thematic programmes and studies

One of the most illustrative examples supporting the conclusions of ABA concerning indirect causal relation and trophic cascades was derived from Svalbard (Ims and Ehrich 2013; Box 12.3). By means of comprehensive statistical analysis of population time series of all the year-round resident vertebrate species in the Isfjorden area (sibling vole, Svalbard reindeer, Svalbard ptarmigan and arctic fox) Hansen et al. (2013) showed that “a second-order disturbance in the cryosphere” in terms of ground icing, due to “rain-on-snow events” (ROS), was the key driver of the year-to-year dynamics of focal animal community (Hansen et al. 2013). The trophic cascade in this case was bottom-up in the order: rain-on-snow →ground icing →reindeer population dynamics →reindeer carrion abundance →arctic fox population dynamics. MOSJ indicators provided an important input to this analysis (Adventdalen reindeer population size, Adventdalen/Sassendalen Arctic fox den occupancy, Svalbard rock ptarmigan bag statistics), but essential state variables had to be obtained from other sources. Arctic fox population growth had to be derived analytically from den occupancy rates combined with data on litter sizes. The sibling vole population monitoring is no longer a part of MOSJ. ROS events had to be derived from more detailed meteorological data than provided by MOSJ. Finally, the causal link between reindeer population dynamics and ROS was drawn based on detailed information of reindeer fecundity (Stien et al. 2012b), summer climate warming (Section 3.1.1) and density-dependent reindeer population growth (Hansen et al. 2011), while the trophic link between the arctic fox population dynamics and reindeer could not have been made explicit without data on the abundance of reindeer carrion (Eide et al. 2012).

The assessment of the highly influential trophic links between herbivore populations dynamics and vegetation in Svalbard is also in need of an ecosystem-based approach because the changes in vegetation communities and feedback on herbivore populations dynamics typically involve cascading plant – plant and soil – plant interactions (van der Wal et al. 2004; Van der Wal and Brooker 2004; van der Wal and Hessen 2009; Sjögersten et al. 2010; Sjögersten et al. 2011). The impacts of the rapidly increasing populations of geese are in this context of considerable concern (Ims et al. 2013;

Pedersen et al. 2013ab) as they may involve most components of the food web (see Figure 5) and even biophysical processes in the soils (Ims and Ehrich 2013).

3.2.7.3 Conclusion

Recent analyses emphasising terrestrial ecosystem processes in Svalbard have revealed how summer warming (extended plant growth seasons length) combined with extreme winter climate events (ROS and ground ice) cause strong cascading impacts in the terrestrial food web. Also the impacts of herbivores, and in particular the impacts of geese, involve indirect pathways both in the biotic and abiotic domains of the Svalbard tundra ecosystem. Hence, there is now empirical evidence that ecosystem-based approaches to research, monitoring, assessments and management are highly warranted.

To become a vehicle for ecosystem-based monitoring and assessments MOSJ needs to change its approach from its present emphasis on a few separate indicators to a new focus on relevant causal links and processes that are known to rule the Svalbard ecosystem at the present, and those that can be hypothesised to become more important in scenarios of future environmental change. Based on the anticipated overwhelming impacts of climate on terrestrial arctic ecosystems in the near future (Meltofte 2013), conceptual models should be used to outline such climate impacts in combination with other stressors. Such conceptual climate and management impact path models for the Svalbard terrestrial ecosystem are already developed and quality-assured by means of the COAT Science plan (see Section 2.2 and Ims et al. 2013). Moreover, the COAT plan devises protocols for how to obtain the relevant state variable at those matching temporal and spatial scales that are needed for quantitative analyses of cause–effect relations.

Importantly, quantitative analyses of trends and cause–effect relations need to go way beyond the "trend lines" presently provided by MOSJ web pages. Indeed, we advise against drawing simple trend lines through time series data that typically are subject to outlying observations, temporal autocorrelation and measurement errors. Furthermore, the recent case-study of Hansen et al. (2013) illustrates the advances needed in terms of multivariate stochastic modelling to estimate cause-effect relations of climate impacts. Further advances in statistical modelling of impact of climate and management action on compartment of the food webs (formulated conceptually in figure 5) are proposed in the COAT Science plan (Ims et al. 2013). The COAT Science plan also provides guidelines for reporting and providing public access to complex monitoring data.

4 Conclusions and recommendations

4.1 State of the Svalbard terrestrial environment versus national goals

The present assessment has been mandated to evaluate the state of the terrestrial environment in Svalbard with regard to four criteria/aims given in the national goals for the environment (Prop1.S.2011-2012). It is to be noted that these criteria/aims are interdependent both because they are nested (i.e. hierarchically related) and because the environmental impacts may interact (e.g. traffic and harvesting).

4.1.1 Impacts of traffic

The level of traffic in Svalbard over the last decades has increased substantially for all of the MOSJ traffic indicators. Traffic does provoke certain physiological and behavioural responses in those terrestrial animal species that have been specifically studied in this respect. Such responses are however, quite local, modest and short-term and are as yet not likely to translate into population level effects. Interactive effects with other more influential stressors (climate) have not been studied. Such studies may be warranted due to increases in future traffic levels (beyond the present levels) and climate change. Impact of human trampling on vegetation may be expected to be locally high in areas with a high frequency of this disturbance. Monitoring on sites recently selected for such vegetation impact studies are needed for estimating the magnitude of such effects.

4.1.2 Impacts of harvesting

Harvest levels of Svalbard terrestrial wildlife appears to be stable, relatively well managed and low. The highest harvest levels relative to the size and productivity of local populations are probably experienced by the arctic fox. Arctic fox populations, subjected to harvesting in Svalbard, have shown changes in demographic structure, production potential and genetic structure, so that the criterion that "the population's composition should not be altered notably" needs closer scrutiny. In this context the term "notably" implies inclusion of some qualitative value-based (normative) assessment perhaps beyond our expertise. However, we note that even in the case of the arctic fox, harvesting appears to be sustainable in terms of the absence of clear changes in the size of the breeding population.

Arctic fox (*Vulpes lagopus*). Photo Eva Fuglei, Norwegian Polar Institute

4.1.3 Impacts and risk of human activities on the environment

The national goal is here expressed as "restrict impact and risk of impact on the environment …resulting from human activities". Local activities include the two issues dealt with above (traffic and harvesting). To reduce the risk of adverse effect of harvesting the development of the arctic fox population in the areas most subjected to intensive harvesting needs to be monitored closely. On the other hand, too low harvesting of in particular the pink-footed goose, and a continued increase of its population in Svalbard, constitute a profound risk factor for grazing/grubbing sensitive tundra plant communities. Changes of these plant communities are likely in turn to have cascading negative impact on the other herbivores. A sensible recommendation is to support management actions that reduce the population of the pink-footed goose.

Some risks are associated with the spread of non-native species introduced to Svalbard. However, such risks are most profound under future climate change where non-native species, which presently are found very locally and under particular conditions in Svalbard, may become invasive dominants in major habitats in the future. Indeed, no assessments of future environmental risks in the Arctic make sense unless they are made in anticipation of climate change, arguably in itself an impact of human activities (albeit mostly outside the Arctic region).

With regard to climate impacts, considering the recent trends in climate development in Svalbard (see Section 3.1.1), the terrestrial ecosystem is presently on the border of experiencing "novel climate"; i.e. combinations of climatic conditions beyond the empirical range of current observations and ecological impact studies. Presently, the most profound climate changes are lower frequencies of very low winter temperatures and higher frequencies of high summer temperatures. These new climate conditions are likely to pave the way for the establishment of introduced species. Considering future climate changes high risks of strong ecological impacts are in particular due to "rain-on-snow-events (ROS)" in the winter that presently affect all harvested resident vertebrate species in Svalbard. Harvesting levels need to be carefully adjusted in case of more severe and higher frequency of ROS. However, milder winters are coming together with warmer and longer summers, as well as different precipitation patterns, and the cumulative effects of these changes are difficult to predict. Moreover, the highly dramatic, but probable, scenarios of climate change over the next decades make long-term predictions about impacts and risks almost impossible to derive. In such a situation impact and risk assessments need to be based on continuously updated knowledge obtained from adaptive ecosystem-based monitoring systems that are far more comprehensive than what is presently in place in the Arctic (Meltofte 2013).

4.1.4 Maintenance of biodiversity, wilderness and reference areas for research

The national goal at this point is expressed as "in Svalbard the extent of wilderness-like areas shall be maintained, biodiversity be conserved nearly non-impacted by local activities, and the value of conservation areas should be secured as reference areas for research". The term "wilderness-like areas" is open for normative judgments that are beyond the expertise of this evaluation committee. Thus, we restrict our assessment to the issue of biodiversity and research reference areas, which may to some extent also relate to the wilderness concept.

It follows from the assessments above (sections 4.1.1-4.1.3) that the state of the terrestrial ecosystem in Svalbard and its imbedded biodiversity is at the present relatively little impacted by human activities in Svalbard, especially considering the limited spatial extent such activities have relative to the total extent of the land areas in Svalbard. In particular, the large areas protected as national parks, with rather strict regulation of human activity, contribute to achieving the strategic goal of Svalbard being "one of the best managed wilderness areas in the world". If suitable "reference areas for research" is meant to imply ecosystems that are not affected by local human activity, this goal is also to a large extent achieved.

However, we will emphasize one caveat in this context. Conservation and management of arctic biodiversity concern endemic species and ecosystem processes and functions, which integrity first and foremost depends on the maintenance of "normal" arctic environmental conditions. Climate change, to the extent it is now projected for the near future, will represent a severe disturbance that places arctic biodiversity at acute risks of extinctions and collapsing ecosystem functions. No area protection alone will be able to prohibit such severe outcomes regardless of how well they are protected from impact of stressors of local origin. Hence, for this reason management and planning of arctic national parks may need other means than mere protection – for instance, actions that counteract encroachment of non-native species. Svalbard being a high-arctic archipelago quite distant from sources of southern invaders may in a circumpolar setting take the role as one of the last refuges for arctic biota on a globe subjected to a much warmer climate.

4.1.5 Final comment on national goals

The four goals/criteria above, which emphasize mostly local issues and stressors that may impact the terrestrial environment in Svalbard, appear to be outdated with respect to the current recognition that climate change is expected to soon overrule all other impacts. Even though global change clearly needs global actions, even local management could plan to mitigate and possibly counteract impacts that are deemed undesirable. Revisions of national environmental goals, management and monitoring plans of arctic ecosystems need to take the impact of climate change into explicit account. Also to be recognized is that "Svalbard is a place in the circumpolar Arctic" and that management of conservation of arctic biodiversity is presently a profound international concern. Hence, such international perspectives need to be expressed both in the formulation of goals (which presently are mainly locally or nationally oriented) and in the plans for management and monitoring.

4.2 The design of MOSJ Terrestrial: General critiques and recommendations

Critiques and recommendations with regard to the design and role of MOSJ Terrestrial have been detailed in the concluding subsections of the Ecological state assessment (Section 3.2). Here we summarize the overarching points:

4.2.1 Critiques

- The stated ambitions of MOSJ is in line with the perspective of ecosystem-based monitoring and accordingly, the ecological state indicators included in MOSJ terrestrial include some important state variables of the Svalbard ecosystem. However, MOSJ is still missing fundamental components of the terrestrial ecosystem that are needed for making proper ecosystem state assessments. In particular, by not including precise annual measurement of key components of major plant communities in Svalbard, MOSJ will be unable to document state shifts in the ecosystem that may have pervasive effect on biodiversity. Moreover, by not including monitoring of the rapidly changing population of geese and nonnative invasive species, MOSJ will not be able to advice on mitigation actions of such major disturbances potentially affecting many aspects of the terrestrial ecosystem, including redlisted species.
- The present assessment of the state of the terrestrial environment in Svalbard, has been overly reliant on empirical information from "thematic programmes and studies" beyond what is included in MOSJ. Presently, most of these "thematic programmes" are only temporary projects not secured by means of stable funding, infrastructure and personnel.
- Some of the major pressure indicators in MOSJ are not represented in terms of state variables that are expected to exert strong impacts on the ecosystem and/or do not match the spatial or temporal scales of essential environmental pressure-response relations. This regards for instance essential climate variables. In this respect MOSJ fails with respect to its aim of being a system that facilitates effective integration of environmental data.
- The MOSJ approach that emphasises presentation of simple trends and assessments of single indicators does not facilitate the detection of causal relations and the application of ecosystem-based approaches to unravel impact pathways

of environmental pressures and to advise on rational management actions. When arctic ecosystems are subjected to such vast and fast changes as they are likely to be under future climate change, a fundamental problem of the indicator approach is "what indicators indicate" will not be consistent through time. On the other hand, ecosystem-based monitoring that focuses on the dynamics of pressure-response relations by means of an adaptive selection of a larger set of state variables, circumvents such problems due to non-stationary ecosystem dynamics. The trend depictions currently made in the MOSJ web pages in terms of running linear regression lines though population time series subjected large inter-annual variation with both components of processes stochasticity and observation errors might be outright deceiving and hence should be avoided. Reporting of significant ecological changes needs to be underpinned by quality-assured statistical modelling reflecting the ecological and statistical processes that most likely generate the data.

- The "redlist perspective" of terrestrial biodiversity monitoring (cf. section 1.2) is mostly lacking in MOSJ as current monitoring includes only 4 of 71 (6%) of the redlisted species in Svalbard and has low focus on hotspots of biodiversity. This omission, if intentional, needs to be more explicitly motivated in the mandate of MOSJ.
- Monitoring of terrestrial indicators is presently restricted to a few sites in western Spitsbergen (Figure 6), and by this limited geographic scope MOSJ Terrestrial is not really a monitoring system for Svalbard as such, and indeed not at all for Jan Mayen. It is also important in this respect to more clearly recognize that Svalbard is a place in the circumpolar Arctic, so that priorities within MOSJ are more explicitly aligned with international priorities and activities.

4.2.2 Recommendations

- A radically revitalized monitoring system for the Svalbard terrestrial ecosystem should adopt the state-of-the-art paradigm of adaptive ecosystem-based monitoring. Adopting this gold standard for monitoring as basis for rational ecosystem management is perfectly in line with the strategic national goal that Svalbard should be "one of the best managed wilderness areas in the world". In order to factually take an internationally leading role, beyond the rhetoric and in terms of factual science, Norway must make stronger priorities and allocate substantial more resources and personnel to long-term environmental research and management in the Norwegian Arctic. At the present other nations (USA, Denmark and Canada) allocate more resources and run more comprehensive long-term ecological research and monitoring systems in the terrestrial Arctic (Ims et al. 2013). MOSJ needs to move from the present meagre collection of three animal monitoring targets, which by themselves only have restricted value as indicators of the state of the ecosystem, to a substantially larger set of monitoring targets and state variables (see Table 1) that allows for comprehensive assessments of the prosesses shaping future states of arctic ecosystems.
- New thematic programmes feeding into MOSJ Terrestrial need be established according to quality-assured science plans and run with adequate, secure and long-term funding. In particular, in face of the extreme expected changes in arctic climate, the establishment of a major climate change impact programme for Svalbard tundra ecosystems, such as planned in terms of COAT, is very timely and urgent. With a fully established "COAT Svalbard", complemented with three smaller thematic programmes specifically targeting introduced species, redlisted species and effects of traffic, MOSJ will be much more able to fulfil its aims than what is presently the case. Table 1 provides a minimum list of monitoring targets state and variables that ought to be included to make these thematic programmes operative. As just has been performed in the context of COAT, each of the thematic programmes ought to develop detailed science plans that identify monitoring targets, state variables and processes relations that should be monitored according to quality-assured protocols. Moreover, as planned for COAT the thematic monitoring programmes should be mandated to themselves be responsible for frequent analyses, assessment and reporting of environmental pressure–ecological impact relations. The thematic programmes should also be mandated to have open data access policies.
- If based on scientifically strong thematic programmes that themselves perform reporting, quality-assurance and assessments according to a regular cycle (see Ims et al. 2013), MOSJ could take a more heuristic role in the integration and dissemination of new knowledge across different thematic programmes and ecosystems (terrestrial and marine) in Svalbard and Jan Mayen, so as to better facilitate the essential links between science, policy making, management and stakeholders.

Marsh saxifrage (*Saxifraga hirculus*). Photo: Harald Faste Aas, Norwegian Polar Institute

Table1
Monitoring targets and associated state variables for the four proposed thematic programmes to be included in MOSJ as proposed in the main text, where P: Predictor (or pressure) targets and R: ecological response targets (cf. Ims 2013). Only state variables with high priority are included with two levels (A and B). Priorities for the thematic programme COAT are based on Ims et al. (2013) – where level A means that the variable is necessary to analyse pressure–response relations according to the conceptual models shown in Figure 5. For introduced species priorities are made according to Sysselmannen (2013), while for traffic according to Hagen et al (2010). For red-listed species only species described in the main text are included and a complete list with priorities must be made according to a new specific assessment of red-listed species in Svalbard and on Jan Mayen. The status column refers to the present funding of the state variables; NF: no funding and no present monitoring, UF: unstable funding, but there are current or past monitoring activities, F: funding that appears stable, there is current monitoring. Locations are: S: Spitsbergen, B: Brøggerhalvøya, N: Nordenskiöld Land, Z: Zeppelin Station in Ny-Ålesund.

Thematic Programme	**Target (P/R)**	**State variable**	**Interval**	**Location**	**Method**	**Priority**	**Status**	**Comment**
COAT								Targets according to impact models (cf. Fig. 5) Description of monitoring design and methods in Ims et al. (2013)
	P: Climate							
	Weather	Air temperature	1 hr	B & N	Met stations	A	F	Existing stations, plus new base and module stations in COAT
		Precipitation	1 hr	B & N	Met stations	A	F	New base and module stations in COAT
		Growth season	1 day	Svalbard	Satellite, temp measurements	A	F	
	Snow	Snow cover duration	1 day – 1 yr	B & N	Ground- and satellite-measurements and snow models	A	F	Temporal resolution depending on method
		Snow depth	1 day – 1 yr	B & N	“	A	NF	“
		Snow structure	1 week-1 yr	N	“	B	NF	“
	Ground ice	Areal extent	1 yr	B & N	Ground- and satellite-measurements and snow models	A	NF	Temporal resolution depending on method
		Ice thickness	1 day – 1 yr	B & N	Ground measurements and snow models	A	NF	“
		Timing of icing	1 day	B & N	“	A	NF	“
	Permafrost	Permafrost depth	1 yr	N	Ground measurements	B	NF	Present measurements at Jansonhaugen are not biologically relevant. New measurements needed for biologically relevant layer, not presently included in COAT
	P: Harvest							
	Reindeer harvest	Harvest offtake	1 yr	N	A Number of harvested animals per sex and age class	A	F	
	Ptarmigan harvest	Harvest offtake	1 yr	S	A Number of harvested birds	A	F	
	Arctic fox harvest	Harvest offtake	1 yr	S	A Number of harvested animals	A	F	
	P:Pollution							
	POPs	POPs in Arctic fox	1 yr	S	Autopsy of fox carcasses and organ analyses	A	F	Input from “MOSJ Pollution”
	Plant nutrients	NO_3, SO_4	1 day	Z	“	A	F	“
	R: Ecological							
	Svalbard reindeer	Abundance	1 yr	N & B	Population surveys	A	F	
		Demographic structure	1 yr	N & B	Population surveys	A	F	
		Body condition	1 yr	N	Body mass and jaw measurements	A	UF	Harvest samples, a 20-yr series of individual body measurement from Reindalen
	Svalbard rock ptarmigan	Abundance	1 yr	N	Population survey	A	F	
		Demographic structure	1 yr	S	Wing samples from harvest	A	F	Need to be calibrated against field surveys
	Arctic fox	Abundance	1 yr	N & B	Population surveys	A	F	
		Reproductive success	1 yr	N & B	“	A	F	
		Demographic structure	1 yr	S	Age and sex structure from harvest	A	F	
		Body condition	1 yr	S	Samples from harvest	A	F	
		Prevalence of zoonoses	1 yr	S	“	A	UF	Rabies, toxoplasmosis and *Echinococcus*
	Geese	Abundance	1 yr	S	Population survey in wintering areas and colony surveys on Spitsbergen	A	UF	Pink- footed and barnacle goose. Colony surveys on Spitsbergen are to be developed within COAT
		Reproductive success	1 yr	S	“	A	UF	“
		Predation	1 yr	S	Surveys in selected colonies	B	NF	
	Plant communities	Biomass and growth of all functional groups	1 yr	N	Field survey in Semmeldalen in all habitat strata	A	UF	Ongoing 12- year monitoring series, but no secure funding
		Vegetation greenness and onset of spring	1 yr	S	Satellite and ground measurements	A	UF	Only satellite products have stable funding
	Forage plants	Biomass of grasses and sedges in marshes	1 yr	N	Field surveys	A	NF	Important for reindeer and geese
		Biomass of reindeer forage plants	1 – 5 yr	B	Field surveys	A	UF	Ongoing monitoring series from 1978 (approx. 5 yr. intervals), but no secure funding
		Biomass and phenology of ptarmigan forage plants	1 day – 1 yr	N	Field surveys	A	NF	
		Goose grubbing	1 – 5 yr	S	Field surveys	A	NF	Surveys on Spitsbergen are to be developed within COAT

Thematic Program	Target (P/R)	State variable	Interval	Location	Method	Priority	Status	Comment
INTRODUCED SPECIES								
	P: Traffic							
	Cruise tourism	Number of people going ashore	1 yr	S	Official statistics	B	F	Indicates pressure related to introduction of seeds
	R: Ecological							
	Sibling vole	Abundance and distribution limits	1 yr	N	Field surveys	A	NF	Is included in COAT plan
	Echinococcus multilocularis	Prevalence rates in sibling vole	1 yr	N	Autopsy of vole carcasses	A	NF	“
	Anthriscus sylvestris	Abundance and distribution limits	1 yr	N	Field surveys	A	NF	Hotspot in Barentsburg and nearby seabird colonies
	Achillea millefolium, Alchemilla subcrenata, Barbarea vulgaris, Deschampsia caespitosa, Poa annua, Rumex acetosa, Stellaria media, Taraxacum ruderalia aggregate, Ranunculus acris aggregate, , Tripleurospermum maritimum	Abundance and distribution limits	1 yr	N	Field surveys	B	NF	Hotspots in Longyearbyen, Barentsburg and Pyramiden
RED LISTED SPECIES								Monitoring design is not developed for most of the targets; priorities remain to be done
	P: Climate							From COAT monitoring
	R: Ecological							
	Brent goose		1 yr	S	Colony surveys on Spitsbergen are to be developed within COAT		NF	
	Thermophilic plant community I	Abundance	1 – 5 yr	N	Field surveys in Colesdalen		UF	Rare species with expected positive effect of climate change: *Betula nana* ssp. *tundrarum, Campanula rotundifolia* ssp. *gieseckiana, (Empetrum nigrum), Euphrasia wettsteinii,* and *Vaccinium uliginosum* ssp. *microphyllum*
	Thermophilic plant community II	Abundance	1 – 5 yr	S	Field survey Bockfjorden		NF	Rare thermophilic species with low genetic with expected negative effect of climate change: *Arenaria humifusa*, *Botrichium lunaria, Euphrasia wettsteinii, Carex capillaris* ssp, . *fuscidula, Puccinellia* sp. *Sibbaldia procumbens, (Tofieldia pusilla)*
		Grazing pressure	1 – 5 yr	N	“			
	Species related to permafrost	Abundance	5 yr	S	Field surveys		NF	Rare species depending on permafrost*: E.g. Sagina caespitosa, Arenaria humifusa, Pleuropogon sabinii*
		Reproduction	5 yr	S	Field surveys			
TRAFFIC								
	P: Cruise tourism							
		Number of people going ashore*	1 yr	S	Official statistics	A	F	Need to be scaled down to numbers per site
		Number of landing sites*	1 yr	S	“	A	F	
	R: Ecological							
	Plant communities	Cover of functional groups*	5 yr	S	Field surveys in selected sites (See Fig. 6)	A	UF	First measurements made in 2009, have not been repeated according to plan
		Cover of non-vegetated substrate*	5 yr	S	“	A	UF	“
		Degree of wear*	5 yr	S	“		UF	“

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