Theme session E

Poleward shifts and ecological changes of arctic and subarctic zooplankton and fish in response to climate variability and global climate change

Conveners: Hein Rune Skjoldal (Norway), Carin Ashjian (US), and Louis Fortier (Canada)

High latitude marine ecosystems are characterized by substantial climate-driven seasonal, inter-annual and decadal environmental variability that defines the phenologies of the ecosystem. Large calanoid copepods of the genera *Calanus* and *Neocalanus* dominate the biomass but smaller calanoid and cyclopoid copepods are dominant numerically. Species of *Calanus* and *Neocalanus* have life cycles with strong seasonality, ranging from multiple generations per year for species such as *Calanus finmarchicus* in the southern part of their range to multi-annual life cycles for Arctic species such as *Calanus glacialis* and *Calanus hyperboreus*. These large calanoid copepods use ice algae, phytoplankton, and microzooplankton to reproduce and grow during spring and summer, storing lipid reserves to survive the winter often at depth. Other smaller micro- and mesozooplankton (e.g., the copepods *Oithona similis* or *Microcalanus* spp.) similarly use spring production but remain active for more protracted periods or year-round. The small polar cod (*Boreogadus saida*) still largely dominates pelagic fish assemblages of subarctic and arctic seas in many areas, but other forage fish such as capelin (*Mallotus villosus*) and sand lance (*Ammodytes* spp) also are important.

The large copepods form essential links in the food webs between phytoplankton, microzooplankton, and planktivorous fish, seabirds and mammals such as large baleen whales. These upper trophic level consumers use the seasonal pulse of zooplankton production and occurrence to feed, grow and store energy for reproduction and wintering. Many of them have pronounced seasonal migrations in high latitude ecosystems in which they come to feed during the productive summer season on the large zooplankton including calanoid copepods, krill and amphipods. Polar cod is a major prey for seabirds, seals, and toothed whales and may influence up to 75% of the energy transfer between the zooplankton and higher trophic levels in some areas of the Arctic.

Ongoing climate change will have significant impacts on environmental seasonality and associated plankton phenology, production, and distributions that can cascade upwards to the upper trophic level consumers. Many studies already have documented northward shifts in distributions or abundances of plankton, fish and other groups in response to warming in northern high latitude marine ecosystems. In this theme session, we invited presentations on how climate variability and change influence distribution of zooplankton and fish, and their roles in the wider marine ecosystems of high-latitudes.

There were six presentations in the session, five oral and one poster. This was lower than expected; an ESSAS conference in Tromsø in June on the same general subject probably attracted presenters which otherwise could have contributed to our theme session.

The six presentations provided examples of biological responses to climate variability and change for zooplankton and fish from various locations both inside and outside the wider Arctic and Subarctic area. Hein Rune Skjoldal, in his introduction as co-convenor, provided some examples of recent and ongoing changes in the Barents Sea ecosystem. Since 1980, the

Atlantic water flowing into the Barents Sea has warmed by about 2°C and the area of winter sea ice has been reduced by about 0.4 million km2, or about 50%. This has been associated with marked changes in the ecosystem, including increased abundance of krill species and northward and northeastward shifts in distribution of fish species. Atlantic cod has expanded north to the shelf edge to the Arctic Ocean, overlapping with, and feeding on capelin throughout the summer period, thereby contributing to a recent collapse of the Barents Sea stock of capelin.

Hanna Murphy and colleagues re-visited the situation for the capelin stock at Newfound, which showed a pronounced collapse in 1991 coinciding with the collapse of the Newfoundland cod. They showed that the subsequent poor recruitment of capelin after 1991 was associated with more rapid growth and earlier age of maturation but with spawning later in the season in the years after 1991 with poor recruitment. The seasonal delay in spawning was associated with more persistent onshore winds which are unfavorable for larval dispersal and survival.

The capelin stock at Iceland has shown a marked westward shift in migration and distribution in the Iceland Sea in recent years. Astthor Gislason and Kristinn Gudmundsson presented data on two species of *Calanus* in the Iceland Sea for the period 1990-2016. *Calanus finmarchicus* was associated with the warmer Atlantic water while C. hyperboreus was most abundant in the colder waters offshore in the Iceland Sea. The two species responded oppositely to climate variability, with *C. finmarchicus* increasing and *C. hyperboreus* decreasing with a warming trend.

Karl-Michael Werner and colleagues had examined relationships between climatic conditions and the historical abundance fluctuations of Atlantic cod in western Greenland. This cod stock was very large in the warm period in the 1920s and 30s, but declined dramatically with the onset of colder conditions in the 1960s. Meteorological and oceanographic conditions 'up-stream' in the East-Greenland Current and the Denmark Strait were found to correlate well with the decline, which was explained as a combination of unfavorable climate conditions and overfishing. In discussion, the point was raised about the connection between the cod at Greenland and the cod stock in Iceland.

Two of the presentations were using data on demersal fish from bottom trawl surveys in relation to temperature. Lingbo Li and colleagues examined vertical changes in distribution of eight demersal (groundfish) species by size bin in relation to sea bottom temperature variability over an extensive shelf area from the eastern to western Gulf of Alaska. They detected ontogenetic shifts for all species. They also found downward movements of several species in warm years in the central and eastern area where there was a vertical gradient in temperature, but the shift was less clear in the western area where the vertical temperature gradient was weaker.

Elisabeth Henderson and Janet Nye presented results on thermal envelopes for fish species collected in trawl surveys on the northeastern USA continental shelf. The thermal conditions shifted to higher temperature in autumn compared to spring, which was discussed in relation to thermal preferences and limits for the fish species. The study was planned to be extended to also include zooplankton species.

Dariusz Fey and Jan Weslawski presented a poster on growth of polar cod *Boreogadus saida* in two fjords at Svalbard. The growth was higher in the fjord with subarctic (Kongsfjorden) than the fully Arctic (Rijpfjorden) conditions. Additionally, data on otolith growth-fish growth relationship were presented.

Climate variability and climate change are of fundamental importance for the science on the dynamics of marine ecosystems and for the ecosystem approach to their management, based on integrated ecosystem assessment. These are the two pillars of ICES activities (science and advice). We need to continue to collect examples from case studies of the roles of climate variability and change on marine ecosystems to steadily increase our basic understanding of how marine ecosystems work and how they are impacted by climate change. In particular, we need to be alert to situations where the dynamics swing outside the envelope of conditions experienced in the past as climate change is likely to become more severe in the next decades.