Arctic Ocean Acidification Assessment:

2018 Summary for Policymakers

AMAP

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Introduction

Oceans around the world are acidifying, primarily due to absorbing carbon dioxide (CO_2) from the atmosphere. Ocean acidification — commonly defined as an ongoing fall in pH of seawater — poses a threat to marine organisms, ecosystems and human societies that depend upon them.

Some of the fastest rates of acidification are occurring in the Arctic, due mainly to the higher capacity of colder water to absorb CO_2, but also due to dilution by river run-off and ice melt, and the inflow of naturally low pH waters from the Pacific. Changes are already evident in the Arctic Ocean's marine carbonate system – which, among other things, has been shown to influence growth, reproduction and ultimately survival in some organisms. These changes may cause significant ecological shifts in the coming decades.

These shifts could, in turn, have significant socio-economic consequences, not only for Arctic communities, but more widely. These concerns were referenced in the Fairbanks Declaration of 11 May 2017, when ministers representing the eight Arctic states, and representatives of the six Permanent Participant organizations, noted "with concern the vulnerability of Arctic marine ecosystems to the impacts of ocean acidification", and called for continuing study and awareness raising regarding those impacts and their consequences.

In 2013, AMAP undertook its first scientific assessment of the changing state of ocean acidification in the Arctic and provided an Arctic-wide perspective on the rapid increase in seawater acidity. Its report concluded that:

- Ocean acidification is affecting the Arctic marine environment and ecosystems, and the region is especially vulnerable to its effects;
- Arctic marine ecosystems are highly likely to undergo significant change as a result, with direct and indirect effects on Arctic marine life; and
- While some marine organisms will respond positively, others will be disadvantaged, possibly to the point of local extinction.

The 2013 assessment made a number of recommendations to the Arctic Council, including the rapid reduction of greenhouse gas emissions, enhanced research and monitoring to better understand the processes driving acidification and its effects, and the implementation of adaptation strategies to help societies in the region respond.

In 2014, work began on this second assessment. Its initial objectives are to update the understanding of chemical and biological responses to ocean acidification, evaluate how ecological systems may respond, consider how downstream global systems might be affected by Arctic Ocean acidification, and deliver guidance for management of change. In addition, the Arctic Council requested that the socio-economic and cultural consequences of ocean acidification for Arctic communities be researched, through case studies. The case studies are intended to begin to place acidification in the wider context of other environmental changes affecting the Arctic, local communities, and regional and global economies.

This Summary for Policymakers offers a review of the latest science relating to regional ocean acidification, the biological responses to it, an overview of the case studies and their associated findings, and recommendations for the Arctic Council.

The lead authors of the Arctic Ocean Acidification assessment have confirmed that the assessment report and its derivative products, including this Summary for Policymakers, accurately and fully reflect their scientific assessment.[1]

[1] A full list of authors of *the AMAP Assessment 2018: Arctic Ocean Acidification*, on which this summary report is based, can be found on page iv of the same. See www.amap.no for details.

Ocean acidification, and why it's important

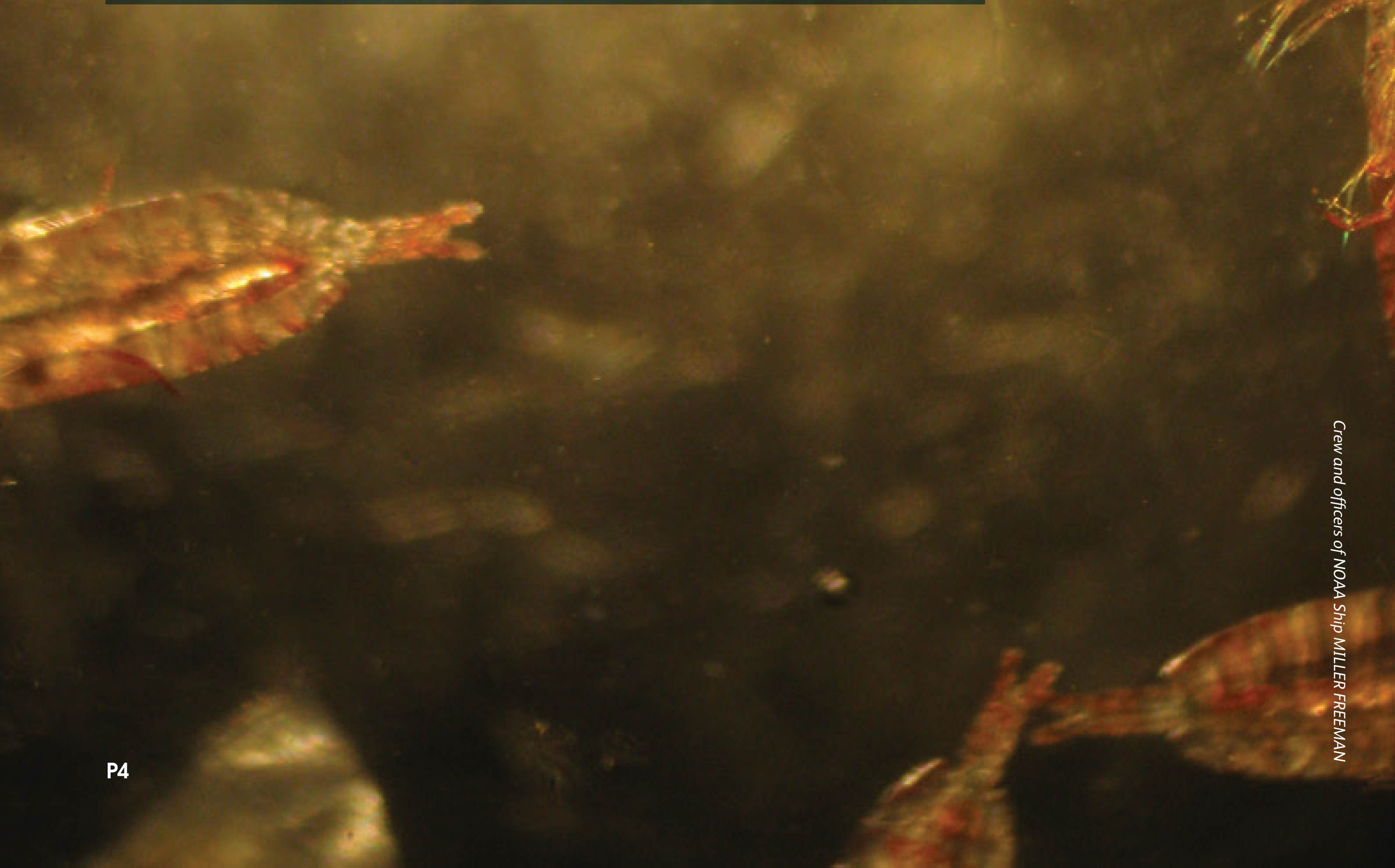
The acidity of the world's oceans is rising likely faster than at any time during the past 55 million years, primarily due to greater amounts of carbon dioxide (CO_2) in the atmosphere.

CO_2 is absorbed by seawater, reducing its pH level (i.e. increasing its acidity), which in turn influences many important chemical and biological processes. Although acidification will not actually make seawater acidic (that is, with a pH level below 7), CO_2 does lower its calcium carbonate saturation state. This measures the chemical propensity of seawater to become potentially corrosive to calcium carbonate, which many marine organisms use to build shells or skeletons.

As well as affecting the ability of some marine organisms to form shells, ocean acidification can affect plant and animal development, their behavior and, indirectly, the quality and availability of food.

The biological effects of ocean acidification are difficult to assess, especially because this process is taking place at the same time as other major changes, such as ocean warming, oxygen depletion and, at high latitudes, sea ice loss. Laboratory experiments and field observations show a wide range of direct and indirect effects of acidification, some negative and some positive.

However, despite difficulties in isolating its effects, ocean acidification, alongside other ecosystem stressors, is likely to affect the abundance and distribution of fish stocks and marine animals of commercial and cultural importance to communities in the Arctic and beyond.



Crew and officers of NOAA Ship MILLER FREEMAN

The developing science

Our scientific understanding of ocean acidification is deepening as more data are collected relating to the chemistry of the Arctic Ocean and the responses of marine organisms. In addition, models used to project future conditions and impacts continue to be refined. This latest assessment builds on the previous one by reviewing and synthesizing research published over the last five years relating to the marine chemistry of acidification and to its biological impacts, supplemented by older studies where newer research has not been carried out.

Fundamentally, however, the key findings of the 2013 assessment regarding the science remain the same, namely that: Arctic marine waters are experiencing widespread, rapid, but non-uniform acidification; ocean acidification is having direct and indirect effects on Arctic marine life; and Arctic ecosystems are highly likely to undergo significant change as a result of ocean acidification and other environmental changes.

Conditions relevant to acidification

Arctic Ocean acidification

The acidification of the Arctic Ocean is increasingly evident, with continued observations showing a rapidly changing marine carbonate system.

However, high natural variability of the carbonate system makes it difficult to obtain a clear picture of acidification in the Arctic Ocean. It is influenced by the seasons, driven by a complex interplay between seasonal biological production, temperature variability, freshwater supply and ice cover.

Despite this natural variability, projections suggest that, with ongoing net carbon emissions, Arctic Ocean acidification will continue over the remainder of this century.

In addition to absorption of CO_2 from the atmosphere, ocean acidification is also driven by the decomposition of organic (i.e. carbon-containing) matter fed into the ocean from rivers, and by the oxidation of methane (CH_4) from thawing subsea permafrost. This methane oxidation has the potential to cause rapid and massive ocean acidification.

In some areas of the ocean, particularly in relatively shallow coastal shelves, these processes currently play a much more important role than that of atmospheric CO_2 in determining the rate and extent of ocean acidification. In some regions of the Siberian shelf, for example, decaying organic matter from thawing subsea permafrost and from river run-off results in marine CO_2 concentrations that are well above even those levels expected in the atmosphere by the end of the century.

These processes influence relatively high pH water that enters the Arctic Ocean from the North Atlantic, which is then mixed with lower pH water that flows in from the Pacific. This modified Arctic water then flows out into the North Atlantic through the Canadian Arctic Archipelago and the Fram Strait. The regions of the North Atlantic that are influenced by these outflows are both biologically productive and support important commercial fisheries. Accelerated acidification as the result of enhanced atmospheric CO_2 uptake and the decomposition of organic matter within the Arctic Ocean thus has the potential to impact not only the ecosystems of the central Arctic Ocean, but also ecosystems downstream in the North Atlantic.

The biological response

Ocean acidification is likely to affect Arctic organisms and ecosystems to an extent that human societies that exploit or depend on them will be harmed.

Responses of marine life to acidification are likely to be complex and situation specific. While many organisms are expected to be negatively affected, some may benefit. Also, the magnitude and perhaps even direction of these responses will depend upon other features of the organism and its habitat, such as its life-stage, location, and season.

Human activities are causing a range of impacts, in addition to ocean acidification, which complicate biological responses to the latter. A particularly important impact is ocean warming which, in many cases, tends to increase organisms' sensitivity to acidification and changes their geographic ranges. Similarly, changes to the availability of light, caused by sea ice retreat and increased land-derived inputs, can change responses of species to acidification. Humans are also changing the occurrence of key organisms; extracting some that could restrict their range, while potentially introducing others via increased shipping through the Arctic. The interactions between these impacts will make anticipating future changes to species and ecosystems more difficult.

Changes to individual species will potentially change interactions between species, shifting the balance of ecosystems away from their current condition. For example, ocean acidification may favor some non-calcifying algae, changing pelagic ecosystems and shifting benthic habitats from coralline algae, and the kelp they facilitate, to simple mat-algae dominated ecosystems. Changes to lower-level organisms such as bivalves or mollusks could have cascading effects through the food chain and affect predators such as Pacific walrus and bearded seals.

Further complicating the issue is the degree to which organisms will acclimatize to acidification in the near term and, over longer timescales, adapt to changed environmental conditions. Most studies to date have looked at responses over days or months; less well studied is the potential for adaptation. For example, natural selection has been found in experiments to alleviate the effects of severe acidification in just two generations of one species of copepod, a type of small crustacean.

Adaptation through natural selection is likely to be greatest among species with large populations, which benefit from greater genetic variation, and those species with short generation times. However, it is unclear whether adaptation in Arctic species will be rapid enough in the context of rapid forecasted ocean acidification.

NOAA News April 30 2014

Exploring the socio-economic effects of ocean acidification

The Arctic and subarctic regions are home to important and valuable fisheries. They yield a tenth of the global commercial catch, and subsistence fisheries provide vital nutritional and cultural services to Arctic residents.

Ocean acidification threatens these fisheries, both directly, by altering the growth, development or behavior of marine life, and indirectly, by altering foodwebs and predator-prey relationships. The future effects of ocean acidification will not be uniform across the region, nor can they be reliably predicted.

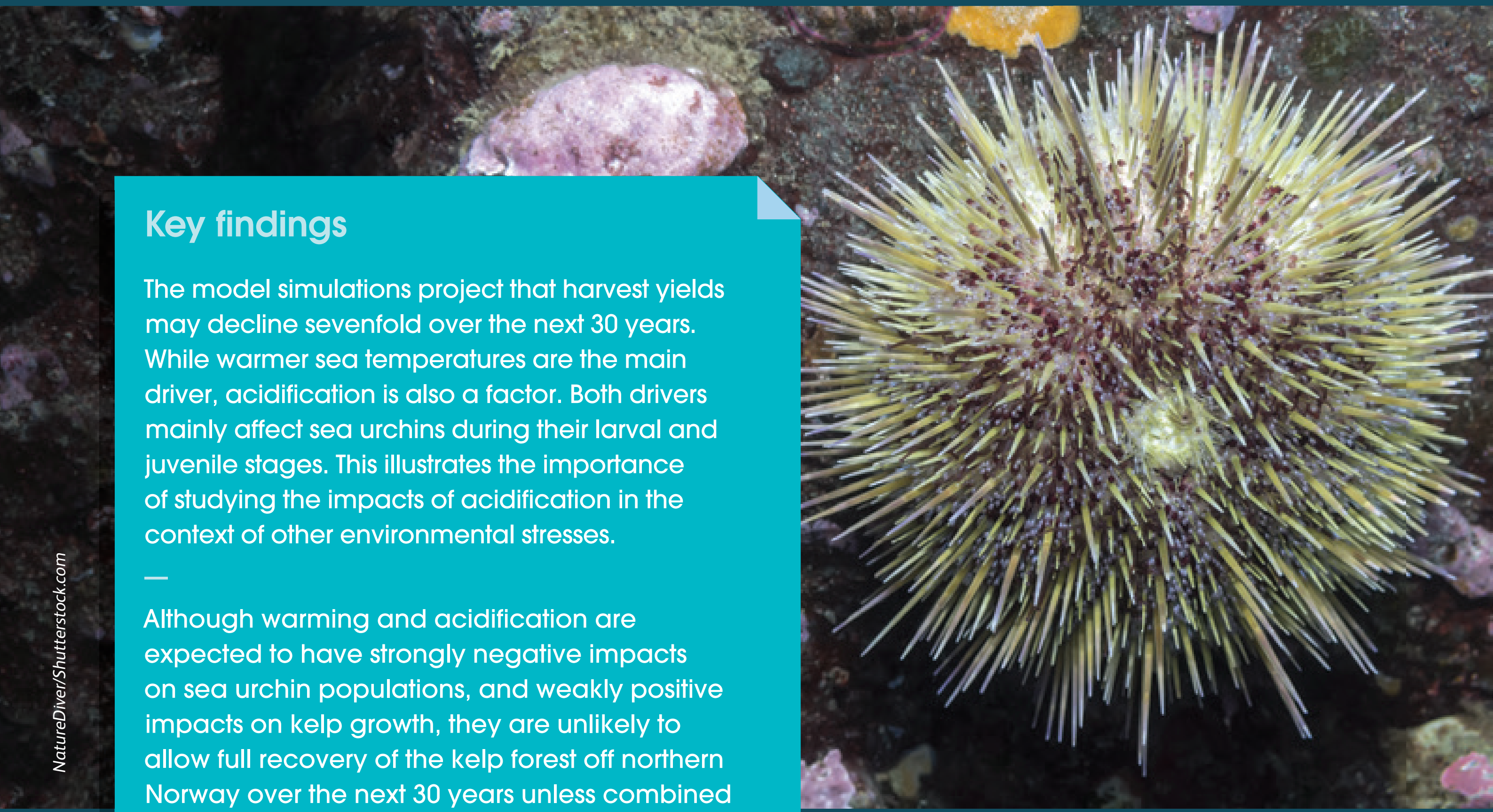
Future ocean acidification, in combination with other environmental stressors, particularly ocean warming, is likely to be sufficient to cause changes in Arctic organisms and ecosystems to an extent that will affect communities that depend upon them. An additional issue is the influence that socio-economic trends, such as developments in global seafood markets, will have in determining the future value of Arctic fisheries.

To better explore these impacts, AMAP commissioned five case studies, summarized over the following pages, along with their key findings.

Case studies

- Norwegian kelp and sea urchins
- Barents Sea cod
- Greenland shrimp fishery
- Alaska's fishery sector
- Arctic cod in the Western Canadian Arctic

Norwegian kelp and sea urchins



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Key findings

The model simulations project that harvest yields may decline sevenfold over the next 30 years. While warmer sea temperatures are the main driver, acidification is also a factor. Both drivers mainly affect sea urchins during their larval and juvenile stages. This illustrates the importance of studying the impacts of acidification in the context of other environmental stresses.

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Although warming and acidification are expected to have strongly negative impacts on sea urchin populations, and weakly positive impacts on kelp growth, they are unlikely to allow full recovery of the kelp forest off northern Norway over the next 30 years unless combined with a rigorous urchin cull.

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The model provides a useful tool to help optimize the harvesting of sea urchins and kelp and broader ecosystem management in the context of a changing climate.

Sea urchins are in high demand globally, and there is a large and so far commercially unexploited stock of green sea urchins off the coast of northern Norway. The urchins feed off forests of kelp, which has been commercially harvested in Norway for more than 50 years and which can be overgrazed by sea urchins unless they are culled.

This study sought to understand how ocean acidification (and warming as a co-stressor) might affect urchin harvest yields. It also considered what management strategies might be employed to maximize sea urchin yield while allowing for kelp forest regrowth. Researchers created a model to investigate optimal minimum size limits for harvested sea urchins to maximize the yield of present-day and future harvests.

ANGHI/Shutterstock.com

Barents Sea cod

Distribution of the Northeast Arctic cod stock in the Barents Sea

Miroslav Halama/Shutterstock.com

Key findings

Ocean acidification greatly increases the risk of fishery collapse, compared to the risk from ocean warming alone.

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This means that, under continued warming and future acidification, the fishery is likely to be able to support a much smaller fishing industry, with lower employment. At an optimal sea temperature – slightly higher than at present – and without acidification, the model suggests that a sustainable catch of 900,000 tonnes a year is possible, producing net annual revenues of 2.3 billion Norwegian kroner (corresponding to about USD285 million).

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When ocean acidification under business-as-usual assumptions is added to the model, the fishery can only support an annual catch of 150,000 tonnes a year, worth around 300 million Norwegian kroner.

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Even with the best adaption efforts, the fishery may be at risk of collapse by the end of the century. However, in the medium term, adaptive fisheries management can help to reduce this risk, and help the fish stock adapt to a changing environment.

Northeast Arctic cod (*Gadus morhua*) has been a commercially important fishery for centuries, and is likely to provide an early warning system for the impacts of ocean warming and acidification.

Warming has been shown to affect the distribution of Northeast Arctic cod. So far, it has benefited the fishery, helping stocks to increase in recent years. However, further warming is expected to have negative effects, as the survival rates of juvenile cod begin to decline in response. The effects of acidification are less well understood, but there is evidence that it could result in increased mortality and reduced catch. Less well understood are the likely combined effects of these two factors.

The case study describes a model developed to examine the combined effects of fishing, warming, and acidification, with the ability to vary each of the factors independently.

Greenland shrimp fishery

Key findings

Although the Greenland shrimp fishery is a relatively straightforward object of study, high levels of uncertainty at all stages of analysis, from the rate of acidification, to its biological, ecological and economic impacts, compound to make bio-economic modeling ineffective in terms of improving on current fishery management.

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The work highlights the most important gaps in scientific knowledge, such as the understanding of likely short- and long-term changes in the fishery's biological and ecological conditions, caused by ocean acidification, and the likely reaction of consumers to changes in the taste and appearance of shrimp.

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While bio-economic modeling cannot reduce uncertainty regarding appropriate harvesting levels, there are actions that can be taken to better manage change under conditions of uncertainty.

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Management actions include the need for better monitoring of ecosystem changes, including to prey and predators, and particularly for co-operating with Canada, which fishes northern shrimp on its side of the Baffin Bay/Davis Strait area. Doing so would help build stock resilience.

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Building economic resilience through, for example, diversifying Greenland's fish processing industry into other species and increased education and job training outside fisheries, would reduce potential impacts from declining shrimp yields.

Shrimp is important to Greenland's economy, accounting for between a third and almost a half of the overall value of the country's fisheries in recent years. Northern shrimp appear to be relatively resilient to the direct effects of ocean acidification, although indirect effects could be more significant. For example, changes to shrimp predators could affect shrimp numbers, while acidification could affect market demand for the product: consumers rated shrimp exposed to more acidic waters lower for appearance and taste.

The Greenland shrimp fishery is currently well studied and well managed. The assessments of the size and health of the fishery are state-of-the-art, and the catch quotas are set to support the fishery's sustainability. Nonetheless, the case study attempted to build an end-to-end bioeconomic model to better understand how the fishery might respond to ocean acidification and other environmental stressors, and the socio-economic implications of those changes.

Alaska's fishery sector

Ted Teske, National Institute for Occupational Safety and Health

Important commercial, subsistence and recreational fisheries in Alaska are found in environments facing rapid change, particularly in terms of temperature and acidification. However, prior to the case studies in this assessment, end-to-end studies of how changes in seawater chemistry could affect resources of importance to specific communities have not, to date, focused on Alaska or other high-latitude regions.

In this case study, researchers developed an index to measure risk faced by different regions within Alaska from ocean acidification. It combined hazard, assessed in terms of changes to ocean chemistry, exposure, in terms of the importance of certain marine species to human communities, and vulnerability, in terms of human reliance on a given species, and the ability of societies to adapt effectively to their decreased availability.

Key findings

Many of the marine organisms likely to be most affected by ocean acidification, such as mollusks, are important to both highly productive commercial fisheries and to traditional subsistence ways of life.

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The impacts of ocean acidification are uneven: southern Alaska faces the greater risk, due to its dependence on susceptible species for nutrition and income, the forecasted rapid change in chemical conditions and, as a rural area, its low job diversity, employment, and education levels, as well as its high food costs.

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Studies that combine scientific and socio-economic data provide a means of identifying threats to communities from environmental change, and can help them to develop strategies to reduce risks and to adapt.

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Measuring vulnerability at the local level can help to understand the regional processes at work, and support the development of localized policies to reduce risk.

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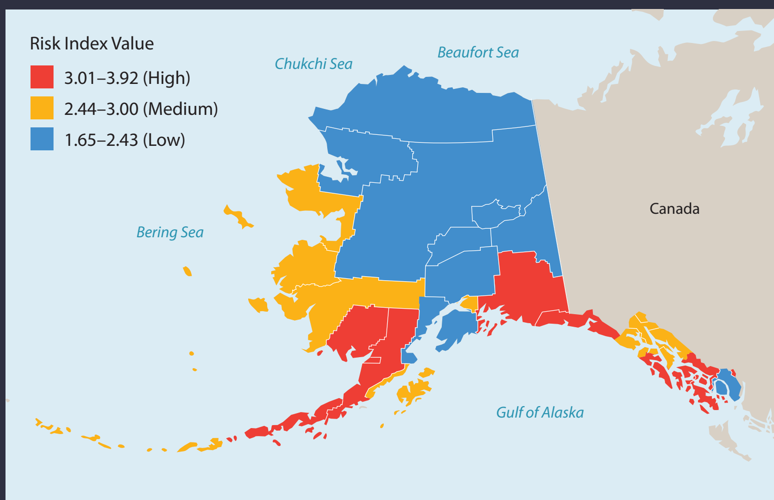
A detailed look at the red king crab fishery in Bristol Bay found that acidification is expected to cause a long-term decline in the harvest, with direct and indirect economic consequences, although the precise effects will also be greatly influenced by world market demand.

Individual components of the final ocean acidification risk index for each census area.



Arctic cod in the Western Canadian Arctic

Danny Kent, Ocean Wise Vancouver Aquarium

While there are, at present, no commercial fisheries in the Western Canadian Arctic, Arctic cod (*Boreogadus saida*, also termed polar cod) is a key forage species for the food web that supports the region's Indigenous communities. Potential changes to the availability of Arctic cod are of great importance to local communities, and there is already evidence of its distribution shifting northwards as the Arctic Ocean warms.

Modeling and analysis tools were combined with observations to identify the potential effects of climate change and ocean acidification on marine ecosystems in the region, with particular emphasis on Arctic cod. The analysis brought together traditional and local knowledge and Western science. Among other things, it combined climate models, our understanding of how marine organisms respond to environmental changes, and observed and projected changes in species distribution.

Key findings

Climate change and ocean acidification are likely to cause significant changes in species composition in the western Canadian Arctic, potentially leading to changes in ecosystem structure and in Inuit subsistence fisheries.

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The abundance of Arctic cod could decline, while other forage species, such as capelin and sandlance, are likely to migrate northwards into the region.

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Warming waters and sea-ice retreat are likely to lead to increased productivity and a greater potential harvest, commercial or otherwise, with ocean acidification having a modest negative effect, primarily on invertebrate harvests.

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The decrease in Arctic cod abundance could affect its predators, including culturally important species hunted by Inuit, such as ringed seals and beluga. However, if species that Indigenous people depend upon for food are able to adapt to alternative prey, climate change impacts are likely to be positive in terms of food security.

Recommendations

The case studies undertaken for this assessment resulted in a number of conclusions about how ocean acidification and other environmental stressors may affect specific Arctic ecosystems and the communities that rely on them. Detailed recommendations developed in response can be found in the full assessment report.

That said, the three recommendations arising from the 2013 assessment still stand. The Arctic Council should:

1. Urge the Arctic States, Observer states, and the international community to reduce emissions of greenhouse gases as a matter of urgency.

2. Support enhanced research and monitoring efforts that expand understanding of ocean acidification processes, how they interact with other environmental stressors, the effects on Arctic marine ecosystems, and their subsequent socio-economic impacts.

3. Urge the Arctic States to implement strategies to help Arctic communities build greater resilience in the wider context of environmental, social and economic change in the Arctic, tailored to local and societal needs.

The case studies also offer a number of general observations and recommendations. Specifically:

Addressing the causes

- Ocean acidification and its impacts will worsen if greenhouse gas emissions continue at their present rate. The Arctic Council should urge the Arctic States, Observer states, and the international community to reduce emissions of greenhouse gases as a matter of urgency.

Enhancing research

- The effects of ocean acidification, in combination with other stressors such as warming, are highly uncertain. That uncertainty is compounded when other environmental, social and economic responses and trends are also considered. There is a need for multi-stressor research into how Arctic species are likely to respond.
- Ecosystem changes should be monitored in such a way that allows for the identification and differentiation of the impact of each stressor on the ecosystem, as well as the potential synergistic effects of multiple combined stressors.
- Monitoring should also be intensified in the North Atlantic, given the biological, commercial and subsistence importance of fisheries in these waters and the impact of outflow of increasingly acidified water from the Arctic Basin. Regional fishery management organizations, OSPAR and the Arctic Council should cooperate to do so.
- There is a need for more Arctic-specific research into ocean acidification and its effects, whether regarding impacts on species, habitats or economic consequences. Currently, the lack of such research means many findings are extrapolated from research undertaken experimentally or in other geographic regions.
- Indigenous knowledge, and traditional and local knowledge has been included in this assessment to a limited extent, and future work would benefit from increased involvement of communities in monitoring and research projects.
- There is a need for research into longer-term responses of Arctic species and ecosystems to ongoing environmental change. Laboratory research and *in situ* monitoring of physiological responses and genetic adaptation will be key to improving predictions of these responses over time.
- Encouraging appropriate bodies to conduct research and monitoring of Arctic Ocean acidification must continue to be a high priority for messaging from the Arctic Council. Cooperation between Arctic countries and with other relevant organizations such as OSPAR and ICES would also be helpful.

Building resilience

- A lack of certainty about the interplay between biological changes and social and economic impacts of ocean acidification should not preclude action. Actions on resilience should be directed towards providing communities with flexibility, adaptability and economic and ecological adaptation in the face of change and uncertainty.
- There is need for a unified monitoring program to support adaptation actions in the Arctic and also to provide Arctic communities with the tools and training to conduct local, unified research and monitoring.
- There is a need for more scientific research on Arctic fisheries and flexible and adaptive fishery management regimes that can respond both to the effects of acidification and to the migration of fish stocks due to warming and other environmental changes.
- Studies that integrate science and socio-economics can help communities identify threats posed by environmental changes, and develop strategies to adapt. Local communities should develop resilience strategies with the support of policymakers, targeted scientific research, Indigenous knowledge, and traditional and local knowledge. These might include policies that promote economic diversification, and provide job training and educational opportunities, as well as increased access to alternative sources of protein to reduce regional risk levels.

AOA 2018 Summary for Policymakers

This document presents the Summary for Policymakers of the 2018 Arctic Ocean Acidification (AOA) Assessment. More detailed information on the results of the assessment can be found in the 2018 AOA Assessment Report. For more information, contact the AMAP Secretariat.

AMAP, established in 1991 under the eight-country Arctic Environmental Protection Strategy, monitors and assesses the status of the Arctic region with respect to pollution and climate change. AMAP produces science-based policy-relevant assessments and public outreach products to inform policy and decision-making processes. Since 1996, AMAP has served as one of the Arctic Council's six working groups.

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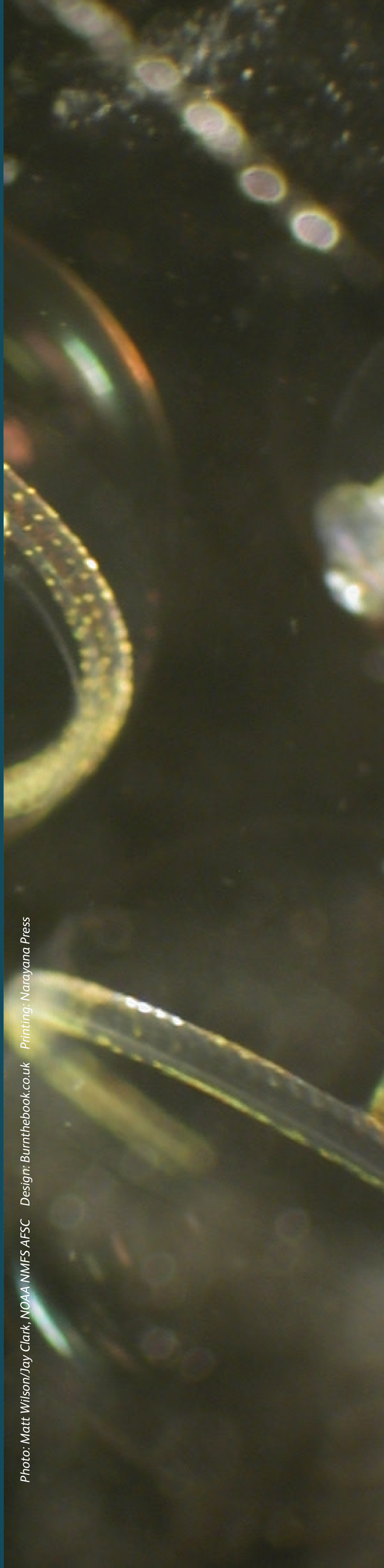

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