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Change is coming to the northern oceans

Anne B. Hollowed and Svein Sundby

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INSIGHTS

Biofuel models and measurements *p. 1095*

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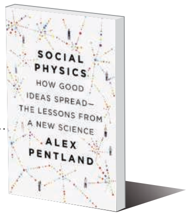

PERSPECTIVES

Cod catches at Senjahopen on the Norwegian coast.

ECOLOGY

Change is coming to the northern oceans

Cod and pollock abundances and distributions shift as climate and ocean conditions change

By **Anne B. Hollowed**[1] *and* **Svein Sundby**[2]

The cold-temperate regions of the North Pacific and North Atlantic oceans, from about 40°N latitude to the Arctic fronts, support large and productive fisheries (*1*), particularly in the northernmost regions: the Bering Sea in the Pacific and the Barents Sea in the Atlantic. The two main near-bottom fish species in the Bering and Barents seas are walleye pollock (*Gadus chalcogrammus*) and Atlantic cod (*G. morhua*), respectively. In the past decade, the two species have responded differently to ocean warming. These response patterns appear to be linked to a complex suite of climatic and oceanic processes that may portend future responses to warming ocean conditions.

The largest Atlantic cod stock, Northeast Arctic (NEA, Arcto-Norwegian) cod (*2*), feeds in the Barents Sea up to the Arctic front and spawns farther south along the Norwegian coast. Year-class strength is governed by a complex suite of processes during the first year of life. Temperature serves as a proxy for several of these processes. Some studies found that strong year classes were formed at the beginning of warm phases (*3*), whereas others reported that high water temperature was a necessary but not sufficient condition for the formation of strong year classes (*4*). Interannual temperature variations influence recruitment from year to year, but longer-term variations also influence stock structure and distribution. During warming phases, the spawning stock biomass gradually builds up and the cod spawn farther north, whereas in cooling phases, spawning stock biomass decreases and spawning occurs farther south (*5*).

Since the 1980s, increasing ocean temperatures have been accompanied by a steady increase in spawning stock biomass

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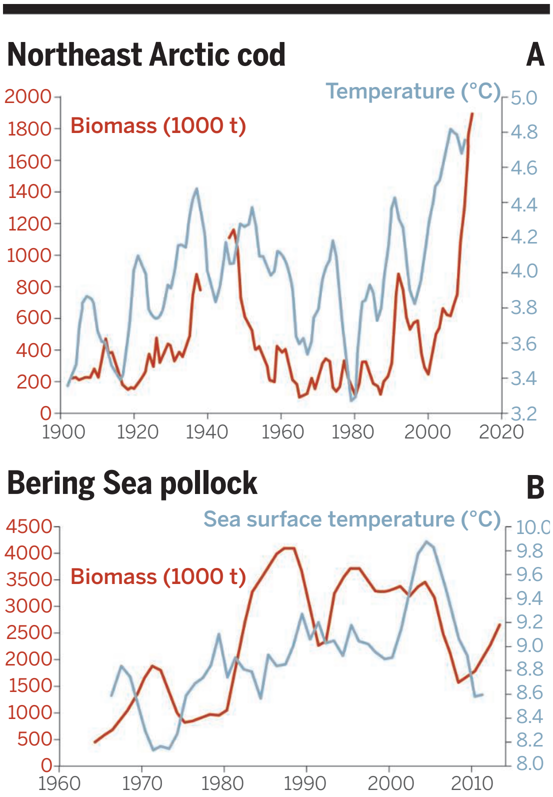
of NEA cod, reaching more than 2 million metric tons (see the figure, panel A) and a record-high northward distribution in 2012 (*6*). The increase in abundance and the poleward displacement of the cod stock reflects a general pattern in other components of the ecosystem, from zooplankton to plankton-eating and fish-eating fish (*6*). A similar change was observed during the mid-20th century warming from the 1920s to the 1940s (*7*).

These findings suggest that the trends in the distribution and abundance of NEA cod are related to both direct and indirect temperature influences on the cod (*5*). These effects include food web changes and changes in fishing pressure. Since 2000, reductions in NEA cod due to fishing and natural causes were below the increases due to reproduction and growth, whereas during the cool period of the 1960s and 1970s, losses due to fishing and natural causes exceeded replenishment from growth and reproduction (*6*). History has shown that it is more difficult to keep catches within the more restrictive quotas that are set during cool phases when stock size is low than in warming phases, when quotas increase due to increased productivity of the stock. This implies that historically annual fishing changes may have amplified the downward trend of the NEA cod stock abundance during cooling phases and the upward trend of the stock during warming phases.



Response to seawater temperature trends. The productivity of cod in the Barents Sea and pollock in the Bering Sea varies in concert with the changing climate. (**A**) Five-year moving average of annual mean temperature, cod catches (1903 to 1938), and cod spawning stock biomass (since 1946) in the Barents Sea. (**B**) Five-year moving average SSTs over the southeast Bering Sea shelf region (July to September) and walleye pollock spawning biomass. For data sources, see (*15*).

On the opposite side of the Arctic, the Bering Sea pollock stock is the largest in the northeast Pacific Ocean. Bering Sea pollock typically spawn in the southeastern Bering Sea and feed throughout the middle and outer shelf regions. They generally avoid bottom waters below 0°C and are thus mostly found in the southern Bering Sea (*8*). In warm years, when very cold bottom waters are confined to the north, pollock tend to expand across the shelf.

The pollock spawning stock consists of several age groups, and trends in abundance therefore represent a lagged response to previous patterns in year-class strength (see the figure, panel B). Pollock year-class strength is governed by a complex suite of ecological processes, including prey quality, quantity, and availability; predation (including cannibalism); and accumulation of sufficient energy reserves to allow overwintering (*9*). Ocean temperature and timing of seasonal sea ice retreat influence these processes by affecting stratification, biogeography, and the timing and intensity of spring blooms (*10*).

Climate forcing has influenced trends in ocean temperature variation in the Bering Sea (*11*). The late 1970s marked the onset of a period of warm SSTs that persisted through the 1990s (see the figure, panel B). Since then, the region experienced an exceptional warm period from 2000 to 2005, followed by sustained cold bottom temperatures and moderate SSTs from 2006 to 2013 (*11*). Based on empirical analyses of available data, summer SSTs appear to be related to survival in the first year of life (*9*, *10*). The relation between spawning biomass and the 5-year running mean of summer SST is less clear for pollock than for cod, possibly because of nonlinear responses to environmental conditions and because the pollock stock has historically been fished at sustainable levels.

The response of seafloor fish species in the border regions between the boreal and Arctic domains to climate variability may provide clues to how future anthropogenic climate change will influence fish stocks and marine ecosystems at high latitudes. Atlantic cod has already reached the shelf break between the Barents Sea and the deep Polar Basin (*6*); no further advancement toward the North Pole is possible for this shelf species. Instead, the species may advance eastward along the Siberian Shelf as new cod habitats open due to the loss of sea ice at the Siberian shelf and the Northeast Passage. In the northern Bering Sea, sea ice is expected to continue to form in fall and winter, leaving a remnant cold pool in summer, and the northern regions of the Bering Sea are thus likely to remain generally inhospitable to pollock (*12*). Projections of annual survival of young of the year are more uncertain because of the complex suite of interacting processes that govern their survival. Interdisciplinary programs that target these processes will improve the scientific understanding of climate change impacts on these important fish stocks. ■

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15. Data sources, panel A: Annual mean temperatures from Kola Section station number 4-7 at depths of 0 to 200 m, from the Polar Research Institute of Marine Fisheries and Oceanography, Murmansk (www.pinro.ru); Northeast Arctic cod catches from (*2*); Northeast Arctic spawning stock biomass from (*13*). Panel B: SSTs from (*10*); spawning stock biomass from (*14*).

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