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Comparative studies of climate effects on polar and subpolar ocean ecosystems, progress in observation and prediction: an introduction

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Background to and content of this part-product of the second ESSAS (Ecosystem Studies of Sub-Arctic Seas) symposium is provided, along with a call for future work of such nature to be continued, expanded, and enhanced, specifically with a view to determining global variations in resources and dynamics attributable to climate change.

Keywords: ecosystem studies, ESSAS, GLOBEC, IMBER, Subarctic seas.

The current IMBER Regional Programme "Ecosystem Studies of Sub-Arctic Seas" (ESSAS) was established in 2005 as a GLOBEC programme to address the need to understand how climate change affects and will affect marine ecosystems of subarctic seas and their sustainability. Subarctic seas became the focus because they support stocks of commercial fish that generate a major portion of the fish landings in the nations bordering them, as well as supporting subsistence fishers along their coasts, and vast numbers of marine birds and mammals. Since its inception, ESSAS has been conducting research to compare, quantify, and predict the impact of climate variability and global climate change on the productivity and sustainability of subarctic marine ecosystems. When it started, ESSAS held an Open Science Meeting (OSM) in 2005 in Victoria, Canada (Hunt *et al.*, 2007), and this was meant to be a guidepost of where we were in terms of our understanding of marine ecosystems of subarctic seas.

ESSAS held its second OSM entitled "Comparative studies of climate effects on polar and subpolar ocean ecosystems: progress in observation and prediction" from 22 to 26 May 2011 in Seattle, WA, USA. That meeting provided an opportunity to showcase the progress made within ESSAS and to identify remaining knowledge gaps and future research needs. The meeting was attended by 195 scientists from 13 countries and included 98 oral and 61 poster presentations.

The first day of the OSM included a parallel set of three 1-day and two half-day topical workshops on: Biological consequences of a decrease in sea ice in Arctic and subarctic seas; Arctic–Subarctic interactions; Zooplankton life histories; Developing metrics to compare field observations and model results; Comparative analyses of gadoid and crustacean dynamics; and Comparative analyses of marine bird and mammal responses to climate change. The workshops were followed the next day by the opening of the main meeting, which instead of the usual introductory speeches by dignitaries, began with eight elementary and junior high-school students from the Pribilof Islands of St Paul and St George off the coast of mainland Alaska, USA, who gave a joint presentation entitled "Discovering the Pribilof Domain". The people of those islands, who are mostly of Aleut descent, depend almost exclusively upon the sea for their food and livelihood. The students attend marine science camps during summer where, with guidance from their teacher/scientist Michelle Ridgway, they conduct studies into the marine ecosystem around their islands using some of the latest oceanographic techniques. Their presentation addressed the climate of the Pribilofs; the physical oceanography surrounding the islands;

phytoplankton and zooplankton; principal fish and shellfish species and their life histories; marine mammals; and socio-economic consequences of fish and fisheries. During their studies of the flora and fauna, the students discovered only the second known population of a species of large brown marine algae, *Aureophycus*, near St George Island. The only other known population of that species is in Japan. The students integrated traditional knowledge with conventional scientific knowledge to learn more about their marine ecosystem. They subsequently presented a poster on their research and stayed for the duration of the meeting, taking in many sessions and asking questions. Their presentation was followed by plenary talks by invited speakers who covered various aspects of the three parallel afternoon theme sessions, a format that was continued each day of the OSM.

The various theme sessions through the week included: Comparative studies of polar and subpolar ecosystems; New observations and understanding of eastern and western Bering Sea ecosystems; Modelling marine ecosystem dynamics in high latitude regions; Nutrients, biogeochemistry, and acidification in a changing climate; International Polar Year (IPY) studies; National ESSAS programmes: Recent advances; Anticipating socio-economic and policy consequences of global change; and Interactions between gadoids and crustaceans—the roles of climate, predation, and fisheries. On the final day of the meeting, brief summaries from each of the workshops and the parallel topic sessions were given by one of the session co-chairs to inform all participants of some of the main findings under each topic. An unusual feature was a presentation by the award-winning Norwegian band "The Science Fair", who played original compositions created to express scientific issues as music. A wrap-up to the OSM was provided in the form of three specially invited lectures, one on phytoplankton production by Kevin Arrigo, one on fish and fisheries by Steve Murawski, and one on human dimensions by Keith Criddle.

Primary publications are important products from symposia and this one is no exception. Three special volumes will appear from this ESSAS OSM. One is from the theme session on Interactions between gadoids and crustaceans that will be published as a special section in *Marine Ecology Progress Series*. Another is being assembled from papers presented in the Bering Sea theme session, as well as additional results from the Bering Sea Ecosystem Study (BEST) and the Bering Sea Integrated Research Project (BSIRP), and will appear in *Deep Sea Research II*. The current volume is the third and contains selected papers from the other theme sessions.

The volume is organized geographically, stretching from the Sea of Okhotsk in the Pacific, through into the Arctic and the Atlantic, and ending in the Barents Sea. In addition, one paper deals with the Antarctic. The papers cover ecosystem components from physics to marine mammals to humans. The first paper is a regional review of the ecosystem of the Sea of Okhotsk with special emphasis on its fish populations and how they are impacted by climate variability. It supplements earlier reviews published in Hunt *et al.* (2007) that describe general ecosystem features of other subarctic regions and is meant to be a benchmark against which future change may be measured. ESSAS has been encouraging increased dialogue between natural and social scientists, and four papers herein touch upon human dimension aspects. A paper on the effects of climate on the fish in the Shiretoko World Natural Heritage area off Hokaido, Japan, includes a discussion on the implications for policy and adaptation research as well as consideration of socio-economic aspects. An analysis of management practices in the Bering Sea and Gulf of Alaska fisheries has been carried out, including how they have impacted coastal communities, what has worked, what has not worked, and for whom it has worked or not worked. Small communities cannot follow shifts in fish stocks or relocate away from restricted spatial management measures. Moreover, small fishery-dependent communities have little opportunity for economic diversification. The consequences of climate-induced change in social-ecological systems will manifest themselves most prominently in communities least able to weather the loss of their resource base. Finally, two papers examine the potential economic impacts of climate warming on the distribution and costs of operation of the eastern Bering Sea walleye pollock (*Theragra chalcogramma*) fishery.

Papers in this issue of the *ICES Journal of Marine Science* cover a wide variety of topics. In one, for example, satellite imagery was used to explore phytoplankton changes in the Bering and Chukchi Sea regions. The authors focused on the Bering Sea and adjacent Arctic regions and presented a new model of primary production that takes into account inherent optical properties and adjusts for particulate matter in the water, such as coloured dissolved organic matter and non-algal particles. The model improves the estimates and yields lower values than previous methods. Another study in the same region revealed enhanced annual net primary production where sea ice has decreased during recent years, indicating that light has been main factor limiting production. Long-term trends have not been spatially uniform, e.g. the Chirikov Basin has seen a 30% increase in primary production, whereas no trend is evident in the Bering Sea.

Effects of variability in environmental conditions on the seabirds of Hudson Bay and off Newfoundland are described in two papers. In Hudson Bay, the timing of ice break-up has advanced by 3 weeks in nearly three decades, while the timing of egg-laying by thick-billed murres (*Uria lomvia*) has advanced by just 6 days. The resulting timing mismatch has resulted in decreased growth rates of chicks, which grow best when the gap between ice break-up and egg-laying is short. Also, changes in nestling diets from ice-associated Arctic cod *Boreogadus saida* to other fish coincided with an abrupt reduction in the sea ice in the mid-1990s. Off Newfoundland, the timing of capelin (*Mallotus villosus*) spawning has been earlier in warm years, and capelin spawning hotspots have tended to be absent during northern gannet (*Morus bassanus*) and common murre (*Uria aalge*) chick-rearing. This lack of accessible prey resulted in a significant decrease in the percentage of capelin delivered to the chicks of these two seabird species, and hence lowered their fledging condition. Another paper in this issue focuses on tagging studies in Disko Bay off West Greenland that were employed to examine the use of this area for feeding by bowhead (*Balaena mysticetus*) and humpback (*Megaptera novaeangliae*) whales. These whales show minimal spatial overlap, because the bowheads head out of the Bay on their northward migration around the same time that humpbacks enter the bay to feed on capelin.

A series of four papers discusses results from the Iceland Sea Ecosystem Project, an ESSAS regional study, and Iceland's contribution to the International Polar Year. The papers cover the regional physical oceanography and the pelagic community, especially zooplankton and capelin, during a 3-year project in the years 2007–2009. Increases in temperature and salinity were

caused by a greater influence of Atlantic waters in the Iceland Sea, through both increased inflows in Denmark Strait in the south and over the Jan Mayen Ridge in the northeast. At the same time, sea-ice coverage decreased noticeably. The Iceland Sea is a meeting place of Arctic and Atlantic species of zooplankton, with their distributions strongly influenced by the water-mass type. Within the Iceland Sea, there are 3–4 trophic levels excluding birds and mammals, with herbivorous copepods, primarily *Calanus hyperboreus*, occupying the lowest trophic level, and capelin and blue whiting (*Micromesistius poutassou*) the highest. The adults of these two species share similar prey so are competitors. The pattern of capelin distribution indicated northward displacement of 0-group capelin and westward displacement of older capelin in recent years. These changes in distribution are thought to be related to changes in both population abundance and environmental conditions. There are indications of an earlier and/or more northerly spawning around Iceland in recent years.

In another paper covering Icelandic waters, it is shown that, during recent warm years, Atlantic mackerel (*Scomber scombrus*) immigrated into the region from the Norwegian Sea for summer feeding, resulting in the development of a new fishery in Iceland. Mackerel records back to 1890 show that their abundance around Iceland generally increases during warm periods. The recent warming may have contributed to their extension into Icelandic waters, but they may also have migrated there to feed on the relatively abundant zooplankton at a time when zooplankton availability in the Norwegian Sea was in significant decline. The latter is hypothesized to be because of predation by the large populations of pelagic fish there. Consistent with this hypothesis, another paper shows that the biomass of mesozooplankton in the Barents Sea for the period 1983–2010 varies inversely with the sum of the abundance of planktivorous fish species, such as capelin, Arctic cod (also known as polar cod), herring (*Clupea harengus*), blue whiting, and 0-group fish. Variability in larval transport is the focus of another paper from Norwegian waters on Norwegian spring-spawning herring larvae.

The final paper in the issue compares the spatial organization, mesoscale variability and habitat associations of krill within portions of the Antarctic Peninsula and California Current marine ecosystems. The results suggest that areas of dense aggregations ("hotspots" of krill) occur in both regions near their shelf breaks and moderate levels of eddy kinetic energy, which seem to concentrate krill in favourable habitats and lessen the likelihood of advection away from the system.

The OSM and the papers in this issue have provided new results and methods that expand our knowledge of the subarctic seas. We have come a long way even in the few years since the first ESSAS OSM in 2005. However, to improve our predictions on what will happen under future climate change, more work is needed, including continued monitoring, focused field studies to explore the mechanisms linking climate on ecological changes in the various ecosystems, and modelling to help make the predictions. More and better regional models are required for impact studies too. This in turn requires improved global circulation models (GCMs), because regional models are produced through downscaling of the GCMs. Continuation of the ESSAS work on comparative studies was stressed to provide further insights into the basic processes operating in subpolar regions. These should not only be undertaken within the subarctic seas, but also comparing Arctic and Antarctic regions, and these polar regions with temperate, subtropical, and tropical regions. It was also suggested that these be combined with palaeoecology and laboratory analyses to reveal the complex interactions in marine ecology. Most earlier studies have examined single species, but more complete ecosystem studies examining their structure and function and how these might change in the future are required now. A mechanism is needed to assemble the global patterns of environmental information and biological data, but it is unclear who might lead such an effort.

Symposia such as the OSM require massive support from individuals and organizations to plan and carry them out. We acknowledge and thank all those who helped make the ESSAS OSM a success, and especially the following: Michio J. Kishi (Japan) co-convened the meeting with two of us (GLH and OSA). The Scientific Steering Committee consisted of Kenneth Denman (Canada), Shin-ichi Ito (Japan), James Overland (USA), Sei-ichi Saitoh (Japan), Michael Sigler (USA), Yvonne Walther (Sweden), and Paul Wassmann (Norway) along with three of us (KFD, EJHH, and GLH). The PICES Secretariat helped GLH with some of the local organization. The meeting could not have taken place without the generosity of our sponsors. Internationally, there were the International Council for the Exploration of the Sea (ICES), the North Pacific Marine Science Organization (PICES), Integrated Marine Biogeochemical Ecosystem Research (IMBER), and the Global Ocean Observing System (GOOS). National sponsors included the Alaska Department of Fish and Game, NOAA's Alaska Fisheries Science Center, the Arctic Section of NOAA, the Office of Polar Programs' Arctic Natural Sciences Program at the US National Science Foundation, the North Pacific Fisheries Management Council, the North Pacific Research Board, and the School of Aquatic and Fishery Sciences, University of Washington. Finally, we thank those associated with the *ICES Journal of Marine Science*, especial Audrey Geffen, Andy Payne, and Margaret Searle, who helped to prepare this set of papers for publication.

Reference

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