

List of contents

Executive Summary: Compiled research	2
1 Background	4
2 Introduction	4
3 Summary of research needs from Theme Session P: Arctic Ecosystem Services: Challenges and Opportunities	6
4 Research needs on climate-related changes in the Arctic Ocean and cryosphere	6
5 Research needs for Arctic ecosystems and biodiversity	9
6 Need for monitoring in Arctic Ocean: contaminants, climate, acidification	11
7 Needs for interdisciplinary Arctic state and process studies	12
8 New research challenge: Litter/plastics in the Arctic Marine Environment	15
9 Panel discussion of research needs related to Arctic marine ecosystems and ecosystem services	17
7 Final remarks	19
References	19
Agenda	20
List of Participants	21
Report of Theme Session P: Arctic ecosystem services: challenges and opportunities	22

AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Arctic Ecosystems and Ecosystem Services

Riga, Latvia, 20 September 2016

Executive Summary: Compiled research

Based on the presentations and discussions at the AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Arctic Ecosystems and Ecosystem Services, a number of priority research needs were identified.

More detailed understanding of the main large-scale features of Arctic Ocean circulation at various depth layers is needed to develop better conceptual models linking the Arctic cryosphere and hydrosphere so that climate-related changes can be anticipated. The most prominent changes in the cryosphere are anticipated to occur in the seasonal ice zone. Given the scale and implications of these climate-related changes, there is need for *multidisciplinary, decadal-long research programs in the seasonal ice zone*, where the challenges are greatest. An interdisciplinary focus on the seasonal ice zone should investigate physical-biological interactions, ecosystem characteristics including timing and productivity, acidification and contaminants. These studies could be conducted on specific sectors of the Arctic and later integrated on a pan-Arctic basis. This requires the support of many countries and organizations in the Northern Hemisphere to respond to the scale of the challenge. Concentrating research on the seasonal ice zone is important because this zone includes the ice edge and the shelf area, which support fisheries and contain other important resources. Innovation and the development of new technologies to study these remote areas are also important.

Process studies are extremely important. They provide quantitative understanding of the mechanisms controlling climate variability and change as well as the observations needed to improve models. Multiple process studies are required to determine how variations in one process influence other processes. Combined and integrated process studies are essentially two or more studies that are co-located and contemporaneous and can provide multivariate data sets with sufficient information for the parameterization or validation of models or remote data products. These studies include processes that impact both natural and social science components. An important goal of future studies in the Arctic should be to identify, characterize, and model both the positive and the negative feedbacks in the Earth-Ocean system.

There is a lack of data on *Arctic marine ecosystems*, and few data for fish in the Arctic Ocean; it is crucial that such data be collected before fisheries begin in this area. For predicting the potential impact of climate change on Arctic marine ecosystems and their biological communities, a better understanding of regional heterogeneity in the Arctic is needed, as climate-warming effects will vary depending on such features as hydrography, bathymetry, productivity and biodiversity. Information is needed to determine the sensitivities of species and whole communities to climate-related perturbations such as temperature increase. Factors controlling or limiting primary production in the Arctic Ocean are poorly known and are very important for climate projections.

A key research need is to develop *conceptual frameworks of how Arctic ecosystems could evolve* in the coming years. Developing an integrated conceptual model of the changes anticipated in productivity, trophic structure and biodiversity of Arctic ecosystems by the ongoing exposure of the Arctic Ocean is a pressing need. This could provide the structure for coordinating interdisciplinary research and setting priorities. Research should be directed at documenting the changes in ecosystem components (from microbes to top predators) in as comprehensive a manner as possible.

Development is needed of *new technologies*, such as new camera systems for digital photography, a new generation of autonomous underwater vehicles (e.g., gliders), further development of underwater microscopes and new sensors to analyze water-soluble constituents *in situ*. To address the need for broader geographical coverage, technologies need to be developed to characterize select properties over broader areas; they could include remote observatories, floats, buoys, ROVs, gliders or drones. Increased use of unmanned aircraft systems is also needed.

Coordinated measurements are needed of key properties and processes in representative areas of Arctic shelves and basins. Among important research needs are improved remotely operated observatories, targeted long-duration time series studies of primary and secondary production and the cycling of bioactive compounds, and the development of coupled biogeochemical models that use Arctic-appropriate parameterizations.

There is need to establish a more *comprehensive all-year network of monitoring stations* in the Arctic Ocean as well as deployment of drifting and moored platforms in both the surface and deeper waters. This could provide needed seasonal and long-term observations. Furthermore, temporally appropriate time series studies of key components during the \pm polar night are needed. Multiyear time series sites should be established with state and process measurements to gather these data. This requires the development of new technologies that could deliver potentially useful information during the polar night.

Additional research needs include:

- Investigation of the effects of increasing amounts of freshwater in Arctic Ocean surface waters on, for example, circulation;
- Investigation of the effects of Arctic Ocean acidification on marine organisms;
- Analysis of species composition and fish stocks in the marine areas currently accessible, both pelagic and benthic, as a basis for long-term monitoring programs for key species and ecosystems;
- Screening for new chemicals arriving in the Arctic via long-range transport;
- Studies of the distribution and effects of plastics and microplastics in Arctic ecosystems;
- Synthesizing historical baseline information to better understand how climate-related environmental shifts will influence ecosystem structure and function in the future.

1 Background

Arctic marine ecosystems are experiencing rapid change, primarily as a consequence of the rapidly changing climate. The sea-ice cover is decreasing rapidly, surface water temperatures are increasing and increased absorption of atmospheric carbon dioxide is causing ocean acidification. Increasing human activities in the Arctic are also influencing the marine ecosystems.

The Arctic Monitoring and Assessment Programme (AMAP), as a partner in the Horizon 2020 coordination and support action EU-PolarNet, is responsible for promoting trans-Atlantic research activities between EU countries and the USA and Canada and, as one aspect of this, to hold international stakeholder workshops to determine common research needs that can be provided as input to the central EU-PolarNet requirement, namely, to develop an Integrated European Polar Research Programme together with an implementation plan. An important aspect of EU-PolarNet is 'connecting science with society' under which dialogue and cooperation with relevant Arctic stakeholders will ensure their input to the formulation of this research programme. The AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Arctic Ecosystems and Ecosystem Services was the second of four AMAP-organized stakeholder workshops to identify and formulate key Arctic research needs over the five years of the project. The central theme of this workshop was research needs to obtain a better understanding of Arctic marine ecosystems and ecosystem services, especially living marine resources, and the factors that influence their functioning, from oceanographic and biogeochemical processes to the many human uses of this area, including fisheries and shipping, in the light of the many changes occurring in the Arctic associated with climate change.

The stakeholder workshop was held in association with the Annual Science Conference (ASC) of the International Council for the Exploration of the Sea (ICES). ASC Theme Session P on 'Arctic ecosystem services: challenges and opportunities' held on the morning of 20 September, provided scientific input and research ideas for the stakeholder workshop in the afternoon.

The format of the workshop, after the introductory presentations setting the background and aims, comprised presentations by several experts from around the Circumpolar North on a specific theme followed by discussion by the participants of the ideas presented and identification of research needs requiring further work. The workshop participants, as a group, then considered all material presented to identify key themes and approaches.

2 Introduction

Representatives of the two co-sponsors of the workshop, the AMAP Secretariat and EU-PolarNet, provided the overall background for the workshop.

Lars-Otto Reiersen, AMAP Executive Secretary, welcomed the participants to the workshop. He noted the significance of this workshop to identify research needs relating to the Arctic marine environment and ecosystems and ecosystem services that can be provided to the European Commission in relation to their funding activities. The results should also be useful to AMAP, ICES and others coordinating or conducting international or national investigations in the Arctic.

Dr Nicole Biebow, Project Manager of EU-PolarNet, the other co-sponsor of the workshop, presented a brief overview of this activity. She stated that polar issues have been rising up in the

political agenda across Europe over the past decade because the rapid changes occurring in the Polar Regions are significantly influencing global climate with consequences for global society. As a result, the European Union and its executive body, the European Commission (EC), attribute an increasing importance to science and innovation in the high latitudes for a variety of reasons. As a first step in this direction, the EC launched a five-year coordination and support action –EU-PolarNet ó Connecting Science with Societyø which will work in close cooperation with the EC during these five years to shape Europeø polar research and policy agenda. EU-PolarNet is the largest consortium of expertise and infrastructure for polar research, comprising 17 countries represented by 22 of Europeø internationally respected multidisciplinary research institutes. EU-PolarNet is working closely together with the EC by providing support and advice on all issues related to the polar regions.

EU-PolarNet is establishing an ongoing dialogue between policy-makers, business and industry leaders, local communities and scientists to increase mutual understanding and identify new ways of working that will deliver economic and societal benefits. The results of this dialogue will be brought together in a plan for an Integrated European Research Programme for the Antarctic and the Arctic. This will be co-designed with all relevant stakeholders and coordinated with the activities of many other polar research nations beyond Europe, including Canada and the United States, with which consortium partners already have productive links. The AMAP/EU-PolarNet Workshop on Research Needs for Arctic Marine Ecosystems is one important step in obtaining input from researchers and stakeholders for the Integrated European Polar Research programme. An affiliated partner, the European Polar Board, is supporting the work and will ensure that the legacy of EU-PolarNet will be sustained.

Activities of EU-PolarNet so far include contributing to the finalization of three funding calls under the Horizon 2020 work program for 2016/2017 dedicated to the Arctic. These calls were designed with partners from Canada and the United States as part of the implementation of the Trans-Atlantic Ocean Research Alliance between the EU, Canada and the USA. EU-PolarNet will continue to assist the EC in defining calls for the 2018-2020 H2020 program, which will allocate a significant amount of funding to Arctic and Antarctic research.

Publicly available deliverables of the project so far include a report on prioritized objectives in polar research (D2.1), a catalogue of all existing European polar infrastructure (D3.2), and an inventory of existing polar monitoring and modelling programs (D2.3). Current priority work includes a process to develop about six white papers addressing urgent polar research questions. These white papers will be developed jointly by stakeholders and scientific experts using a –Dahlem conference methodologyø Further information can be found on <http://www.eu-polarnet.eu/>.

The workshop organizer and meeting rapporteur, Janet Pawlak, AMAP Deputy Executive Secretary, emphasized the importance of this workshop as one of the stakeholder contributions to the further development of prioritized objectives for Arctic research and ultimately the Integrated European Research Programme for the Arctic. As Arctic marine ecosystems and ecosystem services is only one of many research topics for the Arctic, this workshop should aim to identify the most important research needs on this topic. These research needs will be included in the report she will prepare based on the presentations and discussions at the workshop for submission to EU-PolarNet as a stakeholder contribution on Arctic marine ecosystems and ecosystem services. The report is also a project deliverable to the European Commission for its information and use.

3 Summary of research needs from Theme Session P: Arctic Ecosystem Services: Challenges and Opportunities

Candace Nachman, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service, USA, Co-Chair of Theme Session P, provided an overview of research needs identified in the presentations and discussions at the session. For predicting the potential impact of climate change on Arctic marine ecosystems and their biological communities, a better understanding of regional heterogeneity in the Arctic is needed, as climate-warming effects will vary depending on such features as hydrography, bathymetry, productivity and biodiversity, for which better data are needed in many parts of the Arctic Ocean and its regional seas. Information is needed to determine the sensitivities of species and whole communities to climate-related perturbations such as temperature increase, as different species have different temperature sensitivities and optima for growth and thus will respond differently to climate change. An understanding of the resilience of whole communities to invasive species is also needed, and this will vary according to regional conditions. Data are lacking on the effects of ocean acidification in the Arctic marine environment, where acidification is occurring more rapidly owing to the cold waters.

With the opening of the Arctic to more human activities, particularly oil and gas installations and shipping, there is a need to develop risk assessment models and management tools to predict potential impacts of oil leaks and spills on fish species in the various Arctic regions. This should also include risks in relation to the introduction of invasive species from the increase in shipping activities.

A lack of data on Arctic marine ecosystems is a major issue. In some regions there are few data for the region or for an important resource; for others, data may exist but they have not been digitized or are not available. In particular, there are few to no data for fish in the Arctic Ocean; it is crucial that such data be collected before fisheries begin in this area.

4 Research needs on climate-related changes in the Arctic Ocean and cryosphere

Paul Wassmann, professor of marine ecology at UiT ó The Arctic University of Norway, Tromsø, stated that nowhere on earth is climate change more conspicuous than in the seasonal ice zone that surrounds the core pack ice of the Arctic Ocean. Over the course of a year, the seasonal ice zone shrinks with the growing extent of sea ice during winter and expands greatly during spring and summer as the ice cover melts. At present, the seasonal ice zone comprises two-thirds of the total Arctic Ocean area, with an increasing trend of 2% per year. Simultaneously, more than 70% of the total sea ice volume has already melted, the melt season has increased by one month, the ice moves more rapidly and, as the average thickness is now less than 1 m, trans-Arctic transport by ships becomes more realistic. These extreme changes in the Arctic cryosphere and its ecosystems create extraordinary demands on the marine biota. The extent of the changes and the speed of change are outside the 'empirical window'; there are no historical analogues, making it impossible to predict future states of these extremely changing ecosystems. Ecosystem models only have predictive power when the system is close to equilibrium, not when it is outside. Moreover, climate change is accompanied by the development of new industries, new infrastructure and new sources of pollution, the cumulative effects of which are extremely difficult to predict. Nonetheless, sustainable management of marine ecosystems and resources, the ultimate goal for the five coastal nations on the Arctic Ocean, demands significant research emphasis as it is the only essentially unexploited ocean still available to humanity.

What is so special about the Arctic Ocean? It has only 1% of the world ocean volume, but has 25% of the world continental shelf area and 35% of the world's coastline. Twenty of the world's 100 longest rivers flow into the Arctic Ocean, discharging 11% of global river runoff. The Arctic region contains only 0.05% of the global population, but 15% of global petroleum production, 22% of estimated undiscovered petroleum and many metal and non-metal resources. Arctic shelf regions support some of the richest global fisheries. Norway alone produces about 15 million fish servings per day from the Barents Sea, which provides about seven wild fish meals per European citizen per year.

The Arctic seasonal ice zone is very dynamic owing to rapid changes in sea-ice conditions. Depending on such factors as wind direction and ocean currents, it may consist of anything from isolated, small and large ice floes drifting over a large area to a compact edge of small ice floes pressed together in the form of solid pack ice. The seasonal ice zone supports many vulnerable environmental processes, and it currently occupies a geographical area as large as Europe (Figure 1). It is the strongest indicator of climate change, but little attention is being given to it because so few people live in the Arctic.

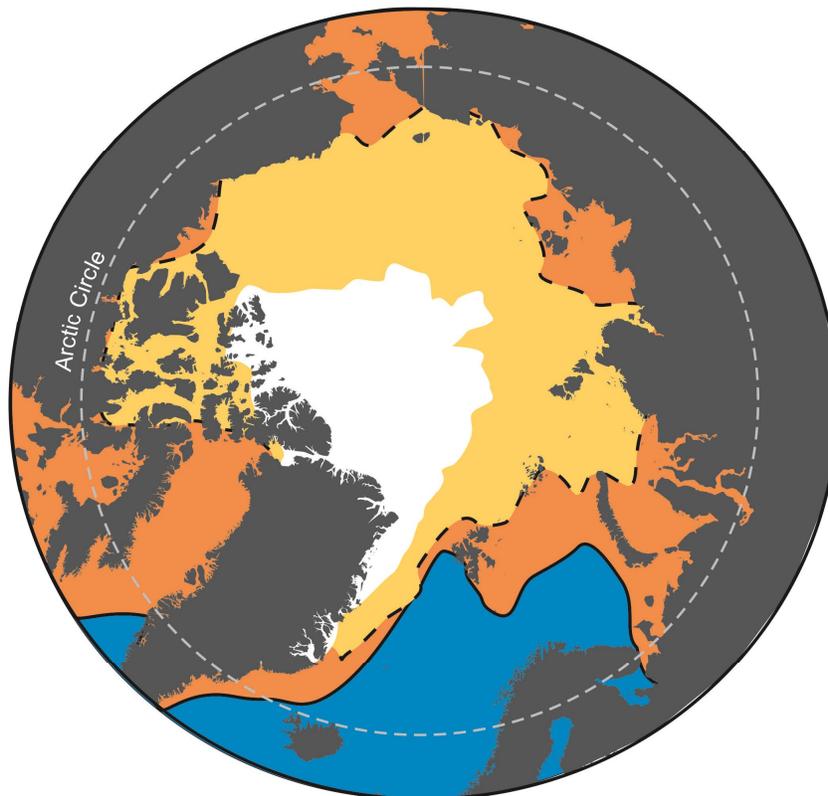


Figure 1. Changes in the summer seasonal ice zone in the Arctic. The orange color shows the seasonal ice zone 30 years ago, while the yellow color shows the current extent during summer.

The research needs on climate-related changes in the Arctic Ocean and cryosphere are manifold, not least because the ocean with the world's greatest climate change is also humanity's least-known ocean. In addition to the generic credo of 'more research is needed' what are the particular research challenges to manage the Arctic Ocean in a sustainable manner? An evaluation of the research needs on climate-related changes in the Arctic Ocean and cryosphere requires that we see the proportions of the problem correctly and that we evaluate them together with the needs of humanity in an

objective manner. In this regard, it is clear that the loss of Arctic sea ice has emerged as the leading signal of global warming. The sea-ice extent in summer has decreased dramatically together with a great loss of multi-year ice; ice loss is exacerbated by an increase in drift speed of sea ice and a longer melt season. Overall, there has been a loss of about 75% of ice volume in the past three decades.

The circulation in the Arctic Ocean is influenced by circulation patterns in the Pacific and Atlantic Oceans. While there is a general understanding of the principal large-scale features of Arctic Ocean circulation at various depth layers, many details are missing. This understanding is needed to develop better conceptual models linking the Arctic cryosphere and hydrosphere so that climate-related changes can be anticipated. The most prominent changes in the cryosphere now and in the decades to come are anticipated to occur in the seasonal ice zone. These changes include changes in the extent and thickness of the sea-ice cover and changes in the melt season, with associated changes in seawater stratification, nutrient levels and availability, and the composition of biota. An interdisciplinary focus on the seasonal ice zone should investigate physical-biological interactions, ecosystem characteristics including timing and productivity, acidification and contaminants. These studies could be conducted on specific sectors of the Arctic and later integrated on a pan-Arctic basis.

The seasonal ice zone has an importance beyond the Arctic. The location and duration of the seasonal ice zone affects shipping through this region, fisheries, oil and gas exploration, and minerals extraction. The atmospheric and oceanographic conditions of the seasonal ice zone also influence weather variability down to 30 to 40 °N.

Research needs regarding the influence of changes in the cryosphere on the seasonal ice zone include:

- Estimating the influence of Arctic amplification on the atmospheric uptake of carbon dioxide in the seasonal ice zone;
- Projecting changes in fisheries, both fish species and abundances, in the seasonal ice zone;
- Projecting changes in the biodiversity of the seasonal ice zone.

Other research needs regarding the Arctic cryosphere include investigations of the implications of the melting of the Greenland Ice Sheet in relation to increased ocean stratification, carbon dioxide uptake, biological production and mid-latitude weather. Implications of permafrost thaw on bacterial breakdown of organic matter in the Arctic Ocean also need investigation.

Given the scale and implications of these climate-related changes, there is need for multidisciplinary, decadal-long research programs in the seasonal ice zone, where the challenges are greatest. This requires the support of many countries and organizations in the Northern Hemisphere to respond to the scale of the challenge. Sustainable development of the Arctic Ocean demands knowledge-based ecosystem and resource management, and currently this knowledge is inadequate.

In the discussion of this presentation, it was considered that given the importance of the seasonal ice zone for the whole world, there is a need to better understand and better articulate these connections and the importance of this area to a broader public. People living outside of the Arctic are not aware of how climate change in the Arctic may affect them. Many political decisions are based on industry

needs, not on peoples needs; the loss of sea ice in the Arctic benefits industry very much. Politicians appreciate these economic opportunities, without being aware of the negative aspects of the enormous influence of climate change on Arctic ecosystems. Political reasons have also resulted in the greatest amount of U.S. research funding going to the Antarctic, with considerably less allocated to the Arctic.

On the positive side, however, the U.S. has closed all fisheries in the Arctic because the knowledge base for fisheries regulations does not exist at this time. Furthermore, Norway has the only system of knowledge-based ecosystem management, whereby there is a need to be able to determine risks to the ecosystem and permission is required from parliament for commercial activities to be conducted in the Arctic.

5 Research needs for Arctic ecosystems and biodiversity

Victor Smetacek, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany, stated that the ongoing retreat of Arctic summer sea-ice extent is a tragic reality that should, nevertheless, be seized upon by the scientific community and used as a heaven-sent (literally) opportunity to address questions that could not have been addressed otherwise: it is an ocean-scale colonization experiment. Massive, extensive phytoplankton blooms have already been observed under the melting sea-ice cover. Spring and autumn blooms typical of temperate regions are also already appearing in open waters of the Arctic Ocean. Northward migration of some species, including a key diatom (*Neodenticula seminae*) and zooplankton species (copepods and amphipods), has also been reported, all indicating that colonization of the opening pelagic habitat is already occurring. This calls for efforts to coordinate international research activity on the scale of a giant experiment.

Because the questions pertain to all fields of marine science, developing an integrated conceptual model of the changes anticipated in productivity, trophic structure and biodiversity of Arctic ecosystems by the ongoing exposure of the Arctic Ocean is a current pressing need. This could provide the structure for coordinating interdisciplinary research and setting priorities. Baselines have been established by cruises that ventured into the multi-year ice fields before 2007. Research should now be directed at documenting the changes in ecosystem components (from microbes to top predators) in as comprehensive a manner as possible. The changes will be manifested in successive shifts in annual cycles in the course of the coming years. Following the sequence of events in the plankton and benthos will provide new insights into the functioning of marine ecosystems and enable the formulation of hypotheses that could be successively tested as the new ecosystems develop.

Traditionally, colonization experiments have been carried out by terrestrial and benthic ecologists to identify pioneer species and the stages in maturity undergone by the affected ecosystems. They also offer the opportunity to assess the impacts of bottom-up and top-down factors in shaping ecosystem structure and functioning. This is the first time that this opportunity is being offered at an oceanic scale to pelagic scientists, and by extension, also to fisheries biologists and benthologists. The response of indigenous species to the Great Exposure (or call it Illumination) and their interaction with boreal invasive species, introduced from the Pacific and Atlantic Oceans, will shed light on temperature adaptations, dispersal ability and many other organism properties. The first and foremost research need is to overcome disciplinary boundaries by developing conceptual frameworks of how Arctic ecosystems could develop in the coming years. This can be achieved by holding brainstorming workshops with specified goals. Encouragement could come from funding agencies

for integrated proposals in which over-arching hypotheses are investigated. Other associated activities could include the identification of sensitive regions that could be designated as marine protected areas.

The development of new technologies, such as new camera systems to study and quantify plankton *in situ*, could also be supported. A sizeable part of the human brain is devoted to processing visual information, but so far we have only seen what instruments of our making show us: the history of advances in marine sciences is a history of the development of methodology and instruments (our extended sense organs). Seeing is believing, but the marine scientific community so far has had to believe without seeing. No one has observed functioning pelagic ecosystems the way terrestrial ecologists can examine their systems; experiments with plankton carried out *in vitro* have proved to be of limited application. However, the perspectives opened by digital photography and the new generation of autonomous underwater vehicles (e.g., gliders) are enormous: the application of recently developed underwater microscopes will literally open new vistas for our brains to work with. It is time to enhance our efforts to study pelagic organisms *in situ*, to accompany and enhance the information coming from omics studies.

The new era of visualization described here will prove invaluable for fostering interdisciplinary cooperation as it will make marine biota accessible to all. Optically arresting images and videos that convey the feeling of declining Reynold's numbers on the performance of the organisms, from whales to microbes in the water column and benthos, will lead to eye-opening insights for scientists that can even be shared directly with the public. The effect on the latter in terms of understanding the issues at stake, at a time when marine ecosystems are becoming more vulnerable to industrial-scale exploitation, cannot be overemphasized. We owe it to the less charismatic biota—the workhorses of the oceans regulating our climate—to place them in the limelight that they deserve.

In the discussion of this presentation, the issue of visualization was considered important. More technical development and coordination is needed to produce appropriate means to visualize processes in the marine ecosystem. The U.S. National Oceanic and Atmospheric Administration (NOAA) is experimenting with unmanned observation systems; however, this requires a considerable amount of resources and work as well as partnering, particularly with industry.

Another issue is that most decisions affecting the Arctic are made by people who have never visited the Arctic. Given that scientists must fight for every data point they receive, education of the public so that they elect politicians who will support work in the Arctic is important. There is now a movement in some countries, for example, Norway, to sponsor annual visits to the Arctic for small groups of people so that they gain a better understanding of the conditions and greater empathy for Arctic issues. In Canada, a recent two-week cruise on an icebreaker was held for interested people who could afford the high cost. A public event, "Arctic Matters Day" was held in the U.S. earlier in the year to provide visualization on why the Arctic matters to everyone; similarly, the U.S. Department of State initiated a project where representatives from all 50 states wrote about what the Arctic meant to them to highlight the U.S. chairmanship of the Arctic Council (April 2015 to May 2017).

It was noted that innovation is now required as part of EU-funded projects; proposals need to indicate societal relevance, particularly job creation, as well as innovations that will result from the project. In general, there is a greater pressure for scientists to take social scientists into their work.

6 Need for monitoring in Arctic Ocean: contaminants, climate, acidification

Lars-Otto Reiersen, AMAP Executive Secretary, stated that the Arctic Monitoring and Assessment Programme (AMAP) was established in 1991 with a mandate to monitor and assess the state of the Arctic environment with respect to pollution and climate issues, including effects on ecosystems and humans. In this connection, AMAP defined an "ideal" monitoring program including atmospheric, terrestrial, freshwater, marine and human health sub-components to gather the necessary information needed to perform scientific assessments of levels, trends and effects of contaminants, and of climate change and ocean acidification. The results of these assessments are used to provide science-based policy-relevant information.

The AMAP monitoring program is implemented largely through ongoing national monitoring and research activities in the eight Arctic countries, and to varying degrees. This reflects the fact that, although the program identifies "essential" and "recommended" measurements, there are no mandatory requirements for implementation. In this respect, AMAP/Arctic Council differs from other arrangements and organizations such as OSPAR and HELCOM that have Conventions with a legally binding status. Notwithstanding this, monitoring and research efforts by Arctic and non-Arctic countries and their institutions – both agencies and universities – have allowed AMAP over the years to produce a number of high-quality scientific assessments.

AMAP marine monitoring activities over the past 25 years have confronted a number of challenges regarding different aspects of marine monitoring and observations, equipment, sensors, data handling, etc., as well as the research needs to achieve a better coverage of the Arctic Ocean and its adjacent seas.

AMAP is also a large consumer of data from many sources. Although short-term research programs are major sources of data, satellites have provided valuable information about sea-ice extent for more than three decades and ice-tethered profilers have collected data on such properties as temperature, salinity and dissolved oxygen and carbon dioxide in Arctic seawater for the past decade. Under the GEOTRACES program, marine biogeochemical cycles of trace elements and their isotopes are being studied in the Arctic Ocean, among other marine areas. Russia has operated drifting ice stations, but many have now melted away; aside from that, most Russian monitoring stations are on land, with little monitoring activity in the Arctic Ocean. However, a Russian institute recently cooperated with a Norwegian institute in extensive surveys of the Barents Sea, comprising hydrographic and plankton stations as well as bottom and pelagic trawl stations. Norway has conducted cruise surveys in the Barents Sea for over one hundred years, studying oceanographic conditions, plankton and other marine properties.

Ocean acidification is being studied in many areas of the Arctic Ocean, with particularly intensive monitoring in the Greenland Sea and the Barents Sea. The abundance of commercial species of fish in these two regional seas is also heavily monitored. Other monitoring programs include monitoring of nutrient concentrations in coastal waters of parts of the Canadian Arctic as well as a program to monitor marine mammals at many locations in the Canadian Arctic.

The monitoring of concentrations of environmental contaminants in marine biota, including shellfish, fish, marine birds and marine mammals, is being conducted regularly in most Arctic countries, but the number of samples is small and the geographic distribution is sparse.

The use of new instrumentation to study the conditions in the Arctic is very important. AMAP has developed guidelines for the use of unmanned aircraft systems (UAS) for the collection of scientific data in the Arctic.

Given the rapidity of climate change in the Arctic there are needs for:

- Establishment of a more comprehensive all-year network of monitoring stations in the Arctic Ocean;
- Deployment of drifting and moored platforms at both the surface and in deeper waters;
- Increased use of unmanned aircraft systems;
- Development of new sensors to analyze water-soluble constituents *in situ*;
- Development of new models to elucidate combined effects of climate change, contaminants and other stressors in the Arctic and adjacent seas.

Research is needed to:

- Investigate the effects of increased temperatures on Arctic marine species;
- Investigate the effects of increasing amounts of freshwater in Arctic Ocean surface waters on, for example, circulation;
- Investigate the effects of Arctic Ocean acidification on marine organisms;
- Analyze species composition and fish stocks in the marine areas currently accessible, both pelagic and benthic, and prepare long-term monitoring programs for key species and ecosystems;
- Screen for new chemicals arriving in the Arctic via long-range transport.

In the discussion, it was noted that there are very few data for the Central Arctic Ocean and, with the aging of research vessels operating in the Arctic, it was difficult to know how information on this area will be obtained. On the other hand, concentrating research on the seasonal ice zone is clearly important because this zone includes the ice edge and the shelf area, which are much more interesting to national funding agencies given the fisheries and other resources in this area. Emphasis on innovation and the development of new technologies to study these remote areas was also considered important.

7 Needs for interdisciplinary Arctic state and process studies

Richard Rivkin, Professor in the Department of Ocean Sciences, Memorial University, Newfoundland, emphasized the need for interdisciplinary state and process studies in the Arctic. The Arctic Ocean is a relatively shallow Mediterranean sea, surrounded by land, receiving more than 10% of global freshwater discharge and containing about 1% of the ocean volume and about 4% of the ocean area. It is cold, highly stratified and large areas are both seasonally ice covered and dark. These conditions create both research challenges and opportunities.

The hydrography, ecology and biogeochemistry of the Arctic Ocean are unique and the outflows are important drivers for global circulation, heat flux and climate. The Arctic is experiencing extreme global warming that is leading to a reduction in ice cover with concomitant changes in circulation patterns, seawater chemistry, vertical mixing, primary and secondary production and a greater ease of access by invasive species, including human tourists. Although the Arctic has been studied during scientific research expeditions since the 1800s, there are large gaps in our understanding of the distribution and control of the main ecosystem components, and of the factors controlling the

seasonal cycles of important biological, chemical and biogeochemical processes, especially those occurring during the dark boreal winter. Thus, process studies are extremely important. Process studies provide quantitative understanding of the mechanisms controlling climate variability and change and they provide the observations needed to improve models. Multiple process studies are required to determine how variations in one process influence other processes. Combined and integrated process studies are essentially two or more studies that are co-located and contemporaneous and can provide multivariate data sets with sufficient information for the parameterization or validation of models or remote data products. Field programs in the Arctic are by nature interdisciplinary and include processes that impact both natural and social science components.

Earth systems interact through both linear and non-linear processes that can vary on different spatial and temporal scales. Focused studies of key processes underpinning the Earth's climate system are critical to obtain an understanding of the ocean's role in climate dynamics and potential feedbacks. An important goal of future studies in the Arctic should be to identify, characterize and model both the positive and the negative feedbacks in the Earth-Ocean system.

One of the issues inherent in multidisciplinary process studies is that of scale. Multiple spatial and temporal scales characterize an individual disciplinary science and its applications. This is matched by an equally broad range of spatial and temporal scales when comparing disciplines (Figure 2). This requires that research questions be developed both around trans-disciplinarity and at multiscale perspectives to understand the current and future states of the Arctic. There is also now a need to include social science components in large research projects.

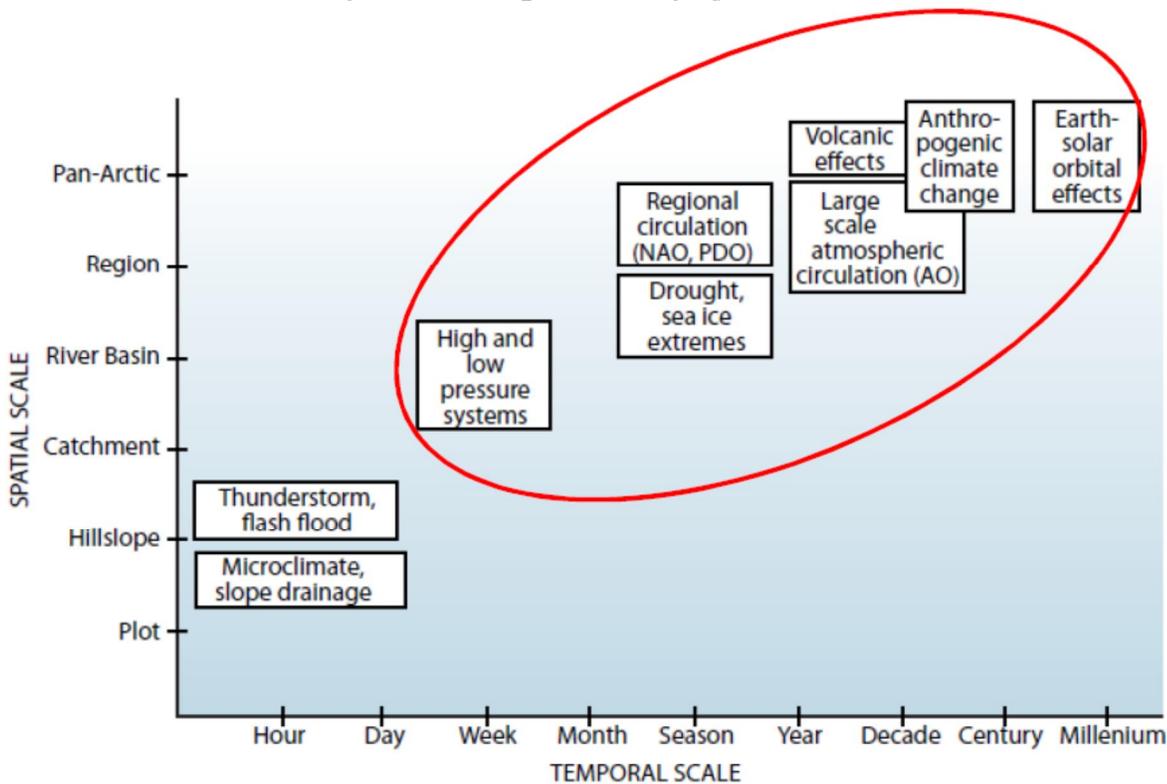


Figure 2. Spatial and temporal scales related to weather and climate dynamics. NAO = North Atlantic Oscillation; PDO = Pacific Decadal Oscillation; AO = Arctic Oscillation. Source: U.S. Arctic Research Commission, 2010.

A good starting point for the development of research questions is to determine what we know already and, from that, what do we know that we do not know. In other words, to identify what are the process uncertainties, we need to know the current state of knowledge in the field. In terms of the Arctic, we know that the open water area in the Arctic Ocean increased significantly (25627%) between 1998 and 2012. Over this same period, annual net primary production increased about 30%, with the largest increases occurring on the interior shelves and smaller increases on inflow shelves; outflow shelves experienced a net decrease. Increased annual net primary production was often associated with reduced sea-ice extent and a longer phytoplankton growing season. However, there are many uncertainties associated with these estimates of primary production and with the consequences of observed changes. Among other questions, there is uncertainty concerning the contributions of open-water, under-ice and bottom-ice primary production. Factors controlling or limiting primary production in the Arctic Ocean are not known, and if it is the nutrient supply that is limiting, the question is whether production is sustained on new or regenerated nutrients. Major questions include: 1) What is the composition of the phytoplankton community? 2) Is there downward export and sequestration of organic matter? 3) Is there export from the food web, or is there retention or remineralization? Answers to these three questions have major consequences for climate projections.

To begin to predict future environmental conditions in the Arctic, a full understanding of the past is needed. The Arctic Ocean is changing rapidly. To have a complete understanding of how these environmental shifts will influence ecosystem structure and function in the future, it is critical to synthesize historical baseline information.

Much baseline information still needs to be collected on a broad basis in the Arctic. The Arctic Ocean is very heterogeneous, with about half of the area occupied by shelves whose physical, chemical and biochemical characteristics appear to differ. Furthermore, past observations are discontinuous in both space and time. To address this need for broader geographical coverage, new technologies need to be developed and used to characterize select properties over broader areas. These technologies could include remote observatories, floats, buoys, ROVs, gliders or drones. Coordinated measurements are needed of key properties and processes in representative areas of Arctic shelves and basins.

Seasonal and long-term observations are also needed. Early studies suggested that ice-covered areas were unproductive, with long periods of zero productivity. However, it has now been shown that the Arctic winter and polar night are key periods during which ecologically important processes mediated by metazoa and biogeochemically mediated transformations by heterotrophic microbes take place. It is critically important to obtain temporally appropriate time series studies of key components during the polar night. Multiyear time series sites need to be established with state and process measurements to gather these data. This requires the development of new technologies, such as perhaps satellite products in addition to ocean color that could deliver potentially useful information during the polar night. Remote observatories would be useful as well as determining potential proxies for the information needed.

Thus, there is a strong need for coordinated research in the Arctic, as well as a compiled summary of historical and the best current information. This can be used to determine critical data needs and a hierarchical assessment of what information will provide the most or best incremental information per unit effort or cost. Data uncertainties need to be evaluated and model outputs assessed (Figure 3).

Among the important research needs for future Arctic studies are improved remotely operated observatories, targeted long-duration time series studies of the primary and secondary production, and the cycling of bioactive compounds, and the development of coupled biogeochemical models that use Arctic-appropriate parameterizations.

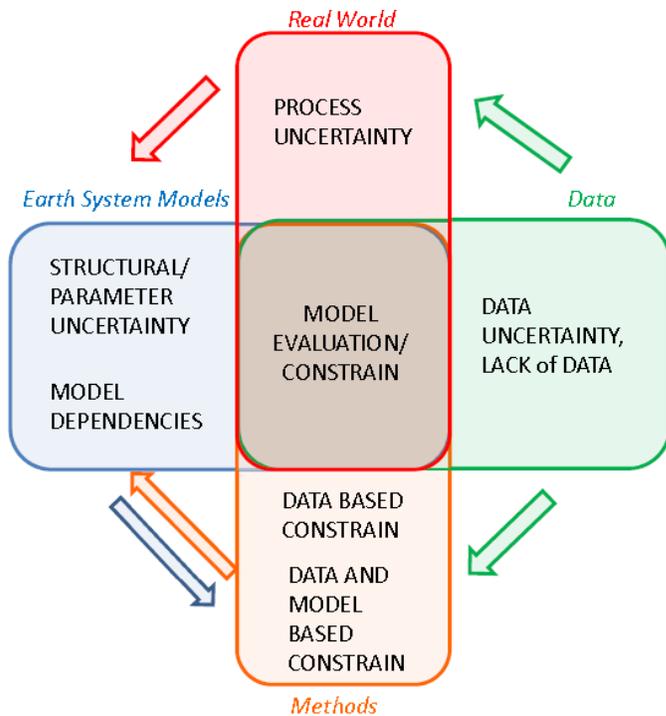


Figure 3. Possible conceptual approach to integrate process studies for future Arctic research needs. Dalmonech et al., 2014.

8 New research challenge: Litter/plastics in the Arctic Marine Environment

Tina Schoolmeester, GRID-Arendal, a Norwegian non-profit foundation that works with the United Nations Environment Programme and other agencies to support environmental decision-making and raise awareness, stated that marine plastic pollution is a worldwide problem. Of the approximately six billion tonnes of plastic produced since the 1950s, it is estimated that between 86 and 150 million tonnes of plastics have ended up in the sea (UNEP and GRID-Arendal, 2016). Between 50% and 90% of litter in the ocean is plastics or microplastics (<5mm).

Plastics are durable and quickly redistributed by ocean currents between the different regions of the global ocean. This means that plastic pollution originating elsewhere has also ended up in polar waters. It has been estimated that between 16,200 tonnes and 1.9 million tonnes of plastic are imported annually to the Arctic from the North Atlantic and the Bering Sea (Zarfl and Matthies, 2010). Recent research has already identified the occurrence of plastic pollution in all Arctic marine reservoirs, namely coastal areas, sea surface waters, the water column, the sea floor and, very important in the light of climate change, within sea ice.

Because Arctic coastal areas are sparsely populated and human activities at sea are still limited, the potential local contribution of plastic debris and microplastics is relatively small compared to other areas. However, very little is known regarding input from rivers flowing directly into the Arctic.

Large rivers flowing into the Arctic, particularly some of the large Russian rivers, originate in populated areas and carry litter and plastics to the Arctic, littering the shores of Siberia. Forecasted increases in human activities, particularly maritime activities such as shipping and fisheries, in the Arctic Ocean could change the relative importance of local sources.

Currently there is a wide variation in estimates of the amount of plastics transported to the Arctic. Both the quantitative and qualitative data are too sparse to obtain an overall understanding of total amounts, concentrations and transport paths of plastics into and within the Arctic. This warrants further research efforts in order to identify the potential impact on organisms.

While the overall impact of plastic debris on Arctic biota remains uncertain, available studies clearly confirm that a plastic diet does not contribute to healthy marine organisms and ecosystems. The ingestion of macroplastics results in poor nutrition, mechanical damage to the stomach, and a decline in health and even death, including by entanglement in marine plastic debris. Even less is known about the effects of microplastic ingestion; however, owing to the ubiquitous presence of microplastics, they can be potentially ingested by a broad range of organisms from zooplankton at the base of the food chain, all the way to commercial species and apex predators such as seabirds and marine mammals. The impact of ingestion can be mechanical and/or chemical through the potential bioaccumulation of the toxic substances associated with plastic, such as phthalates, polybrominated diphenyl ethers, polycyclic aromatic hydrocarbons and styrenes. In addition to ingestion, plastic debris can affect organisms through entanglement, serve as vectors for the dispersion of invasive species, and smother habitats in accumulation hot spots.

The fragmented and discontinuous nature of the available knowledge does not allow a clear enough assessment of either the global or the Arctic-specific impacts of marine plastics. Further research is needed to identify and quantify local Arctic sources (both land- and sea-based) and fluxes through the various input pathways, as well as to quantify oceanic input from outside the Arctic. There is a need to determine the amounts and concentrations of plastics and microplastics in Arctic surface waters, the water column, sea ice and seabed sediments as well as to understand the relationship between sources and sinks to identify areas vulnerable to accumulation. A better understanding is also needed of the uptake into biota.

Regarding impacts, there is a need for investigation of the impacts of plastics and microplastics at the species and population levels of organisms in the Arctic. This should include both mechanical impacts from ingestion and entanglement, as well as chemical impacts from ingestion and the bioaccumulation of toxic substances within or adsorbed to the plastics and possible consequences for human health of consumption of affected biota. Furthermore, there is a need to understand the mechanisms of plastic as vectors for inputs of pollutants and invasive species into the Arctic.

The effect of the colder Arctic climate on plastic degradation also needs better study.

Finally, government frameworks for prevention, remediation and adaptation strategies and policies should be urgently designed to address the already identified sources and pathways in order to guarantee healthy Arctic marine ecosystems and the services that they provide.

9 Panel discussion of research needs related to Arctic marine ecosystems and ecosystem services

To start off the panel discussion, Anne Hollowed, NOAA National Marine Fisheries Service (NOAA Fisheries), Alaska Fisheries Science Center in Seattle, described the NOAA Fisheries Climate Science Strategy, which was adopted to strengthen the underlying science regarding climate-related impacts on marine and coastal ecosystems and their influence on fisheries. The objectives of this strategy are to build and maintain an adequate science structure, track changes and provide early warnings, understand the mechanisms of change, project future conditions, develop adaptive management strategies as well as robust management strategies, and ultimately create climate-informed biological reference points for use in fisheries management. Regional action plans have been prepared under this strategy, including one for the southeast Bering Sea. Integrated interdisciplinary research teams have been established to implement the action plans, using both remote and *in situ* monitoring and modelling in relation to a core suite of ecosystem observations and indicators, with the aim of making six- to nine-month projections of the climate to use for fisheries predictions. Work is also being conducted to determine ecosystem thresholds for management actions.

In the discussion, it was stressed that there is a need to do considerably more monitoring of the conditions in the Arctic Ocean. However, the question was raised as to why monitoring of fisheries should be considered so important when fish do not constitute a large component of that ecosystem. The view was expressed that monitoring the biogeochemistry of the Arctic Ocean and its regional seas was the most important at this stage, as the role of marine mammals, fish and complex metazoa is relatively small in terms of biogeochemical changes. This reflects the concern that a tipping point has been passed in the ocean with regard to atmospheric CO₂. Even if the production of CO₂ is stopped, the ocean will start outgassing rather than absorbing CO₂, raising the question of how changes in the ocean can be managed if this tipping point has been passed. This also has an influence on the balance between remediation and adaptation.

Nonetheless, fisheries clearly provide an ecosystem service and thus fisheries monitoring is important. Additionally, although fisheries do not affect the CO₂ balance in the ocean, given that fisheries will be seriously affected under RCP8.5, the value of fisheries resources could be used to enhance global acceptance of limiting greenhouse gas emissions. Furthermore, with less sea ice, there may be more fish in the Arctic Ocean, although it is not known which species would be enhanced. Predicting these changes requires the development of representative fisheries scenarios.

It was further noted that the management of fisheries on the high seas is very poor. As there is yet little fishing in the Arctic Ocean itself, there is the possibility that a better management structure could be developed now so that when there are more fish a good management structure will already exist.

Fishing should not be allowed in ice-dependent ecosystems until a clear understanding of these ecosystems and the level of a sustainable harvest has been obtained. An environmentally based concept of sustainability needs to be developed. Given that there is no equivalent of CCAMLR in the Arctic, at present there is no institutional basis for cooperative, sustainable fisheries management.

Ecosystem services can be provided at a range of different levels. Carbon sequestration is a major global ecosystem service. Understanding the fate of production is important to knowing climate

change impacts in the ocean. However, the area of the Arctic Ocean is relatively small and the amount of nutrients is so small that little carbon sequestration can be anticipated. Furthermore, most macrofauna have been overharvested by humans, leaving microbiology as the most promising to study. Several hundred years ago, coastal areas had a much greater large animal biomass than they do today. Major species have been removed from the system, so we cannot know the original system. This has been witnessed in the Southern Ocean with the influence the loss of whales has had on the krill population.

There is also the issue of biodiversity: large organisms depend on systems that we do not understand. Another issue regarding biodiversity is that we are changing the ways of observing systems and they are not comparable with previous types of observations. We will not have comparable data sets and there is a need to deal with this.

The need for research includes observations and models and both should be linked to parameterization. Attempts should be made to parameterize processes so that they can be applied to broad geographical areas; however, as the temperature regime is different for different areas, the geographically related temperature-dependent response for a species can be different from its seasonal temperature response. A long-term goal is also to downscale global climate models so we can obtain reasonable information on impacts on a smaller geographical scale.

As an example of a regional observation program, a research project has been established in the southeastern Bering Sea and in the Chukchi Sea to determine the variability of production, both the interannual variability and the decadal variability, so that changes arising from climate change can be determined. This monitoring will need to be conducted for a decade for this variability to become evident.

It was noted that making recommendations from the workshop depends on the aims that such research are intended to achieve. Climate change is important for everyone, including what is changing and how it is changing. There is already a lot of research being conducted, so the question is whether there is a need for another incremental effort or do we want to get more than another set of data points. Here we have spoken about interdisciplinary work and conveying the results to the public, to make connections that have not yet been made. There is a need to determine the questions and to pay attention to what has already been done rather than simply starting new studies.

As this workshop is being held to provide research topics to the European Commission, the question was raised as to what are the hot topics that could be attractive to politicians. The EC is looking for themes with societal relevance. One topic with societal relevance concerns how the Arctic is influencing mid-latitude weather patterns. If the Arctic is not understood and taken into account, the ability to predict mid-latitude weather is diminished. It is also important to develop communication methods to convey to the general public in a meaningful way the implications and effects of climate change in the Arctic, given that so few have visited an Arctic area.

Other questions and ideas arising in the discussion included the following:

- What can ecosystem research do with regard to COP21 targets? How will COP21 influence society?
- How do these changes affect Indigenous peoples who are dependent on local animals for their food supplies?

- How can we develop technologies for people living in the Arctic that they can use to track conditions? community-based monitoring tools? This could include intelligent observations with cameras. Crowd research on the internet could be employed to get people interested;
- Good governance is important to the Arctic;
- Cooperation should be enhanced with Asian countries, particularly China, India, Japan and South Korea all of which are eager to cooperate, in research and monitoring in the Arctic.

7 Final remarks

The Co-Chairs Candace Nachman and Susanne Kortsch thanked the speakers and participants for their contributions to the workshop. On behalf of AMAP, Lars-Otto Reiersen expressed his appreciation, noting that much good information had been presented and discussed. From EU-PolarNet, Nicole Biebow stated that the workshop had been very informative, and now the most relevant issues need to be conveyed to the EU-PolarNet consortium.

References

Dalmonech, D., Foley, A.M., Anav, A., Friedlingstein, P., Friend, A. D., Kidston, M., Willeit, M., and Zaehle, S. 2014. Challenges and opportunities to reduce uncertainty in projections of future atmospheric CO₂: a combined marine and terrestrial biosphere perspective. *Biogeosciences Discussions*, 11:208362153. doi:10.5194/bgd-11-2083-2014

UNEP and GRID-Arendal. 2016. Marine Litter Vital Graphics. United Nations Environment Programme and GRID-Arendal. Nairobi and Arendal, www.unep.org, www.grida.no

U.S. Arctic Research Commission. 2010.

Zarfl, C. and Matthies, M. 2010. Are marine plastic particles transport vectors for organic pollutants to the Arctic? *Marine Pollution Bulletin*, 60:181064. doi: 10.1016/j.marpolbul.2010.05.026

MEETING AGENDA

20 September 2016	
Radisson Blu Hotel Latvija, Elizabetes 55, Riga, Latvia	
Theme session P: Arctic Ecosystem Services: Challenges and Opportunities (Co-sponsored by AMAP, EU-PolarNet, and ICES)	
Co-Chairs: Candace Nachman (USA), Susanne Kortsch (Norway)	
Time	
10:00 – 13:00	Theme Session P: Arctic Ecosystem Services: Challenges and Opportunities (see attachment)
13:00 – 15:00	Lunch
AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Arctic Ecosystems and Ecosystem Services	
Co-Chairs: Candace Nachman (USA), Susanne Kortsch (Norway)	
Time	
14:00 – 14:30	Opening and welcome <i>Lars-Otto Reiersen, AMAP Executive Secretary</i> Context of the workshop: Research needs defined for EU-PolarNet work <i>Nicole Biebow, AWI, Project Manager EU-PolarNet</i> Aims and outcome of the workshop <i>Janet Pawlak, AMAP Secretariat – Rapporteur</i>
14:30 – 15:30	Summary of research needs from morning session <i>Candace Nachman, NOAA National Marine Fisheries Service, USA</i> Research needs on climate-related changes in the Arctic Ocean and cryosphere <i>Paul Wassmann, University of Tromsø</i> Research needs for Arctic ecosystems and biodiversity <i>Victor Smetacek, Alfred Wegener Institute</i> Discussion
15:30 – 16:30	Need for monitoring in Arctic Ocean: contaminants, climate, acidification <i>Lars-Otto Reiersen, AMAP Executive Secretary</i> Needs for interdisciplinary Arctic state and process studies <i>Richard Rivkin, Memorial University of Newfoundland</i> New research challenge: Litter/plastics in the Arctic Marine Environment <i>Tina Schoolmeester, GRID Arendal</i> Discussion
16:30 – 17:00	Coffee Break
17:00 – 17:45	Panel discussion – Research needs for Arctic Marine Ecosystems
17:45 – 18:00	Final remarks and closing of meeting

AMAP/EU-PolarNet Stakeholder Workshop on Research Needs on Arctic Ecosystems and Ecosystem Services

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Theme Session P

Arctic ecosystem services: challenges and opportunities

Conveners: Candace Nachman (USA) and Susanne Kortsch (Norway)

The Arctic environment is changing rapidly. In the Arctic, surface temperatures are rising twice the global average rate, and sea ice cover is declining dramatically. From the rapidly changing climate to the increase in human activities, there are many challenges affecting Arctic marine ecosystems. These challenges are being addressed in three Arctic regions in the ongoing Arctic Council project "Adaptation Actions for a Changing Arctic (AACA)".

The Arctic Monitoring and Assessment Programme (AMAP), a working group of the Arctic Council, and EU Horizon 2020 Coordination and Support Action EU-PolarNet co-sponsored this session. The session was well attended and consisted of 13 oral presentations and three poster presentations.

Presentations, P:450, P:502, and P:433, highlighted the role of heterogeneity of the Arctic with respect to hydrography, bathymetry, productivity regimes, and biodiversity. An important point that emerged from this session was that because of this heterogeneity; climate-warming effects will vary across the Arctic ecosystems. P:450 highlighted how variations in the response of hydrography differed between sub-regions within the Kara Sea, but, overall, ice condition was found to be the most important variable affecting hydrography. P:502 highlighted how differences in the resilience of Arctic benthos to perturbations, such as invasions, varied among five Arctic regions, with the two northernmost regions (i.e., the North Water Polynya and the Canadian Archipelago) being more resilient to invasions but less resilient to loss of ice-associated organisms such as sea-ice algae. The benthic communities of the Chukchi, Amundsen, and Beaufort Sea displayed less resilience. The authors of paper P:433 examined whether domain, temperature, and latitude matter with respect to climate change impacts on fish by studying six shelf domains. The Bering and Barents Seas were the most productive of the shelves, whereas the Chukchi and Beaufort Seas were less productive. The models indicated the biggest changes are expected in the 2080-2100 time period. The authors concluded if we do nothing to mitigate the causes of climate change, we will see significant warming.

Presentations P:178, P:644, and P:129 presented evidence that species and whole community sensitivity to perturbations (e.g., temperature increase or invasive species) from climate warming will vary throughout the Arctic. For example, saffron cod and polar cod, although in the same family of fishes, have different temperature sensitivities and optima for growth and will respond differently to climate change. Whole communities may be more or less resilient or sensitive to perturbations, such as invasive species. Also, fish eggs may have different sensitivity to oil. P:178 showed food availability, temperature, and fishing are important drivers of Icelandic cod stocks. During warm-water regimes, food availability becomes an even more important driver, indicating that as the high-latitude ecosystems continue to warm, this effect may become even more pronounced. Even if fishing effort was removed from the model, there was still a significant effect of temperature. P:644 illustrated that gadoids have unique thermal responses, implying growth efficiencies are temperature-dependent and climate warming will not affect all gadoid species in Arctic waters equally. A

laboratory experiment showed saffron cod performed well at higher temperatures. The most negative effect from climate warming will be on polar cod (*Boreogadus saida*), a key species in the marine Arctic, which provides a unique and valuable ecosystem service by efficiently channeling rich lipid energy to higher trophic levels at cold temperatures. P:129 described how continued warming and loss of sea ice is projected to shift the Chukchi Sea ecosystem from a benthic-dominated system to a more pelagic-dominated system. The authors conducted integrated ecosystem surveys during August to September in 2007, 2012, and 2013 in the U.S. Chukchi Sea. More juvenile pink salmon were captured in 2007, a warmer year, which likely increased pelagic productivity that led to larger (i.e., higher marine survival) and more abundance of juvenile pink salmon compared to the colder years of 2012 and 2013.

Scientists estimate the ocean is 30% more acidic today than it was 300 years ago. Because the waters of the Arctic are both old and cold, scientists expect the Arctic to experience the effects of ocean acidification faster and more seriously than lower latitudes. Data are currently lacking regarding effects of ocean acidification in the region. The authors of P:248 used biological and economic models to determine what may happen in the Baffin Bay/Davis Strait shrimp fishery as a result of ocean acidification. However, at this stage, it is hard to say whether shrimp in Greenland are affected by ocean acidification. P:268 described a study looking at the effect of food concentration on Atlantic cod survival and found no effect. The authors also described preliminary results regarding temperature effects on the western Baltic stock of Atlantic cod. The correlative analyses revealed strongest impact of temperature on recruitment in November and March. They found the stock collapsed even before a 2° Celsius increase, and, with increasing temperatures, profits are likely to decrease.

With diminishing sea ice, anthropogenic activities such as shipping and oil and gas exploration and development have increased in the Arctic. Presentations P:647, P:280, and P:445 described the risks associated with various anthropogenic activities and presented risk management and assessment tools. Using the Lofotens and Barents Sea, Norway, Howell *et al.* (P:647) developed a risk management tool to predict a range of possibilities regarding impacts of oil development on fish species in the region, running the model in hind cast. The model is still being developed and tested. They found that haddock eggs are more vulnerable to potential oil spills than cod eggs. Therefore, key species need to be investigated separately.

An increase in shipping leads to the increased possibility of oil spills and the spread of invasive species. To date, most risk assessments have only focused on single species and are qualitative. Nevalainen *et al.* (P:280) developed a model using a holistic food-web approach.

Species are not equally sensitive to oils spills, but data are limited. Therefore, models should focus on key functional groups instead of individual species. The models should be probabilistic to take uncertainty into account. Warming Arctic conditions and increased shipping favor the establishment of temperate invasive species in the region. Howland *et al.* (P:445) are using models to determine the likelihood of suitable habitat for invasive species in areas of the Canadian Arctic, with a focus on benthic species in port areas. They found sea surface temperature, ice concentration, and bathymetry to be the most important variables for species spread, and nearly all species exhibited future poleward gains. Currently, they are conducting screening level risk assessments to rank 30 species through a rapid assessment tool.

It became evident during the session that lack of data of the Arctic marine ecosystems is a major issue. In some cases, there truly are no data regarding a certain region or resource; however, in other cases, data have been collected but are not readily available. Both are problematic. Researchers have been reviewing logbooks of United Kingdom expeditions to the Arctic conducted between 1930 and 1977 (P:559) with data from the logbooks of 1930-1959 already digitized. They have uncovered data from cod catches and cod diet studies that will allow comparisons with today's data and conditions. The final paper (P:405) discussed the importance of filling the data gap in the central Arctic Ocean. There are data on the physical oceanography, lower trophic levels, and seabirds and marine mammals, but there are relatively little to no data available for fish in the Arctic Ocean. With the signing of a declaration by the five Arctic coastal states in July 2015 and the continuing negotiations between the five Arctic coastal states, China, the European Union, Iceland, Japan, and Korea to sign an agreement that they will not fish in the central Arctic Ocean until more fish data are available, it is crucial to fill the data gap. International collaboration on the science will be key to filling in the missing middle.

Paper P:502 (Friscourt *et al.*) won Best Oral Presentation by an Early Career Scientist.