FISHERIES MANAGEMENT AND THE ARCTIC IN THE CONTEXT OF CLIMATE CHANGE
Abstract

Climate change is expected to significantly affect the Arctic Ocean, primarily through warming and reduction of ice cover. Models suggest that fisheries in the Arctic will benefit from increased primary productivity, expansion of distribution ranges of mainly low to medium resilience boreal commercial species and availability of new fishing grounds, especially in international waters not covered by Regional Fisheries Management Organizations. The EU Arctic policy should further develop international collaboration in research and monitoring, and address future fisheries governance issues.
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<th>Description</th>
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<tbody>
<tr>
<td>ABA</td>
<td>Arctic Biodiversity Assessment</td>
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<tr>
<td>AC</td>
<td>Arctic Council</td>
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<td>ACOM</td>
<td>Advisory Committee (ICES)</td>
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<td>AFWG</td>
<td>Arctic Fisheries Working Group</td>
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<td>AMO</td>
<td>Atlantic multi-decadal oscillation</td>
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<td>AMSP</td>
<td>Arctic Marine Strategic Plan</td>
</tr>
<tr>
<td>AO</td>
<td>Arctic Oscillation</td>
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<tr>
<td>AOAS</td>
<td>Arctic Ocean and Adjacent seas</td>
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<tr>
<td>CAFF</td>
<td>Conservation of Arctic Flora and Fauna</td>
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<td>CCAMLR</td>
<td>Commission for the Conservation of Antarctic Marine Living Resources</td>
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<tr>
<td>CMIP5</td>
<td>Coupled Model Intercomparison Project Phase 5</td>
</tr>
<tr>
<td>CP</td>
<td>Contracting party or Contracting Parties</td>
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<tr>
<td>CA</td>
<td>Convention Area</td>
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<tr>
<td>DBEM</td>
<td>Dynamic Bioclimate Envelope Model</td>
</tr>
<tr>
<td>EAM</td>
<td>Ecosystem approach to management</td>
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<tr>
<td>EBM</td>
<td>Ecosystem-based management</td>
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<tr>
<td>EBMM</td>
<td>Ecosystem-based marine management</td>
</tr>
<tr>
<td>EEZ</td>
<td>Exclusive Economic Zone</td>
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<tr>
<td>ENSO</td>
<td>El Niño-Southern Oscillation</td>
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<tr>
<td>EP</td>
<td>European Parliament</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organisation of the United Nations</td>
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<tr>
<td>GIF</td>
<td>East Greenland/Iceland/Faeroe Islands</td>
</tr>
<tr>
<td>HCR</td>
<td>Harvest Control Rule</td>
</tr>
<tr>
<td>IASC</td>
<td>International Arctic Science Council</td>
</tr>
<tr>
<td>ICCAT</td>
<td>International Commission for the Conservation of Atlantic Tuna</td>
</tr>
<tr>
<td>ICES</td>
<td>International Council for the Exploration of the Sea</td>
</tr>
<tr>
<td>IUU</td>
<td>Illegal, unreported and uncontrolled</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>JRNFC</td>
<td>Joint Russian-Norwegian Fisheries Commission</td>
</tr>
<tr>
<td>LME</td>
<td>Large Marine Ecosystem</td>
</tr>
<tr>
<td>MOU</td>
<td>Memorandum of understanding</td>
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<tr>
<td>NAFO</td>
<td>Northwest Atlantic Fisheries Organization</td>
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<td>NASCO</td>
<td>North Atlantic Salmon Conservation Organization</td>
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<td>NCC</td>
<td>Norwegian Coastal cod</td>
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<td>NEAC</td>
<td>North-East Arctic cod</td>
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</table>
**NEAFC**  North East Atlantic Fisheries Commission  
**NAO**  North Atlantic Oscillation  
**NSIDC**  National Snow and Ice Data Center  
**PA**  Precautionary approach  
**PAME**  Protection of the Arctic Marine Environment  
**NIPAG**  NAFO/ICES *Pandalus* Assessment Working Group  
**PDO**  Pacific Decadal Oscillation  
**RA**  Regulatory area  
**RCP**  Representative Concentration Pathway  
**RFMO**  Regional Fisheries Management Organization  
**SAON**  Sustained Arctic Observation Network  
**SCICOM**  Science Committee (ICES)  
**SES**  Social-ecological systems  
**SSB**  Spawning Stock Biomass  
**SST**  Sea surface temperature  
**SSTA**  Sea surface temperature anomalies  
**TAC**  Total Allowable Catch  
**UNCLOS**  United Nations Convention on the Law of the Sea  
**VMS**  Vessel Monitoring System  
**WG**  Working Group  
**WTO**  World Trade Organization  
**YOY**  Young-of-the-year
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EXECUTIVE SUMMARY

Background

Climate change is of increasing concern, especially in the Arctic. The Arctic Ocean and Adjacent Seas (AOAS) cover a vast area, with a variety of different habitats and ecosystems, differing in many ways, including in terms of effects of climate change. The latest Intergovernmental Panel on Climate Change report, the most comprehensive analysis of global climate change to date (Bindoff et al., 2013; Collins et al., 2013; Flato et al., 2013; Kirtman et al., 2013) along with other comprehensive assessments such as those by the Arctic Council and the International Arctic Science Committee (ACIA, 2004, 2005) have concluded that warming is undoubtedly taking place and that the Arctic region is and will continue to be one of the most affected regions of the globe. Increasing temperature, decreasing summer ice cover and ocean acidification are expected to significantly affect primary production, trophic structure, community composition, biodiversity and fisheries. Modelling of climate change effects in the Arctic indicates continued decrease of ice cover in the long term, with some scenarios forecasting an ice-free Arctic in the summer by the middle of this century. New navigation routes will open and new fishing grounds will become available. Little is known of the fragile Arctic marine ecosystem and how it will be affected by the combined effects of climate change and the expansion of fisheries to previously untouched areas. It is also not clear if present governance regimes and bodies are adequate for dealing with the potential development of new fisheries.

Aim

Against this background, the European Parliament (EP) has commissioned this study on 'Fisheries management and the Arctic in the context of climate change', which was awarded to Blomeyer & Sanz.

- The aim of the present study is to provide a comprehensive review and analysis of the implications of climate change for the Arctic ecosystem and the potential development of new fisheries, and make recommendations that can help prevent threats to the fragile Arctic ecosystem. To this end, the authors of this study have reviewed climate related changes in the Arctic over the past decades as well as the latest climate change scenarios for the 21st century;
- reviewed the fish and fisheries of the AOAS, with emphasis on the resilience of commercial fish species and the implications of changes in distribution and the potential development of new fisheries;
- analysed the trends, state of the stocks and the potential impacts of climate change on five of the most important commercial species: North East Atlantic (NE) cod, Greenland halibut, Capelin, Polar cod and Northern shrimp;
- evaluated the role of the different management bodies and existing governance regimes;
- made some forecasts with regard the future development of fisheries in the AOAS, based on the available literature;
- identified gaps and made recommendations for research and Arctic policy.

This study is based on a wide range of sources of information, including primary literature, climate assessment reports, fisheries working group reports, the Fisheries and Agricultural Organization (FAO), national fisheries and oceanographic organizations, NGOs such as the
World Wildlife Fund (WWF), online data bases such as FishBase (www.fishbase.org) and European Union documents.

**Findings**

The **Arctic has only 10% (63) of the total (633) fish species of the AOAS**, with only 3 considered commercial, compared to 58 commercial species for the whole AOAS (Meltofte, 2013). Arctic species have adapted to life in a highly variable environment, with most occupying a narrow temperature range, and except for Polar cod, they are largely bottom dwelling and do not undertake long distance migrations (Christiansen *et al.*, 2014), making them particularly sensitive to climate change, invasive species and fishing. Based on FishBase (Froese and Pauly, 2000), the majority of the commercial species of the AOAS are classified as having low resilience (60%), 24% are medium resilience, with only 16% having high resilience.

Of the **five commercial species selected for analysis**, the biomass of the NE cod stock has increased dramatically in recent years, with evidence of expansion of range and new spawning grounds. In general, Greenland halibut stocks have been fairly stable over the past, while Northern shrimp stocks have declined in recent years, possibly due to a combination of predation, overfishing and less suitable environmental conditions. Polar cod is one of the most abundant marine species but has little commercial value. Capelin shows strong variability in abundance, with reduced catches in recent years.

In addition to short-term environmental variability, largely associated with the **North Atlantic Oscillation (NAO)**, abundances of AOAS resources are heavily influenced by species interactions and fishing, highlighting the importance of an **ecosystem based** approach to **management (EBM)**. For example, the abundance of key forage species such as capelin strongly influences cod population dynamics.

There is a general consensus that **climate change will result in increased productivity in the Arctic**, and that with increasing temperature, there will be a "**borealization**" of the Arctic fish community, with potential for some species to expand their distribution to the Arctic. Among species with such a potential are Polar cod, capelin and Greenland halibut. However, other species such as cod are not expected to expand to the high Arctic. Factors governing the movement and potential of commercial species to expand to the Arctic include suitable thermal conditions and habitats, spawning grounds, migration corridors, the availability and abundance of suitable prey and the match-mismatch between larvae and the production cycle of their zooplankton prey (Hollowed *et al.*, 2013a). Due to the depth of the Arctic Ocean and the fact that most commercially important sub-Arctic species inhabit the continental shelf and shelf slopes that are mostly found within the exclusive economic zones or the Arctic states, it is unlikely that significant Arctic fisheries will develop.

Understanding of the effects of climate change in the Arctic is hampered by **lack of data and gaps in knowledge**. Many exploited species are considered "data-poor" and cannot be assessed using classical methods (e.g. catch-at-age approaches). Research is needed on stock structure of the main commercial species, trophic ecology and dynamics, vulnerability, ecosystem modelling, and on the combined effects of temperature, pH, and oxygen on growth, bioenergetics, survival, recruitment and abundance. **Effective international collaboration in monitoring and research in the Arctic is essential** for understanding the potential impacts of climate change on the Arctic and fisheries in the Arctic and is key to the implementation of an **Ecosystem Approach (EA)** to management.
Uncertainty about the consequences of climate change must be addressed with improved monitoring, data collection and modelling at regional and local scales.

With shrinking ice cover and warming of the sea water, new fishing grounds will become available, mostly in international waters not currently covered by regional fisheries management organizations (RFMO) such as the North Atlantic Fisheries Organization (NAFO) or the North East Atlantic Fisheries Commission (NEAFC), raising questions of sustainability and governance. However, it should be noted that the Arctic coastal states have adopted a precautionary approach (PA) with regard to future development of fisheries in areas not within the jurisdiction of current RFMOs.

In general, most of the major sub-Arctic commercial stocks can be considered well managed, with Arctic coastal states responsible for stocks within their Exclusive Economic Zones (EEZs) and management of shared stocks in international waters by RFMOs. Although good examples of international cooperation can be found, such as the Joint Russian-Norwegian Fisheries Commission (JRNFC), there are some cases where disagreements have arisen over Total Allowable Catch (TAC) for shared stocks such as NAFO area Northern shrimp and Greenland halibut.

Governance must keep pace with new developments, especially changing migration patterns and displacement of stocks to new areas. A good example is the recent dispute over Atlantic mackerel catches and TACs arising from expansion of the distribution to Icelandic and other waters. Thus, there may be a need for an international body that coordinates the fisheries management in the Arctic, especially in the international waters beyond the control of the Arctic nations and jurisdiction of existing RFMOs, which will become available with shrinking of the ice cap.

In conclusion, the EU Arctic Policy should be further developed along these lines, with support and funding for greater collaboration, improved governance and more research. The implementation of eco-system based marine management (EBMM) at the regional level is hampered by the existing European governance system that cannot adequately deal with the complex challenges (Raakjaer et al., in press). The development of institutional structures that can coordinate fishing in the Arctic as well as cooperate with other sectors such as shipping and oil and gas production is recommended.
1. INTRODUCTION

1.1. Objective

Climate change has become of major concern, especially in the Arctic where the rate of warming is greater than at lower latitudes, resulting in decreasing snow cover and sea ice, and increasing seas surface and upper ocean temperature. There is strong evidence that climate change is affecting the entire Arctic marine and terrestrial ecosystems (Jeffries et al. 2014).

The Arctic marine ecosystem is fragile and poorly studied compared to more temperate northern regions, with relatively little known about how the fauna and flora will respond to the warming trends. The reduction in summer ice extent, opening up new areas to navigation and potentially providing opportunities for the development of new fisheries is a concern given the scarcity of studies on Arctic species and their resilience to changing environmental conditions and exploitation.

The study’s overall objective is to contribute to a better understanding of the Arctic marine ecosystem, with particular emphasis on the marine living resources and the potential impact of climate change. The study will provide information on the fish species of the Arctic region, their main characteristics and their resilience. A more in depth analysis is provided for five of the most important commercial and therefore better-studied species: Northeast cod (Gadus morhua), Polar cod (Boreogadus saida), Capelin (Mallotus villosus), Greenland halibut (Reinhardtius hippoglossoides) and Northern shrimp (Pandalus borealis). An overview of climate change in the Arctic region is provided and the potential for changes in distribution and movement of species into the Arctic from the boreal region is evaluated based on published modelling studies. The study also examines existing fisheries management bodies and fisheries governance in light of the possibility of development of new fisheries in previously inaccessible areas in the Arctic. The study also aims to identify gaps and make recommendations and policy-relevant advice for decision makers tasked with addressing the threats of climate change to the Arctic marine environment.

1.2. Methodology

This study is based on an exhaustive literature review about climate change in the Arctic, the Arctic marine ecosystem, the ichthyofauna¹ of the Arctic and sub-Arctic, the biology, ecology, fisheries and stock assessment of five of the most important commercial species (NE Atlantic cod, Polar cod, Northern shrimp, Greenland halibut and capelin), the resilience of Arctic fishes, the potential for invasive species, and relevant fisheries organizations and governance.

In addition to the primary literature (peer review scientific publications), obtained via ScienceDirect or directly from the authors, the authors used Intergovernmental Panel on Climate Change (IPCC), Arctic Biodiversity Assessment (ABA), Arctic Climate Impact Assessment (ACIA) and other assessment reports, as well as ICES fisheries working group documents (e.g. Arctic Fisheries Working Group). The study is also based on information from Regional Fisheries Organizations, namely the North East Atlantic Fisheries Commission (NEAFC), Northwest Atlantic Fisheries Organization (NAFO), and the Joint Russian-Norwegian Fisheries Commission (JRNFC), North Pacific Marine Science Organization

¹ ichthyofauna: the indigenous fishes of a region or habitat.
(PICES), and the Fisheries and Agricultural Organization of the United Nations (FAO). Relevant European Union documents were also consulted.

**Other sources of information** included National fisheries and oceanographic institutes, such as Marine Fisheries Institute of Iceland, Institute of Marine Research of Norway, Greenland Institute of Natural Resources, Department of Fisheries and Oceans (Canada), All-Russia Research Institute of Marine Fisheries and Oceanography, and the National Marine Fisheries Service of the U.S, and NGOs and other stakeholders such as the World Wildlife Fund (WWF). Species-specific data on biology, ecology and resilience was obtained from FishBase ([www.fishbase.org](http://www.fishbase.org)), the online, global database of fish species.

In addition to the literature review, an **expert consultation** (questionnaire survey) focusing on organizations and individuals involved with fisheries in the North Atlantic was carried out.2

**This study will focus on the fisheries of in the following areas:**

- The northern part of the northeast Atlantic (FAO Major Fishing **Area 27**, see Map 1),
- the northern part of northwest Atlantic (FAO Major Fishing **Area 21**, see Map 2), and
- the Arctic Sea (FAO Major Fishing **Area 18**, see Map 3).

In **Area 27**, the main ICES fishing areas of interest are I (Barents Sea), II (Norwegian Sea, Spitzbergen and Bear Island), V (Iceland and Faeroe Grounds), and XIV (East Greenland). Both Subareas I and II consist of North-east Atlantic Fisheries Commission (NEAFC) Regulatory Areas (Divisions Ia and IIa1, IIb1) and non-NEAFC Regulatory Areas (Divisions Ib and IIa2, IIb2).

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2 The main topics for discussion included: a) How effective do you consider current governance arrangements in the Arctic? b) What needs to be improved with regard to governance? In your view, are the following issues the main challenges? Reaching agreements on TACs and allocations (e.g. the expansion of the distribution of mackerel to Icelandic waters and the resulting dispute over quotas) and management measures; The sustainable exploitation of deep-sea stocks of species with low resilience; Uncertainty and lack of information about the stock status of some species; The implementation of the Ecosystem Based Approach to Management; c) Do you see any need for EU action? d) What are priorities for the future?
Map 1: The Northeast Atlantic (Major Fishing Area 27) with the ICES fishing areas for statistical purposes

Source: [www.fao.org](http://www.fao.org)
The Major Fishing Area 21, the Northwest Atlantic, corresponds to the North Atlantic Fisheries Organization (NAFO) Convention Area. It includes waters north of 35°00’N latitude, between Canada and the west coast of Greenland, to 78°10’N latitude.

**Map 2: The Northwest Atlantic (Major Fishing Area 21) with the NAFO divisions for statistical purposes**

*Source: [www.fao.org](http://www.fao.org)*

*Note: The different colours represent seven subareas.*
**Area 18** covers most of the Arctic Ocean (Map 3) from the meridian of 68°30' east longitude (Russian Federation, coast of Novaya Zemlya archipelago), to the 40°00’ meridian (coast of Greenland).

**Map 3:** The Arctic Sea (Major Fishing Area 18)

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### 1.3. Policy context

**EU interests in the Arctic**

The **European Union has strong links to the Arctic region including historical, geographical, and socio-economic dimensions.** Three Member States — Denmark (in respect of Greenland), Finland and Sweden — have territories in the Arctic, although these are not coastal States with respect to the Arctic marine area. Iceland and Norway are members of the European Economic Area and several other Arctic states such as Canada, Russia and the United States are strategic partners of the EU. Beyond areas of national jurisdiction, the Arctic Ocean contains large areas of high seas that are beyond national jurisdiction and the seabed is managed by the International Seabed Authority. These areas are of strategic interest to the EU in relation to access to natural resources and maritime transport. In view of the role of climate change as a “threats multiplier”, the European Commission and the High Representative for the Common Foreign and Security Policy have pointed out that environmental changes are altering the geo-strategic dynamics of the
Arctic with potential consequences for international stability and European security interests, thus calling for the development of an EU Arctic policy³.

**Communication by the European Commission on the Arctic Region**

The Communication on the "The European Union and the Arctic Region" (COM(2008) 763 final) published by the European Commission in November 2008 set out EU interests in the Arctic, and proposed action for EU Member States and institutions around **three main policy objectives:***

- **Protecting and preserving** the Arctic in unison with its population;
- **Promoting sustainable use of resources**;
- **Contributing to enhanced Arctic governance** through implementation of relevant agreements, frameworks and arrangements, and their further development.

This Communication was built on the **Blue Book** and Action on EU Maritime Policy. The following issues expressed in the Communication are of particular interest, and reflect concerns related to the EU’s maritime and fisheries policy:

a) The region’s sensitivity to **pollution** and **climate change**;

b) Hunting of marine mammals is recognised as crucial for **subsistence of Arctic populations** (indigenous people), but animal welfare should also be taken into account;

c) Support for **research, monitoring and assessments**, including enhanced EU participation in initiatives supported by the Arctic Council;

d) Arctic **hydrocarbon reserves** which could contribute to enhancing the EU’s security of supply concerning energy and raw materials in general, as well as contributing to economic development of the region;

e) Increased productivity in some **fish stocks** as a result of climate change;

f) **Maritime transport** through progressively opening opportunities to navigate on routes through Arctic waters.

In relation to point b) above, the EU implemented restrictions on the **placing of seal products on the EU market** (along with their import, transit and export)⁴ except for those products from hunting "**traditionally conducted by Inuit and other indigenous communities and (which) contribute to their subsistence**". The Regulation provides a derogation for personal use and by-products from hunting regulated by national law, and conducted for the sole purpose of the sustainable management of marine resources.

This proved to be controversial and was heavily criticised by sealers’ organizations, Inuit groups, the fur industry and numerous politicians. Canada subsequently filed a complaint in 2009 at the **World Trade Organization (WTO)** in a bid to have this EU regulation overturned⁵. The WTO came to the decision that the ban on seal pelts imposed by the EU in 2010 undermines the principles of fair trade, but is justified because it ‘fulfils the objective

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⁵ [http://www.wto.org/english/tratop_e/dispu_e/cases_e/ds400_e.htm](http://www.wto.org/english/tratop_e/dispu_e/cases_e/ds400_e.htm)
of addressing EU public moral concerns on seal welfare’. Canada and Norway argued that the ruling sets a dangerous precedent because trade decisions were being made on the basis of morality rather than conservation and science, and decided to appeal the decision. However, the appeal panel upheld the decision in 2014 that the European Union’s ban on the import of seal pelts, oil and meat is justified on moral grounds.

The controversy surrounding this issue of seals reportedly led to the blocking of European Union attaining observer status in the Arctic Council, as implied in the Council Conclusions of 2014 (see following sections).

Development of the EU Arctic Policy

Subsequently the European Council considered EU Arctic policy and passed a resolution adopting the Commissions recommended objectives and setting out the strategic approach, to be based on (as specified in the resolution):

- Effective implementation by the international community of adequate measures to mitigate climate change that are required to preserve the unique characteristics of the Arctic region;
- Reinforced multilateral governance through strengthening and consistent implementation of relevant international, regional and bilateral agreements, frameworks and arrangements;
- The United Nations Convention on the Law of the Sea (UNCLOS) and other relevant international instruments;
- Formulating and implementing EU actions and policies that impact on the Arctic with respect for its unique characteristics, in particular the sensitivities of ecosystems and their biodiversity as well as the needs and rights of Arctic residents, including the indigenous peoples;
- Maintaining the Arctic as an area of peace and stability and highlighting the need for responsible, sustainable and cautious action in view of new possibilities for transport, natural resource extraction and other entrepreneurial activities linked to melting sea ice and other climate change effects.

This was followed by a Joint Communication by the European Commission and High Representative to the European Parliament and the Council on ‘Developing a European Union Policy towards the Arctic Region: progress since 2008 and next steps’. This presents the case for increased EU engagement in Arctic issues, considering the accelerating pace of climate change and economic development in the Arctic region and the need for the European Union to engage more strongly with its Arctic partners to address environmental issues while ensuring sustainable development. This includes the goal of becoming a permanent observer of the Arctic Council and intensification of bilateral dialogues with Arctic states.

The above-referred Joint Communication calls for increased EU investment in climate change research in the Arctic in the context of global and regional action and for Arctic states to co-operate on the basis of the existing international legal order, notably the UN Convention on the Law of the Seas. The Arctic Council is seen as an emerging

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6 Conclusions on Arctic Issues of 8 December 2009, 2985th Foreign Affairs Council meeting Brussels, 8 December 2009.
decision-making regional body, in which all Arctic states, as well as indigenous peoples, are represented.

The EU's Arctic contribution are defined and presented according to:

- Fighting climate change;
- Research on the arctic environment;
- Investments in sustainable development on the North;
- Reducing future uncertainties and monitoring changes in the Arctic region;
- Shipping and maritime safety.

This included for example contributions for research (EUR 20 million/year, 2007-13), regional and cross-border investment (EUR 1.14 billion, 2007-13) and cooperation with our partners in the fields of environment, transport, energy, and maritime safety.

In this Joint Communication, the Commission and High Representative propose to further develop the EU's policy towards the Arctic, placing emphasis on:

- Support research and channel knowledge to address the challenges of environmental and climate changes in the Arctic;
- Act with responsibility to contribute to ensuring economic development in the Arctic is based on sustainable use of resources and environmental expertise;
- Intensify its constructive engagement and dialogue with Arctic States, indigenous peoples and other partners.

The development of policy objectives, following the first communication in the 2008 joint report, has been consistent, although more emphasis is placed on greater engagement, using existing governance structure, and ways of cooperating to meet common challenges.

Of particular interest in relation to fisheries, the EU states, through this Joint Communication, "...its support to the exploitation of Arctic fisheries resources at sustainable levels based on sound scientific advice, while respecting the rights of local coastal communities. A regulatory framework for the conservation and management of fish stocks is called for, which should be established for those parts of the Arctic high seas not yet covered by an international conservation and management system." The possibility of extending the geographic scope of the mandates of Regional Fisheries Management Organisations (RFMOs) is suggested for this purpose. The EU confirms its long communicated view that Arctic inter-state relations in the region are based on the existing international legal order, notably the UN Convention on the Law of the Sea.

Subsequently, the European Parliament passed a resolution on the EU strategy for the Arctic on 12 March 2014 (2013/2595(RSP), requesting the European Commission to develop and put forward a visionary and coherent strategy (and action plan) on the EU's engagement in the Arctic, making sure that EU and Member States' socioeconomic and environmental interests, as well as global biodiversity protection and climate change goals, are taken into account.

This was followed by Council conclusions, 12 May 2014, on developing a European Union Policy towards the Arctic Region, which endorses the 2012 Joint Communication and the 2014 European Parliament Resolution. Furthermore, the Council requests "...
Commission and the High Representative to present proposals for the further development of an integrated and coherent Arctic Policy by December 2015."

In above-referred conclusions, the Council confirms "...that the EU should enhance its contribution to Arctic cooperation, in conformity with international instruments, notably the United Nations Convention on the Law of the Sea." The Arctic Council is recognised as the primary body for circumpolar regional cooperation and expresses strong support for the EU goal of obtaining observer status in this body\(^8\).

Furthermore, "...the Commission and Member States are encouraged to continue their efforts aiming at the swift agreement within the International Maritime Organisation on a mandatory 'Polar Code', which would set out a range of measures and requirements to improve and strengthen maritime cooperation and safety and prevent pollution, including the expected increase in cruise passenger ships in the Arctic."

After the WTO panel issued its decision, upholding the right of the EU to ban seal products, EU-Canada relations appear to be improving. It is expected that the EU will provide support for the certification for Inuit seal products in the upcoming EU-Canada summit in connection with the adoption of the new partnership and free trade agreement\(^9\). The EU currently participates as an observer in the Arctic Council in all but name, but it would have symbolic effect to be acknowledged as such.

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\(^8\) The Council notes on EU-Canada relations and the possibility of resolving the remaining issue so as to allow for the full implementation of the Kiruna decision regarding the EU's observer status in the Arctic Council as soon as possible before the next EU/Canada summit.

2. FISHERIES IN THE ARCTIC – CURRENT STATUS

KEY FINDINGS

- There are **633 fish species in the Arctic Ocean and Adjacent Seas (AOAS)**, of which only **58 are currently exploited**, almost exclusively in the sub-Arctic, boreal areas (e.g. Barents Sea, Norwegian Sea)
- The **majority** (49) are **boreal species**, while 6 are Arctic-boreal and only 3 are Arctic Ocean endemic species.
- **Arctic species** are highly adapted to a narrow thermal window (e.g. antifreeze proteins in the blood) and to a highly variable environment.
- According to an **assessment of resilience**, 35 of the 58 commercial species are classified as low resilience, 14 as medium resilience and 9 as high resilience.
- The **AOAS includes 18 Large Marine Ecosystems (LME)** within which fish and invertebrate stocks may respond differently to climate variability and climate change.
- **Sub-arctic/boreal areas** have some of the largest and most important fisheries in the world, such as cod, capelin and herring.

- There is evidence of "borealization" of the Arctic fish community with warming, as species from the boreal region extend their ranges.
- **Polar cod** (*Boreogadus saida*), an Arctic species, is a very important forage species in the Arctic, with a very large biomass (millions of tonnes), but is of little commercial interest.
- **Capelin** (*Mallotus villosus*), an Arctic-boreal species, is an important prey species for cod and other predators, with strong fluctuations in abundance that supports large fisheries throughout the Arctic.
- Stocks of **Northern shrimp** (*Pandalus borealis*), an Arctic-boreal species, the most important commercial crustacean, have generally declined in recent years, in part due to warming but also because of predation and overfishing.
- The catches of **Greenland halibut** (*Reinhardtius hippoglossoides*), an Arctic-boreal species, have been stable in recent years.

- The biomass of **cod** (*Gadus morhua*), a boreal species, has increased significantly in the NE Atlantic in recent years, with evidence of more northern spawning.
- **Fisheries management** as implemented by Regional Fisheries Management Organizations (RFMO) is largely based on the **Precautionary Approach (PA)** and increasingly on the **Ecosystem based approach (EBS)**.
- Cases of lack of agreement on Total Allowable Catches (TAC) for shared stocks underlines the **need for improved governance** to cope with new, emerging fisheries in the Arctic.

2.1. The Arctic

The Arctic is the **polar region north of Arctic Circle** (66° 33’N), consisting of the Arctic Ocean and parts of the USA (Alaska), Canada, Greenland, Iceland, Norway, Sweden, Finland and Russia. The Arctic Ocean, with a cover of perennial ice, has an area of approximately 15 million km\(^2\) and is bordered by the Barents, Beaufort, Bering, Chukchi, East Siberian, Greenland, Kara, Laptev, Norwegian and White Seas (PAME, 2013; McBride...
et al., 2014). The influx of temperate waters into the Arctic is through the Bering Strait (approximately 10%) and the Atlantic Arctic gateway (approximately 90%). Much of the region is Sub-Arctic and is where most of the commercial fisheries take place (Map 4). The limits of the AOAS region are defined following the International Hydrographic Organization (http://www.iho.int) and on the basis of the Large Marine Ecosystems (LME) concept (Sherman, 1991).

Map 4: The Arctic Ocean and Adjacent Seas (AOAS)

**Source:** Adapted from Christiansen et al. (2013)

**Legend:** ACB = Arctic Central Basin, BAF = Baffin Bay, BAR = Barents Sea, BEA = Beaufort Sea, BER = Bering Sea, CAN = Canadian Arctic Archipelago, CEG = Coastal E Greenland, CWG =, Coastal W Greenland, CHU = Chukchi Sea, GRS = Greenland Sea, HUD = Hudson Bay complex, KAR = Kara Sea, LAP = Laptev Sea, NOR = Norwegian Sea, SIB = East Siberian Sea, WHI = White Sea.

**Note:** The Arctic gateways are shown in yellow. Dashed red line is the Arctic Circle.

2.2. Large Marine Ecosystems of the Arctic region

The Arctic region has a great variety of habitats and ecosystems, with distinct hydrographic, biological and ecological characteristics. These different ecosystems and their fish and invertebrate communities respond differently to climate variability and climate change. Therefore the identification of large marine ecosystems (LMEs) is an essential part of the implementation of an ecosystem-based management (EBM) approach. This approach was adopted as part of the Arctic Marine Strategic Plan (AMSP) by the Arctic Council (AC) in 2004. The most recent revision identified 18 Arctic LMEs (PAME, 2013). Their geographic boundaries are shown in Map 5, while their main characteristics (hydrographic, primary production, ice cover, freshwater input) and ecological features (main fish species, marine mammals and birds) are given in Table 1. Except for LMEs 9, 10, 11 and the southern part of LME 12, all the LMEs are within the geographic area covered by this study (FAO areas 18, 21 and 27).
Map 5: The 18 Large Marine Ecosystems (LMEs) of the Arctic

Source: PAME (2013)
<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Area ($10^6 \text{ km}^2$)</th>
<th>Characteristics</th>
<th>Fish/Fisheries/Ecosystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Faeroe Plateau</td>
<td>0.11</td>
<td>Characteristic circulation pattern, plankton production and composition.</td>
<td>Self-contained fish populations of Atlantic cod (<em>Gadus morhua</em>), haddock (<em>Melanogrammus aeglefinus</em>) and other species.</td>
</tr>
<tr>
<td>2</td>
<td>Iceland Shelf and Sea</td>
<td>0.51</td>
<td>Clockwise circulation around Iceland; northward flowing warm Irminger Current on the western side and the cold East Iceland Current flowing south on the eastern side. Currents associated with distinct plankton communities and production regimes.</td>
<td>Several major commercial fish populations including Atlantic cod, herring (<em>Clupea harengus</em>), haddock and capelin (<em>Mallotus villosus</em>).</td>
</tr>
<tr>
<td>3</td>
<td>Greenland Sea</td>
<td>1.20</td>
<td>Cold East Greenland Current and gyre circulation are prominent oceanographic features; most of the area is covered with sea ice in winter.</td>
<td>Polar cod important; breeding and feeding habitat for populations of harp and hooded seals; home of the East Greenland subpopulation of polar bears.</td>
</tr>
<tr>
<td>4</td>
<td>Norwegian Sea</td>
<td>1.11</td>
<td>Mostly boreal ocean climate, largely ice-free in winter due to northward flow of Atlantic water.</td>
<td>Large pelagic stocks (Norwegian spring spawning herring, blue whiting, <em>Micromesistius poutassou</em>, and mackerel, <em>Scomber scombrus</em>) feeding on copepod <em>Calanus finmarchicus</em> and krill.</td>
</tr>
<tr>
<td>5</td>
<td>Barents Sea</td>
<td>2.10</td>
<td>Warmer boreal and ice-free conditions in the southwestern part; cold and ice-infested conditions in the northern and eastern parts of the Barents Sea, with distinct plankton composition and communities.</td>
<td>Large fish populations including cod, haddock, Greenland halibut (<em>Reinhardtius hippoglossoides</em>), capelin and Polar cod (<em>Boreogadus saida</em>). Large population of harp seals, home to subpopulation of polar bears, two populations of walrus, and several subpopulations of belugas or white whales.</td>
</tr>
<tr>
<td>6</td>
<td>Kara Sea</td>
<td>1.00</td>
<td>Hydrography strongly influenced by freshwater discharge from rivers; ice-covered in winter.</td>
<td>Home to subpopulation of polar bears; important feeding areas for summer aggregations of belugas.</td>
</tr>
<tr>
<td>7</td>
<td>Laptev Sea</td>
<td>0.92</td>
<td>High Arctic; polynya system.</td>
<td>Existence of a migratory population of Polar cod in the western part possible. Distinct walrus population; important feeding grounds for belugas and migratory birds.</td>
</tr>
</tbody>
</table>
## Fisheries management and the Arctic in the context of climate change

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Area ($10^6$ km$^2$)</th>
<th>Characteristics</th>
<th>Fish/Fisheries/Ecosystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>East Siberian Sea</td>
<td>0.64</td>
<td>High Arctic, low productivity.</td>
<td>Important breeding, feeding and staging areas for migratory birds in summer. Also feeding grounds for whales (e.g. bowhead, beluga).</td>
</tr>
<tr>
<td>9</td>
<td>East Bering Sea</td>
<td>1.38</td>
<td>High productivity. More Arctic region is to the north of 61.5°N, from the outer shelf south of Cape Navarin to the Alaska coast.</td>
<td>Major commercial fish populations: walleye pollock (<em>Theragra chalcogramma</em>), flatfishes (e.g. yellow-fin sole (<em>Limanda aspera</em>), Pacific cod (<em>Gadus macrocephalus</em>), Pacific herring (<em>Clupea pallasii</em>), Greenland halibut, rockfishes (<em>Sebastes spp.</em>), capelin and Pacific salmon. Important feeding and breeding grounds for marine mammals (e.g. fur seals).</td>
</tr>
<tr>
<td>10</td>
<td>Alutian Islands</td>
<td>0.22</td>
<td>High productivity due to high content and availability of nutrients through physical processes.</td>
<td>Many local fish stocks, seabird colonies and rookeries for Steller Sea lions.</td>
</tr>
<tr>
<td>11</td>
<td>West Bering Sea</td>
<td>0.76</td>
<td>Kamchatka Current is the prominent oceanographic feature. <em>Neocalanus</em> species and other copepods important for productivity.</td>
<td>Important commercial species include walleye pollock, Pacific herring, Pacific cod, and yellowfin sole. Important forage species: capelin and several species of smelts, migrating mesopelagic fishes and squid. Important populations of marine mammals such as Steller sea lions, harbour seals, and sea otters and breeding colonies and feeding areas for seabirds.</td>
</tr>
<tr>
<td>12</td>
<td>Northern Bering-Chukchi Seas</td>
<td>1.36</td>
<td>Shallow shelf environment with depths of 50-70 m. Persistent northward flow of nutrient rich Pacific water, with high primary productivity. Ice-bound in winter, but ice-free in summer except for the northernmost area.</td>
<td>One or more migratory populations of Polar cod. Important area for marine mammals (whales, walrus, seals) and breeding colonies of sea birds.</td>
</tr>
<tr>
<td>13</td>
<td>Central Arctic</td>
<td>3.33</td>
<td>Consists of deep basins of the Arctic Ocean, with drifting polar pack ice covering the area during most summers (shrinking ice cover with global warming).</td>
<td>Main fish species living in this LME is the Arctic cod (<em>Arctogadus glacialis</em>), with a large and probably migratory population. Several sub-populations of polar bears and ice-associated gulls.</td>
</tr>
<tr>
<td>No.</td>
<td>Name</td>
<td>Area $(10^6 \text{ km}^2)$</td>
<td>Characteristics</td>
<td>Fish/Fisheries/Ecosystem</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------------</td>
<td>-----------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>14</td>
<td>Beaufort Sea</td>
<td>10.11</td>
<td>Three main area components: the southern part of the deep Canada Basin, the shelf along northern Alaska and northwestern Canada. Relatively high primary production due to influence of nutrient-rich Pacific water.</td>
<td>Probable existence of a large migratory population of Polar cod in the eastern Beaufort Sea. Summer feeding grounds for whales (e.g. bowhead and beluga).</td>
</tr>
<tr>
<td>15</td>
<td>Canadian High Arctic-North Greenland</td>
<td>0.60</td>
<td>Strongly influenced by heavy multi-year pack ice, resulting in generally low production.</td>
<td>Two sub-populations of polar bears, narwhals, and migratory birds in the summer.</td>
</tr>
<tr>
<td>16</td>
<td>Canadian Eastern Arctic-West Greenland</td>
<td>1.40</td>
<td>Diverse LME, mostly ice-covered in winter and clear of ice in summer (with some exceptions). Primary production relatively high due to nutrient rich Pacific water flowing from the Arctic Ocean.</td>
<td>Polar cod (several large populations) important, along with capelin, Atlantic cod, Greenland halibut and others. Large migratory populations of marine mammals.</td>
</tr>
<tr>
<td>17</td>
<td>Hudson Bay Complex</td>
<td>1.31</td>
<td>Strong influence of Atlantic water circulating through the deeper parts of Hudson Strait and water of Pacific origin entering from the Baffin Current and from north. Ice-covered in winter with all of Hudson Bay and most of Foxe Basin and Hudson Strait clear of ice during summer.</td>
<td>Many fish species, with Polar cod and capelin as important forage species. Important habitats for migratory birds, and feeding grounds for marine mammals.</td>
</tr>
<tr>
<td>18</td>
<td>Labrador-Newfoundland</td>
<td>0.41</td>
<td>Cold Labrador Current is the predominant feature. Ice-covered in winter, remaining cold in summer.</td>
<td>Major fish stocks of Atlantic cod and capelin in the southern part, and Greenland halibut and other deep-water species along the slope.</td>
</tr>
</tbody>
</table>

Source: Adapted from PAME (2013)

### 2.3. Commercial fish species of the Arctic Ocean and Adjacent Seas (AOAS)

A comprehensive list of the marine fishes of the Arctic Ocean and adjacent seas (AOAS) compiled by C.W. Mecklenburg, O.V. Karamushko, P.D.R. Møller, A. Lynghammar, and J.S. Christiansen (Meltofte, 2013) totals 633 species, of which 63 are classified as mainly Arctic, 32 Arctic-boreal, 457 Boreal and 81 as widely distributed (Table 2). Of the 633 species, 80 (12.6%) are freshwater species, while 44 (6.9%) are found in both marine and fresh water, with 16 species mainly restricted to Arctic waters. Arctic species are those restricted to spawning at sub-zero temperatures and ice-covered areas and are rarely found in sub-Arctic waters, while arctic-boreal species can spawn at sub-zero or above zero temperatures and are found in Arctic and sub-Arctic/boreal seas (Christiansen et al., 2014). Boreal species spawn at temperatures above zero but may venture into sub-zero sub-Arctic/boreal waters for feeding (Christiansen et al, 2014). Widely distribute species...
occur rarely in the Arctic and are found in boreal and subtropical waters (Christiansen et al., 2014). The proportions of arctic (A), arctic-boreal (AB), boreal (B) and widely distributed (WD) marine species in the different parts of the AOAS are shown in Figure 1.

**Figure 1:** Proportions of marine fish species in the AOAS associated with certain zoogeographic patterns

![Diagram showing proportions of marine fish species in the AOAS associated with certain zoogeographic patterns](image)

**Source:** Christiansen et al. (2013)

**Legend:** A = arctic, AB = arctic-boreal, B = boreal and WD = widely distributed.

**Note:** Regional codes are given in Map 4.
Table 2: Estimated number of marine fish species in the AOAS

<table>
<thead>
<tr>
<th>Code</th>
<th>AOAS region</th>
<th>Zoogeographic pattern (N)</th>
<th>A</th>
<th>AB</th>
<th>B</th>
<th>WD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic seas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACB</td>
<td>Arctic Central Basin</td>
<td>12</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>WHI</td>
<td>White Sea</td>
<td>15</td>
<td>1</td>
<td>28</td>
<td>5</td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>KAR</td>
<td>Kara Sea</td>
<td>35</td>
<td>3</td>
<td>21</td>
<td>1</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>LAP</td>
<td>Laptev Sea</td>
<td>37</td>
<td>4</td>
<td>8</td>
<td>1</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>SIB</td>
<td>East Siberian Sea</td>
<td>20</td>
<td>7</td>
<td>5</td>
<td>0</td>
<td></td>
<td>32</td>
</tr>
<tr>
<td>BEA</td>
<td>Beaufort Sea</td>
<td>31</td>
<td>22</td>
<td>13</td>
<td>0</td>
<td></td>
<td>66</td>
</tr>
<tr>
<td>CAN</td>
<td>Canadian Arctic Archipelago</td>
<td>29</td>
<td>21</td>
<td>7</td>
<td>0</td>
<td></td>
<td>57</td>
</tr>
<tr>
<td>HUD</td>
<td>Hudson Bay Complex</td>
<td>24</td>
<td>24</td>
<td>36</td>
<td>4</td>
<td></td>
<td>88</td>
</tr>
<tr>
<td>BAF</td>
<td>Baffin Bay</td>
<td>33</td>
<td>22</td>
<td>21</td>
<td>5</td>
<td></td>
<td>81</td>
</tr>
<tr>
<td>CWG</td>
<td>Coastal West Greenland</td>
<td>16</td>
<td>16</td>
<td>24</td>
<td>3</td>
<td></td>
<td>59</td>
</tr>
<tr>
<td>CEG</td>
<td>Coastal East Greenland</td>
<td>12</td>
<td>10</td>
<td>15</td>
<td>3</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>GRS</td>
<td>Greenland Sea</td>
<td>31</td>
<td>13</td>
<td>10</td>
<td>3</td>
<td></td>
<td>57</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlantic Arctic Gateway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOR</td>
<td>Norwegian Sea</td>
<td>21</td>
<td>16</td>
<td>126</td>
<td>41</td>
<td></td>
<td>204</td>
</tr>
<tr>
<td>BAR</td>
<td>Barents Sea</td>
<td>41</td>
<td>3</td>
<td>89</td>
<td>20</td>
<td></td>
<td>153</td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td>Pacific Arctic Gateway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BER</td>
<td>Bering Sea</td>
<td>16</td>
<td>21</td>
<td>313</td>
<td>35</td>
<td></td>
<td>385</td>
</tr>
<tr>
<td>CHU</td>
<td>Chukchi Sea</td>
<td>20</td>
<td>22</td>
<td>33</td>
<td>0</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entire AOAS</td>
<td></td>
<td></td>
<td>63</td>
<td>32</td>
<td>457</td>
<td>81</td>
<td>633</td>
</tr>
</tbody>
</table>

Source: Christiansen et al. (2013)
Legend: A = arctic, AB = arctic-boreal, B = boreal and WD = widely distributed,
Note: The same species may occur in more than one region.
As expected, the Arctic basin has the highest proportion of Arctic species, while the Arctic gateways (Bering Sea, Barents Sea and Norwegian Sea) have the highest proportion of boreal species.

In addition to fish, there are 67 terrestrial mammals, 35 marine mammals, 154 terrestrial and freshwater birds that breed in the Arctic, 45 marine birds that breed in the Arctic, 6 amphibians and approximately 5000 marine invertebrates (Meltofte, H. (ed.) (2013)).

Of the 634 fish species, 58 (less than 10% of the total) are exploited in the AOAS. Of the 58, 3 are arctic species, 6 are arctic-boreal and 49 are boreal species (Table 3). The most important commercial fish species are North-east Arctic cod (Gadus morhua), North-east Arctic haddock (Melanogrammus aeglefinus), saithe (Pollachius virens), redfish (Sebastes mentella and S. marinus), Greenland halibut (Reinhardtius hippoglossoides), long rough dab (Hippoglossoides platessoides), wolffish (Anarhichas lupus, A. minor and A. denticulatus), European plaice (Pleuronectes platessa), Barents Sea capelin (Mallotus villosus), Polar cod (Boreogadussaida) and immature Norwegian spring-spawning herring (Clupea harengus). The most important commercial fish families in the AOAS are Pleuronectidae (righteye flounders, 18 species), Gadidae (cods, 14 species), and Scorpaenidae (rockfishes, 9 species) (Christiansen, 2013).

Table 3: Exploited marine fishes in the Arctic Ocean and adjacent seas (AOAS), zoogeography, distribution and resilience

<table>
<thead>
<tr>
<th>Fish species</th>
<th>Common name</th>
<th>Zoogeography</th>
<th>Dist.</th>
<th>Resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreogadus saida</td>
<td>Polar cod</td>
<td>Arctic</td>
<td>C</td>
<td>Medium</td>
</tr>
<tr>
<td>Eleginus nawaga</td>
<td>Atlantic navaga</td>
<td>Arctic</td>
<td>C</td>
<td>Medium</td>
</tr>
<tr>
<td>Liopsetta glacialis</td>
<td>Arctic flounder</td>
<td>Arctic</td>
<td>C</td>
<td>Low</td>
</tr>
<tr>
<td>Anarhichas denticulatus</td>
<td>Northern wolffish</td>
<td>Arctic-boreal</td>
<td>NA</td>
<td>Low</td>
</tr>
<tr>
<td>Clupea pallasii</td>
<td>Pacific herring</td>
<td>Arctic-boreal</td>
<td>A, NP</td>
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## Fisheries management and the Arctic in the context of climate change

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<th>Fish species</th>
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<th>Zoogeography</th>
<th>Dist.</th>
<th>Resilience</th>
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<td>Trisopterus esmarkii</td>
<td>Norway pout</td>
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<td>NEA</td>
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</table>

**Source:** Meltofte, H. (ed.) (2013) and Froese and Pauly (2000)

**Legend:** Dist. = Distribution (A = Arctic, C = circumpolar, NA = North Atlantic, NEA = North-east Atlantic, NP = North Pacific Ocean, NEP = North-east Pacific)

### Arctic fisheries take place mostly within ice-free exclusive economic zones (EEZ) of the sub-Arctic/boreal seas

Arctic fisheries take place mostly within ice-free exclusive economic zones (EEZ) of the sub-Arctic/boreal seas (Christiansen et al., 2014). The main targeted species are capelin, Greenland halibut, Northern shrimp and Polar cod. Ice-cover and harsh climate limit fisheries in the Arctic region and most of the catches from the coastal areas are not reported to FAO (Zeller et al., 2011). However, real catches are apparently considerably greater than found in the official statistics for FAO Statistical Area 18 (Arctic Sea). Reconstructed catches for the period from 1950 to 2006 indicate that total catches (950,000 t) are actually 75 times higher than the sum of the catches reported for FAO Statistical Area 18, with most of the catches from the Russian Arctic (Zeller et al., 2011).

The most important fisheries in the AOAS are in the sub-Arctic/boreal areas (Map 4) such as the Barents Sea, the Bering Sea, the Labrador Sea and around Greenland and Iceland, for cod (Gadus morhua), haddock (Melanogrammus aeglefinus), walleye pollock (Theragra chalcogramma), Pacific cod (Gadus macrocephalus), snow crab (Chionoecetes opilio), Atlantic herring (Clupea harengus), Pacific herring (Clupea pallasii), yellowfin sole (Limanda aspera), Northern rock sole (Lepidopsetta polyxystra), salmon (Atlantic salmon, Salmo salar, and several species of Pacific salmon), clams and scallops (Vilhjálmsson and Hoel, 2005; Christiansen et al., 2014, McBride et al., 2014). The areas with the greatest numbers of exploited species (more than 20 species each) are the Bering Sea, the Norwegian Sea and the Barents Sea (Figure 2).

Krill and copepods are also exploited in sub-Arctic waters. The Japanese fishery for krill averages approximately 4,000 t a year, while the Canadian catch is 50 to 300 t per year (McBride et al., 2014). The Norwegian fishery for copepods removes around 1,000 tonnes per year of Calanus finmarchicus (McBride et al., 2014).
Figure 2: Number of marine fish species currently harvested by industrial fisheries in the AOAS

Source: Christiansen et al. (2014)
Note: Regional codes are ACB, Arctic Central Basin; BAF, Baffin Bay; BAR, Barents Sea; BEA, Beaufort Sea; BER, Bering Sea; CAN, Canadian Arctic Archipelago; CEG, Coastal East Greenland; CWG, Coastal West Greenland; CHU, Chukchi Sea; GRS, Greenland Sea; HUD, Hudson Bay Complex; KAR, Kara Sea; LAP, Laptev Sea; NOR, Norwegian Sea; SIB, East Siberian Sea; WHI, White Sea. Note that the same species may be harvested in more than one region.

2.4. Key species and stocks

In this section, a brief overview is given of the biology, ecology, distribution and stock structure of the five species selected for more in depth review in this study.

2.4.1. Polar cod (Boreogadus saida)

Polar cod (Figure 3) is a small (maximum length of 30 cm) Arctic species with a circumpolar distribution, occurring further north than any other marine fish (Figure 4). In ice-free conditions it forms large schools, but is found close to the ice and in cracks and crevices within the ice in winter. Anti-freeze proteins in its blood allow Polar cod to thrive at temperatures below 0 °C, and it prefers temperatures below 4 °C. It is one of two cryopelagic fishes that use sea ice as a habitat and as a spawning substrate (Christiansen et al., 2013).

Spawning takes place in late autumn and early winter. In the NE Atlantic the main spawning grounds are in the SE Barents Sea and east of Svalbard. Polar cod are relatively short-lived, with a lifespan of approximately 6 years. Polar cod mature at 2 to 3 years of age, with most populations having a biased sex ratio in favour of females in the older age classes (www.fao.org). They feed mainly in the water column on zooplankton, krill and shrimp. Polar cod, a key species in the Arctic ecosystem, is the main forage species for marine mammals such as narwhals, belugas and seals, and fish such as Greenland halibut.
It used to be fished mainly in the Russian Arctic and Subarctic. As the only Arctic species that undertakes long-distance migrations, it is also the main source of horizontal transport of energy in the Arctic (Christiansen et al., 2013).

Stock structure is unclear. For example, it is not known if Polar cod found to the northeast of the Barents Sea are part of the Barents Sea stock.

**Figure 3:** Polar cod

![Polar cod](source: www.fao.org)

**Figure 4:** Distribution of Polar cod, with FAO fishing areas and the 200 nautical miles arcs

![Distribution of Polar cod](source: www.fao.org)

*Note:* FAO fishing areas in dashed lines.

### 2.4.2. Capelin (*Mallotus villosus*)

Capelin is a small circumpolar pelagic fish (Figures 5 and 6) that feeds on plankton (mainly copepods, krill and amphipods) (Gjøsæter 1998). It is most abundant in the North Atlantic, the Barents Sea and around Iceland (Olsen et al. 2010). Capelin is a very important forage species for fish such as cod, as well as sea birds and marine mammals. Capelin lifespan is 4 to 6 years and the fish die after spawning. In the NE Atlantic, spawning takes in March-April in shallow water spawning grounds off the northern coast of Norway and Russia and juveniles are found in the central and eastern parts of the Barents Sea. Capelin undertakes feeding migrations to the northern and eastern parts of the Barents Sea during the summer (Olsen et al. 2010).

As a very important forage species, capelin stock dynamics are strongly influenced not only by the commercial fishery and environmental variability, but also by their natural predators, such as cod (ICES 2014a). Stock assessment advice therefore should take into account multi-species interactions. In fact, stocks of the two of the main predators of capelin, cod and haddock, are currently at high levels, raising concern that predation may have a significant impact on the capelin stock (ICES 2014a).

The AFWG assumes a single stock for the Barents Sea region (ICES 2014a).
2.4.3. **Greenland halibut (Reinhardtius hippoglossoides)**

The Greenland halibut (Figure 7) is a relatively large, long-lived flatfish, with a circumglobal distribution (Figure 8). It is found in deep water (200 to 2000 m, but mainly at depths from 500 to 1000 m). The Greenland halibut spawns at depths between 700 and 1500 m in spring-summer, at temperatures of 3-5 °C. The younger fish are found in shallower depths, moving to deeper water later in life (www.fisheries.is).

It is an active, mid-water predator, feeding on shrimps and fishes (cod, Polar cod, eelpouts, capelin and redfish), as well as squids. Several stocks are managed separately by NAFO and NEAFC and countries such as Iceland (www.fisheries.is, www.fao.org).

**Figure 7:** Greenland halibut

Source: www.fao.org
Figure 8: Distribution of Greenland halibut, with FAO fishing areas and the 200 nautical miles arcs

Source: www.fao.org
Note: FAO fishing areas in dashed lines.

2.4.4. Northern shrimp (Pandalus borealis)
Northern shrimp (Figure 9) is widely distributed in the Arctic and Subarctic region (circumpolar), at depths from 20 to 1,330 m on soft bottom of clay and mud. It is particularly abundant off Greenland, Iceland and in the Barents Sea (Figure 10). It is one of the two most important commercial shrimps in the northern hemisphere. The Northern shrimp is a protandric10 hermaphrodite (males turn into females) (Wieland 2005). Life history parameters vary considerably with latitude: northern shrimp in colder waters live longer (more than 10 years), change sex later (6 to 7 years of age) and reach larger sizes than northern shrimp from more southerly latitudes (Nilssen and Aschan, 2009). The Northern shrimp is an important part of the diet of many commercial fish species such as cod and Greenland halibut (ICES 2014a).

Figure 9: Northern shrimp

Source: www.fao.org

Figure 10: Distribution of Northern shrimp, with FAO fishing areas and the 200 nautical miles arcs

Source: www.fao.org
Note: FAO fishing areas in dashed lines.

10 Protandric: (Zool.) having male sexual organs while young, and female organs later in life.
2.4.5. North-east cod (*Gadus morhua*)

The Atlantic cod (Figure 11) is one of the most important commercial species in the world, with a wide distribution from the eastern seaboard of the United States to the sub-Arctic and the North Sea (Figure 12). It is found in temperatures from near freezing to 20ºC, with the larger individuals found in colder waters (0-5 ºC). The Atlantic cod is one of the top predators in its environment and its distribution and growth is strongly associated with the distribution and abundance of the prey such as capelin, herring and Northern shrimp (Olsen 2010, Ottersen *et al.* 2014).

The largest cod stock in the world is the North-east Arctic cod (NEAC) stock (Ottersen *et al.* 2014). Cod stocks are also found around Iceland, around the Faeroe Islands, in the Baltic, the North Sea, in the Irish Sea and in the North-west Atlantic in Canadian and US waters (Georges Bank and Newfoundland). Coastal stocks are also found in Norway, South Greenland and Canada (www.fisheries.is; www.nafo.int).

Figure 11: Atlantic cod

![Atlantic cod](source: www.fao.org)

Figure 12: Distribution of Atlantic cod, with FAO fishing and the 200 nautical miles arcs

![Distribution of Atlantic cod](source: www.fao.org)

Note: FAO fishing areas in dashed lines.

Cod are found mostly on the continental shelf at depths down to 200 m (www.fishbase.org). Although some groups do not undertake extensive migrations, Greenland North Atlantic cod and NEAC perform migrations of 1000 km and 800-900 km, respectively. NEAC cod migrate seasonally from the Barents Sea to the Norwegian coast to spawn, while in the NW Atlantic, warmer temperatures in summer and autumn force cod to migrate from the New England area to the cooler waters of the coast of Labrador (Ottersen *et al.* 2014).

Atlantic cod spawn mainly from December to June (Norwegian coast: February to April, West Greenland: March to June, North Sea: December to May), mostly at temperatures from 0 to 2ºC. The most important spawning grounds in the eastern Atlantic are in the North Sea and the Norwegian coast, while in the western Atlantic the main spawning grounds are on Georges Bank and the area south of the Grand Banks (www.fao.org)
Growth rates are highly temperature dependent. For example, four-year-old cod from the Celtic sea (average temperature ca. 10ºC), averaging approximately 90 cm in total length, are twice the size cod of the same age living in the much colder Barents Sea (ca. 4 ºC) (de Young et al. 1999). Cod growth rates are also strongly influenced by the abundance of their main prey species (ICES 2014a). Cod can live 20 years and can attain a maximum size of 2m in total length.

Although Atlantic cod in the Barents Sea, the Norwegian Sea and in the coastal areas differ in terms of life history characteristics (for example growth and maturation rates), geographic distributions, migration patterns and even genetics, it is not clear how much mixture there is and what different populations or sub-populations exist (ICES 2014a). For stock assessment purposes, AFWG considers it appropriate to assess NEAC separately from the Norwegian coastal cod (NCC). NEAC are found in the Barents Sea and adjacent waters, in temperatures above 0ºC and their spawning grounds are along the Norwegian coast, between 67º30' and 70º N (ICES, 2014a). Young-of-the-year (YOY) or 0-group fish NEAC are widely distributed in the Barents Sea (ICES, 2014a).

2.5. Fisheries and landings

In this section the fisheries, landings, stock assessment and management of the five selected species are presented and discussed in more detail. Although the focus is on NE Atlantic, information is also provided for NW Atlantic fisheries (NAFO region) and Iceland, and global catches in the case of species with a widespread or circumglobal distribution. The section is based mainly on the 2014 AFWG report (ICES, 2014a), the STECF (2012) review of scientific advice for 2013, and material from the FAO (www.fao.org), NAFO (www.nafo.int), the Marine Fisheries Institute of Iceland (www.fisheries.is) and the Institute of Marine Research of Norway (www.imr.no).

A variety of gears are used in the AOAS fisheries, with demersal trawls, longlines and gillnets the most important gear for the demersal species, and purse seine and pelagic trawls accounting for most of the catches of the pelagic species (Table 4).

<table>
<thead>
<tr>
<th>Species</th>
<th>Directed fishery by gear</th>
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<th>As by-catch in fleet(s)</th>
<th>Location</th>
<th>Agreements and regulations</th>
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<td>TR, TS</td>
<td>Northern coastal areas to south of 74ºN</td>
<td>Bilateral agreement, Norway and Russia</td>
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<tr>
<td>NE Atlantic cod</td>
<td>TR, GN, LL, HL</td>
<td>All year</td>
<td>TS, PS, TP, DS</td>
<td>North of 62ºN, Barents Sea, Svalbard</td>
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<td>Greenland halibut</td>
<td>LL, GN</td>
<td>Seasonal</td>
<td>TR</td>
<td>Deep shelf and at the continental Slope</td>
<td>Q, MS, RS, RG, MBH, MBL</td>
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</tbody>
</table>
### 2.5.1. Polar cod

#### 2.5.1.1. Fisheries and catches

Polar cod used to be fished intensively by former USSR, Norwegian, Danish and German Democratic Republic fleets in the Barents Sea, White Sea and in Soviet waters in the 1970s ([www.fao.org](http://www.fao.org)). Global landings reached a maximum of 348,000 tonnes in 1971. Since then the landings declined to less than 70,000 tonnes in recent years (prior to 2012-2013) with most of the catches by the Russian fleet (Figure 13). However, in 2012-2013, no landings were reported from the NE Atlantic or from the NAFO area ([www.barentsportal.com](http://www.barentsportal.com)).

There appears to be little economic interest in this species that has a large biomass in the Barents Sea that could support a substantial fishery. The most recent Norwegian acoustic surveys in the Barents Sea indicate that the stock size is probably between 1.5 and 2 million tonnes ([www.barentsportal.com](http://www.barentsportal.com)).

**Figure 13: Landings of Polar cod**

![Graph showing landings of Polar cod from 1950 to 2010](source: data from [www.fao.org](http://www.fao.org))
2.5.1.2. **Assessment and management**  
There is no assessment or management advice for Polar cod.

2.5.2. **Capelin**  
2.5.2.1. **Fisheries and Catches**  
Catches of capelin are highly variable, following strong fluctuations in abundance. Capelin is one of the most abundant marine fish species, with biomass of up to 8 million tonnes in certain years (ICES 2014a). Global landings from FAO show a peak in catches of 4 million tonnes in the 1977, with several lesser peaks in the subsequent period (Figure 14).

In the Barents Sea fishery capelin are targeted using pelagic trawls and purse seines and are also caught as by-catch in fish and shrimp trawls. While the Norwegian catch is taken mainly by purse seine (75%), with the rest taken by smaller coastal vessels using trawls and purse seine, the Russian fleet uses pelagic trawls. Low TACs and the development of new markets for frozen capelin for human consumption have resulted in the change in recent years from a largely industrial fishery (fishmeal and fish oil for aquaculture) to one that nowadays is largely for human consumption (ICES, 2014a).

Barents Sea catches increased rapidly from 224,000 t in 1965 to 2,986,000 t in 1977, declining thereafter (Figure 15).

**Figure 14: Global landings of capelin**

[Graph showing global landings of capelin from 1950 to 2010]

**Source:** data from [www.fao.org](http://www.fao.org)
In the NAFO area landings of capelin peaked at 367,000 t in 1975, declined sharply in the next 5 years, increased to 173,000 t in 1990, and decreased to less than 50,000 t a year since 1993 (Figure 16) (www.nafo.int).

2.5.2.2. Assessment and management
The Barents Sea capelin fishery has been regulated by a bilateral fishery management agreement between Russia (former USSR) and Norway since 1979, with separate TACs for the winter and the summer-autumn fisheries. There has been no autumn fishery since 1999, except for a small experimental fishery in some years. Under the bilateral agreement, the summer-autumn fishery has been closed (between 1 May and 15 August until 1984, and from 1 May to 1 September since 1984. Additional measures include a
minimum landing size of 11 cm (AFWG strongly recommends that only mature capelin are fished during the period from January to April). The commercial fishery was closed three times: from the autumn of 1986 to the winter of 1991, from the autumn of 1993 to the winter of 1999, and from 2004-2008, when the capelin stock was low (Figure 15. A commercial fishery in the winter started again in 2009 (ICES 2014a).

The reference point adopted by the JRNFC for the capelin fishery since 2002 is a Blim (SSBlim), where the rule is that with 95% probability, at least 200,000 t of capelin should be allowed to spawn (Blim = 200,000 t). Based on the scientific advice, the TAC for 2014 was reduced considerably to 65,000 t, from 200,000 t in 2013. This was due to reduced individual growth rates resulting in a reduction in spawning biomass (ICES 2014a).

Barents Sea stock size has been quite stable since 2008. An acoustic survey of total stock size resulted in an estimate of 3.96 million t in 2013, with about 37% (1.47 million t) of the stock biomass consisted of maturing fish (>14.0 cm). Except for 1989, recruitment was poor for approximately two decades, from 1985 to 2005. In recent years the trend has been for higher (above average), but variable recruitment (Figure 17).

For the Iceland-East Greenland-Jan Mayen area (Subareas V and XIV and Div IIa west of 5W), the joint Iceland-Greenland-Norway management plan stipulates an escapement biomass of 400,000 t at the end of the fishing season. An acoustic survey to estimate the biomass of immature (age 1 and 2) capelin is used to set a preliminary TAC, with an initial quota of 2/3 the TAC, taking into consideration the required 400,000 tonne escapement. During the fishing season, the TAC is adjusted on the basis of a second survey (www.fisheries.is).

**Figure 17: Recruitment (0-group abundance index) of Barents Sea capelin**

![Figure 17: Recruitment (0-group abundance index) of Barents Sea capelin](source: data from ICES (2014a))
2.5.3. Greenland halibut
2.5.3.1. Fisheries and Catches
Greenland halibut global catches have averaged around 100,000 t a year since 1970, with relatively little variability in recent decades (Figure 18) (www.fao.org).

Figure 18: Global landings of Greenland halibut

Greenland halibut is caught on the deep shelf and at the continental slope, mainly with bottom longlines and gillnets and as by-catch in trawls. Landings peaked in 1970 (ca. 90,000 t; Figure 19). From 1984 to 2013, landings in the NE Atlantic ranged from 8,602 t to 33,320 t, with an average of 16,821 t (Figure 19). Almost all of the NE Greenland halibut caught are by the Norwegian and Russian fleets. Landings have increased steadily since 2008, reaching 21,461 t in 2013 (ICES 2014a)

Figure 19: NE Atlantic Greenland halibut historical landings

Source: ICES (2014a)
NAFO Greenland halibut catches have increased over the years, varying between 60,000 and 80,000 t in recent years (Figure 20).

**Figure 20: NAFO Greenland halibut landings**

Source: data from www.nafo.int

A single stock of Greenland halibut is assumed for the East Greenland/Iceland/Faeroe Islands (GIF) region. Total landings in the GIF region increased steadily from 1976 to over 60,000 tonnes in 1989, with most of the catch during this period from Icelandic waters. Since 2000, landings have ranged between 20,000 and 25,000 tonnes, with similar amounts caught in fishing grounds in Greenland and Iceland (ICES 2014a).

### 2.5.3.2. Assessment and management

No analytical assessment is done for NE Greenland halibut and there is no information on exploitation rates (fishing mortality). ICES advice is based on landings and survey trends (total biomass, mature female biomass and length distributions). Biomass has been stable or increasing since 1992, but the trend is not clear after 2006 (ICES 2014a).

Management is based on Total Allowable Catch (TAC), minimum landing sizes (45 cm), maximum by-catch of undersized fish (15% by number per haul), technical measures (grids to reduce by-catch) and seasonal and area restrictions. As there is considerable uncertainty with regard the current assessment, no attempts have been made to develop reference points for the NE Greenland halibut stock.

The Joint Russian-Norwegian Fisheries Commission (JRNFC) establishes TACs for the NE Atlantic. In 2011 the TAC for 2012 was 18,000 t. The following year it was raised to 19,000 tonnes and kept the same for 2013. Landings exceeded the TAC in 2012 and 2013 due to the problem of by-catch of Greenland halibut in trawl fisheries targeting other species. In previous AFWG reports, it was suggested that catches above the mean of approximately 13,000 t for the period from 1992 to 2009 would reduce the ability of the stock to rebuild.

Stock assessment for the GIF Greenland halibut stock is based on a surplus production model, using catch per unit effort (CPUE) from the Icelandic fishery. Results of stock assessment suggest that the stock biomass is low and fishing mortality is high. A five-year bi-lateral management plan was adopted by Greenland and Iceland in May 2014. Under the management plan the Greenland halibut will be managed according to the precautionary
principle, on the basis of the F_{msy} recommended by ICES, and that 56.4% of the TAC is for Iceland and 37.6% for Greenland. The TAC for the GIF region for the 2014/2015 quota year was set at 25,000 tonnes. However, Greenland and Iceland could not come to an agreement with the Faeroe Islands, which account for smaller landings of Greenland halibut (over 2,000 tonnes in 2012 and 2013) (www.fisheries.is).

2.5.4. Northern shrimp
2.5.4.1. Fisheries and Catches
Northern shrimp are fished with bottom trawls, with the most important fisheries in the NE Atlantic (Barents Sea), Iceland and Greenland. Total global landings increased steadily from the mid-1950s to more than 400,000 t in 2004, declining ever since (Figure 21).

**Figure 21: Global landings of Northern shrimp**

![Figure 21: Global landings of Northern shrimp](image)

Source: data from [www.fao.org](http://www.fao.org)

The Northern shrimp fishery in Subareas I and IIb (Barents and Norway Seas) is exploited mainly by Norwegian and Russian vessels. Highest landings above 100,000 tonnes were recorded in the 1980s, but have declined since to 21,000 t in 2010. A small fishery exists in Division IVa (Fladen Ground). Landings ranged from 500 to 6,000 t in the period from 1990 to 2000, and there has been a decline since. In Divisions IIIa and Division Iva East (Skagerrak and Norway Deep), 10,000 to 15,000 t were landed each year from 1985 to 2009.

NAFO Northern shrimp catches increased sharply to a maximum of 332,000 t in 2004, but then declined to 190,000 t in 2013 (Figure 22). In Iceland, an offshore Northern shrimp fishery started in the mid-1970s, reaching maximum landings of over 65,000 t in 1994-1997. Landings decreased to only 860 tonnes in 2006 and recovered to 7,000 tonnes in 2013.
2.5.4.2. Assessment and management

The Joint NAFO/ICES Pandalus Assessment Working Group (NIPAG) carries out stock assessment and the provision of management advice for a number of Northern shrimp stocks. NAFO stocks assessed include NAFO Divisions 3M, 3LNO, Subareas 0 and 1, and stocks in the Denmark Strait and off East Greenland. ICES Northern shrimp stocks are Skagerrak and Norwegian Deep (ICES Divisions IIIa and IVa East), Barents Sea and Svalbard area (ICES Sub-areas I & II), and Fladen Ground (ICES Division IVa). Stock assessment is based on survey and catch and effort data, using various methods, including surplus production models (ICES, 2014b).

Northern shrimp stocks have been in decline or at low levels in recent years, with a moratorium in recent years in NAFO Division 3M, landings less than TACs in Divisions 3LNO, (ICES, 2014b), TACs set progressively lower and lower in Subareas 0 and I, and the Denmark Strait and East Greenland stock at a low level. In the NE Atlantic region, landings of the Skagerrak and Norway Deep stock, exploited by Norway, Denmark and Sweden have also been decreasing even as TACs were successively reduced. In this fishery, the Nordmore grid, a by-catch reduction device, is mandatory. The Barents Sea and Svalbard Northern shrimp, considered a single stock, has a partial TAC for the Russian fleet and is partly regulated by effort control. Norwegian and Russian vessels fish the whole area, while other nations are restricted to the Svalbard fishing zone and the international waters of the “Loop Hole”. The stock was close to carrying capacity in 2010 but has since declined. The latest analysis suggests that with catches of up to 70,000 t, the risk of exceeding $F_{\text{max}}$ is less than 10% (ICES, 2014b). The Fladen stock (ICES IVa) decreased since 1998, with no landings reported since 2006 (ICES 2014b).

In Iceland, the fishery is managed by TAC and stock assessment is based on surveys. Stock biomass in recent years has been near the historic low and recruitment has been below the average since 2004. The recommended TAC of quota year 2014/2015 is 5,000 t. There is no international management of catch division agreement for the shared stock off East Greenland (ICES, 2014b).

Several problems regarding management of NAFO Northern shrimp stocks should be noted. Canada and Greenland set independent and autonomous TACs for the stock in Subareas 0 and I, while Denmark (representing Faeroe Islands and Greenland) has not agreed with Division 3LNO TACs since 2003 and sets its own, much higher TACs (www.fisheries.is).
2.5.5. **North-east Atlantic cod**

2.5.5.1. **Fisheries and Catches**
The Atlantic cod is caught mainly with bottom otter trawls and pelagic trawls ([www.fao.org](http://www.fao.org)). Other gear used to catch cod include longlines, gillnets, Danish seines, purse seines, twin beam trawls, light trawls, shrimp trawls, cod traps and pound nets. The major fishing grounds for cod are in the boreo-arctic region, mostly around Iceland, in the Barents Sea, off Newfoundland and West Greenland, in the Norwegian Sea, off Spitzbergen, and around Bear Island, with Iceland and Norway accounting for the biggest landings in recent years. In the period from 1950 to the present, global landings of Atlantic cod peaked at almost 4 million tonnes in the late 1960s, and then declined steadily to a minimum in 2007, with a gradual recovery since (Figure 23). In the NE Atlantic, landings have varied considerably, from less than 300,000 t to over 1.3 million tonnes, with a steady increase in recent years (Figure 23). The increase in abundance has been accompanied by an increase in recruitment for the same period (ICES 2014a).

**Figure 23: Annual landings of North Atlantic cod**

In the NE Atlantic landings of cod have varied considerably over the last seventy to eighty years, form a maximum of over 1.3 million tonnes in 1956 to the lowest level of 212,000 t in 1990. Over the last two decades landings have averaged around 600,000 t, and have increased steadily since 2008-2009, to 966,000 t in 2013 (Figure 24) (ICES 2014a).
Fisheries management and the Arctic in the context of climate change

Figure 24: NE Atlantic (ICES Sub-area I, Division IIa and Division IIb) cod total landings

[Graph showing landings (1000 tonnes) from 1961 to 2012]

Source: data from ICES (2014a)

NAFO Atlantic cod catches declined dramatically since the late 1960s, from a maximum of almost 1.9 million tonnes to less than 100,000 t per year since the mid-1990s (Figure 25) (www.nafo.int).

Figure 25: NAFO Atlantic cod landings

[Graph showing landings (1000 tonnes) from 1960 to 2013]

Source: data from www.nafo.int

Icelandic cod landings have declined steadily from a maximum of more than half a million tonnes in 1955 to 223,000 t in 2013, caught mainly by trawl (46%) and longlines (34%). Icelandic fishers also fish NE cod in the Barents Sea, with landings ranging from about 1,500 t to almost 18,000 t from 1998 to 2013, and in the Greenland shelf where landings reached more than 400,000 t a year in the 1960s. Since then landings have decreased, averaging less than 20,000 t a year during the last 10 years.
2.5.5.2. Assessment and management

Stock assessment of NA cod is based on catch-at-age analysis. The following reference points were defined in 2003: $B_{\text{lim}} = 210,000$ tonnes, $B_{\text{pa}} = 460,000$ tonnes, $F_{\text{lim}} = 0.74$ and $F_{\text{pa}} = 0.4$. The AFWG defined $F_{\text{msy}}$ at $F=0.40$ and $B_{\text{trigger}}$ is set at the $B_{\text{pa}}$ level (ICES 2014a).

Total stock biomass has increased in recent years and was estimated to be about 3.1 million tonnes in 2014. Spawning stock biomass of the NE Atlantic cod (ICES subareas I and II) has increased strongly over the past decade and in 2014 was estimated to be about 1.8 million tonnes, one of the highest ever. This is well above the $B_{\text{lim}}$ of 0.21 million tonnes, around which the SSB fluctuated for most of the period from the 1950s to the late 1980s. The increase in SSB is associated with a sharp decrease in the fishing mortality, from very high $F$ values in the mid-1990s, with maximum values around 1.0/year, to $F$ values below the $F_{\text{msy}}$ of 0.4, in recent years. Recruitment has also increased in recent years, with the 0-group abundance index reaching a peak of around $450 \times 10^9$ age 0 cod in 2011 (Figure 26).

Figure 26: Recruitment of NE Cod

![Recruitment of NE Cod](source: data from ICES (2014a))

Stock assessment of Icelandic cod is based on catch-at-age data and the TAC is based on the biomass of age 4 and older cod. $B_{\text{trigger}}$ and $B_{\text{lim}}$ reference points of 220,000 t and 125,000 t calculated in 2010 are the basis of the Harvest Control Rule (HCR) that stipulates a decrease in harvest rate (landings as a proportion of the reference biomass) if the spawning biomass falls below $B_{\text{trigger}}$ (www.fisheries.is).

Icelandic cod spawning biomass has increased steadily since the mid-1990s and at the beginning of 2014 was approximately 411,000 t. However, recruitment has been below the average over the last 10 years, indicating that the increase in biomass can be largely attributed to a decrease in fishing mortality. Based on the estimated reference biomass of 1,106,000 t and the 20% HCR, the TAC for the 2014/2015 quota year was set at 218,000 t (www.fisheries.is).
2.6. **Vulnerability and resilience**

Vulnerability and resilience have become key concepts in the climate change literature (Daw et al., 2009). Vulnerability or susceptibility to a threat such as climate change depends on the adaptive capacity of an individual, a stock, a population or a community. From the fisheries science perspective, resilience is the capacity of a population or a stock to compensate for additional mortality (such as fishing related mortality), by means of density dependent mechanisms affecting population growth through changes in survivorship and birth rates. Resilience is to a great extent a function of life history characteristics (Winemiller 2005). A conceptual model of vulnerability is presented in Figure 27, where sensitivity, potential for impact, and adaptive capacity, together define vulnerability (Daw et al. 2019). This model has been used to evaluate the potential impact of climate change on species and fisheries. For example, Hollowed et al. (2013a) revised the model and used it to evaluate the potential of commercial species in the Bering, Barents and Norwegian Sea to extend their distribution to the Arctic.

**Figure 27: Conceptual model of vulnerability**

Fish are characterized by remarkable life history plasticity; growth rates, age and size at maturity, fecundity, longevity, among other demographic parameters, can change with population abundance and environmental conditions (Winemiller et al. 2005). At low levels of population abundance, fish populations have the ability to increase rapidly by means of mechanisms such as higher growth rates, earlier size at maturity and greater fecundity (Rose et al. 2001). This compensatory ability is not the same for all species. In general, small, short-lived, fast growing, early maturing species (i.e. "r-selected" species) such as most small pelagics (anchovies, sardines, mackerel) have greater compensatory ability and resilience, with higher intrinsic growth rates and shorter doubling time than larger, longer-lived, slower-growing, late maturing species (i.e. "K-selected" species) such as halibut or cod. Persistence of heavily exploited stocks, especially small pelagic, with fishing mortality rates several times greater than natural mortality rates is evidence of the compensatory capacity and resilience of fish populations and stocks. In general, environmental factors tend to play a more important role in the population

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**Source:** Adapted from Daw et al. (2009)

**Note:** The word "system" can be interpreted as country, region, community, sector, social group or individual.
dynamics and abundance of r-selected species than K-selected species, which are more influenced by fishing mortality (Rose et al. 2001).

A species or a population can be classified into one of four categories of resilience (high, medium, low and very low) based on life history parameters (Musick, 1999; Froese and Pauly, 2000; Table 5). FishBase (Froese and Pauly, 2000) automatically assigns resilience categories based on four of the parameters in Table 5: K, tm, tmax and fecundity when it corresponds to a minimum number of eggs or pups per female per year. If data on decline in abundance or biomass are available, thresholds for decline over at least 10 years or three generations can be used to assess vulnerability to extinction (Table 5). In this study, we use the FishBase resilience classification as well as resilience defined on the basis of population doubling time, from literature values of the intrinsic growth rate: very short doubling time (1 year), short (to 3 years), medium (to 9 years), or long (greater than 9 years), following Rose (2005).

### Table 5: Values of selected life-history parameters suggested for classifying the resilience of fish populations or species

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
<th>Very low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold</td>
<td>0.99</td>
<td>0.95</td>
<td>0.85</td>
<td>0.70</td>
</tr>
<tr>
<td>rmax (1/year)</td>
<td>&gt; 0.5</td>
<td>0.16 – 0.50</td>
<td>0.05 – 0.15</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>K (1/year)</td>
<td>&gt; 0.3</td>
<td>0.16 – 0.30</td>
<td>0.05 – 0.15</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Fecundity (1/year)</td>
<td>&gt; 10,000</td>
<td>100 – 1000</td>
<td>10 – 100</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>tm (years)</td>
<td>&lt; 1</td>
<td>2 – 4</td>
<td>5 – 10</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>tmax (years)</td>
<td>1 - 3</td>
<td>4 - 10</td>
<td>11 - 30</td>
<td>&gt; 30</td>
</tr>
</tbody>
</table>

**Source:** Musick (1999); Froese and Pauly (2000)

**Note/legend:** Threshold (explained in text), rmax = intrinsic growth rate of the population or stock, K = von Bertalanffy growth parameter, tm = age at maturity, and tmax = maximum age.

The population resilience of the four fish species of this report according to the FishBase and the Rose (2005) classifications are given in Table 6. Only capelin and Greenland halibut are classified as high and low resilience species respectively, by both classifications. Greenland halibut is a "K-selected" species and is expected to be less resilient to fishing than capelin, a more "r-selected species".
Table 6: Summary of environmental limits and population resilience

<table>
<thead>
<tr>
<th>Fish species</th>
<th>Common name</th>
<th>D(m)</th>
<th>T(C)</th>
<th>Sp(mo)</th>
<th>SPT(C)</th>
<th>IR1</th>
<th>IR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. saida</td>
<td>Polar cod</td>
<td>100 to 700</td>
<td>-1 to 4</td>
<td>12 to 3</td>
<td>-1 to 2</td>
<td>3</td>
<td>Medium</td>
</tr>
<tr>
<td>M. villosus</td>
<td>Capelin, NW Atl.</td>
<td>1 to 400</td>
<td>-1 to 2</td>
<td>6 to 7</td>
<td>3.5 to 10</td>
<td>3</td>
<td>High</td>
</tr>
<tr>
<td>M. villosus</td>
<td>Capelin, NE Atl.</td>
<td>10 to 250</td>
<td>-1 to 2</td>
<td>3 to 4</td>
<td>1.5 to 6.5</td>
<td>3</td>
<td>High</td>
</tr>
<tr>
<td>M. villosus</td>
<td>Capelin, Iceland</td>
<td>10 to 400</td>
<td>-1 to 2</td>
<td>3 to 4</td>
<td>2 to 7</td>
<td>3</td>
<td>High</td>
</tr>
<tr>
<td>M. villosus</td>
<td>Capelin, Greenland</td>
<td>1 to 600</td>
<td>-1 to 2</td>
<td>3 to 4</td>
<td>1.9 to 8.5</td>
<td>3</td>
<td>High</td>
</tr>
<tr>
<td>R. hippoglossoides</td>
<td>Greenland halibut</td>
<td>300 to 2000</td>
<td>0 to 4</td>
<td>2 to 4</td>
<td>0 to 4</td>
<td>9</td>
<td>Low</td>
</tr>
<tr>
<td>G. morhua</td>
<td>Atlantic cod</td>
<td>10 to 500</td>
<td>-1 to 10</td>
<td>3 to 7</td>
<td>-0.5 to 6</td>
<td>3</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Source: Rose (2005) and FishBase (www.fishbase.org)

Legend: D(M) = depth range, T(C) = feeding temperature range in ºC, Sp(mo) = spawning months, IR1 = index of resilience (Rose, 2005), IR2 = resilience (FishBase: Low, Medium and High)

Considering all 58 commercial species in Table 3, only 9 are classified in the High resilience category, with 14 classified in the Medium resilience category, and the majority (35) classified in the Low resilience category.

Many commercial species of shrimp are relatively short-lived, fast growing and the impact of environmental variability on population dynamics is generally more important than fishing. However, the Northern shrimp is a species with significant latitudinal variation in life history parameters, with the more northern populations that live in colder temperatures having greater longevity and reaching a larger size than those living in warmer conditions (Wieland 2005). Thus, resilience to climate change probably varies considerably among the different populations and throughout the geographic distribution of the species.

Wiedmann (2014) and Wiedmann et al. (2014) compiled 6 life history traits (longevity, age at maturity, maximum body size, length at maturity, fecundity and offspring size) for 76 Barents Sea fish species and carried out a multivariate analysis to explore temporal and spatial life history variation at the community level. They found a latitudinal gradient in life history characteristics, with species from the south-west Barents Sea being more "K-selected" than those from further north in the colder, Arctic NE Barents Sea Region. With warmer temperatures, they detected a "borealization" of the Arctic fish community, which has important implications for EBM and for climate change.
2.7. Key actors and governance

In this section we introduce the main actors and review their roles, with particular emphasis on the bodies and organizations involved in assessment and management of the five species selected for this study and others in the North Atlantic region of the AOAS. We also provide a review of the existing governance in light of the expected expansion of fisheries to new fishing grounds in international waters that are becoming accessible with shrinking ice cover.

2.7.1. Key actors

The Regional Fisheries Management Organizations (RFMO) responsible for management of resources of high seas resources in the area of interest are the North Atlantic Fisheries Organization (NAFO) and the North East Atlantic Fisheries Commission (NEAFC). A number of other national and intergovernmental bodies are involved in the assessment and managing of coastal resources of commercial stocks of the Arctic Ocean and adjacent seas (AOAS). The most relevant are: Joint Russian-Norwegian Fisheries Commission (JRNFC), International Council for the Exploration of the Seas (ICES), National Marine Fisheries Service, US (NMFS), All Russia Research Institute of Marine Fisheries and Oceanography (VNIRO), Institute of Marine Research, Norway (IMR), Marine Research Institute, Iceland (MRI), Greenland Institute of Natural Resources (GINR), Department of Fisheries and Oceans, Canada (DFO). Detailed information, data and scientific advice are available on the web pages of the above bodies and organizations. Another important institution, involved in environmental monitoring, statistical data collection and conservation issues related to fisheries is the Arctic Council (AC). A number of Non-Governmental Organizations (NGO) influence policies and monitor compliance, the most important of which form the Arctic NGO Forum11.

2.7.1.1. Northwest Atlantic Fisheries Organization (NAFO)

The Northwest Atlantic Fisheries Organization (www.nafo.int) currently has 12 members: Canada, Cuba, Denmark (Faroe Islands and Greenland), European Union, France (Saint Pierre and Miquelon), Iceland, Japan, South Korea, Norway, Russia, Ukraine and the USA and its headquarters are located in Dartmouth (Nova Scotia, Canada). NAFO is an intergovernmental organization with a mandate to provide scientific advice and management of fisheries in the NAFO Regulatory Area (RA), the portion of the NAFO Convention Area in international waters of the north-western part of the Atlantic Ocean, outside the coastal 200 miles Exclusive Economic Zones (EEZs) (Figure 28). NAFO is the successor to the International Commission of the Northwest Atlantic Fisheries (ICNAF). The ICNAF was established in 1949 by the International Convention for the Northwest Atlantic Fisheries (having Newfoundland, Iceland, the UK and the USA as the initial signatories), held its first meeting in 1951 and was formally dissolved in 1979 as a consequence of the extension of national jurisdictions to 200 miles (Anderson, 1998).

Figure 28: The NAFO Convention Area

Source: www.dfo-mpo.gc.ca/international-new/media/images/NAFOmap-carpteOPANOlg-eng.jpg
NAFO has as a primary objective the optimum utilization, rational management and conservation of the fishery resources of the Convention area, through international cooperation and collaboration, as outlined in the NAFO Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries, signed on 24 October 1978. As a first step towards a reformed Convention, taking into consideration the Ecosystem Approach (EA) to fisheries, the "Amendment to the Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries" was adopted in 2007, and has to date been ratified by six NAFO member governments: Norway, Canada, the European Union, Cuba, the Russian Federation and Iceland.

Currently, **NAFO regulates 17 stocks**, including Flemish Cap cod (Division 3M), Grand Bank (Division 3NO) cod and capelin, Greenland halibut in Subarea 2 and Division 3KLMNO, and Northern shrimp in Divisions 3M and 3LNO. Catches in the NAFO area catches increased from 2.3 million t in 1960 to a maximum of 4.6 million t in 1968, declining steadily thereafter to a minimum of 1.5 million t in 2013.

NAFO does not manage sedentary species such as bivalves or species managed by other fishery bodies, such as salmon (NASCO) and billfishes and tunas (ICCAT). Redfish stocks (*Sebastes* spp.), found in the CAs of both NAFO and NEAFC are jointly managed by both NAFO and NEAFC.

NAFO fisheries management is based on the Precautionary Approach (PA), multi-year management plans for some species, the Ecosystem Approach, Risk Based Management Strategies and Management Strategy Evaluation. Specific management objectives are: to restore to or maintain the stock at B_{msy}, eliminate overfishing, apply the precautionary approach, minimize harmful impacts on living marine resources and ecosystems and preserve marine biodiversity. On this basis, a moratorium is currently in place for five species, including Atlantic cod (Division 3NO), capelin and shrimp. TACs for 2015 for cod (Division 3M) and Greenland halibut are 13,795 and 11,543 t respectively.

In addition to TACs, a number of other management and monitoring measures are in place, including continuous tracking of fishing vessels by means of the NAFO Vessel Monitoring System (VMS), the use of observers on board fishing vessels, at-sea inspections, obligatory use of by-catch reduction devices in the shrimp fishery, and closed areas (18 areas within the Convention area considered vulnerable to bottom trawls).

### 2.7.1.2. North-East Atlantic Fisheries Commission (NEAFC)

The North-east Atlantic Fisheries Commission ([www.neafc.org](http://www.neafc.org)) is a RFMO with headquarters in London. The NEAFC Convention (the Convention on Future Multilateral Cooperation in North-East Atlantic Fisheries) was signed on 18 November 1980 and has been in force since 17 March 1982. The area of competence of the NEAFC is the Northeast Atlantic and the Arctic (Figure 29). Most of the NEAFC Convention Area is under the fisheries jurisdiction of NEAFC’s Contracting Parties (CP): Denmark (in respect of the Faeroe Islands and Greenland), the European Union, Iceland, Norway, and the Russian Federation. However, three large areas are international waters and constitute the NEAFC Regulatory Area, for which it can recommend fisheries management measures to its Contracting Parties (Figure 29).

The long-term conservation and optimum utilisation of the fishery resources in the Convention Area, while providing sustainable economic, environmental and social benefits, is the objective of NEAFC ([www.neafc.org](http://www.neafc.org)). **NEAFC implements management and control measures for various fish stocks** as well as measures to protect the
environment from trawling and other fishing activities. NEAFC does not manage any Atlantic cod, Polar cod, Greenland halibut, Northern shrimp or capelin stocks (www.neafc.org).

Management decisions are taken by the Parties, which make up the commission, based on scientific advice for all stocks received from ICES, under a memorandum of understanding (MOU). Decisions are made by simple majority or, by 2/3 majority where the Convention requires a qualified majority, with each Contracting Party having one vote. Management advice is based on the PA as well as the EA.

The **main species** are redfish, mackerel, haddock, herring, blue whiting and approximately 50 deep-sea species. Catches in 2011 amounted to 2.7 million tonnes, with herring (1.34 million t), mackerel (930,000 t) and deep-sea species (203,000 t) accounting for more than 90% of the total catch.

A **new NEAFC scheme of control and enforcement** entered into force on 5 January 2015. Control measures cover authorisation to fish, notification of fishing vessels, marking of gear, removal and disposal of unmarked or illegal fixed gear, retrieval of lost fixed gear and labelling of frozen fish. Monitoring and enforcement measures include recording and communication of catch and fishing effort, use of VMS, inspections at sea and port state control of foreign fishing vessels.

The **main challenges** facing NEAFC are with regard to reaching agreement on TACs (the expansion of the distribution of mackerel to Icelandic waters and the resulting dispute over quotas is a good example) and management measures, the sustainable exploitation of deep-sea stocks of species with low resilience, uncertainty and lack of information about the stock status of some species, and the implementation of the EAM.

**Figure 29: Map of the NEAFC area**
2.7.1.3. Joint Russian-Norwegian Fisheries Commission (JRNFC)
The Joint Russian-Norwegian Fisheries Commission (www.jointfish.com), established in 1975, manages the most important shared fish stocks (NE cod, haddock, Greenland halibut and capelin) of Norway and Russia in the Barents Sea and the Norwegian Sea. Fish stocks are assessed annually and TACs established by ICES, based on research and catch data from the different countries.

The two countries exchange information on catches of quota-regulated species in each other's economic zone, as well as statistics for cod, haddock, capelin, blue whiting and shrimp in ICES I and II areas on a monthly basis (www.jointfish.com).

The competence of the Commission includes decisions on management strategies, quota allocation and technical properties of the fishing gears. JRNFC has also the competence to implement control systems to ensure the decisions made by the commission are followed by the fishing industry. The JRNFC thus decides on the total annual catch (TAC) and on allocation of the TAC to Russia and Norway. It also decides on catch quotas to third countries (for example, 14.15% of the total quota for NE cod).

After the size and allocation of the TAC is decided by the JRNFC, the national management bodies (Federal bureau of Fisheries in Russia, Ministry of Fisheries and Coastal Affairs and Directorate of Fisheries in Norway) divide the national quota according to fleet groups, vessel quotas, and gears to be utilized.

In recent years the JRNFC has moved to implement long term management plans for stocks such as the NE Arctic cod and capelin stocks that are in accordance with the precautionary approach to fisheries.

2.7.1.4. International Council for the Exploration of the Sea (ICES)
The International Council for the Exploration of the Sea (www.ices.dk) is an intergovernmental organization established in 1902 (founding countries were Denmark, Finland, Germany, the Netherlands, Norway, Sweden, Russia, United Kingdom) and received a legal foundation and full international status in 1964 (by then also including Belgium, United States, France, Portugal, Poland, Latvia, Estonia, Spain, Ireland, Iceland and Italy). At present it also includes Canada and Lithuania, and Italy is no longer a member. The ICES statistical areas are shown in Figure 30.

The main role of ICES is to coordinate and promote scientific knowledge and to provide advice that best guarantees the sustainability of the marine environment. It has a key role in producing advice for international organizations and commissions including, among others, the NEAFC and the EU Commission. ICES is active in coordinating and developing science, monitoring and providing scientific advice on fisheries in the Arctic. A strategy for ICES work in the Arctic was adopted by the ICES Member Countries and is part of the ICES Strategic Plan for the period 2014–2018 (http://ices.dk/explore-us/Action Areas/Pages/Arctic.aspx). ICES cooperates with the Arctic Council and International Arctic Science Council (IASC) within the framework of several working groups and activities:

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12 Flow of information for advice production in http://www.ices.dk/SiteCollectionImages/advice/how-is-advice.gif
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- Arctic Monitoring and Assessment Programme (AMAP). [http://www.amap.no](http://www.amap.no)
- Conservation of Arctic Flora and Fauna (CAFF) ([http://www.caff.is](http://www.caff.is))
- Protection of the Arctic Marine Environment (PAME) ([http://www.pame.is](http://www.pame.is))
- International Arctic Science Council (IASC) and its ICARP III process (International Conference in Arctic Research Priorities, [http://icarp.arcticportal.org/](http://icarp.arcticportal.org/))
- Meetings of Scientific Experts on Fish Stocks in the Arctic Ocean ([http://icarp.arcticportal.org/](http://icarp.arcticportal.org/))
- The joint AC and IASC Sustained Arctic Observation Network (SAON).

ICES is awaiting a decision on its application to join the Arctic Council as an observer.

The production of advice is based on the work of expert groups, where national representatives review the available information, define reference terms for future research and produce a report where, if appropriate, management advice is first proposed. Workshops are also promoted to address special issues. The Science Committee (SCICOM) oversees the output of both the expert groups and the workshops. The Advisory Committee (ACOM) integrates the information of different expert groups and workshops. At the top of the ICES hierarchy is the Council, the principal decision and policy-making body of ICES, formed by the ICES President and two delegates appointed by each of the 20 member countries. ICES undertakes other tasks, such as statistical data collection, and is supported by many other administrative and coordination groups.

Artic fisheries, within the framework of the ICES, are assessed by the Arctic Fisheries Working Group (AFWG) which performs assessments of cod, haddock, saithe, redfish, Greenland halibut, Northern shrimp and capelin, in ICES areas I and II (Barents Sea and Norwegian Sea). The first meeting of this group was held in 1959 and this is the longest running group still in existence. Advice provided by the AFWG is used by JNRFC, Norway, and NEAFC.


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13 [http://www.ices.dk/community/groups/Pages/AFWG.aspx](http://www.ices.dk/community/groups/Pages/AFWG.aspx)
Figure 30: ICES statistical areas (roman numerals)

2.7.1.5. Arctic Council (AC)
The Arctic Council (www.arctic-council.org) is a high-level intergovernmental forum that promotes cooperation, coordination and interaction among the Arctic States. It was formally established in 1996 by the Ottawa Declaration, with the aim of addressing issues of concern to Arctic Indigenous communities and other Arctic inhabitants, especially sustainable development and environmental protection in the Arctic. Canada, Denmark, Finland, Iceland, Norway, Russian Federation, Sweden and the United States of America are member states, while Arctic Athabasca Council, Aleut International Association, Gwich’in Council International, Inuit Circumpolar Council and Russian Association of Indigenous Peoples of the North and Saami Council are permanent participants.

The Chairmanship of the AC rotates every two years between the eight member states. At present Canada holds the Chairmanship for the biennial 2013-2015 (assumed Chairmanship 15 May 2013), and the US will follow.

Activities of the AC are carried out within the framework of six working groups: Arctic Contaminants Action Programme, Arctic Monitoring and Assessment Programme, Conservation of Arctic Flora and Fauna, Emergency Prevention, Preparedness and
Response, Protection of Arctic Marine Environment and Sustainable Development. Membership of the working groups consists of experts from different ministries, government agencies and scientists. Working groups address a wide range of subjects, from climate change to emergency response.

Several Task Forces are appointed at Ministerial meetings to work on specific issues for a limited amount of time. Consisting of experts from the Working Groups and representatives from the member states, these become inactive after achieving their desired results. **Four Arctic Council Task Forces (TFs)** are currently active: a TF on **Arctic Marine Oil Pollution Prevention**, a TF on **Black Carbon and Methane**, a **Scientific Cooperation TF** and a TF to **Facilitate the Circumpolar Business Forum**.

### 2.7.1.6. Arctic NGO Forum

The Arctic NGO Forum ([www.arcticngoforum.org](http://www.arcticngoforum.org)) was established in 2011 to "provide a consistent way for NGOs concerned with Arctic environmental issues to get together, exchange ideas and perspectives and provide advice to the global Arctic community". The European Commission Directorate General for the Environment has provided initial funding for a period of three years in order to establish the Forum and to attract wider funding support.

The partners of the Forum include **institutions of different nature; grassroots movements, scientific and higher education, private foundations and non-profit organizations committed to nature conservation and local governments**. The partners of the Forum are: Alaska Wilderness League (US), Alternatives North (Canada, grassroots approach), Arctic Portal (comprehensive gateway to Arctic polar science), Bellona Foundation (international environmental NGO based in Norway, towards sustainable solutions to environmental problems), Circumpolar Conservation Union (raises awareness of the importance of the Arctic and promotes respect for human rights of Arctic communities and peoples), EarthJustice (public interest law organization to protect natural resources and wildlife), Friends of the Earth / Norges Naturvernforbund (Norwegian Society for the Conservation of Nature) Greenpeace, Arctic Council Indigenous Peoples Secretariat, International Polar Foundation (communication and education on Polar science), Northern Forum (with representatives of local governments of eight countries), Oceana (international organisation focused solely on ocean conservation), Pacific Environment (US, promotes grassroots activism in the Pacific Rim), University of the Arctic (consortium of higher education institutions), Wetlands International (global organization dedicated to the protection of wetlands) and World Wildlife Fund (WWF).

### 2.7.2. Arctic Governance

The existing **framework for fisheries management**, with global, regional and national components is applicable to the Arctic. The 1982 United Nations Convention on the Law of the Sea (United Nations, [www.un.org](http://www.un.org)), along with the implementing United Nations Fish Stocks Agreement (United Nations, 1995) and FAO initiatives for responsible and sustainable fisheries such as the FAO Code of Conduct for Responsible Fisheries (FAO, 1995a) and the Precautionary Principle (FAO, 1995b), provide the global legal framework for the management of living marine resources, with the Law of the Sea giving sovereign rights to coastal states within Exclusive Economic Zones of 200 nautical miles. The UN Fish Stocks Agreement (United Nations, 1995) provides the basis for the precautionary and ecosystem based approaches in management and regional cooperation and enforcement of regulations in high seas fisheries.
At present fisheries management of Arctic fisheries, in the Atlantic zone, is undertaken by the Arctic countries in the case of coastal resources within the 200 mile EEZ and by NAFO and NEAFC for high seas stocks, under advice of scientific bodies of the RFMOs and ICES.

The coastal states to the ice-covered central Arctic Ocean (Canada, Denmark/Greenland, Norway, Russia and the US) have adapted a precautionary approach with regard to development of new fisheries in these international waters. For example, these countries have agreed to only authorize fishing by national vessels in these waters within the framework of regional fisheries management organisations or agreements based on international standards (pers. comm., Vidar Landmark, Director General, Norwegian Ministry of Trade, Industries and Fisheries).

Despite a large number of bodies where cooperation in research and management occurs, a comprehensive, Arctic-specific legal regime is lacking (Isted, 2009). The only organization working at the global Arctic level, with objectives that include monitoring and conservation of resources, is the Arctic Council, but it does not have legally binding obligations, permanent independent secretariat or structural funding (Koivurova and Molenaar, 2009). Despite this, the five Arctic States, the United States, Canada, Denmark (Greenland), Norway and Russia (Figure 3) have signed the Ilulissat Declaration 14 (Arctic Ocean Conference, Ilulissat, Greenland, 27 – 29 May 2008), where a clear appropriation of Arctic issues in made by these five states, and the Arctic Council is identified as the vehicle to pursue cooperation and scientific coordination in the Arctic: "This framework (Law of the Sea) provides a solid foundation for responsible management by the five coastal States and other users of this Ocean through national implementation and application of relevant provisions. We therefore see no need to develop a new comprehensive international legal regime to govern the Arctic Ocean". No specific reference to fisheries issues is made in the Ilulissat Declaration.

In the Atlantic region, only four of the Arctic states (United States excluded) will have to deal directly with adjustments in fisheries governance practices in the eventuality of a reduced ice cover and opening of new fishing grounds to commercial fishing. Despite this, other neighbouring countries, such as Iceland and the United Kingdom may have fisheries resources affected by ecologic changes brought about by changes in the circulation patterns and, like the EU (Rudloff, 2010), have declared interest in Arctic policies.

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Another situation will interact with ice cover shrinking to increase tension in the area: the extension of continental shelves to the 350 nm\textsuperscript{15}, according to the United Nations Convention on the Law of the Sea (UNCLOS)\textsuperscript{16}. Although sovereign rights between 200 and 350 nm do not extend to the water column, exploitation of minerals (oil and natural gas) is likely to affect the ecosystem and therefore have a negative impact on fisheries. The combination of these two unfolding realities, melting ice at the surface and disputes over the sea floor, may lead to territorial conflicts that deteriorate the existing cooperation among Arctic countries and have an adverse effect on fisheries management.

\textsuperscript{15} http://www.stimson.org/infographics/evolution-of-arctic-territorial-claims-and-agreements-a-timeline-1903-present/
\textsuperscript{16} http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf
Given potential new economic activities in the Arctic, from exploitation of fossil fuels, opening of new shipping routes and availability of fishing stocks, a **new governance model has been proposed** involving the creation of a new, strong regulatory body for the Arctic. In the specific case of fisheries this option would require the **creation of a new RMFO** to address, specifically, the Arctic Ocean. This option is the one that better guarantees strong governance of Arctic resources, forcing stakeholders and Arctic countries to achieve consensus and agreements and providing the opportunity for integrated management (Koivurova and Molenaar, 2009, Ridgway, 2010). It will also favour the closure of identified gaps in management and information integration towards the Ecosystem Approach (Koivurova and Molenaar, 2009).

The need to involve countries, other than the five signatories of the Ilulissat Declaration on Arctic resource management, will depend, in part, on how the final map of the extension of the continental shelves will be. Figure 32 shows a speculative image, at this point, of the EEZ extended to 350 nm.

**Figure 32: Limits of Arctic coastal state jurisdiction**

Source: Macnab et al. (2007)

Note: The lighter blue area represents the combined Exclusive Economic Zones of Arctic states, darker blue areas a possible delimitation of extended platforms.
3. CLIMATE CHANGE IN THE ARCTIC

### KEY FINDINGS

- **There is strong evidence for warming**, decreased sea ice, decreased multi-year ice and increase in summer melt area in the Arctic.

- **A nearly ice-free Arctic by the middle of this century** is possible according to the latest high emissions scenario model projections of the Intergovernmental Panel on Climate Change (IPCC).

- Within the Arctic Ocean and Adjacent Seas (AOAS), there is considerable variability in temperature and salinity trends, extent of ice melt, underlying the importance of regional scale monitoring.

- It is important to distinguish between **climate variability and climate change**.

- **Climate variability is short-term**, and in the North Atlantic region is associated mainly with the North Atlantic Oscillation (NAO).

- At the **individual level**, climate change impacts include changes in physiology, morphology, growth, reproductive capacity, mortality, distribution and behaviour.

- At the **population level** climate change influences dispersal and recruitment.

- At the **community level** climate change may influence species interactions (competition and predation) and result in "regime shifts", with dramatic changes in community composition and structure that may last a decade or more.

- The relationships between climate variability and recruitment and abundance are still poorly known.

#### 3.1. Temperature

The Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC) is the most comprehensive analysis of global climate change to date (IPCC, 2013). In the Coupled Model Intercomparison Project Phase 5 (CMIP5), a total of 138 models were used for four Representative Concentration Pathway (RCP) scenarios: RCP2.6, RCP4.5, RCP6.0, and RCP8.5. Relative to 1986–2005, the models agree on large-scale patterns of warming at the surface. Model results indicate that **land is going to warm faster than the ocean**, and the Arctic region (67.5° N to 90°N) **is projected to warm more than other regions** (very high confidence). Figure 33 shows the global surface temperature change for the four emission scenarios averaged over all CMIP5 models. Vertical bars represent likely ranges for global temperature change by the end of the 21st century (2081-2100), relative to 1986–2005 for the four scenarios (Collins et al. 2013).
**Figure 33:** Global mean temperature change averaged across all Coupled Model Intercomparison Project Phase 5 (CMIP5) models (relative to 1986–2005) for the four Representative Concentration Pathway (RCP) scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5

*Source:* Collins *et al.* (2013)

*Legend:* RCP2.6 (dark blue), RCP4.5 (light blue), RCP6.0 (orange) and RCP8.5 (red). Likely ranges for global temperature change by the end of the 21st century are indicated by vertical bars.

Depending on the forcing scenario, the CMIP5 models show that the Arctic (67.5°N to 90°N) **will warm between 2.2 to 2.4 times the global average warming** for 2081-2100 compared to 1986-2005. CMIP5 annual mean surface air temperature anomalies (°C) from the 1986–2005 reference period for the four emissions scenarios for the Arctic are:

- RCP2.6: 2.2 ± 1.7 (-0.5, 5.0)
- RCP4.5: 4.2 ± 1.6 (1.6, 6.9)
- RCP6.0: 5.2 ± 1.9 (2.1, 8.3)
- RCP8.5: 8.3 ± 1.9 (5.2, 11.4)

The models for the Arctic show that warming has a distinctly seasonal character, with peaks in early winter (November to December) and warming is least in summer when excess heat at the Arctic surface goes into melting ice or is absorbed by the ocean (IPCC, 2013).

### 3.2. Ice extent

The **major findings of the Fifth Assessment of the IPCC reports** with regard Arctic sea ice and the Greenland Ice sheet are the following (Bindoff *et al.*, 2013; Collins *et al.*, 2013; Flato *et al.*, 2013; Kirtman *et al.*, 2013; Vaughan *et al.*, 2003):

- Arctic sea ice extent decreased at a rate of between 3.5 and 4.1% per decade from 1979 to 2012, with the most rapid decrease in summer and autumn. Ice extent in September 2007 and September 2013 was 37% and 49% less respectively relative to 1979 to 2000 (Figures 34, 35);
- It is estimated that three quarters of summer Arctic sea ice volume has been lost over the past three decades;
- The extent of Arctic perennial (summer minimum) and multi-year sea ice (that has survived two or more summers) decreased between 1979 and 2012, at rates of 11.5 ± 2.1% per decade (0.73 to 1.07 million km² per decade) and 13.5 ± 2.5% per decade (0.66 to 0.98 million km² per decade), respectively;
From 1980 to 2008, the average winter sea ice thickness within the Arctic Basin decreased between 1.3 and 2.3 m, while sea ice drift speed has increased;

From 1979–2012, the annual period of surface melt on Arctic perennial sea ice is estimated to have lengthened by $5.7 \pm 0.9$ days per decade and the duration of ice-free conditions increased by nearly 3 months in the region between the East Siberian Sea and the western Beaufort Sea;

The Greenland ice sheet has lost ice during the last two decades and the rate of loss has increased since 1992;

The summer melt area has increased over the last decades, with record-setting temperatures, ice loss by melting and marine-terminating glacier area loss since 2007.

**Figure 34: Arctic September sea ice extent**

![Arctic September sea ice extent](image)

**Source:** Bindoff et al. (2013)

**Legend:** Red and grey lines are simulations. The black line is based on data from the National Snow and Ice Data Center (NSIDC).

**Figure 35: Decadal trends (%) in anomalies in ice extent, in different sectors of the Arctic and mean circulation pattern of sea ice**

![Decadal trends in ice extent](image)

**Source:** Vaughan et al. (2013)

**Legend:** Arrows show the average direction and magnitude of ice drift.
As the annual mean global surface temperature rises, CMIP5 projections indicate that there is a high probability that the Arctic sea ice cover will continue to shrink and thin all year round during the 21st century (Collins et al., 2013). High emissions scenario (RCP8.5) results show that the Arctic Ocean is likely to become nearly ice-free in September before the middle of this century (Figure 36) (Collins et al., 2013).

**Figure 36:** CMIP5 model simulations of sea ice extent (ocean area where sea ice concentration exceeds 15%) change under RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios relative to the 1986-2005 reference period for (a) Northern Hemisphere February and (b) Northern Hemisphere September

![Figure 36](image)

*Source:* Collins et al. (2013)

*Legend:* Solid curves show the multi-model means and the shading denotes the 5 to 95% range of the ensemble.

The decreased ice extent and longer ice-free period is expected to contribute to greater primary productivity, resulting in greater fluxes of organic material to the bottom (Figure 37) as well as more zooplankton for fish such as Polar cod. However, overall increases in productivity will depend on possible changes in plankton communities as well as the lag between the phytoplankton bloom and the grazers (zooplankton) (Meltofte, 2013).

**Figure 37:** Conceptual model of seasonal plankton succession under present and future conditions

![Figure 37](image)

*Source:* Meltofte (2013)
3.3. Water temperature, salinity and acidification

Assessment of trends in water temperature, salinity and acidification in the Arctic region are made difficult by multi-decadal variability, regional variability and the lack of historical data. Data from 1950 to 2010 indicate that seawater temperatures have risen since the 1970s, and subsurface pulses of relatively warm, Atlantic origin waters have been detected around the Eurasian basin (Rhein et al., 2013). There is also evidence of warming of Arctic surface waters in the Canadian basin, from 1993 to 2007 (Rhein et al., 2013).

With the observed decline in sea ice and release of freshwater from multi-year sea ice in recent decades, a decrease in salinity should be expected. Contrasting changes in salinity in different regions of the Arctic have been reported, that can be attributed to the effects of Ekman transport and sea ice formation and melt (Rhein et al., 2013). Nevertheless, in the period from 1992 to 1999, freshening of all regions throughout the Arctic as well as increased freshwater transport out of the Arctic was detected.

Ocean acidification, resulting mainly from the uptake of CO₂ from the atmosphere, leads to decreasing pH in the long term (Rhein et al., 2013). Since the beginning of the industrial era, ocean pH has decreased by 0.1 (Rhein et al., 2013). Ocean acidification is particularly important in the Arctic because solubility of CO₂ is greater at low temperature (Christiansen et al., 2013).

3.4. Climate, fish and fisheries

The distribution and abundance of fish is affected by environmental and physical processes acting on different temporal and spatial scales (de Young et al., 2009; Checkley et al., 2009). Climate variability is associated with short-term processes such as daily, seasonal and annual changes, whereas climate change is a term related to longer-term processes that occur with very long time scales, persisting for decades to centuries. Changes related to tides, lunar phase and seasonal upwelling are examples of short-term processes. Inter-annual processes last for several years and may be characterized by a degree of periodicity. An example of such a process is the El Niño-Southern Oscillation (ENSO) phenomenon that influences fisheries throughout the Pacific, and especially the small pelagic fisheries off the coast of Peru (Alheit and Bernal, 1993). Although the ENSO occurs in the tropical Pacific, it has far reaching affects, influencing rainfall as far away as Australia and Africa.

Short-term processes can have significant but short-term effects on spatial distribution, productivity and recruitment because the duration of the process or event is usually less than the lifespan of the fish. For example, shifts in a population's geographic range associated with small changes in temperature can occur on an annual or seasonal basis (MacCall, 1990).

In the North Atlantic, the dominant mode of climate variability, especially in winter, is the North Atlantic Oscillation (NAO) (Hurrell, 1995. The NAO index is calculated as the difference of atmospheric pressure at sea level between the Icelandic low and the Azores high (Hurrell, 1995). The NAO influences the strength and direction of westerly winds and storm tracks across the North Atlantic. The NAO positive phase is associated with intense Icelandic low and strong Azores high, strong westerly winds and warmer weather and more rainfall in northern Europe. In contrast, the negative NAO phase results in cooler temperatures in northern Europe. The NAO influences large-scale circulation in the North Atlantic, sea surface temperature (SST) and consequently fisheries through changes in primary and secondary production and recruitment of commercial fish species (Ottersen et
For example, changes in SST and plankton composition and availability in the North Sea in the 1960s to 1970s lead to the "Gadoid outburst", a series of years of exceptional recruitment of gadoid species such as Atlantic cod (Gadus morhua) (Beaugrand et al., 2003).

Often sharing phases with the NAO, the Arctic Oscillation (AO) is a climate index of the state of the atmospheric circulation over the Arctic. In the negative AO index phase, a weaker polar low pressure system results in weaker Westerlies, allowing cold Arctic air to push further south than during the positive AO index phase when stronger Westerlies keep cold Arctic air in the north.

On a longer temporal scale than changes related to phenomena such as ENSO and NAO are changes in community structure persisting over decades known as "regime shifts". One of the best examples is from the Bering Sea and Gulf of Alaska, where cycles between warm and cold regimes on a multi-decadal time scale resulted in dramatic changes, with a shift from an epibenthic community dominated largely by cold water crustaceans such as Northern shrimp (Pandalus borealis) in the early 1970's to a community dominated by warmer water species of fish such as walleye pollock (Theragra chalcogramma) and Pacific cod (Gadus macrocephalus) (Anderson and Piatt, 1999). These changes had significant effects on the local commercial fisheries (Anderson and Piatt, 1999) and are associated with the basin-scale Pacific Decadal Oscillation (PDO) index, defined as the leading empirical orthogonal function (EOF) of monthly sea surface temperature anomalies (SSTA) over the North Pacific (poleward of 20° N) after the global mean SST has been removed, or the first principal component of North Pacific monthly sea surface temperature (poleward of 20ºN). In the warm or positive phase of the PDO index, surface waters are warm in the NE Pacific but cool in the NW Pacific, while in the cool phase surface waters are cool in the NE Pacific but warm in the NW Pacific. Phase shifts occur about every 20 to 30 years.

A similar regime shift occurred in the West Greenland region, where Atlantic cod dominated the fisheries from 1950 to 1970 before a drastic reduction in recruitment and spawning stock biomass associated with a shift in the NAO, with decreased water temperature. Lower temperatures and decreased cod predation favoured an increase in Northern shrimp in the 1980s and 1990s, with important socio-economic consequences (Michel et al., 2013). The trends have reversed over the past decade and with expected warming over the coming decades, it is expected that cod will continue to increase, while the shrimp decline (Figure 38).

**Figure 38: Catches of West Greenland cod and Northern shrimp**

![Graph showing catch data]

*Source: ACIA online, in Christiansen et al. (2013)*
On a longer temporal scale, the Atlantic multidecadal oscillation (AMO) is an on-going series of long-duration changes in the SST of the North Atlantic Ocean, with a maximum difference of about 0.55 °C between extremes of cool and warm phases that may last for 20-40 years (Alheit et al., 2014). Evidence from paleoclimate proxies such as tree rings and ice cores suggests that these changes have been occurring for at least 1,000 years and are therefore natural and not due to human induced effects on climate (Alheit et al., 2014). The AMO is the leading component of natural low-frequency temperature variability in the North Atlantic and has been shown to have profound effects on the marine environment and fisheries from the North Sea to the boreal and Arctic systems (Edwards et al., 2013). During the warm AMO phase from the 1930 to the 1960’s for example, the distribution of cod extended northward approximately 1000 km along the coast of Greenland (Drinkwater, 2006), and Norwegian spring-spawning herring increased almost ten-fold in biomass while at the southern limit of their range, herring were replaced by sardine (Toresen and Ostvedt, 2000).

Barange and Perry (2009) and Brander (2010) reviewed the effects of climate change on ecosystems, fish and fisheries. At the individual level, climate change impacts performance of different life history stages through changes in physiology, morphology, growth, reproductive capacity, mortality, distribution and behaviour, while at the population level climate change influences dispersal and recruitment. Climate change may bring about community level changes through effects on species interactions, namely competition and predation. Climate change can indirectly bring about changes in productivity, structure and composition of marine ecosystems.

According to Barange and Perry (2009) marine species are strongly influenced by temperature, with optimal conditions for growth at the mid-range of the distributional temperature limits. Species adapted to colder waters may have difficulty in providing enough oxygen to tissues as water temperature increases and along with it metabolic demands, with larger individuals generally reaching their thermal aerobic limits sooner than smaller fish. Temperature effects may be compounded by interactions with other factors such as pH and oxygen. For this reason, the Dynamic Bioclimatic Envelope Model (DBEM) approach has been used to model the effects of climate change on distribution and abundance (Cheung et al., 2011).

Climate variability and change can also strongly influence spawning and reproduction, given that species have adapted spawning times and locations to particular physical (e.g. temperature, salinity) conditions and biological (e.g. food) conditions that maximize reproductive success (Barange and Perry, 2009).

Several hypotheses linking climate variability and changes to recruitment and abundance of marine fishes have been proposed. For example, the optimal environmental window hypothesis of Cury and Roy (1989) implies that recruitment is maximized under average, or "optimal" conditions, and therefore any deviation from these conditions due to short-term climate variability or long-term climate change is likely to lead to less successful recruitment. Since conditions at the extremes of the distributional range of a species are usually less optimal, the hypothesis predicts that recruitment will generally be less successful at the distributional limits. Similarly, according to Bakun's (1996) Triad hypothesis, disruption of optimal conditions of enrichment, concentration and retention processes will result in poor recruitment. On the other hand, under the Hunt et al. (2002) oscillating control hypothesis, developed for the southern Bering Sea, bottom-up control (plankton production) of recruitment occurs in cold years while top-down control (cannibalism and predation) is more important in warm years.
The potential impacts of climate change on fisheries are summarized in Figure 39.

**Figure 39: Ecological, direct and socio-economic impacts of climate change on fisheries and some examples of each**

Source: adapted from Daw et al. (2009)
4. **FORECASTING**

**KEY FINDINGS**

- Numerous observations and simulations show a **poleward shift in distribution of many species as a result of climate change**, the limit of which depends on environmental and habitat preferences of specific species.

- There is generally a **high or at least some potential** for commercially important fish species to **expand in distribution and abundance**.

- Depending on conditions, spectacular changes may occur in the area of Greenland and adjacent areas (**regime shift**), which are under stronger influence by Arctic climate;

- Potential **catches** of North Atlantic fishes are projected to **increase** by roughly **30% by 2050**.

- Effective **fisheries management** is considered to be the main factor determining the future of fisheries in the Arctic region. The effects of climate change are considered to be of relatively less importance.

- The **Precautionary Approach (PA)** is recommended for fisheries management in the Arctic, with emphasis on combating illegal, unreported and unregulated (IUU) fishing, and improving management, cooperation and research.

- **New economic opportunities** are envisaged as a result of climate change such as the opening of Arctic shipping lanes, enhanced access to oil, gas, and mineral resources and increased production in forestry and fisheries.

- These **economic developments** are expected to be **rather moderate** and will be driven, to a large extent, by global demand for resources rather than by climate change.

- Although **climate change** is affecting Arctic **indigenous communities**, it is not considered the most important of multiple stressors in play.

- **Arctic communities** are part of social-environmental systems that are characterized by **high resilience**, accustomed to constantly changing environments, although not to the more extreme warming scenarios.

4.1. **Impacts of climate change on marine ecosystems**

Impacts on marine ecosystems of global changes related to temperature, winds and acidification can be predicted, in some cases with considerable confidence (Barange and Perry, 2009). Over short time scales (a few years) the following impacts are expected (with **high confidence**):

- Negative impacts on the physiology of fish because of limited oxygen transport to tissues at higher temperatures;

- changes in distribution;

- fluctuations in abundance through impacts on recruitment;

- changes in timing of life history events (such as spawning), especially in plankton and short-lived, fast growing "r-selected" species.

Expected impacts at intermediate time scales (from a few years to a decade) are the following:
• Temperature related physiological stress and seasonal and interannual variations in climate will effect recruitment and therefore abundance (high confidence);
• impacts will be strongest at the extremes of species distribution ranges;
• impacts will be greatest on short-lived, "r-selected" species;
• community composition will change with changes in abundance;
• changes in community composition will likely impact structure and productivity of marine ecosystems (intermediate confidence due to unpredictability of compensatory dynamics).

At long time scales (multi-decadal):
• Impacts will depend largely on changes in net primary production and its transfer to higher trophic levels (predictions are of lower confidence);
• there is greater confidence in predictions at the regional scale because of greater knowledge of the processes involved and the food webs;
• decreased long-term primary productivity (with considerable regional variability) is predicted by most models, as phytoplankton community composition changes to smaller forms.

Long-term ecological changes in Arctic marine systems that are "very likely to happen" are summarized in Table 7.

**Table 7:** Potential ("very likely to happen") long-term ecological changes in Arctic marine systems as a result of climate warming

<table>
<thead>
<tr>
<th></th>
<th>Phytoplankton</th>
<th>Zooplankton</th>
<th>Benthos</th>
<th>Fish</th>
<th>Marine mammals and seabirds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td>Increased production in Arctic Ocean, Barents and Bering Sea shelves.</td>
<td>Difficult to predict; depends on timing of phytoplankton blooms and water temperature.</td>
<td>Difficult to predict; depends on timing of plankton blooms and water temperature. Crab and shrimp production may decline.</td>
<td>Depends on timing of plankton blooms and drift patterns of eggs and larvae.</td>
<td>Declines in ice associated species and increases by temperate species; seabird production dependent on changes in food availability.</td>
</tr>
</tbody>
</table>
### Impacts of climate change on stocks

A number of recent studies have predicted the impacts of climate change on the fish and fisheries of the Arctic and Sub-arctic region (Cheung et al., 2011, 2013; Hollowed et al., 2013; Lam et al., 2014; McBride et al., in press). Based on the revised Daw et al. (2009) conceptual framework for assessing the vulnerability of marine fish and fisheries to climate change, to enable an evaluation of the potential for commercially exploited species in the Bering, Barents and Norwegian Seas to move farther into the Arctic region, Hollowed et al. (2013) predicted the potential future distribution of 17 commercial fish and invertebrate species or taxonomic groups, including NE Atlantic cod, capelin, Greenland halibut and Polar cod (Table 8). The authors concluded that there is **high potential** for Polar cod, **some potential** for capelin and Greenland halibut, but **low potential** for NE Atlantic cod to expand to the Arctic.

<table>
<thead>
<tr>
<th>Species composition and diversity</th>
<th>Phytoplankton</th>
<th>Zooplankton</th>
<th>Benthos</th>
<th>Fish</th>
<th>Marine mammals and seabirds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depends on mixing depth: deep mixing favours flagellates.</td>
<td>Adaptable Arctic copepods favoured.</td>
<td>Cold-water species decline in abundance; warm water species increase.</td>
<td>Cod (<em>Gadus morhua</em>), herring (<em>Clupea harengus</em>), Pollock (<em>Pollachius pollachius</em>), some flatfish likely to move north and become more abundant; capelin (<em>Mallotus villosus</em>), Polar cod (<em>Boreogadus saida</em>), Greenland halibut (<em>Reinhardtius hippoglossoides</em>) will have restricted range and decrease in abundance.</td>
<td>Declines of polar bears, ringed, harp, hooded, spotted, ribbon and possibly bearded seals. Increases of harbour and grey seals. Possible declines of several whale species. Ivory gulls, small auk species likely to decline.</td>
<td></td>
</tr>
<tr>
<td>Species composition and diversity</td>
<td>Phytoplankton</td>
<td>Zooplankton</td>
<td>Benthos</td>
<td>Fish</td>
<td>Marine mammals and seabirds</td>
</tr>
<tr>
<td>----------------------------------</td>
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<td>------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Depends on mixing depth: deep mixing favours flagellates.</td>
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<td>Cold-water species decline in abundance; warm water species increase.</td>
<td>Cod (<em>Gadus morhua</em>), herring (<em>Clupea harengus</em>), Pollock (<em>Pollachius pollachius</em>), some flatfish likely to move north and become more abundant; capelin (<em>Mallotus villosus</em>), Polar cod (<em>Boreogadus saida</em>), Greenland halibut (<em>Reinhardtius hippoglossoides</em>) will have restricted range and decrease in abundance.</td>
<td>Declines of polar bears, ringed, harp, hooded, spotted, ribbon and possibly bearded seals. Increases of harbour and grey seals. Possible declines of several whale species. Ivory gulls, small auk species likely to decline.</td>
<td></td>
</tr>
</tbody>
</table>

Source: Loeng (2005); Barange and Perry (2009)
### Table 8: Present and potential future distributions of key fish stocks in the North Atlantic

<table>
<thead>
<tr>
<th>Species</th>
<th>Present distribution</th>
<th>Potential future distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic cod (<em>Gadus morhua</em>)</td>
<td>Found throughout the North Atlantic, In the NE Atlantic, spawning grounds are off the coast of northern Norway (Lofoten Islands). Larvae are found in the Barents Sea and along the west coast of Spitsbergen. Adult distribution: south-western Barents Sea in cold years, more eastern and northerly distribution in warm years. Limiting factor: temporal match between larvae and their prey (zooplankton); especially important at high latitudes with short growing season.</td>
<td><strong>Low potential</strong> for Atlantic cod to establish spawning grounds in the Arctic because it is a demersal shelf species, spawning in coastal waters and is therefore unlikely to spawn in the deep Arctic Ocean. Furthermore, successful recruitment at high latitudes will depend on match-mismatch between larval production and prey (zooplankton) production. Feeding migrations to the Arctic will depend on temperature and food availability.</td>
</tr>
<tr>
<td>Capelin (<em>Mallotus villosus</em>)</td>
<td>Found in the Bering and Barents Seas and the Arctic, spawning in the summer in shallow waters.</td>
<td>Capelin population size fluctuates considerably, largely as a function of prey. Capelin could <strong>potentially expand</strong> in the Arctic if feeding conditions are suitable.</td>
</tr>
<tr>
<td>Polar cod (<em>Boreogadus saida</em>)</td>
<td>Polar cod is a circumpolar, high-Arctic species. The main spawning grounds are in the south-eastern parts of the Barents Sea, with some evidence for spawning to the east of Svalbard as well.</td>
<td>Given appropriate temperature and feeding conditions, there is <strong>high potential</strong> for Polar cod to expand into the Arctic Ocean. However, since spawning takes place under ice, it is likely that spawning areas will change with the reduction in ice cover.</td>
</tr>
<tr>
<td>Atlanto-scandian herring (<em>Clupea harengus</em>)</td>
<td>Spawning takes place along the Norwegian coast, with a Barents Sea nursery area, and migration to the Norwegian Sea overwintering and feeding grounds of 3 to 4 year old herring. To date, the west of Spitzbergen is the northernmost limit of the species.</td>
<td>There is <strong>potential for expansion</strong>, but this will depend on future increases in temperature in the Arctic as well as density-dependent factors.</td>
</tr>
<tr>
<td>Greenland halibut (<em>Reinhardtius hippoglossoides</em>)</td>
<td>Greenland halibut is widely distributed in the northern Atlantic and Pacific oceans. The spawning grounds in the northeast Atlantic are along the continental slope of northern Norway and Svalbard. Larvae are found north of Svalbard and eastward to the Kara sea. Immature fish are found mainly in the central part of the Barents Sea.</td>
<td>Given the right temperature and feeding opportunities, there is <strong>potential</strong> for movement of Greenland halibut adults into the Arctic Ocean shelves and slopes. However, expansion of spawning grounds to the Arctic ocean will depend on availability of suitable spawning grounds and oceanographic conditions affecting larval transport and survival.</td>
</tr>
<tr>
<td>Beaked Redfish (<em>Sebastes mentella</em>)</td>
<td>Beaked redfish adults reproduce over the shelf break, while juveniles are found over the Barents Sea shelf and adults undertake open water summer feeding migrations.</td>
<td>Beaked redfish have <strong>high potential</strong> for expansion into the Arctic, under suitable temperature and feeding conditions.</td>
</tr>
</tbody>
</table>
Fisheries management and the Arctic in the context of climate change

<table>
<thead>
<tr>
<th>Species</th>
<th>Present distribution</th>
<th>Potential future distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow crab (Chionoecetes opilio)</td>
<td>Snow crab is currently found in the northern regions of the eastern Bering Sea shelf and has been reported from the Beaufort Sea. Studies have identified corridors for advection of larvae north and there is evidence of northward expansion in warm years.</td>
<td>There is a high potential for movement to Arctic shelf seas.</td>
</tr>
</tbody>
</table>

Source: Adapted from: Hollowed et al. (2013a)

With regard the other species/taxonomic groups, Hollowed et al. (2013a) concluded that four species (Pacific Ocean perch, Sebastes alutus; Northern rock sole, Lepidopsetta polyxystra; Pacific cod, Gadus macrocephalus; and walleye pollock, Theragra chalcogramma) had low potential for moving to the Arctic, some skates (4 species), and yellowfin sole (Limanda aspera) had some potential, while five species had high potential: Greenland shark (Somniosus microcephalus), Arctic skate (Amblyraia hyperborean), and Bering flounder (Hippoglossoides robustus). Limiting factors include appropriate thermal conditions, shallow shelf areas acting as a barrier, availability of suitable prey for larvae, fidelity or spawning locations and reliance of specific prey such as krill (Hollowed et al., 2013 a, b).

ACIA (2005) refers to the warming of the 1920s and the early 1930s, which was followed by spectacular changes in the fish fauna in the Northwest Atlantic, Greenlandic waters in particular. Cod and herring began to spawn in large numbers in the waters off Iceland. This warm period was characterized by the regular appearance of more southerly species such as mackerel and tuna, for example in Iceland, while cold-temperate species such as haddock (Melanogrammus aeglefinus), saithe (Pollachius virens), and herring (Clupea harengus) became fairly common in Greenlandic waters. The occurrence of cod off west Greenland extended north to the Disco Bay. Based on this, ACIA considered that ‘warm water’ pelagic species such as blue whiting (Micromesistius poutassou) and mackerel (Scomber scombrus) are likely to occur in the area in higher concentrations and more regularly than in the past. Current observations provide support to these predictions. More detail is provided in the following section but one such example is the growing occurrence of the iconic Bluefin tuna in the waters of Iceland and Greenland17.

It is open to debate whether the potential for the expansion of Atlantic cod is high or low. Hollowed et al. (2013a) consider primarily the stock off northern Norway and not the Icelandic stock and formerly large stocks off West Greenland and in the Grand Banks of Canada. Expansion of these currently depleted stocks is possible but appears to depend strongly on various environmental conditions (not only temperature) and predator-prey relationships.

Box 1: One possible scenario

<table>
<thead>
<tr>
<th>Cod in West Greenland</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACIA (2005) considers that a scenario of moderate warming could result in significant increases in the catch of many species. For example, a self-sustaining cod stock could be established in West Greenland as was present in the past. Historical records suggest that a possible sustainable catch of about 300,000 tonnes could be maintained (Figure 40). However, if this occurs, the catches of Northern shrimp (<em>Pandalus borealis</em>) are expected to decrease substantially (estimated to decrease by around 30% of the present level). Such a shift would roughly double the export earnings of the Greenlandic fishing industry (presumably at current prices), which would correspond to about the same amount as that presently paid by Denmark to subsidize the Greenland economy (ACIA 2005).</td>
</tr>
</tbody>
</table>

Figure 40: Catches of cod in East and West Greenland since the 1920s

Northern shrimp is of particular importance to Greenland and concerns the stock off West Greenland, which is shared with Canada. The Greenland fishery for Northern shrimp grew from about 80,000 tonnes in 1998 to about 150,000 tonnes in the period 2004-2008. Peak biomass was reached in 2005 and since then recruitment to the fishery has fallen steadily, so that current biomass has fallen to levels observed in the late 1990s. Accordingly, the scientific advice for 2013 was that catches should not exceed 80,000 tonnes, meaning that the fishery has decreased to almost half of former levels.18

During the expansion of the Northern shrimp fishery, an extension of the fishing grounds was observed (e.g. Wieland 2005). The Greenland Institute of Natural Resources indicates that this trend has now been reversed, where a contraction of the fishing grounds is evident. Survey data indicate furthermore that the presence of cod is increasing in the fishing grounds of shrimp and thus contributing to decrease through predation. Although not entirely clear, it appears that there may be a decreasing trend for Northern shrimp as a result of the changing environment and an increase of predation.

4.3. Impacts of climate change on fisheries

While walleye or Alaska pollack is the dominant species in the Bering Sea fisheries, the Barents Sea is dominated by a cod-capelin system occasionally disturbed by inflow of herring from the Norwegian Sea. Groundfish dominate in Icelandic and Faroese fisheries, with the addition of pelagic species such as capelin, herring and mackerel. In the colder Greenlandic waters, crustaceans are of most importance (Northern shrimp and snow crab), along with Greenland halibut. There are substantial fisheries for beaked redfish, which span into international waters, although these are generally in decline due to overexploitation.

Cod is the most highly prized species for human consumption caught in the Arctic. It is remarkable how the fishery for the Northeast Arctic cod has grown from a fishery of about 212 thousand tonnes in 1990 to almost a million tonnes (966,000 tonnes) in 2013, bearing in mind that the stock is exploited sustainably. ICES considers that the adult stock size is large enough and fishing pressure is low enough to ensure an optimal use in the long term.\(^\text{19}\)

Northeast Atlantic stocks of herring, blue whiting and mackerel have become massive fisheries or are in the process being rebuilt in order to attain previous large catches. These stocks migrate and are exploited in the context of Coastal States Agreements in the Northeast Atlantic, although there has been lack of agreement in the past (see Box 2).

In relation to fisheries, Arctic Climate Impact Assessment (ACIA)\(^\text{21}\) concluded in 2005 that the impacts of climate change on the fisheries sector of the region's economy were difficult to assess, primarily due to data issues.\(^\text{22}\) However, changes in the distribution and migration patterns of fish stocks were considered likely. Various factors such as higher primary productivity, increases in feeding areas, and higher growth rates may lead to more productive fisheries in some regions of the Arctic. Invasions by new species into the Arctic and competition with native species was observed and expected to intensify. However, the extinction of existing arctic fish species was considered unlikely.

It is notable that ACIA considered fisheries management to be the main factor determining the future of fisheries in the arctic region. The effects of climate change were considered to be of relatively less importance. The possible economic and social costs of adjusting to climate change were considered relatively minor, unless major climate change occurred (extreme scenarios).

\(^\text{19}\) http://ices.dk/sites/pub/publication%20reports/advice/popular%20advice/cod-arct_popular.pdf
\(^\text{20}\) http://gis.ices.dk/popadvice/
\(^\text{21}\) http://www.acia.uaf.edu/pages/scientific.html
\(^\text{22}\) Note that there have been major advances in coupled atmosphere-ocean modelling since the time of ACIA, thus providing crucial information such as temperature, water mass mixing, upwelling, etc.
Box 2: Conflicts in response to change

<table>
<thead>
<tr>
<th>Adjusting to changing migration and distribution of the mackerel stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>A major challenge for a fisheries management regime is to adjust to possible changes in distribution and migration patterns of stocks. Changes in fish stock migration patterns in the past have disrupted established resource management arrangements and triggered conflicts between countries. A recent example is the northwest expansion of mackerel, which has led to conflict between the EU, Faeroe Islands, Iceland, Norway and most recently Greenland. The migration and feeding patterns of mackerel changed in recent years, shifting further northwest into Faeroese, Greenlandic and Icelandic waters. Iceland started fishing mackerel and the Faeroese increased their catch, which was objected to by the EU and Norway. Some mackerel fishing has been carried out in the Greenlandic EEZ and catches are expected to increase. Negotiations have been on-going and the Faeroe Islands, EU and Norway have reached an agreement on the quota shares. Greenland and Iceland have not agreed on shares, leaving the total distribution of the quota share unresolved. These coastal states are members of the North East Atlantic Fisheries Commission and have the obligation to co-operate on fisheries conservation and management, and to find solutions to conflicts.</td>
</tr>
</tbody>
</table>

Source: SADA (2014)

A recent assessment came to similar conclusions (SADA, 2014). Although commercial fisheries in Arctic regions are based on relatively few species, the dynamics of the marine ecosystems are not well understood. Market forces are considered to be another important driver through the supply and demand of fish products globally. The authors indicated that the effective fisheries management may have a greater impact on Arctic fisheries than the potential environmental effects of climate change, thus the importance using the precautionary approach. Moreover, the authors did not consider it likely that the changes in Arctic fisheries will be significant in the period to 2030 under the current management regime.

Thus, the SADA (2014) recommendations to the EU concern management and trade-related issues, which are:

- Improve management, co-operation and research;
- Continue to combat illegal, unreported and unregulated (IUU) fishing;
- Reduce fishing capacity;
- Secure inflow of Arctic seafood into EU markets.

Quantitative forecasting of the impacts of climate change on fisheries will typically involve modelling, making use of outputs from coupled biophysical models. It is important to bear in mind that all models will include uncertainties in both model structure and parameter values (Hollowed et al. 2013b). Increasing the complexity of the model or modelling approach may be desirable for the purpose of realism, but this may introduce considerable uncertainty, thus limiting its usefulness.

Another issue concerns the spatial resolution of models. Until recently, the output from global circulation models was considered reliable at the scale of ocean-basin. However, there is generally a need for much finer resolution, at the level of coastal shelves to project climate impacts on fish and fisheries (Hollowed et al. 2013b). Fortunately, this situation is improving constantly at a fast pace.
A recent review by Hollowed et al. (2013c) considers the trade-offs associated with different modelling approaches to assess climate effects on fish and shellfish. No single modelling approach was considered capable of addressing all aspects of climate change impacts on living marine resources.

Most of the available studies concern a limited number of fish species in specific regions due to the complexity of the issue. In relation to the Arctic, there are only a few studies that address this region specifically or as part of global perspectives. These are presented in the following.

4.3.1. Dynamic Bioclimate Envelope Modelling

Cheung et al. (2009) attempted to forecast the impacts of climate change on global marine biodiversity. The model used takes into account the distributional ranges of 1066 exploited marine fish and invertebrates, and projects the impacts of climate change scenarios forward to 2050. According to model predictions, climate change may lead to numerous local extinctions and dramatic species turnover of over 60% of the present biodiversity. Species invasion is predicted to be most intense in the Arctic and the Southern Ocean, as well as a general shift in distribution towards the poles for most of the studied species (by 45–59 km per decade).

The same modelling approach was used to estimate the effects of climate change on maximum fisheries catch potential on a global scale (Cheung et al. 2010). Here, additional considerations were introduced into the modelling process. Empirical equations were used to estimate primary production (using climate model outputs) and to estimate the approximate MSY of each of the modelled species. Maximum catch potential was predicted to increase by an average of 30–70% in high-latitude regions and to decrease by up to 40% in tropical regions, as a result of climate change in the period 2005-2055. The highest increases in catch potential were predicted for Norway, Greenland, USA (Alaska) and Russia (Asia).

Taking into account ocean acidification and reduction in oxygen content was found to reduce growth performance, increase the rate of range shift, and lower the estimated catch potentials (10-year average of 2050 relative to 2005) by 20–30% relative to simulations without considering these factors (Cheung et al. 2011).

A recent study by Lam et al. (2014) is particularly relevant for this study, as it is a continuation of the modelling approach used by W.W.L. Cheung and colleagues, but directed specifically at forecasting marine capture fisheries in the Arctic. Total fisheries catch and revenue (or value of fish landed) was predicted to increase by about 39% (14–59%) by 2050 relative to 2000.

The estimates of projected potential catches are given in Table 9. Catches by European countries are projected to increase by 20% to 41%. The effects of ocean acidification are predicted to have relatively low negative impacts, which would be expected in Arctic regions where there are relatively low catches of molluscs and other calcifiers. The exception to this is Finland where ocean acidification is for as yet unexplained reason predicted to lead to an increase in catch potential.

23 See, for example, table 1 in Hollowed et al. (2013).
Table 9: Catch by country under three scenarios: Current; Climate Change; and Climate Change plus Ocean Acidification

<table>
<thead>
<tr>
<th>Countries</th>
<th>Current</th>
<th>CC</th>
<th>% Change</th>
<th>CC+OA</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>6.1</td>
<td>7.7</td>
<td>27</td>
<td>7.4</td>
<td>20</td>
</tr>
<tr>
<td>Faeroe Islands</td>
<td>77.3</td>
<td>105.8</td>
<td>37</td>
<td>102.4</td>
<td>32</td>
</tr>
<tr>
<td>Finland</td>
<td>0.04</td>
<td>0.05</td>
<td>20</td>
<td>0.05</td>
<td>25</td>
</tr>
<tr>
<td>Greenland</td>
<td>91.8</td>
<td>122.3</td>
<td>33</td>
<td>118.2</td>
<td>29</td>
</tr>
<tr>
<td>Iceland</td>
<td>692.6</td>
<td>974.4</td>
<td>41</td>
<td>962.7</td>
<td>39</td>
</tr>
<tr>
<td>Norway</td>
<td>917.6</td>
<td>1283.9</td>
<td>40</td>
<td>1235.2</td>
<td>35</td>
</tr>
<tr>
<td>Russian Fed</td>
<td>530.8</td>
<td>719.0</td>
<td>35</td>
<td>693.4</td>
<td>31</td>
</tr>
<tr>
<td>Sweden</td>
<td>15.2</td>
<td>20.2</td>
<td>33</td>
<td>19.6</td>
<td>29</td>
</tr>
<tr>
<td>USA</td>
<td>12.8</td>
<td>20.5</td>
<td>60</td>
<td>19.5</td>
<td>52</td>
</tr>
<tr>
<td>USA (Alaska)</td>
<td>0.6</td>
<td>1.4</td>
<td>129</td>
<td>1.4</td>
<td>126</td>
</tr>
<tr>
<td>Total</td>
<td>2344.8</td>
<td>3255.2</td>
<td>39</td>
<td>3159.8</td>
<td>35</td>
</tr>
</tbody>
</table>

Source: Lam et al. (2014)

Legend: CC = (Climate Change); CC + OA = (Climate Change plus Ocean Acidification)

Note: I - The projected change is calculated for 2050 in relation to 2000. (Unit: 103 tonnes; II - The uncertainty of the estimates are not presented here, but are given in Annex I, Table A.

The clear winners appear to be the USA and in particular the state of Alaska, with predicted increases in potential catch of 60% and 129%, respectively. It should, however, be noted that Alaska is the only area of the USA that is within the Arctic.

Projections of increases in revenue, fishers’ income, fishing cost, household incomes and economy-wide impacts followed a very similar pattern to catch projections (Annex I). For example, the economic impact, which is calculated as the total revenue multiplied by an estimated economic impact multiplier, is projected to increase by 38% under the climate change scenario and a slightly lower increase of about 32% when considering ocean acidification (Table 10; Annex I, Tables C, D). In general, a projected increase of 38-39% was estimated for economic variables under the climate change scenario and a slightly lower increase of about 32-35% when considering ocean acidification (OA). This was also the case on a country-by-country basis, where the projected catch increases generally apply to economic variables as well. The exception to this was again Finland, where for example economic impact is predicted to be over 1700 % (Table 10)24.

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24 This may be an artefact of the model, possibly related to the low importance of fisheries in Finland and their geographical location close to the boundaries of the Arctic.
Table 10: Economic impact by country under three scenarios: Current; Climate Change; and Climate Change plus Ocean Acidification (Unit: USD millions)

<table>
<thead>
<tr>
<th>Countries</th>
<th>Current</th>
<th>CC</th>
<th>% Change</th>
<th>CC+OA</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>30.0</td>
<td>37.9</td>
<td>26</td>
<td>36.1</td>
<td>20</td>
</tr>
<tr>
<td>Faeroe Islands</td>
<td>153.1</td>
<td>209.2</td>
<td>37</td>
<td>200.7</td>
<td>31</td>
</tr>
<tr>
<td>Finland</td>
<td>0.01</td>
<td>0.14</td>
<td>1173</td>
<td>0.01</td>
<td>18</td>
</tr>
<tr>
<td>Greenland</td>
<td>1515.5</td>
<td>1980.8</td>
<td>31</td>
<td>1891.5</td>
<td>25</td>
</tr>
<tr>
<td>Iceland</td>
<td>1254.8</td>
<td>1756.5</td>
<td>40</td>
<td>1701.8</td>
<td>36</td>
</tr>
<tr>
<td>Norway</td>
<td>3117.6</td>
<td>4341.6</td>
<td>39</td>
<td>4143.8</td>
<td>33</td>
</tr>
<tr>
<td>Russian Fed</td>
<td>478.9</td>
<td>648.8</td>
<td>35</td>
<td>620.2</td>
<td>30</td>
</tr>
<tr>
<td>Sweden</td>
<td>16.0</td>
<td>21.0</td>
<td>31</td>
<td>20.2</td>
<td>26</td>
</tr>
<tr>
<td>USA</td>
<td>102.3</td>
<td>171.2</td>
<td>67</td>
<td>162.6</td>
<td>59</td>
</tr>
<tr>
<td>USA (Alaska)</td>
<td>2.6</td>
<td>6.0</td>
<td>133</td>
<td>5.9</td>
<td>130</td>
</tr>
<tr>
<td>Total</td>
<td>6670.7</td>
<td>9173.0</td>
<td>38</td>
<td>8782.9</td>
<td>32</td>
</tr>
</tbody>
</table>

Source: Lam et al. (2014)
Legend: CC = (Climate Change); CC + OA = (Climate Change plus Ocean Acidification)
Note: The uncertainty of the estimates is not presented here, but is given in Annex I, Table D.

Considering the global nature of the research by Cheung et al. (2009, 2010, 2011) and the possibility of downscaling it for the Arctic (Lam et al. 2014), it is important to draw attention to some characteristics of the modelling approach.

The **modelling approach uses a Dynamic Bioclimate Envelope Model** (DBEM), defined as a set of physical and biological conditions that are suitable to a given species (Cheung et al. 2009). This DBEM simulates how changes in temperature, oxygen content (represented by O2 concentration) and pH (represented by H+ concentration), as well as other variables such as ocean current patterns, salinity and sea-ice extent, would affect growth and distribution of marine fishes and invertebrates, which are outputs from global coupled carbon cycle-climate models (Lam et al. 2014). The modelling steps can be summarized as:

**Step 1**: use available estimates of species spatial distribution, which are based on known or inferred range and habitat preferences (resolution of 30' lat. by 30' long.);25

**Step 2**: define the suitability of different environmental conditions for each species by overlaying environmental data (1971-2000);

**Step 3**: estimate an environmental profile for each species, associating relative abundance to environmental data (i.e. sea surface and bottom temperature, coastal upwelling, salinity, distance from sea-ice, and habitat types (seamounts or others in the case of the Arctic);

**Step 4**: use output from four different global coupled carbon cycle-climate models such as SST, sea-ice coverage, salinity and advection;

**Step 5**: for each grid cell estimate future relative abundance of a species using a logistic population growth model, with the carrying capacity in each cell expressed as a function of habitat suitability for the species. Adult movement and larval dispersal were modelled through advection and diffusion, with the rate of dispersal being affected by the abundance, carrying capacity and current dispersal patterns, while growth, mortality and

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25 In the study by Lam et al. (2014), only 62 species of marine fishes and invertebrates were considered, which contributed up to 93% of the total revenue from fisheries in the 2000s in Arctic countries.
reproduction rates are affected by changes in metabolic rates expressed as a function of temperature, oxygen and pH, which were estimated by applying an ecophysiology model (Lam et al. 2014);

**Step 6:** use an empirical model to a species’ maximum catch potential (MSY) based on the total primary production (estimated from the climate models) within its exploitable range, the area of its geographic range, and its trophic level, including terms for correcting biases from the observed catch potential.

Some **key limitations to this modelling approach** are (Cheung et al. 2009; Lam et al. 2014):

- Current data on spatial distribution of species is considered uncertain;
- Accurate estimates of population and dispersal parameters were not available; thus, they were estimated by indirect methods (empirical equations);
- Species adaptation capacity was not considered;
- Only a selection of coupled atmosphere and ocean model were considered, reducing the inherent variability of forecasting results;
- The effects of ocean acidification are particularly uncertain;
- Anthropogenic impacts such as fishing, pollution, etc., are not taken into account.

These are considerable uncertainties, but generalising from Cheung et al. (2009), the direction of the results are likely and follow existing theory on the possible effects of climate change. However, the magnitude of the projections should be considered uncertain and should be interpreted more in the sense of possible positive or negative effects.

Ignoring human activity, fishing in particular, is a key issue that needs to be addressed. Humans have the capacity to amplify or minimise climate effects and including human activity is therefore essential to provide meaningful and realistic climate change projections. This is needed in order to develop effective tools or approaches for adaptation and mitigation strategies (Barange et al. 2010).

**4.3.2. Size-based Community Modelling**

Blanchard et al. (2012) coupled a physical–biogeochemical model (itself coupled to a climate model) with a dynamic, size-based food web model to predict the future effects of climate change on fish biomass and production in 11 large regional shelf seas, with and without fishing effects. These included many of the most productive shelf seas (i.e. 28 large marine ecosystems and 107 EEZ and adjacent areas).

Two size-based community models were developed corresponding to pelagic predators and benthic detritivores. Such models capture the properties of food webs that describe energy flux and production at a particular size, independent of species' ecology (Blanchard et al. 2012). Moreover these models incorporate growth and mortality processes, which can be linked up to fishing mortality and changes in primary production as well as temperature effects.

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26detritivores: an organism, such as a bacterium, fungus, or insect, that feeds on dead plant or animal matter.
A 'business as usual' scenario was used from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRESA1B) to force a high-resolution coupled physical–biogeochemical model in order to obtain size-based estimates of changes in production and biomass by 2050 (Blanchard et al. 2012).

Model predictions showed that changes in potential fish production are closely related to changes in phytoplankton production (Figure 41). Potential fish production was estimated to decrease by 30–60% in tropical shelf and upwelling seas, primarily in the eastern Indo-Pacific, the northern Humboldt and the North Canary Current (Blanchard et al. 2012). On the other hand, the production of pelagic predators was projected to increase by 28–89% in high latitude shelf seas (Blanchard et al. 2012). In the Nordic shelf seas (Jan-Mayen, Greenland, Iceland, Norway), overall fish biomass density was projected to increase by over 30%, without the effect of fishing. Note that this is in agreement with Lam et al. (2014).

**Figure 41: Climate change impacts (in %) on primary production by 2050**

As would be expected, the effects of climate change depended on how heavily fished the community was. When assuming a low fishing mortality rate of 0.2 year\(^{-1}\), climate effects were most prominent, whereas fishing effects dominated when mortality rates were high, 0.8 year\(^{-1}\) (Blanchard et al. 2012).

According to Blanchard et al. (2012), the low primary production of cold-water ecosystems are associated with higher susceptibility to fishing effects, which is linked to slow relative growth rates. Model predictions indicated that fishing effects caused ecosystems to become more variable over time as a result of shifts towards smaller size and higher growth rates in fish communities. Thus, heavily fished ecosystem states were found to be less resilient to climate change compared with unexploited or lightly exploited ecosystem states.

Some key limitations to the approach used were (Blanchard et al. 2012):

- It is a simplified approach used to model the potential effects of climate change on large marine ecosystems;
Only one possible forcing scenario was used (i.e. one global climate model), thus masking considerable variability;

Model generated catches were comparable with reported catches (1992-2001), but community-wide fishing mortality rates within these ecosystems are not well known;

There may be bias in the catch data as a result of misreporting;

The size-based approach used does not provide predictions of catches from on a species-by-species level, so it is not possible to consider the effects of climate change and fishing on individual species.

This modelling approach makes considerable progress by including the effects of fishing and presents plausible results, which also conform to theory. It is reassuring that in the absence of fishing, the results are comparable to those presented by Cheung et al. (2009, 2010) and Lam et al. (2014).

A major caveat is that this approach cannot be used to forecast single species populations. Although total fish production in an ecosystem may be maintained, there may be significant and unpredictable switches in the species contributing to overall fish biomass (Blanchard et al. 2012). This is an important limitation, since fisheries are highly selective in terms of their targets.

4.3.3. Incorporating a Bio-economic Model

Merino et al. (2012) followed the same modelling approach using size-based methods. The primary focus of the study was small pelagic production to meet the demands of aquaculture and human consumption, but incorporating a bio-economic model, considering market forces of supply and demand (Figure 42).

Taking the specific case of Norway, a clear 'winner' in this context, potential fishmeal production was predicted to increase by up to 27% as a result of the impacts of climate change on small pelagic fisheries (Merino et al. 2012) If current fishmeal imports were maintained and the feeding efficiency of salmon was brought down below 327, this would support a 50% increase in salmon production.

Merino et al. (2012) conclude that marine ecosystems may be able to sustain current and increased per capita consumption rates through 2050, provided that effective fisheries management measures are implemented and that significant technological adaptations are developed. A relatively modest 6% increase in the potential catches of 'large' pelagic fish and a 3.6% increase of 'small' pelagic fish was predicted in the top-twelve fishmeal producing nations.

However, Merino et al. (2012) noted that current trends in fishmeal price indicate a growing demand for marine products, resulting in a high fishmeal price and adding pressure on the sustainable exploitation of small pelagic species. This is a matter of concern, as this implies that fisheries management should improve in these small pelagic fisheries in order to mitigate the risk of collapse.

Barange et al. (2014) followed up with a global study considering 67 national EEZs, accounting for about 60% of global fish catches (not only small pelagics). Again, relatively modest increases and decreases were projected in average fish catch potential by

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27 Three kg to produce one kg.
2050: generally below 10% (mean +3.4%) in relation to present yields. However, significant gains of about 30% are expected in the Nordic Seas. The authors emphasized the need for sustainable management and conclude that management effectiveness and trade practices will be determinant in realized gains or losses in global fish catches.

Figure 42: Climate change impacts (in %) on national fisheries production by 2050

Source: Merino et al. (2012)

4.3.4. Concluding remarks

The preceding sections have attempted to identify the possible impacts on climate change on fish and fish stocks. The best way of addressing this is by the combination of expert knowledge (including traditional knowledge) and simulation using models. However, specific modelling studies of the Arctic are limited and thus the need to include more global perspectives that do not necessarily provide much detail on Arctic fisheries. This is expected to improve in the near future, considering recent developments in modelling approaches.

There is general agreement that the effects of climate change on fisheries will be positive in the Arctic. This is however limited by a set of constraints including environmental and habitat preferences of species, as well as species adaptation capacity. For example, geographical extension of important Groundfish stocks into the Arctic Sea would appear to be limited for a lack of ideal habitat (Figure 43). The potential for deep-sea species appears to be higher (e.g. redfish, Greenland halibut), but this will depend more on management, as these stocks have generally been overexploited. Maintaining healthy stocks (high spawning stock biomass) and keeping fishing mortality within sustainable levels is considered crucial (building up resilience), even more important than possible climate impacts.
Figure 43: Left: Trawlable depths (depths of 2,000 meters or less) in the Arctic Ocean (international waters)

Simulations indicate that the positive impacts of climate change on fisheries may be modest. It is possible that greater focus on the Arctic will show that these positive impacts are more substantial. In the North Atlantic, countries such as Norway, Iceland, and Greenland appear as relatively 'big winners', although this is sometimes masked by the process of averaging in global studies. Fisheries generated more than 90% of export earnings in Greenland, around 40% in Iceland and about 6% in Norway in 2010 (SADA 2014), so they stand to gain substantial benefits.

**EU Member States contribute only about 4%** to total Arctic fish catch, but **imports from Arctic countries** such as Canada, Iceland, Norway, Russia, and USA **constitute 39% of the total fish exports** of these countries (SADA 2014).

One should also bear in mind that there is a **framework of fisheries agreements in the North Atlantic**, including bilateral agreements and coastal states agreements, which provide for reciprocal access to and the sharing of fishing possibilities amongst coastal states. This has been developed over years and constitutes intricate and complex relationships amongst countries and the EU. Although climate change, in the Arctic, may have generally positive effects on fisheries productivity, **changes in distribution and migration of straddling stocks may in some cases create potential for conflicts** by changing the balance of quota exchanges and access.

### 4.4. Impacts of climate change on arctic communities and indigenous people

The Strategic Assessment of Development of the Arctic considers the effects of climate change and includes a chapter on social and cultural changes in the European Arctic (SADA 2014). Globalisation and demand for natural resources are considered to be the main driving forces, especially in light of the privatization and commercialization of Arctic

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industries. Demand for Arctic natural resources influences Arctic migration, urbanization, politics, governance and global connections. Social and cultural changes reflect global, particularly western, cultural trends. These forces are expected to intensify with climate change.

As presented in SADA (2014), primary industries and resource extraction strongly link Arctic regions to the global economy and provide resources for social development, but they also expose the regions to market and price fluctuations. Single-industry communities are particularly vulnerable to boom-and-bust cycles. Primary industries tend to often create islands of economic activity, rather than serving as engines of development for entire regions.

New economic opportunities are envisaged as a result of climate change effects such as opening of Arctic shipping lanes, enhanced access to oil, gas, and mineral resources, and increased production in forestry and fisheries. However, the expected developments are considered moderate and are driven primarily by global demand for resources rather than by climate change (Stepien 2014).

Resource exploitation and resistance to certain large-scale developments were key factors in the emergence of indigenous activism and indigenous rights. Indigenous people have increasingly become more active in international fora, with a focus on human rights. Key demands include self-determination, land rights, cultural development, and participation in decision-making (SADA 2014).

The Arctic region is home to a number of indigenous peoples with diverse cultural, social, economic, and historical background, including the Inuit of Russia, Alaska, Canada, and Greenland; Aleut; North-American Natives (Athabascans, Gwich’in, Métis); Sámi people of Fennoscandia; and numerous groups in Russia (e.g., Chukchi, Eveny, Evenky, and Nenets) (Figure 4) (Stepien 2014).

However, it is important to stress that indigenous people make up only about 10% on average of the total Arctic population, out of a total of about 4 million people, ranging from very thinly populated rural areas to increasingly densely populated urban centres (AFPA 2010). Also, the proportion of total population constituted by indigenous peoples varies greatly across Arctic regions, from 2-4% in Russia and Fennoscandia, to 50% in Arctic Canada and almost 90% of total population in Greenland (AFPA 2010).

It is also important to point out that the Arctic economy is characterised by the co-existence and interdependence of a formal and informal economy, and that climate change may affect the various economic sectors differently. The formal 'cash' economy include tourism, fisheries, large-scale mineral and energy development, forestry and reindeer husbandry, while the informal economy consists of small-scale subsistence use of forests, hunting, reindeer herding, fishing and trapping, the latter of importance for cultural practices and identities (Stepien 2014).
Figure 44: Languages spoken by indigenous people of the Arctic

Source: Grid Arendal

Box 3: Climate effects on indigenous people

A changing climate threatens the Inuit

"A number of life altering changes have happened over the last years to Inuit societies. Changes explained only by the changes in weather patterns. The 155,000 Inuit in northern Canada, Alaska, Greenland and Chukotka in the far east of Russia have suddenly – in terms of nature's time scales – been forced to reconsider their traditional life styles. Ways of life that have allowed the Inuit to survive for hundreds of years in what is for most people a harsh environment are now threatened by changes induced by humans far south of the areas where the Inuit live. 'The human rights of the Inuit to decide their own life style and habitat have been threatened as a cause of these changes in nature,' says Sheila Watt-Cloutier, elected Chair of the Inuit Circumpolar Conference, representing the rights of the Inuit. 'Talk to hunters across the North and they will tell you the same story, the weather is increasingly unpredictable. The look and feel of the land is different. The sea-ice is changing. Hunters are having difficulty navigating and travelling safely. We have even lost experienced hunters through the ice in areas that, traditionally, were safe. The melting of our glaciers in summer is now such that it is dangerous for us to get to many of our traditional hunting and harvesting places,' says Watt-Cloutier."

Source: Grid-Arendal and the Inuit Circumpolar Conference

Stepien (2014), who played a key role in the Strategic Assessment of Development of the Arctic (SADA 2014), provides an excellent perspective of Arctic indigenous people in the context of climate change and their capacity for adaptation. He points out that climate change is only one of many stressors affecting Arctic indigenous communities, and it is in many cases not the most important. Also, Arctic communities are characterized by relatively high resilience and are characterized by the capacity to adapt to a naturally
variable Arctic environment. Stepien (2014) points out that indigenous peoples should not be seen as defenceless victims of climate change, industrial developments, and state policies.

It is thus essential to place climate change in context where the current situation of indigenous peoples can be characterized as a life in a 'total environment of change', including economic, environmental, social, cultural, and governance pressures (Stepien 2014). Economic and cultural globalization and modernization are considered to be the main drivers of change in Arctic communities, affecting indigenous communities, driven by global demand for Arctic resources, as well as the availability (and cost) of goods indispensable not only for modern lifestyles, but also for traditional activities where modern technologies are utilized (e.g. fishing, hunting) (Stepien 2014).

Stepien (2014) points out that Arctic communities are characterized by high resilience, adaptable and accustomed to change and argues that adaptation is a crucial part of Arctic life, a necessity and not necessarily a catastrophe. However, it may be that Arctic social-environmental systems may be reaching the limits of their adaptive capacities under the current situation of multiple pressures/drivers, thus making the involvement that of indigenous groups in the elaboration adaptation policies for the Arctic even more urgent (Stepien 2014).

**Box 4: Placing the Arctic in perspective**

<table>
<thead>
<tr>
<th>Plight of the Arctic indigenous people</th>
</tr>
</thead>
</table>
| "The plight of Arctic indigenous peoples is particularly striking as, being themselves marginalized, they inhabit the most developed states, some of which – Canada, Russia, and the US – are among the biggest CO₂ emitters. Although they are citizens of rich states, their life standards are often well below the national averages and they can be considered the ‘third world in the first’. Even though the future impacts of climate change are expected to be felt to a much greater degree in southern latitudes – where millions of people are affected by droughts, water shortages, effects on food production, heat waves, extreme weather events, etc. – the Arctic communities are seen as the first to 'take the heat' and the first who would need to adapt to changing environment. The challenges faced by Arctic communities are, therefore, used in public debate to emphasize the urgency of action. Consequently, researchers have given much attention to understanding the impacts, vulnerability, and adaptive capacity of Arctic peoples. Increasing emphasis is given to the adaptation actions and strategies already at work."

**Source:** Stepien (2014)

Concluding, SADA (2014) formulated the following key messages in relation to Arctic communities and indigenous people:

- Social development in the region is characterised by generally growing, often highly innovative Arctic cities and thinning-out rural areas that face demographic and resource challenges;
- Dependence on extractive/primary industries and support from national budgets to a great extent shapes socioeconomic development (and is expected to continue to do so);
- Accessibility and connectivity, especially intra-regional and cross-border, are among the key concerns;
• Indigenous peoples experience the challenges faced by all Arctic inhabitants in a distinct manner. These challenges need to be addressed in the light of indigenous peoples’ rights;
• Various EU programmes in the North are well aligned with the needs identified by regional actors, primarily because decision-making takes place at the local/regional level.

The following recommendations were given, directed specifically to the EU:
• Give a voice to Arctic communities in policy developments that may affect them;
• Support entrepreneurship and innovation with sensitivity to indigenous youth and gender issues;
• Invest in intra-regional accessibility and connectivity;
• Consider the special needs of Arctic cities in relevant EU policies and programmes.
5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

There is a general consensus based on analysis of existing time series and different modelling scenarios that climate change is a reality and that the Arctic region is where the effects will be most strongly felt in the coming decades, mainly through increasing temperature. Shrinking ice-cover, decrease in ice thickness, decrease in multi-year ice and increased ice drift velocity are expected, with some modelling scenarios predicting an ice-free Arctic in the summer by the middle of this century. It should be noted that although the general trend is for increasing temperature, there is considerable variability from year to year and also from region to region within the Arctic Ocean and Adjacent Seas (AOAS). Such short-term climate variability (as opposed to longer term climate change) is largely driven by the North Atlantic Oscillation (NAO) and has a strong influence on recruitment variability and abundance.

Regime shifts or dramatic changes in the state of a community lasting decades, and associated with NAO and other ocean basin scale phenomena, have occurred in the past and will probably occur in the future, with dramatic consequences for fisheries. A good example is the case of the Northern shrimp and West Greenland cod, where there have been periods of alternating dominance, associated with warming and cooling periods, since the early 20th century. With increased warming, it is expected that cod will dominate and indeed, Northern shrimp fisheries have generally been in decline in recent years, throughout the AOAS, while some cod stocks have grown significantly.

Predicting the overall effects of higher temperatures in the Arctic is difficult, and there is a need of regional and local studies to help understand the changes that may occur in the different Large Marine Ecosystems (LMEs) found in the AOAS and their communities and populations. For example, primary production (the base of the food web) is expected to increase with warming and shrinking of the ice-cover, with the pelagic food web gaining importance in the benthic dominated Arctic system. However, warming could also have negative effects if it increases layering of the water column and oxygen deficiency, or leads to changes in plankton community composition and structure that are not favourable to production higher up the food chain.

The Arctic Ocean is relatively poor in terms of fish species, with only 63 species out of a total of 633 recorded for the AOAS. Of these, only 3 are currently exploited (Polar cod, (Boreogadus saida), Atlantic navaga (Eleginus nawaga) and Arctic flounder (Liopsetta glacialis). Based on life history characteristics, the majority of the estimated 63 commercial fish species of the AOAS are classified as having low resilience (generally long-lived, slow growing, late maturing, i.e. K-selected species), with only 9 species considered as having high resilience (generally short-lived, fast growing, early maturing, opportunistic species, i.e. "r-selected" species). The latter species are less susceptible to increased fishing mortality and their abundance is generally strongly influenced by environmental variability. Thus, such r-selected species tend to have greater inter-annual variation in recruitment and fluctuations in abundance that the K-selected species that are less resilient to increased fishing pressure.

Of the five selected fish species for case studies, capelin is clearly at one end of the life history strategy spectrum (r-selected), while the other three species and especially the Greenland halibut are more K-selected, and less resilient to high fishing mortality. However, it is important to note that even within a species, different populations, sub-
populations and stocks may differ considerably in terms of life history characteristics and resilience, due to different environmental conditions (especially temperature and food) and fishing pressure. This is also true for Northern shrimp, where there is a strong environmental gradient in demographic parameters, with for example greater longevity and later maturity in populations in colder environments.

With the exception of Polar cod for which there is currently no directed fishery, a number of different stocks of the four other species are exploited in the AOAS, including some of the most important fisheries in the world such as the NE Arctic cod, the biomass of which has increased dramatically in recent years due to a combination of favourable environmental conditions and good management practices that have reduced fishing mortality rates to sustainable levels. Greenland halibut catches have been relatively stable in recent years, as have capelin, where biomass in the north-east Atlantic has been in several millions of tonnes in recent years. Northern shrimp stocks have generally been in decline, due to a combination of environmental conditions, predation and over exploitation. Polar cod is one of the abundant marine species in the world, but is of little or no commercial interest.

**Inter-species relationships** (predation and competition) are extremely important in the AOAS, with the abundance of important forage species such as capelin having a strong influence on the abundance and growth of predators such as cod. This underlines the need for ecosystem-based management (EBM) in the AOAS.

The preceding sections have attempted to identify the possible impacts of climate change on fish and fish stocks. This was based on expert knowledge (including traditional knowledge) and simulations, using various modelling approaches. There is general agreement that the effects of climate change on fisheries will be positive in the Arctic, although the potential for increases in abundance and expansion vary from species to species, and endemic fish species might suffer. This is limited by a set of constraints including environmental and habitat preferences of species, as well as species adaptation capacity. Maintaining healthy stocks (high spawning stock biomass) and keeping fishing mortality within sustainable levels is considered crucial (building up resilience), even more important than possible climate impacts. This also involves issues such as cooperation and research, combating illegal, unreported and uncontrolled (IUU) fishing, and reducing fishing capacity.

**Simulations indicate that the positive impacts of climate change on fisheries may be modest, but greater focus on the Arctic is needed.** The few studies available project substantial increases of about 30% in potential fish production by 2050. When considering the effects of fishing, the possible gains become much more modest but this is also related to the assumed fishing mortality (heavy or light fishing). In the North Atlantic, countries such as Norway, Iceland, and Greenland appear as relatively 'big winners', although this is sometimes masked by the process of averaging in global studies. A more nuanced approach to simulating the effects of fishing may yield more optimistic results.

There is generally a high or at least some potential for some commercially important species to expand in distribution and abundance. This is expected to result in changes of relative distribution and migration of stocks. In such cases, there is a potential for conflict as the present agreements of sharing and allocation of fishing opportunities between countries in the North Atlantic are based on traditional patterns of fleet exploitation strategies and traditional fishing grounds for key stocks.
Of the five species considered in this study, Polar cod has the highest potential to benefit from decreased ice-cover and to expand into the central Arctic, while capelin and Greenland halibut have some potential as well. However, although there is evidence already of an expansion of the distribution of NE Atlantic cod, it is unlikely that this species will be able to expand to the high Arctic, namely because of spawning ground limitations (lack of coastal spawning grounds in the deep Arctic). Northern shrimp, adapted to colder waters, is unlikely to profit from warmer conditions, especially if populations of predators such NE cod and Greenland halibut increase.

There is also evidence of expansion of geographic distributions of other species. The "borealization" of the Arctic, along with warming, is likely to have dire consequences for some Arctic species that have a very narrow temperature dependent biogeographical distribution.

Fisheries management of shared stocks and fisheries in international waters of the AOAS is carried out by Regional Fisheries Management Organizations (RFMOs) (North Atlantic Fisheries Organization, NAFO, North-east Atlantic Fisheries Commission, NEAFC), based in most cases on scientific advice from the International Council for the Exploration of the Seas (ICES). In general, the Precautionary Approach (PA) is taken and efforts have been made towards implementing EBM. There are good examples of international collaboration in the management of shared stocks, especially the NE Atlantic cod in the Barents Sea, where Norway and Russia effectively manage fisheries through the Joint Russian-Norwegian Fisheries Commission (JRNFC). In general, it can be concluded that most major sub-Arctic commercial stocks are well managed. However, there are some examples of governance problems, especially where there has been disagreement over Total Allowable Catches (TACs) set by RFMOs and individual nations. It is expected that there will be an increase in legal conflicts due to climate-related shifts in fisheries in the future as species change their distribution and migration routes and expand to new areas. A good example is the Atlantic mackerel in the NE Atlantic that is now abundant in Icelandic and Faeroe waters, and is the cause of a dispute over sharing of TACs.

New economic opportunities are envisaged as a result of climate change such as the opening of Arctic shipping lanes, enhanced access to oil, gas, and mineral resources, and increased production in forestry. However, these economic developments are expected to be rather moderate and are driven, to a large extent, by global demand for resources rather than by climate change (Stepien 2014).

Climate change is only one of multiple stressors affecting Arctic indigenous Communities, and in most cases it is not considered the most important (Stepien, 2014). It is thus essential to place climate change in context where the current situation of indigenous peoples can be characterized as a life in a 'total environment of change', including economic, environmental, social, cultural, and governance pressures. Nonetheless, Arctic communities, and the social-environmental systems they are part of, are characterized by high resilience.
5.2. Gaps and recommendations

5.2.1. Lack of information to achieve the goal of Ecosystem Approach to management

A major gap in the governance of Arctic fisheries is the lack of information to achieve the goal of an ecosystem approach to management. This problem is common to many other regions of the oceans and can be reduced with better coordination and circulation of scientific information, collaborative research among the Arctic States and, mostly through increase in funding of research programmes in the region. The institutions involved in Arctic research are actually well organised and different bodies, namely the Arctic Council, work towards these goals. The third International Polar Year (from 2007 to 2009, www.ipy.org) has helped to draw attention to Arctic issues and has been the motor of numerous projects and expeditions in the Arctic.

Furthermore, if other sectoral activities such as shipping and oil and gas production are considered along with fishing in the context of implementation of the EBMM in the Arctic, the existing European governance system is found lacking, with lack of coordination and no single authority with the responsibility for dealing with problems at the regional level (Raakjaer, in press).

EU Arctic Policy should be further developed, with emphasis on creation of institutional structures that can coordinate fishing and other marine sectors in the Arctic. The EU should also continue to provide major contributions through support programmes for research.

5.2.2. Uncertainty about the consequences of climate change

This problem is being addressed through modelling, but the forecasts have large margins of error (in relation, for example, to temperature changes, geographical alterations in species distributions), making the adaptation of activities such as fisheries, difficult and with high risk of becoming economically unsustainable. Major changes in the ecosystems may occur if the ice cap is severely reduced or disappears during the summer, leading to unpredictable changes in ocean circulation, productivity and ecosystem structure. In such a scenario the precautionary approach is fundamental, and changes in fishing practices that lead to increases in fishing effort should not occur, to avoid compounding two negative effects on fishing stocks, excess fishing effort and environmental changes. Such an approach is particularly important for cold-water species that will have their habitat reduced with the increase in water temperatures.

More simulation studies are needed for the Arctic region specifically, and including greater spatial resolution. Other modelling approaches should be used in order to complement the current understanding of system dynamics and possible projection scenarios.

Careful monitoring should be carried out for the early detection of possible regime shifts. Most projections do not consider extreme climate scenarios, so the changes in such a situation are unpredictable.

EU Arctic Policy should be further developed and the EU should continue to provide major contributions through support programmes.
5.2.3. Improved stock assessment and scientific advice

Fisheries management needs to be improved for some stocks in the North Atlantic, deep-sea stocks in particular, many of which are classified as "data-poor". The available data is deficient but many appear to have been or are being overexploited. The precautionary approach should be used when moving into new fishing grounds and possibly new species.

Annual fisheries negotiations concerning the access and allocation of fishing possibilities in the North Atlantic should start to take into account, if it is not being done already, possible changes in migration and abundance of stocks.

5.2.4. Lack of a body on enforcing power that coordinates fishing in the Arctic

At present, fisheries management is balanced with all areas where commercial fisheries occur under management plans. A positive aspect is that different institutions cooperate and all the Arctic countries participate in all of them. As an example, Canada, Iceland, Denmark (Greenland and Faeroe Islands), Norway, the US and Russia, are all members of NAFO and the ICES, and Iceland, Denmark (Greenland and Faeroe Islands), Norway, and Russia are also members of NEAFC. Despite this, all nations with jurisdiction in the Arctic have their own national laws, (including Greenland and the Faeroe Islands, since they enjoy a status of autonomy in relation to the EU Common Fisheries Policy). If tensions resulting from territorial disputes increase in the Arctic, the cooperation in the fisheries sector may be affected.

It is very important to have an established and effective international management system early on or preferably before the development of fisheries. A good example is the ecosystem-based approach taken by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) in Antarctica, based on the management of krill, the main forage species in the Antarctic food web.

5.2.5. Risk of environmental degradation

The changes occurring in the Arctic due to shrinking of the ice cap may create conditions unfavourable for species that are economic resources at present. The possibility of mineral exploration in the areas that previously were covered with ice, may also lead to environmental impacts that are negative to fish stocks. The consequences may extend to water masses adjacent to the Arctic Ocean, and good coordinated and integrated policies should be defined prior to the events.

5.2.6. Socio-economic considerations

Considering the numerous challenges and pressures/drivers in play, adaptation policies for the Arctic requires greater involvement of indigenous groups and genuine empowerment of Arctic communities.
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ANNEX – MODELLING RESULTS FROM LAM ET AL. (2014)

Table A: Catch by country under three scenarios – Current; Climate Change; and Climate Change plus Ocean Acidification

<table>
<thead>
<tr>
<th>Country or territory</th>
<th>Current Catch ($10^3$ t)</th>
<th>CC Catch ($10^3$ t)</th>
<th>CC+OA Catch ($10^3$ t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>6.11</td>
<td>7.73 (6.58 – 9.09)</td>
<td>7.36 (6.51 – 9.08)</td>
</tr>
<tr>
<td>Faeroe Is</td>
<td>77.29</td>
<td>105.80 (82.81 – 122.68)</td>
<td>102.38 (82.29 – 128.24)</td>
</tr>
<tr>
<td>Finland</td>
<td>0.04</td>
<td>0.048 (0.041 – 0.056)</td>
<td>0.05 (0.03 – 0.06)</td>
</tr>
<tr>
<td>Greenland</td>
<td>91.79</td>
<td>122.26 (100.06 – 144.85)</td>
<td>118.24 (100.11 – 149.96)</td>
</tr>
<tr>
<td>Iceland</td>
<td>692.60</td>
<td>974.41 (838.45 – 1,146.77)</td>
<td>962.69 (830.53 – 1,257.11)</td>
</tr>
<tr>
<td>Norway</td>
<td>917.57</td>
<td>1,283.87 (979.61 – 1,463.80)</td>
<td>1,235.17 (970.04 – 1,527.75)</td>
</tr>
<tr>
<td>Russian Fed</td>
<td>530.78</td>
<td>719.01 (580.64 – 831.70)</td>
<td>693.44 (577.50 – 860.81)</td>
</tr>
<tr>
<td>Sweden</td>
<td>15.18</td>
<td>20.22 (15.97 – 23.69)</td>
<td>19.56 (15.86 – 24.75)</td>
</tr>
<tr>
<td>US (Alaska)</td>
<td>0.62</td>
<td>1.42 (0.8 – 2.22)</td>
<td>1.40 (0.80 – 2.10)</td>
</tr>
<tr>
<td>Total</td>
<td>2,344.78</td>
<td>3,255.21 (2,631.07 – 3,766.00)</td>
<td>3,159.76 (2,600.57 – 3,982.49)</td>
</tr>
</tbody>
</table>

**Source:** Lam et al. (2014).

**Legend:** CC = Climate Change; CC+OA = Climate Change plus Ocean Acidification.
Table B: Landed value (or revenue) by country under three scenarios – Current; Climate Change; and Climate Change plus Ocean Acidification

<table>
<thead>
<tr>
<th>Country or territory</th>
<th>Current Land Value (USD millions)</th>
<th>CC Land Values (USD millions)</th>
<th>CC+OA Land Values (USD millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>9.10</td>
<td>11.50 (9.78 – 13.56)</td>
<td>10.95 (9.77 – 13.56)</td>
</tr>
<tr>
<td>Faeroe Island</td>
<td>72.89</td>
<td>99.62 (80.59 – 114.65)</td>
<td>95.58 (80.36 – 116.87)</td>
</tr>
<tr>
<td>Finland</td>
<td>0.007</td>
<td>0.009 (0.008 – 0.01)</td>
<td>0.008 (0.006 – 0.01)</td>
</tr>
<tr>
<td>Greenland</td>
<td>205.35</td>
<td>268.39 (223.87 – 316.01)</td>
<td>256.30 (223.70 – 317.79)</td>
</tr>
<tr>
<td>Iceland</td>
<td>503.94</td>
<td>705.42 (601.21 – 809.70)</td>
<td>683.45 (599.32 – 847.13)</td>
</tr>
<tr>
<td>Norway</td>
<td>927.86</td>
<td>1,292.14 (1,035.54 – 1,468.97)</td>
<td>1,233.27 (1,029.35 – 1,493.92)</td>
</tr>
<tr>
<td>Russian Fed</td>
<td>191.54</td>
<td>259.52 (210.14 – 298.54)</td>
<td>248.08 (209.59 – 301.98)</td>
</tr>
<tr>
<td>Sweden</td>
<td>5.12</td>
<td>6.69 (5.52 – 7.84)</td>
<td>6.45 (5.49 – 8.09)</td>
</tr>
<tr>
<td>USA</td>
<td>32.99</td>
<td>55.22 (46.94 – 55.22)</td>
<td>52.45 (46.86 – 62.55)</td>
</tr>
<tr>
<td>US (Alaska)</td>
<td>0.83</td>
<td>1.94 (1.09 – 3.01)</td>
<td>1.91 (1.14 – 2.86)</td>
</tr>
<tr>
<td>Total</td>
<td>1,949.62</td>
<td>2,700.44 (2,226.35 – 3,092.73)</td>
<td>2,588.46 (2,205.57 – 3,164.75)</td>
</tr>
</tbody>
</table>

Source: Lam et al. (2014).
Legend: CC = Climate Change; CC+OA = Climate Change plus Ocean Acidification.
Table C: Economic multipliers used to estimate economic impact for each country (multiplying with total revenue or landed value)

<table>
<thead>
<tr>
<th>Countries</th>
<th>Average economic multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>3.30</td>
</tr>
<tr>
<td>Faeroe Is</td>
<td>2.10</td>
</tr>
<tr>
<td>Finland</td>
<td>1.56</td>
</tr>
<tr>
<td>Greenland</td>
<td>7.38</td>
</tr>
<tr>
<td>Iceland</td>
<td>2.49</td>
</tr>
<tr>
<td>Norway</td>
<td>3.36</td>
</tr>
<tr>
<td>Russian Fed</td>
<td>2.50</td>
</tr>
<tr>
<td>Sweden</td>
<td>3.13</td>
</tr>
<tr>
<td>USA</td>
<td>3.10</td>
</tr>
<tr>
<td>US (Alaska)</td>
<td>3.10</td>
</tr>
</tbody>
</table>

*Source*: Lam *et al.* (2014).
### Table D: Economic impact by country under three scenarios—Current; Climate Change; and Climate Change plus Ocean Acidification

<table>
<thead>
<tr>
<th>Country</th>
<th>Current Economic Impacts (USD millions)</th>
<th>CC Economic Impacts (USD millions)</th>
<th>CC+OA Economic Impacts (USD millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>30.03</td>
<td>37.93 (32.27 – 44.75)</td>
<td>36.14 (32.23 – 44.74)</td>
</tr>
<tr>
<td>Faeroe Is</td>
<td>153.07</td>
<td>209.19 (169.24 – 240.77)</td>
<td>200.72 (168.75 – 245.42)</td>
</tr>
<tr>
<td>Finland</td>
<td>0.011</td>
<td>0.014 (0.012 – 0.016)</td>
<td>0.013 (0.01 – 0.016)</td>
</tr>
<tr>
<td>Greenland</td>
<td>1,515.47</td>
<td>1,980.75 (1,652.18 – 2,332.18)</td>
<td>1,891.51 (1,650.88 – 2,345.26)</td>
</tr>
<tr>
<td>Iceland</td>
<td>1,254.81</td>
<td>1,756.50 (1,497.02 – 2,016.14)</td>
<td>1,701.78 (1,492.31 – 2,109.36)</td>
</tr>
<tr>
<td>Norway</td>
<td>3,117.60</td>
<td>4,341.58 (3,479.41 – 4,935.73)</td>
<td>4,143.80 (3,458.61 – 5,019.58)</td>
</tr>
<tr>
<td>Russian Fed</td>
<td>478.85</td>
<td>648.80 (525.35 – 746.35)</td>
<td>620.21 (523.98 – 754.95)</td>
</tr>
<tr>
<td>Sweden</td>
<td>16.03</td>
<td>20.95 (17.28 – 24.55)</td>
<td>20.19 (17.18 – 25.32)</td>
</tr>
<tr>
<td>USA</td>
<td>102.26</td>
<td>171.19 (145.52 – 196.31)</td>
<td>162.59 (145.26 – 193.91)</td>
</tr>
<tr>
<td>US (Alaska)</td>
<td>2.57</td>
<td>6.00 (3.38 – 9.33)</td>
<td>5.92 (3.54 – 8.85)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6,670.70</strong></td>
<td><strong>9,172.91 (7,521.67 – 10,546.13)</strong></td>
<td><strong>8,782.87 (7,553.45 – 10,742.09)</strong></td>
</tr>
</tbody>
</table>

**Source:** Lam *et al.* (2014).

**Legend:** CC = Climate Change; CC+OA = Climate Change plus Ocean Acidification.
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