145 RAPPORTSERIE
NORSK POLARINSTITUTT

Per Fauchald, Per Arneberg, Jørgen Berge, Sebastian Gerland,
Kit M. Kovacs, Marit Reigstad and Jan H. Sundet

An assessment of MOSJ – The state of the marine environment around Svalbard and Jan Mayen

MOSJ Miljøovervåking Svalbard og Jan Mayen

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

Rapportserie/Report Series no. 145

Per Fauchald, Per Arneberg, Jørgen Berge, Sebastian Gerland,
Kit M. Kovacs, Marit Reigstad and Jan H. Sundet

An assessment of MOSJ – The state of the marine environment around Svalbard and Jan Mayen

Norwegian Polar Institute
Fram Centre, NO 9296 Tromsø, Norway

Authors:
Per Fauchald, Norwegian Institute for Nature Research, Tromsø
Per Arneberg, Institute for Marine Research, Tromsø
Jørgen Berge, University of Tromsø – The Arctic University of Norway
Sebastian Gerland, Norwegian Polar Institute, Tromsø
Kit M. Kovacs, Norwegian Polar Institute, Tromsø
Marit Reigstad, University of Tromsø – The Arctic University of Norway
Jan H. Sundet, Institute for Marine Research, Tromsø

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

Technical editors: Ellen Øseth og Gunn Sissel Jaklin, Norwegian Polar Institute
Design: Jan Roald, Norwegian Polar Institute
Front cover photo: Morten Ekker
Printed: May 2014
ISBN: 978-82-7666-301-3
ISSN: 083-0421

Contents

1 Executive Summary

1.1 General status of the ecosystem and impacts from climate change and harvesting

- The impacts caused by non-sustainable harvesting of wildlife and fisheries have been greatly reduced during the last 40 years:
  - » Currently, most threatened species are protected, fishing and hunting are regulated according to international accepted criteria for sustainability, and quotas are set according to scientific advice from relevant international bodies (i.e. ICES; the International Council for the Exploration of the Sea, IWC; the International Whaling Commission and NAMMCO; the North Atlantic Marine Mammal Commission).
  - » One notable exception is the current overharvesting of the Red Listed, long-lived and deep-water dwelling golden redfish (*Sebastes marinus*).
- The ecosystem is in recovery from previous over-harvest:
  - » Several slow-growing species including long-lived marine mammals and deep-water fish show a very slow recovery, and some might never fully recover.
  - » Opportunistic species, invasive species and species with a high growth potential show strong fluctuations and might dominate the ecosystem in pulses.
- Reduced ice cover and increased temperatures have increasing importance for changes in the ecosystem and it is expected that climate change will be the most important human driver of the ecosystem within the next decades. Expected changes include:
  - » Increased primary production due to increased open-water extent and duration.
  - » Shift in the balance of ice-algae and phytoplankton.
  - » Shift in the relative importance of new and regenerated production.
  - » Changes in the availability of lipid-rich arctic zooplankton.
  - » Northward expansion of sub-arctic and temperate species.
  - » New niches becoming available for invasive species.
  - » Decline in some endemic arctic species, especially those who are associated with ice habitats.
- The combined effect of previous over-harvesting and increased impacts from climate warming make management and monitoring challenging because:
  - » The ecosystem shows large fluctuations.
  - » Ecosystem changes are difficult to predict or even explain after they have taken place.
  - » No baseline exists for a “pristine” ecosystem and “status quo” management is therefore not an option.

1.2 Suggested improvements for the MOSJ programme

Management goals

In light of the large changes that have taken place in the ecosystem due to climate change and previous over-harvest, goals that involve maintaining the ecosystem or restoring the ecosystem to a pristine state are unattainable. Several of the environmental goals set by the Norwegian Government are therefore not possible to achieve. Attainable management goals tailored to each of the anthropogenic drivers and ecosystem components would be more appropriate.

Adaptive monitoring

The large ongoing and expected future changes in the ecosystem demand a flexible monitoring system with a tight coupling between applied research and management. Development of such a monitoring system would involve:

- » Stronger collaboration between researchers and managers to address management questions that can be answered by the monitoring system.
- » Continuous scientific synthesis and interpretation of the data and indicators, preferably through a dedicated research programme.
- » Continuous development of relevant indicators that are linked to specific drivers and management questions.

Organization

- » Data are collected by several institutions and in reality include many uncoordinated monitoring programmes. In particular, the Institute for Marine Research (IMR) conducts an annual comprehensive ecosystem survey that includes several of the requested new parameters (see below). In recent years the survey also covers areas that traditionally have been covered by the Norwegian Polar Institute (the shelf west and north of Svalbard, including the shelf break to the Arctic Ocean). There is clearly a need for improved coordination among the institutions and monitoring programme.
- » Selection of parameters and monitoring design should be coordinated and harmonized with international efforts through international organizations such as the Arctic Council’s Conservation of Arctic Flora and Fauna (CAFF).
- » Data collection is funded by a multitude of sources, many of which are temporary. It is important to secure funding for relevant, core long-term data series. Some indicators need increased data collection and improvements in order to answer pressing management questions. This is especially true for arctic zooplankton and marine mammals.

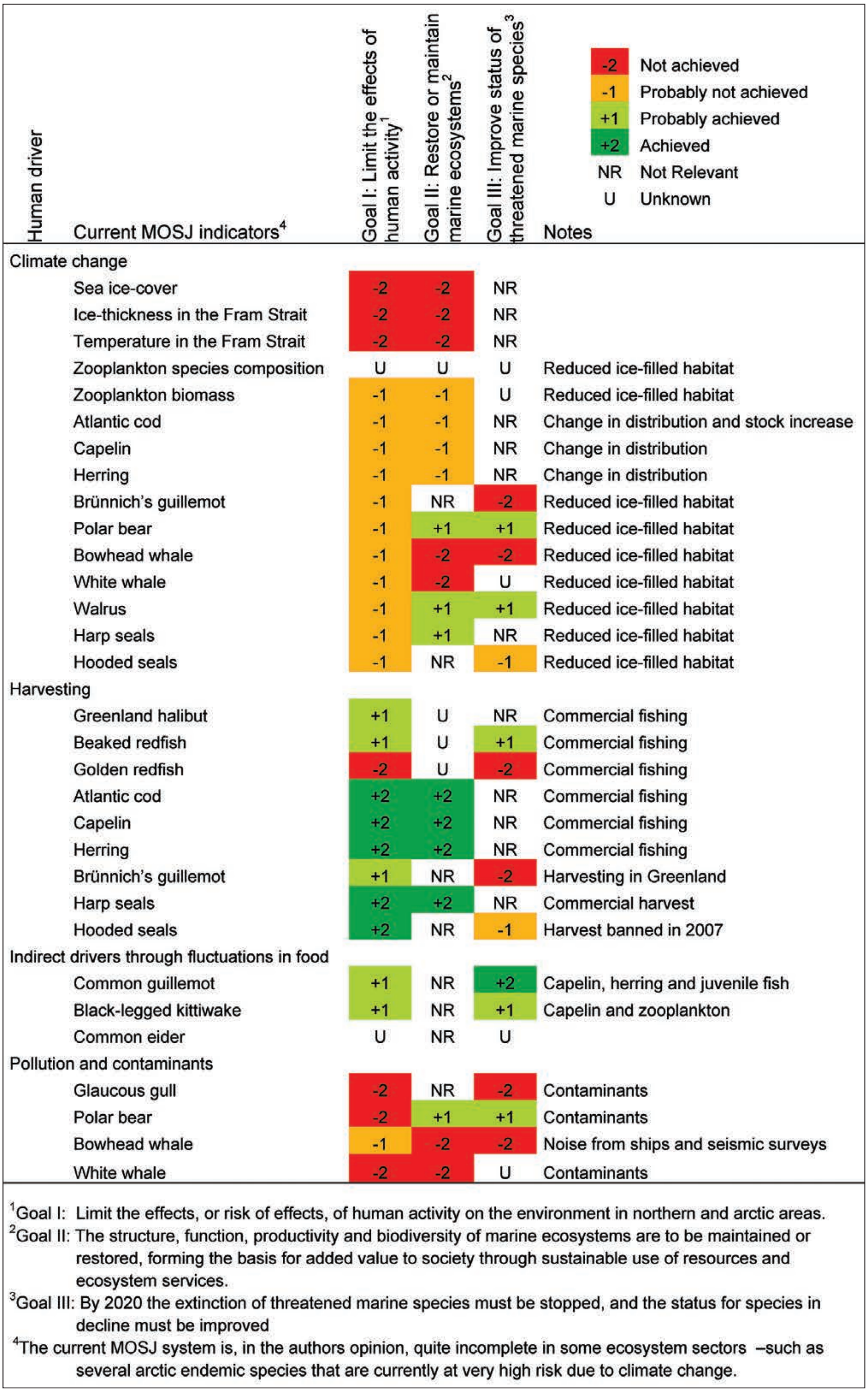
Existing indicators

- » Most indicators are relevant with respect to the environmental goals set by the Norwegian Government.
- » Based on the information on the current MOSJ web-pages it is often difficult to evaluate the monitoring design and methods.
- » How environmental drivers are linked to the indicator is fundamental information for the monitoring programme. Interpretations should always be done within a scientific context and the results should be presented in the scientific literature with an updated synopsis on the MOSJ web-pages.
- » The northeastern and eastern coasts of Spitsbergen and Jan Mayen are under-represented in the programme. More indicators from these areas should be considered.

Human drivers not addressed by MOSJ

Several important human drivers are not currently addressed by MOSJ. Some of these are under development or under consideration. Important drivers not currently addressed are:

- » *Impact of invasive species on the ecosystem.* Ballast water and fouling on ship hulls are the most important vectors for spreading alien marine species around the world. Less ice in the Arctic, due to increasing temperature, will result in increased ship traffic in arctic areas particularly along routes between Europe and Asia (Northern Sea Route and across the Arctic ocean). There are already two abundant invasive species in the Barents Sea; the red king crab and the snow crab. The latter will probably invade the Svalbard area in a short period of time. A flexible monitoring system that



-2	Not achieved
-1	Probably not achieved
+1	Probably achieved
+2	Achieved
NR	Not Relevant
U	Unknown

Human driver	Current MOSJ indicators[4]	Goal I: Limit the effects of human activity[1]	Goal II: Restore or maintain marine ecosystems[2]	Goal III: Improve status of threatened marine species[3]	Notes
Climate change					
	Sea ice-cover	-2	-2	NR	
	Ice-thickness in the Fram Strait	-2	-2	NR	
	Temperature in the Fram Strait	-2	-2	NR	
	Zooplankton species composition	U	U	U	Reduced ice-filled habitat
	Zooplankton biomass	-1	-1	U	Reduced ice-filled habitat
	Atlantic cod	-1	-1	NR	Change in distribution and stock increase
	Capelin	-1	-1	NR	Change in distribution
	Herring	-1	-1	NR	Change in distribution
	Brünnich's guillemot	-1	NR	-2	Reduced ice-filled habitat
	Polar bear	-1	+1	+1	Reduced ice-filled habitat
	Bowhead whale	-1	-2	-2	Reduced ice-filled habitat
	White whale	-1	-2	U	Reduced ice-filled habitat
	Walrus	-1	+1	+1	Reduced ice-filled habitat
	Harp seals	-1	+1	NR	Reduced ice-filled habitat
	Hooded seals	-1	NR	-1	Reduced ice-filled habitat
Harvesting					
	Greenland halibut	+1	U	NR	Commercial fishing
	Beaked redfish	+1	U	+1	Commercial fishing
	Golden redfish	-2	U	-2	Commercial fishing
	Atlantic cod	+2	+2	NR	Commercial fishing
	Capelin	+2	+2	NR	Commercial fishing
	Herring	+2	+2	NR	Commercial fishing
	Brünnich's guillemot	+1	NR	-2	Harvesting in Greenland
	Harp seals	+2	+2	NR	Commercial harvest
	Hooded seals	+2	NR	-1	Harvest banned in 2007
Indirect drivers through fluctuations in food					
	Common guillemot	+1	NR	+2	Capelin, herring and juvenile fish
	Black-legged kittiwake	+1	NR	+1	Capelin and zooplankton
	Common eider	U	NR	U	
Pollution and contaminants					
	Glaucous gull	-2	NR	-2	Contaminants
	Polar bear	-2	+1	+1	Contaminants
	Bowhead whale	-1	-2	-2	Noise from ships and seismic surveys
	White whale	-2	-2	U	Contaminants

[1] Goal I: Limit the effects, or risk of effects, of human activity on the environment in northern and arctic areas.

[2] Goal II: The structure, function, productivity and biodiversity of marine ecosystems are to be maintained or restored, forming the basis for added value to society through sustainable use of resources and ecosystem services.

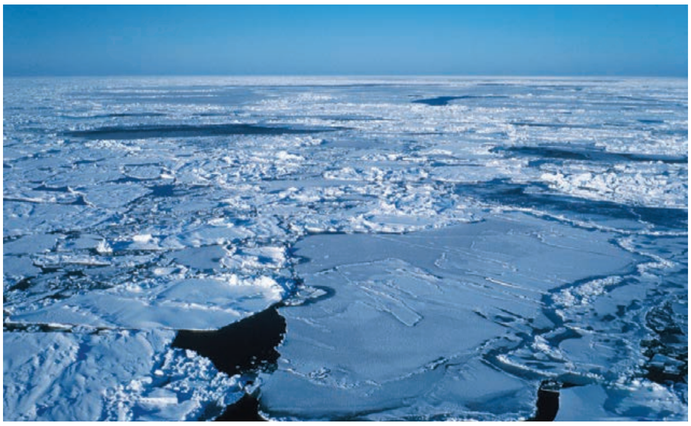
[3] Goal III: By 2020 the extinction of threatened marine species must be stopped, and the status for species in decline must be improved

[4] The current MOSJ system is, in the authors opinion, quite incomplete in some ecosystem sectors –such as several arctic endemic species that are currently at very high risk due to climate change.

Table 1.1
Evaluation of environmental goals stated by the governmental White Paper Prop1.S (2011-2012) with respect to marine MOSJ indicators and human drivers in the marine areas covered by the fishery protection zone around Svalbard and the fishery zone around Jan Mayen. The basis for the evaluation of each indicator is found in chapters 4 to 8 of this report.

Polar bear tracks on sea ice. Photo: Sebastian Gerland, Norwegian Polar Institute

Arctic sea-ice. Photo: Angelika Renner, Norwegian Polar Institute



Sea-ice in the Barents sea. Photo: Sebastian Gerland, Norwegian Polar Institute

captures shifts range and abundance of invasive species and their impact on the ecosystem should be developed and implemented.

- *Impact of fishery by-catch on threatened species.* By-catch of commercial fish species is thoroughly addressed in Norwegian fisheries regulations but may be difficult to enforce due to unrecorded discards. Non-commercial species are however not protected against by-catch through any regulations and small populations of these species may be affected by by-catch via a commercial fishery. Susceptible species and potential detrimental fisheries should be identified and monitored.

- *Impact of bottom trawling/scraping on benthos.* Disturbance from trawling and dredging has wide-ranging impacts on the diversity and productivity of benthic communities. In the Barents Sea, particular attention has been paid to highly vulnerable biota such as deep-sea corals and areas dominated by sponges and sea pens. For obvious reasons these biota are seriously threatened by bottom trawling and there is a strong need for protection. Frequent trawling disturbance of soft sediment communities lead to the proliferation of smaller benthic species with faster life histories. Ultimately, this might have consequences for benthic productivity. A relevant monitoring programme of fishing activity and benthic communities is needed.

- *Impact of ocean acidification on the ecosystem.* The consequence of ocean acidification on ecosystems and biogeochemical cycling is one of the big unknowns. However, ocean acidification might be a serious threat to a+rctic marine ecosystems. Experimental results are so far not conclusive, but the increased acidity and associated increased corrosion of arctic water masses and potential vulnerability of key species, like pteropods, calls for monitoring of pH, as well as vulnerable species and processes.

Ecosystem components not covered by MOSJ

Several ecosystem components are not currently covered by MOSJ. Several of these are under development or under consideration. Important ecosystem components not currently covered are:

- *Phytoplankton and primary production.* The changes in Arctic Ocean ice conditions seen as earlier melting, later freeze up, thinner ice and larger area with seasonal ice, has a great impact on the primary production, allowing a prolonged productive season. The nutrient source for an increased primary production is however critical to its fate. An increased regenerated productivity based on recycling of ammonium in the upper layers, will fuel the microbial food web and increase the metabolic losses in the ecosystem. If, however, additional deepwater nutrients, in terms of nitrate, are supplied through upwelling or increased mixing, the increased productivity can reach harvestable species and increase carbon sequestration to depth. Monitoring physical stratification and mixing, nutrients dynamics, algal cell-size composition, and primary production is necessary to address the fate of primary productivity and potential productivity on higher trophic levels, but also to provide validation data for modelling.

- *Benthos*. The bottom fauna hosts a considerable part of the production and biodiversity of marine shelf ecosystems. Human drivers affecting this part of the ecosystem include disturbance from bottom trawling/dredging, invasive species and climate change. Benthic production is highly dependent on primary production, and temporal changes are often masked by e.g. climatic changes. Studies indicate that the benthic biomass in the Barents Sea has been reduced by as much +as 70% in some areas. Parts of this reduction can be attributed to reduced primary production and perhaps increasing populations of invasive opportunistic decapods, king crab and snow crab, which forage on a wide variety of benthic animals. However, increased bottom trawling is probably also an important factor. A monitoring programme should be in place to disentangle the effect of these different drivers.
- *Littoral zone*. The flora and fauna in the littoral zone in the Arctic is highly influenced by scouring from sea ice. With higher temperature and less ice scouring, substantial changes can be expected in the littoral zone and this process should be considered for monitoring as an effect of climate change.

2 Introduction

The Environmental Monitoring of Svalbard and Jan Mayen (MOSJ) is an umbrella programme that collects and interprets relevant dataseries of the environment in the arctic territories of Svalbard and Jan Mayen. A major goal of the programme is to assess whether the environmental goals set by the Norwegian government have been achieved. In cases where the goals have not been met, the programme should identify the reasons for this, and propose recommendations for management actions.

The present report is the interpretation of the indicator set with respect to the marine environment focusing on the fishery protection zone around Svalbard and the fishery zone around Jan Mayen (Figure 1.1). The objective of the report is twofold. Firstly, based on the indicator set, the report assesses the status of the marine ecosystem and evaluates whether the environmental goals have been achieved. Secondly, the report evaluates the relevance of each individual indicator, the monitoring design and whether the indicator set covers all important human drivers of the ecosystem. Note that the impact from contaminants and pollution is monitored by a specific indicator set and is covered by another report (Gabrielsen et al. 2012a).

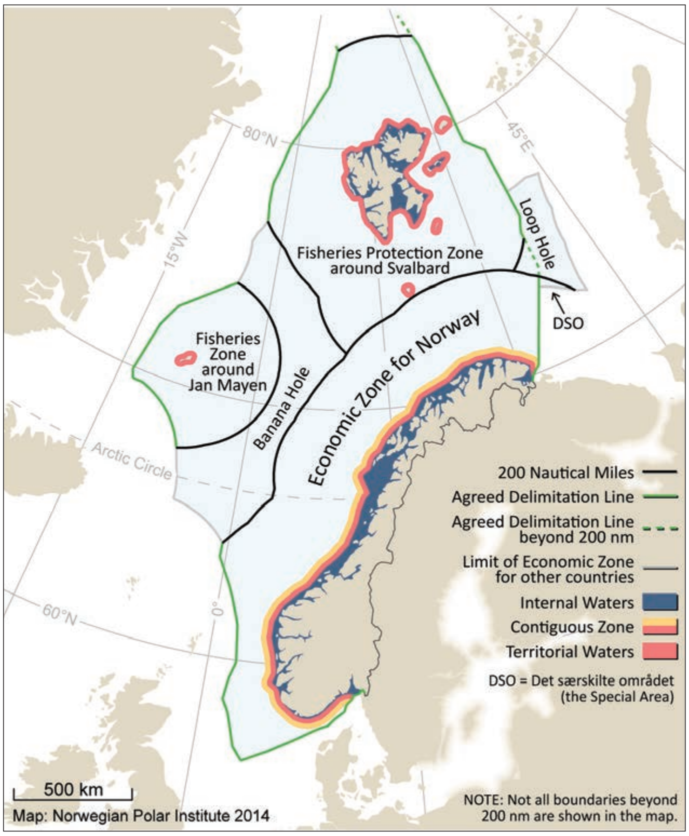


Figure 1.1
Norwegian maritime boundaries (source: www.regjeringen.no)

Chapter 3 describes the criteria used in the evaluation and chapters 4-8 interpret each of the indicators with respect to Ocean Climate, Zooplankton, Fish, Seabirds and Marine Mammals respectively. The marine MOSJ indicators focus on impact from climate change and harvesting. Other important drivers, not currently covered by MOSJ, include invasive species, by-catch in fisheries, bottom trawling and scraping and ocean acidification. Neither are fundamental ecosystem components such as primary production and benthos covered by MOSJ. It should be noted that several indicators covering these drivers and ecosystem components are under development for the MOSJ system.

3 Evaluation criteria

3.1 Relevance and evaluation of environmental goals

It is important that the indicators measure changes relevant to the environmental goals set by the Norwegian Government. In the evaluation, we have specifically addressed whether the indicator is relevant with respect to the goals and whether the goals have been achieved. We used four categories in the assessment of the environmental goals: 1) not achieved, 2) probably not achieved, 3) probably achieved, 4) achieved. Each indicator is discussed in detail in chapters 4 to 8 and the results from the evaluation are summarized in Table 1.1.

With respect to the marine MOSJ, the relevant goals are defined by the governmental White Paper Prop 1.S (2011-2012)
(our translation – Norwegian text in brackets):

I Limit the effects and risk of effects, of human activity on the environment in northern and polar regions.

(Avgrense påverknad og risiko for påverknad på miljøet i nord- og polarområda som følgje av menneskeleg aktivitet.)

Criteria for relevance

a) The indicator monitors a marine environmental parameter with a documented relationship to a human driver, or

b) The indicator monitors a human driver with a documented effect on the marine environment.

II The structure, function, productivity and biodiversity of marine ecosystems are to be maintained or restored, forming the basis for added value to society through sustainable use of resources and ecosystem services.

(Dei marine økosystema sin struktur, verkemåte, produktivitet og naturmangfald skal oppretthaldast eller gjenopprettast og danne grunnlag for verdiskaping gjennom berekraftig bruk av ressursar og økosystemtenester.)

Criteria for relevance

a) The indicator monitors changes in important ecosystem structures or functions such as primary production, trophic interactions, recycling, biodiversity or habitat building, or

b) The indicator monitors a human driver with a documented effect on ecosystem structure or function, or

c) The indicator monitors the sustainability of human use of an ecosystem service.

III By 2020 the extinction of threatened marine species must be stopped, and the status for species in decline must be improved.
(Utryddinga av truga marine arter skal vere stansa, og status for arter i nedgang skal vere forbetra innan 2020.)

Criteria for relevance

a) The indicator monitors demography or population dynamics of a threatened species listed on the Norwegian Red List, or

b) The indicator monitors a human driver with a documented effect on a threatened species listed on the Norwegian Red List.

3.2 Monitoring design

An environmental indicator is per definition a proxy for assessing an on-going or expected environmental change (the monitoring target). The applicability of the indicator therefore relies on an appropriate monitoring design. In this evaluation we have focused on the following criteria:

a) Monitoring target

– Is the target for monitoring clearly defined?

b) Measurement error and unwanted noise

The indicator should be measured with adequate precision, i.e. without too much measurement error and unwanted noise relative to the changes that the indicator is supposed to detect. *– How precise is the measurement of the indicator relative to critical changes in the monitoring target?*

c) Measurement scale

It is important that there is a match between the scale of measurements and the scale of environmental change. *– Is the indicator measured on a spatial and temporal scale that is relevant for the monitoring target?*

d) Confounding factors and bias

The indicator should be an unbiased measure of the monitoring target. Other factors that influence the indicator must therefore be minimized or controlled for in the design or analyses. *– What is the extent to which biases from confounding factors can influence the indicator and to what degree can these be controlled for?*

e) Early detection and time lag

The indicator should provide an early signal for changes in the monitoring target. *– Does the indicator provide an early warning of change?*

f) Reference level

In order to define a level where management actions are relevant, it is necessary that a reference level for the indicator exists. Established reference levels can be based on historical data or levels defined by the management authority. *– Is there a defined reference level or is the time series long enough to provide a historical reference level for the indicator?*

g) Documentation

It is important that the monitoring design, the relevance of the indicator and the reference level is clearly documented. *– Is the documentation of the indicator satisfactory?*

For most of the indicators assessed, we were, due to lack of documentation, unable to assess the effects of measurement error and bias (i.e. b and d). More effort is needed to address these factors in the documentation of the indicators.

3.3 Indicator set

In addition to the evaluation of each indicator, it is necessary to evaluate the total set of indicators. Ideally the indicators should be a representative set of proxies for assessing the goals defined by the Norwegian Government (i.e. 3.1). If for example, many indicators are used to measure the same part of the ecosystem, this will give a biased evaluation with respect to the achievement of the goals in 3.1II. At the same time, it is important that all relevant parts of the system are covered. Finally, it is important that the indicator set is flexible. New and changed human drivers, major ecosystem changes and new knowledge and technology should be reflected by the introduction of new or improved indicators; improvement of the system might also sometimes be achieved by deletion of indicators that are no longer relevant. The following criteria were used:

a. Redundancy – *Do several indicators provide similar information?*

b. Coverage – *Are all important human drivers and parts of the ecosystem monitored? Are all threatened species covered adequately?*

c. Flexibility – *Have new indicators been implemented as a response to changed human drivers, new knowledge and new technology?*

4 Ocean climate

The marine ecosystems in the Arctic are currently being subjected to rapid environmental changes (Symon 2011, Meltofte 2013). Temperature increases in the Arctic are steeper than in the rest of the world and summer temperature is predicted to increase up to 5°C within this century (Solomon et al. 2007). Current dramatic changes in the marine ecosystems are being induced by reduced seasonal and permanent ice cover (Symon 2011). The decline in summer sea-ice extent has accelerated over the past few decades and is occurring faster than predicted by model simulations (Stroeve et al. 2007) with a possible summer ice-free Arctic expected within a few decades (Stroeve et al. 2007, Wang & Overland 2009). Climate change has already impacted Arctic marine ecosystems (Kovacs et al. 2011, Wassmann et al. 2011) and these changes are predicted to continue at increased rates as the ice retreats and the temperature increases further (Kovacs & Michel 2011, Michel 2013). Ecosystem changes include (Kovacs & Michel 2011, Wassmann 2011, Wassmann et al. 2011, Michel 2013):

- Increased primary production due to increased open-water extent and duration.
- Shift in the balance of ice-algae and phytoplankton.
- Shift in the relative importance of new and regenerated production.
- Reductions in the availability of lipid-rich arctic zooplankton and arctic fishes.
- Northward expansion of sub-arctic and temperate species among a wide variety of taxa.
- New niches become available for invasive species.
- Reductions in the number and distribution of endemic arctic species, especially those who are associated with ice-habitats.
- Possible extinctions of sympagic (ice-associated) species.

4.1 MOSJ indicator: Sea-ice cover in the Barents Sea and Fram Strait

Arctic ice-cover is measured by passive microwave satellite imagery (Comiso 1999). The dataset is managed by the National Snow & Ice Data Center (NSIDC) in the USA (http://nside.org/) and covers the entire Arctic. The data has been freely available since 1978 and is used extensively to monitor changes in the perennial and annual sea ice-cover in the Arctic (Stroeve et al. 2007, Comiso et al. 2008). Two large-scale "boxes" in the Fram Strait and the Barents Sea are incorporated into the MOSJ programme to monitor sea-ice

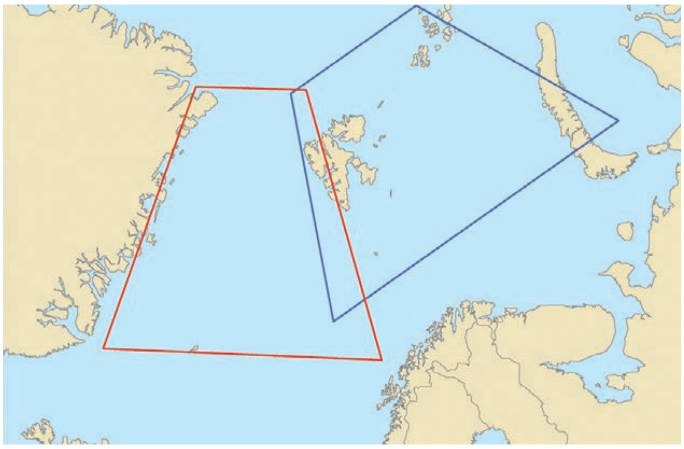


Figure 4.1
Remote sensing monitoring of sea-ice extent in two “boxes”; Fram Strait (red) and Barents Sea (blue).

extent (Figure 4.1). Ice-cover is averaged for April, when the ice extent is at a maximum and September, when the ice extent is at a minimum. The ice cover is defined as the total area covered by more than 15% ice. The ice cover in the Fram Strait box is heavily influenced by the drift of ice from the Arctic Ocean, thus the ice cover in this region also reflects large-scale climatic processes within the Arctic Basin. The ice cover in the Barents Sea box reflects more local processes, and in particular, the characteristic seasonal sea-ice dynamics in the area.

Evaluation of monitoring methods

The NSIDC dataset has been used extensively in a number of studies dealing with sea-ice in the Arctic (see Meier & Haas 2011). The scale and positioning of the boxes fits well with the ice-dependent ecosystems in the Barents Sea and the Fram Strait. There is considerable seasonal and year-to-year variation in these data. Nevertheless, the data series are long enough to detect important trends on a decadal scale.

Results

There has been a negative trend in the ice-cover in both areas and seasons across the monitoring period (Figure 4.2). In the Barents Sea, the decrease since 1979 has been 11.5% and 15.7% per decade in April and September, respectively. In the Fram Strait, the decrease has been 6% per decade for both periods.

Relevance

The observed reduction in ice-cover is corroborated by similar findings in virtually all regions of the Arctic (Meier & Haas 2011). These changes are a result of a warmer Arctic (AMAP 2011) which is very likely due to the observed increase in anthropogenic greenhouse gas concentrations (IPCC 2007). According to assessments done as part of the intergovernmental programme SWIPA (Sea, water, ice and permafrost in the Arctic; Kovacs & Michel 2011, Michel 2013), it is very likely that these changes have major effects on the structure and function of the marine ecosystem around Svalbard and Jan Mayen and that endemic ice-related and threatened species are being affected.

4.2 MOSJ indicator: Ice thickness in the Fram Strait

Moored ULS (Upward Looking Sonar devices) have been operated across the Fram Strait to monitor ice export since 1990. The Fram Strait controls the exchange of water masses between the Arctic Basin and the North Atlantic Seas. Warm saline water flows northwards in the east (the West Spitsbergen Current), while freshwater and ice is transported southward in the west (East Greenland Current). Because most of the ice exported from the Polar Basin is channeled through the Fram Strait, the monitoring of this export is important with respect to the sea-ice production in the Arctic, the ocean climate in the Northwest Atlantic, and even thermohaline circulation on a global scale (see e.g. Aagaard & Carmack 1989, Vinje et al. 1998, Kwok et al. 2004). The MOSJ sea-ice thickness indicator monitors the thickness of the Multi-Year Ice (MYI) (ice more than one year old). With respect to the arctic marine ecosystems encompassed by this report, the export of sea-ice through the

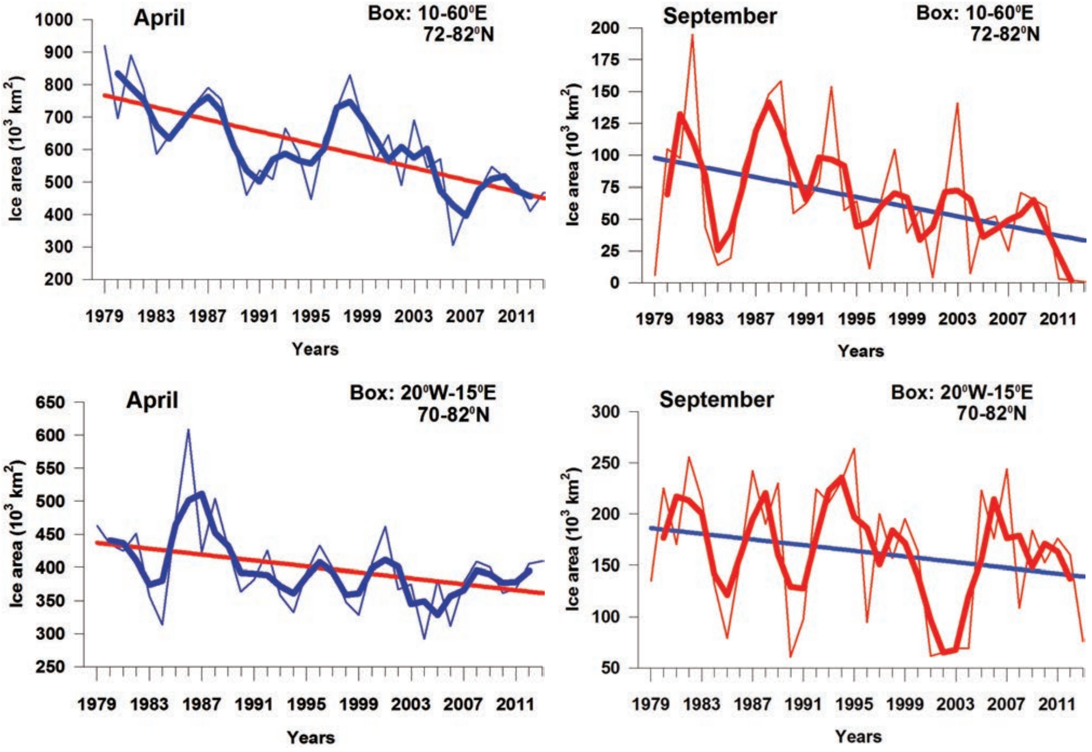


Figure 4.2
Percentage of sea-ice cover in the Barents Sea (top) and the Fram Strait (bottom). Left panel is from April (maximum seasonal ice-cover), right panel is from September (minimum seasonal ice-cover). Thin line is monthly average; thick line is the three years running average. Straight lines show trends from 1979 to present. (Source: www.mosj.npolar.no)

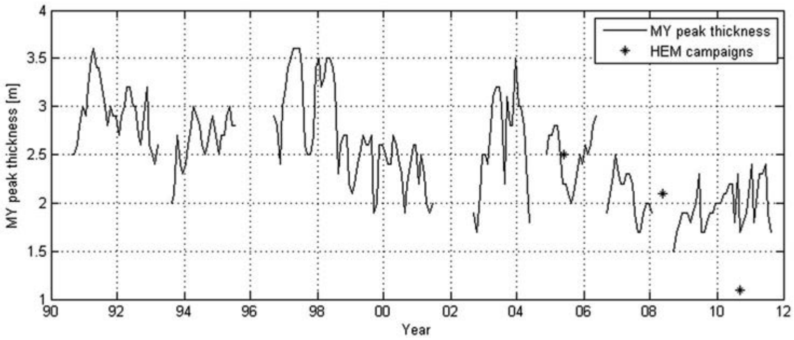


Figure 4.3
Multi-year Ice thickness measured by upward looking sonars across the Fram Strait. Stars are electromagnetic measurements from helicopter (HEM campaigns). (Source: www.mosj.npolar.no)

Fram Strait is likely to influence the concentration, age and thickness of ice in the Greenland Sea. This is important for the ice-related flora and fauna transported with the ice from the Arctic Basin to the Greenland Sea (Hop et al. 2006), as well as the ice-dependent pinnipeds which use the Greenland Sea for birthing and moulting (i.e. harp seal (*Pagophilus groenlandicus*) and hooded seal (*Cystophora cristata*)).

Evaluation of monitoring methods

The data has been used in studies of ice-export from the Arctic Basin (e.g. Vinje et al. 1998, Kwok et al. 2004). There is a lot of variation in sea-ice thickness due to local weather and wind conditions which might overshadow important long-term trends. Additionally, how MYI is separated from First-Year Ice (FYI) is not documented in the indicator description. The link between MYI thickness and ice conditions in the Greenland Sea has not been documented. It might be more effective to measure sea-ice conditions in the Greenland Sea directly by using microwave satellite imagery (see above) for ice assessments for this specific region.

Results

The MYI thickness (Figure 4.3), has decreased from about 3 m in the early 1990s to about 2 m in 2007. From the same time series (1990-2011), Hansen et al. (2013) found that the thickness of MYI was reduced by 32%, the modal peak width of MYI was reduced by 25%, and the fraction of (ridged) ice thicker than 5 m was reduced by 50%.

Relevance

The reduction in MYI thickness is in line with the general trend of sea-ice reduction in the Arctic Ocean. The concentration and status of MYI is vital for ice-related flora and fauna (e.g. Hop et al. 2006), and the drift of ice through the Fram Strait is very likely an important driver for the ecosystems as far south as the Greenland Sea (and perhaps also beyond).

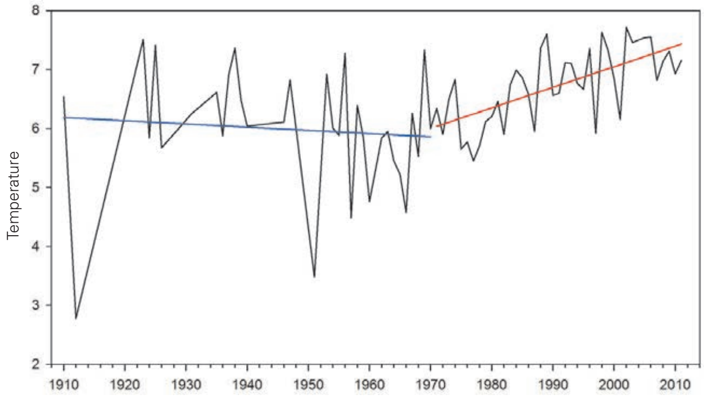


Figure 4.4
Temperature of the West Spitsbergen Current measured as the annual maximum temperature in the Fram Strait. (Source: www.mosj.npolar.no)

4.3 MOSJ indicator: Temperature in the Fram Strait

While the East Greenland current transports cold and fresh Arctic Water southward through the Fram Strait, the West Spitsbergen Current (WSC) transports warm and saline Atlantic Water northward into the Arctic Basin. The temperature and salinity of the WSC has been measured more or less regularly since 1910. The indicator is important for understanding the changing climate in the Arctic (Aagaard et al. 1987). However, it is also an indicator for the ocean climate in the coastal areas of West Spitsbergen (Hop et al. 2006). The indicator is a measure of temperature with standard CTD instruments within the warmest part of the current, i.e. the core of the current. The measurements are done across the Fram Strait between 78°30' and 79°30' latitude.

Evaluation of monitoring methods

Several studies have used temperatures series from the WSC to investigate the effect of the WSC on local climate (e.g. Beuchel et al. 2006, Walczowski & Piechura 2011) . The index is linked to the temperature and volume of the flow within the North Atlantic Current (Spielhagen et al. 2011). The index is therefore correlated with regional climate indices such as the North Atlantic Oscillation (NAO) index (Beuchel et al. 2006). However, there is considerable variation in the index due to local and short term variation in wind-driven currents. The measurements early in the 20th century were infrequent and the estimates in this period are more imprecise than more recent part of the data series. Nevertheless, the index provides a baseline on a century scale and is a relevant indicator for climate change on a decadal scale.

Results

Temperatures were high in the 1920s (Figure 4.4). The temperature then decreased slightly until the 1970s. Since then, the temperature has increased rapidly reaching an maximum in 2002 (7.7°C).

Relevance

The current rate of inflow of warm Atlantic Water into the Arctic Basin through the WSC is unprecedented over the last 2000 years (Spielhagen et al. 2011). This increase is presumably linked to the Arctic amplification of global warming (Spielhagen et al. 2011). Several studies have shown that the WSC temperature, or related indices, is related to changes in the coastal ecosystems of Spitsbergen (e.g. Berge et al. 2005, Beuchel et al. 2006, Carroll et al. 2011, Hindell et al. 2012, Kwasniewski et al. 2012). The North Atlantic Current and WSC also transport meroplankton (planktonic larvae of invertebrates) and fish larvae from the south which might change the local ecosystems via an increased inflow of sub-arctic and boreal species (e.g. Berge et al. 2005).

5 Zooplankton

Herbivorous zooplankton species are a major link between primary producers and higher trophic levels in arctic marine ecosystems, and most fish, seabirds and marine mammals are directly or indirectly dependent on the energy transferred through the zooplankton component of the system (e.g. Hop et al. 2002, Leu et al. 2011, Wassmann 2011). Changes in the species composition and community structure of zooplankton are therefore likely to have effects on the entire food web. The composition, biomass and production of the zooplankton community is determined by bottom-up processes through e.g. climate induced patterns in primary production (e.g. Leu et al. 2011) as well as top-down processes through predation from pelagic fish and jellyfish as well as other predators (e.g. Dalpadado et al. 2003, Eriksen et al. 2012). A change in the zooplankton community is therefore commonly used as an indicator of climate or trophic induced shifts in aquatic ecosystems (e.g. Beaugrand and Ibanez 2004). In light of the ongoing and expected future reduction in sea ice and increased ocean temperature (see chapter 4)

Calanus finnmarchicus, a typical atlantic zooplankton expected to increase around Svalbard with climate change. Photo: Malin Daase, Norwegian Polar Institute

and changes in the composition of the pelagic fish community (see chapter 6), the monitoring of the zooplankton community around Svalbard could provide vital information on the state and development of the marine ecosystem.

Zooplankton research and monitoring in the MOSJ area

Zooplankton research around Svalbard is at a very high international level both in terms of quantity and quality. Several stations and locations are regularly sampled (see below), and some programmes utilize moored observational platforms in the fjords of Svalbard. This is the case for Kongsfjorden and Rijpfjorden, for which baseline levels of variation and community structure are gradually being established. Hornsund (Polish research station) and Billefjorden (UNIS field site) also provide promising monitoring opportunities. In concert, these four locations could provide insight into how zooplankton communities and populations change over time under different climatic regimes. However, baseline studies are critically missing, and there is no coordination or long-term funding in place to secure solid datasets. Fram Centre institutions and their international partners operate the observational platforms (Kongsfjorden, Rijpfjorden, Hornsund and Billefjorden), and a large number of samples are being secured annually. But, these efforts are predominantly financed via short-term projects (typically 3-4 years long) that have no obligations with respect to long-term monitoring. By coordinating (and co-funding) some of these activities, the potential for a MOSJ indicator dataset is very large.

During the last two decades, a research programme has been developed in Kongsfjorden with both zooplankton transects and measurement platforms for relevant background data on the physical environment. Physical ocean data in Kongsfjorden date back to the 1950s, whereas zooplankton sampling commenced in the 1990s. In Rijpfjorden, a comparable programme was initiated in 2006. Many research projects and publications have been based at these two locations which, in combination, offer unique insight into two contrasting climatic domains with two correspondingly different zooplankton communities.

In addition to the monitoring stations in the Spitsbergen fjords, the Institute for Marine Research (IMR) has sampled biomass and species composition of zooplankton in the Barents Sea since 1986 (Eriksen 2012). Most of this effort takes place within the IMR annual ecosystem survey in August-September. In this survey, zooplankton biomass is monitored by net hauls from the bottom to the surface at about 180 sampling stations in the western Barents Sea (ca. 30 stations are in the Arctic Waters around Spitsbergen). Species composition is determined for the stations along the Fugløya-Bjørnøya transect in the southwestern Barents Sea. Some samples are processed with respect to species and stage determination while the larger dataset is usually presented simply by size categories (i.e. <1, 1–2, and >2 mm).

Through several projects funded by the Directorate for Nature Management, the marine invertebrate fauna along the Norwegian coast and Svalbard has been registered into a database (Narayanaswamy et al. 2010). By regularly monitoring selected locations and identifying all zooplankton taxa present, the existing data will provide a solid knowledgebase for monitoring the occurrence of new and more boreal species in the waters around Svalbard. The overlap between zooplankton and benthic indicators is obvious, as many of the dominant benthic taxa have pelagic larval stages. Examples of boreal species extending their distributional limits northward into Svalbard waters include the zooplankton species *Themisto compressa* (Kraft et al. 2013) and the blue mussel (*Mytilus edulis*) (through transport of pelagic larvae) (Berge et al. 2005). An indicator of the total-taxa-present in the water column could provide a useful starting point for monitoring purposes.

Zooplankton community in the MOSJ area

The meso-zooplankton community in Svalbard waters is dominated by three *Calanus* species: *Calanus finmarchicus*, *Calanus glacialis* and *Calanus hyperboreus*. *C. finmarchicus* is an Atlantic species and its occurrence is associated with the inflow of Atlantic Water. Specifically, *C. finmarchicus* is transported with the warm West Spitsbergen Current (WSC) into the coastal areas in west Spitsbergen and eventually into the Arctic Ocean north of Spitsbergen (e.g. Hop et al. 2002). In contrast *C. glacialis* and *C. hyperboreus* are of arctic origin. *C. glacialis* has its main distribution in the relatively shallow arctic shelf seas whereas *C. hyperboreus* is an oceanic species associated with deep water.

The species composition in the waters of Spitsbergen is accordingly dependent on the inflow of Atlantic Water. All three species are primarily herbivorous and accumulate energetic reserves in the form of lipids during spring and summer. The size and energy content of the different *Calanus* species determine their value as food sources for higher trophic levels. The arctic species, *C. glacialis* and *C. hyperboreus* are larger and contain 10 and 25 times more energy (lipids), respectively, than the Atlantic species *C. finmarchicus* (Falk-Petersen et al. 2009). The life cycle of the various *Calanus* species is closely linked to the timing of the algal bloom (Falk-Petersen et al. 2009). For the arctic *C. glacialis,* the timing of reproduction is synchronized with the ice-algal bloom preceding ice melting, while the maximum growth of the progeny matches the pelagic phytoplankton bloom occurring two months later (Søreide et al. 2010). It is consequently anticipated that changes in the pattern of ice melting will have profound impact for the zooplankton community (Leu et al. 2011).

Macro-zooplankton in the Barents Sea include amphipods, most notably the arctic species *Themisto libellula*, as well as other taxa such as euphausiids (*Thysanoessa* spp.) which are mainly found in Atlantic Water (Søreide et al. 2003). *T. libellula* is a key species in the arctic food-web and an important food source for the polar cod (*Boreogadus saida*) as well as for arctic seabirds and marine mammals. The current reduction in the biomass of amphipods (mainly *T. libellula*) in the Barents Sea has been linked to the reduction of the arctic water masses, with possible implication for the arctic food-web (Dalpadado et al. 2012). On the other hand, herring, capelin and 0-group fish have in recent years apparently benefited from an increased biomass of lipid-rich euphausiids in Atlantic Water (Dalpadado et al. 2012). These results might indicate a trend in which the arctic food web is being replaced by a boreal or sub-arctic food web. There are currently no indicators that specifically monitor the species composition of macro-zooplankton in MOSJ.

In addition to ocean climate and advection, the biomass of zooplankton in the Barents Sea is determined by predation by pelagic fish (Dalpadado et al. 2003); the size of the capelin stock explained 40% of the inter annual variation in the zooplankton biomass in the Barents Sea from 1984 to 2010 (Dalpadado et al. 2012). Similar results have also been reported with respect to the pelagic fish and zooplankton biomass in the Norwegian Sea (Huse et al. 2012). High abundance of jellyfish in the Barents Sea in recent years (Eriksen

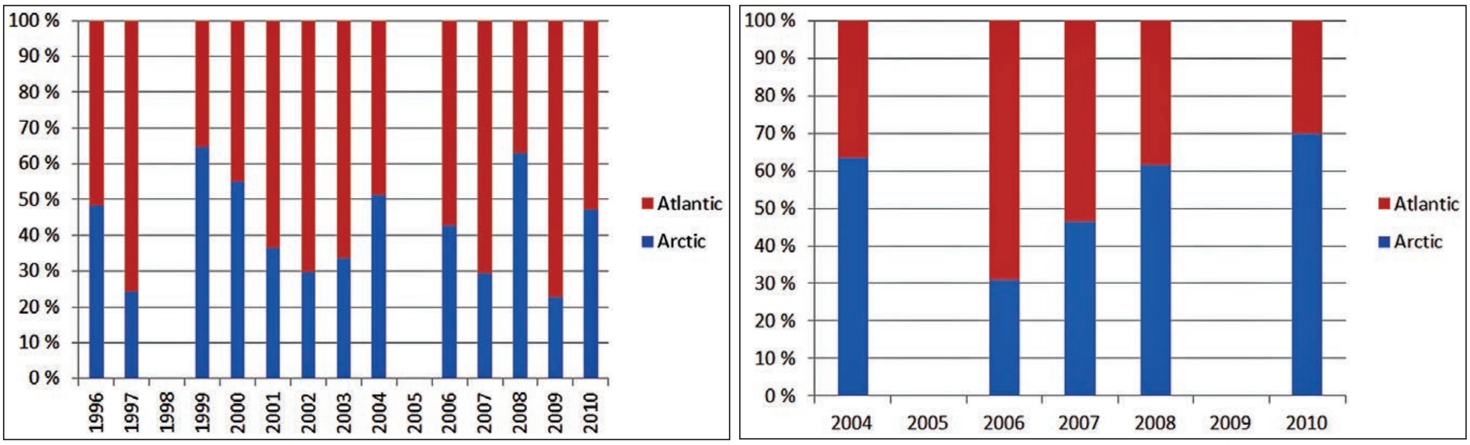


Figure 5.1
Relative occurrence of Arctic *(C. glacialis* and *C. hyperboreus*) and Atlantic (*C. finmarchicus*) zooplankton in Kongsfjorden since 1996 (left) and Rijpfjorden since 2004 (right). (Source: www.mosj.npolar.no)

et al. 2012) is also likely to impact fish larvae and the abundance of meso-zooplankton negatively. Due to different feeding strategies, different planktivorous species will affect the zooplankton community differently. How the current changes in the pelagic fish community and changes in the abundance of jellyfish will affect the species composition of zooplankton in the Barents and Norwegian Seas is unknown.

General recommendations

- Long-term funding for the time series of zooplankton monitoring in Kongsfjorden and Rijpfjorden should be secured.
- There is a need for better coordination of the zooplankton monitoring conducted by the Institute for Marine Research and the Norwegian Polar Institute.
- Indicators monitoring the occurrence of new and boreal zoo plankton species in the waters around Svalbard should be developed.
- A larger portion of the zooplankton samples from the IMR ecosystem survey should be processed with respect to species and stage determination.
- Indicators monitoring changes in the abundance and species composition of macro-zooplankton in Svalbard waters should be developed.
- Indicators of jellyfish abundance in Svalbard waters should be developed.

5.1 MOSJ indicator: Zooplankton species composition

One of the most widely studied species complexes are the three *Calanus* species (*C. hyperboreus, C. finmarchicus* and *C. glacialis*). All three species are believed to be connected to different water masses, and the relative frequency of the two latter are regularly used as indicators for warm atlantic and colder arctic conditions, respectively (Falk-Petersen et al. 2009, Berge et al. 2012, Kwasniewski et al. 2012, Daase et al. 2013). The relative abundance of the Atlantic and the arctic *Calanus* species has been monitored in Rijpfjorden since 2004 and in Kongsfjorden since 1996. The time series are too short to detect any decadal trends, however, the inter-annual variation is related to the inflow of warm atlantic water.

Evaluation of monitoring methods

Sampling is conducted several times annually at fixed stations from the inner to the outer parts of the fjords. The zooplankton is collected by vertical net hauls using a multiple plankton sampler. Organisms are counted and determined to the lowest possible taxa. In addition to these data, oceanography and sedimentation are monitored by fixed moorings. It is a strength that two very different fjords, with different exposure to the West Spitsbergen Current, are monitored. Moreover, the sampling design provides a gradient from the inner part of the fjord to the outer shelf break. It is also valuable that the seasonal dynamics are covered by multiple sampling events each year. Recent research suggests that hybridization might be occurring between *C. glacialis and C. finmarchicus* (Parent et al. 2012); so genetic tools (Gabrielsen et al. 2012b) might be needed to reliably identify the two species in areas of overlapping distribution such as around the Svalbard Archipelago. Routine genetic identification of the species complex could resolve this problem. Nevertheless, species composition might not be an ideal monitoring tool if the species involved are hybridizing. The time series are relatively short and show large inter-annual variability. Longer time series are needed in order to detect trends on a decadal scale. However, the data give detailed information on the seasonal and annual development and species composition of zooplankton.

Due to the recommendations of zooplankton net mesh-size (180-200 µm) by ICES, there is a systematic under-sampling of smaller zooplankton species like *Oithona* spp. (Svensen et al. 2011). When using nets with the finer mesh of 90 µm, they turn out to dominate in abundance through the year, but also in biomass outside the spring and early summer period which is dominated by the large *Calanus*-species. They likely represent an important part of the carbon-turnover at lower trophic levels, being active year around. The same is the case for the small flux-feeding species like *Microsetella norvegica*, found to dominate in Greenlandic coastal waters (Arendt et al. 2013). An increased importance of smaller species will not be detected by the present equipment which mainly sample larger meso-zooplankton species. Neither will a shift in the timing of recruitment of larger copepods, as their early stages also are lost or heavily under-sampled by present methods.

Results

The time-series are too short to detect any decadal trends in the relative occurrence of the atlantic and arctic zooplankton groups (Figure 5.1). However, the inter-annual variation is, according to the online documentation (www.mosj.npolar.no), related to the strength of the inflow of atlantic water. Thus, warm years with strong inflow of atlantic water are associated with high relative abundance of *C. finmarchicus*, while cold years are associated with high relative abundance of the arctic species (Hop et al. 2002, Kwasniewski et al. 2003, Willis et al. 2006). To highlight the connection with climate, a climate indicator should be presented together with the indicators.

Relevance

The indicators monitor how the abundance of atlantic and arctic zooplankton species respond to changes in the flow of warm atlantic water in the WSC. The strength of the WSC is central for the climate in the Arctic Ocean and has been linked to the recent warming of the Arctic (Spielhagen et al. 2011). Changes in the zooplankton community are expected to have profound effects on arctic marine ecosystems.

5.2 MOSJ indicator: Zooplankton biomass

Each autumn IMR and PINRO conduct a comprehesive ecosystem survey in the Barents Sea (Eriksen 2012). Zooplankton is monitored at ca. 180 stations in the western Barents Sea by WP2 net hauls. Maps provided by the yearly survey reports (see www.imr.no) indicate a relatively stable spatial distribution of zooplankton in recent years with low concentrations in the central Barents Sea and high concentrations in the south, and in the western part, including the areas west of Spitsbergen (Figure 5.2). Analyses of the time-series in the period 1984-2010, show that the zooplankton biomass was negatively related to the size of the capelin stock. In addition, the largest size fraction (zooplankton > 2mm), was positively correlated with the extent of arctic water masses (Dalpadado et al. 2012).

Evaluation of monitoring methods

Data is available from 1984 to the present. Although there is a large amount of local variation due to patchiness, the data show clear patterns in term of large-scale spatial distribution and inter-annual variation. Zooplankton is collected with a WP2 plankton net, vertically towed from the bottom to the surface. Size fractions (<1, 1–2, and >2 mm) are separated, dried and weighed. A change in species composition is expected in the context of climate change.

Results

The autumn distribution of meso-zooplankton has, in recent years, been characterized by a relatively low biomass in the central Barents Sea and a high biomass in the south, in the west and in the area west and north of Spitsbergen (Figure 5.2). The time series from 1984-2010 was recently analyzed by Dalpadado et al. (2012). It showed that 40% of the inter-annual variation in biomass could be explained by a negative relationship with the size of the capelin stock. Moreover, the biomass of the largest size fraction (>2 mm) has decreased in recent years and was positively related to the extent of the arctic water masses.

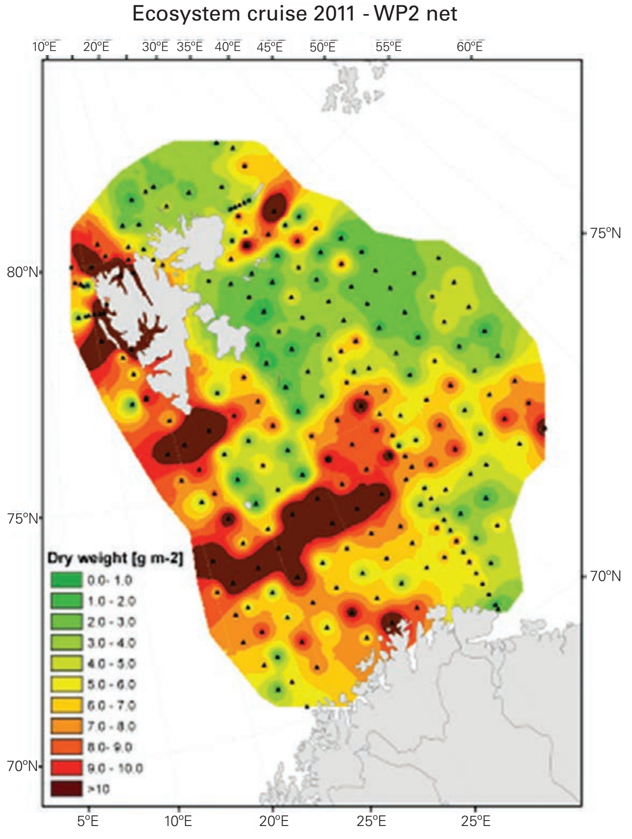


Figure 5.2
Zooplankton biomass during the Barents Sea Ecosystem cruise in August-September 2011. Norwegian data from vertically operated 180 µm meshed WP2 net (bottom-0 m). (From Anonymous 2011).

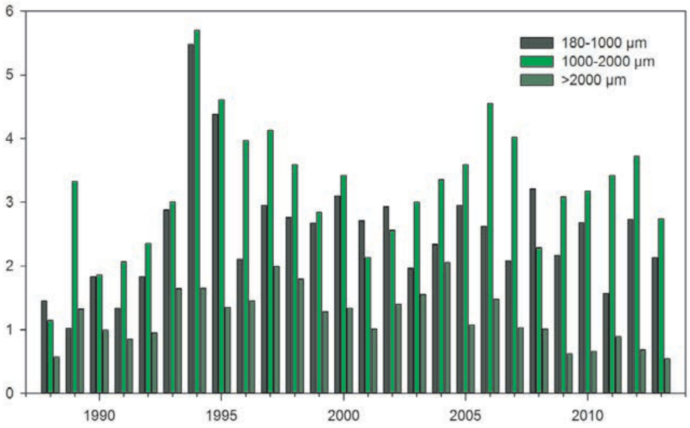


Figure 5.3
Zooplankton biomass (g dry weight/m^2) in the Barents Sea in the period August-September for different size classes. Data from vertically operated 180 µm meshed WP2 net (bottom-0 m). Grey is the smallest size class (180-1000 µm), green is the medium size class (1000-2000 µm) and dark green is the largest size class (>2000 µm). (Source: www.mosj.npolar.no)

Relevance

The indicator monitors the zooplankton biomass for different size fractions in the Barents Sea (Figure 5.3). The indicator aims at detecting changes due to predation from pelagic fish and changes in ocean climate. It is therefore a highly relevant indicator for monitoring.

6 Fish and Fisheries

According to the Millennium Ecosystem Assessment, marine fisheries are currently the most important human driver affecting marine ecosystems on a global scale (MA 2005). Large, long-lived and slow-growing species are especially vulnerable to poorly regulated fisheries. The harvest of these resources often resembles mining operations that serially eliminate fishable populations and move on (Norse et al. 2012). It has recently become evident that human extirpation of key species in marine ecosystems might alter important trophic relationships, which again might result in unexpected ecosystem shifts (Jackson et al. 2001, Casini et al. 2008, Fauchald et al. 2011, Frank et al. 2011). One important problem with monitoring the effect of fisheries is that data usually are available only after the stock has been seriously depleted. Thus, baseline data are usually absent (e.g. Jackson et al. 2001, Rosenberg et al. 2005).

The Barents and Norwegian Seas have traditionally supported some of the largest fisheries and whaling industries in the world, and these ecosystems are accordingly heavily influenced by past and present human harvest (Shevelev et al. 2011). During recent decades, joint Russian–Norwegian management of the fisheries in the Barents Sea has been successful in terms of managing the stocks within safe biological limits and the most important stocks are today in good condition (Miljøverndepartementet 2011). Nevertheless, fishing removes a considerable amount of biomass from the system, affects size and age distributions of targeted species (e.g. Ottersen et al. 2006), affects non-targeted species, such as seabirds, through e.g. by-catches (e.g. Strann et al. 1991) and, finally, impacts bottom fauna through trawling (e.g. Jennings & Kaiser 1998).

Possible effects on the marine ecosystem from fisheries therefore include:

- Extirpation of vulnerable species through direct fishing or by-catch
- Ecosystem fluctuations due to changed trophic interactions

- Habitat alteration through bottom-impacts from fishing gear
- Indirect effects on rare or endangered species that are competing with the fisheries for food

Better monitoring of exploited stocks, combined with the implementation of national and international regulations, has to a large extent reduced the problem of overfishing in the Barents and Norwegian Seas. However, different species show variable recovery rates from previous periods of overfishing. While the rcovery of slow-growing groups such as marine mammals, some top-predators and deep-water fish might take several decades or even centuries, the recovery of Atlantic cod and pelagic schooling fish can occur within a few years. Such differences are likely to cause large fluctuations in the "succession" of the ecosystem, with potential for transient dominance of succeeding key species that might differ from a natural state. The Norwegian Sea is accordingly dominated by what might be a transient dominance of different pelagic fish species (i.e. herring, blue-whiting and mackerel) while the Barents Sea is currently dominated by a record-high Atlantic cod stock. Concurrent with these changes, the Barents and Norwegian Seas are being subjected to reduced ice-cover and increased ocean temperature. These changes are likely to increase the total primary production and boreal fish species are expected to expand northward. In the past few years Atlantic cod has occurred in large concentrations around the Svalbard Archipelago and herring and mackerel are found in the fishery zone around Jan Mayen as well as in the southern part of the fishery protection zone around Svalbard. Continuation of these changes will presumably have a strong impact on the arctic food web, which has traditionally been dominated by arctic cod and lipid-rich zooplankton species that play central roles in the diet of seabirds and marine mammals.

General recommendations

All fish indicators reported in MOSJ are based on stock assessments conducted for the purpose of fisheries management. These assessments are published by the International Council for the Exploration of the Seas' (ICES) advice for the different fish stocks. However, in light of the large changes that are currently occurring in the arctic waters around Svalbard and Jan Mayen with respect to ocean temperature, ice cover and the northward expansion of boreal species, there is an urgent need to develop indicators that specifically monitor:

- Changes in the spatial distribution of boreal and sub-arctic species such as Atlantic cod, capelin, mackerel, herring and blue-whiting
- Changes in the abundance and spatial distribution of arctic cod
- Changes in the spatial distribution of fishing activities

With respect to the fisheries, MOSJ reports catch statistics for six species: Greenland halibut, golden redfish, beaked redfish, Atlantic cod and capelin. Presented alone, without a reference to the status of the stock, these data give little information of the sustainability of the fisheries. When data are available, fishing mortality ($F = Catch/Abundance$) is a better parameter (Walters & Martell 2004). Estimates of F are commonly used by ICES to evaluate the sustainability of Atlantic fisheries (ICES 2013a) by comparing F with a biological reference point. Within the ICES's framework (ICES 2013a), this reference point is a level of fishing mortality (F_{lim}) that, if exceeded, is estimated to bring the stock size below a level (B_{lim}) where there is an unacceptably high probability that recruitment will be negatively affected. Keeping F below F_{lim} and the stock above B_{lim} may, however, not be considered as a sufficient protection, and fishing mortality is therefore also often compared with a precautionary level (F_{pa}). In ICES, F_{pa} is typically set to the level of fishing morality that is estimated to give maximum sustainable yield in the fisheries (F_{MSY}). In this report we present estimates of fishing mortality and reference levels as indicators of the impact of fisheries where these are available. In addition, we present other relevant time series used to assess the status of the fish populations.

6.1 Slow-growing, deep-water fish

Three slow-growing fish species inhabiting relatively deep water are included in MOSJ: Greenland halibut (*Reinhardtius hippoglossoides*), beaked redfish (*Sebastes mentella*) and golden redfish (*Sebastes marinus*). These are long-lived species that are found along the slope of fishing banks, the continental slope and in deep channels on the continental shelf in the North Atlantic. Slow growth, long life expectancy and schooling behavior during parts of their life-cycle, make these species particularly vulnerable to unregulated fisheries. Several stocks of fish species have accordingly collapsed or declined substantially due to intensive fishing during the 20th century (Bowering & Nedreaas 2000, Koslow et al. 2000). Intensive fishing has also greatly reduced the populations covered by this report. Golden redfish is currently listed as *endangered* and beaked redfish is listed as vulnerable (VU) in the Norwegian Red List (Kålås et al. 2010). The ecosystem effects of severely reduced deep-water fish populations and deep-water trawling is largely unknown (but see Roberts 2002, Bailey et al. 2009). Based on fishing and monitoring data, ICES provides an assessment on the status of the stocks and the fisheries in their annual advice (ICES 2013e, f, b). The data on stock status for the three species are however in several cases limited. Defined management targets (reference points) with respect to fishing mortality and stock size are therefore lacking.

6.1.1 MOSJ indicator: Greenland halibut (*Reinhardtius hippoglossoides*)

The fishery for Greenland halibut in the Northeast Atlantic was unregulated until 1992 and the spawning stock biomass reached historically low levels during the 1990s (Bowering & Nedreaas 2000). The regulations of the fisheries from 1992 onward have probably improved the status of the stock (ICES 2013f).

Evaluation of monitoring methods

The time series of stock status presented in MOSJ is based on VPA models of commercial catch-at-age data. However, these data have been disregarded by ICES because of problems with age determination. It is thought that the previous age determination methods have overestimated the growth rate and underestimated the longevity of the species, and have likely produced overly optimistic estimates of the stock's production (Treble et al. 2008). The present ICES advice (ICES 2013f) is based on two scientific surveys in the Barents Sea. Despite the uncertainty, an exploratory assessment has been performed and is accepted as indicative for stock trends. We therefore also present the trend in fishing mortality as well as the long-term trend in total catches and results from the survey in the Barents Sea below.

Greenland halibut. Photo: Fredrik Broms, Norwegian Polar Institute

Results

Based on the exploratory assessment, fishing mortality increased continuously for more than a decade before 1990, and peaked in 1991 at 0.65. Regulations introduced in 1992 reduced the total catch from about 20 000 to about 10 000 tons (Figure 6.1). Accordingly, F decreased abruptly and in 2011, F was estimated to 0.05 which is the lowest level estimated for all years in the analysis. A maximum

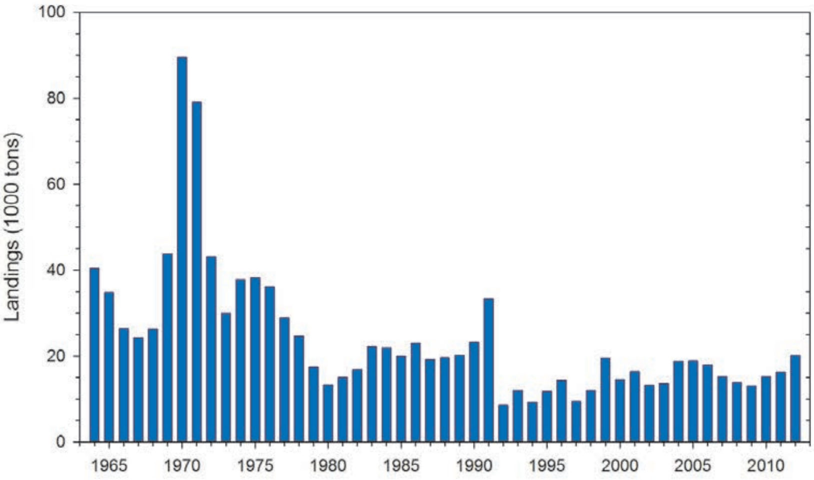


Figure 6.1
Landings of Greenland halibut (*Reinhardtius hippoglossoides*). From (ICES 2013f)

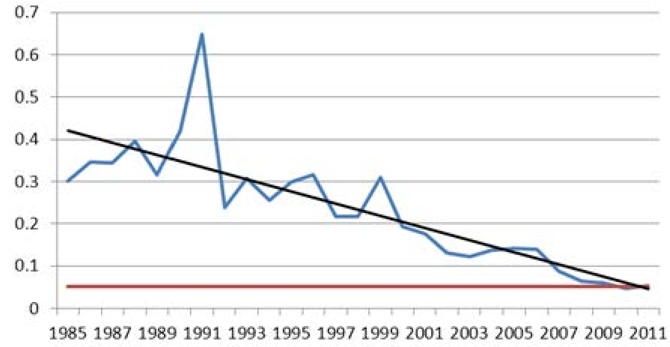


Figure 6.2
Greenland halibut (*Reinhardtius hippoglossoides*). Annual fishing mortality (blue line) relative to the proposed maximum levels above which the fishing mortality over time probably will impair recruitment (red line). Black line is the overall trend in fishing mortality. From Russkikh et al. (2013).

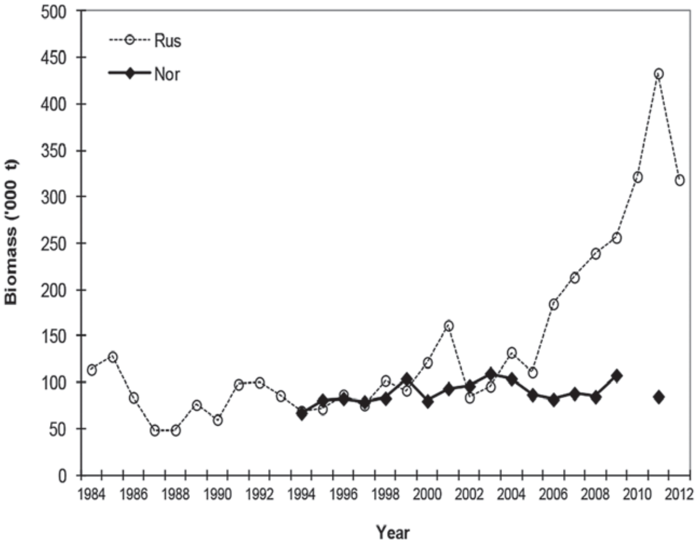


Figure 6.3
Greenland halibut (*Reinhardtius hippoglossoides*) Total biomass estimates from the Norwegian Greenland halibut survey along the continental slope in August and the Russian autumn trawl survey. The Norwegian survey was not conducted in 2010. From ICES (2013f)

exploitation rate of 5% has been suggested to be sustainable for long lived species when the stocks show no sign of reduced reproductive potential (Russkikh et al 2013). This corresponds to a fishing mortality of 0.05 y^1; this level is regarded as a reference for the maximum sustainable *F* (Figure 6.2).

Both the VPA analyses and surveys indicate that the stock has been growing since the 1990s (Figure 6.3). The catches have increased slowly and the ban on the directed fishery was cancelled by the Joint Russian–Norwegian Fisheries Commission (JRNFC) in 2009. For 2012, the ICES advice was a harvest of 15000 tons. The total landing was 20 000 tons. It is not known whether the current harvest level will allow for a continued rebuilding of the stock.

Relevance

Fishing of deep-water fish species has a well-documented effect on the marine environment (Roberts 2002). The indicators presented in MOSJ describe fishing pressure and the status of the targeted stock. The importance of Greenland halibut for the marine ecosystem is largely unknown. Diet studies of hooded seals (Haug et al. 2007), do not support the assertion that Greenland halibut is a staple food item in the diet of hooded seal as stated by the indicator description in MOSJ. However, the indicator does measure the sustainability of human use of an ecosystem service. Greenland halibut is not listed on the Norwegian Red List.

6.1.2 MOSJ indicators: Beaked redfish (*Sebastes mentella*)

Fisheries for species of the genus *Sebastes* have been the largest and the longest standing deep-water fisheries in the North Pacific and North Atlantic (Koslow et al. 2000). These species are long-lived with a life span of more than 50 years, a late maturation (10-14 years old at first reproduction), the males and females aggregate to mate, and they are commonly fished in poorly regulated international waters. These characteristics make them highly vulnerable to over-fishing.

After intensive fishing of beaked redfish in the Barents Sea in the 1970s and 80s, the population is now at a very low level and it is listed as Vulnerable (VU) on the Norwegian Red List. At present, the landings are relatively low and due to an almost complete recruitment failure from 1996-2003, the stock will probably not sustain any increased harvest level for several years (ICES 2013b). The stock is in recovery and the current protection of juveniles from by-catch is an important measure in the attempt to achieve a more viable population.

Evaluation of monitoring methods

No reference points are in place for evaluating the sustainability of the fishing or the status of the stock (ICES 2013b), and there are some uncertainties in the assessments. Still, catch statistics are reliable and the assessment model is considered to be an appropriate basis for advice (ICES 2013b).

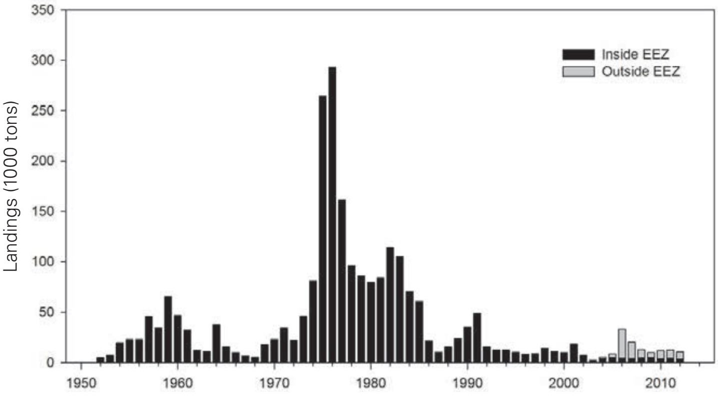


Figure 6.4
Total international landings of Beaked redfish (*Sebastes mentella*) 1952–2012 in national and international waters. From ICES (2013b)

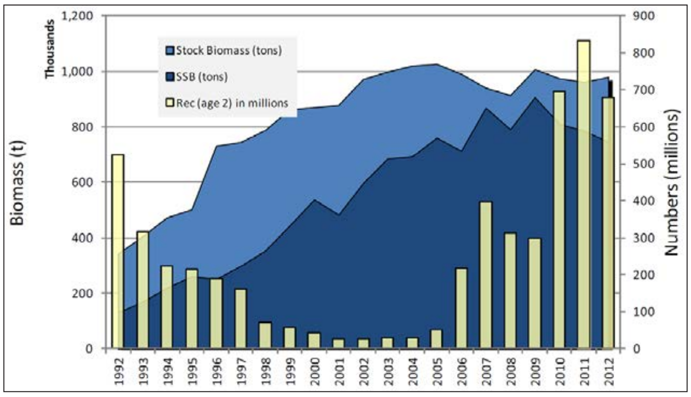


Figure 6.5
Beaked redfish (*Sebastes mentella*). Recruitment-at-age 2, spawning-stock biomass, and total stock biomass estimated from statistical catch-at-age for the period 1992–2012. Spawning-stock biomass has steadily increased from 1992 to 2009. Due to recruitment failure during the period 1996–2003, the spawning-stock biomass is decreasing. From ICES (2013b)

Results

The major fishery for beaked redfish in the Barents and Norwegian Seas was conducted by Russia and other East European countries in an area from south of Bjørnøya towards Spitsbergen in the 1970s and 80s. The fishery peaked during the 1970s with landings of almost 300 000 tons in 1976 and then decreased abruptly thereafter (Figure 6.4, Planque et al. 2012). Since 2004, a directed pelagic fishery has developed in international waters in the Norwegian Sea with a maximum catch of 33 000 tons in 2006.

The population was subject to almost complete recruitment failure from 1996-2003, with signs of improved recruitment in recent years (Figure 6.5, Planque et al. 2012). However, due to late maturation, the spawning stock will still reflect the previous period of poor recruitment for several years to come. In order to rebuild the stock, it is vital that the juvenile age groups are given strong protection from being caught as by-catch in any fishery, e.g., the shrimp fisheries in the Barents Sea and Svalbard area.

The management of the fishery is complicated by the fact that the beaked redfish is fished in both national (Barents Sea) and international (Norwegian Sea) waters under the jurisdiction of JRNFC and NEAFC (North East Atlantic Fisheries Commission), respectively. The fishery in international waters is an Olympic fishery with an assigned TAC (total allowable catch). The fishery in the Barents Sea is a by-catch fishery with specific by-catch regulations. No division of TAC between areas or countries has been agreed upon.

For many years, ICES advised no directed fishery on beaked redfish, however, after a new assessment model was accepted in 2012, ICES decided to give advice on catch levels. For 2014, ICES advises a status quo catch of 24 000 tons and additionally suggests that the measures currently in place to protect juveniles should be maintained.

Relevance

Fishing of deep-water fish species has a well-documented effect on the marine environment (Roberts 2002). The indicator describes the fishing pressure and the status of the targeted stock. The importance of beaked redfish for ecosystem function is largely unknown. However, the indicator measures the sustainability of the human use of an ecosystem service and it monitors important drivers and population parameters for a species listed on the Norwegian Red List.

6.1.3 MOSJ indicator: Golden redfish (*Sebastes marinus*)

Over-fishing has reduced the population of golden redfish in the Norwegian and Barents Seas to very low levels. Although protection measures have been implemented, there is little sign of improvement. The most serious threats to the population are the directed fishery and by-catch in various fisheries. The fishing mortality exceeds what is considered to be sustainable (ICES 2013e).

Evaluation of monitoring methods

No reference points are in place for fully evaluating the sustainability of the fishing or the status of the stock. However, the assessment model and input data are considered to be appropriate for providing management advice (ICES 2013e).

Results

Catches of golden redfish have declined during the recent decades (Figure 6.6) and have now stabilized at around 5-7000 tons annually. As the landings declined during the 1990s, surveys (Figure 6.7) and commercial CPUE showed a substantial reduction in abundance and the stock is currently at a historically low level. The year classes in the last decade have been very low and declining. Presently, this stock is in a very poor condition. Given the low productivity of this species, this situation is expected to remain for a considerable period.

Golden redfish is currently being caught in a directed fishery and as by-catch in the pelagic trawl fisheries for herring and blue whiting in the Norwegian Sea. The current fishing mortality is around 0.33 (Figure 6.8), which is very high compared to the natural mortality of 0.05, and probably well above a sustainable level for a redfish species. Due to the low spawning stock biomass (below any possible reference points) and poor recruitment, ICES advises no directed fishery on this stock and suggests further restrictions in by-catch regulations. It is important to protect the juvenile age groups from being caught as by-catch in, e.g. the shrimp fisheries in the coastal areas as well as in the Barents Sea and Svalbard region.

Relevance

Fishing of deep-water fish species has a well-documented effect on the marine environment (Roberts 2002). The indicator describes the fishing pressure and the status of the targeted stock. The importance of golden redfish for ecosystem function is largely unknown. However, the indicator measures the sustainability of the human use of an ecosystem service and it monitors important drivers and population parameters for a species listed on the Norwegian Red List.

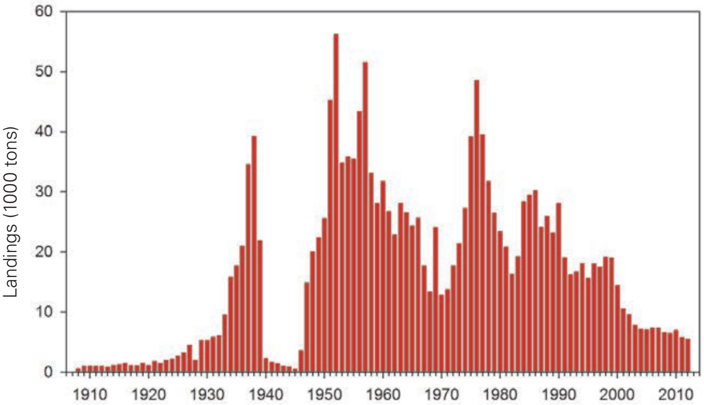


Figure 6.6
Total international landings of Golden redfish (*Sebastes marinus*). From ICES (2013e).

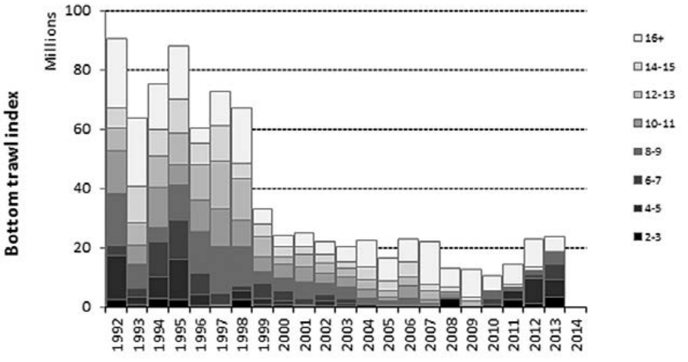


Figure 6.7
Golden redfish (*Sebastes marinus*). Abundance index (by age) from the Norwegian bottom trawl surveys 1992-2011 in the Barents Sea.

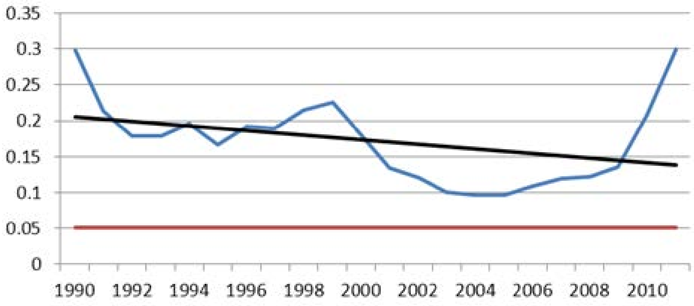


Figure 6.8
Golden redfish (*Sebastes marinus*). Annual fishing mortality (blue line). No limit reference points have been suggested or adopted, and data are shown relative to what is assumed to be the natural mortality in the stock (red line, M=0.05). Black line is the overall trend in fishing mortality. From Russkikh et al. (2013).

6.2 Cod, capelin and herring

Herring (*Clupea harengus*), capelin (*Mallotus villosus*) and Atlantic cod (*Gadus morhua*) have central trophic functions in the Barents Sea ecosystem. Capelin is an important predator on zooplankton and an important prey species for cod, seabirds and marine mammals (Hamre 1994, Gjøsæter et al. 2009). Juvenile herring from the Norwegian Spring Spawning Herring stock grow up in the Barents Sea before they enter the Norwegian Sea at an age of three or four years old. The juvenile herring is an important predator on zooplankton in the southern Barents Sea and they are also prey for top-predators in the system. Moreover, herring consume capelin larvae and the abundance of juvenile herring influences the fluctuations in the capelin stock (Hamre 1994, Hjermann et al. 2010, Johannesen et al. 2012a). Cod is an important top predator in the Barents Sea which forages extensively on capelin, young herring, polar cod (*Boreogadus saida*) and shrimp (*Pandalus borealis*) (Johannesen et al. 2012b). The Barents Sea cod stock is currently the largest in the world and in contrast to other continental and shelf ecosystems in the North Atlantic where heavy exploitation has diminished the ecological role of cod (Link et al. 2009), the Barents Sea can currently be characterized as a “cod dominated” ecosystem (Johannesen et al. 2012b).

Fluctuations in the populations of cod, herring and capelin are governed by a complex interplay between climate, trophic interactions and fishing (Hjermann et al. 2010, Stige et al. 2010, Dalpadado et al. 2012, Johannesen et al. 2012a, Lilly et al. 2013). At present, the fishery is strictly regulated and extensive monitoring programmes ensure that the fishery is conducted within sustainable limits. Ocean climate is an important driver affecting zooplankton production, recruitment and the spatial distribution of the three species. Changes in the spatial distribution will affect the trophic interactions and combined with differential changes in recruitment and growth, the ecosystem can undergo changes with respect to the dominance of key species and functional groups.

The MOSJ indicators for fish and fisheries are based on ICES’s fishery assessments and they allow assessment of the sustainability of the fisheries. However, the current northward expansion of herring, mackerel (*Scomber scombrus*) and blue whiting (*Micromesistius poutassou*) in the Norwegian Sea, and Atlantic cod and capelin in the Barents Sea, are probably linked to a combination of changed harvest pressure, reduced ice cover and increased ocean temperature. An invasion of these species will have significant impacts on the arctic marine ecosystems around Svalbard and Jan Mayen. Indicators should be developed to monitor the changes in the distribution of these species and their associated fisheries. In particular, the current changes might reflect an ongoing displacement of an arctic food web including lipid rich zooplankton and polar cod (*Boreogadus saida*). Polar cod is an important prey species for top predators including fish, seabirds and marine mammals, and it is recommended that the spatial distribution and abundance of polar cod should be included in MOSJ.

6.2.1 MOSJ indicator: Arctic cod (*Gadus morhua*)

Atlantic cod is the dominant top-predator in the Barents Sea. The stock (Northeast Arctic cod) is now at a record high level and the current fishery on cod is sustainable. Possibly due to climate warming and increased abundance, the stock has moved into more arctic waters in recent years. These changes might have profound effects on the coastal ecosystems around Svalbard.

Evaluation of monitoring methods

The datasets used in the assessments of Barents Sea cod are extensive; they include catch statistics and annual surveys (ICES 2013d). The time series are long; estimates for stock size and harvest date back to 1946 (ICES 2013d).

Results

Based on the most recent estimates of the spawning stock biomass (SSB, Figure 6.9), ICES classifies the stock as having full reproductive capacity and concludes that it is being harvested sustainably. The SSB has been above Bpa since 2002 and is now at a record high level, while the total stock biomass is at a level not seen since the early 1950s.

Both landings and stock size have increased since the 1990s, however, the fishing mortality has decreased in the same period and is currently below F_{lim} and F_{pa} (Figure 6.10). F is accordingly in the range that is associated with high long-term yield and low risk of depleting the production potential. The accepted harvest control rule gave a TAC advice for 2014 of 993 000 tons.

The geographical distribution of cod is expanding to the north and east (Figure 6.11). This is probably related to the high temperatures observed in the Barents Sea in recent years as well as the high stock abundance.

Relevance

Cod is an important predator species in the Barents Sea ecosystem. The MOSJ indicators report the status of the stock and fishing intensity. Fishing is obviously an important human driver, but the status of the stock is also influenced by changes in climate and the dynamics of key prey species.

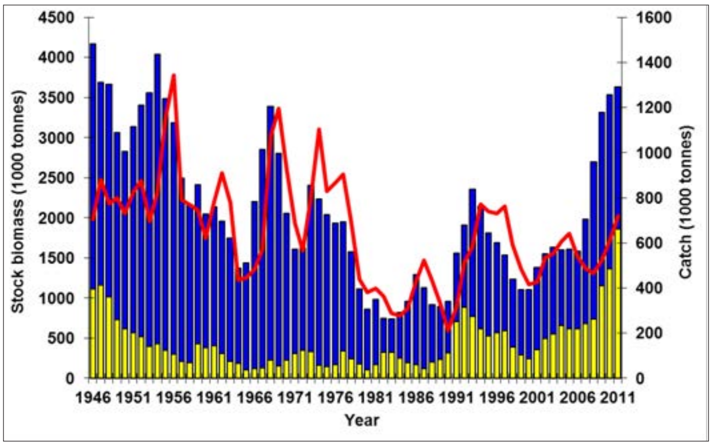


Figure 6.9
Northeast Arctic cod (*Gadus morhua*). Spawning stock biomass (yellow bars), total stock biomass (age 3 and older, blue bars) and landings (red curve).

Northeast Arctic cod (*Gadus morhua*). Photo: Fredrik Broms, Norwegian Polar

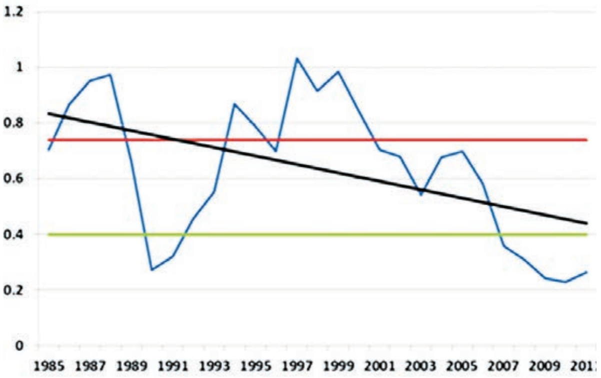


Figure 6.10
Northeast Arctic cod (*Gadus morhua*). Annual fishing mortality (blue line) relative to the limit levels above which the fishing mortality will impair the recruitment (red line) and precautionary level (green line). Trends in fishing mortality is shown as black line. From Russkikh et al. (2013)

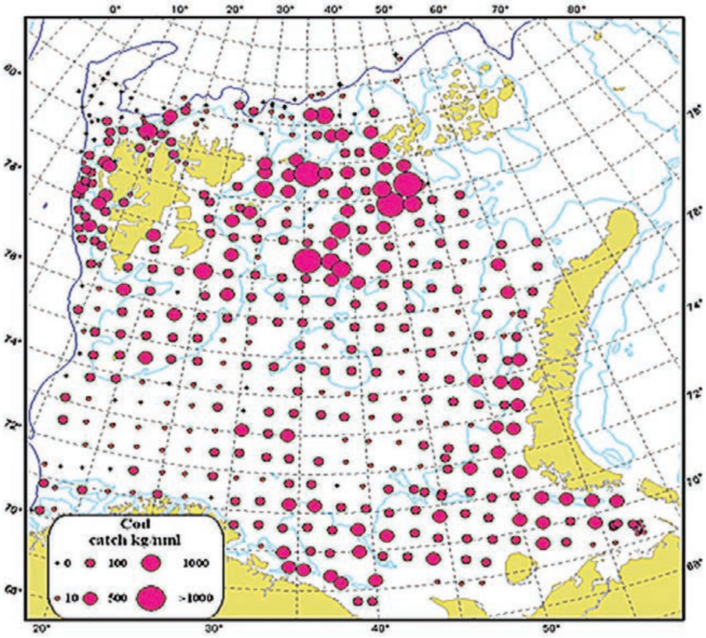


Figure 6.11
Distribution of Northeast Arctic cod (*Gadus morhua*), August-September 2012.

Capelin. Photo: Fredrik Broms, Norwegian Polar Institute

6.2.2 MOSJ indicator: Capelin (*Mallotus villosus*)

Similar to other important pelagic forage fish species (Bakun 2006), the capelin stock in the Barents Sea exhibits large fluctuations which have strong impact on the ecosystem (Gjøsæter et al. 2009, Hjermann et al. 2010). Recent fluctuations have mainly been due to heavy predation on capelin larvae by juvenile herring. The capelin fishery has played a minor role (Hjermann et al. 2010). The stock has been relatively stable since 2008 and is currently considered to be within safe biological limits (ICES 2013c). An expansion of the stock into more arctic waters due to ocean warming (Ingvaldsen & Gjøsæter 2013) might reflect an ongoing displacement of the Arctic food web in the northern Barents Sea (Dalpadado et al. 2012).

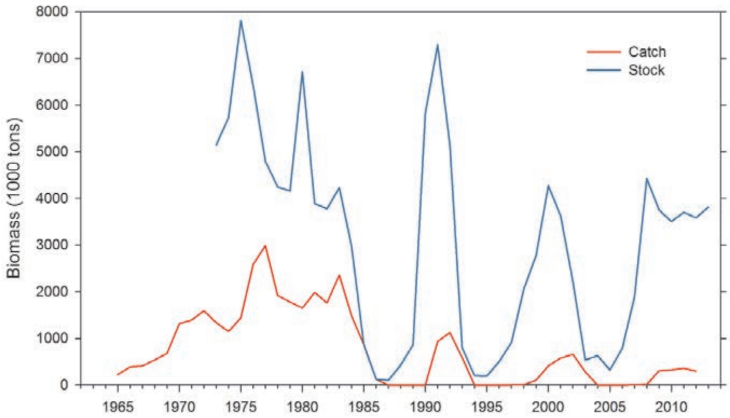


Figure 6.12
Barents Sea capelin (*Mallotus villosus*). Total stock (1+) and total landings, 1973–2012.

Evaluation of monitoring methods

The capelin stock is assessed annually via an extensive Russian–Norwegian acoustic survey in September. Data are available since 1972. Based on a model including growth, maturity and mortality (including predation from cod and fishing), the predicted spawning biomass the following spring is calculated. Quotas are determined so as to ensure that the spawning stock biomass remains above 200 000 tons (B_{lim})(ICES 2013c).

Results

The capelin stock in the Barents Sea has collapsed three times since the mid-1980s (Figure 6.12, Gjøsæter et al. 2009, Hjermann et al. 2010). The main cause of these collapses was predation on capelin larvae from large year classes of juvenile herring (Hjermann et al. 2010). The direct fishery for capelin is prudent; the quota decision consider the importance of capelin as a prey for cod and the fishery has been stopped during and after periods of collapse (Figure 6.12, ICES 2013c). The most recent moratorium lasted from 2004 to 2008. Since then, the landings have increased, however the stock has been relatively stable. Based on the most recent estimates of SSB and recruitment, ICES classified the stock as having full reproductive capacity (ICES 2013c). The maturing component in autumn 2012 was estimated to be 2 000 000 tons and the spawning stock biomass in April 2013 was predicted to be 500 000 tons. The spawning stock in 2013 consisted of fish from the 2009 and 2010 year classes, but the 2009 year class dominated. Observations during the international 0-group survey in August-September 2012 indicated that the 2012 year class is very strong.

In years of high abundance, capelin expand northward and eastward in the Barents Sea (Fauchald et al. 2006). However, in recent years capelin are found further north also because of reduced ice cover and higher temperatures (Ingvaldsen & Gjøsæter 2013). Increased temperatures have probably also increased the availability of lipid-rich Euphausiids, enhancing the growth of capelin (Dalpadado et al. 2012). These changes likely reflect an ongoing displacement of the arctic food web, including polar cod and arctic zooplankton species, in the northern Barents Sea (Dalpadado et al. 2012).

Relevance

Capelin is an important forage fish species in the Barents Sea ecosystem. The indicators report the status of the stock and catch statistics. Fishing is however not the most important factor affecting the status of the stock. The capelin population is heavily influenced by changes in climate and the dynamics of both its predators and prey species.

6.2.3 MOSJ indicator: Herring (*Clupea harengus*)

The stock of Norwegian spring spawning herring (NSS herring) has shown large fluctuations the last fifty years with considerable impacts on the pelagic ecosystems of the Barents and Norwegian Seas.

The stock is currently fished according to a precautionary principle and fishing is considered to be sustainable. Due to poor year-classes since 2004, the stock is currently decreasing and the abundance of juvenile herring in the Barents Sea is at a low level. Possibly due to temperature increase and reduced zooplankton abundance in the Norwegian Sea, the stock of adult herring has expanded towards Svalbard and Jan Mayen. The ecosystem effects of currently invading boreal pelagic key species, such as herring and mackerel (*Scomber scombrus*), on the marine ecosystems around Svalbard and Jan Mayen is unknown.

Evaluation of monitoring methods

The data used for the assessment of NSS herring by ICES are extensive; they include catch statistics and annual surveys (ICES 2013g). Catch statistics and estimates for stock size date back to 1950.

Results

NSS herring is an important component of the pelagic complex in the Norwegian Sea (Huse et al. 2012, Utne et al. 2012) and the southern Barents Sea (Hamre 1994). NSS herring spawn along the mainland coast of Norway. The larvae drift into the Barents Sea were they reside until they return to the Norwegian Sea at an age of 3 to 4 years. Juvenile herring is an important component of the Barents Sea ecosystem because they feed on capelin larvae and may cause the capelin stock to collapse when large herring year classes enter the area (Hamre 1994). No fishing activity for juvenile herring takes place in the Barents Sea. Monitoring of juvenile herring rather than the adult part of the stock is therefore reported to MOSJ. However, the feeding migration of mackerel and adult herring in the Norwegian Sea, has in recent years expanded towards the north and west and entered the waters around Svalbard and Jan Mayen (Figure 6.13, Nøttestad et al. 2013). In 2012, NSS herring was accordingly fished in the fishery protection zone west of Bjørnøya and in the fishery zone around Jan Mayen (ICES 2013g). This pattern is expected to continue with increased water temperatures and reduced ice-cover. The impact of these species on the arctic ecosystem is unknown.

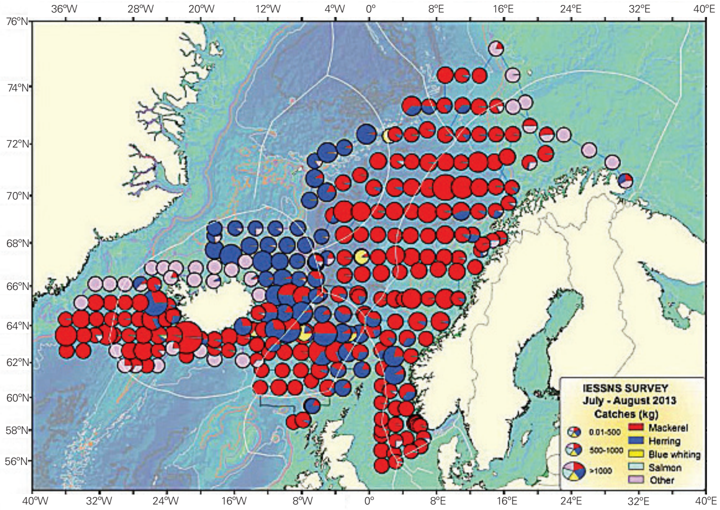


Figure 6.13
Pelagic fish in the Norwegian Sea. Distribution and spatial overlap between mackerel (red), herring (blue), blue whiting (yellow) and salmon (violet) from joint ecosystem surveys conducted onboard M/V *Libas* and M/V *Eros* (Norway), M/V *Finnur Friði* (Faroe Islands) and R/V *Arni Fridriksson* (Iceland) in the Norwegian Sea and surrounding waters between 2 July and 9 August 2013. From Nøttestad et al. (2013).

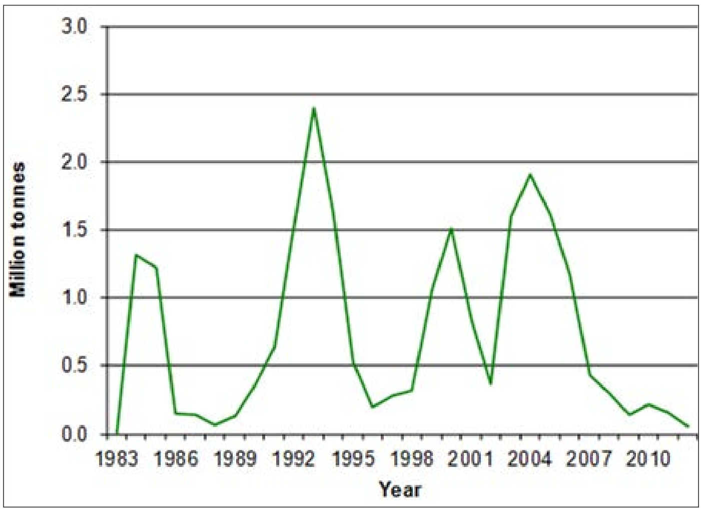


Figure 6.14
Herring (*Clupea harengus*). Abundance of age 1 and 2 Norwegian spring-spawning herring (calculated by VPA).

Management of this stock is conducted according to an agreement between the EU, Faroe Islands, Iceland, Norway, and Russia and is based on a precautionary approach. Currently, ICES classifies the stock as having full reproductive capacity and concludes that it is being harvested sustainably (ICES 2013g). The 2002 and 2004 year classes dominate the current spawning stock which was estimated to be 5.1 million tonnes in 2012. This is, however, very close to the *Bpa* (5.0 million tons), and the SSB is expected to fall below *Bpa* in 2014. The year classes 2005-2012 are all below the long-term average. The amount of juvenile herring in the Barents Sea has been at low levels for several years, perhaps at a record low in 2013 (Figure 6.14).

Relevance

Herring is an important pelagic fish species in the Norwegian and Barents Seas. The indicators report the status of the stock. Important pelagic species in the Norwegian Sea have recently expanded into the arctic waters covered by MOSJ. Under the expected conditions of ocean warming and reduced ice cover, this trend might reflect a permanent change in the arctic ecosystems around Svalbard and Jan Mayen.

7 Seabirds

Seabirds are conspicuous, relatively easy to monitor and they are in most cases toward the top of the marine food chain, presumably making them sensitive to changes in the marine ecosystem. For these reasons, seabirds have been suggested to be sentinel organisms for monitoring changes in marine ecosystems (Cairns 1988, Piatt et al. 2007). In line with this, the MOSJ programme has selected five seabird species from four different ecological groups based on habitat preference and foraging mode. Population dynamics is monitored for each species and population changes are expected to reflect changes in the status of the ecosystem.

However, the use of seabirds as indicators of marine ecosystems is a complicated task (Durant et al. 2009). Because seabirds are affected by many environmental factors simultaneously, it can be hard to disentangle the specific impact from e.g. human harvest, bycatch in fishing gear, food availability, predation, oil spill or pollution. To sort the different factors out, it is often necessary to collect additional data on e.g. demography, diet and migration pattern. For several seabird species breeding in Norwegian waters, such data are now available via the SEAPOP programme (www.seapop.no). In particular, the tagging of seabirds with miniature geolocators has revolutionized our know-ledge of migration patterns making it possible to pinpoint specific threats.

The population of common guillemot (*Uria aalge*) on Bjørnøya is increasing but has not recovered completely from a large population decline in the 1980s. The population is currently approx. 120 000 pairs and is by far the largest and most important colony in the Barents Sea. The population increase suggests favorable environmental conditions in the Barents Sea including persistent good feeding conditions (0 group cod, juvenile herring and capelin). In contrast, the population of the more arctic sister species, the

Brünnich's guillemots (*Uria lomvia*), has decreased by one third in Svalbard since 2000. Except for a recent decrease in the abundance of arctic amphipods there is currently no indication of poor feeding conditions in the Barents Sea. The population decline is correlated with changes in a climate index; the sub-polar gyre on the wintering grounds off the coast of South Greenland, suggesting a climate-induced ecosystem change affecting food availability in these areas. The population of glaucous gull (*Larus hyperboreus*) on Bjørnøya has decreased by 70-80% since the 1980s. This decrease is thought to be due to long-transported organochlorine pollutants. The breeding population of kittiwakes (*Rissa tridactyla*) on Spitsbergen declined in the late 1990s but has been relatively stable the last ten years. In contrast to the mainland populations, monitoring data suggest that kittiwakes in Svalbard are currently experiencing fairly favorable environmental conditions.

Due to small or declining populations, several seabird populations in Norway are currently threatened. The reasons behind the declines are probably related to food availability. Four of the species monitored by MOSJ (kittiwake, Brünnich's and common guillemots and glaucous gull) are listed on the Red List for Svalbard (Kålås et al. 2010) and three species (Brünnich's and common guillemots and common eider (*Somateria mollissima*) are selected as indicators of the CAFF (Circumpolar Arctic Flora and Fauna) biodiversity programme (Kurvits et al. 2010).

For the Brünnich's guillemot and kittiwake, monitoring is carried out in several colonies on West Spitsbergen and on Bjørnøya. The variation among colonies is large, and multi-colony monitoring is necessary to interpret changes in the populations on a regional scale. The population changes in East Spitsbergen are generally unknown and the population changes detected in West Spitsbergen might not be representative of the entire Svalbard population. Single-location monitoring is problematic with respect to the interpretation of the status of the common eider (only monitored in Kongsfjorden on the west coast of Spitsbergen) and the glaucous gull (only monitored on Bjørnøya).

All time-series, except for the monitoring on Jan Mayen, were initiated in the 1980s. Time-series with a time span of thirty years marginally allow for the detection of changes in the populations due to decadal changes in e.g. climate or prey abundance. Furthermore, the establishment of causal relationships between the observed population changes and environmental drivers need additional data on e.g. breeding success, adult survival, diet and migration patterns. In this context it is also crucial to establish whether an observed trend is valid for a single species, a single colony or a region.

The population estimates for seabirds in MOSJ are based on counts of the number of breeding birds within established plots in selected colonies. The counts are generally done 4-8 times during each breeding season. This is a relatively straightforward measurement that gives little room for measurement error. However, the biases might be relatively large especially with respect to colony attendance and deferred breeding, which is associated with environmental conditions during breeding such as nest predation and at-sea prey availability. In order to disentangle the different factors, additional data on breeding success and adult survival would be beneficial. Finally, a colony might move due to changes in environmental factors. Such changes would dramatically complicate the use of fixed plots. It is assumed that the applied methodology has implemented routines that take such changes into consideration.

General recommendations

- It is important to secure the continuation of the SEAPOP programme.
- Recent advances in tracking technology are revolutionizing seabird ecology as a discipline. A co-ordinated effort is needed to take full advantage of this new opportunity.
- A representative sampling of colonies is a prerequisite in order to make inference about the population on a regional scale. Single colony monitoring is not advisable unless the colony represents the majority of the regional population.
- East Spitsbergen should preferably be included in the monitoring programme for kittiwakes and Brünnich's guillemots.

In the following, we give an interpretation for each indicator. The indicators for Jan Mayen (common and Brünnich's guillemots) are not included since these time series were initiated as late as in 2011. In addition to the five species listed under MOSJ, a monitoring programme for the high-arctic ivory gull (*Pagophila eburnea*) was started on Spitsbergen in 2009. This species has recently been included in the MOSJ programme but the time-series are still very short.

7.1 MOSJ indicator: Brünnich's guillemot (*Uria lomvia*)

MOSJ parameters: Breeding population in colonies on West Spitsbergen and Bjørnøya

Brünnich's guillemot is a pelagic diving arctic auk. It is listed as near threatened (NT) on the Red List for Svalbard (Kålås et al. 2010). The listing was due to a decline of approx. 4% p.a. in the abundance in all the monitored locations in Svalbard since the mid-nineties. The species remains numerous in Svalbard and a recent breeding survey (2005-2012) indicates a population of about 850 000 pairs for the Svalbard Archipelago (Bakken & Pokrovskaya 2000). However, the synchronous decline across colonies is dramatic, and the Svalbard population is threatened by quasi-extinction (more than 90% reduction in the population within the next 50 years) (Descamps et al. 2013). The populations on Iceland and Greenland are also currently declining. Recent analyses suggest that the population decline in Svalbard might be due to a large-scale climate-forced ecosystem change on the wintering grounds (Descamps et al. 2013).

Evaluation of monitoring methods

Population change is monitored on fixed plots within the colonies. Several colonies are monitored annually. In addition, adult survival and breeding success are monitored in several colonies. Combined with new studies of migration pattern using miniaturized geo-locators (GLS) (Steen et al. 2013), these data will provide vital information to identify causes for the observed negative trends in the population.

Results

Seven colonies on West Spitsbergen are monitored and reported to MOSJ; all show the same declining trend during the last decade (Figure 7.1). The population on Bjørnøya shows the same declining trend since the late 1990s (data not shown). The simultaneous decline in the West Spitsbergen colonies commenced in the period between 1994 and 1998 (Descamps et al. 2013). Currently, the populations of Brünnich's guillemots on Greenland and Iceland are also declining (Gaston & Irons 2010, Egevang et al. 2012), suggesting that Brünnich's guillemots might be facing a large-scale problem common to many of the populations in the North Atlantic. The colonies monitored on Spitsbergen are all located on the west side of the archipelago. The situation for the colonies on East Spitsbergen is unknown. However, if the monitored colonies are representative, the observed trend suggests a reduction in the Svalbard population with one third since 2000.

After breeding and until late September, Brünnich's guillemots are found in large numbers in the northern Barents Sea, where they probably feed on capelin, polar cod, krill and amphipods (Fauchald 2011). A study where individuals were tagged with miniature geo-locators (GLS study) showed that birds from the West Spitsbergen and Bjørnøya colonies differed in their migration patterns (Steen et al. 2013). The Spitsbergen birds move out of the Barents Sea earlier, they migrate longer distances and they come back later than the Bjørnøya birds. Wintering areas are mainly along the coast of the

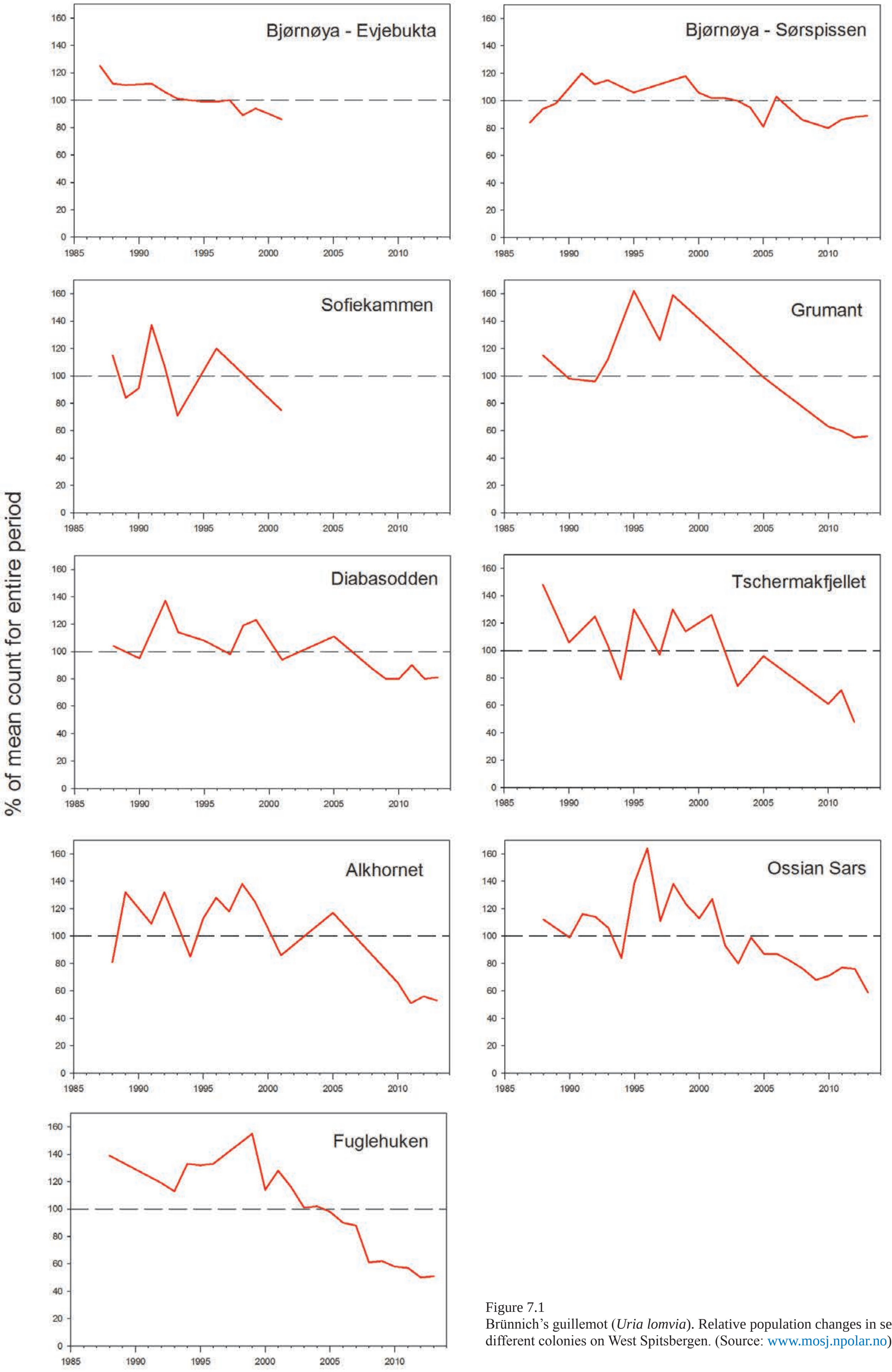


Figure 7.1
Brünnich’s guillemot (*Uria lomvia*). Relative population changes in seven different colonies on West Spitsbergen. (Source: www.mosj.npolar.no)

Brünnich's guillemot. Photo: Tor Ivan Karlsen and Hallvard Strøm, Norwegian Polar Institute

southern Greenland and the strait between Iceland and Greenland (Denmark Strait). A few of the instrumented birds spent the winter in the Labrador Sea. These findings corroborate previous ringing studies (Bakken & Mehlum 2005). The GLS-logger study indicates that the birds come back to the Barents Sea in the period from February to April. At sea studies in the Barents Sea show that a large number of Brünnich's guillemots follow the spawning migration of capelin towards the coast of Norway and the Kola Peninsula in late winter (Fauchald & Erikstad 2002).

The Labrador Sea, southern Davis Strait and Denmark Strait are major wintering areas for many of the North Atlantic populations (Gaston et al. 2011, Steen et al. 2013). Birds wintering in these areas are harvested by hunters from southwest Greenland and Newfoundland (Falk & Durinck 1992, Boertmann et al. 2004). In the 1980-90s, the estimated annual harvest was between 280 000 and 380 000 individuals in Greenland (Falk & Durinck 1992) and about 220 000 individuals on Newfoundland and Labrador (Chardine et al. 1999). Harvest has undoubtedly been an important factor for the decline in the populations in Greenland (Boertmann et al. 2004). However, a combination of stricter hunting regulations, fewer hunters and declining seabird populations has reduced the harvest of seabirds in recent years (Merkel 2010). Hunting in the winter area is therefore probably not the reason behind the recent decline in the Svalbard population. Another explanation for the decline might be food limitation in the Barents Sea and/or in the wintering area in the northwest Atlantic. Currently, there is no apparent indication of food-shortage in the Barents Sea; the stocks of polar cod and capelin are fluctuating but at relatively high levels. However, in concert with the reduction in the area covered by arctic water, the abundance of the arctic amphipods, most notably *Themisto libellula* has declined in recent years (Dalpadado et al. 2012). The food situation in the wintering area is unknown, though a recent study found that the decline in the Svalbard populations coincided with a weakening of the sub-polar gyre in the region where the birds overwinter (Descamps et al. 2013). This weakening is related to the recent warming of the North Atlantic.

Relevance

The indicator monitors population dynamics of a threatened species listed on the Norwegian Red List.

7.2 MOSJ indicator: Common guillemot (*Uria aalge*)

MOSJ parameters: Breeding population on Bjørnøya

The common guillemot is a pelagic diving auk. It is listed as vulnerable (VU) on the Red List for Svalbard (Kålås et al. 2010). The common guillemot population in the Barents Sea was decimated by declines of 70-90% during the winter 1986-87 (Vader et al. 1990). The population on Bjørnøya has increased since the population crash, but the population is still lower than before the crash. The Bjørnøya colony is by far the largest in the Barents Sea and is central for sustaining a viable Barents Sea population.

Evaluation of monitoring methods

The population is monitored in fixed plots. The Bjørnøya colony represents the major part of the Barents Sea population. Data on demography, diet and movements outside the breeding season are available.

Results

The common guillemot population in the Barents Sea was decimated by declines in the order of 70-90% during the winter 1986-87 (Vader et al. 1990). This decline was evident in all the monitored colonies, and was most likely a consequence of mass mortality of adults and recruits due to starvation (Vader et al. 1990). The mortality coincided with a historically low abundance of the three main food items for this seabird species; capelin, juvenile herring and 0-group cod in the Barents Sea (Erikstad et al. 2013). Several colonies on the Norwegian mainland are still declining, possibly due to predation from white-tailed eagles. However, the colony on Bjørnøya has been increasing since 1987 by approx. 7 % p.a. (Figure 7.2). Currently, the Bjørnøya colony is by far the largest in the Barents Sea, numbering approx. 111 000 pairs in 2006. The Norwegian mainland colonies comprise approx. 17 000 pairs. Thus, the Bjørnøya colony is crucial to sustaining a viable population of common guillemots in the Barents Sea. The Bjørnøya colony has not yet recovered completely from the 1986-87 decline; this colony was estimated to contain about 245 000 breeding pairs in 1986.

Geolocation studies show that common guilllemots from colonies in the Barents Sea stay in the southern part of the Barents Sea the year round (Steen et al. 2013, Erikstad et al. unpublished data). This is corroborated by at sea observations (Fauchald 2011). In contrast to the common guillemots, Brünnich's guillemots apparently avoided starvation in the winter 1986-87 by migrating out of the area. Moreover, it should be noted that while common guillemots on Bjørnøya and Hornøya (eastern Finnmark), are currently increasing

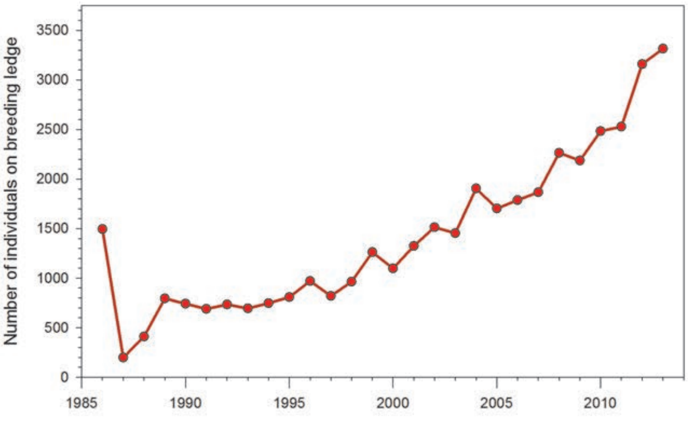


Figure 7.2
Common guillemot (*Uria aalge*). Population development on Bjørnøya (number of breeding pairs). (Source: www.mosj.npolar.no)

in numbers, Brünnich's guillemots are experiencing a population decline (see above). The stationary behavior of common guillemots makes them more suitable as indicators for the pelagic Barents Sea ecosystem compared to Brünnich's guillemots or kittiwakes. The strong growth of common guillemots on Bjørnøya suggests that the feeding conditions have, on average, been good in the Barents Sea the last 25 years.

Relevance

The indicator monitors population dynamics of a threatened species listed on the Norwegian Red List.

7.3 MOSJ indicator: Black-legged kittiwake (*Rissa tridactyla*)

MOSJ parameters: Breeding population in colonies in West Spitsbergen and Bjørnøya

The kittiwake is a pelagic surface-feeding gull. It is listed as Near Threatened (NT) on the Red List for Svalbard (Kålås et al. 2010). After a decline in the population in West Spitsbergen from 1995-2000, the population has been stable. No trends are detectable for the population on Bjørnøya.

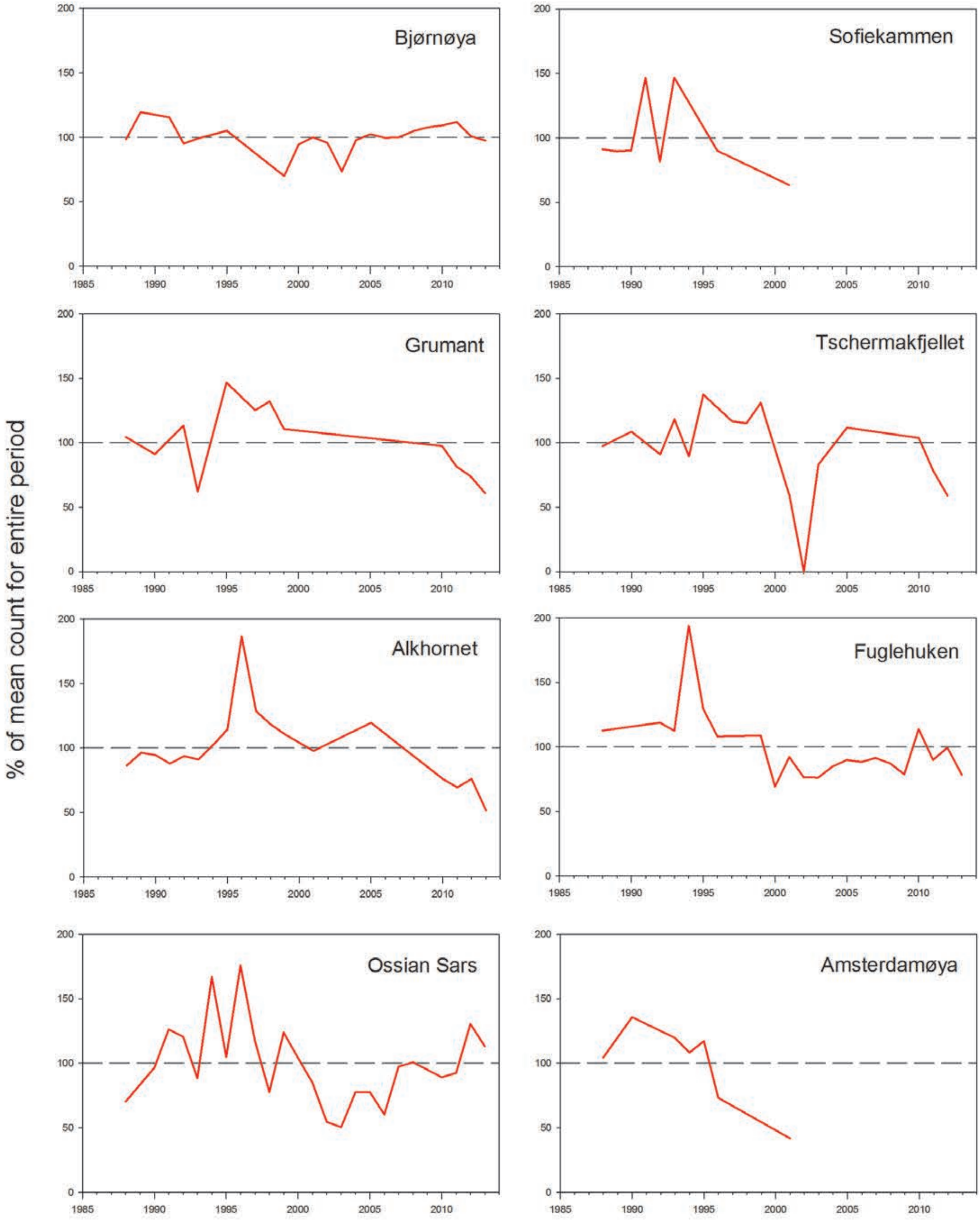


Figure 7.3
Kittiwake (*Rissa tridactyla*). Relative population development (as percent of average population size) on West Spitsbergen and Bjørnøya (Source: www.mosj.npolar.no)

Evaluation of monitoring methods

The population is monitored in fixed plots. Several colonies are monitored simultaneously. Data on demography, diet and movements outside the breeding season have been collected in several colonies.

Results

In West Spitsbergen, the kittiwake colonies showed, similar to the Brünnich's guillemots, a marked decline from 1995 to 2000 (Figure 7.3). However, in recent years the population has been relatively stable. The Bjørnøya colony does not show any particular trend during this period (Figure 7.3). This is in contrast to the kittiwake populations on the Norwegian mainland, which have been declining since the 1990s, and where the species is currently listed as Endangered. Compared to the colonies on the mainland, the breeding success in West Spitsbergen and Bjørnøya has been relatively good in recent years (Barrett et al. 2012). Annual adult survival from 2008-2011 was estimated to 85.8 % for a colony in Grumantbyen (Barrett et al. 2012). This is within the range measured in the colonies on the mainland in the same period (82.7 – 87.1 %) (Barrett et al. 2012) and also within the normal range of adult survival in kittiwakes (Sandvik et al. 2005).

The migration pattern of kittiwakes from North Atlantic colonies has recently been mapped by a geolocation study (Frederiksen et al. 2012). After breeding, birds from the Barents Sea colonies are found in an area east of Spitsbergen. This is corroborated by at sea studies that find high concentrations of kittiwakes in this area in September (Fauchald 2011). In November most birds have migrated to their major wintering areas on the Newfoundland-Labrador Shelf and the Labrador Sea. According to Frederiksen et al. (2012), this is the major wintering area for kittiwakes from all colonies in the North Atlantic. However, some birds do also stay in the North Sea during winter. Birds start to migrate back to the Barents Sea in late winter. In light of this general migration pattern, (Reiertsen 2013) found a strong correlation between the survival of kittiwakes on Hornøya (Southern Barents Sea) and the abundance of capelin in the Barents Sea, but also a correlation between kittiwake survival and the abundance of the pteropod; *Thecosomata* spp. in the wintering area in the Northwest Atlantic.

Relevance

The indicator monitors population dynamics of a threatened species listed on the Norwegian Red List.

Black-legged kittiwake. Photo: Ann-Kristin Balto, Norwegian Polar Institute

7.4 MOSJ indicator: Common eider (*Somateria mollissima borealis*)

MOSJ parameters: Breeding population and clutch size in Kongsfjorden, Spitsbergen

The common eider is a coastal benthic-feeding duck. It is not listed on the Norwegian Red list. However, due to circumpolar declines in many populations of eiders, CAFF (Conservation of Arctic Flora and Fauna) developed an action plan for eiders in 1997 (CBird 1997) and the common eider was selected as an indicator of change in CAFF's Arctic Biodiversity Trends 2010 (Merkel & Gilchrist 2010). The population in Kongsfjorden shows no particular abundance trend. The inter-annual fluctuations due to local ice conditions combined with nest predation by arctic foxes are large. It is not known whether this is a common pattern for the Svalbard population.

Evaluation of monitoring methods

The population is monitored by counting nests and clutch sizes on islands in Kongsfjorden, Spitsbergen. To evaluate whether the population changes monitored in this fjord are representative for Svalbard, there is a need for monitoring data from other areas.

Common eider on nest. Photo: Geir Wing Gabrielsen, Norwegian Polar Institute

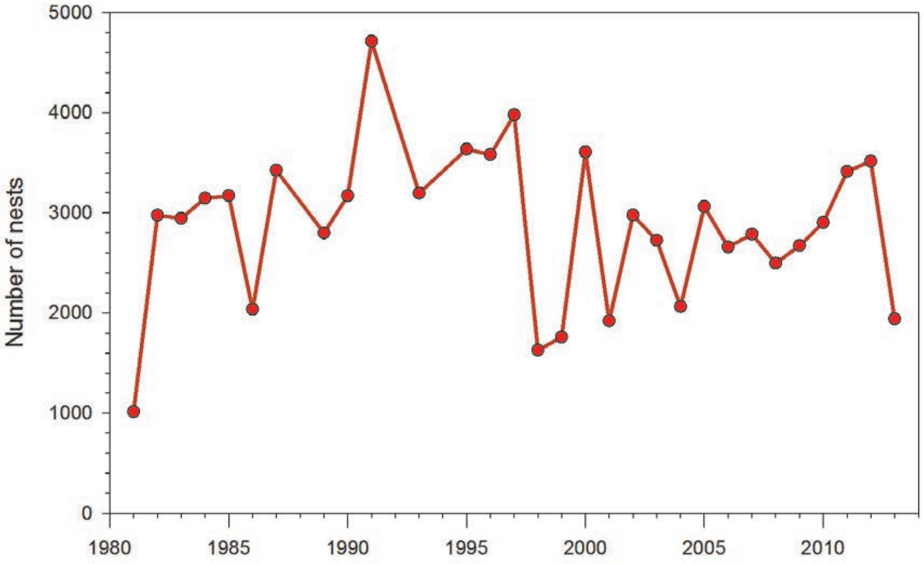


Figure 7.4
Common eider (*Somateria mollissima*). Population development in Kongsfjorden, Spitsbergen (number of occupied nests). (Source: www.mosj.npolar.no)

Results

Intensive harvesting of eggs and down probably reduced the population of common eiders on Spitsbergen considerably during the last century (Mehlum 1991). These activities were prohibited in 1963. In the 1980s, the total population numbered 12 000-17 000 and 1500-3500 breeding pairs on the west and east coasts, respectively (Prestrud & Mehlum 1991). The common eider has been monitored in Kongsfjorden since 1981 (Figure 7.4). During this period, the local population has shown large fluctuations (between 1500 and 4500 nests). This variation is mainly due to nest predation combined with local ice-conditions. Arctic foxes are important nest predators of common eiders, and while the presence of land-fast ice around the breeding colony makes access possible to them, early ice-breakup renders colonies inaccessible (Mehlum 2012, Hanssen et al. 2013). Thus, due to large local variation in breeding success, the time series is unsuitable for interpreting population changes on a regional scale.

Although some common eiders might overwinter in the ice-free areas on the west coast of Spitsbergen, most birds migrate to Northern Iceland and the Norwegian mainland during winter. As a gregarious bird, common eiders are sometimes affected dramatically by diseases. For example, avian cholera has reduced the population in some colonies in the Hudson Strait (Merkel & Gilchrist 2010). During winter, the Spitsbergen eiders wintering in the south (Norwegian mainland and Northern Iceland), might experience threats such as hunting, drowning in fishing gear, poor feeding conditions and oil spills.

Relevance

The indicator monitors population dynamics of a species selected as an indicator of change in CAFF's Arctic Biodiversity Trends 2010 (Merkel & Gilchrist 2010).

7.5 MOSJ indicator: Glaucous gull (*Larus hyperboreus*)

MOSJ parameter: Population size on Bjørnøya

The glaucous gull is a large pelagic surface-feeding gull. It is a generalist predator and during breeding it is an important predator on eggs, chicks and adults of other seabirds. It is listed as Near Threatened (NT) on the Red List for Svalbard (Kålås et al. 2010). The population size in Svalbard is 4000 – 10 000 pairs. The Bjørnøya colony is the largest in the Barents Sea region. The population on Bjørnøya has declined by ca. 70-80% from 1987 to 2012. The situation for the species on Spitsbergen is unknown, but monitoring in Kongsfjorden was initiated in 2012. If the Bjørnøya situation is representative for the rest of the Svalbard population, the situation for the species in Svalbard is critical (Erikstad & Strøm 2012). The main reason for the decline on Bjørnøya is thought to be high levels of long-transported organochlorine pollutants that have been subject to bio-magnification through the food chain.

Evaluation of monitoring methods

The population is monitored by counting nests on the southern part of Bjørnøya. Data on the Spitsbergen population is critically needed. Monitoring in Kongsfjorden was initiated in 2012.

Results

In a total count on Bjørnøya in 1986, the population was estimated to 2350 pairs. In a similar count in 2006, the estimated population size was 700 pairs. This decline is reflected by the changes observed in the monitoring plot on the southern part of the island, showing a decrease from 210 pairs in 1987 to 34 pairs in 2012 (Figure 7.5). It is clear that high levels of long-transported organochlorine pollutants (OC) in adults have reduced adult survival and reproduction on Bjørnøya (Bustnes et al. 2003) and that this factor has contributed strongly to the observed decline in the population (Erikstad & Strøm 2012). However, other environmental factors have probably also had an impact (Erikstad & Strøm 2012), and it has been shown that the effect of OCs is intensified under poor environmental conditions (Bustnes et al. 2006). Other environmental factors that might have contributed to the observed decline are reduced feeding conditions, nest predation from arctic foxes and competition from an increasing population of great skuas.

Relevance

The indicator monitors population dynamics of a threatened species listed on the Norwegian Red List. The Bjørnøya colony is the largest in the Barents Sea region and this colony is probably important for maintaining the population in the region.

Figure 7.5
Glaucous gull (*Larus hyperboreus*). Population development on Bjørnøya (number of breeding pairs at study site). (Source: www.mosj.npolar.no)

8 Marine mammals

Summary

Marine mammal species currently represented within MOSJ include four high arctic endemic species – polar bears (*Ursus maritimus*), bowhead whales (*Baleana mysticus*), white whales (*Delphinapterus leucas*) and walruses (*Odobenus rosmarus rosmarus*) – and two North Atlantic pack ice seals; harp seals (*Pagophilus groenlandicus*) and hooded seals (*Cystophora cristata*). Available monitoring data show mixed signals for Svalbard marine mammal populations in terms of trends, largely because of their varied histories with respect to exploitation, but also because different species will display varied responses to the on-going changes taking place in the environment. Some species that were dramatically overharvested in the past in the Svalbard area are increasing in numbers post protection, despite the fact that their primary breeding or foraging habitats are almost certainly declining because of climate change induced reductions in sea ice (e.g. polar bears, walruses).

The most intensive MOSJ programme is directed to polar bears. Time series for denning on Hopen and Kong Karls Land have shown that reduced sea ice in the autumn has resulted in a reduced number of dens in these areas. Cub production is showing a marginally significant reduction, though the production of yearlings shows no significant trend over time. Likewise, male body condition has remained stable over the monitoring period. Abundance trends are unknown; a new survey is planned for 2015.

Cetacean monitoring within MOSJ currently includes local distributional data for bowhead whales and white whales based on NPI's Marine Mammal Sighting Database, which includes reporting from a broad spectrum of the marine visitors to Svalbard (cruise tourist industry, coast-guard, researchers, and other marine visitors to the archipelago).

Pinniped species in MOSJ currently include the benthic feeding walrus and the two pack-ice breeding, North Atlantic species. Walruses are showing strong signs of recovery following 60+ years of protection. Harp seals and hooded seals, the two pack-ice breeding species are currently showing opposite trends. Harp seals are increasing because of reduced harvesting pressure in recent years compared to previous decades. Hooded seals have declined precipitously since World War II. The declines went unnoticed because of a lack of population monitoring, despite significant hunting pressure. Hooded seals are now Red Listed and protected, but climate change induced deterioration of their breeding habitat is likely to complicate their recovery. The numerical trends of these two species are well covered by current monitoring, but explanatory power is lacking.

MOSJ & marine mammals

Marine mammals are highly conspicuous, charismatic megafauna throughout the Arctic Region. Coastal species are important resources for indigenous peoples throughout much of the circumpolar Arctic and some species have been the subject of historical, or in some cases on-going, commercial exploitation. Additionally, marine mammal populations are primary attractions for arctic cruise tour operators in Svalbard. They are sentinel ecosystems indicators, that reflect change at lower trophic levels, and they are sensitive to environmentally-induced systems change (Moore 2008, Kovacs et al. 2011a), which makes them ideal subjects for monitoring (e.g. Moore 2008, Ragen et al. 2008, AMSA 2009, Grebmeier et al. 2010). Many species are already displaying impacts from climate change (Kovacs et al. 2011a for a review).

The Arctic Council's Conservation of Arctic Flora and Fauna (CAFF) – Marine Expert Monitoring Group has developed a comprehensive plan for monitoring marine biodiversity, including marine mammals (Gill et al. 2011). Focal ecosystem components (FECs), parameters, indicators and drivers of change in the Arctic have been identified. The five marine mammal FECs selected are the polar bear, bowhead whale, white whale (beluga), walrus and ringed seal. The most important "drivers" that are thought to have potential influences are: 1) climate; 2) harvest (directly of marine mammals or via fisheries targeting their prey), 3) industrial development; 4) contaminants; 5) alien species; 6) tourism; 7) diseases/parasites; 8) scientific research activity and 9) shipping. The monitoring parameters chosen to assess potential impacts of these drivers through scientific monitoring are: 1) distribution; 2) abundance; 3) habitat selection; 4) stock structure (genetics/telemetry); 5) body condition; 6) contaminants (please note – contaminants monitoring programmes within MOSJ are being evaluated by a separate panel); and 7) harvest statistics. The relative importance of the drivers will vary regionally across the arctic and local prioritizations will be essential to maximize the value of monitoring activities in all areas, including Svalbard.

8.1 MOSJ indicator: Polar bear (*Ursus maritimus*)

MOSJ parameters:

- Dens on Kongsøya (compared to fall sea ice) – annually and dens on Hopen (compared to fall sea ice) – 3-year interval
- Natality and litter production – annual updates
  - » Adult females with cubs/adult females (cub production rate)
  - » Adult females with yearlings/adult females (yearling production rate)
- Male body condition
- The polar bear is listed as Vulnerable (VU) on the Red List for Svalbard (Kålås et al. 2010).

Harvesting of the Svalbard polar bear population started about 1870 and for the next 100 years ~300 polar bears were harvested annually (Lønø 1970). Polar bear numbers were heavily depleted by the time they became protected in Svalbard in 1973. Svalbard's polar bears are part of the Barents Sea subpopulation, which extends east to Franz Josef Land (Russia) and north into the pack ice. This population's size has been estimated only once, in August 2004 when some 2650 polar bears (95% CI approximately 1900–3600) occupied the region (Aars et al. 2009). Lack of earlier estimates make it impossible to know trends with certainty, but a variety of data suggest that the population grew substantially between the time they were protected (1973) and the 1980s (Larsen 1986). Additionally, Derocher (2005) concluded from demographic data that numbers likely continued to increase through until at least 2000. Annual adult survival rates of polar bears in their prime years (5 to 15 years old) are very high, (~95-98%) in Svalbard (Wiig 1998). Although the polar bear's sea ice habitat has declined, and will likely continue to do so in the next decades around Svalbard (Durner et al. 2009, Regehr et al. 2010), the current population size is still likely to be well below both the historical stock size and the current carrying capacity, so the population is expected to continue to increase despite the fact that climate change effects are expected to negatively impact the rate of growth (via cub survival, increased starvation mortality etc). Habitat loss is certainly the main threat to Svalbard polar bears. Thus, MOSJ monitoring parameters have been selected to detect "early" warning signs related to sea ice losses and conditional changes that would be expected due to declines in their primary prey – ice-dependent seals.

Recommendations

- Population size: The size of the polar bear population in the Barents Sea was estimated in August 2004 (appr. 2650 bears, 95% CI appr. 1900-3600).The next survey is currently being planned for execution in 2015. Surveys should be planned at regular intervals over the coming decades.
- Telemetry data: Tracking data have been essential in interpreting Svalbard bear ecology. Bears have been equipped with collars continuously since the 1990s, with more than 200 collars having

Polar bear on land. Photos: Geir Wing Gabrielsen, Norwegian Polar Institute

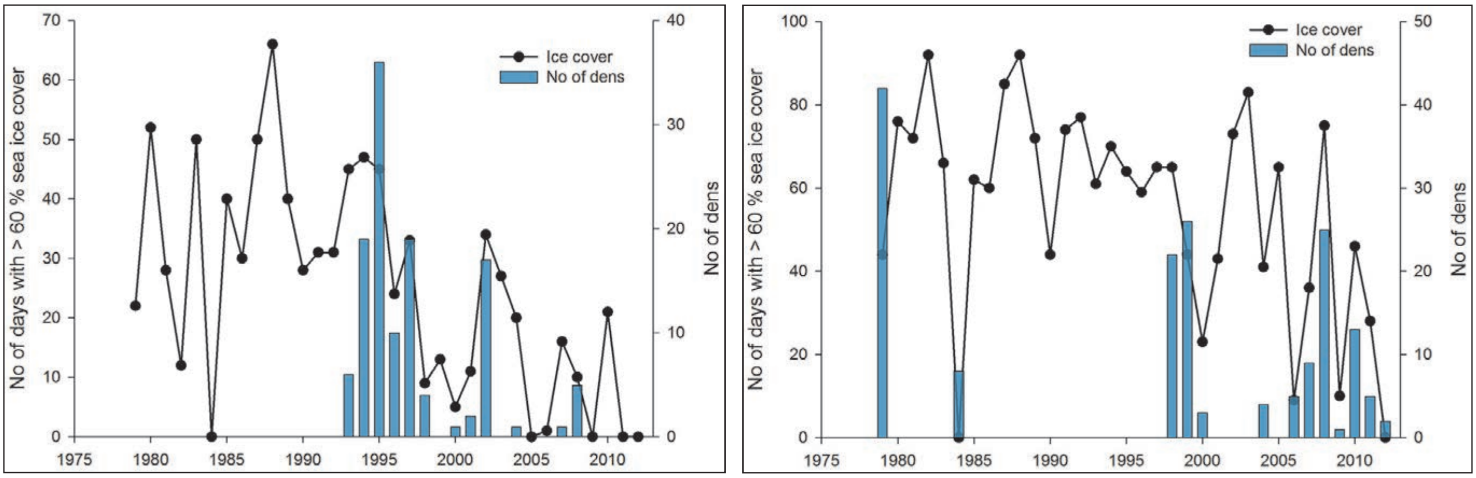


Figure 8.1
Polar bear (*Ursus maritimus*). Number of dens (blue bars) and ice-cover (line) on Hopen (left) and Kong Karls Land (right). (Source: www.mosj.npolar.no)

been deployed. Habitat use strategies can only be studied efficiently using telemetry data for this highly mobile species, and it is very likely that the current change in habitat distribution will affect the bears that migrate over long distances between the pack ice and the islands versus the more local bears that remain around the islands, very differently. Thus, it could be useful to include a habitat use index in MOSJ, to be able to monitor such changes.

Results

Denning and ice-cover

Monitoring of sea ice in relation to denning frequency at sites in the south and eastern parts of Svalbard have demonstrated that denning distribution has responded to changing sea ice patterns in Svalbard. Hopen was a favoured area for denning a decade or more ago, but sea ice does not regularly extend that far south during the autumn any longer, and hence females no longer den at this isolated island (Figure 8.1). Kong Karls Land also has fewer dens than in the past, presumably also because of a general reduction in sea ice (Figure 8.1). The degree to which individual female polar bears are flexible in the choice of denning sites is not known and hence it is difficult to interpret whether or not shifting patterns of denning site choice might have implications for reproductive output of the population.

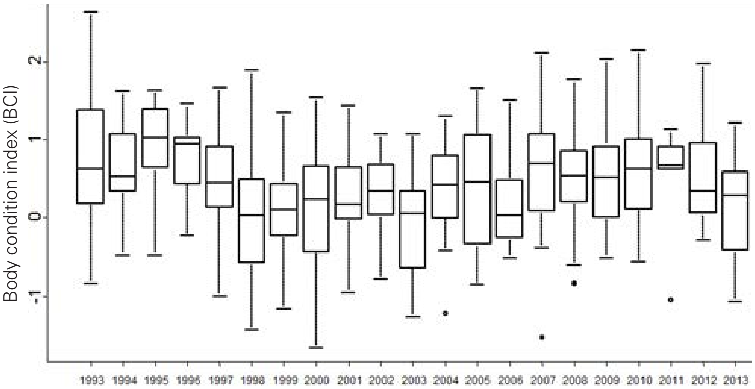


Figure 8.2
Polar bear (*Ursus maritimus*). Box-Whiskers plot (maximum, minimum, quartiles and median) of male body condition index. (Source: www.mosj.npolar.no)

Male body condition

Polar bears are pinnacle predators in the Arctic and body condition is likely a good reflection of prey availability (at least for bears in their prime). MOSJ presents data on male body condition (to avoid the many issues of the differing status of reproductive status of females). There is no time trend in the data (Figure 8.2) i.e. condition has remained the same over an extended period. The data shows a lot of inter-annual variability that is correlated with the Atlantic Oscillation.

Natality and litter production

Cub production shows a marginally significant decline over the monitoring period (Figure 8.3). This pattern is (perhaps unduly) influenced by two high cub production years in 1994-1996 and should be analysed both with and without these outliers. In these two years many females with cubs were caught shortly after they had left their dens at Hopen, which was the base for the NPI's capture programme these years. Early arrival of sea ice in the autumn periods these years led to many females denning there (Figure 8.1). Cub production is correlated with the Arctic Oscillation (where milder weather in one spring is reflected in low cub production the following year). The cub-related data in MOSJ currently suffers from a forced shift in the location of operation of the programme (northward) and thus may be complicated by internal geographic patterns within the Archipelago rather than being reflective of the population's reproduction capacity.

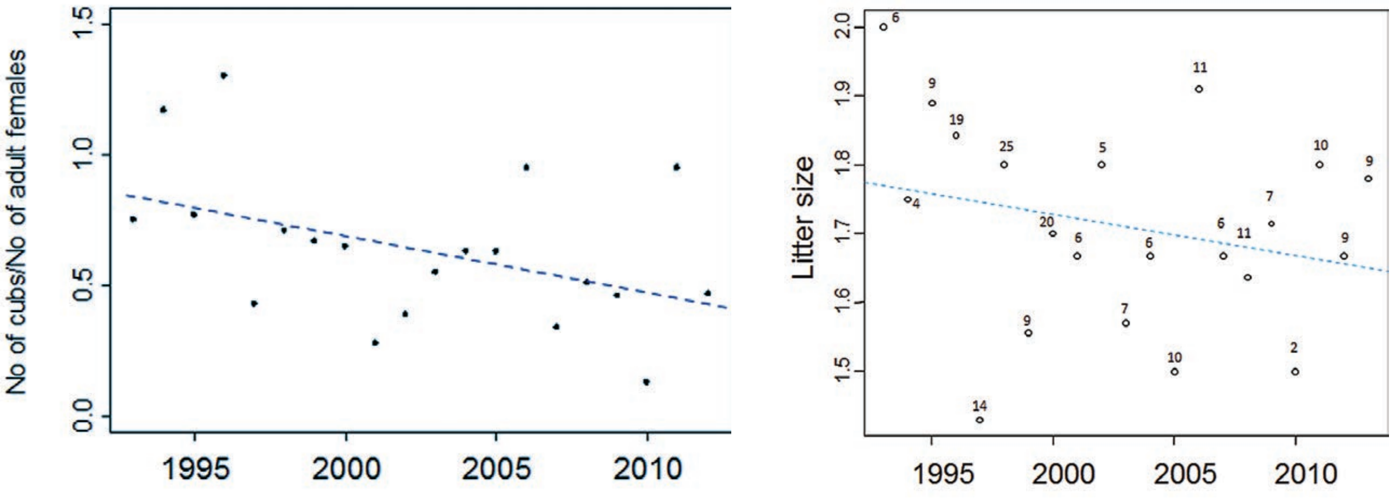


Figure 8.3
Polar bear (*Ursus maritimus*). Cub production (number of cubs / female) (left) and litter size (right). (Source: www.mosj.npolar.no)

Polar bear with cub. Photo: Janne Schreuder, Norwegian Polar Institute

Production of yearlings may be a better parameter for following the population's reproductive well-being because cub mortality is naturally very high; this parameter is also included in MOSJ. For example, the average annual yearling production rate from 1993 to 2012 was 12.5%, compared to 36.9% for cub production and there is no correlation between cub production one year and yearling production the year after. This indicates that most adult females in fact lose their cub(s) during the first year. No time trend or association with Arctic Oscillation was found for the yearling production i.e. yearling production is stable (Figure 8.4).

Evaluation of monitoring methods

The MOSJ den monitoring at the two selected areas has shown a northward shift in denning over the last two decades, but on-going monitoring of these sites is likely of limited value given that Hopen is no longer used by the bears and Kong Karls Land also has very few dens. Den monitoring should be reviewed and an adaptive strategy employed if this parameter is retained in the programme. The reproductive data are very valuable data, particularly the yearling production rates. Body condition is also very useful for tracking "health" of the population, though age should be incorporated into these analyses in the future. The Svalbard data sets for reproduction and condition are one of three global data series on polar bears with such a long time line and are highly valued for time-trend analyses. Svalbard data is particularly valuable because it is the only non-harvested, intensively monitored population of this species.

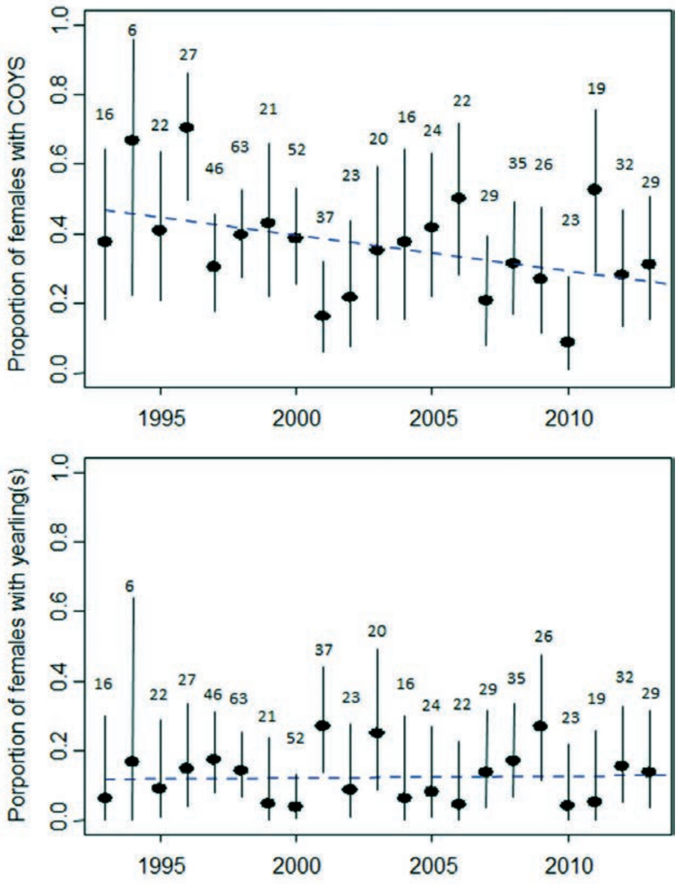


Figure 8.4
Polar bear (*Ursus maritimus*). Proportion of females with cubs (top) and yearlings (bottom). (Source: www.mosj.npolar.no)

Relevance

The indicators monitor demography or population dynamics of a threatened species listed on the Norwegian Red List.

8.2 MOSJ indicator: Bowhead whale (*Baleana mysticus*)

MOSJ Parameter: Observations of the species

The bowhead whale is listed as Critically Endangered (CR) on the Red List for Svalbard (Kålås et al. 2010).

The bowhead whale is the only baleen whale that lives its entire life in arctic waters. Across its circumpolar range it is tightly associated with sea ice and is often found in particularly high-productivity areas during summer, travelling along ice edges or occupying areas containing polynyas (Heide-Jørgensen & Laidre 2004). This species is a slow-swimming plankton feeder that exhibits a strong dietary preference for lipid-rich arctic calanoid copepods, though it does exhibit dietary flexibility across its global range (Laidre et al. 2008). Because of its slow-swimming habits, non-aggressive nature, and the fact that bowheads are so fat that they float when they are killed – this species fell prey to the earliest commercial whaling activities in the north and were heavily depleted throughout their range (Woodby and Bodkin 1993). Bowheads do not reach sexual maturity until they are 20+ years of age and they live to an age of over 200 years. Females produce calves at 5+ year intervals. These extremely conservative life-history characteristics make the species vulnerable to over-exploitation or environmental perturbations, and complicate population recovery.

The largest stock of bowhead whales occurred historically in Spitsbergen waters, but the bowhead whales in this region were brought to the brink of extinction by excessive harvesting by the 1800s (Allen and Keay 2006). Jonsgård (1981) suggested that the Spitsbergen stock might actually have been driven to complete extinction, but deKorte and Belikov's (1994) report of calves being sighted in the early 1980s in the Franz Josef Land area suggests that the stock managed to continue to exist in very small numbers.

Bowhead whales are likely to be particularly sensitive to increasing ocean noise and increasing ship traffic accompanying development in the Barents Region (Guerra et al. 2011, Reeves et al. 2012).

Recommendations

The rarity of the species in Svalbard limits Norway's ability to do full CAFF monitoring protocols. But, the successes of the two survey efforts by the Norwegian Polar Institute and partners in the past decade (2006, 2010), and the knowledge gleaned on the ecology of the species via tracking a single individual marked during the 2010 survey (Lydersen et al. 2012), suggest that some regular monitoring effort directed to this species could be successful (see Gilg and Born 2005, Heide-Jørgensen et al. 2007, Schweder et al. 2010 for other regions). Additionally, passive acoustic monitoring in the Fram Strait documented the presence of bowheads from early November until late April (Moore et al. 2011, Stafford et al. 2012), and a singing complexity suggesting that this region is a breeding area.

- Consideration of a more complete monitoring effort directed to this species should be undertaken (following CAFF recommendations – see Gill et al. 2011, but noting the lack of hunting in our region and the rarity of the species).
- MOSJ could incorporate data from the passive acoustic monitoring array that is currently operating in Fram Strait and Svalbard waters.

Results

Christensen et al. (1992a) suggested that the Svalbard stock consisted of some tens of animals in the early 1990s. But, in the past two decades there has been an increasing number of reports of sightings in the Svalbard area (Wiig et al. 2007a, 2010) as well as near Franz Josef Land (Maria Gavrilo, pers. comm.)

Evaluation of monitoring methods

The MOSJ sighting data is useful for documenting sightings that occur in the region, but it does not provide any explanatory potential and is complicated by uncontrollable effort variation (increasing boat traffic of multiple types).

Relevance

The current indicator in MOSJ is not actually biological monitoring. It simply documents the presence of a threatened species listed on the Norwegian Red List, and is useful background for designing possible monitoring activities in the future.

8.3 MOSJ indicator: White whale (*Delphinapterus leucas*)

MOSJ Parameter: Observations of the species

The white whale is listed as Data Deficient (DD) on the Red List for Svalbard (Kålås et al. 2010).

White whales have a broad circumpolar distribution. They are found throughout the Arctic and sub-Arctic waters of the Northern Hemisphere. Historically this species has been subjected to exploitation throughout its range by subsistence hunters and in some cases such as in Svalbard commercial operations (e.g. Hoel 1949, Heide-Jørgensen and Wiig 2002). The relatively tight, at least seasonal affiliation white whales have with sea ice throughout their range makes climate change related sea ice losses a concern with respect to this species (Kovacs et al. 2011a).

In Svalbard, Norway, a shore-based fishery existed for white whales until the middle of the last century. It is thought that more than 15 000 white whales were taken from this population in a series of hunts, principally during the late 1800s, that severely depleted the population (Collett 1911-12, Lønø and Øynes 1961, Kjaer 2011). The white whale fishery came to an end in the 1960s and this species became protected in Norwegian waters in the following decade (Anon. 1978). Pods of whales numbering from a few individuals up to a few hundred individuals are seen with some regularity. But, no population abundance estimate is available for the Svalbard white whale population.

Data from Svalbard white whales are particularly important in a global context because this is one of the few stocks of this species that is not hunted. Abundance data are available for most of the 20 stocks of white whales in the Arctic, the exceptions occurring in Russia and Norway – trend data are available for five stocks (CAFF ABA 2013). Ice edges and tidal glacier fronts are known to be

White whales. Photo: Fredrik Broms, Norwegian Polar Institute important local habitats for these whales in Svalbard and both habitat types are declining. Additionally, their primary prey – polar cod – is likely to be negatively impacted by climate change and predation from killer whales (*Orcinus orca*) is expected to increase (Higdon et al. 2011). Monitoring is required to document responses of white whales in Svalbard to climate change and other possible stressors. Time-series data are available for distribution/habitat selection and "health" screening.

Recommendations

Research conducted by the Norwegian Polar Institute and partners has documented distribution and diving behavior via the deployment of satellite-linked time-depth recorders (Lydersen et al. 2001, 2002); diet analyses of white whales from Svalbard – assessed through fatty-acid profiling (Dahl et al. 2000); acoustic behaviour of white whales in Svalbard has been studied (Karlsen et al. 2002) and genetics (O'Corry-Crowe et al. 2010) and white whale health studies have been performed (Tryland et al. 2006a). Contaminant levels in white whales in Svalbard have also had research attention via the opportunities for sampling in the ecology programmes (Andersen et al. 2001, 2006, Wolkers 2004, 2006, Tittlemeir et al. 2002). These animals bear the heaviest contaminant burdens of any wildlife species thus far measured in Svalbard for most of the toxins assessed – higher than polar bears (Villanger et al. 2011). Some of this research data could provide a good basis to establish monitoring activities on this population.

- Consideration of a more complete monitoring effort directed to this species should be undertaken (following CAFF recommendations – see Gill et al. 2011 – but noting the lack of hunting in our region).

Results

Sighting data suggest that white whales remain the most numerous species among the resident cetaceans in Svalbard.

Evaluation of monitoring methods

The MOSJ sighting data is a useful tool for documenting sightings that occur in the region, but it does not provide any explanatory potential and is complicated by uncontrollable effort variation (increasing boat traffic of multiple types).

Relevance

The indicator notes the presence of a threatened species listed on the Norwegian Red List, but does not constitute biological monitoring.

8.4 MOSJ indicator: Walrus (*Odobenus rosmarus rosmarus*)

MOSJ parameter: Population size (summer, Svalbard) – Five-year interval

The walrus is listed as Vulnerable (VU) on the Red List for Svalbard (Kålås et al. 2010).

Walruses occur within an almost circumpolar range, occupied by two subspecies, the Pacific (*O. r. divergens*) and the Atlantic walrus. This species is an important subsistence resource for many aboriginal communities, and a favourite target for arctic marine cruise tourism in Svalbard. Walruses were once extremely abundant in the Svalbard Archipelago, but 350 years of unregulated harvest brought them to the brink of extinction (Norderhaug 1969) before they became protected in 1952 (Anonymous 1952). Born (1984) summarized observations of walruses in the Svalbard area from 1954-1982 and concluded that the summering stock was about 100 animals, and that there had been an increase in numbers since 1970. In 1993, a total of 741 walruses were observed in Svalbard based on maximum numbers of animals counted at various haul-out sites during fixed-wing and ground surveys performed over the period from August-October (Gjertz and Wiig 1995). As suggested by Born (1984), and later confirmed by satellite tracking (Wiig et al. 1996) and genetic studies (Andersen et al. 1998), the walruses in Svalbard are part of a larger, common Svalbard – Franz Josef Land population. Based on this fact and an assumed equal sex ratio, Gjertz and Wiig (1995) suggested that this shared population consisted of a minimum of 1450 walruses (age 2+, plus an unknown number of calves). These reports supported the general impression of a slow recovery taking place, based on increasing numbers of sightings of walruses at an increasing number of haul-out sites in Svalbard (Norwegian Polar Institute's Fauna and Marine Mammal Sighting Databases). The sex ratio within Svalbard over the decades between the 1950s and 1990s was highly skewed. Most walruses repatriating the Archipelago were males; females were tightly restricted to only a few haul-out sites in the Northeast corner of Nordaustlandet and accounted for only a few percent of the population. This is in marked contrast to the 33% of population that was comprised of females during the harvesting in the 1800s (Wiig et al. 2007b).


Walruses. Photo: Tor Ivan Karlsen, Norwegian Polar Institute

Walruses feed on benthic invertebrates (mostly clams) and benthic environments are thought to be particularly vulnerable to changes in ice-cover because they have always been "pulsed" with nutrients in the Arctic during the spring ice melt (e.g. Grebmeier et al. 2006, 2010). It is expected that production will be more tightly cycled in the pelagic system in an Arctic with less sea ice. Declines in sea ice thus have the potential to impact walrus distribution quite directly, determining winter breeding distribution, as well as indirectly via the abundance and distribution of their food. This walrus population is not harvested, which makes it a very important comparative site for exploited populations. Almost all other Atlantic walrus stocks have declined markedly during the last 50 years, while the Svalbard population has been increasing. Some distribution/movement/habitat selection data from satellite tracking (Freitas et al. 2009), diet (Skoglund et al. 2010) and health and disease data (Prestrud et al. 2007, Tryland et al. 2009) are available. Additionally, the

Norwegian Polar Institute has remotely monitored haul-out behaviour of walruses at five selected haul-out sites in Svalbard. The purpose of this monitoring is to obtain knowledge on the dynamics of site-use, in addition to addressing potential impacts of tourist visitation on haul-out behaviour. A single picture is taken every hour throughout the summer season; cameras are deployed in late June/start of July, which corresponds to the time when these sites become free of ice and available for walruses, and they are retrieved at the end of September-start of October. Despite several logistical set-backs, there are more than 37 000 pictures in this database (including summer 2012) making this a unique time series on walrus behaviour in a global context. This is valuable data in itself, but will also be the basis for assessing potential effects of tourist and other visitations at these sites.

Recommendations

Several parameters can easily be included in MOSJ without addition costs:

- Total number of haul-out sites used by walruses within Svalbard
- Number of sites containing mother – calf pairs
- Camera monitoring of site visitation
- Consideration of a more complete monitoring effort directed to this species should be undertaken (following CAFF recommendations – see Gill et al. 2011 – but noting the lack of hunting in our region).

Results

The first systematic abundance survey within MOSJ was conducted in 2006. This survey covered all known terrestrial haul-out sites within Svalbard (n=79) during a tight time window (1-3 August). Seventeen haul-out sites were occupied by animals when the survey was flown. The digital photographs of the active sites contained 657 animals. An extensive behavioural data set from satellite-relay-data-loggers was used to correct for animals that were in the water at the time of the survey. The resulting estimate was 2629 (95% CI: 2318– 2998). The second survey in this MOSJ time series was flown in 2012; the results are currently undergoing scientific review and will be posted as soon as this process is complete. The data show a marked increase in population numbers.

Evaluation of monitoring methods

Population abundance is the primary mammalian “metric” for assessment and hence should remain the top priority for walrus monitoring in MOSJ. The methods employed are of a high internationally accepted standard, but behavioural data for females need to be added to the models as this segment of the population is increasing and updated data for males would also be valuable given the changes the physical environment is undergoing in Svalbard. Additionally, routine tracking (at intervals), providing distributional data should be incorporated into the monitoring effort.

Relevance

The indicator monitors the population of a threatened species listed on the Norwegian Red List.

8.5 MOSJ indicator: Harp seals (*Pagophilus groenlandicus*)

MOSJ parameters: Pup production and estimated population size in the East Ice and West Ice.

The harp seal is not listed on the Red List for Svalbard (Kålås et al. 2010).

The harp seal is a gregarious pack-ice breeder that occurs in the North Atlantic. Three populations are recognized, according to their breeding locales – off the east coast of Canada, in the White Sea in Russia (East Ice) and just north of Jan Mayen Island (West Ice), Norway (Lavigne and Kovacs 1988). All three populations are harvested commercially, and there is increasingly large subsistence harvests taking place in Greenland. Harp seals live a pelagic life outside the breeding season, preferring areas that contain pack-ice. All populations undertake long seasonal migrations, summering within the Arctic and accumulating most of their annual energy intake in high arctic waters. They feed on schooling invertebrates and especially small schooling fish such as capelin and polar cod (e.g. Wathne et al. 2000, Haug et al. 2004).

Harp seals from both the West Ice and the East Ice populations are found in the Svalbard area in summer and autumn. This species is monitored because it is commercially harvested and the population status can be influenced very directly by hunting pressure, as has been seen in the past. Additionally, this species is an ice-affiliated species and hence is likely to be negatively impacted by climate change in the decades to come (Kovacs et al. 2011a). Availability of suitable ice has already become an issue for harp seals at their southern-most breeding area off the east coast of Canada and complete breeding failure occurs in this area more frequently now than a few decades ago (e.g. Bajzak et al. 2011, Johnston et al. 2012). Additionally, unprecedented high numbers of harps seals have been found concentrated along central west Greenland in recent years in winter, suggesting that whelping might already be shifting northward (Rosing-Asvid 2008); large herds have also been seen unexpectedly far north, in Svalbard in late winter (Kovacs et al. 2011a).

Recommendations

Abundance estimates (in this case via pup production estimates) are definitely the primary monitoring parameter and this data collection should remain the top priority for MOSJ. But explanatory variables should also be explored. Harp seals have not been the subject of

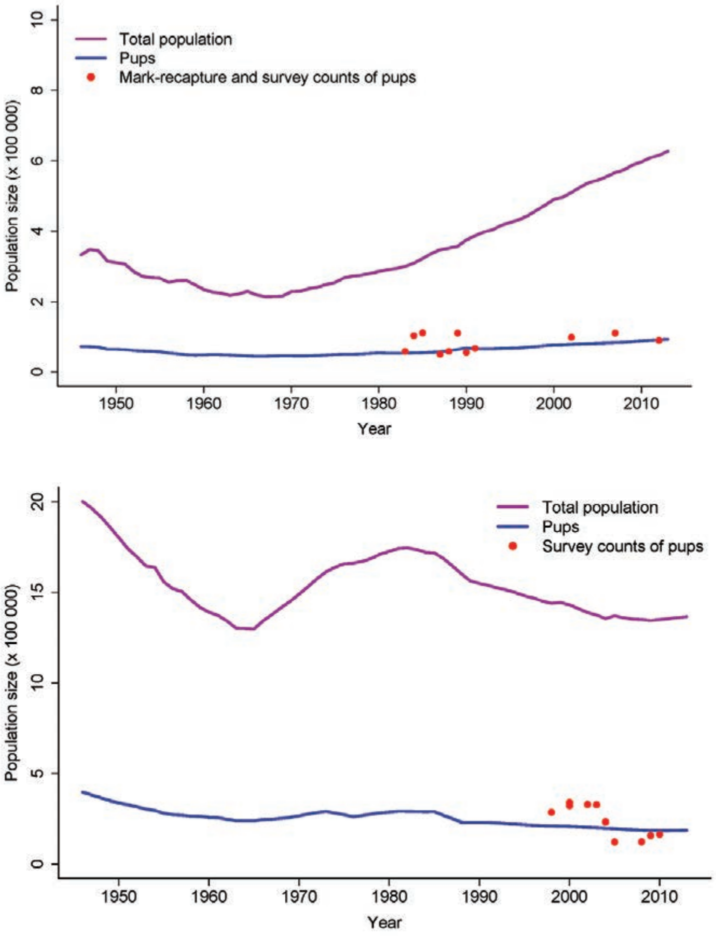


Figure 8.5
Harp seal (*Pagophilus groenlandicus*). Population development for the West Ice (top) and the East Ice (bottom). Purple line is modeled population size, hatched blue line is modeled number of yearlings and red dots are counts. See Øigård et al. (2013b) for modeling details. (Source: www.mosj.npolar.no)

CAFF monitoring development plans – so additional, appropriate monitoring elements need to be designed for this species. But, the population estimate work currently conducted is supported by extremely valuable time-series regarding age at sexual maturity, age specific ovulation rates and pregnancy rates and condition data. Condition data show a marked decline in body condition, which provide valuable context regarding potential climate change impacts on this population (Øigård et al. 2013a). The data mentioned above should be considered for possible inclusion in MOSJ. Dietary tracking is also something that could be considered for MOSJ, as changing prey abundance, species composition and distributions are likely to affect this species.

Results

Currently, harp seals are abundant, numbering some 8+ million animals in total in the North Atlantic. The Jan Mayen breeding group is increasing, and currently numbers >650 000 animals (ICES 2011). The East and West Ice populations are showing opposite trends (Figure 8.5). The East Ice harp seals pup production has been in decline during the past decade, dropping from over 300 000 in 1998-2003 to 163 000 in 2010 (ICES 2011), while the West Ice stock has continued to increase through this period.

The MOSJ web page suggests that there is no good explanation for the situation in Russia, but mentions that difficult ice conditions and reduced female fertility might be possible causes. Additionally, it is hypothesized that some part of the population might have shifted to unknown new breeding areas outside the White Sea (which seems unlikely). Russian scientists have made somewhat stronger statements regarding climate change being the cause of poor breeding-ice conditions which were exacerbated in some years by ship traffic moving through the harp seal breeding patches in light ice years, but also mention that pollution effects, competition for fish resources (particularly capelin declines) and hunting levels may have also contributed to the observed reductions (e.g. Chernook and Boltnev 2008, Zabavnikov et al 2008).

It must be noted that the West Ice population has been in recovery since the early 1970s, following over-exploitation during the 1950s and 1960s that had reduced the population; the increasing trend followed the implementation of stricter hunting regulations. West Ice animals are suffering from decreased condition (Øigård et al. 2013a), so it is particularly important that monitoring be continued and research conducted to provide explanations of changes in this population. Prey deficits in the past have caused major harp seal declines and intense negative interactions with coastal fisheries (e.g. Nilssen et al. 1998).

Evaluation of monitoring methods

The monitoring of the Norwegian and Russian populations, which have been jointly managed for an extended period of time, has mainly been aimed at providing a sound basis for fixing hunting quotas. The most important data have been estimates of pup production based on tag-recovery experiments (1983-91) and more recently aerial counts (2002 and 2007) in the West Ice and in the White Sea (1998-2009). Pup production estimates, historical hunting data and reproduction parameters are fed into a population model that is used to calculate both the total stock size and the hunting potential of the population (e.g. Haug et al. 2006, Salberg et al. 2009). ICES requires that the population estimate be updated every five years year with new input data. Parameters reported in MOSJ are the pup production numbers for both the East Ice and West Ice populations (as well as providing the model outputs for total population sizes). This monitoring is being conducted at a high standard, using internationally recognised methods.

Relevance

The indicator monitors the population of a harvested species and is consequently an indicator of the sustainability of human use of an ecosystem service.

8.6 MOSJ indicator: Hooded seals (*Cystophora cristata*)

MOSJ Parameters: Pup production and estimated population size in the West Ice.

The hooded seal is listed as Endangered (EN) on the Red List for Svalbard (Kålås et al. 2010).

Similar to the harp seal, the hooded seal is another North Atlantic pack-ice breeder. Hooded seals give birth in whelping patches off the east coast of Canada, in the Davis Strait and in the West Ice (north of Jan Mayen Island, Norway). Their breeding period is somewhat later in the pack-ice season and more concentrated than that of harp seals and this species prefers heavier ice conditions for birthing (Lavigne and Kovacs 1988). They form loose herds, on large floes with "family" trios spread at some few hundred metre intervals in years with good ice conditions (Kovacs et al. 1996). Hooded seals are deep divers that feed on squid and deep-dwelling fish species such as red fish (Sebastes spp) (Haug et al. 2004). This species forages throughout the Nordic Seas as far south as Iceland and around the Faeroes.

Recommendations

Given the precipitous decline in the Norwegian hooded seal stock it is important to continue regular survey efforts at the current five-year intervals. Consideration should also be given to increasing monitoring efforts directed toward explanatory variables, within the limits of minimal research harvests (see above for harp seals).

Results

The global abundance of hooded seals is ~ 600 000 animals, 80% of which are contained in the Northwest Atlantic stocks. A delay in the mean age at primiparity and reduced pregnancy rates have been documented for the largest sub-population in Canada, which are thought to be based on an ecosystems change (Frie et al. 2012). But the greatest change has been seen in the Northeast Atlantic where the stock has declined by approximately 80% during the period since the World War II (Salberg et al. 2008); the magnitude of this population decline put the entire species on the IUCN Red List (IUCN 2008). Deteriorating sea-ice conditions are likely partially responsible for this dramatic reduction, but overharvesting that took place in the 1950s and 1960s contributed to the declines. West Ice hooded seals were harvested very heavily compared to the stock size (in hindsight), when virtually no scientific data was available to set quotas. Flying surveys had been attempted in the 1950s but failed due to bad weather. A survey attempt was made again in 1994, but it was also terminated because of bad weather conditions (T. Haug, pers. comm.). Some fertility data was collected 1990-1994. The first successful aerial survey in 1997 suggested that

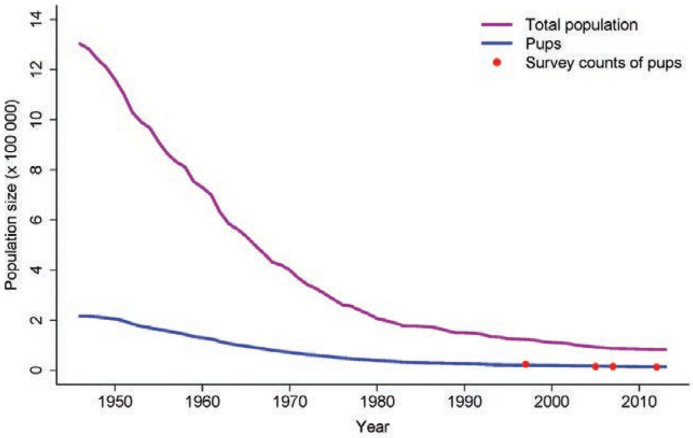


Figure 8.6
Hooded seal (*Cystophora cristata*) in the West Ice. Purple line is modelled population size, hatched blue line is modelled number of yearlings and red dots are counts. See Øigård et al. (2014) for modelling details. (Source: www.mosj.npolar.no)

the population was much smaller than had been thought. The low numbers were confirmed by another survey in 2005 and yet again in 2007, at which time the commercial hunt was terminated. The two latter aerial surveys suggested a population of ~ 80 000-100 000 hooded seals; the number was quite stable between the surveys, at a level of 10-15% of the population size of the 1960s (Figure 8.6). In a recent study, the total abundance in 2013 was estimated to be 84 020 (95% c.i. 68 060–99 980) (Øigård et al. 2014). Furthermore, the model used in this study predicted a decreasing population size of about 7% over the next 10 years, assuming no hunt. The reason for the negative trend is probably a combination of predation from polar bear and climate change (Øigård et al. 2014).

Evaluation of monitoring methods

The methods used to monitor this population are the same as those used for harp seals (please see above).

Relevance

The indicator monitors the population of a threatened species listed on the Norwegian Red List.

8.7 Additional pinniped species not currently included in MOSJ

Two additional pinniped species (harbour seals and ringed seals) have recently been removed from the MOSJ website because data were "out of date". New data are available for one of these species – harbour seals (*Phoca vitilina*) and it is therefore possible to return this species to the MOSJ programme if this is deemed desirable.

8.7.1 Possible MOSJ indicator: Harbour seal (*Phoca vitulina*)

The harbour seal is listed as Vulnerable (VU) on the Red List for Svalbard (Kålås et al. 2010).

The small population of harbour seals living and breeding on Prins Karls Forland, Svalbard, is the world's northernmost population of this widely dispersed phocid seal species. They are a proverbial *"canary in a coal mine"*, being at the outermost part of their natural species range. In contrast to the ice-affiliated seals, predictions for Svalbard harbour seals are very positive given current climate change scenarios and they are logistically quite easy to work with for monitoring purposes (Lydersen and Kovacs 2010a,b,c).

This population is genetically isolated from neighbouring populations in Greenland, Iceland and the Norwegian mainland (Andersen et al. 2010). A recent population assessment of these seals suggests a significant population increase from earlier count data that concluded that there were approximately 1000 animals; the 2009/2010 count is ~1800 animals (Lydersen and Kovacs 2010a-d, Merkel et al. 2013). A northward expansion of the distribution is also taking place (NPI sighting data base and telemetry work currently under analyses) and a significant diet shift from a polar cod dominated diet in the autumn to an Atlantic cod dominated autumn diet has been demonstrated (Colominas et al. 2012). Health studies suggest that the Svalbard population of harbour seals is free from *Toxoplasma gondii* infection, though this parasite is prevalent in many marine mammals in Svalbard (Jensen et al. 2010), but this population is positive for Phocine herpesvirus (Roth et al. 2013). This species is also redlisted on the Norwegian mainland where fisheries interactions, and intentional shooting have recently reduced the population by >50%. Increasing fisheries activities in northern waters could represent a greater risk to the local habour seal population. The currently increasing trend and distributional spread of this species could also have implications for ringed seal in coastal waters of Svalbard. Dietary overlap between the two was quite extensive when ringed seal diets were explored last (Andersen et al. 2004, Labansen et al. 2007).

Recommendations

The unique status of this "temperate" species in the Norwegian arctic should be considered by the MOSJ steering board. The contrasts between ringed seals and harbour seals in Svalbard provide valuable "system change" inferences; additionally, the two species might have complex ecological interactions/overlap. Harbour seals are switching diet, maintaining health and condition levels and expanding both distribution and numbers. This is likely in marked contrast to ringed seals, and might represent competitive stress for ringed seals in the region (see below). Potential MOSJ parameters include:

- Population size – aerial survey
- Distribution (& habitat selection – telemetry)
- Stock structure (genetics)
- Diet – scat analyses
- Health and disease screening(s)

8.7.2 Possible MOSJ indicator: Ringed seal (*Pusa hispida*)

The ringed seal is currently not listed on the Red List for Svalbard, but its status is under revision by the national Red List Committee.

Ringed seal. Photo: Bjørn Frantzen, Norwegian Polar Institute

Recommendations

Suggestions for consideration for MOSJ monitoring of ringed seals in Svalbard include the CAFF defined parameters:

- Abundance/density estimation of ringed seals – *first step monitoring available breeding habitat via remote sensing (sea ice maps)*
- Distribution and habitat selection – *satellite tracking at five-year intervals*
- Stock structure – genetics (& telemetry) – *first local genetics study being written up at the moment – repeat at 10 year intervals*
- Population parameters/age structure and vital rates – *from annual hunter collections – started in 2012-13*
- Ringed seal diet – *intervals of 5-10 years*
- Body condition (*annually from hunter sampling*) and "health status" of ringed seals from Svalbard – *should be done concurrently with scientific collections for diet assessment.*

8.7.3 Possible MOSJ indicator: Bearded seal (*Erignatus barbatus*)

Similar to ringed seals, bearded seals are an ice-dependent Svalbard resident that is likely to be heavily impacted by climate change. They are however quite different in many aspects of their ecology, including being naturally less abundant, and being the largest as opposed to the smallest of the northern phocid ("true") seal. This species has a patchy distribution throughout the circumpolar Arctic; two subspecies are recognised, one in the Pacific and one in the Atlantic, though there is no set geographic demarcation lines between them). Their preferred habitat is drifting sea ice in areas over shallow coastal shelves. Most bearded seals remain in coastal waters throughout the year, though some animals occupy off-shore pack-ice areas within the arctic shelf seas (e.g. such as the free-floating pack-ice in the Barents Sea). Bearded seals are found at low densities in all of Svalbard's fjords on a year-round basis, wherever ice is available.

Pups are born in Svalbard in early to mid-May, normally on floating ice, ideally first-year floes breaking off land-fast ice. Moulting of their old hair and replacement of their new coat follows in mid-June and the preferred habitat for this event is also sea ice because the seals prefer to remain on the ice, basking in the sun; circulating the skin and keeping it warm promotes rapid and efficient moulting of the hair. When the animals must moult in the water, the process is much slower and more energetically costly. Polar bears are the main predator of bearded seals but walruses, killer whales and Greenland sharks may also take bearded seals, particularly pups. There are reasons to believe that all of these natural sources of mortality will increase for bearded seals in a warming Arctic.

Bearded seal. Photo: Bjørn Frantzen, Norwegian Polar institute

Recommendations

- Consideration of monitoring efforts directed to this species should be undertaken; this has not been done in detail in the past. Available data on pup production and pup growth from "normal" ice conditions for the Archipelago, and also during the period of dramatic change in the mid-2000s, that could serve as a base-line for a globally unique monitoring programme on this high arctic seal ice-associated species. Challenges in determining the abundance of bearded seals will necessitate the use of local abundance indexes (local pup-production could serve as such an index: Temple/Billefjorden vs Kongs-/Krossfjorden could provide a hunted vs unhunted contrast), which should be explored in pilot studies prior to consideration of implementation of this parameter within MOSJ.

Literature

Aagaard K, Carmack E (1989) The role of sea ice and other fresh water in the Arctic circulation. Journal of geophysical research. Oceans 94(C10): 14485-98

Aagaard K, Foldvik A, Hillman SR (1987) The West Spitsbergen Current: disposition and water mass transformation. Journal of geophysical research. Oceans 92(C4): 3778-84

Aars J, Marques TA, Buckland ST, Andersen M, Belikov S, Boltunov A, Wiig Ø (2009) Estimating the Barents Sea polar bear subpopulation size. Marine mammal science 25(1): 35-52

Allen RC, Keay I (2006) Bowhead whales in the eastern Arctic, 1611–1911: population reconstruction with historical whaling records. Environment and history 12(1): 89–113

Andersen LW, Born EW, Gjertz I, Wiig Ø, Holm LE, Bendixen C (1998) Population structure and gene flow of the Atlantic walrus (*Odobenus rosmarus rosmarus*) in the eastern Atlantic Arctic based on mitochondrial DNA and microsatellite variation. Molecular ecology 7(10): 1323-36

Andersen G, Kovacs KM, Lydersen C, Skaare JU, Gjertz I, Jenssen BM (2001) Concentrations and patterns of organochlorine contaminants in white whales (*Delphinapterus leucas*) from Svalbard, Norway. Science of the total environment 264(3): 267-281

Andersen SM, Lydersen C, Grahl-Nielsen O, Kovacs KM (2004) Autumn diet of harbour seals (*Phoca vitulina*) at Prins Karls Forland, Svalbard, assessed via scat and fatty-acid analyses. Canadian journal of zoology 82(8): 1230-1245

Andersen M, Gwynn JP, Dowdall M, Kovacs KM, Lydersen C (2006) Radiocaesium (^{137}Cs) in marine mammals from Svalbard, the Barents Sea and the North Greenland Sea. Science of the total environment 363: 87-94

Andersen LW, Lydersen C, Frie AK, Rosing-Asvid A, Hauksson E, Kovacs KM (2011) A population on the edge: genetic diversity and population structure of the world's northernmost harbour seals. Biological journal of the Linnean Society 102(2): 420-439

Anonymous (2011) Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea, August-October 2011. Bergen: Institute of Marine Research. (IMR/PINRO joint report series, 2011:3)

Arctic Council (2009) Arctic marine shipping assessment 2009: report. Tromsø

Arendt KE, Juul-Pedersen T, Mortensen J, Blicher ME, Rysgaard S (2013) A 5-year study of seasonal patterns in mesozooplankton community structure in a sub-Arctic fjord reveals dominance of *Microsetella norvegica* (Crustacea, Copepoda). Journal of plankton research 35(1): 105-120

Aars J, Marques TA, Buckland ST, Andersen M, Belikov S, Boltunov A, Wiig Ø (2009) Estimating the Barents Sea polar bear subpopulation size. Marine mammal science 25(1): 35-52

Bailey DM, Collins MA, Gordon JDM, Zuur AF, Priede IG (2009) Long-term changes in deep-water fish populations in the northeast Atlantic: a deeper reaching effect of fisheries? Proceedings of the Royal Society. B: biological sciences 276(1664): 1965-9

Bajzak CE, Hammill MO, Stenson GB, Prinsenberg S (2011) Drifting away: implications of changes in ice conditions for a pack-icebreeding phocid, the harp seal (*Pagophilus groenlandicus*). Canadian journal of zoology 89(11): 1050-1062

Bakken V, Mehlum F (2005) Wintering areas and recovery rates of Brunnichs's guillemots *Uria lomvia* ringed in the Svalbard archipelago. Arctic 58(3):268-275

Bakken V, Pokrovskaya IV (2000) Brünnich's guillemot *Uria lomvia*, pp.119-124. In: The status of marine birds breeding in the Barents Sea region / T. Anker-Nilssen et al. Tromsø. (Norsk Polarinstitutt. Rapport, 113)

Bakun A (2006) Wasp-waist populations and marine ecosystem dynamics: navigating the "predator pit" topographies. Progress in oceanography 68(2/4):271-288

Barrett R, Anker-Nilssen T, Bustnes JO, Christensen-Dalsgaard S, Descamps S, Erikstad KE, Lorentsen SH, Strøm H, Systad GH (2012) Key-site monitoring in Norway 2011. Trondheim: Norwegian Institute for Nature Research. (SEAPOP short report, 2012:1)

Beaugrand G, Ibanez F (2004) Monitoring marine plankton ecosystems. II: long-term changes in North Sea calanoid copepods in relation to hydro-climatic variability. Marine ecology, progress series 284:35-47

Berge J, Johnsen G, Nilsen F, Gulliksen B, Slagstad D (2005) Ocean temperature oscillations enable reappearance of blue mussels Mytilus edulis in Svalbard after a 1000 year absence. Marine ecology, progress series 303: 167-175

Berge J, Gabrielsen TM, Moline M, Renaud PE (2012) Evolution of the Arctic Calanus complex: an Arctic marine avocado? Journal of plankton research 34(3): 191-5

Beuchel F, Gulliksen B, Carroll ML (2006) Long-term patterns of rocky bottom macrobenthic community structure in an Arctic fjord (Kongsfjorden, Svalbard) in relation to climate variability (1980-2003). Journal of marine systems 63(1/2): 35-48

Boertmann D, Lyngs P, Merkel FR, Mosbech A (2004) The significance of Southwest Greenland as winter quarters for seabirds. Bird conservation international 14(2): 87-112

Born EW (1984) Status of the Atlantic walrus *Odobenus rosmarus rosmarus* in the Svalbard area. Polar research 2(1): 27-45

Bossart GA (2011) Marine mammals as sentinel species for oceans and human health. Veterinary pathology 48(3): 676-690

Bowering WR, Nedreaas KH (2000) A comparison of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) fisheries and distribution in the Northwest and Northeast Atlantic. Sarsia 85(1): 61-76

Burek KA, Gulland FMD, O'Hara TM (2008) Effects of climate change on arctic marine mammal health, pp.S126-S134. In: Arctic marine mammals and climate change / ed. HP Huntington and SE Moore. Ecological Society of America. (Ecological applications, 18:2 Suppl.)

Bustnes JO, Erikstad KE, Hanssen SA, Tveraa T, Folstad I, Skaare JU (2006) Anti-parasite treatment removes negative effects of environmental pollutants on reproduction in an Arctic seabird. Proceedings of the Royal Society. B: biological sciences 273(1605): 3117-22

Bustnes JO, Erikstad KE, Skaare JU, Bakken V, Mehlum F (2003) Ecological effects of organochlorine pollutants in the Arctic: a study of the glaucous gull. Ecological applications 13(2): 504-515

CAFF (Conservation of Arctic Flora and Fauna) 1999. Incorporating ringed seals into CAFF and AMAP: U.S. CAFF delegation discussion paper (Document VII/10-9)

Cairns DK (1988) Seabirds as indicators of marine food supplies. Biological oceanography 5(4): 261-271

Carroll ML, Ambrose WG, Levin BS, Locke WL, Henkes GA, Hop H, Renaud PE (2011) Pan-Svalbard growth rate variability and environmental regulation in the Arctic bivalve *Serripes groenlandicus*. Journal of marine systems 88(2): 239-251

Casini M, Lövgren J, Hjelm J, Cardinale M, Molinero JC, Kornilovs G (2008) Multi-level trophic cascades in a heavily exploited open marine ecosystem. Proceedings of the Royal Society. B: biological sciences 275(1644): 1793-1801

CBird (1997) Circumpolar eider conservation strategy and action plan / by the Circumpolar Seabird Working Group. Akureyri: CAFF

Chardine JW, Collins BT, Elliot RD, Levesque H, Ryan PC (1999) Trends in the annual harvest of murres in Newfoundland and Labrador. Bird trends 7: 11-14

Chernook VI, Boltnev AI (2008) Regular instrumental aerial surveys detect a sharp drop in the birthrates of the harp seal in the White Sea, pp.100-4. In: Marine mammals of the Holarctic: collection of scientific papers after the fifth international conference, Odessa, Oct.14-18 2008. Moscow: Marine Mammal Council

Christensen I, Haug T, Øien N (1992) Seasonal distribution, exploitation and present abundance of stocks of large baleen whales (*Mysticeti*) and sperm whales (*Physeter macrocephalus*) in Norwegian and adjacent waters. ICES journal of marine science 49(3): 341-355

Collett R (1912) Norges pattedyr. Aschehoug. (Norges hvirveldyr, 1)

Colominas R (2012) Harbour seal diet in a changing Arctic (Svalbard, Norway). University of Bergen. Master of science thesis

Comiso JC (2000) Bootstrap sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS. Boulder: National Snow and Ice Data Center

Comiso JC, Parkinson CL, Gersten R, Stock L (2008) Accelerated decline in the Arctic sea ice cover. Geophysical research letters 35(1): L01703 (6 pp.)

Daase M, Falk-Petersen S, Varpe Ø, Darnis G, Søreide JE, Wold A, Leu E, Berge J, Philippe B, Fortier L (2013) Timing of reproductive events in the marine copepod *Calanus glacialis*: a pan-Arctic perspective. Canadian journal of fisheries and aquatic sciences 70(6): 871-884

Dahl TM, Lydersen C, Kovacs KM, Falk-Petersen S, Sargent J, Gjertz I, Gulliksen B (2000) Fatty acid composition of the blubber in white whales (*Delphinapterus leucas*). Polar biology 23(6): 401-9

Dalpadado P, Ingvaldsen R, Hassel A (2003) Zooplankton biomass variation in relation to climatic conditions in the Barents Sea. Polar biology 26(4): 233-241

Dalpadado P, Ingvaldsen RB, Stige LC, Bogstad B, Knutsen T, Ottersen G, Ellertsen B (2012) Climate effects on Barents Sea ecosystem dynamics. ICES journal of marine science 69(7): 1303-16

de Korte J, Belikov SE (1994) Observations of Greenland whales (*Balaena mysticetus*), Zemlya Frantsa-Iosifa. Polar record 30(173): 135-6

Derocher AE (2005) Population ecology of polar bears at Svalbard, Norway. Population ecology 47(3): 267-275

Descamps S, Strøm H, Steen H (2013) Decline of an arctic top predator: synchrony in colony size fluctuations, risk of extinction and the subpolar gyre. Oecologia 173(4): 1271-82

Durant JM, Hjermann DØ, Frederiksen M, Charrassin JB, Le Maho Y, Sabarros PS, Crawford RJM, Stenseth NC (2009) Pros and cons of using seabirds as ecological indicators: review. Climate research 39(2): 115-129

Durner GM et al (2009) Predicting 21st century polar bear habitat distribution from global climate models. Ecological monographs 79(1): 25-58

Egevang C, Merkel F, Labansen A (2012) Grønlands lomvie-kolonier: en opsummering af polarlomvieoptællinger. Nuuk: Grønlands Naturinstitut

Eriksen E (ed.) 2012. Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea, August-October 2012. Bergen: Institute of Marine Research. (IMR/PINRO joint report series, 2012:2)

Eriksen E, Prozorkevich D, Trofimov A, Howell D (2012) Biomass of scyphozoan jellyfish, and its spatial association with 0-group fish in the Barents Sea. PLoS ONE 7(3): e33050 (10 pp.)

Erikstad KE, Strøm H (2012) Effekter av miljøgifter på bestanden av polarmåke på Bjørnøya sluttrapport til Svalbards miljøvernfond. Tromsø. (Norsk Polarinstitutt. Kortrapport, 25)

Falk-Petersen S, Mayzaud P, Kattner G, Sargent JR (2009) Lipids and life strategy of Arctic Calanus, pp.18-39. In: Fifty years of Norwegian-Russian collaboration in marine research / ed. T Haug et al. Taylor & Francis. (Marine biology research, 5:1 – thematic issue 2)

Falk K, Durinck J (1992) Thick-billed murre hunting in West Greenland, 1988-89. Arctic 45(2): 167-178

Fauchald P (2011) Sjøfugl i åpent hav: utbredelsen av sjøfugl i norske og tilgrensende havområder. Tromsø: Norsk institutt for naturforskning. (NINA rapport, 786)

Fauchald P, Erikstad KE (2002) Scale-dependent predator-prey interactions: the aggregative response of seabirds to prey under variable prey abundance and patchiness. Marine ecology, progress series 231: 279-291

Fauchald P, Mauritzen M, Gjøsæter H (2006) Density-dependent migratory waves in the marine pelagic ecosystem. Ecology 87(11): 2915-24

Fauchald P, Skov H, Skern-Mauritzen M, Johns D, Tveraa T (2011) Wasp-waist interactions in the North Sea ecosystem. PLoS ONE 6(7): e22729 (10 pp.)

Fiskeridepartementet (1952) Kongelig resolusjon 20. juni [om fredning av hvalross]. Oslo

Frank KT, Petrie B, Fisher JAD, Leggett WC (2011) Transient dynamics of an altered large marine ecosystem. Nature 477(7362): 86-89

Frederiksen M et al (2012) Multicolony tracking reveals the winter distribution of a pelagic seabird on an ocean basin scale. Diversity and distributions 18(6): 530-542

Freitas C, Kovacs KM, Ims RA, Fedak MA, Lydersen C (2009) Deep into the ice: over-wintering and habitat selection in Atlantic walruses. Marine ecology, progress series 375: 247-261

Frie AK, Stenson GB, Haug T (2012) Long-term trends in reproductive and demographic parameters of female Northwest Atlantic hooded seals (*Cystophora cristata*): population responses to ecosystem change? Canadian journal of zoology 90(3): 376-392

Gabrielsen GW, Evenset A, Frantzen S, Gwynn J, Hallanger IG, Kallenborn R, Pfaffhuber KA, Routti H, Sagerup K (2012a) MOSJ statusrapport 2011 miljøgifter. Tromsø. (Norsk Polarinstitutt. Rapportserie, 137)

Gabrielsen TM, Merkel B, Søreide JE, Johansson-Karlsson E, Bailey A, Vogedes D, Nygård H, Varpe Ø, Berge J (2012b) Potential misidentifications of two climate indicator species of the marine Arctic ecosystem: *Calanus glacialis* and *C. finmarchicus*. Polar biology 35(11): 1621-8

Gaston AJ, Irons D (2010) Seabirds: murres (guillemots), pp.35-37. In: Arctic biodiversity trends 2010: selected indicators of change / ed. T Kurvits et al. Akureyri: CAFF

Gaston AJ, Smith PA, Tranquilla LM, Montevecchi WA, Fifield DA, Gilchrist HG, Hedd A, Mallory ML, Robertson GJ, Phillips RA (2011) Movements and wintering areas of breeding age thick-billed murre *Uria lomvia* from two colonies in Nunavut, Canada. Marine biology 158(9): 1929-41

Gilg O, Born EW (2005) Recent sightings of the bowhead whale (*Balaena mysticetus*) in Northeast Greenland and the Greenland Sea. Polar biology 28(10): 796-801

Gill MJ et al (2011) Arctic marine biodiversity monitoring plan. Akureyri. (CAFF monitoring series report, 3)

Gjertz I, Wiig Ø (1995) The number of walruses (*Odobenus rosmarus*) in Svalbard in summer. Polar biology 15(7): 527-530

Gjøsæter H, Bogstad B, Tjelmeland S (2009) Ecosystem effects of the three capelin stock collapses in the Barents Sea. Marine biology research 5(1): 40-53

Grebmeier JM, Cooper LW, Feder HM, Sirenko BI (2006) Ecosystem dynamics of the Pacific-influenced northern Bering and Chukchi Seas in the Amerasian Arctic, pp.331-361. In:

Structure and function of contemporary food webs on Arctic shelves: a pan-Arctic comparison / ed. P Wassmann. (Progress in oceanography 71: 2/4)

Grebmeier JM, Moore SE, Overland JE, Frey KE, Gradinger R (2010) Biological response to recent Pacific Arctic sea ice retreats. EOS: transactions 91(18): 161–2

Guerra M, Thode AM, Blackwell SB, Macrander AM (2011) Quantifying seismic survey reverberation off the Alaskan North Slope. Journal of the Acoustical Society of America 130(5): 3046-58

Hamre J (1994) Biodiversity and exploitation of the main fish stocks in the Norwegian - Barents Sea ecosystem. Biodiversity and conservation 3(6): 473-492

Hansen E, Gerland S, Granskog MA, Pavlova O, Renner AHH, Haapala J, Løyning TB, Tschudi M (2013) Thinning of Arctic sea ice observed in Fram Strait, 1990-2011. Journal of geophysical research. Oceans 118(C10): 5202-21

Hanssen SA, Moe B, Bårdsen BJ, Hanssen F, Gabrielsen GW (2013) A natural antipredation experiment: predator control and reduced sea ice increases colony size in a long-lived duck. Ecology and evolution 3(10): 3554-64

Harvell CD, Kim K, Burkholder JM, Colwell RR, Epstein PR, Grimes DJ, Hofmann EE, Lipp EK, Osterhaus ADME, Overstreet RM, Porter JW, Smith GW, Vasta GR (1999) Emerging marine diseases: climate links and anthropogenic factors. Science 285(5433): 1505-10

Haug T, Nilssen KT, Lindblom L (2004) Feeding habits of harp and hooded seals in drift ice waters along the east coast of Greenland in summer and winter. Polar research 23(1): 35-42

Haug T, Stenson GB, Corkeron PJ , Nilssen KT (2006) Estimation of harp seal (*Pagophilus groenlandicus*) pup production in the North Atlantic completed: results from surveys in the Greenland Sea in 2002. ICES journal of marine science 63(1): 95-104

Haug T, Nilssen KT, Lindblom L, Lindstrøm U (2007) Diets of hooded seals (*Cystophora cristata*) in coastal waters and drift ice waters along the east coast of Greenland. Marine biology research 3(3): 123-133

Heide-Jørgensen MP, Laidre KL (2004) Declining extent of open-water refugia for top predators in Baffin Bay and adjacent waters. Ambio 33(8): 487-494

Heide-Jørgensen MP, Wiig Ø (eds.) 2002. Belugas in the North Atlantic and the Russian Arctic. Tromsø: North Atlantic Marine Mammal Commission. (NAMMCO scientific publications, 4)

Heide-Jørgensen MP, Laidre K, Borchers D, Samarra F, Stern H (2007) Increasing abundance of bowhead whales in West Greenland. Biology letters 3(5): 577-580

Higdon JW, Hauser DDW, Ferguson SH (2011) Killer whales (*Orcinus orca*) in the Canadian Arctic: distribution, prey items, group sizes and seasonality. Marine mammal science 28(2): E93-E109

Hindell MA, Lydersen C, Hop H, Kovacs KM (2012) Pre-partum diet of adult female bearded seals in years of contrasting ice conditions. PLoS ONE, 7(5): e38307 (10 pp.)

Hjermann DØ, Bogstad B, Dingsør GE, Gjøsæter H, Ottersen G, Eikeset AM, Stenseth NC (2010) Trophic interactions affecting a key ecosystem component: a multistage analysis of the recruitment of the Barents Sea capelin (*Mallotus villosus*). Canadian journal of fisheries and aquatic sciences 67(9): 1363-75

Hoel A (1949) Ishavsfangst – fangstnæring, pp 706-861. In: Norsk fiskeri- og fangsthåndbok / ed. J Strøm. Oslo: Cammermeyer. Vol 1

Hop H et al (2002) The marine ecosystem of Kongsfjorden, Svalbard. Polar research 21(1): 167-208

Hop H, Falk-Petersen S, Svendsen H, Kwasniewski S, Pavlov V, Pavlova O, Søreide JE (2006) Physical and biological characteristics of the pelagic system across Fram Strait to Kongsfjorden, pp.182-231. In: Structure and function of contemporary food webs on Arctic shelves: a pan-Arctic comparison / ed. P Wassmann. (Progress in oceanography 71: 2/4)

Huse G, Holst JC, Utne K, Nøttestad L, Melle W, Slotte A, Ottersen G (eds.) 2012. Effects of interactions between fish populations on ecosystem dynamics in the Norwegian Sea: results of the INFERNO project. Taylor & Francis. (Marine biology research, 8:5/6 – thematic issue 4)

ICES (2011) Report of the Working group on harp and hooded seals (WGHARP). Copenhagen: International Council for the Exploration of the Sea. (ICES CM, 2011. ACOM, 22)

ICES (2013a) Advice basis June 2013. Copenhagen. (ICES advice, 2013: book 1)

ICES (2013b) Advice on beaked redfish (*Sebastes mentella*) in subare as I and II. Copenhagen (ICES advice, 2013: book 3)

ICES (2013c) Advice on capelin in Subareas I and II, excluding division IIa west of 5°W (Barents Sea capelin). Copenhagen. (ICES advice: 2013, book 3)

ICES (2013d) Advice on cod in Subareas I and II (Northeast arctic cod). Copenhagen. (ICES advice, 2013: book 3)

ICES (2013e) Advice on golden redfish (*Sebastes marinus*) in subareas I and II. Copenhagen. (ICES advice, 2013: book 3)

ICES (2013f) Advice on Greenland halibut in subareas I and II. Copenhagen. (ICES advice, 2013: book 3)

ICES (2013g) Advice on herring in subareas I, II and V, and in divisions IVa and XIVa (Norwegian spring-spawning herring). Copenhagen. (ICES advice, 2013: book 9)

Ingvaldsen RB, Gjøsæter H (2013) Responses in spatial distribution of Barents Sea capelin to changes in stock size, ocean temperature and ice cover, pp.867-877. In: Climate effects on the Barents Sea marine living resources / ed. T Haug et al. Taylor & Francis. (Marine biology research, 9:9 – thematic issue 7)

Jackson JBC et al. (2001) Historical overfishing and the recent collapse of coastal ecosystems: review. Science 293(5530): 629-638

Jennings S, Kaiser MJ (1998) The effects of fishing on marine ecosystems. Advances in marine biology, 34: 201-352

Jensen SK, Aars J, Lydersen C, Kovacs KM, Åsbakk K (2010) The prevalence of *Toxoplasma gondii* in polar bears and their marine mammal prey: evidence for a marine transmission pathway? Polar biology 33(5): 599-606

Johannesen E, Ingvaldsen RB, Bogstad B, Dalpadado P, Eriksen E, Gjøsæter H, Knutsen T, Skern-Mauritzen M, Stiansen JE (2012a) Changes in Barents Sea ecosystem state, 1970-2009: climate fluctuations, human impact and trophic interactions, pp.880-9. In: Variability of the North Atlantic and its marine ecosystems during 2000-2009: proceedings of an ICES/NAFO symposium .../ ed. P Wiebe et al. (ICES journal of marine science, 69:5)

Johannesen E, Lindstrøm U, Michalsen K, Skern-Mauritzen M, Fauchald P, Bogstad B, Dolgov AV (2012b) Feeding in a heterogeneous environment: spatial dynamics in summer foraging Barents Sea cod. Marine ecology, progress series 458: 181-197

Johannessen OM, Miles MW (2010) Critical vulnerabilities of marine and sea ice-based ecosystems in the high Arctic, pp.S239-48. In: Climate hotspots: key vulnerable regions, climate change and limits to warming. Berlin: Springer. (Regional environmental change, 11:1 Suppl.)

Johnston DW, Bowers MT, Friedlaender AS, Lavigne DM (2012) The effects of climate change on harp seals (*Pagophilus groenlandicus*). PLoS ONE 7(1): e29158 (8 pp.)

Jonsgård Å (1981) Bowhead whales, Balaena mysticetus, observed in Arctic waters of the eastern North Atlantic after the second world war. Report of the International Whaling Commission 31: 38-92

Karlsen JD, Bisther A, Lydersen C, Haug T, Kovacs, KM (2002) Summer vocalisations of adult male white whales (*Delphinapterus leucas*) in Svalbard, Norway. Polar biology 25(11): 808-817

Kelly BP, Bengtson JL, Boveng PL, Cameron MF, Dahle SP, Jansen JK, Logerwell EA, Overland JE, Sabine CL, Waring GT, Wilder JM (2010) Status review of the ringed seal (*Phoca hispida*). National Oceanic and Atmospheric Administration. (NOAA Technical Memorandum, NMFS-AFSC-212)

Kjær KG (2011) Serial slaughter: the development of the north Norwegian sealing fleet, 1859-1909. Polar record 47(240): 1-20

Koslow JA, Boehlert GW, Gordon JDM, Haedrich RL, Lorance P, Parin N (2000) Continental slope and deep-sea fisheries: implications for a fragile ecosystem, pp.548-557. In: Ecosystem effects of fishing: proceedings of an ICES/SCOR symposium …/ ed CE Hollingworth. (ICES journal of marine science, 57:3) (ICES marine science symposia, 210)

Kovacs KM, Lydersen C (2008) Climate change impacts on seals and whales in the North Atlantic Arctic and adjacent shelf seas. Science progress 91(2): 117-150

Kovacs KM, Michel C (2011) Biological impacts of changes in sea ice in the Arctic, pp.9.32-9.52. In: Snow, water, ice and permafrost in the Arctic (SWIPA): climate change and the cryosphere / ed. C Symon. Oslo: Arctic Monitoring and Assessment Programme

Kovacs KM, Lydersen C, Overland JE, Moore SE (2011) Impacts of changing sea-ice conditions on Arctic marine mammals. Marine biodiversity 41(1): 181-194

Kraft A, Berge J, Varpe Ø, Falk-Petersen S (2013) Feeding in Arctic darkness: mid-winter diet of the pelagic amphipods *Themisto abyssorum* and *T. libellula*. Marine biology 160(1): 241-8

Kurvits T, Alfthan B, Mork E (eds.) 2010. Arctic biodiversity trends 2010: selected indicators of change. Akureyri: CAFF

Kwasniewski S, Hop H, Falk-Petersen S, Pedersen G (2003) Distribution of Calanus species in Kongsfjorden, a glacial fjord in Svalbard. Journal of plankton research 25(1): 1-20

Kwasniewski S et al (2012) Interannual changes in zooplankton on the West Spitsbergen Shelf in relation to hydrography and their consequences for the diet of planktivorous seabirds, pp.890-901. In: Variability of the North Atlantic and its marine ecosystems during 2000-2009: proceedings of an ICES/NAFO symposium .../ ed. P Wiebe et al. (ICES journal of marine science, 69:5)

Kwok R, Cunningham GF, Pang SS (2004) Fram Strait sea ice outflow. Journal of geophysical research. Oceans 109(C1): C01009 (14 pp.)

Kålås JA, Viken Å, Henriksen S, Skjelseth S (eds.) 2010. The 2010 Norwegian red list for species. Trondheim: Artsdatabanken

Labansen AL, Lydersen C, Haug T, Kovacs KM (2007) Spring diet of ringed seals (*Phoca hispida*) from northwestern Spitsbergen, Norway. ICES journal of marine science 64(6): 1246-56

Laidre KL, Stirling I, Lowry LF, Wiig Ø, Heide-Jørgensen MP, Ferguson SF (2008) Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change, pp.S97-S125. In: Arctic marine mammals and climate change / ed. HP Huntington and SE Moore. Ecological Society of America. (Ecological applications, 18:2 Suppl.)

Larsen T (1986) Population biology of the polar bear (*Ursus maritimus*) in the Svalbard area. Oslo. (Norsk Polarinstitutt. Skrifter, 184)

Lavigne DM , Kovacs KM (1988) Harps & hoods: ice breeding seals of the Northwest Atlantic. University of Waterloo press

Leu E, Søreide JE, Hessen DO, Falk-Petersen S, Berge J (2011) Consequences of changing sea-ice cover for primary and secondary producers in the European Arctic shelf seas: timing, quantity and quality, pp.18-32. In: Arctic marine ecosystems in an era of rapid climate change /ed P Wassmann. (Progress in oceanography, 90)

Lilly GR, Nakken O, Brattey J (2013) A review of the contributions of fisheries and climate variability to contrasting dynamics in two Arcto-boreal Atlantic cod (*Gadus morhua*) stocks: persistent high productivity in the Barents Sea and collapse on the Newfoundland and Labrador Shelf, pp.106-125. In: Norway-Canada comparison of marine ecosystems (NORCAN) / ed. KF Drinwater and P Pepin. (Progress in oceanography, 114)

Link JS, Bogstad B, Sparholt H, Lilly GR (2009) Trophic role of Atlantic cod in the ecosystem. Fish and fisheries 10(1): 58-87

Lydersen C, Kovacs KM (2010a) Status and biology of harbour seals (*Phoca vitulina*) in Svalbard, pp.47-60. In: Harbour seals in the North Atlantic and the Baltic / ed. G Desportes et al. Tromsø: North Atlantic Marine Mammal Commission. (NAMMCO scientific publications, 8)

Lydersen C, Kovacs KM (2010b) One animal's loss is another animal's gain. Norwegian Polar Institute. Annual report, 2009: 20

Lydersen C, Kovacs KM (2010c) Svalbards stedegne sjøpattedyr og klimatrusselen, pp.64-67. In: Sjøens pattedyr 2010 / ed. A Bjørge et al. Bergen: Institute of Marine Research. (Fisken og havet, særnummer, 2010:2)

Lydersen C, Kovacs KM (2010d) Selene og hvalrossen. Svalbardposten 62(24): 19

Lydersen C, Martin AR, Kovacs KM, Gjertz I (2001) Summer and autumn movements of white whales (*Delphinapterus leucas*) in Svalbard, Norway. Marine ecology, progress series 219: 265-274

Lydersen C, Nøst OA, Lovell P, McConnell BJ, Gammelsrød T, Hunter C, Fedak MA, Kovacs KM (2002) Salinity and temperature structure of a freezing Arctic fjord, monitored by white whales (*Delphinapterus leucas*). Geophysical research letters 29(23): 2119 (4 pp.)

Lydersen C, Freitas C, Wiig Ø, Bachmann L, Heide-Jørgensen MP, Swift R, Kovacs KM (2012) Lost highway not forgotten: satellite tracking of a bowhead whale (*Balaena mysticetus*) from the critically endangered Spitsbergen stock. Arctic 65(1): 76-86

Lønø O (1970) The polar bear (*Ursus maritimu*s Phipps) in the Svalbard area. Oslo. (Norsk Polarinstitutt. Skrifter, 149)

Lønø O, Øynes P (1961) White whale fishery at Spitsbergen. Norwegian whaling gazette 50(7): 267-287

MA (2005) Millennium Ecosystem Assessment synthesis report. Washington DC

Mehlum F (ed.) 1991. Eider studies in Svalbard. Oslo. (Norsk Polarinstitutt. Skrifter, 195)

Mehlum F (2012) Effects of sea ice on breeding numbers and clutch size of a high Arctic population of the common eider Somateria mollissima, pp.143-153. In: The Second International Symposium on the Antarctic Research (ISAR-2) / ed. P Wadhams et al. Amsterdam: Elsevier. (Polar science, 6:1 – special issue)

Meier WN, Haas C (2011) Changes in the physical state of sea ice, pp.9.4–9.18. In: Snow, water, ice and permafrost in the Arctic (SWIPA): climate change and the cryosphere / ed. C Symon. Oslo: Arctic Monitoring and Assessment Programme

Meltofte H (ed.) 2013. Arctic biodiversity assessment: status and trends in Arctic biodiversity, synthesis. Akureyri: CAFF

Merkel FR (2010) Seabird harvest, pp.89-91. In: Arctic biodiversity trends 2010: selected indicators of change / ed. H Kurvits et al. Akureyri: CAFF

Merkel F, Gilchrist G (2010) Seabirds. Common eider, pp.38-40. In: Arctic biodiversity trends 2010: selected indicators of change / ed. H Kurvits et al. Akureyri: CAFF

Merkel B, Lydersen C, Yoccoz NG, Kovacs KM (2013) The worlds's northernmost harbour seal population: how many are there? PLoS ONE 8(7): e67576 (11 pp.)

Michel C (2013) Marine ecosystems, pp.486-527. In: Arctic biodiversity assessment: status and trends in Arctic biodiversity (full report) / ed. H Meltofte. Akureyri: CAFF

Miljøverndepartementet (1978) Forskrift om forvaltning av vilt og ferskvannsfisk på Svalbard og Jan Mayen. Oslo (11. august 1978; nr 3765)

Miljøverndepartementet (2011). Oppdatering av forvaltningsplanen for det marine miljø i Barentshavet og havområdene utenfor Lofoten. Oslo. (Stortingsmelding, 2010/11: 10)

Moore SE (2008) Marine mammals as ecosystem sentinels. Journal of mammalogy 89(3): 534–540

Moore SE, Stafford KM, Melling H, Berchok C, Wiig Ø, Kovacs KM, Lydersen C, Richter-Menge J (2012) Comparing marine mammal acoustic habitats in Atlantic and Pacific sectors of the high Arctic: year-long records from Fram Strait and the Chukchi Plateau. Polar biology 35(3): 475-480

Narayanaswamy BE, Renaud PE, Duineveld GCA, Berge J, Lavaleye MSS, Reiss H, Brattegard T (2010) Biodiversity trends along the western European margin: review. PLoS ONE 5(12): e14295 (19 pp.)

Nilssen KT, Haug T, Øritsland T, Lindblom L, Kjellqwist SA (1998) Invasions of harp seals Phoca groenlandica Erxleben to coastal waters of Norway in 1995: ecological and demographic implications. Sarsia 83(4): 337-345

Norderhaug M (1969) Hvalrossens (*Odobenus rosmarus*) forekomst i Svalbardområdet 1960-1967. Norsk Polarinstitutt. Årbok 1967: 146-150

Norse EA et al (2012) Sustainability of deep-sea fisheries. Marine policy 36(2): 307-320

Nøttestad L et al (2013) Cruise report from the coordinated ecosystem survey (IESSNS) with M/V ”Libas”, M/V “Eros”, M/V “Finnur Fríði” and R/V “Arni Fridriksson” in the Norwegian Sea and surrounding waters, 2 July - 9 August 2013: working document to ICES … Bergen: Institute of Marine Research

O'Corry-Crowe G, Lydersen C, Heide-Jørgensen MP, Hansen L, Mukhametov LM, Dove O, Kovacs KM (2010) Population genetic structure of North Atlantic beluga whales (*Delphinapterus leucas*) from West Greenland, Svalbard and the White Sea. Polar biology 33(9): 1179-94

Ottersen G, Hjermann DØ, Stenseth NC (2006) Changes in spawning stock structure strengthen the link between climate and recruitment in a heavily fished cod (*Gadus morhua*) stock. Fisheries oceanography 15(3): 230-243

Overland JE, Wang M (2010) Large-scale atmospheric circulation changes associated with the recent loss of Arctic sea ice. Tellus. Dynamic meteorology and oceanography 62(A1): 1–9

Parent GJ, Plourde S, Turgeon J (2012) Natural hybridization between *Calanus finmarchicus* and *C. glacialis* (Copepoda) in the Arctic and Northwest Atlantic. Limnology and oceanography 57(4): 1057-66

Piatt JF, Sydeman WJ, Wiese F (2007) Introduction: a modern role for seabirds as indicators. Marine ecology, progress series 352: 199-204

Planque B, Johannesen E, Drevetnyak KV, Nedreaas KH (2012) Historical variations in the year-class strength of beaked redfish (*Sebastes mentella*) in the Barents Sea. Ices journal of marine science 69(4): 547-552

Prestrud P, Mehlum F (1991) Population size and summer distribution of the common eider *Somateria mollissima* in Svalbard, 1981-1985, pp.9-20. In: Eider studies in Svalbard / ed. F Mehlum. Oslo. (Norsk Polarinstitutt. Skrifter, 195)

Prestrud KW, Åsbakk K, Fuglei E, Mørk T, Stien A, Ropstad E, Tryland M, Gabrielsen GW, Lydersen C, Kovacs KM, Loonen MJJE, Sagerup K, Oksanen A (2007) Serosurvey for *Toxoplasma gondii* in Arctic foxes and possible sources of infection in the high Arctic of Svalbard. Veterinary parasitology 150(1/2): 6-12

Ragen TJ, Huntington HP, Hovelsrud GK (2008) Conservation of Arctic marine mammals faced with climate change, pp.S166-S174. In: Arctic marine mammals and climate change / ed. HP Huntington and SE Moore. Ecological Society of America. (Ecological applications, 18:2 Suppl.)

Reeves RR (1998) Distribution, abundance and biology of ringed seals (*Phoca hispida*): an overview, pp.9-45. In: Ringed seals in the North Atlantic / ed. MP Heide-Jørgensen and C Lydersen. Tromsø: North Atlantic Marine Mammal Commission. (NAMMCO scientific publications, 1)

Reeves R, Rosa C, George JC, Sheffield G, Moore M (2012) Implications of Arctic industrial growth and strategies to mitigate future vessel and fishing gear impacts on bowhead whales. Marine policy 36(2): 454-462

Regehr EV, Hunter CM, Caswell H, Amstrup SC, Stirling I (2010) Survival and breeding of polar bears in the southern Beaufort Sea in relation to sea ice. Journal of animal ecology 79(1): 117–127

Reiertsen TK (2013) Seabirds, climate and prey: a population study of two seabird species. University of Tromsø. Ph.D. dissertation

Roberts CM (2002) Deep impact: the rising toll of fishing in the deep sea. Trends in ecology & evolution 17(5): 242-5

Rosenberg AA, Bolster WJ, Alexander KE, Leavenworth WB, Cooper AB, McKenzie MG (2005) The history of ocean resources: modeling cod biomass using historical records. Frontiers in ecology and the environment 3(2): 84-90

Rosing-Asvid A (2008) A new harp seal whelping ground near South Greenland. Marine mammal science 24(3): 730-6

Roth SJ, Tischer BK, Kovacs KM, Lydersen C, Osterrieder N, Tryland M (2013) Phocine herpesvirus 1 (PhHV-1) in harbor seals from Svalbard, Norway. Veterinary microbiology 164(3/4): 286-292

Russkikh AA, Kovalev YA, Nedreaas KH (2013) Fisheries, pp.43-56. In: Joint Norwegian-Russian environmental status report on the Barents Sea Ecosystem: update for current situation for climate, phytoplankton, zooplankton, fish and fisheries in 2011 / ed. P Arneberg et al. Bergen. (IMR/PINRO joint report series, 2013:3)

Salberg AB, Øigard TA, Stenson GB, Haug T, Nilssen KT (2009) Estimation of seal pup production from aerial surveys using generalized additive models. Canadian journal of fisheries and aquatic sciences 66(5): 847-858

Sandvik H, Erikstad KE, Barrett RT, Yoccoz NG (2005) The effect of climate on adult survival in five species of North Atlantic seabirds. Journal of animal ecology 74(5): 817-831

Schweder T, Sadykova D, Rugh D, Koski W (2010) Population estimates from aerial photographic surveys of naturally and variably marked bowhead whales. Journal of agricultural, biological and environmental statistics 15(1): 1-19

Shevelev MS, Sunnanå K, Gusev EV (2011) History of fisheries and hunting, pp.495-514. In: The Barents Sea: ecosystem, resources, management - half a century of Russian-Norwegian cooperation / ed. T Jakobsen and VK Ozhigin. Trondheim: Tapir

Skoglund EG, Lydersen C, Grahl-Nielsen O, Haug T, Kovacs KM (2010) Fatty acid composition of blubber and dermis of adult male Atlantic walruses (*Odobenus rosmarus rosmarus*) in Svalbard, and their potential prey. Marine biology research 6(3): 239-250

Solomon S, Qin D, Manning M, Marquis M, Averyt K, Tignor MMB, Miller HL, Chen Z (eds.) 2007. Climate change 2007: the physical science basis / contribution of Working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press

Spielhagen RF, Werner K, Sørensen SÅ, Zamelczyk K, Kandiano E, Budeus G, Husum K, Marchitto TM, Hald M (2011) Enhanced modern heat transfer to the Arctic by warm Atlantic water. Science 331(6016): 450-3

Stafford KM, Moore SE, Berchok CL, Wiig Ø, Lydersen C, Hansen E, Kalmbach D, Kovacs KM (2012) Spitsbergen's endangered bowhead whales sing through the polar night. Endangered species research 18(2): 95-103

Steen H, Lorentzen E, Strøm H (2013) Winter distribution of guillemots (Uria spp.) in the Barents Sea. Tromsø. (Norsk Polarinstitutt. Report series, 141)

Stige LC, Ottersen G, Dalpadado P, Chan KS, Hjermann DØ, Lajus DL, Yaragina NA, Stenseth NC (2010) Direct and indirect climate forcing in a multi-species marine system. Proceedings of the Royal Society. B: biological sciences 277(1699): 3411-20

Strann KB, Vader W, Barret RT (1991) Auk mortality in fishing nets in Norway. Seabird 13: 22-29

Stroeve J, Holland MM, Meier W, Scambos T, Serreze M (2007) Arctic sea ice decline: faster than forecast. Geophysical research letters 34(9): L09501 (5 pp.)

Svensen C, Seuthe L, Vasilyeva Y, Pasternak A, Hansen E (2011) Zooplankton distribution across Fram Strait in autumn: Are small copepods and protozooplankton important? Progress in oceanography 91(4): 534-544

Symon C (ed.) 2011. Snow, water, ice and permafrost in the Arctic (SWIPA): climate change and the cryosphere. Oslo: Arctic Monitoring and Assessment Programme

Søreide JE, Hop H, Falk-Petersen S, Gulliksen B, Hansen E (2003) Macrozooplankton communities and environmental variables in the Barents Sea marginal ice zone in late winter and spring. Marine ecology, progress series 263:43-64

Søreide JE, Leu E, Berge J, Graeve M, Falk-Petersen S (2010) Timing of blooms, algal food quality and *Calanus glacialis* reproduction and growth in a changing Arctic. Global change biology 16(11): 3154-63

Tittlemier S et al (2002) Global distribution of halogenated dimethyl bipyrroles in marine mammal blubber. Archives of environmental contamination 43(2): 244-255

Treble MA, Campana SE, Wastle RJ, Jones CM, Boje J (2008) Growth analysis and age validation of a deepwater Arctic fish, the Greenland halibut (*Reinhardtius hippoglossoides*). Canadian journal of fisheries and aquatic sciences 65(6): 1047-59

Tryland M, Thoresen SI, Kovacs KM, Lydersen C (2006) Serum chemistry of free-ranging white whales (*Delphinapterus leucas*) in Svalbard. Veterinary clinical pathology 35(2): 199-203

Tryland M, Lydersen C, Kovacs KM, Thoresen SI (2009) Serum chemistry reference values in free-ranging North Atlantic male walruses (*Odobenus rosmarus rosmarus*) from the Svalbard Archipelago. Veterinary clinical pathology 38(4): 501-6

Utne KR, Hjøllo SS, Huse G, Skogen M (2012) Estimating the consumption of *Calanus finmarchicus* by planktivorous fish in the Norwegian Sea using a fully coupled 3D model system, pp. 527-547. In: Effects of interactions between fish populations on ecosystem dynamics in the Norwegian Sea: results of the INFERNO project / ed. G Huse et al. Taylor & Francis. (Marine biology research, 8:5/6 – thematic issue 4)

Vader W, Barret RT, Erikstad KE, Strann KB (1990) Differential responses of common and thick-billed murres to a crash in the capelin stock in the southern Barents Sea, pp.175-180. In: Auks at sea: proceedings of an international symposium …/ ed. SG Sealy. Cooper Ornithological Society. (Studies in avian biology, 14)

Villanger GD, Lydersen C, Kovacs KM, Lie E, Skaare JU, Jenssen BM (2011) Disruptive effects of persistent organohalogen contaminants on thyroid function in white whales (*Delphinapterus leucas*) from Svalbard. Science of the total environment 409(13): 2511-24

Vinje T, Nordlund N, Kvambekk Å (1998) Monitoring ice thickness in Fram Strait. Journal of geophysical research. Oceans 103(C5): 10437-49

Walczowski W, Piechura J (2011) Influence of the West Spitsbergen Current on the local climate. International journal of climatology 31(7): 1088-93

Walters CJ, Martell SJ (2004) Fisheries ecology and management. Princeton University Press

Wang M, Overland JE (2009) A sea ice free summer Arctic within 30 years? Geophysical research letters 36(7): L07502 (5 pp.)

Wassmann P (2011) Arctic marine ecosystems in an era of rapid climate change, pp.1-17. In: Arctic marine ecosystems in an era of rapid climate change /ed P Wassmann.
(Progress in oceanography, 90)

Wassmann P, Duarte CM, Agusti S, Sejr MK (2011) Footprints of climate change in the Arctic marine ecosystem. Global change biology 17(2): 1235-49

Wathne JA, Haug T, Lydersen C (2000) Prey preference and niche overlap of ringed seals *Phoca hispida* and harp seals *P. groenlandica* in the Barents Sea. Marine ecology, progress series 194: 233-9

Wiig Ø, Gjertz I, Griffiths D (1996) Migration of walruses (*Odobenus rosmarus*) in the Svalbard and Franz Josef Land area. Journal of zoology 238(4): 769-784

Wiig Ø, Bachmann L, Janik VM, Kovacs KM, Lydersen C (2007a) Spitsbergen bowhead whales revisited. Marine mammal science 23(3): 688-693

Wiig Ø, Born EW, Gjertz I, Lydersen C, Stewart REA (2007b) Historical sex-specific distribution of Atlantic walrus (*Odobenus rosmarus rosmarus*) in Svalbard assessed by mandible measurements. Polar biology 31(1): 69-75

Wiig Ø, Bachmann L, Øien N, Kovacs KM, Lydersen C (2010) Observations of bowhead whales (*Balaena mysticetus*) in the Svalbard area 1940 – 2009. Polar biology 33(7): 979-984

Willis K, Cottier F, Kwasniewski S, Wold A, Falk-Petersen S (2006) The influence of advection on zooplankton community composition in an Arctic fjord (Kongsfjorden, Svalbard). Journal of marine systems 61(1/2): 39-54

Wilson SJ, Murray JL, Huntington HP (eds.) 1998. AMAP assessment report: Arctic pollution issues. Oslo: Arctic Monitoring and Assessment Programme

Wolkers H, van Bavel B, Derocher AE, Wiig Ø, Kovacs KM, Lydersen C, Lindstrøm G (2004) Congener-specific accumulation and food chain transfer of polybrominated diphenyl ethers in two Arctic food chains. Environmental science & technology 38(6): 1667-74

Wolkers H, Lydersen C, Kovacs KM, Burkow I, van Bavel B (2006) Accumulation, metabolism and food-chain transfer of chlorinated and brominated contaminants in subadult white whales (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) from Svalbard, Norway. Archives of environmental contamination and toxicology 50(1): 69-78

Woodby DA, Bodkin DB (1993) Stock sizes prior to commercial whaling, pp.387-407. In: The bowhead whale / ed. JJ Burns et al. Lawrence, KS. (Special publications of the Society for Marine Mammalogy, 2)

Zabavnikov VB, Egorov SA, Zyryanov SV, Shafikov IN (2008) About current situation with harp seal White Sea population (*Phoca groenlandica*): scientific based, complex system view on problem, pp.606-9. In: Marine mammals of the Holarctic: collection of scientific papers after the fifth international conference, Odessa, Oct.14-18 2008. Moscow: Marine Mammal Council

Øigård TA, Lindstrøm U, Haug T, Nilssen KT, Smout S (2013a) Functional relationship between harp seal body condition and available prey in the Barents Sea. Marine ecology, progress series 484: 287-301

Øigård TA, Haug T, Nilssen KT (2013b) From pup production to quotas: current status of harp seals in the Greenland Sea. ICES journal of marine science: doi.10.1093/icesjms/fst155. (9 pp.)

Øigård TA, Haug T, Nilssen KT (2014) Current status of hooded seals in the Greenland Sea: victims of climate change and predation? Biological conservation 172: 29-36

RAPPORTSERIE · REPORT SERIES 145
NORSK POLARINSTITUTT · NORWEGIAN POLAR INSTITUTE 2013