IMBeR Regional Programme

Ecosystem Studies of the Subarctic and Arctic Seas

The Challenge: To compare, quantify and predict the impact of climate variability on the productivity and sustainability of Subarctic and Arctic marine ecosystems.

The ESSAS Regional Program addresses the need to understand how climate change will affect the marine ecosystems of the Sub-Arctic and Arctic Seas and their sustainability. These seas support stocks of commercial fish that generate a major portion of the fish landings of the Nations bordering them. They also support subsistence fishers along their coasts, and vast numbers of marine birds and mammals. Climate-forced changes in these systems will have major economic and societal impact.

***Accomplishments (2015-2021)**: ESSAS organized a series of workshops and scientific sessions, resulting in synthesis papers or special issues in scientific journals, and led a Belmont Forum project on the "Resilience and Adaptive Capacity of Arctic Marine Ecosystems" (RACArctic) to conduct a retrospective synthesis of the drivers of resilience and adaptive capacity in natural and human systems (GC-I) and develop scenarios for possible changes in high-latitude systems (GC-II). Some key findings include:*

1. High-latitude marine ecosystems, in particular the main gateways into the Arctic, are undergoing a major transformation affecting all ecosystem components, including many fish stocks and the people that depend on them. Responses to recent warm conditions differ between the Atlantic and Pacific gateways. Major changes in commercially important cod species appear to be food-mediated. Declines in the quality and quantity of lipid-rich zooplankton during recent warm conditions, and their effects on survival, were associated with the collapse of Pacific cod in the Gulf of Alaska and declines in eastern Bering Sea walleye pollock. In contrast, Atlantic cod appear to be thriving during recent warm conditions, in spite of changes in the Barents Sea zooplankton community driven by declining sea ice and increased advection of warmer Atlantic water.

Theme section in ICES Journal of Marine Science: **(1)** Drinkwater, K. F., Harada, N., Nishino, S. et al. (In Revision) Possible future scenarios in the Gateways to the Arctic for Subarctic and Arctic marine systems: I. Climate and physical–chemical oceanography. **(2)** Mueter, F. J., Planque, B., Hunt, G. L. et al. (In Press) Possible future scenarios in the Gateways to the Arctic for Subarctic and Arctic marine systems: II. Prey resources, food webs, fish and fisheries. **(3)** Haynie, A.C., Huntington, H. P., Eide, A. et al. (In Prep). Possible future scenarios in the Gateways to the Arctic for Subarctic and Arctic marine systems: III. Are Northern Fishery Management Systems Prepared for Change? A Comparison of Management Systems in Alaska, Norway, and Japan.

2. Two workshops and special issues on polar cod (Boregadus saida), a keystone species throughout the Arctic, have greatly expanded our understanding of the life history and ecology of this important species. Two scientific highlights are: (a) the population structure of polar cod supports the existence of at least four major groups in the Alaskan Arctic, western Canadian waters, eastern Canadian waters, and European waters; and (b) a combination of bottom-up processes, a lack of phenotypic plasticity, and competitive interactions with other species will likely result in declining abundances of polar cod populations at the southern limits of their range, and increasingly at higher latitudes. Earlier ice retreat and warmer summer temperatures affect growth and condition of young polar cod through temperature-dependent effects on physiological rates and indirect effects mediated by prey availability. These effects, and competition with species that are more resilient to higher temperatures, will likely result in the replacement of polar cod in many regions with unknown consequences for seabirds, marine mammals and ultimately people living in Arctic and Subarctic regions where cultural identity, food security and socioeconomic systems are closely linked with marine ecosystems.

Mueter et al. 2016, Polar Biology 39: 961-967, https://doi.org/10.1007/s00300-016-1965-3; Mueter et al. 2020, Polar Biology 43(8): 945-950. https://doi.org/10.1007/s00300-020-02696-1

3. Sea ice loss has impacts on the ocean's uptake of CO2 and on the growth of sea-ice algae. Recent studies quantified CO_2 fluxes in the Arctic Ocean and adjacent seas from 1997 to 2014. Annual CO_2 uptake was estimated to be 180 ± 130 TgC, corresponding to approximately 10% of the total uptake

in the world's oceans. To better quantify ice-algal production, ESSAS investigators led a multi-model inter-comparison of ice-algal productivity under the biogeochemical working group of the Forum for Arctic Ocean Modeling and Observational Synthesis (FAMOS) project. Simulations of ice-algal productivity suggest that the amplitude of interannual variability was much larger than that of long-term changes, with no statistically significant long-term trend in most sub-sea areas and models. Both positive and negative correlations were found between annual primary production and sea-ice thickness in early spring and a balance between stable habitat and sufficient light transmitted to the bottom of the sea ice was necessary to maintain the ice-algal productivity.

Yasunaka *et al.*, 2016 (Polar Science 10, 323–334, https://doi.org/10.1016/j.polar.2016.03.006). Yasunaka *et al.* 2018 (Biogeosciences 15, 1643–1661. https://doi.org/10.5194/bg-15-1643-2018). Watanabe *et al.* 2019 (Journal of Geophysical Research -Oceans 124, 9053–9084. https://doi.org/10.1029/2019JC015143.

4. The ESSAS working group on the Paleo-Ecology of Subarctic and Arctic Seas (PESAS) has documented large variability in environmental conditions and in the size, diets and abundances of marine species over several millennia. These past fluctuations hold promise to inform future impacts of climate change. Therefore, PESAS partnered with the ESSAS working group on Analogues of an Arctic in Rapid Transition (analogueART) to link past variability in selected biological measures with current trends along natural gradients of temperature and CO_2 conditions that may serve as analogues of future climate states. PESAS also partnered with the Ocean's Past Initiative (OPI) to expand its network of North Atlantic environmental/maritime historians, archaeologists and paleoecologist and to bring more North Pacific scholars into the OPI network.

2019/20 special issue in Quaternary Research:
Hambrecht et al. (doi:10.1017/qua.2019.35)
Clark et al. (doi:10.1017/qua.2018.140)
Keighley et al. (doi:10.1017/qua.2018.150)
Holm et al. (doi:10.1017/qua.2018.153)
Edvardsson et al. (doi:10.1017/qua.2018.147)
Jørgensen et al. (doi:10.1017/qua.2019.86)
Khasanov et al. (doi:10.1017/qua.2020.27)
West et al. (doi:10.1017/qua.2020.70)

AnalogueART synthesis:
Rastrick et al. (ICES Journal of Marine Science, doi: /10.1093/icesjms/fsy128)

Future plans (2021-2024): We aim to conduct the following activities with specific metrics of success:

- *Integrate paleo-ecological research and research on natural analogues of high CO_2 systems (GC-I) to better anticipate and model future changes in high latitude systems (GC-II). 2-3 workshops that result in a synthesis paper demonstrating the utility of this approach to climate research.*
- *Contribute to the development of regional modelling approaches that integrate climate, fisheries & human dimensions (GC-II). ESSAS scientists will participate in developing proposals to support this integration. We aim for two successful national and one international proposal.*
- *Develop integrated studies of oil spill impacts on Arctic fish that combine laboratory results and field models (GC-I, GC-II). We will conduct 2-3 workshops that facilitate comparative studies across the Pacific and Atlantic Arctic, resulting in a special issue in a peer-reviewed journal.*
- *Further promote the development of pan-Arctic research by holding Annual Science Meetings, conducting international workshops, annually organizing 2-3 scientific sessions at international meetings (e.g. as ICES, PICES, Ocean Sciences/AGU), and convening one open science meeting by 2025 relevant to all Subarctic and Artic seas (GC-I, GC-II, GC-III).*
- *Create a more stable funding base for ESSAS Annual Science Meetings, workshops and scientific sessions to increase our reach within the polar research community and to recruit new participants, including early career scientists (ECS). Our goal is to recruit at least one ECS to the ESSAS SSC and to raise funds for 3-4 ECS to participate in each annual meeting.*