CLIMATE AND THE

***Harald Loeng** considers ecosystem responses to the changing Arctic climate and debates the possible effects on fish populations.*

Conditions in the Arctic have always been challenging. Dramatic seasonal changes, low temperatures, and extensive ice cover combine with a high proportion of shallow continental shelves and a large supply of freshwater from rivers and melting ice to create a truly unique marine ecosystem. While a number of highly specialized organisms have, over time, adapted to the Arctic's environment, they are constantly challenged by the extreme intra-annual variations.

Current climate models and trends in observations indicate that the polar ecosystems will change significantly in the coming decades. The Arctic and Subarctic sea ice are already melting. Both the extent and thickness of the sea ice has declined rapidly over the last few decades. It remains uncertain as to how quickly the ice will decrease, but it is believed that the Arctic's summer sea ice will eventually disappear. When this happens, it will open up a lot of water, and scientists are already looking at what might happen in the marine ecosystem.

Climate change and fish

Climate variability affects ecological processes in a multitude of ways. These effects on the dynamics of the marine ecosystems may have potentially important

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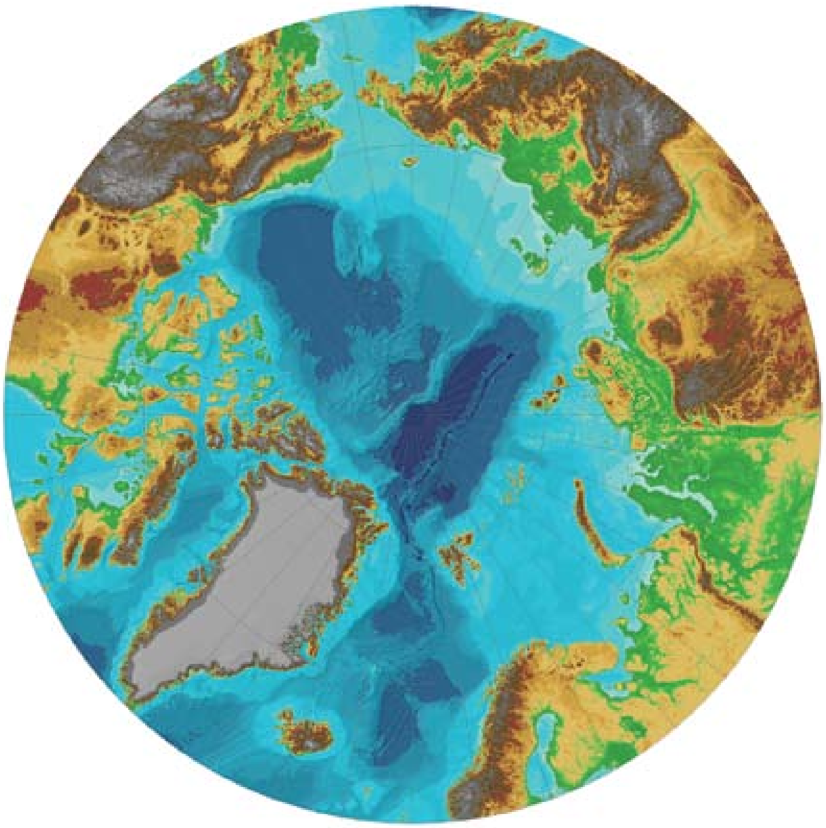
implications for commercial fisheries. The abundance and distribution of commercially important fish and shellfish stocks in marine ecosystems associated with long-term temperature changes is one such example.

Attempting to predict the response of commercially important species to further climate change is of great interest to scientists, governments, and fishing communities. While acknowledging the present limitations in understanding, several scientists have synthesized existing information to develop conceptual models of how climate change will impact marine ecosystems. One question that weighs heavily is the possibility of evaluating the potential for commercially important fish stocks to migrate from Subarctic areas into the Arctic Ocean or other Arctic continental shelf seas. Significant progress has already been made in identifying mechanisms by which climate change can affect fish population dynamics through understanding how climate change will impact shifts in the distribution of fish species and developing climate models to predict the future effects of climate change on species distribution. There are several examples of how increased temperature has encouraged northward fish migration or greater productivity of southern species, for example, in the North Sea.



Fish may be affected both directly and indirectly by climate change and variability. Directly, fish can be affected physiologically, including their metabolic and reproductive processes. Indirect effects may result from changes in their biological (predators, prey, species interactions) and abiotic (habitat type and structure) environments. Added to these processes are the ecological responses to climatic variation, which may be immediate or lagged, linear or nonlinear, and may result from interactions between climate and other sources of variability (such as the amplification or damping of climate effects due to fishing).

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What might happen?

Qualitative assessments have identified several factors that will govern the potential expansion and movement of commercially important fish and shellfish species into the Arctic. Important environmental factors include spatial distribution of suitable thermal conditions, availability of prey, and depth of migration corridors into, or out of, the Arctic Ocean. Key life history and behavioural characteristics include growth potential, fidelity to spawning sites, foraging flexibility, thermal tolerances, habitat depth, and projected spawning-stock size.

Advective corridors must be available for immigration to the new region, thermal windows must be suitable for survival at key life stages, and suitable prey must be available. Due to their direction and intensity of flow, ocean currents on the eastern boundary of the Arctic Ocean are more favourable to immigration. While distances between similar habitat types are relatively small along the shelf areas of the Barents Sea, topography may influence the potential for immigration into the Arctic. Fram Strait, for example, is the only deep-water connection between the Arctic Ocean and the surrounding seas.

Although fish that exhibit the appropriate life history adaptations may be more likely to expand or move into the high Arctic than other species, the processes governing survival are spatially and temporally complex. Some species, such as capelin (*Mallotus villosus*), Greenland halibut (*Reinhardtius hippoglossoides*), and cod (*Gadus morhua*), are already living close to the Arctic Ocean. However, considerable uncertainty remains whether these species will be able to successfully colonize the region. Despite the fact that many species may have evolved temporal patterns of feeding and reproductive behaviour that maximize survival, if climate change shifts the temporal match with key aspects of their life history, survival may be affected.

Primary and secondary production

The anticipated loss of seasonal sea ice is expected to lead to higher phytoplankton production in the Arctic. Higher phytoplankton production should normally result in increased zooplankton production. However, the species composition of *Calanus* and other zooplankton

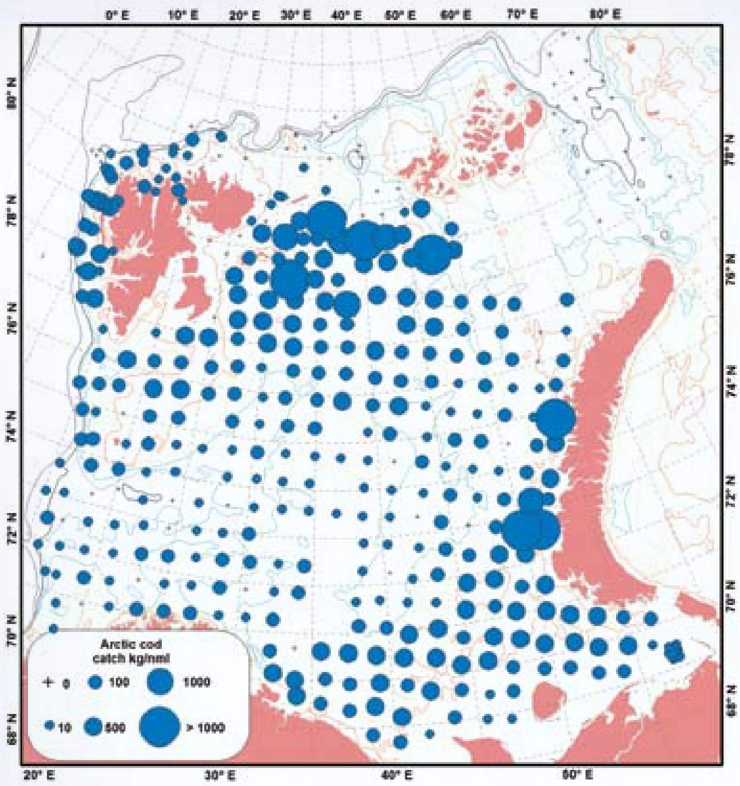
groups could be strongly affected, similar to what was seen for *C. finmarchicus* and *C. helgolandicus* in the North Sea, thus making the overall effect on zooplankton production difficult to predict. Subsequently, zooplankton abundance, distribution, and species composition may strongly affect recruitment, growth, and migration of many fish species.

Cod

Cod recruitment in the Barents Sea is positively correlated with temperature, but it is unknown if this will continue to be the case if temperature increases outside the range for which we have observations. An improved understanding of the physiological and behavioural responses of cod to changes in environmental conditions and the responses of other components of the marine ecosystem are required for future projections of cod abundance. A more northward and eastward shift in cod distribution than observed in recent years has been suggested under climate change, with the potential of penetrating as far as the Kara Sea. However, as cod is a demersal species, it will not migrate into the Arctic Ocean itself because of the great depths, and the distribution observed during autumn 2011 is close to the northernmost distribution we can expect.

Pelagic species

Pelagic species that exhibit long-distance feeding migrations may be capable of utilizing the Arctic Ocean as a summer feeding area if temperature and food conditions are suitable. However, retrospective studies suggest that pelagic foragers predominantly



▲ *The Northeast Arctic cod stock geographical distribution 2011.*

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track gradients in prey. Gradient-tracking foragers are more likely to conserve energy and forage on local prey sources. Therefore, the emergence of foraging migrations into the Arctic is expected to evolve over a considerably longer time period.

Possible impacts on the capelin population under climate change have also been explored. As the ice edge retreats farther north and the Polar Front shifts northeastward, feeding areas for capelin may also shift northeastward, a result consistent with distributional changes observed between cold and warm years. Capelin spawning areas may also shift, from the southern border of the Barents Sea (Finnmark and Murman coasts) to the eastern border (southeastern Barents Sea and Novaya Zemlya), where some spawning has been observed in previous warm periods.

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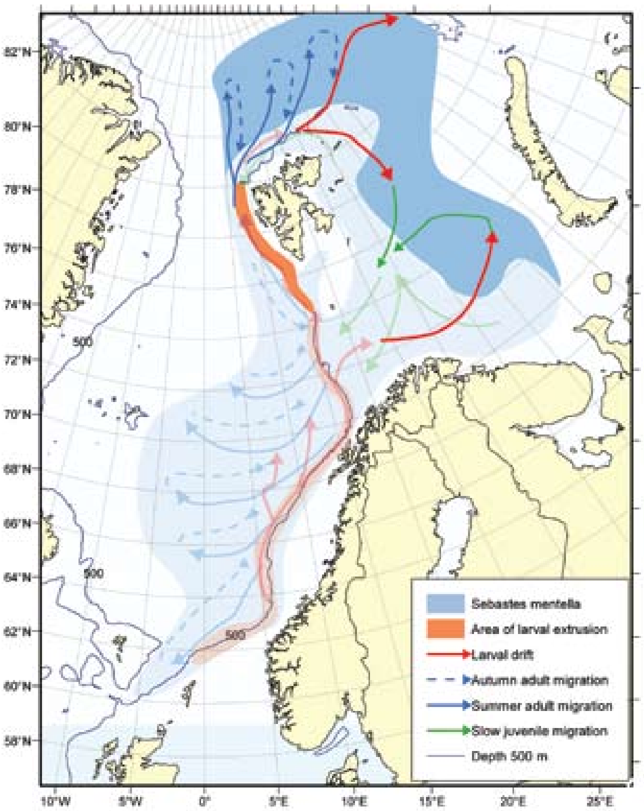
Polar cod (*Boreogadus saida*) is an important part of the ecosystem in the northern part of the Barents Sea. It is possible that a northward extension of the distribution of capelin may force polar cod to move even further north, and this stock could possibly be negatively affected by a warmer climate.

Deep-water species

Greenland halibut have already been observed on the shelf break between the Barents Sea and the Arctic Ocean as far east as the St. Anna Trough in the Kara Sea. Other species that have taken the opportunity to migrate northwards include redfish (*Sebastes* spp.). Redfish are normally found only in Atlantic water masses. However, juveniles are now widely distributed over the western Barents Sea shelf, while reproducing adults concentrate on the shelf break when extruding larvae. In the case of *Sebastes mentella* (beaked redfish), adults are distributed in open water during summer feeding migrations. The potential for redfish to expand into the Arctic is related to the expansion of Atlantic water masses; reproducing adults can potentially expand



▲ *Hypothesized expansion of the distribution area of redfish under future ocean climate in the Barents Sea and surrounding areas. Shaded areas and arrows indicate current distribution areas and migration routes. Plain colour areas and arrows indicate the potential expansion of distribution and migration routes. Adapted from Nedreaas* et al. *(2011)*

ICES role in the Arctic

ICES has several expert groups that deal with species living in the Subarctic and the Arctic border. However, ICES should look beyond stock size and development and consider relevant processes that determine distribution and migration in these areas.

What action could ICES take?

- provision of leadership on Arctic issues at North Atlantic scale that are a priority to ICES (enhanced research coordination);
- increase efficiency and focus of the extant ICES science capacity with respect to strategic priorities and shorter-terms needs (improved governance);
- expand ICES science capacity in a directed manner to address specific gaps through engagement of scientists in Member Countries and through partnerships (enhanced science capacity).

over the northern and eastern sides of the shelf break, and beaked redfish can potentially expand into the open Arctic Ocean during summer months, given appropriate temperature and feeding conditions.

Marine mammals

Seals (*Phocidae*) and polar bears (*Ursus maritimus*) are highly dependent on sea ice throughout the year. The disappearance of summer ice combined with the reduction in ice-covered areas in winter could have detrimental effects for these animals as well as providing a further influence on the dynamics on the stocks on which they prey.

The future

Climate change and variability will alter the distribution and productivity of species (but it will depend on temperature and food availability). While guesses and predictions will continue to be made for this region, we will have to wait for the answer.

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