Strategic Initiative – The Arctic Ocean Ecosystem (SI_ARCTIC)

Project leader: Randi Ingvaldsen; Co-leader: Tore Haug

Overall objective: to develop a knowledgebase on the state and variability of the present and future Arctic Ocean ecosystem and to explore potential options for providing ecosystem-based advice in a changing climate context.

Description of WPs :

WP0 Project management and dissemination. PI: R Ingvaldsen.

WP0 will focus on ensuring efficient coordination and management of SI_ARCTIC. The WP will secure project planning and tracking; that reports are prepared and delivered on time; that communication of administrative and technical information is made to partners; coordination of monthly SI leader team meetings and annual SI and Advisory board meetings, and dissemination of results. Gunnar Sætra is part of the Department of Communication at IMR and will lead the outreach activities in accordance with the dissemination plan given in the grant application form. Information about the project management and organization is given in section 3.3.1.

WP1 Exploration and mapping. PI: T Haug.

WP1 will focus on obtaining an ecosystem description of the Arctic Ocean. The WP will provide a baseline exploration study of which species are present in the waters under Norwegian jurisdiction of the Arctic Ocean and their distribution (see Appendix 1 for map of study area). Such information will mainly be achieved through field observations, but also through review of historical data (including Russian and NORSEX/MIZEX data) and literature. The WP will plan and conduct the

extension of the ecosystem surveys into the Arctic Ocean in 2014 and 2015, and the baseline study in 2016. The knowledge gained and the data obtained will provide a necessary baseline to further analyses, process studies and numerical modelling performed in other WP's. Key questions addressed in WP1 include:

Q1.1. What are the main physical/chemical oceanographic properties of the Arctic Ocean historically and today? What is the current status with respect to ocean acidification?

Q1.2**.** What are the major spatial patterns in biomass distribution of primary and secondary producers?

Q1.3**.** Which fish species (pelagic and demersal), benthic species, phytoplankton and zooplankton organisms, marine mammals and sea birds are the key players in the Arctic Ocean today?

Q1.4. Which of the current Arctic Ocean communities of pelagic and demersal species are a continuation of more southerly distributions of the Barents and Norwegian Seas, and which species are representatives of separate Arctic Ocean communities?

WP work plan/tasks:

T1.0. Planning and conducting extension of the ecosystems in 2014 and 2015, and a baseline study in 2016 using the planned Norwegian research vessel that will be able to operate in multiyear ice or renting an alternative ice-going vessel.

T1.1.

• A regional quantification of the physical and chemical properties of waters under Norwegian jurisdiction in the Arctic Ocean will be obtained from the regional surveys, historical data and by utilizing data from satellites and other auxiliary sources.

• Current status of ocean acidification will be assessed using carbonate chemistry data from analyses of water samples from the SI_ARCTIC surveys and other available data.

T1.2.The spatial distribution of phytoplankton, micro-, meso- and macrozooplankton species abundance and composition will initially be explored using historical data. For phytoplankton biomass satellite information will be collected and assembled to time series.

T1.3-4. The species distribution (plankton, fish, benthos, marine mammals) present in the Arctic Ocean today will be identified by utilizing own data, e.g. from recent ecosystem surveys, historical data based on literature review, expansion of the ecosystem surveys and the baseline study in 2016. The same data, in combination with utilizing data from relevant time series, will give the possibility to assess which of the species are continuations of more southerly distributions of the Barents and Norwegian Seas, and which species represent separate Arctic Ocean communities. For particular groups, samples will be obtained for genetic analyses in order to enhance our understanding of key zooplankton in light of regional differentiation (population genetic structure), advective flux and how transport/migration of species relates to populations in adjacent regions/basins. Extension of the IMR continental slope survey in autumn 2015 (EggaNOR) into the Arctic Sea slope to examine deep-sea fish occurrences and distribution will be considered, enhancing the survey with benthos sampling in that area.

WP2 Functioning of the Arctic Ocean ecosystem. PI: Å Høines.

WP2 will focus on process studies to explore particular hypotheses or assumptions and to determine of vital rates and parameters that are important for the functioning of the Arctic Ocean ecosystem in the study region. Process data is important for improving ecosystem models and for prediction of changes in ecosystem processes under current and future environmental change. WP2 will provide input to WP3, 4 and 5 by analyses of data from WP1. Key questions addressed in WP2 include:

Q2.1. What are the dominant processes regulating the inflow of Atlantic Water through Fram Strait and its impact on the Arctic Ocean heat content, vertical stratification and ice cover?

Q2.2. How does variations in water mass distribution, ice cover and freshwater affect the ocean chemistry and acidification state? How will changes in ocean acidification affect the ecosystem?

Q2.3. What are the regional differences with respect to phytoplankton species composition, abundance and growth, and how are these related to the ambient zooplankton dynamics? What are the nutrient uptake rates, growth and environmental requirement for key phytoplankton species? What are the role of zooplankton feeding activity and rates?

Q2.4. To which extent is the phytoplankton blooms and their associated biomass subject to loss through sedimentation?

Q.2.5. What are the response of key zooplankton species to the magnitude and quality of available food?

Q2.6. How is the trophic structure of selected important faunal components of the ecosystem (primary food source, trophic pathways and establishment of food web members' relative trophic position). How do the key zooplankton species relate to the presence of important invertebrate, fish and marine mammal predators? What are prey-predator links between the Arctic Ocean shelf-slope/seabed and fish resources?

WP work plan/tasks:

T2.1**.** Analyses of current meter data (from joint Fram Centre moorings in combination with Fram Center project A-TWAIN), ADCP-data, hydrographic data from own surveys, satellite ice concentration data and available results from numerical modelling will be conducted to identify the dominant processes regulating the heat content of the Arctic Ocean.

T2.2.

• Hydrographic data (CTD and water samples) from surveys will be combined with satellite data of ice cover and measurements of pH/CO2/in situ studies of melt water inorganic carbon chemistry (from water samples, surface and deeper) to determine the processes regulating the ocean acidification state. Ocean acidification state will be determined from measurements of the carbonate system and nutrients.

• Novel techniques will be applied to study the effect of ocean acidification on zooplankton by investigating calcifying zooplankton and measurements of shell composition and state of dissolution. Isotope tracers will be used as proxies to investigate historical evolution of carbonate system and pH.

T2.3-5. Studies of nutrient uptake for phytoplankton (uptake kinetic studies) under different environmental conditions will be conducted and microzooplankton grazing experiments on natural phytoplankton performed. As part of the process studies, expanded primary production estimates (*in situ*) will be made at selected sites. Process studies involving incubation of key zooplankton species (tentatively copepods and krill), will be undertaken at the baseline study in 2016 during routine sampling on transects and regional surveys covering the northern Barents Sea shelf, slope and deep Arctic Ocean. Diets of dominant copepods and potential predators (krill, amphipods, gelatinous plankton, and fish) will be obtained from traditional stomach analyses using light and electron microscopy and optionally molecular methods (Nejstgaard et al., 2003). This will be compared with prey species abundances at the sampling site using morphological and molecular approaches to species identification of the pelagic assemblage (Bucklin et al., 2010) including gelatinous forms (Ortman et al., 2010). In addition stable isotope methods will be used to add more knowledge about the trophic interaction at lower trophic levels. Deposition of body fat, gonad maturation, grazing rate and egg production rate will be mapped for selected species. Grazing rates of *Calanus* and *Metridia* and tentatively the krill *Thysanoessa* spp. will be estimated on algae and microzooplankton (Nejstgaard, et al., 2001), and related to *in situ* prey densities.

T2.6.

• Data on diet composition and prey preference of selected fish species (capelin, polar cod) from the surveys will be compared to samples of the relevant zooplankton.

• By mapping the catch from demersal trawl hauls, both predatory fish and their benthic invertebrate prey will be investigated and quantified. To measure trophic structure in pelagic, benthic, and coupling of the benthic-pelagic systems, traditional stomach analyses, fatty acid analyses, and stable isotopes analyses for selected important faunal components of the ecosystem (primary food source; algae and POM, trophic pathways and establishment of food web members' relative trophic position) will be made. This will be done for selected case-studies, guided by a pilot study (Isfjord-2012, see Appendix 1 for geographical regions).

• Pelagic productivity will be compared with the benthic productivity. Predictive empirical models and regressions have been constructed to estimate secondary production of benthic invertebrates from easily obtained parameters and variables (Brey, 2012).

• Historical data (1997-2010) on diet composition and prey preference of the most important mammal predator, the harp seal, will be compared to new seal samples and samples of meso-zooplankton (euphausiids and amphipods) from the surveys.

WP3 Changes in the Arctic Ocean ecosystem. PI: H Gjøsæter.

WP3 will focus on exploring particular hypotheses or assumptions that are crucial for ongoing and future changes in the Arctic Ocean ecosystem in the study region. Estimation of the carrying capacity of the ecosystem will be an important issue. WP3 will provide input to WP4 and 5. WP3 will largely be based on the results from WP2 as well as numerical models. Key questions addressed in WP3 include:

Q3.1. How will changes in Atlantic inflow, stratification, ice cover and ocean acidification affect the future Arctic Ocean?

Q3.2. Which conditions are necessary for organisms that presently are confined to the Barents or Norwegian Sea, to expand their distribution area northwards and establish in the Arctic Ocean? Of particular interest would be zooplankton (copepods, euphausiids and amphipods) and pelagic fish species like polar cod, capelin and herring as well as deep-sea fish as Greenland halibut and beaked redfish. Can these and other species expand their distribution into the Arctic and still spawn in the same areas as before, or are there more northern areas that will be suitable for spawning?

Q3.3**.** What are possible prey-predator links between the Arctic Ocean shelf-slope/seabed and possible future fish resources?

Q3.4. What impact would a possible increased migration of foraging whales have on the existing arctic resources?

Q3.5. What would the effect of further ice reduction be on populations of pagophilic species?

Q3.6. What would happen to Arctic grazers (fish, seals, whales, birds) if their traditional lipid rich prey species are replaced by more boreal and lipid-poor species ("junk food")?

WP work plan/tasks:

T3.1.

• Analyses of the relation between Atlantic inflow and stratification will be conducted using moored instruments and hydrographic data from the surveys to evaluate if the vertical stratification of the Arctic Ocean can be eroded from below. This will increase the knowledge about changes in ice cover and heat content, with corresponding changes in production, associated with ongoing and future changes in the Atlantic inflow.

• To investigate future changes in physical and chemical state requires knowledge of the baseline conditions as well as long-term studies (WP1-2). Ocean acidification state will be investigated at specifically sensitive sites such as spawning grounds and sites of habitat building organisms such as sponge and coral reefs to increase the knowledge of ongoing and future changes.

• Satellite observations on ocean colour will be used to investigate changes in phytoplankton biomass/distribution and to limited extent speciation changes (change/shift in calcifying versus non-calcifying phytoplankton.

T3.2.

• Quantitative estimates of zooplankton will be made, and together with nutritional value of the dominating planktonic species used to evaluate how much pelagic fish could be sustained by these food resources.

• Individual-based larval drift modelling will be conducted to investigate potential drift of offspring of some species (e.g., capelin, polar cod and/or Greenland halibut) into the Arctic Ocean if future spawning includes spawning sites further north (around Svalbard/ Novaya Zemlya and along the Arctic Ocean slope respectively) where predictions show that future conditions could potentially become similar to those found at present spawning grounds.

T3.3. By combining knowledge on trophic relations among fish and benthic organisms further south with new information about benthic communities along the continental shelf and slope, hypotheses about possible prey-predator links there can be formulated and, if the relevant fish species inhabit these areas, tested.

T3.4. Data on migration of baleen whales from the 2014 and 2015 surveys will be compared to data from older surveys to investigate increased migration and the impact on the resources assessed.

T3.5. The effect of reduced sea ice cover on harp seals will be investigated using data on condition and fertility obtained from sampling on commercial sealers and pup production from own surveys.

T3.6. Plankton data from the surveys will reveal if the plankton community really change and boreal species replace the more Arctic ones, and data on condition of selected top predators will reveal if condition have changed from historical values. Analyses of genetic markers, fatty acids and stable isotope composition may signal population changes. The IMR already has performed such analyses for harp seals and minke whales, while similar data could be made available through cooperation with ongoing projects (c.f. EU-BASIN and ECCO) for key zooplankters. Through comparative analyses this could shed light on advective flux and how transport or migration of species relates to populations in adjacent regions/basins, as well as trophic interactions and food web structure.

WP4 Ecosystem-based advice. PI: LL Jørgensen**.**

The key task of WP4 is to 1) explore options for providing ecosystem-based scientific advice and 2) to prepare for a better defined advisory process at the IMR, utilizing also integrated ecosystem assessments. Drawing on WP1, 2 and 3, this WP will also contribute to the further development of long term monitoring (WP5). Scientific advice on the management of the living marine resources is provided by the International Council for the Exploration of the Seas (ICES) and the scientific committees of the North Atlantic Marine Mammals Commission (NAMMCO) and the International Whaling Commission (IWC) in the case of marine mammals. While stock-specific assessments and advice will be required also in the future, there is an increasing demand for ecosystem-based management where the cumulative impact of all stressors on the marine environment is taken into account. An important task is therefore to contribute to the development of scientific advice to address such concerns also in the Arctic. An aim of WP4 is to examine integrated assessments and advice relevant for management authorities. The IMR has been commended in evaluations for its advisory capacity regarding the living marine resources, while being criticized for being unclear when giving advice regarding the marine environment. SI_ARCTIC provides an opportunity to break new ground in this respect in the Arctic, thereby strengthening Norway´s leading position in marine management. As the IMR should be consistent in its advisory practices, WP4 aims to enhance the advisory processes internally in the organization. Key questions addressed in WP4 include:

Q4.1. What are the objectives (maintain diversity, optimize recruitment and survival rate) of ecosystem-based management strategies and what type of tools (models, indicators etc) are used to give advice about the marine environment?

Q4.2**.** How can integrated assessments be designed and performed? How can the IMR´s current research surveys contribute to such assessments? What, if any, changes are required?

Q4.3. How can the internal advisory processes in the IMR be enhanced by integrated assessments and how can such insights be communicated to international scientific bodies and management authorities?

WP work plan/tasks:

T4.1.

• Review definitions of terms and concepts for giving integrated advice, with the aim of clear, understandable and consistent terminology when providing advice for Arctic marine ecosystems .

• Conduct literature studies on the variety of advisory bodies dealing with management.

• Conduct a literature review on models and frameworks for integrated assessments and ecosystem based advice for the marine environment and the living marine resources.

T4.2. (should be done together with WP2)

Arrange workshops to develop strategies for reliable assessments of status and predictions of the physical-chemical environment and the living marine resources in the Arctic, and how to adopt to these in a framework for integrated assessment and advice. Explore a few, but robust strategies by which the IMR will deliver integrated ecosystem-based management advice.

T4.3.

• Publish on integrated ecosystem-based management strategies, nationally and internationally.

• Suggest models for how the IMR should organize the advisory process for northern areas.

WP5 Design a long-term monitoring program. PI: M Chierici.

WP5 will focus on developing a program suited for present and future monitoring of the waters under Norwegian jurisdiction in the Arctic Ocean. Long-term monitoring is crucial for tracking natural fluctuation and thereby detection of changes in the ecosystem. A Norwegian monitoring program will be developed in concert with Monitoring programs like AMAP and the Circumpolar Biodiversity Monitoring Program (CBMP). In CBMP, a suite of common biological parameters and indicators have been developed to report on change across Arctic marine ecosystems, and a set of key abiotic parameters for monitoring relevant to marine biodiversity have been identified. Optimal sampling schemes have been developed for each of these components, with the aim that joint methods can be employed across the Arctic. The project has also identified a set of Arctic marine areas, by which monitoring results will be organised and reported. WP5 will combine the developments from CBMP and the results in WP1-4 to design a long-term monitoring program suitable for research in, and a framework for ecosystem based advice of the waters under Norwegian jurisdiction in the Arctic Ocean. The ecosystem monitoring should in this respect not be understood as solely based on observations, but rather as observations in combination with numerical modelling. Key questions addressed in WP5 include:

Q5.1**.** What sampling strategies should be applied to the waters under Norwegian jurisdiction in the Arctic Ocean?

Q5.2. Which indicator areas for long-term monitoring of the waters under Norwegian jurisdiction in the Arctic Ocean should be defined?

Q5.3. What new methodology is necessary, and can be developed, and what other data sources (satellite data, buoys, gliders) could add valuable information for long-term monitoring?

Q5.4. What kind of numerical modelling (general circulation models, regional downscaling of climate models, bio-physical and/or ecosystem models) is needed?

WP work plan/tasks:

T5.1. Evaluation of relevant existing data series and monitoring programs will be done in concert with the results from CBMP.

T5.2. Identify other data sources (satellite data, buoys, gliders) available and assess the necessity of developing new methodology, in particular for the partly or fully ice covered regions. This task will be done in concert with the implementation of the CBMP monitoring plan, which is currently under way.

T5.3. Investigate and define necessary output from numerical modelling performed to complement the observational activities.

T5.4. Based on the results of WP1-3 and CBMP, identify indicator areas in the waters under Norwegian jurisdiction suitable for early detection of changes in the Arctic Ocean ecosystem.

T5.5. Based on the results of WP1-3 and the tasks above, define the sampling strategies (e.g., new survey in Arctic spring/which sampling/annually or every second/third year) that has to be applied to obtain the ecosystem-based and integrated management for waters under Norwegian jurisdiction in the Arctic Ocean as outlined in WP4.