Polar and Sub-Polar Marine Ecosystems Workshop

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At the 2009 GLOBEC Open Science Meeting (Victoria, B.C., Canada), the GLOBEC regional programs ICED (Integrating Climate and Ecosystem Dynamics) and ESSAS (Ecosystem Studies of Sub-Arctic Seas) collaborated to convene a two-day (June 22–23) workshop on "*Comparison of Processes and Climate Impacts in Sub-Arctic and Antarctic Marine Ecosystems: Observations and Modeling Approaches*" where anticipated responses to climate change of marine ecosystems in both regions were considered. Eileen Hofmann (U.S.A.) and Eugene Murphy (U.K.) served as convenors from ICED, and George Hunt (U.S.A.), Bernard Megrey (U.S.A.), Sei-ichi Saitoh (Japan) and Hyoung-Chul Shin (Korea) acted as convenors from ESSAS. Approximately 40 scientists participated in this workshop, which included several members of the PICES community who gave presentations on North Pacific regions. In all, 18 talks were presented.

The workshop examined differences between Antarctic and sub-Arctic marine ecosystems, and the processes that create these differences, including ecosystem structure and function, and the effects of physical forcing such as sea ice, winds, and advection on interspecies interactions at lower, mid and upper trophic levels, and species productivity. This forum provided an opportunity for the scientific communities in both regions to compare their approaches. Participants also reviewed progress toward developing functional end-to-end models to study the effects of climate on marine ecosystems. The outcome of the workshop will be a synthesis paper for the OSM special issue, as well as a white paper or blueprint to move forward with further comparative studies of these polar marine ecosystems.

The workshop was introduced by Eileen Hofmann and discussion sessions were led by Ken Drinkwater (Norway), Eileen Hofmann, George Hunt and Eugene Murphy. The workshop was structured into four topic areas, each with a series of presentations followed by a discussion period.

Topic 1: Setting the stage – Climate studies

Talks were presented by Charles Greene (U.S.A.) and Eugene Murphy that included material on the role of large-scale climate patterns on regional marine ecosystems. Greene focused on the northwest Atlantic and the importance of remote climate forcing, such as the two modes of high-latitude climate variability: the North Atlantic Oscillation and the Arctic Oscillation for influencing regional ecosystem responses. He also explored the relative importance of climate forcing for bottom-up ecosystem impacts and overfishing in top-down impacts. Implications of these findings were discussed for the management of northwest Atlantic shelf ecosystems and their living resources during the coming decades. Murphy concentrated on the impacts of large-scale climate variability of the Southern Ocean marine ecosystem. There, bottom-up forcing by physical processes appears to dominate ecosystem variability. As in the northwest Atlantic, advective processes are important in the Southern Ocean, both for re-supply of critical nutrients, and as a mechanism for mixing of zooplankton stocks and transport of krill to sub-Antarctic regions such as South Georgia. In the Antarctic, as in the sub-Arctic systems, seasonal sea ice cover plays a critical role in the timing of production and in the use of this production by krill and the availability of the krill to top predators.

Topic 2: Arctic and Antarctic system comparisons

Four papers were presented on this topic. Hyoung Chul Shin *et al*. discussed the relationship between the amount of chlorophyll in the water and the amount of krill. He contrasted the layered nature of krill aggregations away from the ice in open water and the more compact aggregations or schools of krill near the ice edge. Hunt compared the effects of current orientation on Arctic and Antarctic marine systems, using as indicators, the seabird faunas of the two polar regions. In the Northern Hemisphere, community similarity is strongest meridionally and relatively weak at comparable latitudes on the two sides of the North Atlantic or North Pacific, a reflection of the north–south orientation of their boundary currents. In contrast, in the Antarctic, patterns of seabird community similarity are strongest in an annular orientation and weaker between latitude bands, a function of the annular orientation of the major current systems of the Southern Ocean. Hunt speculated that the difference in circulation patterns between the Northern and Southern Hemispheres might forestall incursion of temperate species to Antarctic waters, whereas temperate species are already increasing in number and biomass where northward flowing currents are carrying them to the sub-Arctic.

Hofmann *et al*. described the Southern Ocean GLOBEC Program objectives as focused on understanding the physical and biological factors that contribute to Antarctic krill (*Euphausia superba*) growth, reproduction, recruitment, and survivorship throughout the year. The questions posed reflected a broad view of the Antarctic marine ecosystem and included studies of the habitat, prey, predators, and competitors of Antarctic krill, as well as studies specifically centered on Antarctic krill biology and physiology. Overwintering strategies were highlighted as an important but largely unknown component of the Antarctic ecosystem. Murphy *et al*. gave an overview of the modeling efforts that

will occur in ICED as a follow-on to the Southern Ocean GLOBEC program (Fig. 1). They discussed how Southern Ocean ecosystems are changing rapidly, and that these changes constitute a major challenge to develop circumpolar views of the structure, function, and response to change. This is a key to developing ecosystem models that can predict the impacts of climate and harvesting in the Southern Ocean.

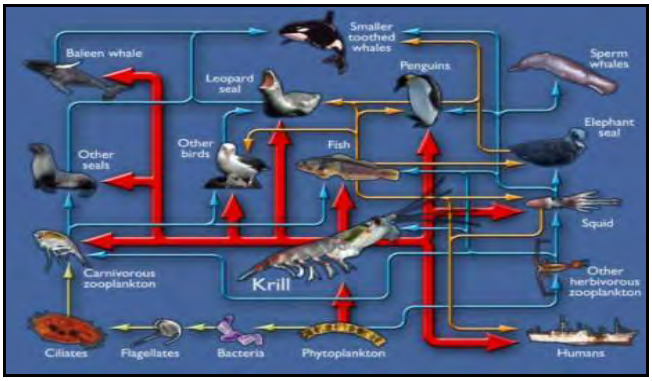

Fig. 1 Antarctic marine food web (compiled by the British Antarctic Survey) – schematic of the Scotia Sea food web. The primary food web pathways that are dependent on Antarctic krill (Euphausia superba) *are indicated by red arrows. The importance of alternative pathways (blue, green and yellow arrows) involving other zooplankton species, fish and squid are being increasingly recognized.*

Topic 3: Lower trophic level comparisons

Six talks addressed aspects of lower trophic level ecology in the sub-polar and polar seas. Two of the papers discussed variability of chlorophyll distribution in northern and southern seas. Kohei Mizobata (Japan) *et al*. (presented by Sei-ichi Saitoh) described recent drastic sea ice reduction and changes in ocean circulation in the western Arctic Ocean, and how changes in ocean physics impact both climate and marine ecosystems. For instance, recent changes in the spatio–temporal distribution of chlorophyll were linked to long distance basinward transport of high chlorophyll waters, intensified Beaufort clockwise ice–ocean circulation, increased light availability, and increased horizontal advection from the shelf of the Chukchi Sea. For the South Atlantic sector of the Southern Ocean, Jisoo Park (Korea) *et al*. described research results explaining the dominant temporal and spatial patterns of chlorophyll. Variations in levels of chlorophyll there have a periodicity of approximately 7 years, while periodicity in the northern region of the Drake Passage seemed to relate more to the Southern Oscillation.

Three papers focused on the importance of biophysical coupling for the distribution and abundance of zooplankton. Erica Head (Canada) *et al*. compared the ecology of the copepod *Calanus finmarchicus* in the Norwegian and Labrador Seas. Despite its more northerly location, the spring bloom generally starts earlier in the Norwegian Sea. Within each sea, however, there are regional and inter-annual differences in temperature and spring bloom dynamics. The responses of *Calanus finmarchicus* populations to these differences include differences in physical characteristics, physiological rates and seasonal cycles. As temperatures in the Norwegian and Labrador Seas increase up to a certain threshold, the authors suggested that the timing of life history events for *C. finmarchicus* will likely be advanced, and that the time spent in the near-surface layers will probably decrease, although the effect on net productivity may not be large. Sally Thorpe (U.K.) *et al*. described the results of modeling the life cycle and distribution of Antarctic krill in the peninsula region of Antarctica. Krill has a heterogeneous distribution and a large proportion of its circumpolar population located in the southwest Atlantic sector. These populations are believed to be maintained from upstream krill stocks and are closely associated with sea ice which provides a critical habitat during winter. The interaction of the krill with the sea ice can create regions of rapid dispersal or increased retention. Model results showed that variations in currents and the location of the ice edge in the northern peninsula region can affect whether krill there will be advected toward Bransfield Strait or toward South Georgia. On much smaller spatial and temporal scales, Lewis Incze (U.S.A.) *et al*. showed that internal wave fields in the Gulf of Maine are displaced toward the surface during periods of strong tidal flow (internal tides) over shallow banks. The interaction of the waves with the surface layer (convergence, divergence and shearing) results in the formation of ephemeral, but very dense, surface patches of euphausiids, and an ensuing rapid feeding response by herring, marine mammals and birds. The coupled biophysical processes associated with internal waves and topographic forcing can help explain observations of geographic feeding patterns among some predators, and should add to our understanding of temporal variability and possible future changes in these patterns.

The final paper in this topic session was presented by Kenneth Drinkwater who showed how comparative studies within the sub-Arctic seas provided insights into the role of physical forcing on the biological components of marine ecosystems. Two major ESSAS studies were highlighted: (1) NORCAN (Comparison of Marine Ecosystems of Norway and Canada) that compared aspects of the Barents Sea/Norwegian Sea with the Labrador Sea and shelves; and (2) MENU (Marine Ecosystem Comparisons of Norway and the United States) that compared the Bering Sea and Gulf of Alaska in the Pacific with Georges Bank/Gulf of Maine and the Barents/Norwegian Seas in the Atlantic.

Topic 4: Arctic and Antarctic top predator studies

Six papers were presented in this section. James Lovvorn (U.S.A.) *et al*. assessed habitat needs of Spectacled Eiders, a threatened species that winters in pack ice of the Bering

Sea. Data on benthic prey, sea ice, and weather were linked using a spatially-explicit simulation model of eider energy balance that integrated field, laboratory, and remote sensing studies. Thresholds of adequate resources were identified; the resilience of these food webs to perturbation may depend strongly on spatial heterogeneity in communities. Explicit consideration of such spatio–temporal effects, and the physical and biological factors that maintain heterogeneity, may be critical to modeling long-term patterns in benthic food webs that lead to top predators. Martin Renner (U.S.A.) *et al*. modeled the distribution and abundance of Northern Fulmars, a seabird, in relation to physical parameters and fishing activity in the Bering Sea. In many parts of their range, the diet of fulmars has been supplemented by offal and discards from fishing vessels. Model results suggest that the pattern of population changes since 1975 have responded more strongly to changes in fishing practices and the availability of offal than to climate variability.

Fig. 2 A female southern elephant seal, with a Sea Mammal Research Unit CTD tag, at Livingston Island, South Shetland Islands, Antarctica. These tagged seals can provide information on not only their preferred foraging locations, but also on the spatial and temporal distribution of water masses as they move from one location to another. Photo provided by D. Costa (University of California, Santa Cruz, U.S.A.).

Three papers addressed aspects of the ecology of pinnipeds in polar regions. John Bengtson (U.S.A.) provided a nice comparison of the use of the sea-ice environment by seals in the Antarctic and the Arctic and sub-Arctic seas. These animals are important components of the marine ecosystem, both because of their consumption of prey, and because they, in turn, are prey for other top predators. Despite the distance between the poles, he showed that there were striking similarities between the roles of species in the north and the south in terms of their dependence on sea ice and their use of open water. Shifting patterns in the distribution, timing, and other characteristics of seasonal sea ice are critical factors determining breeding success and rates of survival, and for some species, such as the ring seal in the Arctic, the loss of summer sea ice is likely to severely impact their populations. Elephant seals (Fig. 2) figured prominently in two of the papers. Anne-Cecile Dragon (France) *et al*. presented results from a new generation of temperature and salinity satellite-relayed data loggers, collecting temperature and salinity throughout the top 1000 m of the water column covering a vast area of the Southern Ocean extending from the Polar Front to the Antarctic continent. Foraging movements of many individuals allowed precise location of foraging areas, and provided detailed oceanographic information at low cost from areas that are logistically difficult to sample. Daniel Crocker (U.S.A.) *et al*. characterized habitat utilization and foraging behavior of three common seal species in the western Antarctic Peninsula using Satellite Relay Data Loggers. Their results suggest that elephant seals forage in a greater range of habitat types, and that crabeater seals are more dependent on sea ice and would thus be more impacted by climate change.

Konstantin Rogachev **(**Russia) *et al*. explained the mechanism for transport of warm Alaskan Stream water into the Oyashio and Kamchatka region by eddies, rather than by a continuous flow. Results suggest that warming in the Oyashio is likely linked to the penetration of warm Alaskan Stream water westward, and that warming in the Okhotsk Sea is likely linked to the increased transport of warm water westward by the Alaskan Stream and Aleutian eddies. The abundance and vertical migratory behavior of mesopelagic fish species in the region, such as lanternfish (Fig. 3), play a major role in the oceanic food web and these changes in hydrography are likely to affect their ecology.

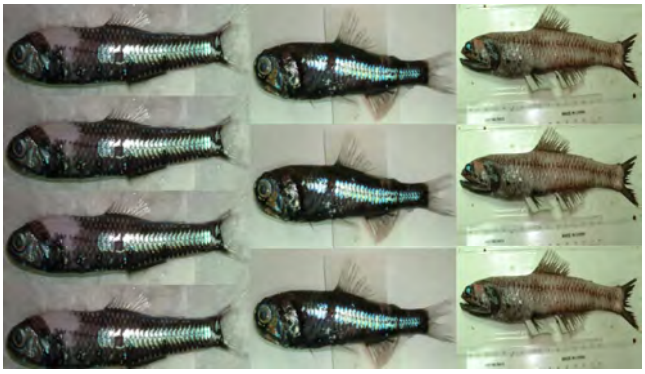

Fig. 3 Lanternfishes are important mesopleagic fish that produce sound scattering layers. Photo provided by L. Budnikova and K. Rogachev (Pacific Oceanological Institute, Russia).

Workshop discussions pointed to a number of overarching issues that will lay the foundation for future research to identify differences and similarities between Antarctic and sub-Arctic marine ecosystems, and to facilitate more effective management of natural resources in both regions. As we see ESSAS and ICED change over to IMBER, there is the opportunity to take a broader approach to ecosystem comparisons, including other ecosystems and biogeochemical cycles, as well as the more conventional approaches to ecosystem study.

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