ABSTRACTS - WORKSHOP PRESENTATIONS

WKS1 - Paleo-Ecology of Subarctic and Arctic Seas (PESAS) Planning Workshop

June 11, 14:00

Distributed Long-term Observation Networks of the Past': the recovery of deep paleoecologies in the sub-arctic North Atlantic

George Hambrecht, Cecilia Anderung, Seth Brewington, Andrew Dugmore, Ragnar Edvardsson, Francis Feeley, Kevin Gibbons, Ramona Harrison, Megan Hicks, Guðbjörg Ásta Ólafsdóttir, Marcy Rockman, Konrad Smiarowski, Richard Streeter, Vicki Szabo, and Thomas McGovern

This presentation conceptualizes archaeological data as 'Distributed Long-term Observation Networks of Human Ecodynamics in the Past' (DONOP). This concept is used to describe a number of ongoing projects utilizing data from sub-arctic North Atlantic archaeological sites to produce environmental and biological data that can be used to build more robust records of past species demographics, understand these demographics in the face of human as well as environmental and climatic pressure, and finally to recover lost genetic variation, in both wild and domestic animals.

June 11, 14:20

Managing zooarchaeological data to address shifting baselines: the NABO Experience

Thomas McGovern, Thomas Ryan, Colleen Strawhacker, Anthony Newton, Richard Streeter, Ramona Harrison, Frank Feeley, Megan Hicks, Seth Brewington, George Hambrecht, and Grace Cesario

The North Atlantic Biocultural Organization (NABO, www.nabohome.org) was founded in 1992 as an international, interdisciplinary research and education cooperative aimed at better connecting natural and social science, environmental history, environmental humanities, and community engagement in island heritage and environmental activism across the North Atlantic. In 1997 NABO hosted an international workshop in NYC that brought together 27 zooarchaeologists active in the broader region and which created the basis for a common animal bone recording standards. This approach has since evolved into the NABONE digital package and over a hundred animal bone collections (archaeofauna) are now recorded using this system (many now also produced by common excavation standards). Sites in NABONE extend from Arctic Norway to Shetland, Orkney, N Scotland, Faroes, Iceland, Greenland and Arctic Canada and from Iron Age to near present periods. This highly comparable data resource provides a rich trove of paleoenvironmental and cultural information of potentially wide application to PESAS,

NorFish, and allied efforts to better mobilize the records of the past to serve the future by addressing the widely recognized “shifting baselines” pathology. However, the NABO data sets are currently not easily searchable and need organization and the application of a modern cutting edge data discoverability and access system. This system is now under development through an NSF-funded CyberARC project led by Colleen Strawhacker of NSIDC with the zooarchaeological component led by Tom Ryan of CUNY. This paper provides an overview of the NABONE resources and the ongoing development of new data discoverability tools aimed at better mobilizing this resource.

WKS2 - Climate change impacts on nearshore fish habitats in the Arctic

June 11, 09:00

Predicting Barents Sea fish stocks from upstream hydrographic variability

Anne Britt Sandø, Marius Årthun, Ute Daewel, Corinna Schrum, Noel Keenlyside and Bjarte Bogstad

Marine ecosystem dynamics are a complicated interplay between physical and biological factors. Fish stocks are furthermore affected by both management and environmental factors and, hence, are inherently difficult to predict. Here, we have however shown that it is possible to predict a significant part of interannual fish stock variability in the Barents Sea based on upstream hydrographic variability several years in advance. A discussion of the mechanisms of interactions between fish stocks and temperature has not been the focus here. Rather, we have assessed to what extent observed upstream hydrography can be used to predict Barents Sea fish stocks and identified the most skillful hydrographic predictors. Other studies have identified other potential predictors for fish stocks in the Barents Sea, although with a shorter prediction horizon. In conclusion, we have demonstrated that changes in Barents Sea fish stocks are to a large extent associated with a lagged response to temperature changes observed in the subpolar North Atlantic which propagate northward along the Atlantic water pathway towards the Barents Sea. The associated time lag enables skillful predictions of Barents Sea fish stocks several years in advance and could provide valuable advice on fisheries management. The importance of upstream hydrography to fish stocks warrants continued monitoring of the Norwegian Atlantic Current and its extension into the Barents Sea.

June 11, 09:20

Arctic cod in the Russian Arctic: new data from the Siberian seas

Natalia Chernova

There is increasing interest in nearshore processes and their influence on fish biota in the Arctic. The key fish species in the entire Arctic is the Polar (or Arctic) cod *Boreogadus saida*. It is the most numerous species and important in food chains of cold-water ecosystems. The life cycle of the species is rather well known for the Barents Sea populations but the biology and migration of the polar cod from the Siberian seas are poorly known at present. I will present the results of large-scale trawl surveys in which I participated. Transects on the western shelf of the Kara Sea (2012, August-September) included about 174 demersal and 107 pelagic trawling stations. Transects in the Laptev Sea and neighboring East-Siberian waters (2014, August-October) included about 166 demersal and 120 pelagic trawling stations. *Boreogadus* results will be

presented. These data provide a baseline that may help to understand processes in nearshore Arctic fish communities under climate change.

June 11, 09:40

Towards a process based understanding of climate change consequences on ecosystems

Trond Kristiansen, Charles Stock, Michael Alexander, Øystein Varpe, Anne Hollowed, Kirstin Holsman, Ken Drinkwater and Elizabeth Selig

Ocean variability has long been known to show strong decadal and multi-decadal variability that significantly affects the weather and climate of the North Atlantic and Pacific Oceans as well as the Arctic Ocean. Past observations of ecosystem responses to climate variability can provide an overall understanding of how future climate change will impact marine resources. Here, we consider how four large marine ecosystems (LMEs), the southeast Bering Sea, the Northeast US Shelf, the Norwegian Sea, and the Barents Sea differ in their response to climate change and how the local processes play important roles in shaping the interactions between physics and biology. Particularly, we focus on how these selected ecosystems have historically responded to climate variability and discuss some of the implications future climate change may have on these systems. We also analyze how the physical properties of each of these ecosystems are expected to change in the future and discuss possible consequences for the marine ecology such as primary production, functional diversity, and ecosystem composition. Finally, we discuss key areas of future research including how to use a mechanistic framework to more quantitatively assess how key ecosystem processes will be impacted by climate change.

June 11, 10:00

A decade in review: Physical conditions structuring annual variation in nearshore Arctic forage fish communities

Johana Vollenweider, Ron Heintz, Mark Barton, Kevin Boswell, Leandra Sousa, Alexei Pinchuk

The Arctic nearshore offers critical ecosystem services to an abundance of juvenile forage fish. These unique habitats will be impacted differently than offshore habitats from effects of reduced sea ice, increased wind storms, oil drilling, shipping, infrastructure development, coastal erosion, and terrestrially-derived freshwater. We characterize the abundance and community composition of nearshore Arctic forage fish in relation to oceanographic and physical habitat features structuring annual variability over the span of a decade. Specifically, we conducted beach seine sampling from 2004 to 2015 at the same 10 locations every August in three distinct water bodies near Barrow, Alaska, including the Chukchi and Beaufort Seas, and Elson Lagoon. Catches fluctuated between dominance of either Arctic cod (*Boreogadus saida*) or capelin (*Mallotus villosus*), with several species of sculpin consistently present. Along with fish sampling, we made

concurrent measurements of sea surface temperature and salinity. Additional physical habitat examined in our analysis include wind speed and direction, sea-ice conditions, and the large-scale climate Arctic Oscillation Index. Understanding the physical conditions which support proliferation of different Arctic fish species will be important in predicting future productivity in the Arctic.

June 11, 10:50

Seasonality in nearshore habitats near Pt. Barrow, AK

Ron Heintz, Mark Barton, Kevin Boswell, Seth Danielson, C. Li, Brenda Norcross, Alexei Pinchuk, Leandra Sousa and Johana Vollenweider

The region around Point Barrow, Alaska is an ideal location examining how warming conditions will influence nearshore ecosystems at high latitudes. Point Barrow is an oceanographically dynamic location demarking the boundary between the Chukchi and Beaufort Seas. Freshwater outflows from Elson Lagoon, just to the east of Point Barrow on the Beaufort Sea coast, contribute to the dynamism. We sampled the fish communities residing there by beach seining during the ice-free period from 2013-2015. Sampling was conducted weekly and our goal was to obtain baseline information on seasonal changes in the community composition, age structure, diets and trophic status. Within years, species richness increased in the weeks following ice retreat and catches were dominated by age-0 fish. The most frequently encountered taxa included cottids, slender eelblenny, Arctic shanny, capelin, Pacific sand lance, and gadids. Temperature and salinity covaried between years so that there was much greater habitat variability in warm years. Winds influence salinity by forcing fresh water out of the lagoon or retaining it in the lagoon. Coincidently, catches were highest in warm years. The energy density of the fish was consistent across years and generally lower than observed in conspecifics collected farther offshore. We found the region around Pt. Barrow to be complex and speciose. It serves as an important nursery area for juvenile forage fish and continued warming is certain to influence its current status.

June 11, 11:10

Thermal growth condition determines the productivity of coastal nursery habitat for juvenile cod

Benjamin Laurel, David Cote, Robert Gregory, Lauren Rogers, Halvor Knutsen, and Esben Moland Olsen

Coastal regions are considered to be important nursery habitat for many cod species in the Sub-Arctic and Arctic, yet they are highly dynamic in terms of seasonal and annual temperature variation that could impact growth and survival. We analyzed coastal time-series from the Gulf of

Alaska, Newfoundland and Norway to test the hypotheses that the thermal growth potential of juvenile cod (Atlantic cod *Gadus morhua*, Pacific cod *Gadus macrocephalus* and Greenland cod *Gadus ogac*) provides some indication of survival likelihood in the first year of life under varying temperature regimes. Results indicated a strong positive link with growth potential and survival, with poor survival linked to low growth potential from cold winters (Newfoundland) and recent warmer summers (Norway). We conclude that temperature-dependent growth strongly influence the productivity of coastal habitats among regions, and temporal changes in growth potential (e.g., via climate change) will likely impact habitat quality by way of size-dependent mortality or spatial shifts to deeper, offshore areas.

June 11, 11:30

A comparison of temporal trends in fish community structure of three sub-Arctic coastal areas

David Cote, Caren Barcelo, Benjamin Laurel, and Robert Gregory

Coastal marine ecosystems are extremely productive and serve as important nursery areas for many commercially important species. Unfortunately, these systems are also extremely vulnerable to anthropogenic perturbations, including climate shifts. Comparisons of long term monitoring data from sub-Arctic coastal areas in Bonavista Bay, Newfoundland (since 1996), Kodiak Island, Alaska (since 2006) and Skagerrak, Norway (since 1919) suggest that juvenile gadid recruitment may be strongly linked to area-specific growth conditions. While all of the study areas are under the influence of climate change, the growth potential and the corresponding response of resident gadids differs across areas. Fish community data are also available for each of the study areas, where directional temporal shifts in community structure (including the arrival of new species, declines in overall species richness and biomass) are evident. This contribution aims to compare the nature of fish community shifts and assess whether they mirror the findings of single-species gadid recruitment studies.

June 11, 13:30

Heterogeneity in zooplankton communities near the Alaskan Arctic coast and the resulting effects on planktivorous fish feeding habits

Alexei Pinchuk

Nearshore environment plays an important role in the Arctic ecosystem providing vital habitat for a variety of organisms including numerous anadromous and marine fishes. We synthesized data on composition and distribution of zooplankton, fish diets and physical processes that may influence pelagic communities in the coastal Chukchi and Beaufort seas to address the following fundamental questions: how do variable oceanographic conditions structure zooplankton communities near the Alaskan Arctic coast during ice-free summer time, and how may planktivorous predators benefit from these changes? Nearshore zooplankton assemblages on the

seaward side of the coast were strongly influenced by the strength of the buoyancy-driven Alaska Coastal Current (ACC) inhabited by numerous small copepods. Strong and persistent northeasterly winds appeared to arrest ACC flow and promote advection of large lipid-rich Arctic zooplankton into the nearshore, where they became a preferred prey for Arctic cod. An abundant brackish-water (<20 PSU) community dominated by copepod *Limnocalanus macrurus/grimaldii* developed in the stratified waters far inside Elson Lagoon during summer. These lipid-rich copepods are an excellent source of energy for euryhaline predators capable of tolerating low salinity, but, probably, are inaccessible to true marine species. The duration and success of the *Limnocalanus* production season may be important to survival and year-class strength of cisco (*Coregonus* spp.) juveniles, which perform ontogenetic migration from tundra lakes and rivers to estuarine nursery areas each summer after spawning.

June 11, 13:50

TBA

Xénia Weber

June 11, 14:10

Tissue turnover rates and trophic discrimination in Arctic sculpin (*Myoxocephalus scorpioides*): A new perspective on Arctic trophic dynamics

Mark Barton, Kevin Boswell, Ron Heintz, Johanna Vollenweider, and Brenda Norcross

As the impacts of climate change and anthropogenic activities become increasingly pervasive in the Arctic, so does the need for a comprehensive baseline with which to compare and contrast changing ecosystem dynamics. Recent studies have used stable isotope analysis to investigate trophic structures and pathways within several Arctic marine environments. Controlled lab-based isotope experiment have shown that the parameters used in food web models are more complex than early works had indicated, and yet very few controlled experiments have been used to identify appropriate parameters for Arctic species. We carried out a controlled lab-based isotope study on a common Arctic nearshore fish species, the Arctic sculpin (*Myoxocephalus scorpioides*), to determine tissue turnover rates and trophic discrimination factors. This experiment indicated that sculpin livers, muscle and fin have slow isotope turnover rates for δ13C (93, 129, And 126 days, respectively) and δ15N (115, 129, and 166 days, respectively). Trophic discrimination factors were high for δ13C (2.5 to 3 ‰), and low for δ15N (1.5 to 3 ‰). We propose these parameters be used for Arctic fish species in food web models and discuss the theoretical implications for future isotope studies.

June 11, 14:30

The interaction of temperature and diet quality in determining the condition of juvenile saffron cod (*Eleginus gracilis*) and Arctic cod (*Boreogadus saida*): results from combined laboratory and field based approaches

Louise Copeman and Benjamin Laurel

Climate models indicate the Arctic will undergo dramatic environmental change with increased global warming. These effects will likely be the most severe in nearshore waters that serve as nursery habitat for juvenile gadids throughout Alaska. Increasing temperatures will likely be coupled with changes in freshwater input that will in turn significantly affect nearshore marine food webs. Both Arctic cod (*Boreogadus saida*) and saffron cod (*Eleginus gracilis*) are ecologically important in Alaskan coastal waters, however, little is known about their growth, feeding ecology or energy allocation during the juvenile stage. We used both field and laboratory approaches to understand the early energetics of juvenile Arctic and saffron cod in relation to changes in temperature and food availability. Field collections of age-0 and age-1 juvenile gadids showed significant trends in condition metrics both within and between species. Both species showed increased lipid per wet weight with standard length up until the first over-wintering period. Arctic cod had higher levels of total lipids and storage lipids in both muscle and liver tissues than Saffron cod. Energetic differences, both within and among these gadids, may stem from regional trophic and thermal conditions. Fatty acid biomarkers indicate Arctic cod have a higher reliance on Calanoid copepods than saffron cod and laboratory experiments show distinct differences in growth and lipid storage under varying temperatures. These data suggest Arctic cod and saffron cod will likely respond differently to regional nearshore warming, such that energetic contribution of these forage fish to higher trophic levels could be transformed in the wake of further climate change.

June 11, 14:40

Trophic vulnerability of 0-group Atlantic cod (*Gadus morhua*) and saithe (*Pollachius virens*) A case study investigating the juveniles' feeding pattern and identifying valuable nursery habitats in the Icelandic Westfjords

Anja Nickel

Rapid environmental change due to anthropogenic impacts currently threaten marine ecosystems and increase the pressure on the vulnerable early life stages of many marine organisms. In this study, I examine trophic vulnerability of 0-group Atlantic cod (*Gadus morhua*) and saithe (*Pollachius virens*) during late summer and fall. This period coincides with the Atlantic cod juvenile settlement from the pelagic to the benthic habitat in the northwest of Iceland. It is a critical period for both species as growth in the first summer and fall may determine winter survival. Results from previous studies have identified clear habitat preferences of juvenile

gadoids for structured habitats such as maerl beds and macro-algae. In Iceland, both habitat types are exploited and affected directly and indirectly by anthropogenic activities. In the current study, I investigate the diets of 0-group cod and saithe juveniles and discuss the relevance of trophic preferences and trophic competition for nursery ground conservation and management. The feeding patterns of the 0-group juveniles revealed that both species are opportunistic feeders with a wide range of prey organisms. Despite that, there is high overlap in the foraging niche of cod and saithe, suggesting the potential for trophic competition between and within the two species. Juveniles of both species exhibited similar feeding patterns during most of the study time. During the sampling period from late July until November, the proportion of benthic prey items gradually shifted until the diet mainly contained pelagic organisms. From late October on, cod and saithe feeding patterns started to diverge, which indicates more specialized foraging habits. 0-group saithe were larger throughout the sampling period. The results of the current study emphasize the need for further research investigating the early life stages of exploited fish species and the implementation of management measures for their nursery grounds in coastal waters.

WKS3 - Using natural analogues to investigate the effects of climate change and ocean acidification on northern ecosystems

June 11, 10:00

Investigating local and regional adaptation using natural analogues of climate change

Peter Thor

Organisms maintain their function through a myriad of physiological regulation processes. Many of these processes are involved in buffering changes in the outside environment. Accordingly, marine organisms will have to response physiologically to future changes in temperature and pH in the face of global change. The vast majority of empirical studies assessing biological effects employ acute tests in which organisms are exposed during very short periods of time. These tests fail to register the full effect of a changing environment. They do not test for long term evolutionary effects such as adaptation, parental effects, and various kinds of transgenerational effects. A series of different studies have circumvented these shortcomings by employing natural analogues of global change. Some of these show that populations may react to changes through adaptation but also by phenotypic plasticity (acclimatisation). Thus, when using this approach, care should be taken to properly separate effects of evolutionary changes and phenotypic plasticity.

June 11, 11:20

Applying CO_2 seep approaches to other natural analogues of ocean acidification

Jason M. Hall-Spencer and Marco Milazzo

We have been involved with many projects using natural gradients in seawater carbonate saturation to assess the effects of ocean acidification in the Mediterranean. Observations at CO2 seeps off Ischia, Methana and Vulcano have shown very similar effects of acidification at the ecosystem level. We will describe the types of colonization and transplant experiments that have worked well to reveal the mechanisms that cause changes in microalgal, macroalgal and sessile invertebrate communities. We have also carried out work on more motile organisms such as phytoplankton, meroplankton and fish. Most regions of the planet do not have coastal CO2 seeps but there are great opportunities for using other types of natural gradients in carbonate chemistry to determine responses to acidification, such as fjords and upwelling areas to assess regional responses. In this workshop talk we will explore the baseline physicochemical surveys needed to establish natural analogue sites and the sorts of experiments and observations that can work well (and what to avoid!) at such locations.

June 11, 14:00

Monitoring pteropods and carbonate chemistry along natural gradients to investigate OA effects in Arctic waters

Melissa Chierici and Agneta Fransson

Recent and previously collected data on the carbonate chemistry and ancillary parameters are used to discuss the regional differences in variability and drivers in the Arctic Ocean, the Barents Sea. Since 2011, carbonate chemistry data in the Arctic Ocean has increased substantially due to the initiation of two major research projects with multi-institutional participants. We use a combination of sampling platforms such as water column measurements along repeated transects and underway measurements of surface-water carbonate system measurements for seasonal study to reveal current variability (seasonal and interannual) in areas with expected large gradients such as the Fram Strait, Svalbard fjords and basins. In 2012 sampling of calcifying organisms such as *Limacina helicina* in Svalbard waters. In the next years, the combined sampling was expanded to include also waters in area north of Svalbard and the Barents Sea. Data from 6 years of studies in Fram Strait will be used represent areas with large contrasts. Fram Strait is the main gateway for exchange of Arctic and Atlantic waters entering the Arctic Ocean and studies here may also give an integrated signal of the climate stressors affecting the Ocean Acidification state in the Arctic Ocean. These studies showed larger variability than anticipated and was connected to variability in the outflow of polar waters, the amount of freshwater, and mixing of different water masses. Along the Norwegian coast, carbonate chemistry was influenced by the fresh and cold coastal current, and the carbon values were lower than the off-shore ocean. A similar effect was observed at the marginal ice zone in the northern Barents Sea. Biological activity was also an important driver for the observed changes in the carbonate chemistry and the effects of these changes were observed at some locations. Data from contrasting Svalbard fjords were sampled during cold and warm years to investigate climatic drivers and sea-ice time series were used to investigate the role of sea ice. A recent study showed that processes within the sea ice, such as $CaCO_3$ dissolution/formation, contributes to sustain pCO_2 undersaturation in the surface waters. To investigate the effects of OA on organisms, the aragonite forming pteropod *Limacina helicina* was sampled in addition to the water chemistry in most areas and we discuss the possibility of using *L. helicina* as a sentinel organisms and some of the challenges.

ABSTRACTS - ORAL PRESENTATIONS

Monday, June 12

June 12, 09:00 (Invited Opening Presentation)

Rapidly changing high latitude ecosystems - necessity of and opportunities by implementing holistic, science-based management

Mette Skern-Mauritzen, Erik Olsen, and Geir Huse

Unprecedented and rapid changes are ongoing in the high latitude ecosystems, due to climate warming. In the Barents Sea, boreal species are increasing and expanding while arctic species are decreasing and contracting, altering both the structure and dynamics of this ecosystem. Human impacts increase, fueled by both climate warming and Blue growth; fisheries are mowing northwards into previously unfished habitats, harvesting more species over more trophic levels. Aquaculture is increasing, and less sea ice opens for more petroleum-related activities and shipping. There is an urgent need for a holistic management of these ecosystems, based on best available scientific knowledge. While the challenges grow, the resources for research and management remains limited. However, here we argue that recent development in both scientific approaches and science-management interface may increase the value for money. Methods relying on cross stock, cross species and cross-system similarity all add informational value to data collected both within and outside the system being managed, enabling us to provide relevant information and advice to management even in data-limited and data-poor situations. Also, novel scientific tools and processes developed with the transition to ecosystem-based management, super-ensemble modeling approaches, management strategy evaluations, integrated ecosystem assessments and ecosystem advice to management, all bridge science and management in new ways, having the potential to significantly increasing information flow and utility of scientific knowledge. Yet obstacles remain, and here we pinpoint some of these obstacles and discuss possible solutions.

June 12, 09:30 (Invited - S8)

Mechanisms for science to shape US Marine Conservation Policy

Richard Merrick
Scientist Emeritus, NOAA Fisheries, Woods Hole, MA, USA

Conservation of Living Marine Resources in the US is guided by a series of legislative mandates, all of which call for management to be guided by scientific advice. Implementation of the Acts is provided by Federal scientists and managers with the expectation the former will provide the "Best Scientific Information Available (BSIA)". BSIA must consider science generated by academic, industry, and NGO scientists, as well as other stakeholders. Despite the best intentions

of these Acts, difficulties remain in providing this advice. Managers may not be able to communicate or may not know what advice they need. Scientists and stakeholders external to the Federal family may also find it difficult to have their science appropriately considered, and consequently feel disenfranchised. Scientists may also have different agendas than managers and policy makers, based on their own normative values, and may not be seen as a source of unbiased objective information. There are, however, ways to deal with these difficulties. One approach is through Integrated Ecosystem Assessments (IEAs), where scientists and managers jointly define and track project goals and targets. Another example can be found in the National Environmental Policy Act, as well as the National Standards established under the US Fishery Conservation and Management Act, all of which provide clear guidance on how both internal and external scientific information can be provided to fishery managers. One final example is NOAA's Scientific Integrity Policy which provides guidance to NOAA scientists on methods by which Federal scientists can provide advice which may be contrary to NOAA Agency policy. Ensuring that there is a free and open exchange of scientific information, and that this advice is communicated to and used by managers and policy makers, is the ultimate key to successful conservation.

June 12, 10:00 (Invited - S8)

International collaboration and Arctic science: Finding ways to work together

Anne Christine Brusendorff
ICES Secretariat, Copenhagen, Denmark

ICES, as an international scientific organization has a broad systems-based approach to science cooperation in the Arctic. ICES work is based on a comprehensive enduring science programme, supported through a wide-range of expert working groups. ICES is working towards improved integrated ecosystem understanding, and the science for integrated ecosystem assessments (IEA). Current work developing an IEA, including an ecosystem overview for the Central Arctic Ocean, is bringing together experts from ICES, the Arctic Council (PAME), and PICES. This IEA work brings experts together across disciplines, relating to both the work in the Arctic Council (e.g.; sensitivity and vulnerability in relation to shipping activities) and the meetings of Scientific Experts on Fish Stocks in the Central Arctic Ocean (FiSCAO – developing a joint scientific and research and monitoring programme), as well as understanding of climate and ecosystem variability. While science organizations like ICES, and others must work together to provide a transparent and trusted evidence base, it is equally important to have a mechanism for setting priorities and objectives, and to involve governments and the relevant sectors, understanding their objectives and incentives. This is a necessary basis for understanding the implications of trade-off decisions in a multiple use context. The foundation of ICES work on Arctic issues is in the Arctic Fisheries Working Group, which for nearly 60 years have been conducting assessments of cod, haddock, saithe, redfish, Greenland halibut, and capelin stocks in the Barents Sea and Norwegian Sea), including ecosystem considerations. The latter includes specific interactions between species and the unique Arctic foodweb, as well as the hydrographic developments and climate change in the Arctic. Although perhaps most well-known for advice on fishing opportunities, ICES is working with PICES to respond to the need for credible, objective and innovative science advice on the impacts of climate change on marine ecosystems. The joint ICES–PICES strategic initiative on Climate Change Impacts on Marine Ecosystems, coordinates northern hemisphere

efforts to understand, estimate and predict the impacts of climate change on marine ecosystems. ICES is keen to work with others to improve scientific understanding in the arctic using our North Atlantic experience as a credible scientific adviser to decision-makers, engagement and dialogue with governments and stakeholders, and professional data management.

June 12, 11:00 (Invited - S4)

The Pacific Arctic region: a window into shifting benthic populations in response to ecosystem change

Jacqueline Grebmeier[1], Lee Cooper, Monika Kedra, and Sue Moore
[1]University of Maryland Center for Environmental Science, USA

A key ecological organizing principle for the northern Bering Sea and the adjoining southern Chukchi Sea in the Pacific Arctic is that the shallow, seasonally productive waters lead to strong pelagic-benthic coupling to the sea floor, with deposition of fresh chlorophyll coinciding with the spring bloom as sea ice retreats. Both in situ production and advection of upstream phytodetritus to these regions support persistent biological hotspots that connect benthic prey to upper trophic benthivores. This northern marine ecosystem is dominated by marine macroinvertebrates (e.g. clams, polychaetes, and amphipods) that feed on the high production deposited rapidly to the seafloor, which in turn serve as food resources for diving mammals and seabirds, such as gray whales, walruses, and spectacled eiders. Between St. Lawrence Island and Bering Strait and northwards into the Chukchi Sea, the persistence of seasonal sea ice has significantly declined over the past two decades, and along with warming seawater temperatures, these changes have potential ramifications to ecosystem structure. Times-series data over the last 25 years indicate that these regions have experienced a northward shift in macrofaunal composition and a decline in core benthic biomass that matches patterns of reduced sea ice, warming seawater, and changing sediment grain size that relates to varying current patterns. This presentation will discuss these data in the context of both process studies from the region and results from the Distributed Biological Observatory (DBO), an international network of time series transects that is providing a framework to evaluate status and trends on a latitudinal basis in the Pacific Arctic region.

June 12, 11:30 (Invited - S7)

Formation and transport of corrosive water in the Pacific Arctic region

Jessica N. Cross[1], Jeremy T. Mathis, Robert S. Pickart, and Nicholas R. Bates
[1]**NOAA Pacific Marine Environmental Laboratory, Seattle, WA, USA**

Ocean acidification (OA), driven by rising anthropogenic carbon dioxide (CO_2), is one element of rapid change presently occurring in the Pacific Arctic Region (PAR). It has been shown to compound natural variability in carbonate chemistry, producing conditions newly corrosive to biologically important carbonate minerals. Here, we synthesize data from across the PAR to

investigate the formation of waters that are potentially corrosive to biogenic carbonate and their transport into the Arctic Ocean. The data show the seasonal accumulation of CO_2 in colder, denser winter-modified Pacific waters from a variety of mechanisms over shallow shelves during summer and fall, which are subsequently transported off the shelf. In the Chukchi Sea, most of the offshore flux occurs through Barrow Canyon. We estimate that this outflow delivers ~2.24 Tg C yr^{-1} of corrosive winter water to the Arctic Ocean. Downstream of Barrow Canyon, moored data records indicate that 0.5 – 1.7 Tg C yr^{-1} may be returned to the atmosphere via upwelling events along the Beaufort Sea shelf. This efflux is more than sufficient to eliminate corrosivity in the upwelled Pacific halocline waters. However, moored and discrete data records indicate that potentially corrosive Pacific waters are present in the Beaufort shelfbreak jet during 80% of the year, indicating that carbon accumulation far outweighs mitigation created by upwelling. Overall, we estimate that persistent corrosivity of the Pacific halocline is a recent phenomenon that appeared between 1975 and 1985. Over that short time, these potentially corrosive waters originating over the continental shelves have been observed as far as the entrances to Amundsen Gulf and M'Clure Strait in the Canadian Arctic Archipelago. The formation and transport of corrosive waters on the Pacific Arctic shelves may have widespread impact on the Arctic biogeochemical system reaching all the way to the North Atlantic.

June 12, 12:00 (Invited - S7)

Biological effects of Arctic ocean acidification

Peter Thor
Norwegian Polar Institute, Tromsø, Norway

Widespread ocean acidification (OA) have stirred concern mostly about the survival of CaCO3-shell forming species. But OA effects extends far beyond calcification. Marine organisms are affected through disruption by low inter- and intracellular pH of a range of different physiological processes, of which the cellular acid/base regulation may be the most obvious. Studies have shown severe effects in many non-calcifying animal species, some of which constitute key players in the Arctic ecosystem. Important species such as copepods and fish have shown detrimental changes in vital rates and life history traits in experimental OA studies. Furthermore, detailed studies of e.g. metabolism, gene expression patterns, and metabolite turnover show that even in animals displaying apparent tolerance to ocean acidification such tolerance may be uphold only through significant changes in underlying physiological processes (i.e. physiological buffering). Moreover, responses to ocean acidification may differ among developmental stages. While absent in some developmental stages, severe effects in other specific stages may still hamper individual development and population propagation. Lastly, ocean acidification may instil important evolutionary changes in affected populations. While adaptation will serve to alleviate any potential effects of ocean acidification, it may also subtract from the tolerance to other challenges of environmental change.

Parallel Sessions

S8 - Science, Policy and Management

June 12, 13:50

A decision analytic approach to climate change adaptation: Case study from Wainwright, Alaska for strengthening subsistence systems in the Arctic

Tuula Hollmen[1] and Katherine Christie
[1]University of Helsinki, Finland

Climate change is impacting the subsistence livelihoods of many indigenous communities in the Arctic. We conducted a test-case study in the Iñupiat community of Wainwright, Alaska, to explore the Structured Decision Analysis (SDA) process as a tool to help Arctic communities enhance the adaptive capacity of their subsistence systems. The SDA offers a framework for considering complex decisions with uncertainty, and tools to explore how different decision alternatives can meet values-based objectives. We introduced SDA to the community of Wainwright as a way to: 1) assess the vulnerability of the subsistence system to climate change; and 2) enhance the resilience of the subsistence system over the long-term. Using SDA, we identified factors influencing the abundance and accessibility of key marine subsistence species, elicited local observations on population trends over the past decade, assessed the dependence of animals and their successful harvest on sea ice, and ranked the benefits and tradeoffs of different strategies to enhance the safety of subsistence activities in a rapidly changing environment. Wainwright has a highly diverse subsistence system that may in part buffer the negative effects of climate change and a long history of innovative adaptations, including the use of social media to track marine mammal migrations. However, we suggest that SDA provides a tangible way to enhance the array of current strategies used by indigenous communities of the Arctic for climate change adaptation while directly engaging community members to identify specific problems, formulate objectives, and rank alternative adaptive strategies. Furthermore, participatory approaches such as this one can have higher likelihood of being embraced than top-down policy approaches because they consider the challenges, objectives, and cultural practices unique to each community, and empower individuals to proactively strategize about future adaptations.

June 12, 14:10

The many facets of bycatch management in Alaska fisheries

Alan Haynie
NOAA/NMFS, Alaska Fisheries Science Center, Seattle, WA, USA

Bycatch reduction is a central goal of fisheries management in Alaska and elsewhere. With the creation of multi-species catch share programs, halibut bycatch reduction efforts, concerns about

patchy rockfish species, and through actions to reduce Chinook and chum salmon bycatch in the Bering Sea and Gulf of Alaska pollock fisheries, we have seen a variety of new bycatch management programs implemented over the last decade in Alaska. The nature of the bycatch problem is by no means uniform across fisheries. In some cases, such as with endangered sea turtles or seabirds, the goal is complete avoidance. With salmon and halibut bycatch management, the goal is avoidance, but there is a trade-off inherent to catching the quota of the target species that requires that some salmon and halibut be taken because of the frequent co-mingling of the target and bycatch species. In multi-species fisheries such as the BSAI Amendment 80 fishery, scarce species are caught and marketed but are also avoided at some points during the year as vessels attempt to maximize multi-species revenue while not exceeding quota limits for the species with more restricted quotas. Because of these different management objectives and legal requirements, there is no universal mechanism for bycatch reduction. Biological, economic, and other institutional factors such as industry organization and observer coverage all impact the effectiveness and potential bycatch management programs. We discuss how these factors impact which mechanisms appear to be most effective at addressing different problems. As well as presenting a framework for how incentives impact fisher behavior and bycatch outcomes, empirical examples from a variety of North Pacific fisheries are provided.

June 12, 14:30

Invasive crabs in the Barents Sea

Brooks A. Kaiser, Linda M. Fernandez, Melina Kourantidou, and Niels Vestergaard
University of Southern Denmark, Esbjerg, Denmark

The recent invasions of the Red King Crab (RKC) and the Snow Crab (SC) in the Barents Sea represent the sorts of integrated ecological and economic shifts we may expect as climate change affects Arctic seas. Economic incentives and ecological unknowns have combined to change the current and potentially future productivity and profitability of the Barents ecosystem in complex and interacting ways. We examine potential ecological-economic trajectories for these crabs' continued expansions in the Arctic and how the profitability, the joint and national management structures in Norway and Russia, and the uncertainties regarding ecological impacts, co-determine the potential paths. We use these results and tenets of environmental and resource economics to suggest improved management strategies that better integrate the ecological unknowns into management in order to increase social welfare in the long run. We compare differences in the ecology and economics of the two species to enhance understanding of the trade-offs inherent in managing these economically profitable yet risky invaders. We then expand the application by using these ongoing invasions to illustrate the anticipated disruptions (with potentially both positive and negative impacts) from other species introductions or range expansions of commercial species and the management steps that should be taken at earlier stages, including monitoring and preventative measures, in the changing ecological processes to minimize negative impacts.

June 12, 14:50

Science - politics interplay in Arctic fisheries

Alf Håkon Hoel
Institute of Marine Research, Tromsø, Norway

The 2005 Arctic Climate Impact Assessment predicted a number of developments in the marine Arctic that manifest themselves today. A number of fish species, for example, can now be observed at higher latitudes than previously. The ice cover of the Arctic Ocean is shrinking rapidly, and is now down to some 4 million km^2 in late summer. Summer ice cover is likely to continue to decline, and is expected to be gone by mid-century. The ramifications of this for marine ecosystems are hard to predict, but the prospects of fish stocks moving into previously ice covered areas in the Central Arctic Ocean has brought the coastal states (the Russian Federation, USA, Canada, Denmark/Greenland, and Norway) to negotiate an agreement on prevention of the emergence of unregulated fishing in the 2.8 million km^2 High Seas area beyond national jurisdiction there (the 2015 Oslo Declaration). The agreement also provides for the establishment of a research and monitoring program, as well as the initiation of an expanded process to bring several other countries into an agreement on prevention of unregulated fishing. As of 2017, a scientific meeting addressing a science plan for future work on monitoring of fish stocks at high latitudes will be held, and five meetings have been held in the expanded circle of governments (now also including the EU, Iceland, Japan, the Republic of Korea as well as China. Since the inception of this process, science has been critical to the development of political cooperation. The purpose of this presentation is to account for the development of this process from its start almost a decade ago and analyse the interplay between science and politics in this period.

June 12, 15:10

Proactive risk governance framework for maritime activities in the Arctic seas

Tuuli Parviainen[1], Päivi Haapasaari, Annukka Lehikoinen, and Sakari Kuikka
[1]University of Helsinki, Finland

The governance of the Arctic Ocean can be portrayed as a patchwork of different international regimes, bilateral agreements, and national regulations. Due to this fragmented approach, broader international regimes and innovative regulatory measures are considered essential in protecting the Arctic marine environment. Potential oil spills from natural resource extraction and shipping activities pose a significant threat to the Arctic marine environment. However, risk-governing mechanisms are largely underdeveloped in the Arctic: the risk presented by oil spills in polar waters is poorly understood and there is lack of prevention and response mechanisms as well as knowledge on the effectiveness of such measures. In addition, limited research exists on risk communication and the co-management of risks in the Arctic. We present an on-going work that examines current risk governance in terms of shipping and offshore resource extraction. Drawing on examples of risk governance frameworks in the Baltic Sea and in the Atlantic part of the

Arctic Sea protected by the OSPAR Convention, the paper proposes a proactive risk governance framework based on stakeholder participation in the Arctic seas. The benefits of Bayesian network (BN) analysis in risk governance will also be discussed. We explore the possible impacts of proactive risk governance in contributing towards increased understanding and analysis of risks related to potential oil spills; enhancing community-based decision-making; and promoting transparency and enhanced communication between Arctic stakeholders. The main aim, therefore, is to examine how the proposed risk governance framework can contribute towards enhanced decision-making and protecting vulnerable Arctic marine areas.

June 12, 16:00

Cooperative vs Non-Cooperative Benefits in the Black Sea Anchovy Fishery

Sezgin Tunca[1], Lone Grønbæk, and Marko Lindroos
University of Helsinki, Finland

The Black Sea anchovy, *Engrauilus encrasicolus ponticus* (Alexandrov, 1927), the fish species of the Black Sea fishing culture, is no doubt the economically most important harvested species in the Black Sea. The stock has been shared by the 6 riparian states in the region, principally by the Turkish fleet followed by Georgian and Ukrainian fleets. The first aim of this study is to conduct a simple optimization for the effort by Turkish, Georgian and Ukrainian fleets. Secondly, we will construct a cooperative and non-cooperative game theoretical model to determine the net present value flow over time. Further, different coalitions within the game will be investigated to better understand whether the benefits of complete cooperation, partial cooperation or free riding are best for different players. To achieve this goal, surplus production model results from the existing literature were used to construct a bioeconomic model. Recent available economic parameters from the literature and from on-site face-to-face interviews with the fishermen were used to develop the economic extension of the biological model. The outputs of the model will be analyzed comparatively among different game models. The results are will enable us to better understand the current share of benefits for the purpose of establishing good management practices for the Black Sea anchovy fishery in the Black Sea region.

June 12, 16:20

Bio-economic analysis for Arctic Marine Resource Management Policy

Niels Vestergaard
University of Southern Denmark, Esbjerg, Denmark

Future changes in Arctic marine ecosystems will depend as much on global climate change as on our ability to regulate and manage exploitation pressure at sustainable levels. There is a lack of integrated, cross-sectoral ecosystem-based analysis of the Arctic marine management. This analysis is on both the choices for implementing regulatory tools and how they will affect the many ecosystem-dependent values derived from them. The ability to maximize these values depends critically on the ways in which the dynamic bio-economic properties of the resources are impacted by the human behavior induced by the regulations (or lack thereof). In this paper, I

speculate about likely changes in future Arctic fisheries based on a scenario building approach. The dimensions are 1) climate changes and the likely impacts in the Arctic, 2) the sectoral development of important marine sectors (fishing, shipping, mining etc.), and 3) governance structure development. The development in each of these dimensions is uncertain and central elements in the analysis are risk and uncertainty. The results indicate that the future climate changes might involve relative large changes in the ecosystem and hence fish stock, but also that the economic outcome of fisheries depend critical upon the ability to adjust the regulatory regime to capture the values of the ecosystem services.

June 12, 16:40

Learning chains in Arctic oil risk analysis

Sakari Kuikka, Maisa Nevalainen, Jussi Mäkinen, Inari Helle, and Jarno Vanhatalo
University of Helsinki, Finland

The probability of major oil accidents in Arctic seas is increasing alongside with increasing maritime traffic. Hence, there is a growing need to understand the risks posed by oil spills to these unique and sensitive areas. So far, these risks have mainly been acknowledged in terms of qualitative descriptions. However, there is an obvious need to develop analysis tools that offer a systematic way to quantitatively assess the consequences of possible oil spills so that the oil-induced risks can be taken into account when new sea routes or previously unexploited oil reserves are utilized. The challenge of oil spill risk analysis in the Arctic area is that there are few existing data sets. Hence, methods are needed to combine knowledge from complementary sources of information. This can be achieved with Bayesian inference which allows combining information from, e.g., existing reports and models, data sets from field and laboratory, and knowledge from experts. Bayesian inference can also be applied sequentially to build a learning chain where the knowledge from previous accidents and studies can be used as prior information for new risk assessments. Moreover, Bayesian analysis allows rigorous treatment of uncertainties related to the assessment providing a comprehensive quantitative risk assessment framework. In this talk, we will summarize the lessons learned from over 15 years of Bayesian oil risk assessment in the Baltic Sea and present how this knowledge can be transferred to the oil risk assessment in the Arctic seas. We present a general Arctic food web model for ecological risk analyses and demonstrate how expert elicitation and heterogeneous species distribution data can be used to assess risks to key functional groups in the Arctic ecosystem. Our results can help identify the most acutely vulnerable parts of the Arctic ecosystem, and thus to guide potential response measures in the case of an accident.

S4 - Shifting habitats, persistent hot spots, and the distribution of benthos, plankton, fish, seabirds and marine mammals - observations, models, mechanisms and effects (Session 1)

June 12, 13:30

The Arctic Marine Pulses Model: linking annual oceanographic processes to contiguous ecological domains in the Pacific Arctic

Sue E. Moore, Phyllis J. Stabeno, Jacqueline M. Grebmeier and Stephen R. Okkonen

The Pacific Arctic marine ecosystem extends from the northern Bering Sea, across the Chukchi and into the East Siberian and Beaufort seas. Food webs in this ecosystem are short, a simplicity that belies the biophysical complexity underlying trophic linkages from primary production to humans. Existing advective and pelagic-benthic coupling models describe processes that connect certain aspects of marine food webs, but do not offer a comprehensive approach to understanding the Pacific Arctic ecosystem. In the course of the Synthesis of Arctic Research (SOAR) project, an Arctic Marine Pulses (AMP) model was developed that depicts seasonal biophysical 'pulses' across a latitudinal gradient by linking processes in four previously-defined contiguous ecological domains, including the: (i) Pacific Arctic domain; (ii) Seasonal Ice Zone domain; (iii) the Marginal domain (i.e., the shelf break and slope); and (iv) Riverine Coastal domain. Some of the biophysical processes included in the AMP model, such as pelagic-benthic coupling on the broad shelves of the northern Bering and Chukchi seas and advection and upwelling of zooplankton along the western Beaufort shelf, have been the focus of long-term studies. Other aspects such as biological processes associated with shifts in seasonal sea-ice phenology and trophic responses to riverine outflow have received less attention. The AMP model provides an annual spatiotemporal framework to guide research on dynamic ecosystem processes during the recent period of rapid biophysical changes in the Pacific Arctic. The model aims to encourage integrated research to track seasonal sea-ice and current-flow dynamics, coincident with variability in nutrients, benthic and pelagic production, and upper-trophic species occurrence to provide a foundation for the development of predictive human-inclusive ecosystem models for the Pacific Arctic region.

June 12, 13:50

Shifting biogeography of **Calanus***' cousins? Insights from a Pan-Arctic study on the connectivity and demographic history of* **Pseudocalanus** *spp. populations*

Jennifer M. Questel, Ole N.S. Aarbakke, Leocadio Blanco-Bercial, Fredrika orrbin, **Claudia Halsband**, Russell R. Hopcroft, and Ann Bucklin

Pseudocalanus species are frequently highly abundant and ecologically important links to higher trophic levels in coastal ecosystems of the northern hemisphere. Three species of the copepod genus exhibit widespread distributions over polar and sub-polar latitudes of the northern hemisphere: *P. minutus*, *P. newmani* and *P. acuspes*. To reveal both their demographic history and patterns of population connectivity we report findings based on phylogeographic modeling of the mitochondrial cytochrome oxidase I (COI) gene for the three populations from Atlantic and Pacific sectors of the Arctic Ocean. We aim to provide new insights into how a warming Arctic with diminishing sea-ice cover may reduce barriers to gene flow and alter population connectivity among Arctic and Subarctic marine organisms.

June 12, 14:10

Fish embryo physiology and climate change: Estimating habitat suitability for key Arctic fish under contrasting IPCC emission scenarios

Flemming Dahlke, Martin Butzin, Jasmine Nahrgang, Atlte Motensen, Velmurugu Puvanendran and Hans-Otto Pörtner, and **Daniela Storch**

Arctic seas are projected to warm and acidify faster from antropogenic CO_2 emissions than any other marine area on earth. Key Arctic fish are considered at risk from habitat loss if climate change continues unabated, but a cause-and-effect understanding is lacking. Incomplete acclimation capacities of embryos and larvae identifies them as a bottleneck during ontogeny with respect to direct effects of ocean warming and acidification. Here, we assess the effects of OA on embryonic thermal sensitivity of Atlantic cod (*Gadus morhua*) and polar cod (*Boreogadus saida*). OA aggravates thermal constraints on aerobic metabolism, resource allocation and thus survival of both species. The survival data were used to map changes in spawning habitat suitability (SHS) under contrasting IPCC emission scenarios – RCP2.6 (+1.5°C) vs. RCP8.5 (+3.5°C and OA). Predicted reductions in SHS reach -40% and -80% under RCP8.5 for Atlantic and polar cod, respectively. While Atlantic cod may colonize previously unavailable Arctic regions, polar cod is likely to lose most of its spawning habitats in the Barents Sea within a century also due to declining sea-ice cover. By contrast, stabilizing global warming at 1.5°C above preindustrial levels (RCP2.6) will avert severe habitat loss and associated impacts at ecosystem and socioeconomic levels.

June 12, 14:30

The Hinlopen area – a regional hotspot north of Svalbard?

Randi Ingvaldsen, Yngve Børsheim, Harald Gjøsæter, E. Hallfredsson, Tore Haug, Liz L. Jørgensen, Tor Knutsen, and S. Menze

The area north of Svalbard is characterized by large gradients in environmental factors like sea-ice cover, ocean currents, ocean temperatures, and bathymetry. This in turn fosters gradients in biodiversity and species standing stock. Based on three years (2014-2016) with observations from

the SI_ARCTIC project, we combine physical oceanographic measurements (ocean currents and temperature) with observation on zooplankton, fish, benthos and marine mammals from the area north of Hinlopen with focus on describing observed gradients in biomass and diversity. In this region, we find relatively high biomass of demersal fish and benthos, substantial concentrations of zooplankton, and, in some years, quite a few whales. The biomass/diversity seems to be linked to a complex suite of environmental conditions including: dynamical features of the ocean currents due to bathymetry at the shelf and on the shelf break towards the Arctic Ocean; Atlantic Water flow along the shelf break; and sea ice conditions. There are substantial changes between years, which probably are linked to atmospheric forcing affecting sea-ice cover and possibly local cross-shelf exchange.

June 12, 14:50

Seasonal variations and ecological importance of mesopelagic sound scattering layers in the high Arctic

Maxime Geoffroy, Malin Daase, Jørgen Berge, Martin Graeve, Marine Cusa1, Néstor Santana Hernández, and **Stig Falk-Petersen**

In August 2016, a mesopelagic sound scattering layer (SSL) was consistently detected with a multifrequency echosounder in Whalers Bay, north of Svalbard, in the lower part of the Atlantic water mass (2-4°C; 400-600 m). Net sampling confirmed that the SSL was mainly composed of large zooplankters (i.e. *Themisto libellula* and *Meganyctiphanes norvegica*) and juvenile pelagic fish (mainly *Boreogadus saida*, *Leptoclinus maculatus* and *Sebastes* spp.). During the polar night in January, the SSL occupied a similar temperature range but was detected shallower, between 0 and 400 m, and was mainly composed of redfish (*Sebastes* spp.), *Thysanoessa* spp., and capelin (*Mallotus villosus*). Temperature and the vertical distribution of prey were likely the main factors influencing the distribution of the large zooplankters and pelagic fish, in particular in winter when upwelling events could have advected prey within the SSL. Fatty acid trophic markers from key species in the SSL provided new insights in trophic transfers in this part of the Arctic Ocean, and we suggest that the prevalence of a high-energy SSL when the ice edge retracts northwards might explain the large Dutch bowhead whaling that took place in Whalers Bay between 1670 to 1800, as well as recent observations of whale aggregations. This study is a part of the RCN funded ArcticABC and Marine Night projects (http://www.mare-incognitum.no/) and of the Arctic Size project at the University of Tromsø.

June 12, 15:10

Habitat distribution patterns of demersal fish in the Eastern Bering and Chukchi Seas: comparing multivariate climatic and bioclimatic velocities

Irene D. Alabia, Jorge Garcia Molinos, Sei-Ichi Saitoh, Toru Hirawake, and Franz J. Mueter

Species habitat distributions are tightly coupled with the climate-driven environmental changes. Here, we explored the summer (June-July) habitat distributions of the key demersal fish species in the Eastern Bering and Chukchi Seas using species distribution models, developed from 24 years (1993-2016) of bottom trawl survey data and satellite-derived environmental factors. From the habitat model outputs, we examined the rates of the habitat shifts (bioclimatic velocities) amongst species during the contemporary historical climate. We also explored the corresponding rates of multivariate climate shifts (climatic velocities) and compared these with species-specific bioclimatic velocities. In doing so, we were able to elucidate the time-lagged responses of species habitat to the recent climate changes that could lead to differential shifts in species distributions. Similarly, our approach provided information on the species-specific sensitivity and exposure to climate variability which, in turn, are critical for marine conservation and resource management of demersal fisheries in the region.

June 12, 16:00

Contrasting trends in abundance and distribution of warm and cold water demersal fish on the Icelandic shelf during a recent regime shift

Olafur S. Astthorsson and Jón Sólmundsson

Bottom temperature in the warm water on the shelf south of Iceland has increased by about 1-2°C since 1996 and a few years later this increase was reflected in the cold water off the north coast. This change has been used as a reference to investigate the abundance and distribution of fish stocks during two temperature regimes: a cold one from 1985-1996 and a warm one from 2003-2016. Data on demersal fish were obtained from standardized surveys (550 stations, 20-500 m depth) in March 1985-2016. On the basis of temperature association and abundance, 50 of the most abundant fish species were ranked for temperature affinity and then changes in abundance and distribution of representatives at the warm and cold extremes and at intermediate water investigated. Of the ten species having the greatest warm water affinity, all but one showed a positive change in abundance during the warm period. Six species (silvery pout, blackbelly rosefish, grey gurnard, greater forkbeard, lantern shark, Norway pout and Norway redfish) showed more than 100% increase between the two periods. Most of the warm water species also showed a clockwise distributional shift northwards during the warm period. Of the ten species/groups having greatest cold water affinity, all but one showed decrease in abundance during warm period. Northern alligator fish and snake blennies showed the greatest decrease (respectively 70 and 53%) while 6 species/groups (polar sculpin, Greenland halibut, five cold water eelpouts combined, Vahl´s eelpout, hookear sculpin, polar sculpin and polar cod) showed 10-50% decrease. Cod and haddock are in Icelandic waters living near the mean temperature of their overall distribution range. During the warm period abundance of cod has increased (27%)

and distribution shifted only slightly to the north. Haddock demonstrated a much greater increase in abundance (58%) and a marked northward shift in center of distribution (ca. 200 km).

June 12, 16:20

Visualization of species distribution patterns in warm and cold phases to understand the effects of climate forcing in the transition between subarctic and arctic systems (Bering and Chukchi seas)

Matthew R. Baker and Anne B. Hollowed

Using species distribution patterns in warm and cold phases to understand the effects of climate forcing in the subarctic and arctic frontal zones (Bering and Chukchi seas). The eastern Bering Sea has been characterized by a recent series of successive multi-year warm and cold phases that provide insight to how individual species respond to climatic forcing on relatively short intervals. These patterns may be instructive in understanding how species will respond to directional shifts in climate and the implications for essential fish habitat and species interactions. Using data collected through the Alaska Fisheries Science Center bottom trawl surveys, we contrast species distribution in abundance and variation in abundance, species- and stage-specific temperature-depth profiles, and shifts in community composition in distinct ecoregions over the available time series and in recent warm (2000-2005, 2014-2016) and cold (2006-2011) phases. Species distribution patterns are overlaid on dynamic (e.g., temperature) and static (e.g., substrate, depth, current) environmental variables. Individual species threshold responses to temperature are also illustrated through random forest models with an aim to determine how species associated with various benthic habitat structure might experience expanded or constrained habitat availability in response to shifts in temperature. A distinct comparison of the dynamics of arctic and subarctic species is provided. Comparisons between the southeastern Bering Sea, northern Bering Sea and Chukchi Sea are considered in the context of opportunities and constraints for northward movement of species ranges and implications for species interactions.

June 12, 16:40

Environmental factors affecting the spatial distribution and overlap of cod and capelin in the Barents Sea

Johanna Fall, Lorenzo Ciannelli, and Edda Johannesen

Cod and capelin are commercially and ecologically important species in the Barents Sea, and their predator-prey interaction has been central to the survival and recruitment of both species. In recent years, the effect of low capelin abundance on the cod population has been small, something that was not the case during capelin stock collapses in previous decades. Now, we are facing another new situation with a cod stock that has grown almost as large as before the start of industrialized fishery, while the capelin stock once again has collapsed. This novel state may result in changes of overlap and trophic interaction between these two species. It is thus of

interest to further disentangle the environmental and biological processes that influence the spatial overlap between the two species, and the subsequent consumption of capelin by cod. Using data from annual autumn and winter surveys of the Barents Sea, we use generalized additive models to explore spatially variant and invariant effects of environmental variables, such as temperature and depth, on the distributions of cod and capelin. In addition, we fit models with threshold formulations to explore possible effects of contrasting regimes on the distributions, such as periods of low and high capelin abundance. Based on these relationships, we predict the probability of spatial overlap between cod and capelin in different locations and under different environmental conditions. Predation from cod is included as a component of natural mortality in the stock assessment of capelin, based on the population size of cod and the average amount of capelin consumed by cod. Our predictions will be useful in future attempts to improve this estimate of mortality, with the aim of making it spatially explicit and less sensitive to variation is sampling time and effort.

June 12, 17:00

*Environmental and biological influences on the southern distribution of Polar cod (*Boreogadus saida*)*

Jennifer M. Marsh and Franz J. Mueter

Polar cod (*Boreogadus saida*) is the most abundant and ubiquitous fish species throughout the Arctic Ocean. As such, they serve an important ecosystem role linking upper and lower trophic levels and transferring energy between the benthic and pelagic realms. Our objective is to explore what limits the southern distribution of polar cod in the Pacific and Atlantic sectors by examining time series of survey, oceanographic and sea-ice data. We quantify the variability in the southern extent of the polar cod distribution in the Barents and Bering seas, and off the coast of Iceland and Newfoundland to determine potential mechanisms (lagged sea-ice extent, bottom temperature and potential predators and competitors) driving the variability. We hope to gain insight into how the distribution of polar cod may shift as climate warming continues to increase sea temperatures and reduce ice cover in the Arctic.

June 12, 17:20

Exploring the dispersal and connectivity of Arctic cod and saffron cod early life stages in the Pacific Arctic using a biophysical transport model

Cathleen Vestfals, Franz Mueter, Colleen Petrik, Benjamin Laurel, Janet Duffy-Anderson, Seth Danielson, Katherine Hedstrom, Alex De Robertis, and Enrique Curchitser

Arctic cod (*Boreogadus saida*) and saffron cod (*Eleginus gracilis*) are the most abundant and ubiquitous fish species in the Arctic marine ecosystem, providing an important trophic link between plankton and apex predators. While our understanding of their basic biology and life history is relatively good at the species level, little is known about their life history in Alaska's

Arctic (e.g., spawning locations are currently unknown and information about the distribution of their early life stages is limited). To address these critical knowledge gaps, we developed an individual-based, biophysical transport model (TRACMASS) coupled to a high-resolution ocean circulation model (PAROMS) to identify potential spawning locations and examine the connectivity between the Chukchi and Beaufort seas. Summer distributions of age-0 Arctic and saffron cod from acoustic-trawl surveys conducted in 2012 and 2013 as part of the Arctic Ecosystem Integrated Survey project (Arctic Eis) were used to initialize the IBM, which was run backwards in time to infer likely origins of water masses. Growth and transport of Arctic and saffron cod early life stages was modeled from hypothesized spawning locations, and simulated distributions and size compositions during summer were compared to observations made during the Arctic Eis surveys. Connectivity between the Chukchi and Beaufort seas was examined by seeding the model with particles based on observed summer distributions, and running it forward in time until the fish reached a size corresponding to the onset of migration to deeper waters. Species-specific differences in transport pathways were evident, as were interannual differences, suggesting that larval transport and connectivity are sensitive to environmental forcing. This research provides important information on the dispersal of Arctic gadid early life stages in Alaskan waters and provides a better understanding of climate change impacts on these key species by examining changes in their growth and dispersal under variable climate forcing.

S7 - Ocean Acidification

June 12, 13:30

Sea-ice carbonate chemistry and influence of biogeochemical processes and glacial water in Arctic fjords

Agneta Fransson (Invited)

Sea-ice cover in the Arctic Ocean and in Arctic fjords is decreasing and is undergoing changes from multi-year ice to first-year ice due to climatic changes such as warming. These changes will have consequences for sea-ice biogeochemistry, sea-ice-air CO_2 fluxes and ocean acidification. From several investigations of sea-ice and seawater carbonate chemistry in Spitsbergen fjords, we found large weekly, seasonal and inter-annual variability in the chemistry and biogeochemical processes within the sea ice. During 12 days of young ice growth, sea-ice salinity, total alkalinity (A_T), total dissolved inorganic carbon (C_T) and dissolved inorganic nutrients (DIN) decreased mainly due to ice-brine rejection to underlying seawater. Ice-incorporated bacteria clearly influenced the carbonate chemistry as increased partial pressure of CO_2 (pCO_2) while there was no clear effect of ice-algae photosynthesis or ikaite (calcium carbonate) precipitation in this study. Frost flowers and brine skim significantly affected ice-air CO_2-gas exchange. Variability in freshwater discharge also affected the sea-ice carbonate chemistry. Between the late winters in 2012 and 2013 in Tempelfjorden, large differences were observed; late winter 2012 was milder than winter 2013 with later sea-ice formation and thinner ice. The two contrasting years clearly showed that the influence of freshwater affected the chemical and physical characteristics of the sea ice and seawater. The lowest A_T was observed in winter 2012 near the glacier front coinciding with the highest freshwater fractions (glacial water). Relatively high AT in relation to salinity was observed mainly in winter 2012, which could either be a result of ikaite precipitation in the sea ice (dissolved during analysis) or calcite and dolomite minerals originating from the bedrock/glacial freshwater.

June 12, 13:50

Arctic Ocean CO_2-carbonate chemistry: dynamics in the marginal ice zone and deep water acidification

Elizabeth Jones, Adam Ulfsbo, Michiel Rutgers van der Loeff, Hein de Baar, and Leif Anderson

Arctic Ocean CO_2-carbonate chemistry: dynamics in the marginal ice zone and deep water acidification The Arctic Ocean is undergoing rapid transition due to climate change. Surface warming and increased sea ice melt have freshened the upper ocean and exposed the surface to the atmosphere. These changes have direct impacts on air-ice-ocean carbon dioxide (CO_2) exchange, seawater carbonate chemistry and ocean acidification. The CO_2-carbonate chemistry of the Arctic Ocean and sea ice was investigated during the GEOTRACES expedition TransArc II

onboard FS Polarstern in August-October 2015. The sea surface, including ice-covered and open waters, was under-saturated with respect to atmospheric CO_2. Intense biological production reduced surface water CO_2 to create strong sinks for atmospheric CO_2 in the marginal ice zone. Dissolved inorganic carbon and total alkalinity were low and variable in sea ice and melt ponds, compared to ice-edge waters. The carbonate chemistry of sea-ice meltwater directly influences surface water CO2 and ocean acidification in the polar mixed layer. In intermediate (100-1500 m depth) waters, significant increases in anthropogenic CO2 in the Nansen Basin (0.74 ± 0.10 mol C $m^{-2}yr^{-1}$) and Amundsen Basin (0.95 ± 0.25 mol C $m^{-2}yr^{-1}$) have led to a reduction in pH of 0.02-0.05 units over the last two decades. The rapid acidification at these depths has lowered calcium carbonate saturation states. Accumulation of anthropogenic CO2 is consistent with the notion of increasing anthropogenic carbon concentrations in waters of Atlantic origin entering the Arctic Ocean.

June 12, 14:10

Simulated impact of glacial runoff on CO_2 uptake and aragonite saturation state in the Coastal Gulf of Alaska

Darren Pilcher, Samantha Siedlecki, Albert Hermann, Kenneth Coyle, Jeremy Mathis, and Wiley Evans

The Coastal Gulf of Alaska (CGOA) receives substantial summer freshwater runoff from glacial meltwater. This glacial runoff has a significant impact on global sea-level rise, in addition to the regional circulation and biology, yet there has been relatively little research on the direct impact to the inorganic carbon chemistry system. Recent field observations suggest that glacial runoff contains corrosive water with relatively low alkalinity, leading to seasonal manifestations of ocean acidification in coastal environments containing vulnerable species. We use a regional ocean biogeochemical model to quantitatively assess the impact of this process on annual CO_2 uptake and aragonite saturation state (Ω). We find that current low-alkalinity glacial outflow suppresses summer CO_2 uptake and reduces Ω on the coastal shelf. However, the alkalinity of glacial runoff is highly dependent on the glacial source. Thus, a projected shift in the glacial runoff composition due to continued climate warming may alter the alkalinity concentration and impact the local carbon cycle. We find that this shift can increase annual carbon uptake by 1.9-2.7 TgC yr^{-1} and reduce the extent of current glacially derived low Ω events. Our results demonstrate the importance of this relatively unconstrained regional carbon-climate feedback that has potential impacts on the CGOA ecosystem as well as coastal ecosystems in other glaciated regions.

June 12, 14:30

Long-term trend of pH and $CaCO_3$ saturation state in the deep convection region; the Labrador Sea

Kumiko Azetsu-Scott, Stephen Punshon, and Lorenza Raimondi

The Labrador Sea Water (LSW) is formed each year in the Labrador Sea by winter deep convection and spreads to the intermediate and deep waters of the North Atlantic. Together with Northeast Atlantic Deep Water (NEADW) and Denmark Strait Overflow Water (DSOW), both being formed in the Nordic Seas and flowing into the Labrador Sea at depths, some of the LSW contributes to the upper part of North Atlantic Deep Water and is incorporated into the meridional overturning circulation. Therefore, atmospheric CO_2 sequestered to the Labrador Sea is stored in the deep ocean, potentially for hundreds of years, and the Labrador Sea provides a conduit for long-term storage of atmospheric CO2. A time-series study from 1996 to 2015 shows a steady increase of dissolved inorganic carbon (DIC) concentration in all water masses in the Labrador Sea. In the newly-ventilated LSW, NEADW and DSOW, DIC concentration increased by 0.86 μmol·kg-1·year-1, 0.61 μmol·kg-1·year-1 and 0.71 μmol·kg-1·year-1, respectively. The pHtotal and aragonite saturation state (Ωarg) decreased by 0.002 year-1and 0.004 year-1 in the newly ventilated Labrador Sea, while no trend in pH and Ωarg were observed in NEADW and DSOW. Saturation horizons varied between 2220 m to 2540 m with the average of 2340m lying in the NEADW, and show no significant shoaling during the study period. A combination of $CaCO_3$ dissolution at the sediment/water interface and respiration, and subsequent mixing within the water masses during the transit of these water masses to the Labrador Sea may attribute to the apparent steady state in NEADW and DSOW and the saturation horizon in the Labrador Sea.

June 12, 14:50

Formation, distribution and transport of corrosive (low pH) waters in the Arctic. A model study

Dag Slagstad and Ingrid Ellingsen

Increasing CO_2 concentration in the atmosphere lead to a corresponding increase in the ocean CO_2. Since the partial pressure of CO_2 in the ocean becomes lower with decreasing temperatures, high latitude seas absorb relatively more CO_2 than low latitude seas. High CO_2 concentration increases acidity and lowers the concentration of carbonate ions, which is of crucially importance for shell-building marine life. When the saturation state of calcium carbonate becomes undersaturated the sea water will be corrosive to shells or skeletons made of aragonite or calcite. SINMOD is a coupled hydrodynamic-ice-ecosystem model system established for the Arctic Ocean and the Nordic Seas. A carbon module simulates the transport, mixing, biological transformation and sinking, air-sea interaction and riverine input of inorganic carbon and alkalinity. The ice model handles brine rejection as well as rejection of carbon and alkalinity during formation and further experience with low temperatures. We present results on carbon flux and carbonate saturation from present climatic regime using historical CO_2 concentrations and atmospheric forcing (ERA INTERIM) using IPCC's climatic scenarios rcp4.5 and rcp8.5 for the 21st century.

June 12, 15:10

Projected changes in ocean acidification in the Arctic: effects of ongoing regional modelling

Morten D. Skogen, Solfrid S. Hjøllo and Jerry Tjiputra

Physical fields from the global climate model NorESM under RCP4.5 emission scenario has been downscaled using the ROMS ocean model, and this downscaled physics has been used as forcing for the NORWECOM.E2E ecosystem model including a module for ocean acidification. Focusing on OA state variables and air-sea fluxes of CO_2 and DMS, a comparison is made between the results from the global and regional model for the period 2010-2070 for the Nordic and Barents seas, and the results are compared to other projections and validated against recent observations.

June 12, 16:00

Interaction between temperature and pH on growth and respiration of the planktonic copepod, Calanus finmarchicus

Jeffrey Runge, David Fields, Cameron Thompson, Caroline Durif, Steven Shema, Reidun Bjelland, Anne Berit Skiftesvik, and Howard Browman

In a previous study, we found no negative effect of three pCO_2 concentrations ranging between a control (580 µatm, the ambient concentration at the Austevoll Research Station's seawater intake) and predicted mid-range (1200 µatm) and high (1900 µatm) future levels on physiological rates and processes determining vital rates of the planktonic copepod, *C. finmarchicus*. However, small but significant treatment effects were found in body length and mass (in terms of dry, carbon and nitrogen mass), notably a somewhat larger body size at the mid-pCO_2 treatment. We could not determine whether this result was an artifact of our sampling methods or a real, putatively beneficial effect. In a follow-up study, we reared *C. finmarchicus* from eggs to adult at 12°C and 16°C in seawater with non-limiting food and near ambient (600 µatm) and high (1200 µatm) CO_2 concentrations. The high temperature and high CO_2 treatment represents extreme conditions likely to be encountered by the species at the southern margins of its biogeographical range in the future. Dry weight, C and N mass, lipid content and respiration were measured on stages CV and adult female immediately after molting into the stage. By measuring at a precise marker in the copepod life cycle, this new approach allows accurate comparison of growth and respiration across treatments. The results show a significant increase in mass and respiration rate at 12°C and high CO_2 concentrations. At the higher temperature, respiration rates were significantly increased but body mass was unchanged. These suggest the potential for elevated CO_2/lower pH in the future ocean to have a beneficial effect on *C. finmarchicus* growth rates at

expected temperatures within the copepod's habitat. At extreme temperatures expected at it's southern margin, the results indicate inconsequential effects on growth rate.

June 12, 16:20

Ocean acidification in the Fram Strait-Barents Sea region – effects on modern planktic foraminifera

Siri E. Ofstad, Kasia Zamelcyzk, Tine L. Rasmussen, Melissa Chierici, Angeta Fransson

The ocean has absorbed around one third of the human produced CO_2 through the air-sea interface. However, the increasing level of dissolved CO_2 in the ocean is not without consequences, as it results in a phenomenon referred to as Ocean Acidification (OA). OA induces fundamental changes to the seawater chemistry, reducing pH, the availability of carbonate ions, and the saturation state (Ω) of biologically important calcium carbonate ($CaCO_3$) minerals aragonite and calcite. As the concentration of calcite and aragonite approach undersaturation, it should, in theory, become increasingly harder for organisms such as foraminifera and pteropods to precipitate calcium carbonate shells and skeletons. Planktic foraminifera are microscopic single-celled zooplankton living in the surface ocean. Together with pteropods, planktic foraminifera contribute significantly to the biological carbon pump generating organic and inorganic carbon fluxes down to the deep ocean/seafloor sediment. We have combined planktic foraminifera samples from the water column with water samples from various locations in the Fram Strait-Barents Sea region, including locations with significant amounts of methane seepage. Our aim is to detect a decrease in shell density following the industrial revolution by a comparison with the paleoceanographic record, and to detect differences in shell density between methane seep and non-methane seep sites. We intend to use the Micro-Focus X-ray Computing Tomography (MXCT) – a new robust evaluation method of OA – on the planktic foraminifera to test our hypotheses.

June 12, 16:40

Arctic coralline algae maintain elevated surface pH and carbonate ion concentrations

Laurie Hofmann, Kathryn Schoenrock, and Dirk de Beer

Red coralline algae are projected to be sensitive to ocean acidification, particularly in polar oceans where the carbonate buffering capacity is weak. These algae play key roles as ecosystem engineers in global oceans; thus, their potential sensitivity to global climate change is worrisome, and understanding their calcification mechanism is necessary for making reliable predictions and subsequent policy decisions. Therefore, we investigated the localized carbonate chemistry at the surface of Arctic rhodoliths (free-living coralline algae) and coralline crusts using microsensors. We report, for the first time, surface carbonate ion concentration and pH measurements ([CO32-

]) at the site of calcification. We show that surface pH and [CO32-] are higher than the bulk seawater in the light, and even after hours of darkness. Our results suggest that Arctic corallines have strong biological control over their surface chemistry, where calcification occurs, and that net dissolution in the dark is not currently a threat to these organisms. However, it is still unknown if these algae will be able to elevate surface pH and [CO32-] under ocean acidification conditions.

June 12, 17:00

Natural gradients in carbonate chemistry tell us what to expect

Jason M. Hall-Spencer and S. Agostini

This talk will summarize advances that have been made using natural gradients in seawater pCO_2 to assess the effects of multiple stressors (acidification, eutrophication, warming, invasive species) on a wide range of taxa (e.g. algae, corals and fish). Experiments at CO_2 seeps have shown profound effects of acidification on larval settlement, biomineralization and sublethal stress levels (using transcriptomics). We are also revealing the ecological mechanisms that drive shifts in coastal ecosystems as CO_2 levels rise. Shimoda Marine Station is now leading collaborative international research to assess the likely ecosystem-level effects of ocean acidification in northern latitudes of East Asia. At $\Omega A = 3.3$ (300 ppm CO_2) we have found that calcareous organisms cover most of the intertidal and subtidal rocky substrata yet these groups (e.g. coralline algae, barnacles and oysters) gradually decrease in abundance becoming rare and corroded at sites with seawater $\Omega A < 2.3$ (450-500 ppm). The Japanese seeps show which organisms are resilient to ocean acidification (e.g. Caulerpa spp.) although there is a major fall in the diversity of taxa found at the High-CO_2 stations (900 ppm CO_2). We see opportunities to use these CO_2 seeps as a communication tool to show how carbon dioxide can affect northern latitude livelihoods and seek help in filling knowledge gaps to inform the people that this will affect the most, like those who rely on aquaculture, fisheries and coastal tourism.

June 12, 17:20

When and how to worry about Ocean Acidification: Greenland shrimp case

Brooks A. Kaiser and Lars Ravn-Jonsen

We use a bio-economic model of the Greenland shrimp fishery to study potential OA impacts in Arctic resources. Predicted changes in pH in Baffin Bay describe an anticipated though uncertain drop. Efforts to understand changes in shrimp quantity/quality from OA reflect significant uncertainty and ambiguity about direction and magnitude. Estimates on change in growth parameters show a small, statistically insignificant drop that creates expectation of only limited direct biological shifts in the bio-economic model. Indirect changes to shrimp populations in Baffin Bay from climate change are anticipated due to expected declines in primary production that then result in equivalent reductions in secondary production, but the range could be positive or negative. Thus, the scientific findings on the OA impacts for shrimp are sufficiently

ambiguous that our results find no easily predictable changes in fishery behavior, nor management changes that might accompany it. Current management already includes an assessment model for annual shrimp production including cod predation and involves yearly survey data, a yearly update of the model, and an annual recommendation of catch. With current uncertainty levels, this plan already provides flexibility for management. The long experience of Royal Greenland in the fishery, and its importance in the socio-economic fabric of Greenland, provide more insight into how shifts in shrimp productivity changes from OA might translate to human impacts on the supply side. Efforts to increase lab-level understanding of changes in taste, size, and/or texture should be undertaken that can translate to expected shifts in demand and overall market impacts.

Tuesday, June 13
Plenary Session

June 13, 08:30 (Invited – S1)

The North Atlantic fish revolution, 1500-1700

Poul Holm

Cabot's discovery in 1497 of abundant cod populations around Newfoundland had fundamental geopolitical implications. Through the sixteenth century, marine products were among the first foodstuffs to be thoroughly exposed to globalising processes while climate change (the Little Ice Age) impacted ocean productivity. The Grand Banks fishery offered abundant high-quality low-priced catches to the European market, to new markets further afield in North America and eventually to the slave plantations of the Caribbean. The fish revolution changed the human landscapes around the North Atlantic. In Newfoundland, migration evolved into permanent settlements. In Europe fishermen along the coasts from the Irish Sea to Northern Norway had the choice of migrating across the ocean or give up fishing. Many fishing settlements were deserted as inhabitants took to the road to seek casual work in agriculture or towns. These developments raise questions of the interaction of climate, productivity and preference, which are at the core of understanding human ability to cope and develop. My talk will explore three main questions: (1) what were the natural and economic causes of the fish revolution; (2) how did marginal societies adapt to changes in international trade and consumption patterns around the North Atlantic; and (3) how did consumers, investors, and politics in the major European countries perceive and respond to the fish revolution? The answers may help us understand the role of environment and climate change in the past, how markets impacted marginal communities, and how humans perceived long-term change.

June 13, 09:00 (Invited – S9)

Light, climate change and Arctic pelagic ecosystems

Stein Kaartvedt

Climate change affects geographic distributions of species, and global warming may drive fish and plankton species ranges towards the poles. However, most pelagic species not only have preferences and requirements for temperature, but also strongly depend on the light regime for either food search, predator avoidance or both. As one moves towards the poles, the seasonal changes in light intensity and day length become increasingly extreme, and it thus becomes essential to discriminate the role of the light climate from that of temperatures for biogeographic boundaries of small fish and their zooplankton prey. Also, altered ice cover may affect the distribution of pelagic fish, in turn with potential food chain effects. Such effects may be mediated through changed light conditions, but also the physical structuring of ice cover and ice

floes may define the pelagic habitat and inhabitants through less acknowledged, but potentially important mechanisms. This talk will summarize current knowledge on the effects of photoperiod for some groups of pelagic fish and discuss ideas on how ice cover may affect the distribution of others, with implications for their prey and predators.

June 13, 09:30 (Invited – S5)

Calanus on the edge: biogeographic responses to climate change

Rubao Ji

The lipid-rich copepods of the *Calanus* genus play a critical role in the pelagic food web of mid- and high-latitude oceans. Whether and how their biogeographic boundaries will be impacted by climate change are important but challenging questions due to the interaction of multiple processes operating at different scales. For instance, the underlying large scale changes in temperature and local changes in circulation and food environment can all interact with species life history traits, and have impact on biogeography. In this talk, I will present case studies for *Calanus* species near the edges of their spatial distribution ranges, including one on the northern edge (Arctic) and the other on the southern edge (Gulf of Maine). In both cases, biological-physical coupled individual-based models are used for data integration, sensitivity analysis and hypothesis testing. The results highlight the importance of local dynamics when projecting the impact of ocean warming on the possible shift of biogeographic boundaries.

June 13, 10:00 (Invited -S1)

Practical Fisheries Management in the midst of Climate Change

Jason Link
Senior Ecosystem Advisor and Chief Ecologist, NOAA Fisheries, Woods Hole, MA USA

Evidence for living marine resources responding to a changing climate and oceans is both growing and incontrovertible. These changes manifest themselves in myriads of forms, chief of which is a shift in distribution. Here I briefly review evidence for range shifts in copious marine taxa, both regionally and globally. The story of the global polar shift and tropical crunch is particularly emphasized. Yet it is one thing to document and note these observations. What to do about this shift in fisheries production and distribution remains a major challenge. Returning to typical fisheries management protocols, I explore how and where in the process we can account for these climate change effects. A range of options and "insertion" points exist, with a proposed set of decision trees perhaps a useful first step at addressing the issue. The salient point is that there is significant change, often beyond the range of variance in what we have observed, and despite decades of debate on the relative role of external and internal population factors, we can no longer afford to ignore such impacts of the broader environment. I conclude with a renewed, more focused, action-oriented call for ecosystem-based fisheries management, recognizing that a

systems-based perspective may offer more options, stability and even hope than a taxa-by-taxa basis.

S1 - Paleo-Ecology

June 13, 11:00

Hydrographic changes in the subpolar North Atlantic at the Medieval Climate Anomaly (MCA) to Little Ice Age (LIA) transition inferred from fossil diatoms

Dmitry V. Divine, A. Miettinen, K. Husum, and N. Koc

A network of four marine sediment cores from the northern North Atlantic was used to study hydrographic changes in surface water masses during the last 2000 years with a special focus on the MCA to LIA transition. The cores were recovered from the sites located on main pathways of warm Atlantic water to the Arctic and the cold outflow from the Arctic. The cores were analyzed for planktonic diatoms with a high temporal resolution. Past changes in the spatial distribution of surface water masses were studied using Q-mode factor analysis via typical species compositions in downcore diatom assemblages. SSTs were reconstructed using transfer functions. Analysis revealed a complex regional pattern of changes in the structure of circulation during the MCA/LIA transition (1200-1400 AD). In the Norwegian Sea, the factors associated with assemblages typical for warmer and saline North Atlantic waters are displaced by colder and fresher water dwelling diatoms suggesting an eastward migration of mixed Arctic/Atlantic water masses into the Norwegian Sea. The two cores south of Iceland show a westward propagation of a warm water as evidenced by assemblages, which today are typical for the waters ca 5° farther south. At the SE Greenland Shelf, an abrupt shift in factors associated with different sea-ice zone dwelling diatoms signifies an inflow of the cold and saline mixed water masses from the area north of Iceland. Such regional patterns of hydrographic changes agree well with a hypothesis of a persistent shift in the vigor of the two main branches of the North Atlantic Drift (NAD) during the onset of LIA, namely strengthening of the Irminger current and a parallel weakening of the Norwegian Atlantic current. Modeling studies also corroborate this hypothesis demonstrating the possibility of such shift triggered by persistent negative volcanic/solar forcing during the studied period.

June 13, 11:20

Sea-ice and sea surface temperature changes off West Greenland over the past 11.000 years using the first regional diatom dataset

Diana Krawczyk, Matthias Moros, Jeremy Lloyd, Jacob Høyer, Arto Miettinen, Andrzej Witkowski, and Antoon Kuijpers

Holocene oceanographic conditions in Disko Bay, West Greenland were reconstructed from high-resolution diatom records derived from two marine sediment cores. A modern dataset composed of 35 dated surface sediment samples collected along the entire West Greenland coast accompanied by remote sensing data were used to develop a diatom transfer function to

reconstruct April Sea Ice Concentration (SIC) supported by July Sea Surface Temperature (SST) in the area. Our quantitative reconstruction shows that oceanographic changes recorded throughout the last c. 11000 years reflect seasonal interplay between spring (April SIC) and summer (July SST) conditions. Our records show clear correlation with climate patterns identified from ice core data from GISP2 and Agassiz-Renland for the early to mid Holocene. The early Holocene deglaciation of western Greenland Ice Sheet was characterised in Disko Bay by initial strong centennial-scale fluctuations in April SIC with amplitude of over 40%, followed by high April SIC and July SST. These conditions correspond to a general warming of the climate in the Northern Hemisphere. A decrease in April SIC and July SST was recorded during the Holocene Thermal Optimum reflecting more stable spring-summer conditions in Disko Bay. During the late Holocene, high April SIC characterised the Medieval Climate Anomaly, while high July SST prevailed during the Little Ice Age, supporting previously identified anti-phase relationship between surface waters in West Greenland and climate in NW Europe. This anti-phase pattern might reflect seasonal variations in regional oceanographic conditions and large-scale fluctuations within the North Atlantic Oscillation and Atlantic Meridional Overturning Circulation.

June 13, 11:40

Growth and trophic level of Northeast Atlantic cod in the last millenium

Guðbjörg Ásta Ólafsdóttir, William P Patterson, Gróa Pétursdóttir, Hlynur Bárðarson, Snæbjörn Pálsson, and Ragnar Edvardsson

Growth rate of fish is highly plastic and varies with both food availability and temperature. In the 20th and 21st centuries length-at-age has declined for many commercially exploited fish species, a trend that may reflect fisheries-induced selection. Climate change is also expected to affect fish growth and size at maturation. Long term historical records of fish growth and size are needed to interpret ongoing growth trends in long term context. The medieval and early modern periods were characterized by rapid increase in marine fisheries in the North Atlantic, at the same time as the climate cooled with the onset of the “little ice age” and subsequent temperature fluctuation. Reconstructing growth of Northeast Atlantic cod in this period is therefore of particular interest. In the current study, we examine Atlantic cod otoliths and vertebrae from an archaeological excavation of a historical fishing site in NW-Iceland, dated to AD 970 – AD 1910. First, we use otoliths to estimate and examine change in growth curves and second, we examine stable isotope values δ13C and δ15N from the cod vertebrae, as proxies for environment – particularly temperature – and trophic level. There was a notable reduction in size at age during the 17th century and this was primarily explained by low 0+ juvenile growth. Conversely, during the warmer periods, AD 1300- AD 1500, growth curves were less steep, suggesting reduced adult growth. The reduction in 17th century growth coincided with a recorded temperature minimum as well as low δ13C values whereas the low adult growth in the warm medieval period coincides with lower δ15N values. However, no consistent shifts in growth or trophic level were observed providing a valuable baseline for modern fisheries science.

June 13, 12:00

Reconstructing 2,000 years of walrus foraging in a changing Arctic climate

Casey Clark, Anne de Vernal, Lara Horstmann, and Nicole Misarti

Declines in Arctic sea ice have led to concern about the future health of ice-dependent animal populations. Pacific walruses (*Odobenus rosmarus divergens*) rely on sea ice as a platform for giving birth, molting, and resting between foraging bouts, making this species vulnerable to warming climates and reduced sea-ice coverage. This study uses stable isotope ratios of carbon and nitrogen (δ13C and δ15N) in walrus bone collagen and sea-ice reconstructions to investigate changes in diet and feeding locations across several thousand years. Samples were obtained from archaeological digs, museum collections, and from present day Alaska Native subsistence harvests. Temporal coverage of the compiled dataset extends back as far as ~3,500 years before present (BP), with consistent coverage from ~2,000 BP to present. This timeframe includes two periods of relatively low sea-ice cover and high primary production (2500 –1400 BP, 500 – 350 BP), as well as two periods of relatively high sea-ice cover and low primary production (1400 – 500 BP, 350 – 25 BP). Historic and modern samples span ~100 years, providing finer-scale coverage of the most recent decades of rapid warming and extensive sea-ice loss. Preliminary analyses indicate a broad range of δ13C and δ15N values (-16.9 – -11.6‰ and 9.9 – 18.9‰, respectively) and significant differences in both δ13C and δ15N of walruses from warm and cold periods during the last 2000 years; however, the direction and magnitude of these differences were not consistent, suggesting that sea-ice extent is not the most important factor driving variability in Pacific walrus diet. Walrus foraging appeared relatively unchanged across the last century, with the exception of declines in both δ13C and δ15N during the most recent decade. This study provides novel insight into the impacts of climate change on walrus foraging.

June 13, 12:20

Prehistoric demographic fluctuation in Arctic Norway: correlations to climate change and cultural processes

Charlotte Damm, Marianne Skandfer, Peter Jordan, Erlend Kirkeng Jørgensen, and Kenneth Webb Vollan

With evidence of human settlement from 9500 cal BCE and numerous large scale excavations the archaeological record from Arctic Norway is uniquely suited for studies of long term demographic fluctuations as well as temporal and spatial variations in population density and mobility in the far north. Inevitably though, the nature of the remains from early Arctic Hunter-Gatherers also present source critical challenges for such reconstructions. A new research project based at the Arctic University of Norway will explore the potential of a range of methods to reconstruct multi-scale patterns in prehistoric demography. The insights and approach will be of wider relevance to the circumpolar area, due to the similar character of archaeological and

environmental datasets across the region. The patterns we reconstruct in Arctic Norway will be analysed in order to identify whether changes in demography were linked to impact of climatic and environmental change, or to major culture historical processes, such as the introduction of new technologies or the movement of new populations. This paper provides an overview of the new project and presents some preliminary insights into possible correlations between climate change and fluctuations in population density, size and organisation.

June 13, 13:30

Multi-decadal to millennial scale climate changes during the Holocene

Kana Nagashima

Knowledge of Holocene climate variability is important for complete understanding of the background natural variability and its impact on coastal/marine systems. Earlier, I showed centennial- to millennial-scale Westerly jet-Aleutian Low changes during the Holocene estimated from Aeolian dust records from marine/lacustrine sediments. For example, the Westerly jet was expected to shift northward (following weakened Aleutian Low) during 11.5–10, 7–5, and 3.5–1.5 kyr B.P. with decadal-scale N-S oscillations. Such changes could (at least partly) explain long-term changes in the primary productivity of the North Pacific. Here I compile other paleoclimate proxies from North Pacific and surrounding regions, and discuss the nature and dynamics of the climate variability during the Holocene.

June 13, 13:50

Holocene upper ocean temperature development in the sub-polar North Pacific: spatial patterns, heterogeneities vs. common trends

Lester Lembke-Jene, Ralf Tiedemann, Lars Max, Dirk Nuernberg, Xun Gong, Jianjun Zou, Limin Hu, Gesine Mollenhauer, Gerrit Lohmann

Subarctic regions are most sensitive to climate change, and reversely provide dramatic feedbacks to the global climate. Paleoclimate studies in these regions are of vital importance for a better understanding of the natural processes in the climate system prior to the influences of modern human activities. We show new results based on a collection of sediment cores covering key regions in the Northwest Pacific, with a focus on paleoceanographic changes over the current Holocene warm phase. Analyses of multiple sea surface temperature records from the Okhotsk and Bering Seaa confirm a spatially heterogenous, but no simple warming or cooling pattern over the last 10 ka. We further compare our alkenone-derived SST reconstructions to stable isotope and foraminiferal Mg/Ca-based temperature reconstructions of the upper ocean mixed layer, following a multi-proxy apporach. We find evidence for a baseline change in upper ocean stratification, initiated over the mid-Holocene between 6 and 4 ka. Using results from the high-resolution AWI-ECHAM6 – FESOM Climate Model in a global configuration, with a regional focus on the marginal seas of the Northwest Pacific to provide underlying dynamics, we presume

that extratropical atmospheric dynamics are involved in shaping the climatic baseline configuration of our study region, including a highly dynamic sea-ice cover in the Okhotsk and Bering Sea.

June 13, 14:10

Exploring the relationship between proxy-data of ocean productivity and sockeye salmon in southwestern Alaska from the Mid to Late Holocene

Nicole Misarti, Lester Lembke-Jene, Bruce Finney, Jason Addison, Naomi Harada, Mark Shapely, Ben Fitzhugh, and William Brown

Ocean and lake sediment cores from the subarctic NE Pacific Ocean provide the basis for our understanding of long-term fluctuations in both ocean primary productivity and sockeye salmon (*Oncorhynchus nerka*) abundance beyond the modern instrumental record. Sediments from multiple southwest Alaskan lakes yield proxy data on climate and salmon returns over the past 5000 years, while ocean cores yield information on primary productivity, sea surface temperatures, and species dynamics of phytoplankton groups. Fluctuating numbers of returning sockeye salmon appear to correspond with large scale climate and oceanic change. They also appear to correlate with changes in past human population size on adjacent coastlines, even when the populations in question are not focused on salmon as their major resource. We hypothesize that changes in sockeye salmon stocks can be utilized as a proxy for subarctic NE Pacific upper trophic level productivity, suggesting that a connection exists between large-scale regional ecosystem dynamics and long-term natural climate variability, comprising several trophic levels from photoautotrophic primary producers to top predators (including humans) in the subarctic NE Pacific. We use a compilation of primary productivity proxies (including biogenic opal, CaCO3, and organic carbon), surface/upper ocean temperature reconstructions, nitrogen isotope, and nutrient utilization data from three ocean cores to investigate this hypothesis. In addition, isotope data from five cores retrieved from sockeye spawning lakes, as well as human population models from the subarctic NE Pacific spanning the last 5,000 years will also be used to explore this premise.

June 13, 14:30

Multicentennial record of Labrador Sea primary productivity and sea-ice variability archived in coralline algal Ba/Ca

Phoebe Chan, J. Halfar, W. Adey, S. Hetzinger, T. Zack, G.W.K. Moore, U.G. Wortmann, B. Williams, and A. Hou

Accelerated warming and melting of Arctic sea ice has been associated with significant increases in phytoplankton productivity in recent years. Utilizing a multiproxy approach, we reconstruct an annually-resolved record of Labrador Sea productivity related to sea-ice variability in Labrador, Canada that extends well into the Little Ice Age (LIA; 1646 AD). Barium-to-calcium ratios (Ba/Ca) and carbon isotopes (δ13C) measured in long-lived coralline algae demonstrate

significant correlations to both observational and proxy records of sea-ice variability, and show persistent patterns of covariability broadly consistent with the timing and phasing of the Atlantic Multidecadal Oscillation (AMO). Results indicate reduced productivity in the Subarctic Northwest Atlantic associated with AMO cool phases during the LIA, followed by a step-wise increase from 1910 to present levels – unprecedented in the last 363 years. Increasing phytoplankton productivity is expected to fundamentally alter marine ecosystems as warming and freshening is projected to intensify over the coming century.

June 13, 14:50

Integrating human paleodemography and ecology around the North Pacific Rim

Ben Fitzhugh, William Brown, Nicole Misarti, Katsunori Takase, and Andrew Tremayne

In this talk we present an analysis of paleodemographic histories of human settlement from several regions around the North Pacific Rim. We do this as a step towards evaluating the hypothesis that long-term population dynamics in these regions were driven by bottom-up ecological dynamics with large regional scale patterns that affected food security for hunter-gatherer populations in the past. If the hypothesis is accurate, we expect large enough spatial and temporal scale dynamics to be reflect in the spatial auto-correlation of regional population patterns. We will compare human communities living on marine vs mixed marine-terrestrial and purely terrestrial subsistence economies from the Gulf of Alaska to the Sea of Okhotsk. We predict that marine systems provided more stable food security (lower amplitude fluctuations) compared to terrestrial ecosystems of similar spatial grain. We use large radiocarbon data sets as our primary data set for this analysis and look to connect the results with ecological analyses being conducted by other PESAS colleagues.

S9 - General Open Session

June 13, 11:00

Exploring ecosystem dynamics from the annual pelagic survey in Kongsfjorden in summer

Haakon Hop, Philipp Assmy, Slawek Kwasniewski, Marta Gluchowska, Jozef Wiktor, and Anette Wold

Long-term data sets are important for our understanding of climate-related changes in the Arctic environment and its biological communities. The purpose of the annual pelagic survey in Kongsfjorden during summer is to monitor changes in oceanography, phytoplankton and zooplankton communities in relation to variation in ocean climate. This time series represents the longest of its kind in the Arctic, with annual sampling since 1996 and with subsequent extension to the long-term ecological research observatory Hausgarten (AWI) in Fram Strait. Kongsfjorden functions as a climate-change indicator in the Arctic because it is influenced by variable climate signals related to advection of Atlantic water from the West Spitsbergen Current and Arctic water from the shelf. The inner part of the fjord is most "Arctic" because of cold local water and glacial run-off from large tidewater glaciers. The climate signal is reflected in the community composition of phyto- and zooplankton, as well as fish populations, in the fjord. The Arctic copepod, *Calanus glacialis*, tends to be more abundant during "cold years", when the influx of Atlantic water is low, whereas the smaller Atlantic *Calanus finmarchicus* dominates in "warm" years with a strong influx of Atlantic water. Oceanic warming cycles since 2006 have led to an increased abundance of C. finmarchicus, krill (*Thysanoessa* spp.), Atlantic amphipods (*Themisto abyssorum*), and, particularly, small copepods. Dinoflagellates and smaller flagellates dominate the protist plankton during summer, and the standing stock of *Calanus* is then typically larger than the stock of primary producers, indicating strong top-down control as well as advection of Atlantic pelagic grazers. The Norwegian Polar Institute is responsible for this survey, which is conducted in collaboration with IOPAS, UNIS and UiT. All the data are stored in the Marine database at NPI. This survey is an integral part of MOSJ - Environmental monitoring – Svalbard and Jan Mayen (www.mosj.npolar.no/).

June 13, 11:20

Methne release at underwater mounds in the Barents Sea and its impact on Arctic macro-benthic faunal communities

Emmelie Åström, Arunima Sen, Michael L. Carroll, William G. Ambrose Jr., and JoLynn Carroll

Cold seeps are locations where hydrocarbons emerge from the seabed, fueling chemosynthetic primary production that can support macrofaunal communities via symbiotic relationships or

trophic interactions. Seafloor methane seepage has been localized in association with gas hydrate bearing mounds (~ 380 m water depth), on the western Barents Sea shelf (76° N), south of Svalbard. During the summers of 2015 and 2016, an underwater camera system (TOW-cam) and a remotely operated vehicle (ROV) were used for seafloor mapping and to collect benthic samples for macrofaunal community analysis at this cold seep system. The sea floor was characterized by soft sediments mixed with methane-derived carbonate outcrops and patches of microbial mats. Occasionally, the seabed was densely colonized by obligate chemosymbiotic worms, (Siboglinidae), with up to 8000 ind. m-2 in areas of active seepage, thus demonstrating that chemosynthetic processes are influencing this benthic system. In addition, aggregation of heterotrophic species, (anemones), and also commercially interesting fishes and crustaceans were seen in relation to seep features such as the microbial mats, carbonates and chemosymbiotic worm tufts. The highly-localized seepage drives strong macrofaunal community-level effects over small spatial scales (meters) at these methane seeping mounds. The gas seepage creates a heterogeneous habitat where chemosymbiotic organisms co-occur with conventional fauna of the region.

June 13, 11:40

Why do some redfish grow big and other don't?

Natalia Llopis Monferrer and Benjamin Planque

Redfishes inhabit the boreal and subarctic waters of the North Atlantic Ocean. Golden redfish (*Sebastes norvegicus*) is a long-lived (>50 y), late maturing (>10 y) species of commercial interest, distributed along the coast and shelves of Norway down to approximately 400 m depth. In recent years, analyses of size-at-age data have revealed two distinct growth trajectories for this species. While some individuals appear to grow slowly after reaching sexual maturity (~ 15 years and 37 cm), other individuals continue to grow throughout their lifetime up to sizes that can reach >100cm. The former growth pattern resembles that of the sibling species beaked redfish (*S. mentella*) while the latter is closer to what is reported in the literature for *S. norvegicus*. In this study, we investigate several non-exclusive hypotheses to explain the variation in golden redfish growth patterns: a) growth dependence on environmental conditions, habitat, geography and depth, b) taxonomical misidentification, c) hybridization between *S. mentella* and *S. norvegicus*, d) error in age determination and e) co-occurrence of distinct life-history contingents within a single population. Using empirical observations from fisheries and research surveys in the Norwegian Sea over the last 3 decades, we evaluate the plausibility of these hypotheses and discuss their implication for the dynamics and management of golden redfish in the Northeast Atlantic.

June 13, 12:00

In situ study of the functional response of cod to capelin using broadband acoustics and trawl sampling

Georg Skaret, Johanna Fall, Per Fauchald, Øyvind Fiksen, Harald Gjøsæter, Edda Johannesen, Geir Odd Johansen, and Espen Johnsen

The cod-capelin interaction is one of the most studied ecological interactions in the Barents Sea. More than 360 000 Barents Sea cod stomachs have been sampled and analyzed since the mid-80s, and the cod-capelin link is taken explicitly into account in the stock prediction model used in the capelin assessment. However, the functional response, i.e. how the intake rate of individual cod changes with different capelin densities under different environmental conditions, has not been studied directly in the field. The obvious reason for this is that in situ data providing information on individual cod-capelin interactions are extremely challenging to collect. As part of an ongoing research project, we attempted to use acoustic broadband technology with the aim of acquiring such data. This technology has only recently been made available, and provides a potential for collecting data of much higher vertical resolution than conventional echo sounders. The application of broadband technology enables us to resolve attacking cod and schooling capelin down to single individuals. We aimed at combining the acoustic sampling with frequent stomach sampling from trawl hauls, as well as measurements of hydrography and light conditions. Here we present preliminary results.

June 13, 12:20

INTAROS - Integrated Arctic Observation System - a new EU Horizon 2020 Research and Innovation project

Geir Ottersen and Stein Sandven

INTAROS is the largest of four H2020 projects supporting EU´s increased focus on the Arctic and an important contribution to the implementation of EU´s Arctic Strategy. Professor Stein Sandven, NERSC, Norway coordinates INTAROS, which brings together expertise from 49 collaborating organizations in 20 different countries and has an overall budget of 15,5 M Euros. This talk will present INTAROS in general and especially the contributions towards increased understanding of Arctic marine ecology and related applications to management. The environment in the Arctic region is changing significantly and rapidly, affecting, e.g., natural hazards, extreme weather, sea level change, coastal erosion and ecosystem alterations. Furthermore, human activities are expected to increase, causing additional impact on the vulnerable environment. In order to ensure sustainable development of the Arctic, INTAROS will develop an efficient integrated Arctic Observation System (iAOS) by extending, improving and unifying existing and evolving measurement systems. The project will capitalize on existing observing systems and databases, but will also install new and dedicated instrumentation to measure the marine, atmosphere, cryosphere, and terrestrial environments. These new in-situ

measurements will fill information gaps, complementing remotely sensed data and improving models. An important part of INTAROS is to demonstrate applications based on the iAOS and tailored to support different groups of decision-makers and stakeholders, including researchers, and fisheries and environmental managers. We will use the capabilities of the iAOS to integrate data from a large set of various databases into ecosystem simulation models through a data assimilation approach. The iAOS input will be applied towards testing and running the models NORWECOM, ATLANTIS and ERGOM. Further, INTAROS aims towards expanding the well developed reporting and management systems for fisheries and the environment in the southern Barents Sea and off West Greenland to other parts of the Arctic.

June 13, 13:30

Characteristics of pelagic and demersal fish communities of the US Beaufort Sea

Brenda L Norcross and Brenda A. Holladay

Knowledge of fish communities in the central and eastern US Beaufort Sea was very limited until a recent multi-year study. In the open-water seasons of 2012, 2013 and 2014, multi-disciplinary cruises were conducted over almost 400 km. Pelagic fish were sampled by a midwater trawl with a 1 mm mesh codend; most fishes collected were age-0. In the central region (151–150ºW), there was no shelf-slope component to the pelagic community. In contrast, the eastern area (146–136ºW) had distinct shelf and slope communities. Demersal fish were sampled at the same stations using a 3-m beam trawl with a 4 mm mesh codend. Demersal fish communities displayed distinct differences between shelf and slope habitats, with 200 m being a transition zone. Communities along the shelf had a higher abundance of smaller fishes; whereas, slope communities had fewer, but larger, individuals. Shelf fishes typically had lifespans of about 5–7 years. Slope communities were defined by fishes with life spans of more than 20 years. Depth, temperature, salinity, and water mass affected the structure of both pelagic and demersal fish communities; no one clear cut environmental variable could be identified as the most important because those four factors are confounded. In the US Beaufort Sea, as for all adjacent Arctic Seas, continental shelf communities are different from those on the slope.

June 13, 13:50

*Overlap in the distribution and diet of capelin (***Mallotus villosus***) and Polar cod (***Boreogadus saida***), as related to environmental conditions in the boreal ecosystems of the Newfoundland Shelf and Barents Sea*

Fran Mowbray, Padmini Dalpadado, Harald Gjøsæter, Pierre Pepin, Bjarte Bogstad, Andrey Dolgov, and Irina Prokopchuk

Capelin (*Mallotus villosus*) and polar cod (*Boreogadus saida*) are the primary forage fish species in both the Newfoundland Shelf and Barents Sea Ecosystems, with polar cod tending to be distributed more northerly and in colder waters than the capelin. While physical environmental

factors have been linked to production of capelin, both environmental conditions and abundance are factors in the coincidence and distribution of the two species. In both systems capelin distribution expands, and/or shifts northward in response to increasing population size. However, in recent years the northward expansion of capelin in the Barents Sea has been accompanied by a retraction and decline of polar cod. In a similar period in Newfoundland, capelin has also shifted northward, but distribution of polar cod has remained unchanged. We examine these distribution changes in light of physical environmental conditions including ice conditions, and prey distribution and forage species abundance. We also explore the potential for feeding competition between capelin and polar cod by examining diet overlap using data from 2005-2015 (Barents Sea) and 2008-2015 (Newfoundland) and comparing these new data with available historic data from the Barents Sea. Finally, the environmental drivers of zooplankton community structure and its relation to forage fish feeding and distribution on the Newfoundland-Labrador shelf is examined and the potential implications of ongoing climate related changes discussed.

June 13, 14:10

Changes in biological characteristics of walleye pollock associated with biomass fluctuation in the East Sea during the late 20th century

Minkyoung Bang, Sukyung Kang, Suam Kim, and Chan Joo Jang

Walleye pollock (*Gadus chalcogrammus*, hereafter pollock) is one of the popular fishery species in Korea, and Korea is one of the major producer and consumer of pollock. Pollock used to be one of the most dominant fishery species in South Korean waters until the 1980s. However, its catch had rapidly decreased through the 1990s, and eventually, Korean pollock stock was completely collapsed after 2008. Although it was expected that the biological characteristics of pollock would be adjusted in accordance with the biomass fluctuation, the systematic investigation on pollock resources in South Korean waters was not possible because the major spawning ground located in North Korean waters. The National Institute of Fisheries Science (NIFS) has collected information of pollock in the East Sea since the mid-1960s. Using these data, we tried to investigate biological characteristics of pollock during high (1976-1985) and low (1991-2000) biomass periods. Biological characteristics showed density-dependent growth: Dominance of larger size pollock, higher condition factor, and larger length at maturity in the low biomass period. Concurrently, monthly examination of gonado-somatic index (GSI) revealed that there was a density-dependent process in reproductive property of pollock stock in Korean waters.

June 13, 14:30

Changes in specific gravity of larval Gadoid fish during their development

Hwa Hyun Lee and Suam Kim

Knowledge of the changes in specific gravity of fish eggs and larvae is essential information for modeling their vertical, spatial, and temporal distributions during development. Walleye pollock and Pacific cod are representative subarctic Gadoid species in the North Pacific, and the low seawater temperatures of their habitats result in slow development and growth during their early life history (ELH). Recruitment success of pollock and cod might be partly contributed by the ELH's vertical positioning which is caused by the interaction between organism's specific gravity and the density of surrounding water. The specific gravities at various size classes of pollock and cod larvae were measured using the Egg Density Gradient Apparatus (EDGAR). Totals of 114 pollock and 225 cod larvae were used for instantaneous specific gravity measurements in EDGAR. A concentration of 1:30000 (i.e., 0.0033 %) MS222 (anesthetic) was added to the EDGAR to prevent disturbance of the water column density gradient. Results indicated that the specific gravity (mean±standard deviation, sample size) of prematurely hatched pollock larvae (<3 mm standard length (SL)) showed the lightest (1.0251±0.00049, n=31) compared to normal hatching larvae. In general, the smaller pollock larvae had higher specific gravity (1.02567±0.00169, n=7 for 3.0-4.0 mm SL), which decreased gradually as the larvae grew (1.02561±0.00106, n=17; 1.02539±0.00086, n=21; 1.02525±0.00103, n=38 for 4.0-4.5, 4.5-5.0, and 5.0-6.0 mm SL, respectively). The specific gravity of cod larvae was higher at hatching (1.03655±0.00146, n=4, mean SL=3.69 mm) than pollock larvae; cod larvae also tended to decrease as they got bigger. The specific gravity seemed to be stabilized at 6 days after hatching (1.02590±0.00212, n=14, mean SL=4.70 mm), and the cod larvae could float eventually in the water column. Note that the February sigma-t at the cod spawning ground in Korea was 26.12 in 2012 and 26.62 in 2013.

June 13, 14:50

Are myctophid fish important food for seabirds?

Yutaka Watanuki and Jean-Baptiste Thiebot

Mesopelagic myctophid fish are a key component of marine ecosystems in the World's oceans, linking primary consumers and predators. Among marine predators, seabirds constitute a key group. However, the importance of myctophid fish as food for seabirds has been investigated at the regional scale only, and its overall significance at the global scale remains unaddressed so far. This review of the stomach content analyses from all surveyed seabird species (248 publications, encompassing 269 seabird species (or complex of species) from 13 families or sub-families studied at 165 sites or regions) indicates that myctophids appear to constitute considerable amount of the food in penguins, albatrosses, and petrels, among species foraging in oceanic habitats, especially in high latitudes, and among those feeding often in the night. Recent analyses of the fatty acid signature of stomach oil, which reflects the prey species consumed about a week before sampling, also show that myctophids are an important prey for seabirds exploiting oceanic habitats distant from the colonies. Current efforts to survey seabirds outside of the breeding period, when these central-place foragers may show more oceanic distribution than during the breeding period, may bring considerable change of perspective about the global importance of myctophids as food for seabirds.

June 13, 15:10

Cross-shelf distributions and abundances of seabirds reflect prey distributions and abundances related to the timing of sea-ice retreat in the southeastern Bering Sea

George L. Hunt, Jr., Martin Renner, Lisa Eisner, Kathy Kuletz, Sigrid Salo, Patrick Ressler, Jarrod A. Santora, and Carol Ladd

The potential impacts of future climate warming on marine ecosystems can be assessed by examining the effects of past and present-day variation in climate. Here we report how seabird use of the southeastern Bering Sea responded to interannual variation in ocean-climate conditions by comparing the cross-shelf distribution of seabirds in years of early and late sea-ice-retreat. We predicted that, in years when prey resources were expected to be scarce, seabird species would concentrate in frontal regions where the availability of zooplankton and forage fish might be enhanced. To test this, we used 40 years of surveys on the summer (15 June – 31 August) at-sea distribution and abundance of seabirds and recent data on the distribution of zooplankton and forage fish. We found that, although there were substantial changes in the distribution of seabird species between years with early and late ice retreat, there was no overall shift into frontal regions. Instead, in years with early sea-ice-retreat, seabird species that use the Inner Shelf Domain moved offshore, and species that foraged off the shelf moved toward the shelf, or onto the shelf. In years with early sea-ice-retreat, the euphausiid and the copepod *Calanus marshallae* were scarce and the centers of abundance of *C. marshallae* and euphausiids shifted seaward, but there was little change in the cross-shelf distributions of Neocalanus spp. copepods

S5 - Future Subarctic and Arctic Marine Ecosystems under Climate Change

June 13, 11:00

Bottom water acidification and warming on the Eurasian Arctic Shelves: Dynamical downscaling projections

Phil Wallhead, Richard Bellerby, Anna Silyakova, Dag Slagstad, and Alexander Polukhin

The impacts of global warming and oceanic CO2 uptake on the surface ocean environment have received substantial attention, but few studies have addressed impacts on bottom water at the moderate shelf sea depths that comprise much of the Arctic Ocean, despite their importance as habitats for benthic organisms and demersal fisheries such as cod. We used the SINMOD ocean biogeochemical model to downscale bottom water acidification and warming on the Eurasian Arctic Shelves. A model hindcast produced 14 to 18-year acidification trends that were largely consistent with observational estimates at stations in the Iceland and Irminger seas, for depths < 400 m where model spin-up was sufficient. Projections under SRES A1B scenario revealed a 50-year decline in bottom pH, mostly by 0.15–0.20 units, at depths 50–500 m on the Norwegian, Barents, Kara, and East Greenland shelves. Seasonal bottom water under-saturation with respect to aragonite occurred over most of the Kara Shelf by 2070 and over most of the northern Barents and East Greenland shelves by 2100. Shelf acidification was mainly driven by the accumulation of anthropogenic CO_2, and was combined with warming of 1–3 °C over 50 years as a multi-stressor. Future studies should investigate the potential impacts on Arctic benthic organisms and ecosystems, and should include the Kara Sea and Russian shelves as possible bellwethers of shelf acidification.

June 13, 11:20

Effects of temperature, CO2, and salinity on the dynamics of phytoplankton communities in the western Arctic Ocean

Koji Sugie, Amane Fujiwara, Sohiko Kameyama, Shigeto Nishino, Naomi Harada

The rapid climate change such as warming, sea-ice reduction and ocean acidification in the Arctic Ocean can influence ecosystem dynamics including biogeochemical cycling. This study examined the effects of temperature, CO_2 and salinity on plankton communities in the Arctic Ocean using on-board manipulation experiment during R/V Mirai MR15-03 and MR16-06 cruises. Temperature (control and + ~4°C), CO_2 (control and + 300/500 μatm), and salinity (control and −5%) were manipulated using thermostatic circulator, the addition of high-CO_2 seawater, and pure water, respectively. The higher temperature enhanced the growth of phytoplankton community in terms of chlorophyll-a in both incubations. Nano-sized (~2–10 μm)

phytoplankton growth was increased due to the higher temperature but not CO_2 in the MR15-3 community, whereas the higher CO_2 levels but not higher temperature enhanced their growth in the MR16-06 community. Pico-sized (< 2 μm) phytoplankton growth was unchanged in the MR15-03 community, but that was enhanced in the MR16-06 community under the higher temperature conditions. The effect of lower salinity rarely affected phytoplankton growth. Phytoplankton pigment and nutrient drawdown ratio imply that the contribution of diatom biomass to the total phytoplankton was slightly decreased because of the higher temperature in the MR15-03 community. The growth of larger phytoplankton group (> 10 μm) responded only against temperature increases in both incubations. Our results showed that phytoplankton dynamics in the Arctic Ocean could be altered by each of any perturbations but the responded community differed each other. The higher temperature and CO_2 levels could act as a negative feedback on atmospheric CO_2 concentrations via decreasing large-sized phytoplankton such as diatoms.

June 13, 11:40

Bloom stage characteristics and impact on future productivity in an Atlantic-influenced Arctic marine ecosystem

Marit Reigstad, Lena Seuthe, Ingrid Ellingsen, Maria Lund Paulsen, Carlos Duarte, Elisabeth Halvorsen, Peter Lavrentjev, Kalle Olli, Patricia Matrai, Achim Randelhoff, Marina Sanz-Martin, Dag Slagstad, Camilla Svensen, Jean-Eric Tremblay, Maria Vernet, and Josef Wiktor

Understanding how environmental factors influence the production and flow of energy through the pelagic food web, as well as characterization of different modes in the seasonal productive cycle, are fundamental tools for monitoring and predicting potential future changes in Arctic marine ecosystems. The aim of the present investigation, carried out as part of the CarbonBridge project, was to describe characteristics of the bloom and regenerative phases of the productive cycle in the Atlantic gateway to the Arctic Ocean, and to isolate the most important bloom indicators useful for future studies. A suite of characteristics, including physical, biogeochemical, and biological components, were evaluated for six process stations in May and August in the seasonal ice zone northwest of Svalbard. Size-fractionated Chl-a, the f-ratio (ratio of new- to total production) and community respiration proved to be better indicators of the bloom stage than total Chl a concentrations and total primary production rates in this region. The physical structure of the water masses, as well as grazing impact, provided important explanatory factors. An experimental exclusion of grazers >90 μm resulted in an explosive bloom development in which all nutrients were consumed, and Chl-a concentrations - twice those obtained in in-situ - developed within a week, indicating the importance of top-down regulation. To evaluate how observed patterns and characteristics compare to a continuous bloom development, a simulation of the phytoplankton bloom and grazer development was performed using the physical-biological SINMOD model. The results improve a) our ability to identify the bloom stages in the seasonal ice zone of this region, b) our understanding of potential changes in carbon flow resulting from changes in the relative importance of new- versus regenerated production, and c) our knowledge on how well model simulations and observations compare.

June 13, 12:00

Algal blooms under the new Arctic ice regime

Philipp Assmy, Mar Fernández-Méndez, Lasse Mork Olsen, Hanna M. Kauko, Pedro Duarte, Anette Wold, Haakon Hop, Christopher J. Mundy, Amelie Meyer, Achim Randelhoff, Alexey K. Pavlov, Anja Rösel, Polona Itkin, Harald Steen and Mats A. Granskog

The ice cover of the Arctic Ocean is rapidly transforming from a thicker multiyear ice cover to a thinner and largely seasonal first-year ice cover with significant consequences for the ice-associated ecosystem. During the Norwegian young sea ICE drift expedition (N-ICE2015), we studied ice-algal and phytoplankton blooms under the new ice regime as the sun returned to the Arctic. We observed an early phytoplankton bloom below snow-covered ice resulting from the thinner and more dynamic sea ice that allowed more light transmission to the ocean, especially through leads. The under-ice bloom was dominated by the haptophyte algae *Phaeocystis pouchetii* in contrast to previous under-ice blooms that were dominated by diatoms. This shift in phytoplankton species dominance, associated with early under-ice phytoplankton blooms, could have important implications for the strength of the biological carbon pump and energy transfer in Arctic marine food webs. Preceding the *Phaeocystis* bloom, a smaller bloom of the phototropic ciliate *Mesodinium rubrum* developed at the ice-water interface of a refrozen lead. Apparently, the high light transmission through the thin lead ice (<25 cm) with little snow cover (2-6 cm) facilitated this bloom. In contrast, the diatom-dominated ice-algal bloom that developed in the bottom ice of the refrozen lead was characterized by high levels of UV-protecting compounds, indicative of light stress by the shade-adapted ice algae. Thick snow cover on the dominant first-year and second-year ice limited ice algal growth under these ice types, and the heavy snow load caused negative freeboard during the drift in early June. This led to infiltration of seawater through cracks in the ice and growth of phytoplankton at the snow-ice interface. These snow-infiltration communities have been rarely reported from the Arctic and could be another harbinger of a new Arctic sea-ice regime.

June 13, 12:20

Modelling the response of phytoplankton to storms in the Arctic and Subarctic Oceans

Laura Castro de la Guardia, Mariona Claret, Xianmin Hu, Paul G. Myers, Eric Galbraith

Locally, Arctic Ocean primary production controls the abundance and distribution of Arctic fish and marine mammals. Globally, primary production has a major role in carbon sequestration. Recent warming has increased the number of storms reaching the Arctic Ocean. Through the enhance of mixing, storms increase the supply of inorganic nutrients to surface waters which may have a significant role enhancing the Arctic Ocean primary productivity. We quantify the

contribution of storms by generating two independent experiments using a general circulation model coupled to a biogeochemical model (NEMO-BLING): (a) control simulation with storms, (b) no storms. The results highlight that winds drive up to 45% of the Arctic primary production and carbon export, being more significant in regions such as Baffin Bay, Hudson Bay and the Barents Sea.

June 13, 13:30

Decadal variations in ice algal productivity simulated by a pan-Arctic ice-ocean ecosystem model

Eiji Watanabe

Responses of biogeochemical cycle to the Arctic sea-ice decline have become an important topic for a variety of communities. Activity of ice algae is also important for the biological pump because sinking of their assemblage from the sea-ice bottom to deep seafloors is considered to be much faster than that of pelagic plankton species. Actually, widespread massive depositions of ice algal biomass were detected in the deep Arctic basins. Generally, sea-ice decline plays positive and negative roles in ice algal biomass. For example, sea-ice thinning enhances light penetration into the skeletal layer at the ice-ocean interface. On the other hand, reduction in net thermal ice growth restricts nutrient availability. Retreat of the sea-ice margin causes shrinking of ice algal habitat. Numerical modeling is one of the powerful tools to evaluate the impacts of sea ice decline on ice algal productivity on the pan-Arctic and decadal scales. Whereas the ice algae model has a long history of development, most previous works have been conducted on one-dimensional landfast ice ecosystems. In recent years, the model domain was extended to include the entire Arctic Ocean, and complex ice algal processes were numerically formulated in various ways. The present study addressed interannual and decadal variations in ice algal productivity simulated by a pan-Arctic sea ice-ocean ecosystem model. Relationships among the blooming period, annual total production, and sea ice-volume for a few shelf areas are particularly focused upon. For the analyses, decadal experiments from 1979 to 2013 were performed using a lower-trophic sea ice and marine ecosystem model "Arctic NEMURO" (Arctic and North Pacific Ecosystem Model for Understanding Regional Oceanography) [Watanabe et al., 2015, Biogeosciences]. Future scope for multi-model intercomparison in the Forum for Arctic Ocean Model and Observational Synthesis (FAMOS) project will also be presented.

June 13, 13:50

Primary production for Nordic and Arctic Seas: future projections and model uncertainties

Ingrid Ellingsen and Dag Slagstad

Light and nutrients limit phytoplankton growth in Nordic and Arctic Seas. With the rapid decline in ice cover, the light availability in the Arctic Ocean (AO) increases and the production season

becomes longer. Several studies have reported that an increase in primary production in the AO have been caused by a reduction in the sea-ice cover. However, nutrient limitation will become a key factor. The question is then what levels of productivity we may expect in the AO free of summer ice. In the stratified part of the deeper basins of the AO, little mixing leads to small upward nutrient transfer. As a consequence, the coupled biological, chemical and physical model system SINMOD projects that the productivity in stratified AO waters will at best increase slightly and in some regions even decrease. Earlier published SINMOD results also show a decrease in primary productivity for the Nordic seas and the southern Barents Sea. There are several sources of uncertainty associated with these simulations. In order to address these, we analyse a set of simulations forced with IPPC scenarios (A1B, RCP 4.5 and RCP 8.5). To complement these simulations, we will use a set of additional model experiments. These will be designed to assess sensitivity of simulated primary production to various factors including physical (e.g. changes in atmospheric forcing, changes in freshwater run-off and Pacific Water inflow), biological and chemical (e.g. vertical export and boundary conditions). Results from these experiments and analysis with regard to uncertainty in model projections of productivity will be presented.

June 13, 14:10

Projections of primary and secondary production in the Barents Sea in a future climate

Morten D. Skogen, Solfrid S. Hjøllo, and Phil Wallhead

Physical fields from the global climate model NorESM under RCP4.5 emission scenario has been downscaled using the ROMS ocean model, and this downscaled physics has been used as forcing for the NORWECOM.E2E ecosystem model including a module for ocean acidification. Focusing on OA state variables and air-sea fluxes of CO2 and DMS, a comparison has been made between the results from the global and regional model for the period 2010-2070 for the Nordic and Barents seas, and the results have been compared to other projections and validated against recent observations.

June 13, 14:30

Using past Calanus data to understand future climate responses

Kristina Øie Kvile

Using past Calanus data to understand future climate responses

Calanus copepods are key components in Arctic and Subarctic marine ecosystems as exporters of carbon and energy-rich prey for higher trophic organisms. These ecosystems are influenced by ongoing climate change, and recent data indicate that distributions of *Calanus* species may have already shifted. In order to predict population responses to climate change, we must disentangle which factors shape their distributions. The Arctic *Calanus* congeners are dominant in different

regions, with *C. hyperboreus* dominant in the central Arctic Basin and *C. glacialis* on the shelves. These patterns have been explained by two contrasting views. The bottom-up view suggests that the shorter and highly variable growth season in the central Arctic selects larger and longer-lived *C. hyperboreus* over relatively smaller *C. glacialis*. The top-down view, highlighted by Berge et al. (Journal of Plankton Research, vol. 34, 2012), suggests that the low predation pressure in the central Arctic allows the longer-lived and large-bodied *C. hyperboreus* to survive, whereas higher predation pressure on the shelves selects *C. glacialis* due to their reduced body size, shorter lifespan and increased fecundity. In this study, we use past observations to shed light on future responses to climate change in marine ecosystems. Specifically, we collate pan-Arctic data on stage-specific abundances of *C. hyperboreus* and *C. glacialis* to analyze spatial patterns in reproduction and mortality for these two species. We focus on two key questions: 1) are *C. hyperboreus* and *C. glacialis* exclusively sustaining populations in the Arctic basin and on the shelves, respectively, and (2) are mortality rates higher on the shelves compared to the basin areas? With the hypothetical increase of both pelagic primary production and visual predation in the Arctic basin in response to reduced sea-ice cover and greater availability of light, the relatively short-lived *C. glacialis* may gain advantage over C. hyperboreus in the future.

June 13, 14:50

Climate change impact on Barents Sea ecosystem functioning and vulnerability

Raul Primicerio, Michaela Aschan, Magnus Aune, Marie-Anne Blanchet, Padmini Dalpadado, Andrey Dolgov, Elena Eriksen, Maria Fossheim, Andre Frainer, Lis Lindal Jørgensen, Susanne Kortsch, Ulf Lindstrøm, Mette Skern-Mauritzen, Paul Renaud, and Øystein Varpe

The Barents Sea ecosystem is undergoing rapid structural change driven by climate warming. Ecosystem alterations are particularly extensive in Arctic waters, where poleward distributional shifts of demersal and pelagic fish species bring about changes in species composition and community structure. The restructuring of Arctic marine communities modifies food web configurations and functional characterization, with implications for ecosystem functioning and vulnerability. We address climate-driven changes in ecosystem properties affecting ecosystem functioning and vulnerability, relying on trait-based methods and food web analyses applied to the Barents Sea Ecosystem Survey Data collected by the Institute of Marine Research (Norway) and PINRO (Russia). We find that, in Arctic waters, functional characterization is changing towards an increased importance of larger, more generalist pelagic feeders. These changes in functional characterization, associated with increased seawater temperature and reduced ice coverage, are accompanied by food web reconfigurations leading to increased connectance and decreased modularity. The observed changes affect ecosystem functioning, by e.g. modifying the degree of bentho-pelagic coupling. Ecosystem vulnerability is also being affected, with three of its main components, functional diversity and redundancy, and foodweb modularity, all displaying rapid and extensive change in Arctic waters. The detected changes in functional characterization and foodweb configuration, driven by climate warming, will lead to substantial alterations in the ecosystem functioning and vulnerability of this Arctic marine ecosystem.

June 13, 15:30

Functional changes in arctic rocky-bottom benthos following a climate-driven regime shift

Susanne Kortsch, Raul Primicerio, F. Beuchel, Bodil Bluhm, Jørge Berge, C. Ballantine, A. Keck, and B. Gulliksen

Climate warming has recently triggered regime shifts in Arctic benthic rocky-bottom communities characterized by a macroalgae take-over. Our long-term study (35 y) addresses the structural and functional changes following rapid macroalgal shifts in two Svalbard fjords, and asks whether the macroalgae expansion persisted in the fjords. We find that the macroalgae shift differed between the two study sites. In Kongsfjord, the shift was characterized by high variability since the beginning, involving only one macroalgae species with an annual life cycle, whereas in Smeerenburgfjord, the macroalgae coverage has been relatively stable and persisted since the regime shift in the 2000s, involving different macroalgae species including perennials. Since 2010, the macroalgae coverage has disappeared in Kongsfjord at the investigated depth (15 m), and is possibly relegated to the upper layers due to increased turbidity reducing light levels. The discrepancy in the macroalgae dynamics between the fjords indicates that: 1) life history of macroalgae plays a crucial role for their stability and persistence; 2) the more structurally and functionally complex benthic community in Smeerenburgfjord promotes resilience and persistence of the new community state with macroalgae, whereas the relatively simple community structure with fewer species makes the benthic community in Kongsfjord more unstable. In Smeerenburgfjord, the macroalgae regime shift was associated with a rapid and substantial increase in bryozoans that were not present at the Kongsfjord site. The simultaneous rapid increase in macroalgae and bryozoans may indicate that the macroalgae may act as ecosystem engineers, providing shelter and secondary substrate, whereas bryozoans and hydroids stimulate macroalgal growth further through nutrient release. These results highlight the importance of including species relationships in studies on biological responses to environmental change in order to identify the mechanisms behind the state and resilience of an ecological community.

June 13, 15:50

Sea-ice extent and fish distributions: a fish-eye view on the new Arctic lightscape

Øystein Varpe, Tom J. Langbehn, Malin Daase, and Trond Kristiansen

A gigantic light experiment is taking place in the Arctic. Climate change has led to substantial reductions in sea-ice extent and thickness in the Arctic Ocean. Sea ice, particularly when snow covered, acts as a lid hindering light to reach the waters underneath. Less ice will therefore mean more light entering the water column, with profound effects on pelagic and benthic ecosystems. Responses through primary production are so far well acknowledged. We argue that there is a

need to broaden the view to include light-driven effects on fish, as they depend on light to locate prey. We present results from two models: 1) the Norwegian Earth System Model, which predicts a dramatic increase in the amount of light to reach the future Arctic Ocean, and 2) a prey encounter model adapted for ice-covered waters which predicts that the Arctic pelagic ecosystem is on a non-linear trajectory to become a hot-spot for high latitude summer-feeding. We expect species distributions to track the receding ice-edge, in particular through seasonal migrations. The non-linear change in lightscape renders the Arctic vulnerable to abrupt regime shifts. We discuss drivers of observed shifts in fish distributions, including temperature and food availability, and reflect around how research efforts should be directed to studies of how less sea ice will affect the feeding ecology and habitat use of fish. Our approaches offer mechanistic insights that go beyond statistical correlations and extrapolations, and we hope this will help us better understand how changing biophysical dynamics in the Arctic influence complex ecological processes.

June 13, 16:10

Arctic fish communities or fish communities in the Arctic?

Andrey Dolgov

At present, when speaking on fishes in the Arctic, two terms can be confused that would cause certain misunderstanding. “Arctic fish communities” may be considered as communities of Arctic fish species in terms of biogeography. “Fish communities in the Arctic” means communities of different species from different biogeographic groups (Arctic, boreal, widely distributed, etc.) which can occur in the Arctic geographic region. However, these two terms (and these two groups) differ significantly. Based on the data from the Barents and Kara Seas, Arctic fish communities mainly consist of small- or medium-sized species, which mainly feed on benthic organisms or plankton. Fish communities in the Arctic include more large and medium-sized species and more species that are predatory. Previous research shows that the recent decade observations show borealization of the Barents Sea, i.e. replacing of Arctic fish communities by boreal fish communities. Further borealization may result in disappearance of Arctic fish communities caused by increasing food competition between boreal and arctic species, direct predation of boreal species on Arctic species and by other reasons. Considering the possible future of fisheries in the Arctic, the only one Arctic species (polar cod *Boreogadus saida*) can be regarded as a potential target species, but this fishery would probably be restricted by many factors (e.g. long distances to fishing areas, low price of polar cod, etc.). Other fisheries will be possible only in conditions of further warming of the Arctic and migrating of traditional commercial fishes (mostly boreal species like cod, haddock, redfish etc.) to this area.

June 13, 16:30

Qaqortanik Qilalugarniarneq - the hunt of the white whale. Bridging knowledge of the Greenland warming event 1920-1930 and its environmental impacts on a West Greenlandic fjord

Ann Eileen Lennert and Anders Anker Bjørk

Fisheries are an important resource in many countries, across oceans and along coasts, and, even though it is usually neglected, they bring not only economic value with them but also social value, supporting an important web of cultural practices. In this presentation, we focus on a marine mammal which is entering the Arctic in increasing numbers, the killer whales (*Orcinus orca*), a major predator that may not only reshape the rapidly changing marine ecosystems via top-down forcing but also affect fisheries and cultural costumes through a specific, socially transmitted behavioural factor: depredation. By assessing the current knowledge of the depredation issue at a global scale, as well as the studies of killer whales in the North Atlantic and Arctic waters, we discuss whether an eventual emerging depredation on halibut fisheries in Greenlandic waters should be taken into consideration. We stress a more flexible and cutting edge management regime on the forefront of environmental change and future scenarios. We accentuate an increased recognition of wildlife management also including an understanding of people and that success will be determined largely by political, social and cultural factors. Finally, we conclude that Greenland, being on the cutting edge of change, has high potentiality for building research based on both natural science and traditional knowledge.

S4 - Shifting habitats, persistent hot spots, and the distribution of benthos, plankton, fish, seabirds and marine mammals - observations, models, mechanisms and effects (Session 2)

June 13, 15:50

Benefit of long distance migration for Barents Sea cod

Leonie Färber, Joël Durant, Yngvild Vindenes, and Øystein Langangen

The Barents Sea cod (*Gadus morhua*) undertakes spawning migrations from feeding grounds in the Barents Sea to spawning grounds located along the Norwegian Coast. The cost for this migration reduces the stored energy which is also used for reproduction. We investigated the benefits for this population to make longer and more costly spawning migrations to the farther spawning grounds (South) instead of the nearest ones (North). Previously, increased larval survival has been suggested to offset the migration cost, however, the benefit of increased offspring length has received less attention. Due to warmer temperatures in the southern spawning grounds, offspring will reach faster a larger size than at northern spawning grounds. We tested if offspring benefit of a larger size at age 1 can explain the trade-off for the parents of higher migration costs. We built a female-based size-structured integral projection model (IPM). The model is parametrized by using the Barents Sea cod's vital rate information. From the model, we calculate the long-term population growth rate λ. By comparing the λ of fish that are spawning along the Norwegian coast, we can quantify the needed increase in offspring size to offset migration costs. As expected by our model, the longer the migration is, the smaller λ is. However, an increase in offspring size leading to an increase in λ can compensate the decrease caused by longer migrations. Thus, with a larger offspring size, the migration costs can be higher, reducing the number of offspring, but still have a sustainable population.

June 13, 16:10

Heterogeneity in vessel resiliency to climate variability in the Bering Sea pollock fishery

Jordan T. Watson, Alan C. Haynie, and Franz J. Mueter

Pollock recruitment and spawning biomass in the Bering Sea has fluctuated significantly in concert with environmental changes since the early 2000s. As pollock spatial distributions, densities, and abundances have responded to climatic variability, fishers have reacted in turn. Utilizing ~30,000 trips made by Bering Sea pollock catcher vessels from 2003 – 2015, we found strong correlations between the distances that vessels traveled to fish and both pollock survey abundance and bottom temperatures. During years when colder than average waters drove

pollock populations farther from port (during the summer B season) and closer to the edge of the Bering Sea shelf, many vessels traveled farther, following fish and maintaining high catch per unit effort (CPUE), despite low overall pollock abundance. The temperature and abundance relationships remain difficult to disentangle, however, as recent warm years have all occurred in concert with abundant pollock. Without low abundance warm years for comparison, it is difficult to project the impacts that warming may have on pollock fleets. However, if warm waters yield their predicted poor recruitment, then pollock may require more effort to catch, even when closer to port. This increased effort (decreased CPUE) represents an additional cost to fishers because vessels use significantly more fuel while fishing than while transiting. Longer trips offer complicated trade-offs for fishers. The far-ranging trips overall had statistically similar net earnings per trip day as the shorter trips, suggesting that the higher CPUEs were enough to offset the costs, but many vessels are unable to profitably make these longer trips. As climate changes further, and variability of pollock populations is predicted to increase, understanding the ability of different vessels within the fleet to adapt is critical to efficiently manage the pollock fleet.

June 13, 16:30

Projecting shifts in feeding hot spots: modeling linkages from advection of phytodetritus through benthic food webs to mobile top predators

James R. Lovvorn, Jacqueline M. Grebmeier, and Lee W. Cooper

In a changing Arctic, it is increasingly important to delineate areas adequate to sustain food webs that support top predators. For benthic-feeding endotherms, high intake demand and mobility to seek high food densities often lead to dependence on a small fraction of their total range in a given period. The distribution, structure, and biomass of soft-bottom prey assemblages are closely tied to levels of sediment organic carbon (OC). However, changing wind patterns and resulting lateral advection of settling phytodetritus can alter the extent and location of feeding hot spots over a few years to decades. Food web models for the northern Bering Sea indicate that satellite estimates of primary production are much lower than carbon inputs required by the benthos, and field surveys showed that areas of phytodetrital accumulation often do not correspond to the distribution of bloom production in the upper water column. Models of food web response to altered phytodetrital inputs, when compared to faunal measurements at stations with similar differences in sediment OC, did well in predicting the direction of biomass change in different taxa and which taxa were eliminated with reduced organic inputs; however, the magnitude of modeled responses often differed from those observed. Regular monitoring of benthic assemblages over large areas at high spatial resolution relevant to foraging endotherms is often financially unattainable. However, models that link changing winds as projected by climate models to lateral advection of settled phytodetritus show promise for simulating long-term spatial patterns of benthic food webs in feeding hot spots.

June 13, 16:50

Species invasion and diversity in benthic macrofaunal communities in the Pacific Arctic

Hisatomo Waga, Toru Hirawake, and Jacqueline M. Grebmeier

There is growing evidence of increased Pacific Water transport into the Arctic that is influenced by variations in atmospheric forcing. One of the empirical and theoretical predictions for a future Arctic impacted by increased Pacific water transport is that new taxa will expand or invade the Arctic ecosystem. However, well-documented examples are still scarce due to the limited number of time-series measurements in the Arctic, particularly for benthic organisms. Although benthic organisms are normally stationary and less mobile than fishes, seabirds and mammals, it seems relevant that benthic organisms with pelagic life stages will be less limited in their expansion abilities. In this study, the relationship between the number of benthic macrofaunal taxa and atmospheric forcing was investigated in the Pacific Arctic. Average taxon number of benthic macrofauna for 2010–2012 has increased significantly compared to 2000–2006 on the continental shelf area from south of St. Lawrence Island in the northern Bering Sea to just north of St. Lawrence Island in the Chirikov Basin, likely caused by the difference in magnitude and location of the Aleutian Low. By comparison, the biomass-based Shannon-Weaver diversity index did not reflect the changes in taxon number of benthic macrofauna. These results indicate increased invasion of new taxa into the region for 2010–2012 compared to 2000–2006, but the biomass of new taxa is negligible when compared with the total benthic macrofaunal biomass. Our findings demonstrated indications of ongoing changes that could continually be facilitated by climate change to future Arctic marine ecosystems in the Pacific Arctic region.

June 14, 17:10

Spatial overlap explains recruitment variability in the eastern Bering Sea (part I): empirical observations of Walleye pollock and foraging landscapes

Elizabeth Siddon, Kirstin Holsman, Alex Andrews, Ed Farley, Ron Heintz, and Jim Ianelli

Understanding drivers of recruitment variability in marine fishes increases our ability to project cohort strength under future climate conditions. In the eastern Bering Sea (Alaska), bottom-up processes shape foraging landscapes that ultimately determine the energetic condition and overwinter survival of juvenile fish (e.g., Walleye pollock, *Gadus chalcogrammus*). In 2016, the eastern Bering Sea shelf experienced above-average thermal conditions for the third consecutive year. Multiple-year climate stanzas of warm conditions precipitate a trophic cascade that leads to a restructuring of the prey base, reduced energetic condition of age-0 pollock, and reduced overwinter juvenile pollock survival success. In the previous warm stanza (2000-2005), the pollock population experienced a marked 40% decline. However, field observations in 2016 indicated relatively high abundances of larval and juvenile pollock and laboratory processing showed these juvenile pollock had higher-than-expected energy densities. We propose a spatio-temporal overlap with lipid-rich prey enabled the fish to buffer against poor environmental

conditions and mediating recruitment declines. Further, we utilize empirical observations between 2003-2016 and retrospectively develop an index of spatial overlap between juvenile pollock and foraging landscapes to (i) help explain recruitment variability across thermal regimes in the eastern Bering Sea and (ii) compare the current warm stanza to previous ecosystem responses. We propose the index of spatial overlap forecasts cohort strength and recruitment success for pollock and demonstrates a mechanistic relationship that may be broadly applicable to marine fish populations worldwide. This work is complimentary to modeling efforts presented by Holsman et al. to project pollock recruitment under future scenarios.

June 13, 17:30

The ecosystem response to the late 20th Century cold period in the North Atlantic

Ken Drinkwater and Trond Kristiansen

During the 1970s and 1980s, there was a general cooling in the North Atlantic Ocean. This cooling was part of the multidecadal variability in SSTs known as the Atlantic Multidecadal Oscillation or AMO which has a period of 60-80 years. In this cold period, below average air and sea temperatures predominated, increased ice cover was observed in those regions with seasonal sea ice, and evidence was found of reduced Atlantic inflow into the Northeast Atlantic Ocean. Still during these two decades there was variability, both temporal and spatial, such that in some years and some areas above normal conditions temperature and ice prevailed. The ecological responses included a general shift southward of arctic and boreal fish species and a retreat of the temperate species. Major commercial fish stocks such as Atlantic cod off Greenland and the Norwegian spring-spawning herring collapsed. This was partly driven by climate-induced declines in growth rates and recruitment survival. In contrast, in the more southern range of Atlantic cod, such as the North Sea, the opposite response occurred as the cool conditions lead to improved growth rates and higher abundance. Benthic and nearshore species also underwent distributional shifts and changing abundances. Comparisons with the responses to the warm periods suggest that they were mainly similar but opposite indicating a largely linear response to the climate forcing.

S4 - Shifting habitats, persistent hot spots, and the distribution of benthos, plankton, fish, seabirds and marine mammals - observations, models, mechanisms and effects (Session 3)

June 13, 15:50

Contribution of Calanus *spp. to the mesozooplankton biomass in the Barents Sea*

Johanna Myrseth Aarflot, Hein Rune Skjoldal, Padmini Dalpadado, and Mette Skern-Mauritzen

Herbivore zooplankton play an important role in the marine, pelagic food web converting energy from primary production to food for higher trophic levels in the ecosystem. Copepods of the genus Calanus are predominantly herbivorous and the most important zooplankton in the Nordic and Barents Sea ecosystems, largely due to their high abundances and lipid contents. By comparing data on observed mesozooplankton biomass with data on species abundance from the same research stations, we investigate the contribution of three *Calanus* spp. (*Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus*) to the mesozooplankton biomass in the Barents Sea. The data originate from various research surveys conducted by the Institute of Marine Research (IMR), Norway, over a 30-year period, and comprise ~600 samples from Atlantic, Arctic and mixed waters. We demonstrate that the *Calanus* species jointly drive the mesozooplankton biomass in the Barents Sea, but that the contribution of each of the three species to the mesozooplankton biomass is highly variable both between and within areas. Though the *Calanus* species co-occur in most regions, *C. glacialis* dominate in the Arctic water masses, while *C. finmarchicus* dominate in the Atlantic waters. Young copepodite stages (CI-CIII) have an overall low contribution to total species biomass, which is mostly composed of stages CIV and CV. In the western area of the Barents Sea we observe indications of an ongoing borealization of the zooplankton community, with a decreasing proportion of *C. glacialis* over the past 20 years. The contribution of *C. finmarchicus* to the mesozooplankton biomass in this area appears to have increased during the same period.

June 13, 16:10

One species two life histories: Does the genomic signatures of adaptation in beach vs offshore spawning capelin reveal evolvability towards a changing Arctic environment?

Kim Præbel and Shripathi Bhat

Capelin (Mallotus villosus) is a small salmonid fish that display two alternative life histories within its circumpolar distributional area: a long distance migrating form that spawns offshore and are strictly semelparous or a more resident form that spawns intertidally and can be considered as iteroparous. This divergent life history, within the same species, has been predicted to be associated with a genetic component, but this component has yet to be identified. Divergent life histories within a single species may be regarded as a process of incipient speciation and when this process occurs in sympatry, the theory of speciation predicts that adaptive genomic differences will accumulate as a result of divergent natural selection acting against unbeneficial traits. In other words, adaptive genomic differences are expected to be the main driver of divergence between the two life histories. Here we addressed these two predictions on three replicated systems of capelin spawning offshore vs intertidally from Norwegian waters by comparing divergence at a genome-wide panel of single nucleotide polymorphisms obtained by massively parallel sequencing of Restriction Site Associated DNA libraries (RADseq). Firstly, we explored whether there is a genetic component associated with the divergent life history of this species and secondly, we illuminated whether adaptive genomic differences have accumulated within the two alternative life histories. We discuss the results in light of how a changing Arctic environment may influence the apparent process of incipient speciation.

June 13, 16:30

Summer zoogeography of the northern Bering and Chukchi seas

Franz J. Mueter, Michael F. Sigler, Bodil A. Bluhm, Morgan S. Busby, Edward D. Cokelet, Seth L. Danielson, Alex De Robertis, Lisa B. Eisner, Edward V. Farley, Katrin Iken, Kathy J. Kuletz, Robert R. Lauth, Elizabeth A. Logerwell, and Alexei I. Pinchuk

Ocean currents, water masses, and sea ice formation contribute to determining relationships among biotas of the Bering and Chukchi seas. The Bering Sea communicates with the Chukchi Sea via northward advection of water, nutrients, organic matter, and plankton through Bering Strait. We used summer abundance data from zooplankton, pelagic fish and jellyfish, benthic fish and invertebrates, and seabird surveys conducted concurrently during 2012 to identify the environmental factors that most influence distributions of biota within the US portions of the Chukchi Sea shelf and the northern Bering Sea shelf. Regional differences in summer distributions of biota largely reflected the underlying hydrography. Depth, temperature, salinity, stratification, and chlorophyll a, but not sediment-related or nutrient-related factors, had the largest influence on the distributions of communities. The communities were principally structured from nearshore to offshore and from south to north. Some communities overlapped spatially, indicating shared influential environmental factors or trophic linkages among communities. The gradients in community composition were gradual for benthic taxa, abrupt for zooplankton taxa, and intermediate for pelagic fish/jellyfish and seabird taxa. Three cross-community groupings emerged based on maps of ordination axes and core use areas by taxa; one associated with Alaska Coastal Water (warmer, fresher, nutrient depauperate), a second associated with Bering Strait and the southern Chukchi Sea (colder, saltier, nutrient rich), and a third associated with the northern Chukchi shelf. Gradients in species composition occurred within and between these cross-community groups. The Bering Strait and southern Chukchi Sea

group was characterized by distinct zooplankton and seabird taxa, but was not strongly associated with distinct pelagic or benthic fish and invertebrate taxa. Although comprehensive data were only available for a single year and annual variation may affect the generality of our results, our comprehensive ecosystem survey approach yielded new insights into the ecological relationships of this Arctic region.

June 13, 16:50

Cod diet and food web dynamics: What can we learn from the past?

Rebecca E. Holt, Joël M. Durant, Geir Ottersen, and Bjarte Bogstad

Atlantic cod (*Gadus morhua*) is a dominant predator within the Barents Sea subarctic ecosystem, playing a key role in ecosystem functioning and fisheries. The size of the Barents Sea cod stock has increased in recent years, as a consequence of a successful harvest control rule and favorable temperatures, resulting in an expansion of the stock's feeding area. The present large biomass of cod has a huge food demand, and while it is thought that cannibalism and competition have not increased, knowledge gaps remain in how cod prey varies in space and time as well as the influence of external forcing, such as climate and fishing, on predator-prey dynamics. We use an extensive Norwegian-Russian cod diet database (1984-2015), resolved in both time, space and by age of cod, together with population and hydrographic data to examine the mechanisms generating predator-prey interactions; moving towards a deeper understanding of the trophic connections in the Barents Sea. We extract and present spatio-temporal fluctuations in the diet of Barents Sea cod, illustrating long-term trends both between seasons and years, as well as highlighting the influence of climate. These results provide new insights on key aspects of the structure and function of the Barents Sea ecosystem, which are also partly relevant to other subarctic marine systems.

June 13, 17:10

May Northeast Arctic cod offspring end up at Greenland shelves?

Kjersti Opstad Strand, Svein Sundby, Jon Albretsen, and Frode Vikebø

Individual-based biophysical modelling together with observations are used to estimate dispersal of Northeast Arctic (NEA) cod (Gadus morhua) in their pelagic phase. Our focus has been on the predictive skills of the physical processes linked to the transport and dispersion pattern. We have investigated the significance of off-shelf transport away from the Norwegian continental shelf in relation to the variable meteorological conditions in their drift phase during spring and summer. We have looked at all years from 1978 to 2015, considering both variability within season, as well as between years. Moreover, in relation to the recent warming of the North Atlantic, we have focused on the potential habitat extension of the Northeast Arctic cod towards the northeast Greenland shelf. Our main findings show that transport off the Norwegian continental shelf is highly variable and that northeasterly wind conditions over several days prior to an off-shelf

event is a good proxy for off-shelf dispersal of offspring. Secondly, a fraction of the cod offspring transported off-shelf is able to reach the northeastern Greenland shelf, with high variability between years. Model results indicate that transport to the northeastern Greenland shelf in some years may potentially exceed 12%. The modelled spatial distribution is coinciding with recent observations of immature cod at the northeastern Greenland shelf.

June 13, 17:30

Ticket to spawn: combining economic and genetic data to evaluate the role of climate and harvesting on temporal shifts in spawning location

Øystein Langangen, Leonie Färber, Leif Chr. Stige, Florian K. Diekert, Michael Matschiner, Julia M. I. Barth, Bastiaan Star, Nils Chr. Stenseth, Sissel Jentoft, and Joël M. Durant

Northeast Arctic (NEA) cod is a migratory stock of Atlantic cod. The migration route from the Barents Sea to the spawning grounds along the Norwegian coast may cover more than a thousand km against the prevailing currents. Understanding what drives such energetically costly migration and what influences changes in migration routes and spawning patterns in NEA cod has been a long standing question. Two hypotheses have been put forward explaining patterns in spawning ground use over long time scale (decades to centuries). The first hypothesis suggests that changes in spawning ground use are driven by climate. The second hypothesis suggests the observed changes in spawning ground use are driven by fisheries induced size truncation. Here we investigate phenotypic data to test the empirical evidence for these hypotheses. Specifically, we test for association between mean latitude of spawning and Kola-section temperature and spawning stock size structure using fisheries landing ticket data for 2004-2013. In addition, based on the fisheries landing ticket data set and on size data from individually genotyped fish, we test for geographical differences of the size of spawners at the spawning grounds. We find no association between mean latitude of spawning and mean weight in the spawning stock and that spawner size tends to decrease with decreasing latitude (a proxy for migration distance). As a result, we conclude that the evidence is not supporting the demographic hypothesis.

June 14 - Plenary

June 14, Plenary Session

June 14: 08:30

Vertical mixing in the Subarctic North Pacific and its impact on biogeochemistry and climate

Ichiro Yasuda, Jun Nishioka and Takahiro Tanaka (Invited – S2)

The Subarctic North Pacific and adjacent marginal seas are known to be biologically productive regions. Tide-induced strong vertical mixing in the Kuril Straits, the Aleutian Passes, the eastern Bering shelf edge and the Emperor Seamounts are observed by direct microstructure measurements. The mixing redistributes dissolved-iron concentrations, which regulates the biological productivity in the HNLC Subarctic North Pacific. This process could sustain the high ecosystem productivity in the western North Pacific and in the Green Belt along the eastern Bering Sea shelf break. Changes following the 18.6-year period variability of diurnal tides and mixing is also observed in these regions, and its impact is possibly to extend to climate variability such as the PDO through air-sea interactions along the Subarctic Front. This presentation reviews recent progress on these topics related to mixing and its impact, and introduces an on-going Japanese project "Ocean mixing processes: impact on biogeochemistry, climate and ecosystem (OMIX)".

June 14: 09:00

Early life history phenology among Gulf of Alaska fish species: strategies, synchronies, and sensitivities

Miriam Doyle, Ken Coyle, Suzanne Strom, Al Hermann, Carol Ladd, and Ann Matarese (Invited – S3)

The timing and duration of occurrence of fish eggs and larvae in Gulf of Alaska pelagic habitats is variable, and a high diversity of phenologies is observed among species. Synthesis of four decades of ichthyoplankton data indicates that species diversity and total abundance peaks during spring. Nevertheless, fish larvae occur in the plankton at all times of the year and peak abundance periods vary significantly by species and habitat. Larval size at hatching and at transformation to the juvenile stage is also highly variable and is associated with a variety of larval durations and temporal supply of larval cohorts to pelagic habitats. This diversity of early life phenologies represents trade-offs in adaptation to the pelagic environment, and associated sensitivities may modulate species' responses to environmental variability. For instance, water temperatures, availability of suitable zooplankton prey organisms, and winds and currents vary dramatically on a seasonal scale affecting degrees of synchrony among species with optimal environmental conditions for successful growth, survival and transport of larvae. This synchrony is also affected

by interannual variability in the oceanographic environment. Timing of reproduction and occurrence of early ontogenetic stages is critical to species' interaction with the environment, but intrinsic physiological rates are also important. Species with identical timing of spawning, hatching and peak larval abundance in similar pelagic habitats can have contrasting developmental trajectories that result in divergent ecological patterns later in the larval phase. These early life history strategies, synchronies, and sensitivities will be characterized for the most abundant species in the ichthyoplankton, and discussed in relation to long-term adaptation to prevailing conditions in the Gulf of Alaska as well as potential responses to environmental change. This synthesis will be used to argue that phenology and match-mismatch dynamics remain critical issues for evaluating climate-induced shifts in marine ecosystems and their constituent fish populations.

June 14: 09:30

The responses of sessile deep-water filter feeders to single and multiple anthropogenic stressors

Raymond John Bannister (Invited – S6)

Stable environmental conditions of deep-water marine ecosystems support rich densities of long-lived sessile benthic fauna. Variability in climatic conditions and increased anthropogenic activities in deep-water ecosystems impacts environmental conditions through modifying physio-chemical properties (i.e. temperature, salinity, pH, food availability and nutrients, and suspended particle dynamics). Increased anthropogenic stressors in marine ecosystems places undue stress on the health and functioning of its associated fauna, with increasing evidence that multiple stressors may interact to produce unexpected effects in shallow water ecosystems. For deep-water ecosystems and their associated sessile faunal communities, the effects of anthropogenic stressors and their synergistic effects have received less attention. This dearth of knowledge is despite episodic events of mass mortalities of key benthic organisms being documented in deep-water ecosystems correlated with changes in physio-chemical properties of the environment. This presentation will outline our current state of knowledge on how key deep-water sessile benthic filter feeders respond to the magnitude of anthropogenic stressors (both singular and combined effects) affecting deep-water benthic ecosystems along the Norwegian coastline. Key research findings will be presented from several nationally funded research projects focusing on the effects of sedimentation stress from oil drilling and mining activities, the effects of climate change and ocean acidification and the effects of organic enrichment from aquaculture. This presentation will also highlight the importance of measuring responses of benthic fauna at different biological levels and our current knowledge gaps when it comes to the response of deep-water benthic ecosystems to multiple stressors.

S2 - Advection and mixing and their ecosystem impacts

June 14, 10:30

Long term change in phytoplankton ecosystem in response to decadal scale climate oscillations at central subarctic Pacific and Bering Sea

Osamu Seki, Naomi Harada, Kozo Takahashi, Hiroji Ohnishi, and Makio Honda

The Subarctic Pacific is one of the most productive oceans in the world and thus is thought to play an important role in global carbon cycle. However, a relationship between primary productivity in the regions and climate remains uncertain. In this study, we measured haptophyte (*E. huxleyi*), diatom and dinoflagellate biomarkers (alkenone, C28 sterol and dinosterol) in sinking particles collected by time-series sediment traps moored at the subarctic Pacific (St. K2 and SA) and Bering Sea (St. AB) during 1990 to 2012 in order to decipher how the ecology of major phytoplankton in the regions response to decadal-scale climate oscillations such as El-Nino Southern Oscillation (ENSO) and the North Pacific Gyre Oscillation (NPGO). Distinct seasonal succession of phytoplankton assemblages from diatom dominated high production in spring to moderate production with admixture of diatoms and *E. huxleyi* in autumn is recognized at the three stations every year while dramatic changes in mode of ENSO and the NPGO occurred during the study period. This appears to indicate that the decadal-scale climate oscillations do not necessarily drastically influence the seasonal cycle of phytoplankton ecology. However, we found that the changes in ratios of *E. huxleyi* to diatom biomarker fluxes at Stations SA and AB resemble the records of the ENSO and NPGO indices. Such a correspondence suggests that ENSO and NPGO significantly affect relative production of phytoplankton in autumn with increased *E. huxleyi* biomass relative to diatoms in the subarctic region of the Pacific and the Bering Sea during the periods of strong El-Nino and positive phase of the NPGO. This study shows that subarctic Pacific phytoplankton ecosystem in autumn is sensitive to decadal scale climate oscillations such as ENSO and the NPGO.

June 14, 10:50

Distribution of the Anadyr Water near the Gulf of Anadyr and the Bering Strait

Toru Hirawake, Issei Nakagawa, and Jun Nishioka

Primary production in the Bering Strait (BS) especially in the Russian side is extremely high and it is found not only in spring but also in summer and autumn seasons. It has been suggested that the continuous high phytoplankton activity is attributed to rich amount of nutrients in the Anadyr Water (AW). Although some studies report higher nutrient concentrations in the Gulf of Anadyr (GA), similar level of primary production as the BS is not typically observed in the GA. In this study, we obtained a historical CTD dataset (1930–2005) compiled at the Far Eastern Regional Hydrometeorological Research Institute (FERHRI) in Russia and investigated water mass

structure form the GA to the BS. We analyzed the dataset climatologically because stations of each cruise were sparsely distributed. In August, while the AW with high salinity (>35 PSU) is distributed near the bottom of the GA, the Bering Shelf Water covers the surface of the Gulf. The AW was spread along coast of Russia with some of it found in the surface layers of the BS. The water mass structure in this study suggests that the AW from the AG continuously supports high primary production during summer in the BS.

June 14, 11:10

Dynamics of dissolved and particulate organic carbon in the Chukchi Sea

Jinyoung Jung, Sun-Yong Ha, Jun-Oh Min, Min-Sub Kim, Eun Jin Yang, Kyung-Hoon Shin, and Sung-Ho Kang

Dissolved and particulate organic carbon (DOC and POC) are important components for understanding the regional carbon budget and the global carbon cycle. As the amount of river discharge continues to increase, along with increasing DOC export due to climatic warming and permafrost thawing, the remineralization of terrigenous organic marine-origin matter in the Arctic Ocean can reduce the Arctic Ocean's ability to absorb atmospheric carbon dioxide (CO_2). Thus, a complete understanding of the terrigenous and marine-origin DOC dynamics is required. To investigate the behavior of DOC and POC, and sources of DOC, seawater sampling was carried out over in the Chukchi Sea, including Distributed Biological Observation (DBO) site 3, using a CTD/rosette sampler holding 24-10 L Niskin bottles during Korea research ice breaker R/V Araon cruises (ARA06B, August 1–22, 2015; ARA07B, August 6–19, 2016). δ18O and salinity were also used to estimate DOC inputs by river and sea ice melt, allowing the marine portion of the DOC pool. Concentrations of DOC and POC ranged from 34–116 μM and 5.3–47 μM, respectively. High DOC concentration was observed in the surface layer, suggesting strong influence of terrigenous DOC derived from Arctic river. However, low-salinity water from ice melt diluted DOC concentration in the surface layer. The penetration depth of brine, rejected during sea-ice formation, was observed from the surface layer to 200 m depth, where the contribution of riverine DOC was more than 50%. Our result revealed that sea-ice formation, which injects brine into the underlying seawater, is a key mechanism for delivering riverine DOC into the deeper layer.

June 14, 11:30

Cluster III nifH-harboring microbes dominated diazotroph communities in the Chukchi Sea (western Arctic Ocean)

Takuhei Shiozaki, Amane Fujiwara, Minoru Ijichi, Naomi Harada, Shigeto Nishino, Shinro Nishi, Toshi Nagata, and Koji Hamasaki

Marine nitrogen fixation is now considered to occur not only in subtropical and tropical regions but also in colder regions, although the extent of and the identity of diazotrophs responsible for

nitrogen fixation in the Arctic Ocean remain poorly understood. Here we examined diazotroph community structure and activity in the Chukchi Sea, a marginal sea of the western Arctic, during summer 2015. The diazotroph community determined by Illumina sequencing was mainly composed of Cluster III nifH phylotypes (putative anaerobes), accounting for 60–100% of the total sequences examined except one surface sample. This result is strikingly different from the previous findings in other oceanic regions. The nifH sequences other than Cluster III were mostly affiliated with UCYN-A2 (symbiotic cyanobacteria), which accounted for less than 15% of the total sequences. Nitrogen fixation rates were measurable at all the stations, with the maximum rate of 1.84 nmol L-1 d-1. The nitrogen fixation rates varied in a complex manner, displaying no clear relationship with depth (light intensity) and nitrate concentrations. The nitrogen fixation rate exceeded the nitrate assimilation rate in some nitrate-depleted waters, indicating that the diazotrophs could be an important source of new nitrogen in the Chukchi Sea.

June 14, 11:50

Spatial patterns in zooplankton community response to various habitats in the western Arctic Ocean during summer

Hyoung Sul La, Eunho Kim, WuJu Son, Eun Jin Yang, Kyoung-Ho Cho, Jinyoung Jung and Sung-Ho Kang

Rapid sea-ice reduction could make the western Arctic Ocean an ideal environmental setting for investigation of the impacts of climate change in the pelagic marine ecosystem. To examine the essential factors affecting the distribution of zooplankton abundance, a key component of marine ecosystem, the spatial pattern in the zooplankton communities in the western Arctic Ocean was studied during austral summer. Hull mounted echo sounder and Bongo net (mesh apertures 330 and 505 mm) were used to detect the vertical and horizontal distribution of zooplankton abundance. Conductivity-temperature-depth (CTD) measurements and water samples for nutrients and phytoplankton biomass (chlorophyll a) were conducted to observe the environmental condition of zooplankton habitat in the water column. Zooplankton abundance and carbon contents ranged from 9 to 830 ind. m^{-3} and from 1 to 100 mg m^{-3}, respectively. Copepods were the most dominant taxa of zooplankton abundance. A clear spatial pattern of zooplankton abundance was observed with salinity, phytoplankton biomass, and nutrients in the western Arctic Ocean. This result could provide basic data on the composition and distribution of zooplankton, and will help answer important questions about Arctic marine ecosystems.

June 14, 13:30

Advection domains in the Arctic Ocean

Paul Wassmann, Dag Slagstad, and Ingrid Ellingsen

The central Arctic Ocean is not isolated, but tightly connected to the northern Pacific and Atlantic oceans. Advection of nutrient-, detritus- and plankton-rich waters into the Arctic Ocean forms

lengthy contiguous domains that connect subarctic with the arctic biota, supporting both primary production and higher trophic level consumers. In turn, the Arctic influences the physical, chemical and biological oceanography of adjacent subarctic waters through southward fluxes. However, exports of biomass out of the Arctic Ocean into both the Pacific and Atlantic oceans are thought to be far smaller than the northward influx. Thus, Arctic Ocean ecosystems are net biomass beneficiaries through advection. Climate change affects the Arctic Ocean in a multitude of manners, also through advection. That is e.g. reflected through Atlantification (both in a physical and biogeographical sense) and "Pacification" that currently are observed in the Arctic Ocean. The contiguous advective domain concept by Wassmann et al. (2015) is extended and updated. Emphasis is given to oceanic expatriates of boreal Atlantic and Pacific origin, Arctic residents and neritic Arctic expatriates. Particular emphasis is give to the advection of *Calanus finmarchicus* from the Norwegian Sea and *Calanus glacialis* from the northern Barents Sea into and along the Eurasian shelf.

June 14, 13:50

Wind-driven variability of advection and sea-ice cover in the Barents Sea and some ecosystem impacts

Vidar S. Lien, Øystein Skagseth, Pawel Schlichtholz, Frode B. Vikebø, Hein Rune Skjoldal, and Elena Eriksen

Variability in the Barents Sea ice cover on inter-annual and longer time-scales has previously been shown to be governed by oceanic heat transport. Based on analysis of observations and results from an ocean circulation model we show that the ocean also plays a direct role within seasons. Positive wind stress curl and associated Ekman divergence causes a coherent increase in the Atlantic water transport along the negative thermal gradient through the Barents Sea. The immediate response connected to the associated local winds in the northeastern Barents Sea is a decrease in the sea-ice cover due to advection. Despite a subsequent anomalous ocean to air heat loss due to the open water, increased ocean heat content contributes to maintaining a reduced sea-ice cover. These changes in circulation and ice cover potentially affect biological productivity both directly through advection and distribution of lower trophic levels including ichthyoplankton, and indirectly through changes in ice cover and subsequent physical changes in the water column including light conditions.

June 14, 14:10

Seasonal variation in advection of zooplankton into the Arctic Ocean through Fram Strait

Sünnje L. Basedow, Arild Sundfjord, Elisabeth Halvorsen, Wilken-Jon von Appen, Slawomir Kwasniewski, and Marit Reigstad

The inflow of Atlantic Water (AW) into the Arctic Ocean (AO) is the main mediator of climate change in the Arctic marine ecosystem. Through the inflow of AW changes in temperature and ecosystem structure at lower latitudes are channelled into the AO and impact productivity and carbon cycling there. We analysed the potential of zooplankton to enter the Arctic Ocean through the Fram Strait during different seasons based on data on hydrography, current velocities and the depth distribution of zooplankton. Data were collected with high spatial resolution along a transect crossing the Atlantic inflow west of Svalbard at ca. 79 N in January, May and August 2014, using CTD, ADCP, laser optical plankton counter and Multinet. Based on current measurements (ship-based and moorings) we calculated the mean transport during each of those months and found high inflow rates of zooplankton, far exceeding local production. We discuss implications of zooplankton behaviour and life strategies of Atlantic and Arctic zooplankton species for transport into the AO.

June 14, 14:30

Variations in advection and mixing of water to the north Icelandic shelf and impacts on the ecosystem

Steingrímur Jónsson, Héðinn Valdimarsson, and Andreas Macrander

Iceland lies close to the outflow of Polar water from the Arctic Ocean and sometimes the conditions over the shelf north and east of Iceland are heavily influenced by it, whereas at other times it is surrounded by warm Atlantic water. Direct current measurements of the flow of water to the north Icelandic Shelf have been made continuously since 1994 and are still in place. During this period and for a long time prior to that, hydrographic measurements have also been made on several sections across the shelf off the north coast as well as measurements of various components of the ecosystem. The changes in the ecosystem will be described in relation to changes in the physical forcing. It is demonstrated that local atmospheric conditions are important for timescales from days and at least to the seasonal timescale. On longer timescales, the large-scale atmospheric circulation and large-scale dynamics of the sub-polar gyre and the Arctic Ocean play major roles. This and the fact that there has been over half a century of monitoring of various physical and biological parameters, make this area ideal for studying the effects of shifts in ocean and atmospheric forcing, that can serve as an example of how the ecosystems of the inflow areas in the Arctic Ocean may respond to such changes.

June 14, 14:50

Functional traits of zooplankton in Arctic fjords: spatial/temporal patterns and role of Atlantic water advection

Marta Gluchowska, Wojciech Walkusz, Emilia Trudnowska, Anna Olszewska, Mateusz Ormanczyk, Anette Wold, Haakon Hop, and Slawomir Kwasniewski

The advection of warm Atlantic water (AW) into the Arctic influences not only the thermal and sea-ice conditions in the Arctic Ocean and the adjacent seas but also the Arctic marine biota. Earlier efforts to characterize the response of zooplankton communities to the increasing influence of warm AW were focused mostly on changes in taxonomic diversity and community structure, but how the zooplankton functional role will evolve under future global warming scenarios remains largely unknown. Over the past decade, there has been a growing recognition of the importance of relating the community taxonomic structure to its function, but little has been done for developing the functional traits approach in studies of marine zooplankton. Based on the long-term data collection gathered in the West Spitsbergen fjords (Hornsund and Kongsfjorden) located at the border of subarctic and arctic marine domains, we assessed the seasonal patterns of the zooplankton functional structure and the observed interannual changes possibly connected with the variability in temperature and transport strength of the AW advected into the fjords. Investigation of the structure of the zooplankton functional groups is based on the original database of zooplankton functional traits (morphological, physiological, ecological, behavioural, life history and habitat), built from literature information and our own research. The consequences of changes in the intensity of the AW advection to the West Spitsbergen fjords for controlling the zooplankton community dynamics, taking into account not only the taxonomic, but also functional features, will be discussed. The knowledge of the structure and dynamics of the zooplankton community is important for understanding the functioning of the ecosystems of the Nordic and Arctic Seas in the era of climate change.

June 14, 15:10

Influence of the East Icelandic Current on population dynamics of Calanus finmarchicus *and* Calanus hyperboreus *in the southwestern Norwegian Sea*

Hjálmar Hátún, Inga Kristiansen, Eilif Gaard and Jan A. Jacobsen and Sigrún Jónasdóttir

In the southwestern Norwegian Sea, cold East Icelandic Water (EIW), of Arctic origin, flows south-eastward and warm Atlantic water (AW) northeastward. These two water masses meet and establish the Iceland-Faroe Front (IFF), where the EIW subsides under the AW. Zooplankton data have been sampled in May along a section across the IFF since 1993. In 2003, a sharp temperature increase of ~ 0.6°C was associated with a marked increase in the volume of AW along the section. Simultaneously, north of the IFF a phenology shift was observed in *Calanus finmarchicus* and *Calanus hyperboreus*, an expatriate in the EIW, largely disappeared. It was hypothesized that the changes in the *Calanus* spp. population dynamics was caused by the reduced volume of EIW. Using satellite altimetry, a large spatio-temporal hydrographic database and output from a numerical ocean model, we investigate the variable volume of EIW along the IFF and, with WP-2 samples, show its impact on dispersal, abundance and phenology of the copepods. This frontal variability can, furthermore, be linked to a marked shift in the atmospheric circulation over the Nordic Seas. The reshaping of water mass boundaries might strongly impact the large pelagic fish stock migrating to this region.

June 14, 15:50

Sensitivity of North Sea cod larvae transport to ocean model resolution and inclusion of vertical behaviour

Giovanni Romagnoni, Kristina Øie Kvile, Knut-Frode Dagestad, Øystein Langangen, and Trond Kristiansen

The success of a cod (*Gadus morhua*) year class is strongly dependent on the survival of planktonic eggs and larvae. Understanding larval drift patterns is therefore important to understand the vulnerability of cod populations to climate variation and fisheries. The degree of connectivity between populations may also be affected by drift patterns, with important implications for management. Biophysical modelling is a common tool to investigate drift of marine fish eggs and larvae. Many studies have shown that vertical swimming behavior influences drift patterns and retention. However, the spatial or temporal resolution of the ocean model can also significantly influence modelled drift patterns. Still, most studies apply the ocean model available without assessing the results' sensitivity to resolution. Here, we compare how ocean model resolution and vertical behavior influence predictions of spatial distribution of larvae and connectivity between populations, using North Sea cod as a case study. We coupled a fine (1.6 km, 3 hours) and coarse (4 km, 24 hours) setup of the Regional Ocean Modelling System to a Lagrangian particle tracking model with an integrated cod egg and larval individual-based model, and ran simulations with or without the inclusion of vertical mixing and vertical swimming behavior of larvae. Our results show that connectivity between populations is only marginally influenced by including active vertical movement and by the ocean model resolution; conversely, connectivity is substantially different between years. The overall spatial distribution of particles was influenced by the resolution of the ocean model, suggesting that the importance of using high-resolution models when modelling larvae drift depends on the scale of the problem at hand. Vertical behavior only marginally affected the results, suggesting that, for the case study examined, higher biological detail might not necessarily provide more realistic results.

June 14, 16:10

*Variability of the Norwegian Coastal Current and recruitment of Norwegian Spring Spawning Herring (***Clupea harengus** *L.)*

Øystein Skagseth, Aril Slotte, Erling Kåre Stenevik and Richard Nash

The hydrography of the Nordic Seas, connecting the North Atlantic and the Arctic, shows a broad range of spatio-temporal variability. On the sub-pentadal time scales there is a tight co-variability between the general climate of the Nordic Seas, taken as the heat content of the Nordic Seas, and the cumulative biomass of the large pelagic stocks of the Norwegian Sea. However, in terms of recruitment we will present evidence suggesting that it is the environmental conditions during a

critical period during early life stage that determines the success of the recruitment; peak recruitment years for the Norwegian Spring Spawning Herring (*Clupea harengus* L.) coincide with seasonally anomalous wind and hydrographic conditions in the Norwegian Coastal Current. These results will be further elaborated, and implications in terms of likely future climate change will be discussed.

June 14, 16:30

The contiguous Riverine Coastal Domain

Peter Winsor, Eddy Carmack, and William Williams

The riverine coastal domain (RCD) is a narrow (~10 km), shallow (~10 m) contiguous feature that is driven by continental runoff and extends clockwise ~ 10×10^3 km around northern North America with a similar feature extending around northern Eurasia. It affects light, nutrient and carbon regimes and provides a pathway for the dispersal and migration of marine biota. The two domains are linked by the northern (sub-Arctic components) walls of the Gulf Stream and Kuroshio Extension, thus forming a freshwater transport ring encircling the Northern Hemisphere. The RCD acts as the main connector between terrestrial and marine ecosystems and might become more prominent as terrestrial runoff and local melt is assumed to increase in the near-future climate. Here we present observations of the RCD and also introduce the Coastal Community Ocean Observers (C2O2) program as the ideal approach to observe the RCD over space and time.

June 14, 16:50

The nutrient balance of waters bridging the North Pacific and Western North Atlantic

Jean-Éric Tremblay, Pierre Coupel, Igor Yashayev and Phil Yeats

The western North Atlantic collects large amounts of water from the North and is thus likely to be impacted by changes occurring in the Arctic Ocean (AO) and its remote source waters. For nitrate, outflow from the AO appears to balance inputs from rivers and adjacent oceans despite substantial denitrification in interior sediments and, possibly, anoxic microzones in sea-ice brines. This inconsistency suggests that flow estimates are biased and/or nitrogen (N) cycling is poorly constrained in the AO. The N-deficient status of Pacific-derived water can be traced as far east and south as the Grand Banks from the large residual concentrations of phosphate and silicate. Silicate excess makes the region particularly suitable for diatoms, which sustain efficient food webs, whereas P excess hypothetically fosters N2 fixation somewhere. However, the large-scale nutrient distribution maps from which these inferences are made collate patchy data spanning decades and we do not know if and how the nutrient load of waters bridging the Pacific and Atlantic oceans is changing. Such a change potentially impacts biological productivity regionally as well as globally by modifying the nutrient characteristics of waters that rejoin the

meridional overturning circulation in the western North Atlantic. Using historical data and time-series of observations collected during ArcticNet and the Atlantic Zone off-shelf Monitoring Program, we present trends in the concentrations of nitrate, silicate and phosphate for waters flowing across the Canadian Archipelago and western Labrador Sea and discuss possible connections with remote biogeochemical processes occurring in source waters from rivers and the Pacific sector of the Arctic Ocean.

June 14, 17:10

Latent heat dominated air-sea coupling in the Nordic Seas associated with the Arctic Oscillation

Jinping Zhao and Ken Drinkwater

Despite the correlations of Arctic Oscillation (AO) Index with the averaged surface fluxes for all Nordic Seas are significant, here we try to find the regional contribution of heat fluxes to AO in various current and water mass conditions. By using the NCEP-DOE Reanalysis-2 surface heat fluxes data of 1979-2016, we at the first determine the high correlation regions with the correlation coefficient great than ±0.15. Then the heat fluxes in the high correlation region are averaged and the correlation coefficient with AO is calculated. By this way, much high correlations are identified, indicating the action or feedback in these regions is more significant. The temporal coherence analysis indicates that only the downwelled short-wave radiation and the latent heat vary concurrently with AO Index. AO Index is replaced by the average SLP in Nordic Seas for their close correlation to discuss the physical processes, and the latent heat dominated air-sea coupling in the Nordic Seas is proposed. Our results suggested that the upward air flow in the area of Icelandic Low strongly support the coupling, which transport the surface vapor to form the cloud and built the close relation between downwelling short-wave radiation and latent heat flux. The other heat fluxes all lag about three months, influenced by and feed back to the atmospheric processes and the variation of ocean circulation. Although the AO Index is defined by the EOF method for SLP north of 20°N, it is still a good index to express the latent heat dominated air-sea coupling in Nordic Seas.

S3 - Timing/phenology and match-mismatch: are they critical issues?

June 14, 10:30

Influence of environmental variability on Calanus finmarchicus *abundance in a Subarctic ecosystem: a remotely-sensed approach*

César Fuentes-Yaco, Pierre Pepin, Marc Ringuette, Fran Mowbray, Alejandro Buren, Carla Caverhill, Emmanuel Devred and Yongsheng Wu

The impact of environmental changes on phytoplankton phenology and transfer of energy to higher trophic levels are unclear. Here we focus on relationships between environmental variability and the seasonal phenology and their influence on *Calanus finmarchicus* population development on the Labrador Shelf and Grand Banks of Newfoundland. Satellite-derived data (1998-2015) provide information over synoptic spatial and temporal scales of the ocean's surface temperature (SST) and colour (a proxy for phytoplankton biomass indexed by Chlorophyll-a concentrations CHL). Indices were developed to measure changes in SST and phenology of biological cycles. Both of these properties were characterized using objective metrics such as the initiation, maximum, end and duration of their seasonal (CHL) and annual (SST) phases. Multivariate methods were applied to derive statistically reliable relationships. Principal Component Analyses (PCA) were performed on each indicator and the first four PCs explained approximately 90% of the variance. Using the first four PCA scores of annual SST and spring CHL analyses accounts for 95% of the variability in the anomalies of the *Calanus* spring Population Development Index (PDI) based on a Robust MM (maximum likelihood type) Linear Regression. For the autumn, however, changes in environmental signals explained only 50% of the variance in the fall PDI. The results illustrate that during spring the phytoplankton bloom conditions and *Calanus* first generation are tightly coupled and the environmental signal is clearly recognizable. In contrast, the effect of autumn phytoplankton bloom is complex and the direct effect is less clearly defined, possibly because of the cumulated effects of other drivers (e.g. predation) and the copepod population could contain more than one generation. Initiation and duration of the SST annual cycle arose as important contributors. We are currently investigating the potential significance of these relationships to the production of capelin (*Mallotus villosus*), a key forage species in the NW Atlantic.

June 14, 10:50

Barents Sea cod larvae survival and match-mismatch

Joël M. Durant and Øystein Langangen

In the context of global ecosystem changes driven by long-term modification of environmental conditions, we expect climate change to lead to a decoupling of the food web and disrupting otherwise tight trophic interactions between predator and prey. The variation in year-class strength of fish is thought to mainly result from changes in the availability of planktonic food for fish larvae. In the Barents Sea, many important commercial stocks are spawning along the Norwegian Coast; the eggs and larvae drifting northward with the coastal current to the Barents Sea. Drift studies have shown that their survival is to a large extent determined by the location reached in the Barents Sea. One hypothesis is that the larvae survival depends on the access to food once reaching the Barents Sea and can be described by a match-mismatch relationship. Here we explored the difference in timing between the arrivals in the Barents Sea cod (*Gadus morhua*) larvae and the zooplankton and to what it can explain the variation in cod recruitment. From particles tracking analysis and published relationships, we extracted these timings and using a general additive model explored the effect of asynchrony of events on the cod recruitment. We discuss our results in the light of climate warming and predator-prey interaction.

June 14, 11:10

Phytoplankton phenology in a changing Arctic Ocean

Mathieu Ardyna, Marcel Babin, Michel Gosselin, and Jean-Éric Tremblay

The Arctic Ocean is currently experiencing major and abrupt changes in its atmospheric and oceanic compartments due to climate change. The first emerging ecological consequences to the loss of sea ice are undeniable. While an overall increasing annual primary production (PP) in the Arctic Ocean is observed, studies suggest a decrease in productivity in some areas in response to a local intensification of the vertical stratification of the upper water column. The response of phytoplankton communities to climate change, with potential dramatic impacts extending through all trophic levels of marine ecosystems, remains complex and difficult to predict. We will explore here this fundamental question, with a particular emphasis on biogeography, phenology and productivity of Arctic phytoplankton communities. By combining historical databases and satellite-derived observations, we are able to portray a large variety of trophic regimes and phenological patterns across the Arctic Ocean. We will also present evidence of change in the phytoplankton compartment due to the ongoing borealization of the Arctic Ocean. Finally, we will give some insights on the future of the phytoplankton productivity, which is closely related to phenology, in response in part to the current receding sea-ice cover. Defining predictive scenarios will allow us to better anticipate the possible changes in phytoplankton productivity and community structure and the potential cascading repercussions on the carbon cycle and marine Arctic ecosystems.

June 14, 11:30

Changes in phytoplankton bloom phenology over the North Water (NOW) polynya: a response to changing environmental conditions

Christian Marchese, Camille Albouy, Jean-Éric Tremblay, Dany Dumont, Fabrizio D'Ortenzio, Steve Vissault, and Simon Bélanger

Recent climate models and satellite observations provide evidence of how the Arctic Ocean continues to experience profound marine ecosystem modifications. Some of these environmental changes include significant sea-ice reductions in its extent and thickness, increased freshwater input and stratification of the water column. For instance, the rate of sea-ice production and melt may affect light availability and leading changes in the phytoplankton bloom phenology, which in turns may cause a temporal mismatch between primary producers, Arctic grazers and apex predators. Polynyas, providing favorable conditions for primary producers and upper trophic predators are usually considered as oceanographic "windows" through which it is possible to assess and evaluate the state of the Arctic marine ecosystem. Located at the north end of Baffin Bay, between Greenland and Ellesmere Island (Canadian Arctic), the North Water (NOW) is one of the largest polynyas in the Northern Hemisphere. Here we summarize recent research results on phytoplankton phenology over the NOW polynya. Using remote sensing ocean colour data and a multi-Gaussian approach, we analyzed the bloom phenology variability between 1998 and 2014. Collectively, these outcomes depict the NOW as a climate-sensitive region in which the pelagic marine ecosystem seems to be going toward a decline in chlorophyll-a concentrations. Satellite time series are still too short to differentiate between inter-annual variability, inter-decadal variability and climate change signal. Should these changes persist, however, the NOW may no longer act as a productive regional oasis supporting thriving populations of zooplankton and top predators.

June 14, 11:50

Linking phenology and productivity to **Calanus** *copepods across the Northeast Pacific through satellite ocean colour*

Sofia A Ferreira and Neil Banas

Primary production in the Northeast Pacific (NEP) is responsible for setting the pace for life of a wide range of species. In many parts of the world's oceans, marine primary production displays a distinct seasonality, especially during the spring bloom, and the NEP is no different. This region spans the subtropical California Current System, the Gulf of Alaska, and the Arctic, ice-influenced waters, including the Eastern Bering Sea. In this study, we look at correlations of phytoplankton phenology metrics using 18 years of chlorophyll concentration (CHL), as a proxy for primary production, as well as sea surface temperature (SST). We assess the interplay

between three metrics: seasonal length (bloom duration), bloom magnitude (mean CHL during the bloom), and annual mean SST. These are used to investigate seasonality patterns in the NEP, and to assess whether these patterns (if any) are transferred to life history strategies of higher trophic levels, such as *Calanus marshallae* and other subarctic- adapted, lipid-rich zooplankton. We hypothesize that the crucial *C. marshallae* and other copepod species used in this study are most sensitive to productive season length, as opposed to bloom timing or mean CHL (although all these metrics are correlated to some degree). Experiments with the Coltrane copepod life history model suggest that season length affects copepod population dynamics mainly through overwintering success in the northern NEP, and through number of generations per year in the south.

June 14, 13:30

High–resolution modeling of the vertical migrations of Arctic Calanus *spp.*

Kanchana Bandara, Øystein Varpe, and Ketil Eiane

Diel and seasonal vertical migrations of zooplankton are strategies that maximize fitness in seasonal environments. The periodicity and vertical extent of short time diel migrations more reflect the trade–off strategy between predation risk and growth potential, while longer time seasonal migrations reflect adaptations to seasonality in food source and predation. Field or modeling investigations seldom has sufficient spatial and temporal resolution to provide understanding of why variability in timing of vertical migrations exist across geographical locations. We developed a high–resolution individual based model that predicts the optimal vertical strategy of a copepod occupying a seasonal environment. In the model, individual vertical strategies determine fitness, estimated from a function of expected feeding, growth, survival, and reproduction. The model maximizes fitness by a heuristic process where timing and the depths of diel and seasonal migrations in a given environment is optimized by a genetic algorithm. We parameterized the model with an individual representing Arctic *Calanus* spp., and performed the simulations in several artificial environments located along a latitudinal gradient (60°–80° N) to validate model performance against field investigations.

June 14, 13:50

Interplay between zooplankton life history, advection and timing of the winter-spring bloom as a mechanism controlling spring-summer production at the edge of the subarctic North Atlantic biome

Jeffrey Runge, Nicholas Record, Rubao Ji, Zhixuan Feng, and Cameron Thompson

The Gulf of Maine represents the southern margin of the subarctic North Atlantic biome in the Northwest Atlantic Ocean. Similar to Canadian shelf waters to the north, >90% of the zooplankton biomass captured in plankton nets comprises lipid-rich *Calanus* species, which serve as foundation species structuring diversity of higher trophic levels. In the past decade, the Gulf of

Maine has experienced rapid increases in water column temperature, with the prospect of continued warming at a rate higher than the global average. *C. finmarchicus*, the local dominant *Calanus* species, is sustained in the Gulf of Maine by advection from Canadian waters and growth in the relatively cool Maine Coastal Current, which transports the species to overwintering habitats in deeper basins in the western Gulf of Maine. However, because the temperature at overwintering depths is also rising, acceleration of the timing of emergence from diapause in the following winter-spring is expected. Concurrently, the timing and magnitude of the winter-spring bloom supporting cohort production from the emerging females, historically variable, is expected to become even more so in the future. Here we examine how the interplay among these processes affects the spring production of *C. finmarchicus*, with consequences for the production and structure of the region's pelagic ecosystem.

June 14, 14:10

Temperature sensitivity of Arctic and Sub-Arctic gadids to match-mismatch scenarios

Benjamin Laurel, Louise Copeman, and Brittany Koenker

The Match-Mismatch hypothesis (MMH) has received renewed attention as climatic warming in the Arctic and Subarctic seas is likely disrupting the phenology of predators and prey. However, as fish are poikilotherms, the MMH framework does not fully consider how temperature may impact development times and metabolic demands under changing food conditions. In this study, we incubated eggs and larvae of four ecologically important species of gadids across a range of temperatures in the laboratory. Species included two Arctic residents (Arctic cod *Boreogadus saida* and saffron cod *Eleginus gracilis*), and two Subarctic residents (walleye pollock *Gadus chalcogrammus* and Pacific cod *Gadus macrocephalus*). The goal of the study was to: 1) develop temperature-dependent models of hatch characteristics and larval survival across a range of thermal environments, 2) determine whether and what ontogenetic stage these thermal responses differed among species, and 3) determine the amount of risk each species faces under warm and cold match-mismatch scenarios. Collective results indicate Arctic species have a much smaller thermal window for survival, but within this thermal range, individuals can survive for longer periods in the absence of food than related Subarctic species. In contrast, the high food sensitivity of Sub-Arctic species suggests the MMH has a higher potential to regulate populations in these regions, a mechanism that will likely be exacerbated by further warming and loss of sea ice.

June 14, 14:30

*Redefining the classical dietary niche concept may help identify temporal feeding specialization – a case study on polar cod (***Boreogadus saida***)*

Marine Cusa, Jørgen Berge, and Øystein Varpe

Dietary plasticity could help organisms adjust to climate change induced disturbances in trophic dynamics. If a species is unable to cope with disruptions in prey phenology and in seasonal prey distribution, it may be more vulnerable to intermittent interspecific competition and to predator-prey seasonal mismatch. Using a classical view of ecological niche width, pan-arctic meta-analyses described the ecologically important polar cod (*Boreogadus saida*) as a zooplankton generalist and an opportunist predator, yet concerns remain regarding the effects of changes in prey availability on adult polar cod. We conducted a seasonal diet study in Svalbard fjords to reveal the complex facets of polar cod realized feeding strategies. A spatial and temporal population feeding specialization on the Arctic amphipod *Themisto libellula* in the fall suggests an active selection on this amphipod among some polar cod populations at a period that is significant for energy intake. We observed that the opportunistic feeding strategy adopted by polar cod is affected by seasonality insofar as diet is limited to a few preferred prey species in the fall and diversified during the polar night, potentially as a result of visual constraints on selection ability. Accordingly, we suggest that polar cod can behave as temporal specialists possibly as a response to high abundance of a preferred prey. The lack of an unequivocal agreement on polar cod feeding strategy partly stems from issues related to inconsistencies regarding the characterization of terms pertaining to feeding strategies. Considerable implications come with defining a species feeding strategy and our study illustrates the importance of integrating a temporal and a spatial approach when investigating foraging ecology in the context of a warming climate.

S6 - Multiple Stressors

June 14, 10:30

Comparative analysis of the structure and trends in marine communities of the Newfoundland-Labrador Shelves and Barents Sea ecosystems

Mariano Koen-Alonso, Elena Eriksen, Pierre Pepin, Ulf Lindstrom, Garry Stenson, Paul Renaud, Fran Mowbray, Raul Primicerio, Alida Bundy, Torstein Pedersen, Jamie Tam, and Nina Mikkelsen

The Newfoundland-Labrador Shelves (NL) and the Barents Sea (BS) represent archetypical examples of subarctic marine ecosystems. From an ecological perspective, their groundfish communities have been typically dominated by Atlantic cod, with small pelagic species like capelin at the centre of their food webs, and marine mammals as important top predators. These ecosystems have undergone important changes in their community structures (e.g. major declines/increases in biomass of core species) over the last 3 decades. In addition, they are significantly influenced by changing ocean conditions, and sit on the transition zone between the arctic and temperate zones where changing ice dynamics, resulting from environmental variability and climate change, have important impacts on ecosystem productivity. These areas also share a similar history in human use. Fisheries have been the dominant activity for decades, with offshore oil and gas becoming a predominant economic driver in recent decades. Despite the commonality in their structural elements and many key drivers, the respective marine communities have exhibited markedly different trends in recent decades, and their current status shows a very contrasting picture. While NL underwent a collapse in its groundfish community in the early 1990s, and only recently has started to show modest signals of recovery, the BS ecosystem is experiencing an all-time high in groundfish and increased pelagic productivity. As part of the Co-Arc project, a Norway-Canada collaborative initiative, this presentation will summarize these similarities and differences, and will explore competing and/or complementary hypotheses/mechanisms that could explain these trends. The results of this study will inform future modelling and analysis to be developed as part of the Co-Arc project.

June 14, 10:50

Effects of multiple stressors on the benthic ecosystem in the Barents Sea

Lis Lindal Jørgensen, Raul Primicerio, Maria Fossheim, T. Thangstad, Randi Ingvaldsen, and N. Anisimova

Arctic marine environments are experiencing many human-induced and natural pressures, including climate change, harvest, introduced species, pollution from ship traffic, fossil fuel exploitation, etc. The size and complexity of the Arctic benthos poses many challenges to predict how these potential cumulative pressures affect benthic species and to detect biodiversity

changes. The Barents Sea, one of the shelf oceans in the Arctic, represents a transition from warm Atlantic to cold Arctic waters and consequently an area for climate change studies. Since 2007, the Norwegian-Russian annual ground fish surveys in the Barents Sea, included benthic taxonomists and are still developing standardized monitoring of invertebrates from the fish trawls. The intension is to develop a time and cost efficient method with simple and transparent analysis tools that easily can be adopted by other national ground fish surveys. The data base, including 3073 stations, 23 Phyla, 49 taxon groups, 590 species, abundance and biomass, are continuously developing and improving and presented in a baseline map. Coding species vulnerability toward trawling, temperature affinity, and preference to invasive top-predators can indicate geographical areas of particular concern where these factors act solely or as multiple impact factors. Developing environmental considerations that balance the fishing industry need for the Barents Sea resource services are particularly demanding in geographical areas with multiple impact factors acting simultaneously in a continues natural fluctuating and dynamic Barents Sea. We will present the benthic Norwegian-Russian baseline map and possible indicators to follow effects from climate, as well as trawl and invasive species in the Barents Sea.

June 14, 11:10

Silent multiple stressors: Sublethal signals from the body condition of declining surf and white-winged scoter populations

Marjorie L. Brooks, Jessica L. Hallman Behnke, Eric M. Anderson, and James R. Lovvorn

North American scoter populations declined by about 60% over the last 30-50 years. In other studies of sea ducks, trace elements can deleteriously affect overall body condition. In wild populations, quantifying the causes of poor body condition among a suite of multiple stressors, however, is critical to linking poor organismal condition to lower reproductive success and population declines. Reasons contributing to this challenge include combined censuses of two species, wintering populations that include both resident and subarctic migrants, and lack of seasonal or location comparisons within the same species. Finally, the impacts of multiple sublethal stressors virtually always produce high noise-to-signal ratios—the ultimate non-parametric, multivariate nightmare. To tackle this issue of quantitatively assessing effects of multiple sublethal metals between surf and white-winged scoters, we collected adult male surf (*Melanitta perspicillatta*) and white-winged scoters (*Melanitta fusca*) in December 2005 and March 2006 from three locations in Puget Sound, Washington. We then compared body composition and several biomarkers to bioaccumulation of cadmium (Cd), mercury (Hg), and selenium (Se) in livers and kidneys. From permutational statistics on a resemblance matrix, we compared combined body composition and biomarkers—a sublethal "signature"—to separate: (1) differences in trace element accumulation due to spatial and temporal drivers from declines in body condition due to metals toxicosis. In surf scoters, Se and Cd in liver and kidney explained 21% of the variance in body condition factors. In larger, white-winged scoters, however, body condition differed seasonally but contaminants did not explain body condition. Our investigation demonstrates interspecific differences in vulnerability to toxicants, and the necessity of spatial and seasonal comparisons. Trace element levels in scoters were low compared to other marine

birds. Nonetheless, for surf scoters, even low levels of trace element contaminants, particularly Cd, should be considered in assessing habitat quality for sea ducks.

June 14, 11:30

Combined effects of changes in fishery exploitation, primary production and snow crab invasion on the Barents Sea ecosystem

Torstein Pedersen, N. Mikkelsen, U. Lindstrøm, Paul E. Renaud, H. Blanchet, Georg Skaret, Ingrid H. Ellingsen, Lis Lindal Jørgensen, M-A. Blanchet, L. Morissette and C. Hvingel

Climate and harvesting are important stressors of marine ecosystems. Understanding and accounting for the interactions between multiple stressors are important for sound ecosystem management. The Barents Sea ecosystem has experienced considerable changes in harvesting pressure, climate and species composition the past decades; climate warming and expansion of invasive species have resulted in major changes in species distribution and abundance. The invasive snow crab (*Chionoecetes opilio*), which first appeared in the Barents Sea in 1996, is now established and is continuously expanding its distribution area and biomass. Concurrently, the biomass of the Northeast Arctic cod stock is historically high. Future climate scenarios indicate decreasing sea-ice coverage and changing primary production in the Barents Sea. Effects of climate change, harvesting and invading species have often been studied separately, but it is important to consider the combined effects of these stressors. The main objectives of this study were to investigate ecosystem effects of contemporary changes in i) fishery exploitation, ii) primary production, and iii) abundance of the invasive snow crab, using an Ecopath with Ecosim (EwE) food-web model. Ecopath models were constructed for the Barents Sea for the time-period 1984-2015. The model comprised ca 100 compartments. The models were fitted to time-series (1984-2015) of abundance and catches of fish, mammals and invertebrate groups. To investigate the combined effects of potential future changes in the three stressors; exploitation, primary production and biomass of the invasive snow crab, future scenarios were simulated with different combinations and levels of the stressors. The effects of uncertainty in input parameters on sensitivity and uncertainty in the model output were analysed. The model output results including group biomass composition, fish production and yield and ecosystem properties, were analysed and the effects of the three stressors were assessed as acting synergistically, antagonistically or additively.

June 14, 11:50

Climate change resistance – multiple stressors do not alter Arctic primary production

Clara J. M. Hoppe, Klara Wolf, Nina Schuback, Philippe D. Tortell, Björn Rost

The Arctic Ocean is one of the regions most prone to on-going ocean acidification (OA) and other climate-driven changes, including increased sea surface temperature, sea-ice melt and altered mixing regimes. However, the influence of these changes on Arctic primary productivity, phytoplankton ecology and elemental cycles remains poorly understood. In order to understand how OA, warming and enhanced irradiances (resulting from sea-ice retreat and increased mixed layer stratification) will alter the species composition, productivity and ecophysiology of Arctic phytoplankton, we conducted several incubation experiments with natural plankton assemblages from Davis Strait (63°N), Baffin Bay (71°N) and Kongsfjorden (Svalbard, 79°N). Despite differences during the acclimation period, primary productivity was not significantly affected by OA, warming and enhanced irradiances. This surprising stability in ecosystem function was achieved through functional redundancy of different diatoms species in one instance, but most assemblages were also resistant in terms of taxonomic composition. We postulate high levels of phenotypic plasticity of organisms in concert with a large standing diversity of populations to underlie the observed resilience of Arctic primary producers to climate-dependent environmental change.

June 14, 13:30

Can food limitation increase resilience to elevated pCO2 and temperature?

Samuel P.S. Rastrick, Jiang Zengjie, Helen E Graham, Victoria Collier, Cathinka Krogness, Nia Whiteley, Tore Strohmeier, and Øivind Strand

Elevated costs of maintaining homeostasis under elevated pCO_2 and temperature conditions has been shown to divert energy away from growth and reproduction effecting the function and fitness of marine species. Although these energetic trade-offs have been well demonstrated few studies have investigated how these are affected by changes in the total amount of energy available through feeding. It has been postulated that limited access to food may lower energy availability and increase sensitivity. However, in response to food limitation some suspension feeders such as the invasive tunicate *Ciona intestinalis* can increase clearance rate and absorption efficiency whilst reducing metabolic demand resulting in the maintenance or even elevation of overall energy absorption. We demonstrate that when *C. intestinalis* are exposed to elevated pCO_2 (750 µatm) or temperature (15°C) for 1 month comparatively higher clearance rates, absorption efficiencies, and reduced metabolic demand in response to food limitation actually increases scope for growth and decreases mortality in food limited treatments (filtered seawater), compared to treatments supplied with natural seawater seston. However, this response to food limitation cannot be maintained when elevated temperature and pCO_2 are combined (750 µatm/15°C). Together these experiments show that in some species responses to food limitation may increase resilience to individual stressors during mid-term exposure. In addition, this work demonstrates energy available for production is more dependent on feeding plasticity, i.e. the ability to regulate clearance rate and absorption efficiency, in response to multiple stressors than on more commonly studied changes in metabolic costs.

June 14, 13:50

Deep-sea fish communities at the eastern slope of the Norwegian Sea – environmental gradients and vulnerability to multiple stressors

Elvar H. Hallfredsson and Raul Primicerio

Deep-sea fish species inhabiting the continental slope in the eastern Norwegian Sea show great variability in distribution and abundance. Some of the species are commercially exploited in trawl, longline and gillnet fisheries. Bearing in mind anticipated habitat alterations driven by environmental change, the aim here is to detect patterns in the structure of deep fish communities along environmental gradients, and map their vulnerability to climate warming and harvesting based on temperature affinities and life history characteristics. Based on bottom trawl surveys along the eastern continental slope and deeper shelf areas from approximately 62°N - 80°N, the study identifies major fish communities, or species assemblages, and describes their compositions in terms of species-based and size-based community indicators. Species assemblages are identified and related to season, spatial gradients and depth using multivariate analyses. The vulnerability of individual assemblages to direct and indirect exploitation is assessed relative to the occurrence of red-list species and based on life history traits of the component species. Spatial and temporal variation in deep-sea fish communities is partly related to climatic variation, which may be differently expressed at greater depths compared to what is observed in more shallow, demersal fish communities.

June 14, 14:10

Effect of a fish stock's demographic structure on offspring exposure to possible oil spills

Leif Chr. Stige, Øystein Langangen, Natalia A. Yaragina, Nils Chr. Stenseth, and Geir Ottersen

High fishing pressure has led to demographic changes in many fish stocks, towards increased dominance of young and small spawners. It is feared that these demographic changes increase the stocks' sensitivity to environmental influences, including effects of acute oil spills. Specifically, erosion of demographic structure may reduce the diversity of spawning strategies and the spatiotemporal distribution of the offspring and increase the proportion of a year-class that may potentially be exposed to harmful concentrations of toxins in the case of an oil spill. Indeed, statistical analyses of long-term egg survey data for the Northeast Arctic stock of Atlantic cod *Gadus morhua* have revealed a positive association between the mean age and size in the spawning stock and the distributional extent of the eggs. We here calculate how a large fraction of a year-class is maximally entrained within an area of a given size, and how this fraction depends on spawning stock biomass and mean weight of spawners. We thus quantify the roles of

stock size and demographic structure in influencing potential year-class exposure to geographically bounded events such as oil spills.

S4 - Shifting habitats, persistent hot spots, and the distribution of benthos, plankton, fish, seabirds and marine mammals - observations, models, mechanisms and effects (Session 4)

June 14, 15:30

Habitat conditions of fish species as factors of their distribution shift in Arctic parts of the Barents and Kara Seas

Andrey Dolgov

Changes in species composition and fish community structure in Arctic parts of the Barents and Kara Seas depend primarily on increased water temperature. It results in decreasing of abundance and further disappearance of cold-water Arctic and Arcto-boreal species and appearance and further increasing abundance of warm-water boreal, south-boreal and even widely distributed species. Based on data from several research surveys in the Barents and Kara Seas, analysis of habitat conditions (depth, water temperature and salinity) for different fish species was conducted. Such analysis shows that main factors, determining possible changes in species distribution, are water temperature and depth. Two groups of boreal species and two groups of Arctic species with different possible consequences of their distribution in conditions of further warming are identified. Distribution of boreal species, occurring at rather wide depth range (50-400 m), like cod and haddock, is mainly restricted by water temperature. In conditions of further warming distribution of these species could possibly shift eastwards throughout the almost entire Kara Sea shelf area. Distribution of relatively deep-water (e.g. Greenland halibut and deep-water redfish) and mesopelagic (spotted barracudina, glacier lantern fish) species is also restricted by depth and water temperature. These species can actively migrate or may be drifted by warm currents only alongside continental shelf slopes in the northern parts of the Barents and Kara Seas and further eastwards. Possible changes in distribution of Arctic species are also related to water temperature and depth. Species occurring at rather wide depth range (e.g. polar cod, eelpout, snailfishes) can slowly shift to colder areas of the Kara Sea and further eastwards within shelf areas. In contrast, under warming conditions shallow-water species (e.g., spiny lumpsuckers, Arctic staghorn sculpin) can shift north- and eastwards only within shallow areas and may be exposed to complete disappearance in the absence of such areas.

June 14, 15:50

Formation and persistence of a bowhead whale feeding hotspot (krill trap) near Utqiaġvik/Barrow Alaska

Carin J. Ashjian, Stephen R. Okkonen, Robert G. Campbell, and Philip Alatalo

The Beaufort shelf near Utqiaġvik/Barrow AK is a feeding hotspot for the bowhead whale during the whales' fall migration from the Canadian Arctic to the Bering Sea. Here the whales feed on dense patches of euphausiids (krill) that are often found on this portion of the shelf. The oceanographic and meteorological conditions producing this feeding hotspot were investigated from 2005-2015 using ship-based oceanographic surveys. The formation of the prey hotspot is driven by local wind conditions. Upwelling of water and krill onto the shelf was predictably observed under moderate-to-strong easterly winds; the subsequent retention of these waters and the entrained krill on the shelf occurred when upwelling winds relaxed or shifted to blow from the south or west (the "krill trap"). The abundance and relative proportions of larger adult and juvenile krill vs. krill furcilia varied interannually and likely were related to unresolved larger-scale patterns in krill abundance and transport from the Bering Sea. Wind conditions near Utqiaġvik/Barrow are related to larger-scale meteorological conditions and vary interannually. The mechanistic nature of the krill trap permits prediction of the formation of this feeding hotspot based on local wind conditions alone. Since 1980, there has been an increase in the occurrence of upwelling winds in the fall but a decrease in the number of days when the krill trap is active. Continued declines in the number of days when the krill trap is active could reduce the importance and persistence of this bowhead whale prey hotspot.

June 14, 16:10

At the cutting edge of the future: unravelling depredation, behaviour and movement of killer whales in the act of flexible management regimes in Arctic Greenland

Ann Eileen Lennert and Geatan Richard

Fisheries are an important resource in many countries, across oceans and along coasts, and, even though it is usually neglected, they bring not only economic value with them but also social value, supporting an important web of cultural practices. In this paper, we focus on a marine mammal which is entering the Arctic in increasing numbers, the killer whales (*Orcinus orca*), a major predator that may not only reshape the rapidly changing marine ecosystems via top-down forcing but also affect fisheries and cultural costumes through a specific, socially transmitted behavioural factor: depredation. By assessing the current knowledge of the depredation issue at a global scale as well as the studies of killer whales in the North Atlantic and Arctic waters, we discuss whether an eventual emerging depredation on halibut fisheries in Greenlandic waters should be taken into consideration. We stress a more flexible and cutting edge management regime on the forefront of environmental change and future scenarios. We accentuate an increased recognition of wildlife management also including an understanding of people and that success will be determined largely by political, social and cultural factors. Finally, we conclude that Greenland, being on the cutting edge of change, has high potentiality for building research based on both natural science and traditional knowledge.

June 14, 16:30

A comparison of key marine mammals in the Northeast and Northwest Atlantic

Tore Haug and Garry Stenson

Several marine mammal species in the North Atlantic have adapted to life on high latitudes to the degree that they spend their whole life within the region. These include both seal and whale species. Additionally, several cetacean species migrate into the northern waters to take advantage of high summer productivity and hence feeding opportunities, but spend the rest of the year in their broader, largely temperate distributional ranges. Marine mammals are consumers of secondary production at most trophic levels in the North Atlantic, and because of their large body size and the abundance of some species, they are thought to have an important top-down influences on the structure and function of the communities the occupy. Since some of them have been, or are still harvested, quite comprehensive information is available from research based monitoring on both sides of the North Atlantic. In this review, we aim to compare the status and trends in distribution, abundance, habitat use and trophic interactions for some common key marine mammal species in these two areas.

June 14, 16:50

Contrasting communities of seabirds in subglacial meltwater plume and oceanic water in Bowdoin Fjord, northwestern Greenland

Bungo Nishizawa, Naoya Kanna, Yoshihiko Ohashi, Daiki Sakakibara, Izumi Asaji, Yoshiyuki Abe, Atsushi Yamaguchi, Shin Sugiyama, and Yutaka Watanuki

Seabirds and marine mammals tend to gather at the front of tidewater glaciers terminating in fjords. However, physical and biological processes for their foraging aggregations are not fully understood. To investigate seabird foraging communities along the fjord and explore physical and biological factors for aggregations, we conducted boat-based seabird surveys concurrently with hydrographic measurements (temperature, salinity, turbidity, and chlorophyll) and zooplankton samplings at surface water of Bowdoin Fjord in northwestern Greenland in July 2016. Surface feeders (Black-legged kittiwake *Rissa tridactyla*, Glaucous gull *Larus hyperboreus*, and Northern fulmar *Fulmarus glacialis*) were observed at front of Bowdoin Glacier (within 1 km area from the calving front) where highly turbid subglacial meltwater and the lowest chlorophyll-a concentrations were distributed at the surface. In this area, copepods (37% wet mass) such as *Calanus glacialis* (36% wet mass of copepods) and *C. hyperboreus* (26% wet mass of copepods) and chaetognaths (15% wet mass) including oceanic *Eukrohnia hamata* were distributed. Within the plume of subglacial meltwater, aggregated surface feeders repeated dipping at the surface presumably feeding on these zooplankton and some Black-legged kittiwakes captured small fish (ca. 150 mm). These results indicate that surface feeders observed in the plume of subglacial meltwater may forage aggregated prey at surface via physical forcing such as upwelling. On the

other hand, divers (Little auk *Alle alle*, Thick-billed murre *Uria lomvia*, and Black guillemot *Cepphus grylle*) were mostly distributed outside the fjord where turbidity was lowest. In this area, cnidarians (49% wet mass) and copepods (21% wet mass) including *C. hyperboreus* (40% wet mass of copepods) were dominated. Our study suggests that under the climate change surface feeders are influenced by the changes in magnitude and timing of meltwater discharge from tidewater glaciers, while divers are influenced by the change of oceanic Atlantic currents affecting zooplankton community in this region.

Thursday, June 15

June 15, 09:00 (Invited – S1)

Regional and local scale shifts of Labrador's coastal sea ice platform: ramifications for seal distribution and Inuit winter hunting strategies over the last 500 years

James Woollett, Najat Bhiry, Yann Foury, and Natasha Roy

Archaeological studies at several Inuit winter village sites have provided diverse, multidisciplinary datasets regarding the transformation of terrestrial and marine environments, and of human-environment interactions, along the north-central Labrador coast over the last 500 years. This paper documents shifts in Inuit settlement and subsistence economy in the Nain, Okak and Napaktok Bay regions through analyses of zooarchaeological data and explores their relation to biogeographic shifts among seal populations in northern coastal Labrador related to dynamic sea ice regimes. While a range of published data sources permit the general reconstruction of sea ice conditions in the Labrador Sea and to identify trends therein, they are difficult to apply to local scales that are pertinent to Inuit hunters. Archival remote sensing data can be used to identify recurrent modern ice conditions at local scales that can be linked to particular climatic conditions in different seasons, and that can serve as a proxy for local scale ice conditions in the past. Predictably, archaeological sites located in proximity to polynyas show fluctuations in seal hunting practices (seasonal selection of species and age groups) that are consistent with varying seal habitats and sea ice climatologies within these polynyas. The bulk of Inuit winter settlements however are scattered along Labrador's long ice-bound coast, where a more linear and uniform fast-ice/ice edge sea ice environment pertains. In these areas, Inuit winter settlement and seal hunting strategies target either the ringed seal fast ice habitat, or alternatively the more diverse and risky seaward fast ice-ice edge environment. Areas with more predictable access to the ice edge appear to foster a more stable and substantial Inuit settlement while dispersed prey and travel time in areas dominated by fast ice favour a more mobile winter settlement pattern.

June 15, 09:30 (Invited -S2)

Variability in the transport and latitude of the North Pacific Current: consequences for northeastern Pacific ecosystems

Ryan R. Rykaczewski, Jasmin G. John, Charles A. Stock, and John P. Dunne

Decadal variability in ecosystems of the northeastern Pacific has been attributed to changes in the wintertime intensity of the Aleutian low-pressure system and shifts in the latitude and transport of the North Pacific Current. Periods of more intense low pressure are associated with increased catches of salmon in the Gulf of Alaska. However, in the California Current, such periods are associated with decreased salmon catches, zooplankton biomasses, and productivities of seabirds and demersal fishes. Given projections of poleward shifts in atmospheric pressure systems in response to anthropogenic climate change, improved descriptions of the mechanisms regulating these relationships are important for understanding the implications of future climate change for

the Gulf of Alaska and California Current ecosystems. Here, we explore the hypothesis that an intensified Aleutian low-pressure system is associated with equatorward displacement of the North Pacific Current and decreased advective transport of nutrients and/or zooplankton from the subarctic gyre to the California Current. We use a large-scale biogeochemical model forced by atmospheric fluxes over the historical period to: 1) explore how the position of the North Pacific Current and intensity of the Aleutian low have varied in relation to well-known modes of variability in the region (PDO, ENSO, and NPGO), 2) investigate how the latitude of the current and its bifurcation influences nutrient flux to the California Current and coastal Gulf of Alaska, and 3) consider the relationship between the latitude of the North Pacific Current and other influential ecosystem processes (e.g., upwelling and alongshore transport). Preliminary results indicate that nutrient supply to northeastern Pacific ecosystems is associated with changes in transport of the North Pacific Current, but distinguishing the relative influence of horizontal and vertical transport processes remains challenging.

June 15, 14:30

Moving in, out, and across Arctic and Subarctic Marine Ecosystems: Where do we go from here?

Franz Mueter

ABSTRACTS - POSTER PRESENTATIONS

S1 - Paleo-Ecology of Subarctic and Arctic Seas

S1-P1

Neogene fishes of the Sakhalin Island (Eastern Russia) as predecessors of the modern deep-water fish fauna of the North Pacific

Mikhail Nazarkin

A diverse complex of deep-water fishes has been recently discovered in the Middle-Late Miocene Kurasi Formation of the Sakhalin Island (Far East Russia). The complex contains remains of 29 species from 22 families of 12 orders. The fossil fish community inhabited the northern Sea of Japan during a climatic optimum marked with considerable sea transgression. Over 70% of the fossils belong to pelagic deep-water fauna dominated by two forms of lanternfish (Myctophidae) and followed by deep water smelts (primarily Leuroglossus). Other common taxa included viperfish (Chauliodus), boafish (Stomias), dragon fish (Melanostomias), bristlemouth (Cyclothone), sawtooth eel (Serrivomer), pearleye (Benthalbella), slickhead (Bajacalifornia) and tubeshoulders Holtbyrnia. The majority of the fossils belong to currently existing genera and families, with the exception of now extinct polymerfish (Aulopiformes, Polymerichthyidae). Close resemblance of the Sakhalin fossils to those from the neighboring Japanese Islands, suggests that during Miocene the deep-sea pelagic ichthyofauna was more or less uniform in the entire Sea of Japan. However, many of the deep-sea fishes are absent from the present-day Sea of Japan. The extinction of the deep-water fauna in the Sea of Japan was likely caused by prolonged anoxia resulted from isolation of the basin from the Pacific during Pleistocene glaciations. Today these basins are linked only through narrow shallow straits, which prevent re-colonization by deep-sea organisms. The dominant deep-water fish families occurring in the modern day northwestern Pacific are similar to those from the Miocene deep-sea fauna of the Sea of Japan. Thus, the contemporary deep-sea pelagic fauna in the North-Western Pacific was formed mainly before the Middle Miocene, and has not undergone dramatic changes until present. Evolutionary processes in the deep-water fish communities were slow, despite large fluctuations in sea level and temperature caused by a changing climate in Neogene and Quarternary which primarily affected coastal fishes.

S1-P2

Hydrographic changes in the subpolar North Atlantic at the Medieval Climate Anomaly (MCA) to Little Ice Age (LIA) transition inferred from fossil diatoms

Dmitry V. Divine, Arto Miettinen, Katrine Husum, and Nalan Koc

A network of four marine sediment cores from the northern North Atlantic was used to study hydrographic changes in surface water masses during the last 2000 years with a special focus on the MCA to LIA transition. The cores were recovered from the sites located on main pathways of warm Atlantic water to the Arctic and the cold outflow from the Arctic. The cores were analyzed for planktonic diatoms with a high temporal resolution. Past changes in the spatial distribution of surface water masses were studied using Q-mode factor analysis via typical species compositions in downcore diatom assemblages. SSTs were reconstructed using transfer functions. Analysis revealed a complex regional pattern of changes in the structure of circulation during the MCA/LIA transition (1200-1400 AD). In the Norwegian Sea, the factors associated with assemblages typical for warmer and saline North Atlantic waters are displaced by colder and fresher water dwelling diatoms suggesting an eastward migration of mixed Arctic/Atlantic water masses into the Norwegian Sea. The two cores south of Iceland show a westward

propagation of a warm water as evidenced by assemblages, which today are typical for the waters ca 5° further south. At the SE Greenland shelf an abrupt shift in factors associated with different sea ice zone dwelling diatoms signifies an inflow of the cold and saline mixed water masses from the area north of Iceland. Such regional patterns of hydrographic changes agree well with a hypothesis of a persistent shift in the vigor of the two main branches of the North Atlantic Drift (NAD) during the onset of LIA, namely strengthening of the Irminger Current and a parallel weakening of the Norwegian Atlantic Current. Modeling studies also corroborate this hypothesis demonstrating the possibility of such shift triggered by persistent negative volcanic/solar forcing during the studied period.

S1-P3

Diatom-inferred ocean surface conditions on the SE Greenland shelf during the last millennium

Arto Miettinen, Dmitry V. Divine, Katrine Husum, Nalan Koç, and Anne Jennings

August sea surface temperatures (aSST) and April sea-ice concentrations (aSIC) covering the last 1100 years have been reconstructed at a high temporal resolution of 3–8 years in order to investigate the variability of spring-summer surface conditions along possible forcing factors on the SE Greenland Shelf. The results demonstrate both abrupt changes and a clear centennial-bicentennial variability for the last millennium. The Medieval Climate Anomaly (MCA) between 1000 and 1200 Common Era (CE) represents the warmest ocean surface conditions of the SE Greenland Shelf over the studied interval. The MCA is characterized by abrupt, decadal to multidecadal changes, such as an abrupt warming of ~2.4 °C in 55 years around 1000 CE. Compared to regional air temperature reconstructions, our results indicate a lag of about 50 years in ocean surface warming either due to increased freshwater discharge from the Greenland ice sheet or intensified sea-ice export from the Arctic as a response to atmospheric warming at the beginning of the MCA. A cool phase, from 1200–1890 CE, associated with the Little Ice Age (LIA), ends with the rapid warming of aSST and diminished aSIC in the early 20th century. The oceanic response both to the shorter-term MCA warming and longer-term solar forcing indicates that the SE Greenland Shelf is a climatologically sensitive area where even extremely rapid oceanic changes are possible. The regional influence of the Greenland ice sheet can be prominent in the conditions of warming climate as seen during the early MCA. Oceanic changes can have an impact on global climate through their potential influence on the implications for the Atlantic Meridional Overturning Circulation. This highlights the importance of the Greenland ice sheet and the neighbouring ocean under the present warming conditions.

S1-P4

Evaluation of sea surface temperature reconstructions based on Uk'37 from surface samples of the subarctic Pacific

Lars Max, Lester Lembke-Jene, Kirsten Fahl, Jianjun Zou, Xuefa Shi, and Ralf Tiedemann

Since the alkenone unsaturation index (Uk'37) as a proxy for sea surface temperature (SST) was established about 30 years ago, it has been utilized in numerous paleoclimatic studies to reconstruct global SST variability. Typically, Uk'37 recorded in marine surface sediments shows a linear correlation with the mean annual sea surface temperature (SST). However, in some oceanic regions as the Southern Ocean or subarctic Pacific the Uk'37-based SST often overestimates the mean annual SST, the reasons for this "warming bias" are still discussed controversially. Here we use a compilation of 99 surface sediment samples from Multicores collected in the Bering Sea, the Okhotsk Sea and open ocean sites in the North Pacific to further evaluate the UK'37 temperature proxy in the subarctic Pacific. Sediment surface samples

were analysed for alkenones and the UK'37 index converted to water temperatures using different calibration equations. Uk'37-based SSTs are then compared to instrumental mean annual, seasonal, and monthly sea surface temperature as well as alkenone flux data from sediment traps. Our results show that Uk'37-based SSTs recorded in sediments of the subarctic Pacific poorly correlates to modern mean annual temperatures. On the other hand, reconstructed SSTs fit quite well to modern autumn temperatures when maximum vertical flux of alkenones is indicated by sediment trap studies. We suggest that the observed deviation between alkenone-based SSTs and annual mean temperatures is caused mainly by pronounced seasonality in high-latitude regions and discuss potential implications for paleoclimatic studies.

S2 - Advection and mixing and their ecosystem impacts

S2-P1

Nitrogen and carbon stable isotope ratios of the lower trophic ecosystem in the subarctic western North Pacific

Maki Noguchi Aita, Minoru Kitamura, Toru Kobari, Ichiro Tayasu, Chikage Yoshimizu, Kazuaki Tadokoro, Jun Nishioka, and Naomi Harada

Carbon and nitrogen isotope ratios of biota are controlled by both: 1) biological factors, including prey metabolism and lifestyle of predators, and 2) physical environmental conditions. To evaluate environmental factors (i.e. nutrients and temperature) impact on the marine food web, we studied the seasonal variation of nitrogen and carbon isotope ratios of zooplankton and micronekton in the subarctic site of K2 (47ºN, 160ºE) in the western North Pacific Ocean. Biota were collected from eight depths (0-50, 50-100, 100-150, 150-200, 200-300, 300-500, 500-750, 750-1000 m) using IONESS from February 2010 to July 2011. We examined how Δδ15N/Δδ13C of zooplankton depend on water properties within three distinct water masses: coastal Oyashio, Oyashio and warm-core ring water along the A-line monitoring transect (38N-42.5°N, 144.5-147.5°E) in March 2015. Zooplankton samples were classified using a stereomicroscope into species or genus level, and only adults were sampled for isotopic analysis. Water samples were collected from seasonal and vertical (from the surface to 1000 m depth) profiles in δ15N (NO3+ + NO2-) at K2, and from the surface to 250 m depth on the A-line inwith special reference to nitrogen cycles. The δ15N and δ13C values of amphipods, copepod and omnivorous zooplankton in the surface ocean varied widely with season. We further compared the trophic fractionation of carbon and nitrogen isotopes (Δδ13C, Δδ15N). Our present results clearly show a simple relationship between the Δδ15N and Δδ13C, regardless of species or ecosystem. By analyzing isotopic ratios of zooplankton in combination with this Δδ15N-Δδ13C relation, we can understand what pattern of variability to expect for C and N isotope ratios of higher TLs, such as carnivorous fish and seabirds.

S2-P2

Study of missing nutrients sources in the oligotrophic ocean based on time-series biogeochemical/ physical/meteorological observations in subtropical regions

Makio C. Honda, Eko Siswanto, Yoshikazu Sasai, Akira K. Yoshida, and Meghan Cronin

To study mechanisms of nutrient supply that support ocean productivity in the subtropical oligotrophic region, time-series sediment trap experiments were conducted at station KEO, located in the western North Pacific subtropical region. Meteorological and physical oceanographic observations have been conducted by National Ocean and Atmosphere Administration (NOAA) surface buoy since 2008. Two years of sediment trap data collected between July 2014 and July 2016 revealed that biogenic material fluxes to the deep sea (~ 5000 m) increased mainly between late winter (March) and late spring (June).

Based on sea surface temperature (SST) and vertical profile of water temperature obtained by surface buoy and satellite-based surface chlorophyll-a, this increase was likely attributed to increase of ocean productivity in early spring (March) that was supported by nutrient supply from winter cooling and mixing. On the other hand, fluxes of biogenic materials also increased in October 2014, and between late December 2014 and January 2015 when concentration of nutrient near surface were generally low. According to the change in sea surface heights anomaly (SSHA) and vertical profile of water temperature upper 500 m, cyclonic eddies passed through station KEO in late July-early August 2014 and November 2014 and, as a result, temporal upwelling took place. It is suspected that these events temporally supplied nutrient to upper layer and ocean productivity at subsurface layer might temporally increase resulting increase of fluxes in autumn and winter. During two-years sediment trap experiment period, several typhoons also passed near station KEO. However, the temporal water mixing or subsurface water upwelling that causes nutrient supply was not observed while internal wave took place around pycnocline.

S2-P3

Advection of shelf materials in settling particles off the Barrow Canyon, western Arctic Ocean

Jonaotaro Onodera, Eiji Watanabe, Kohei Mizobata, Yuichiro Tanaka, Kazumasa Oguri, and Naomi Harada

A large amount of shelf material transported to the Northwind Abyssal Plain (Station NAP, 75°N 162°W) in the Chukchi Borderland was previously suggested by interannual sediment trap data and physical oceanographic model experiment. The model suggested the westward advection of oceanic eddies from off the Barrow Canyon contributed to the temporal increase of high settling particle flux at Station NAP. In order to monitor the shelf-basin interaction in upper stream area of Station NAP, annual bottom-tethered mooring with sediment trap and hydrographic sensors were deployed off the Barrow Canyon (Station NBC15t, 72.47°N 155.41°W) from October 2015 to September 2016. The trapped particles contained abundant lithogenic matters suggesting shelf origin. Total mass flux at ~243 m depth of NBC15t ranged from 14.6 to 3413.9 mg $m^{-2}d^{-1}$ before the trap clogged in June 2016. The maximum of total mass flux was one order higher than that at Station NAP. The maxima of total mass flux were observed in the periods of 5-18 October 2015 and 12-24 May 2016. In addition, the underwater camera mounted on sediment trap recorded an image with abundant particles in September 2016. The comparison with hydrographic sensor data suggests that shelf material component of trapped particles in October 2015 and September 2016 are explained by intensified lateral water current in subsurface layer shallower than ~125 m depth where upward ADCP was deployed. Based on the video record of underwater camera, the high flux in May 2016 is probably explained by intensified water current containing abundant particles between the ADCP and sediment trap.

S2-P4

Inter-annual variability in Atlantic Water advection in the Kongsfjorden Transect

Vigdis Tverberg, Ragnheid Skogseth, Finlo Cottier, Arild Sundfjord, Waldemar Walczowski, Mark Inall, Eva Falck, Olga Pavlova, Frank Nilsen, and Else Nøst Hegseth

The West Spitsbergen Current is the largest oceanic heat source for the Arctic Ocean as it follows the continental slope west and north of Svalbard. Warm and saline Atlantic Water from the west Spitsbergen Current has been observed to advect into the Svalbard fjords during summer. However, it has been believed that during winter, the fjords are influenced by advection of Arctic Water and drift ice from the coastal current over the continental shelf. Our comprehensive study of historically available hydrographic data from the Kongsfjorden Transect, comprising the Svalbard fjord Kongsfjorden with adjacent continental shelf and slope, challenges this view. We show large variability in Atlantic Water content on the shelf, especially during winter, although it does not always enter the fjord itself. We suggest that heavy

drift ice conditions on the shelf are associated with winter advection of Atlantic Water into Kongsfjorden in the deepest part of the water column, while absence of drift ice on the shelf is associated with winter advection of Atlantic Water in the surface. The latter has profound effects on the fjord environment, like absence of fjord ice, and timing of the spring bloom. A declining Arctic ice cover will thus have effect the phytoplankton community in Svalbard fjords.

S2-P5

The Atlantic Water boundary current north of Svalbard; seasonality, vertical fluxes and effect on local sea ice cover

A. Sundfjord, A. H. H. Renner, M. Janout, R. Ingvaldsen, A. Beszczynska-Möller, R. S. Pickart, M. D. Pérez-Hernández

The inflow of Atlantic Water through the Fram Strait provides the largest oceanic heat source to the Arctic Ocean. Analysis of a year-long data set of hydrography and currents covering the Svalbard Branch of the AW boundary current north of the Barents Sea shows that strong inflow of warm water in fall and winter is associated with large heat losses along the upper slope. A large fraction of the heat loss can be attributed to vertical processes and this likely contributes to delaying the onset of sea ice formation and also to melt ice that is transported into the area from north and east. Wind-driven upwelling appears to be of little importance near the shelf break in spring and summer but Ekman pumping may contribute to vertical heat transport during winter. Thinner ice, larger ice free areas and longer ice free periods north of Svalbard will enhance local vertical mixing which reduces stratification and may have profound implications for vertical fluxes and ice cover downstream.

S3 - Timing/phenology and match-mismatch: are they critical issues?

S3-P1

Pan-Arctic distribution of the sympagic amphipod* Apherusa glacialis *elucidates life cycle characteristics

Erin Kunisch, Bodil A. Bluhm, Rolf Gradinger, Haakon Hop, Øystein Varpe, Jørgen Berge, Malin Daase, Carolin Arndt, Gerald Darnis, Liza Ershova, Hauke Flores, BjØrn Gulliksen, Elisabeth Halvorsen, Russ Hopcoft, Slavek Kwasniewski, Ole Jørgen Lønne, Igor A. Melnikov, Mikko Vihtakari, Jan Marcin Weslawski, W. Walkusz, and Iris Werner

Sea ice supports a diverse range of sympagic species found under the ice and at the ice-water interface. The amphipod *Aperusa glacialis* is endemic to sea ice. It is regularly found under sea ice across the entire Arctic and provides an important link between ice-derived primary production and upper-trophic level predators. While research has so far focused on its general distribution, the seasonality of its association with sea ice, potential ability to occur away from sea ice and suspected migrations to depth are less clear. We compare pan-Arctic catch data to create an understanding of how this amphipod uses the Arctic Ocean spatially (both in horizontal and vertical dimensions) throughout the year. We include published and current amphipod abundance and presence/absence data to determine where and when *A. glacialis* occurs in association with sea ice and in the water column to depth. Based on these distributional data, inferences on life-cycle adaptations are presented. This study provides a contemporary assessment of this sympagic species during a period of diminishing sea ice coverage in the Arctic Ocean.

S3-P2

Climate effects on phytoplankton blooms in the Barents Sea

Kaixing Dong, Kristina Ø. Kvile, and Leif Chr. Stige

Variations in physical conditions caused by climate change are likely to have large influence on biological conditions of marine organisms including phytoplankton. We here investigated associations between satellite derived chlorophyll data from the Barents Sea and abiotic factors such as sea surface temperature, sea ice concentration, mixed-layer depth and wind speed. We particularly investigated how increased open water area and duration of open water season, through the measured physical factors, associate with phytoplankton phenology. In the seasonally ice-covered region, preliminary statistical analysis results show that the phytoplankton peak on average occurs approximately two weeks after the sea ice concentration falls below 50% in the spring. However, the association is nonlinear: earlier sea ice retreat before the end of May is not associated with earlier timing of the phytoplankton bloom, suggesting that other factors than sea ice prevent a bloom before this time. Earlier sea ice retreat is nonetheless associated with a larger bloom, possibly due to more mixing of nutrients into surface waters. Results further suggest that the relative importance of the different physical factors for phytoplankton dynamics differ among Barents Sea regions.

S3-P3

Mesozooplankton are not herbivores: The importance of microzooplankton in mesozooplankton diets and in Arctic and Subarctic trophic linkages

Robert G. Campbell, Carin J. Ashjian, Evelyn B. Sherr, Barry F. Sherr

Large copepods, such as *Calanus* spp., in Arctic regions typically are described as herbivores, although it has been hypothesized that microzooplankton could constitute a significant component of their diet. Nonetheless, the concept of *Calanus* spp. as herbivores persists in the literature. Grazing experiments conducted in the Bering and Chukchi Seas over several years demonstrated that microzooplankton are important prey for both copepods and euphausiids, with the relative importance of microzooplankton in the diet varying between species and seasons. Microzooplankton were a greater proportion of the copepod diet during summer relative to spring, coincident with a greater proportion of microzooplankton in the available prey field. Microzooplankton were more important prey for the large shelf-slope *C. glacialis* than to the basin species *C. hyperboreus* and were greatly preferred over phytoplankton by the strongly omnivorous *Metridia* spp. at all times of the year. Trophic cascades during grazing experiments could result in significant underestimates of chlorophyll grazing rates by mesozooplankton, especially for those taxa that showed strong preference for microzooplankkon prey. These results further support the growing evidence that most mesozooplankton are not herbivorous, but are omnivorous even during periods of high primary productivity.

S4 - Shifting habitats, persistent hot spots, and the distribution of benthos, plankton, fish, seabirds and marine mammals - observations, models, mechanisms and effects

S4-P1

Age and growth estimates of the invasive red king crab in Norwegian waters

Bodil A. Bluhm, Raouf Kilada, Will Ambrose, Paul E. Renaud, Bill Locke, and Jan Sundet

The red king crab (*Paralithodes camchaticus*) is a large predatory crab that was intentionally introduced to the Barents Sea and adjacent fjords in the 1960s. Its establishment has given rise to a high-value fishery, but has also had negative impacts on habitat and benthic communities. Accurate information on growth and age span is needed to improve management and mitigation strategies, but age determination in crustaceans is difficult due to molting of hard parts. We applied a direct aging method using growth bands found in ossicles of the gastric mill, which are retained through the molt. To validate the annual nature of age band deposition, a sub-sample of the crabs was stained with calcein. The results from staining suggested annual deposition of growth bands based on addition of a single growth band in captive crabs. Band counts in 96 wild-caught crabs (62 males and 34 females) were counted and were found to be repeatable between two readers in a subsample. Band-derived size-at-age data were used to establish a growth curve for male red king crabs with asymptotic size=187.7 mm carapace length (CL), k=0.2, t_0=1.4 y, and r^2=0.78. Maximum band count (assumed to be reflecting age in years) was 13 for male crabs and 9 for females. Variation in both size-at-age and age-at-size data was large, with ≥6 cm CL variation at a given age in males and 4 cm CL in females, and a 5-year span within similar-sized crabs in both sexes. Our study, along with other recent direct aging studies in crustaceans, suggest that this novel technique can further shellfish fisheries management and conservation, and invasive species mitigation, though additional research on the mechanisms generating age-band deposition is required.

S4-P2

Modeling the sympagic-pelagic-benthic coupling processes in the St. Lawrence Island Polynya region, northern Bering Sea

Zhixuan Feng, Rubao Ji, Carin J. Ashjian, Jinlun Zhang, Robert G. Campbell, and Jacqueline M. Grebmeier

The Pacific Arctic Ocean is experiencing significant changes in atmosphere, sea ice, and ocean that may alter the marine ecosystem. The St. Lawrence Island Polynya (SLIP) region in the northern Bering Sea is one of the major biological hotspots. The highly productive benthic communities provide abundant prey for benthic-feeding mammals and seabirds, particularly the endangered spectacled eiders. Yet, major ecosystem shifts are occurring in the SLIP region, such as the observed declining trend in the percent biomass of the medium-sized nuculanid bivalves. Historical hydrographic and biogeochemical measurements and ice-ocean-ecosystem model outcomes are synthesized to elucidate the relationships between wind, sea ice, hydrography, nutrients, and production processes in this high-latitude continental shelf system. The model captures the annual cycles and seasonal patterns of the water column physical structure, nutrients, and primary production, and export production. In the wintertime, the mixing process brings high nutrients from the bottom water to the surface. A spring bloom occurs when light becomes available for photosynthesis and is typically associated with the formation of wind-driven polynyas. In the summertime, a two-layered water column is built up mainly due to thermal stratification. Nitrate and ammonium are gradually depleted in the surface water and concurrent high zooplankton grazing results in low phytoplankton standing stock. Meanwhile, nutrients are accumulated in the bottom water due to benthic remineralization. With later ice advance in recent years, a fall bloom may become more prevalent. The analyses of bottom-up forcing and sympagic-pelagic-pelagic coupling will facilitate the prediction of the persistence or relocation of benthic hotspots and also the development of management strategies to mitigate detrimental effects from climate change in the Pacific Arctic Ocean.

S5 - Future Subarctic and Arctic Marine Ecosystems under Climate Change

S5-P1

*The potential effects of petroleum activities and warmer water on the reproductive success of polar cod (*Boreogadus saida*)*

Morgan Lizabeth Bender, Jasmine Nahrgang, Marianne Frantzen, Maxime Geoffroy, and James Meador

Rapid environmental change in the Arctic with increased influx of warmer Atlantic water, reduced sea-ice coverage, and increased anthropogenic activities, especially petroleum related activities and maritime shipping, are potential stressors for organisms living in the Arctic. Considering their high abundance, widespread distribution and role as a key species in the Arctic, polar cod act as a focal species for studies of climate and as an indicator to understand the effects, mechanisms, and consequences of oil pollution. Polar cod reproductive traits reveal a disparity in population fecundity between Arctic and Atlantic populations and the physiological effects of increased Atlantic water intrusion on the life history traits and reproductive development of polar cod remain unknown. This poster addresses the sensitivity of polar cod to increased water temperature, petroleum exposure and the synergistic effect of these two stressors. A focus on reproductive development, life histories traits, and early life stages provides important insights into sensitive life stages with population level implications. Data is being collected on polar cod vertical distribution and reproductive development in the Arctic and Atlantic water masses around Svalbard, Norway. Experiments expose early life stages and reproducing adults to petroleum to elucidate physiological effects. These studies will help determine the resilience of polar cod to perturbations in the Arctic regarding global warming and potential exposure to petroleum.

S5-P2

ARCtic Marine Resources under Climate Change: Environmental, Socio-Economic Perspectives and Governance (ARC-Change)

Angelika H. H. Renner, Sturla Kvamsdal, Nils Arne Ekerhovd, Alf Håkon Hoel, Bjarte Bogstad, Cecilie Hansen, Geir Odd Johansen, Anne Britt Sandø, and Jan Erik Stiansen

As climate change puts natural, social, and commercial structures in the Arctic under pressure, ARC-Change aims to provide an analysis of physical and biological changes, economic analysis of fisheries agreements subject to these changes, and an analysis of governance and legal frameworks. A model for cross- and interdisciplinary research involving scientists from physics, biology, economics, political science and law, the project will contribute to a synthesized and integrated understanding of opportunities and challenges in a changing Arctic and the development of robust governance and legal frameworks. The project consists of three major parts: 1. An analysis of the effects of climate change on the physical and biological environment with focus on aspects relevant for economic activities (e.g. fisheries, exploitation of natural resources); here, we will use a combined approach with observational data from monitoring programs, and climate and ecosystem models. 2. An analysis of the economic and socio-economic consequences of environmental changes for fisheries and international fisheries management; using the findings from the first part in combination with data from e.g. the Norwegian Directorate of Fisheries' profitability surveys, we will assess the viability of profitable fisheries farther north in the Arctic considering both economic and management factors. 3. An analysis of resource governance institutions and law on national and international level in an Arctic environment that is changing rapidly both in terms natural environment and economic activity; this will include an assessment of the adaptive capacity of existing governance and a review of the legal environment in the Arctic. We present first results regarding potential environmental changes that might affect fisheries. Analyses focus on characteristics and spatial distribution of key habitats such as spawning, recruitment, and feeding areas. We investigate potential

future habitat development and physical and biological characteristics using ecosystem and downscaled climate models.

S5-P3

Arctic Ocean ecosystems: Applied technology, Biological interactions and Consequences in an era of abrupt climate change (Arctic ABC)

Jørgen Berge, Bodil Bluhm, Ingrid Ellingsen, Maxime Geoffroy, Daniel Vogedes, Rahman Mankettikkara, Finlo Cottier, Shane Rodwell, Bernard Hagan, Philip Anderson, Asgeir J. Sørensen, Geir Johnsen, Sturla Haltbakk, Artur Zolich, and Pedro De La Torre

Collecting information over a long time in remote places like the Arctic Ocean is a logistically complex and resource-demanding activity. The Arctic ABC project (NFR project numbers 244319 and 245923), therefore, designs innovative autonomous drifting observatories to be deployed in Arctic ice-covered waters. The infrastructure is based on cutting edge sensor technology, and the autonomous drift stations will provide unprecedented opportunities to conduct scientific exploration supported by modern data acquisition methods in the Arctic Ocean during the polar night. Satellites and electronic systems that work autonomously simplify research in this area because they reduce the need for people to be present on site and can gather more information in a given time than can be achieved during a brief ship-based field expedition. In this project, off-the-shelf electronic equipment is used to implement stand-alone sensors to address specific questions. The environmental data that the autonomous instrumentation reveals are complemented by solid in situ biological sampling and experiments. The biology component focuses around three primary research themes: 1. How do pelagic (water column) species perceive light, in particular during the long dark season? 2. How, when and where do pelagic species conduct vertical migrations in a highly seasonal Arctic, especially during the dark season? 3. Who is present and active under sea ice, in the winter, and what do they feed on? In addition to field and autonomous sampling we use models to test sympagic and pelagic life-history concepts, and to explore and project responses of Arctic ecosystems to climate change and ice cover reduction. Results from the modelling efforts will be analysed in a geopolitical perspective where the interests of states as well as potential gaps in legal regimes for resource utilization are addressed.

S5-P4

Geographic distribution of climate change research in the Nordic seas

Sofia A. Ferreira, A. Kokkalis, M.W. Pedersen, G. Romagnoni, H. Bardarson, S. Bonanomi, W.J. Boonstra, W. Butler, F.K. Diekert, N. Fouzai, M. Holma, R.E. Holt, K.Ø. Kvile, E. Nieminen, K.M. Ottosen, A. Richter, L. Rogers, M. Snickars, A. Törnroos, B. Weigel, J.D. Whittington, P. Woods and J. Yletyinen

Global climate change is affecting marine ecosystems and the human populations that depend on them directly or indirectly for their livelihood. The North Atlantic is a climate change hotspot, thus also a major source for climate change scientific research. In the uncertain times that lie before us, it is crucial to reveal to the scientific community and the public the sheer amount of evidence of climate change, its impact, and the efforts for adaptation. On a previous study, we investigated the temporal trends of scientific production in the Nordic seas across disciplines, highlighting a lack of interdisciplinary in climate change research. Here, we introduce the spatial component of climate change research by investigating the geographic variation of scientific output and the focus of the publications. The objectives of this work are i) to identify the geographic variation of climate change research in the Nordic seas, ii) to investigate the level of connectivity between disciplines, areas, biological groups, and environmental variables, and iii) to discuss potential gaps in climate change research with respect to potential causes and remedies. To meet

our goal, we reviewed more than 1400 scientific publications that focus on climate change in the Nordic seas and categorised them in terms of their focus (discipline, geographical region, environmental variable, or organism). Our results provide valuable insights on climate change research and reveals which areas of research are saturated and which are still underinvestigated. This study will serve as the starting point for discussion on the status and future of marine climate change research. Furthermore, this study shows how the climate change research is geographically distributed in the Nordic Seas, which may indicate where future climate change-driven science will emerge, where the potential future breakthroughs will be more likely to occur, thus where the money will be spent.

S6-Multiple Stressors

S6-P1
Potential risks from microplastics in a warming Arctic

Claudia Halsband, Dorte Herzke, Geir W. Gabrielsen, and Jan H. Sundet

Plastic litter poses a risk for arctic marine ecosystems and human seafood consumption. In addition to physical interference with marine life, degrading plastic may adsorb hydrophobic pollutants from surrounding seawater, as well as leaching chemical additives into the sea, acting as an exposure route of pollutants to marine organisms and eventually to humans via the food chain. The extent of the problem in the Arctic is, however, largely unknown; few data sets exist for plastic abundance, distribution and characteristics in sea ice, the water column and on the sea floor. With climate warming, the Arctic could become a plastic litter source, as currently ice-bound plastic would be released when ice melts and affect Arctic marine biota at all trophic levels. Several Fram Centre projects investigate the fate and behavior of plastics in sea ice, sea water, sediments and Arctic biota and the ecosystem impacts in relation to plastic contamination and associated chemicals. We found that plastics are ubiquitous in all arctic marine matrices (water, sediment, biota), but often in very low concentrations. Microplastics are taken up by arctic taxa (plankton, benthic animals and seabirds), but the ecological effects on populations and communities are unclear, especially when they occur concurrently with the physiological effects of rising temperatures. In birds the physical impacts from plastic themselves (obstruction of intestines) seem to be larger than that of their additives, but this needs further investigation for other biota. Plastic is subject to biofouling, which makes it more bioavailable to feeding animals. Despite these results, the estimation of socio-economic impacts, e.g. in Norwegian seafood production due to microplastics, remains difficult due to large knowledge gaps.

S6-P2
Impacts of environment changes on walleye pollock in the East Sea

Chan Joo Jang, Minkyoung Bang, Sukyung Kang, and Suam Kim

In Korea, walleye pollock (*Gadus chalcogrammus*, hereafter pollock) was one of the dominant fish species until the 1980s, afterwhich the stock biomass considerably decreased, eventually resulting in the pollock stock collapse after 2008. For the possible causes of the collapse, three hypotheses have been suggested: overfishing, warming of seawater, and changes in ecosystem structure/function. In this study, we examined if the collapse of pollock was related to environmental changes in Korean water using atmospheric data (air temperature and wind speed) from Korea Meteorological Administration and oceanographic data (sea surface temperature and zooplankton abundance) from Korea Oceanographic Data Center. A cumulative sum analysis of the air temperature, wind speed, and sea surface temperature indicates that there was a regime shift in the late 1980s when phytoplankton and zooplankton populations

substantially increased. In addition, we found that days for warm water higher than 12˚C in April, which is probably associated with low survival of pollock in early life stage, more frequently occurred after the late 1980s. These changes seem to be related to Arctic Oscillation (AO). Our findings suggest that the environment changes in the late 1980s contribute to the stock collapse of Korean pollock.

S6-P3

The CoArc Project: Energy flow, production, and sensitivity of marine ecosystems in a sea of change

Paul E Renaud, Alida Bundy, Mariano Koen-Alonso, Ulf Lindstrøm, Pierre Pepin, Raul Primicerio, Torstein Pedersen, Garry Stenson, Fran Mowbray, Magnus Aune, Hugues Blanchet, Elena Eriksen, Nina Mikkelsen, Jørgen Berge, and Jamie Tam

Many continental shelf ecosystems in Subarctic and Arctic seas support high-value fisheries with a long history of exploitation. Over a century of management and monitoring of these ecosystems has produced a substantial database on their structure and functioning, and led to development of policies for their sustainable use. Despite this, we struggle to understand divergent trajectories in two such systems: the Newfoundland-Labrador Shelves (NL) and the Barents Sea (BS). Whereas the BS has experienced record high productivity of groundfish stocks, NL has undergone a collapse of these stocks in the past 2-3 decades, with only localized areas of recovery since. Fishing pressure, oceanographic events, and climate change have all been implicated in the collapse of NL groundfish stocks, but many of the same pressures are influencing the BS. Understanding how these drivers, singly and in combination, affect stock size, production, and energy flow through the system will provide insight into the causal mechanisms of observed ecosystem changes, which requires a combination of data compilation, novel analytical approaches, and ecological modeling. This understanding is critical both to understand system response to the various drivers, but also to project response to new stressors, including continued climate change and increased petroleum exploration and extraction targeted for both areas. The CoArc project addresses these issues, both at the individual ecosystem level and through comparative process studies. We also take advantage of an international collaboration, the Arctic Science Partnership, to enhance scientific exchange among partner countries. We will evaluate system sensitivity to ecological and industrial drivers in the two regions and provide this new knowledge for risk assessment and management efforts aimed at increasing sustainability of human activities in these ecosystems.

S7 - Ocean Acidification

S7-P1

Winter-to-spring evolution of Arctic Ocean acidification state in under-ice water and effect of sea-ice processes during N-ICE2015 ice drift project

Agneta Fransson, Melissa Chierici, Philipp Assmy, Paul Dodd, Mar Fernàndez-Mèndez, Mats Granskog, Amelie Meyer, Daiki Nomura, Anja Rösel, Anna Silyakova, and Harald Steen

Ocean acidification in the Arctic Ocean surface waters is affected by physical and biological processes such as sea-ice processes, freshwater supply, vertical mixing, gas fluxes, primary production and bacterial activity. However, there are few winter-to-spring investigations of the effect of sea-ice processes such as thin ice formation after opening of leads and brine rejection on the carbonate chemistry and ocean acidification state in the underlying water. During the N-ICE 2015 Arctic Ocean drift study north of Svalbard (latitude 80° to 83°N, longitude 8°E to 28°E) onboard RV Lance, we gained unique data from winter to spring (January to June 2015). On the winter-to-spring seawater samples, we analysed total

inorganic carbon (DIC), total alkalinity (AT), nutrient concentrations (nitrate, phosphate, silicic acid), salinity and temperature and derived pH, fCO2 and calcium carbonate saturation (Ω). During the study, the carbonate chemistry changed so that pH and fCO2 decreased in the upper 100 meters due to changes in physical and biological processes, and the southward drift from Arctic water to Atlantic water. Vertical mixing, brine rejection, meltwater and primary production influenced the variability of the carbonate chemistry in the mixed layer during the winter-to-summer season.

S7-P2

Seasonal change in ocean acidification state in Kongsfjorden, with implications for calcifying organisms

Agneta Fransson, Melissa Chierici, Haakon Hop, Helen S. Findlay, Svein Kristiansen, and Anette Wold

Seasonal changes (April to July) in ocean acidification state, calcium carbonate ($CaCO_3$) saturation for aragonite (Ωa) and calcite (Ωc), and biogeochemical properties were investigated in 2013 and 2014 in Kongsfjorden, Svalbard. We investigated physical (salinity, temperature) and chemical (carbonate system, nutrient) properties in the water column from the glacier front in the fjord to the West Spitsbergen shelf. The average range of Ωa in the upper 50 m in the fjord in winter was 1.59-1.74 and in summer 1.65-2.66. The lowest Ωa (1.5) was close to the reported critical threshold for aragonite-forming organisms such as the pteropod *Limacina helicina*. In summer 2013, Ωa, pHT and salinity were generally lower than in 2014 as a result of a larger influence of high-CO_2 water from the coastal current, and less Atlantic water. The inner fjord was influenced by glacial water in summer which decreased Ωa by 0.7. Biological CO_2 consumption based on a winter-to summer decrease in nitrate was larger in 2014 than in 2013, suggesting more primary production in 2014. The influence of freshwater decreased Ωa by the same amount as the biological effect increased Ωa. The seasonal increase in temperature only played a minor role on the increase of Ωa. The biological effect showed more inter-annual variability than the effect of freshwater. Based on this study, we suggest that changes in the inflow of different water masses and freshwater directly influence ocean acidification state, but also indirectly by affecting the biological drivers of carbonate chemistry in the fjord.

S7-P3

The interactive effects of changes in CO_2 exposure and food quality on the growth and lipid composition of Pacific cod (Gadus macrocephalus) larvae

Louise Copeman, Thomas Hurst, Scott Haines, Summer Meredith and Kalyn Hubbard

Climate models indicate the Arctic will undergo dramatic environmental change with increased global warming. These effects will likely be the most severe in nearshore waters that serve as nursery habitat for juvenile gadids throughout Alaska. Increasing temperatures will likely be coupled with changes in freshwater input that will in turn significantly affect nearshore marine food webs. Both Arctic cod (Boreogadus saida) and saffron cod (Eleginus gracilis) are ecologically important in Alaskan coastal waters, however, little is known about their growth, feeding ecology or energy allocation during the juvenile stage. We used both field and laboratory approaches to understand the early energetics of juvenile Arctic and saffron cod in relation to changes in temperature and food availability. Field collections of age-0 and age-1 juvenile gadids showed significant trends in condition metrics both within and between species. Both species showed increased lipid per wet weight with standard length up until the first over-wintering period. Arctic cod had higher levels of total lipids and storage lipids in both muscle and liver tissues than Saffron cod. Energetic differences, both within and among these gadids, may stem from regional trophic and thermal conditions. Fatty acid biomarkers indicate Arctic cod have a higher reliance

on Calanoid copepods than saffron cod and laboratory experiments show distinct differences in growth and lipid storage under varying temperatures. These data suggest Arctic cod and saffron cod will likely respond differently to regional nearshore warming, such that energetic contribution of these forage fish to higher trophic levels could be transformed in the wake of further climate change.

S7-P4

Effects of parental acclimation to end-of-century ocean acidification on survival in cod larvae (*Gadus morhua*)

Martina H Stiasny, Felix H Mittermayer, Michael Sswat, Melissa Chierici, Atle Mortensen, Velmurugu Puvanendran, Thorsten B. Reusch, and Catriona Clemmesen

Ocean acidification has been shown to have negative effects on early life stages of many fish species. However, recent research suggests that exposure of the parental generation to the same ocean acidification treatment, through the process of transgenerational acclimatization, can potentially reduce these negative effects. For the first time in a commercially exploited fish species, an experiment was conducted to address the effects of parental acclimation to ocean acidification (OA) on the mortality of larval cod. In that species, earlier experiments have shown that end-of-century levels of OA double daily mortality rates in several cod populations, and lead to severe tissue damage. Adult cod from an aquaculture stock were acclimatized to ambient (400 µatm) and predicted end-of-century pCO_2 conditions (1100 µatm according to the IPCC RCP 8.5) for six weeks prior to spawning in the national cod breeding station in Tromsö. Eggs and larvae were exposed to the parental or opposed treatment and were kept under two different feeding regimes, high and low food. We found lower larval mortality in response to parental CO_2 pre-treatment only along with sufficient food. In contrast, under food limitation, pre-exposure of parents to high CO_2 exacerbated larval mortality under high pCO_2, whereas larvae from ambiently exposed parents showed intermediate mortality levels. This is the first demonstration that acclimation effects partially mediate the adverse effects of OA but only when the larvae are reared under ample resource supply. We hypothesize that excess metabolic resources are needed to build up parental buffering effects in response to ocean acidification.

S7-P5

Atlantic cod larvae (*Gadus morhua*) grow faster under ocean acidification – but is that good news?

Martina H. Stiasny, Michael Sswat, Felix H. Mittermayer, Nalani K. Schnell, Inger-Britt Falk-Petersen, Thorsten Reusch, and Catriona Clemmesen

Climate change is threatening marine ecosystems and ecosystem services through increasing temperatures, but also through ocean acidification, caused by the dissolution of anthropogenic carbon dioxide in the ocean's waters. Evidence is accumulating that fishes, particularly early life stages, are likely affected in a variety of ways. Behavioural effects and developmental impairments have been found for a range of species. However, fundamental information for commercial species is often still lacking, which would allow for up-scaling to population effects and for policy and management to include ocean acidification. We present data on larval stages of Atlantic cod (Gadus morhua) in terms of growth and larval development of two important commercial cod stocks from the Western Baltic and the Barents Sea from experimental data. Ocean acidification showed significant effects on growth. Furthermore, effects were

found on organ development and calcification of the skeletal structure. While growth and ossification of the skeletal structures appear to be enhanced under increased carbon dioxide concentrations, their organ development was comparatively slower. For example, gill filament length was significantly reduced compared to body size, which might suggest aerobic metabolic stress. Additionally, impairments were found in certain organs, particularly in the liver and the eye, in form of lipid vacuolizations. Since *Gadus morhua*, particularly the stock in the Barents Sea, currently supports large commercial fisheries, effects on growth and survival are vital information for the management of the stocks and calls for environmentally sensitive assessments in the future.

S7-P6

Micro-computed tomography: Applications for high-resolution skeletal density and calcification rate determinations. An example using annually-resolved crustose coralline algae

Phoebe Chan

Warming and acidification of the world's oceans are expected to have widespread consequences for marine biodiversity and ecosystem functioning. However, the relatively short record of instrumental observations has hindered our ability to evaluate currently observed changes in the context of long-term variability. Thus, one has to rely upon geochemical and physical proxy information stored in biomineralized shells and skeletons of calcareous marine organisms as in-situ recorders of past environments. Of particular interest is the response of marine calcifiers to changing ocean chemistry through the examination of structural growth characteristics. Here we demonstrate the application of micro-computed tomography (micro-CT) for three-dimensional visualization and analysis of growth, skeletal density, and calcification in slow-growing, annually-banded crustose coralline alga Clathromorphum nereostratum (increment width ~380 μm). X-ray images and time series of skeletal density and calcification rates were generated at various spatial resolutions (20, 40, 60, 80, and 100 μm isotropic voxel spacing) for comparison in a sensitivity analysis. Our results indicate that while both skeletal density and calcification rates do not significantly differ at varying spatial resolutions (the latter being strongly influenced by growth rates), clear visualization of micron-scale growth features and the quantification of structural changes on subannual timescales requires higher scanning resolutions. Accordingly, micro-CT imaging at 20 μm reveals seasonal cycles in skeletal density that correspond to summer / winter variations in skeletal structure. Hence, micro-CT is a fast, non-destructive, and high-resolution technique for structural and morphometric analyses of paleoclimate archives, particularly those that exhibit slow or compressed growth or micrometer-scale skeletal structures.

S7-P7

Interannual and interseasonal pH and CO2 variability Subarctic and Arctic Norwegian surface waters

Marit Norli, Andrew L. King, Kai Sørensen, Emanuele Reggiani, Pierre Jaccard, Philip Wallhead, and Richard G. J. Bellerby

We show the results and plans for future work in the National Ocean Acidification Monitoring Project (Havforsuringsovervåkingen 2013-2020 and Tilførselsprogrammet 2010-2012). Ocean acidification parameters have been measured onboard Ships of opportunity (SOOP's) in the Barents Sea since 2010 (Cargo ship MS Norbjørn) and along the coast of Norway since 2013 (Hurtigruten MS Trollfjord). These time-series in Norwegian waters show the trends (decrease in pH, increase in pCO2 and temperature) and seasonal variations with the impact of fresh water and melt water in the different water types (Arctic,

Atlantic and Coastal water). The FerryBox flow-through sensor system also measures important parameters such as Chl a fluorescence, temperature, salinity, colored dissolved organic matter (CDOM), turbidity (particles) and oxygen – all relevant for explaining the temporal and spatial variability in carbonate chemistry. During the next 4 years of the project we plan to move from manual sampling onboard to sensor-based measurements using a fully automated flow through system for pH and pCO_2, which will greatly improve the spatial and temporal resolution of the measurements and hopefully give some new insight to ocean acidification processes.

S8 – Science, Policy and Management

S8-P1

Using multiple ecosystem models to improve marine resource management in the sub-Arctic and Arctic

Jamie C Tam, Alida Bundy, Mariano Koen-Alonso, Fran Mowbray, Pierre Pepin, and Garry Stenson
Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, N.S., Canada

Subarctic and Arctic marine ecosystems in the North Atlantic are highly productive regions that support a number of human uses including energy (oil) and commercial fisheries. In the last few decades, the Newfoundland Shelf ecosystem has experienced great change, resulting from anthropogenic pressures (heavily exploited groundfish fisheries in the 1970s) and environmental pressures, leading to stock collapses, the imposition of a cod moratorium in 1992 and complete closure of the fishery in 2003, to a fishery that currently exploits shrimp and snow crab. While these periods of dynamic community change in the Newfoundland Shelf ecosystem are well documented, our understanding of these changes and ability to predict future changes has been limited. Here we present a qualitative network model of the Newfoundland Shelf ecosystem, developed by the ICES Working Group for the North Atlantic Regional Seas, and develop a quantitative ecosystem model (Ecopath with Ecosim) to explore these changes. Our aim is to explore the uses of these disparate modeling tools to improve resource management in sub-Arctic and Arctic marine ecosystems as separate tools and in multi-model inference. This work is part of the CoArc Project (a Transatlantic innovation arena for sustainable development in the Arctic) which is focused on the Newfoundland Shelf ecosystem.

S8-P2

The future Barents Sea, get ready!

Benjamin Planque, Christian Mullon, Per Arneberg, Arne Eide, Jean-Marc Fromentin, Sheila Heymans, Alf Håkon Hoel, Susa Niiranen, Geir Ottersen, Anne Britt Sandø, Martin Sommerkorn, Knut Sunannå, Olivier Thebaud, and Thorbjørn Thorvik

How can we be prepared for future changes in the Barents Sea social-ecological-system? To answer this question, we introduce the role of scenario building for research and management and present a scenario method that has been elaborated for marine social-ecological systems. The method starts from building scenarios in single perspectives: 1) fisheries management, 2) ecosystem, 3) ocean climate and 4) governance. Single-perspective scenarios are then combined into multiple-perspective scenarios. The multiple perspective scenarios are then discussed: Is the scenario coherent? How did we get there, is it plausible? Can it be simulated with numerical models? Could it be avoided, or favoured? Are we prepared for this situation? Can we be better prepared and how? The results demonstrate that this framework allows managers, scientists, stakeholders and policy makers to get prepared together to face an uncertain future.

S9 – General Open Session

S9-P1

Where land meets sea: Effects of terrestrial inputs on contaminant dynamics in Arctic coastal ecosystems

Amanda Poste, Guttorm Christensen, Paul Renaud, Anders Ruus, Pernilla Carlsson, Katrine Borgå, Michael Arts, Ken Dunton, Janne Søreide, and Øystein Varpe

Arctic coastal ecosystems are in transition, with multiple (often interrelated) stressors leading to substantial and long-term environmental change. Thawing permafrost, melting glaciers, changes in precipitation and runoff patterns and land-use changes related to increasing human activity in northern regions can lead to changes in the movement of water, nutrients, organic matter and contaminants across the land-ocean interface. Here, we present a new project funded by the Norwegian Research Council ("Where land meets sea: Effects of terrestrial inputs on contaminant dynamics in Arctic coastal ecosystems (TerrACE)"). The TerrACE project focuses on generating quantitative information about terrestrial inputs to coastal waters in Svalbard, and how these inputs can directly and indirectly affect concentrations of contaminants such as mercury and PCBs in affected coastal ecosystems. Key project components include: 1) characterization of riverine water chemistry in the Isfjorden region of Svalbard, 2) a detailed survey of physicochemical conditions (and abiotic contaminants concentrations) along gradients in the influence of terrestrial inputs (i.e. river-fjord and glacier-fjord transects, and sites adjacent to seabird colonies), 3) a quantitative assessment of the effect of terrestrial inputs on energy and contaminant flow through coastal food webs, and 4) the development of a spatially applied Bayesian Network model tool describing the direct and indirect effects of terrestrial inputs on contaminant accumulation in coastal food webs. In this poster, we also highlight key research needs on this theme and present a preliminary conceptual model for the complex interplay between terrestrial inputs to Arctic coastal waters and coastal biogeochemistry, ecology, and contaminant dynamics (transport, fate and food web accumulation).

S9-P2

INTAROS - Integrated Arctic Observation System - a new EU Horizon 2020 Research and Innovation *project*

Geir Ottersen and Stein Sandven

INTAROS is the largest of four H2020 projects supporting EU´s increased focus on the Arctic and an important contribution to the implementation of EU´s Arctic Strategy. Professor Stein Sandven, NERSC, Norway coordinates INTAROS, which brings together expertise from 49 collaborating organizations in 20 different countries and has an overall budget of 15.5 M Euros. This poster presents INTAROS in general and especially the contributions towards increased understanding of Arctic marine ecology and related applications to management. The environment in the Arctic region is changing significantly and rapidly, affecting, e.g., natural hazards, extreme weather, sea level change, coastal erosion and ecosystem alterations. Furthermore, human activities are expected to increase, causing additional impact on the vulnerable environment. To ensure sustainable development of the Arctic, INTAROS will develop an efficient integrated Arctic Observation System (iAOS) by extending, improving and unifying existing and evolving measurement systems. The project will capitalize on existing observing systems and databases, but will also install new and dedicated instrumentation to measure the marine, atmosphere, cryosphere, and terrestrial environments. These new in situ measurements will fill information gaps, complementing remotely sensed data and improving models. An important part of INTAROS is to demonstrate applications based on the iAOS and tailored to support different groups of decision-makers and

stakeholders, including researchers and fisheries and environmental managers. We will use the capabilities of the iAOS to integrate data from a large set of various databases into ecosystem simulation models through a data assimilation approach. The iAOS input will be applied towards testing and running the models NORWECOM, ATLANTIS and ERGOM. Further, INTAROS aims towards expanding the well developed reporting and management systems for fisheries and the environment in the southern Barents Sea and off West Greenland to other parts of the Arctic.

S9-P3

Comparison of UV radiation and CDOM in the Chukchi and East Siberian seas in the Arctic

Sun-Yong Ha, Bo-Yeon Lee, Eun Jin Yang and Sung-Ho Kang

We investigated the penetration of solar radiation on the Chukchi Sea and East Siberian, Arctic from 6 to 19 August 2016 using IBRV ARAON. We measured the intensity of UV radiation, CDOM and UV-absorbing compounds (Mycosporine-like amino acids) in the 14 stations. The penetration depth (Z: 1%) of UV-B, UV-A, and PAR on the middle Chukchi Sea is relatively deeper than at East Siberian stations. The CDOM concentration on East Siberian was relatively higher than the middle of the Chukchi Sea due to the influence of organic matter by river off or melting water from the permanent frozen zone in East Siberia. The penetration depth of UV-B showed an average of around 5 m on the East Siberian Shelf and around 15 m in the middle Chukchi Sea. Also, the CDOM concentration on the Siberian presented higher 0.02 m^{-1} than middle Chukchi Sea (0.01 m^{-1}). The CDOM affected the transmission of UV-B radiation more than UVA and PAR. We suggest that global warming accelerated the melting of the permanent frozen zone in the Siberia, which in turn increases the CDOM concentration in the sea water. Accordingly, CDOM protected the penetration of UV-B in the sea water. The limited UV transmission influenced the phytoplankton community and primary production.

S9-P4

The Use of Satellite Imagery in Subarctic and Arctic Ecosystem Research: 2018 ESSAS Annual Science Meeting

Ken Drinkwater, Franz Mueter, and Sei-Ichi Saitoh

Next year, ESSAS will hold its Annual Science Meeting (ASM) in Juneau Alaska with a focus primarily on the topic of satellite oceanography. Satellites provide valuable information on meteorology, sea ice, ocean circulation, primary production, fish and fisheries, marine mammals and seabirds. Over the years, they have produced environmental and biological time series that have provided insights into the mechanisms controlling physical and biological variability. At the 2018 ESSAS ASM, we seek presentations, both oral and posters, showing the use of satellite imagery in the Subarctic and Arctic regions. Of special interest, will be results from studies using satellite imagery to examine the role of climate on ecosystem processes and on comparative studies between different ecosystems in the Arctic and Subarctic. Other potential topics to be covered during the meeting include the role of the marine ecosystem on humans, past, present and future and biogeochemical processes. Details on the meeting will appear on the ESSAS website in the coming months-stay tuned!

S9-P5
IMBeR: Integrated Marine Biosphere Research

Gro van der Meeren and Lisa Maddison

IMBeR promotes integrated marine research on topics aimed towards sustainable, productive and healthy oceans at a time of global change, for the benefit of society. This is undertaken by its working groups and regional research programmes. The four regional programmes include studies of the Indian Ocean (SIBER), climate impacts on oceanic top predators (CLIOTOP), and two high latitude programmes - ICED (Antarctic waters) and ESSAS (Subarctic and Arctic research). ICED uses a coordinated circumpolar approach to better understand climate interactions in the Southern Ocean, implications for ecosystem dynamics, impacts on biogeochemical cycles, and the development of conservation and sustainable management procedures. ESSAS aims to understand how climate variability and change affect the marine ecosystems and sustainability of Subarctic and Arctic seas, and in turn, how these changes affect humans. IMBeR's overall approach to achieving its goal is to address three Grand Challenges - I: Understand and quantify the state and variability of marine ecosystems; II: Improve scenarios, predictions and projections of ocean-human systems at multiple scales, and III: Improve and achieve sustainable ocean governance. New IMBeR research areas that can be achieved in less than five years are defined in four Innovative Challenges: 1: Understand role of metabolic diversity and evolution in marine biogeochemical cycling and ecosystem processes; 2: Contribute to developing a global ocean ecosystem observational and modelling network to provide Ecosystem Essential Ocean Variables (eEOVs) and improve marine data and information management; 3: Advance understanding of ecological feedbacks in the Earth System, and 4: Advance and improve the use of social science data for ocean management, decision making and policy development. IMBeR´s dedicated Arctic and Antarctic regional programmes, and working groups on topics that cross both natural and social science, provide a unique opportunity for regional comparisons, e.g., polar regions where the many similarities, but also marked differences, enhance understanding of underlying drivers and stressors. Conveying this information to the IMBeR network, together with information on the human dimension, provides far more holistic insight that the regional programmes cannot achieve alone. The geographic range of the IMBeR regional programmes enables ongoing regional research when global focus tends to be on specific regions - like current interest in the Arctic and less focus on Antarctica. IMBeR science is particularly useful when applied to common challenges in different regions. Regional investigations into research questions provide data that can be analysed and modelled comparably, to deliver information for improved management and governance.

S9-P6
AMBON – the Arctic Marine Biodiversity Observing Network in a global context

Katrin Iken, Jacqueline Grebmeier, Seth Danielson, Russ Hopcroft, Lee Cooper, Franz Mueter, Kathy Kuletz, Kate Stafford, R. Eric Collins, Sue Moore, Bodil A. Bluhm, and Robert Bochenek

In November 2014, the National Ocean Partnership Program sponsored three Marine Biodiversity Observation Networks (MBON) as demonstration projects for such an operational and sustainable network on regional, national and global levels. One of these projects is the Arctic Marine Biodiversity Observing Network (AMBON) with focus on the Chukchi Sea continental shelf, funded through an interagency agreement between NOAA, BOEM and Shell Industry. AMBON closes some taxonomic gaps by sampling biodiversity from microbes to whales, it builds on and integrates with existing data, and continues ongoing time series sampling. This work provides important information for scientists, decision makers, resource managers, industry, and other stakeholders with essential data through a publicly accessible database. Beyond the regional scale, AMBON works as a global initiative through links to the Group of Earth Observations – Biodiversity Observing networks (GEO BON). Examples for the

international links are the Circumpolar Biodiversity Monitoring Program (CBMP), a working group of the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF), the pole-to-pole BON initiative, BON in a box, and others. Here we present examples on how the AMBON project contributes to biodiversity monitoring networks from regional to global scales.

S9-P7

Implication of animal personality and movement ecology in resource use of migratory and resident juvenile Atlantic cod (*Gadus morhua*)

Guðbjörg Ásta Ólafsdóttir

The Atlantic cod consists of divergent migratory ecotypes. This life history variation is highly correlated with functional genes but nevertheless to some extent plastic. Migratory tendencies are likely to be correlated to a number of behavioral traits that in turn effect ecology and resource use through smaller scale movement decisions. Based on recent literature on animal personality and movement ecology the subsequent predictions follow, and form the basis of a new research project examining juvenile Atlantic cod; 1) migratory cod (as determined by genotype) will be bolder, more active and faster foragers. In nature, this will manifest as less preference for structured habitats and less plasticity (both in trophic use and behavior) across ontogeny and across environmental contexts; and 2) both ecotypes will be more plastic in early development and behavior (including personality traits), environmental associations and diet will diverge further with age. Testing these predictions has immediate conservation value as the differences describes above will be highly correlated to spatial conservation/management actions. The effects of protected area design on differential survival of behavioral phenotypes has for example received recent attention.

S9-P8

North Pacific Research Board Arctic Program – Research in the northern Bering and Chukchi seas (2017-2021)

Matthew Baker, Danielle Dickson, Betsy Baker

The North Pacific Research Board has launched an Arctic Integrated Ecosystem Research Program to invest approximately $16 million in studying marine processes in the northern Bering and Chukchi Seas in 2017-2021. The program is supported by the Collaborative Alaskan Arctic Studies Program, Bureau of Ocean Energy Management, and the Office of Naval Research. In-kind support has been contributed by the National Oceanic and Atmospheric Administration and the University of Alaska Fairbanks. This coordinated program was developed in cooperation with the Interagency Arctic Research Policy Committee Chukchi and Beaufort Sea Ecosystem Collaboration Team and the U.S. Arctic Research Commission. NPRB is also collaborating and coordinating with several other U.S. agencies and organizations that fund Arctic marine research. International researchers are collaborating via the Pacific Arctic Group (PAG) as well as collaborations developed by individual investigators. PAG participants, including researchers from Canada, China, Japan, Korea, Russia, and the United States, coordinate to sample standard stations in the Chukchi and Beaufort Seas termed the Distributed Biological Observatory (DBO), and the Arctic IERP is contributing. Colleagues from Hokkaido University, the Russian Federal Research Institute of Fisheries and Oceanography (VNIRO), and the Russian Pacific Scientific Fisheries Research Center (TINRO) have expressed interest in collaborating on specific aspects of the Arctic IERP. NPRB will continue to explore opportunities for international collaboration. The goal of the program is to better understand the mechanisms and processes that structure the Arctic marine ecosystem and influence

the distribution, life history, and interactions of biological communities in the Chukchi Sea. NPRB is interested in research that addresses phenology and the alignment in space and time of primary production, secondary producers, and upper trophic level predators. The program will integrate observations collected during spring, summer, and fall in 2017, 2018, and 2019 to better understand how reduced Arctic sea ice and associated environmental changes influence the flow of energy through the marine ecosystem. The specific areas of research interest include: transport, seasonal composition, distribution, and production of phytoplankton, particulate matter, zooplankton, fishes, benthic invertebrates, seabirds, and marine mammals; timing, magnitude and fate of the primary and secondary productivity; partitioning/flux of energy between pelagic and benthic realms; distribution, condition, and standing stocks of large crustacean zooplankton that serve as the prey base for upper trophic level fishes and seabirds; assemblages, distributions, abundances, and condition of larval and early juvenile fishes that influence the recruitment success of later life stages; density of marine mammals and seabirds; and human use of and interaction with the marine environment. Late spring and early summer sampling will occur in 2017 and 2018 in the Bering Strait region. Late summer and early fall sampling will occur in 2017 and 2019 in the eastern Chukchi and western Beaufort seas.

S9-P9

BLING, a novel biogeochemical module for NEMO ocean model, suitable for long-term simulation of ocean primary productivity and gas exchanges

Laura Castro de la Guardia, Mariona Claret, Xianmin Hu, Paul G. Myers, Eric D. Galbraith

BLING (Biogeochemical with Light, Iron, Nutrient, and Gasses) is a biogeochemical model that empirically calculates community production and explicitly simulates the biogeochemical cycles of oxygen (O), phosphate (P), and iron (Fe). There are 4 to 6 prognostic tracers including P, O and the carbonate chemistry. The formulations for growth are based on a mixed Monod-quota scheme, specifically, a in-cell fixed Redfield stoichiometry of C/P, but with variable Fe quota. Ocean productivity and phytoplankton growth are limited by the ambient macronutrient concentrations, light, temperature and the internal availability of Fe. Iron will also limit the light harvesting capacity of phytoplankton, and slow down photosynthesis if in low quantities. We evaluate the first two simulations of the biogeochemical model, BLING, coupled to the ocean model, NEMO3.4, and the sea ice model, LIM2. One simulation ran from the 1st of January 1958 to the 31st of December 2016, and the second from 1st of January 1970 to 31st of December 2016. Both were run on a 0.25-degree resolution regional configuration of the Arctic and Northern Hemisphere Atlantic (ANHA4, http://knossos.eas.ualberta.ca/xianmin/anha/model_configuration.html). Climatology of surface nutrients, oxygen, and chlorophyll-a concentrations are in reasonable agreement with the satellite data and *insitu* observations. Deep ocean concentrations of nutrients and oxygen are strongly affected by the overall density of the water column and are thus influenced by model drift. Atmospheric forcing (e.g. wind and precipitation fields) has an important role defining surface water density and thus, it also strongly influences the model results. Our evaluation shows that simplifications of BLING model do not affect the overall results while still allowing us to do climate simulations to understand regional trends in productivity and gas exchanges.

S9-P10

Windows in Arctic sea ice: light transmission and ice algal response in a refrozen lead

H. M. Kauko, P. Assmy, T. Taskjelle, A. K. Pavlov, C. J. Mundy, P. Duarte, M. Fernández-Méndez, L. M. Olsen, S. R. Hudson, A. Elliott, I. Peeken, G. Johnsen, F. Wang, and M. A. Granskog

The Arctic Ocean is facing rapid changes, including higher light availability for primary producers due to a declining and thinning ice cover. In addition, the speed and dynamics of the sea-ice pack are increasing, which could result in more frequent lead formation and an increase in areas of open water or thin new ice. Little is known about the interaction of solar radiation with thin sea ice and its suitability as a habitat for ice algae. We monitored drifting pack ice north of Svalbard (80–83.5 °N) during the Norwegian young sea ICE expedition (N-ICE2015) in spring 2015. We show that refrozen leads play an important role in light transmission through an ice pack with thick snow cover in spring, with important implications for biological production beneath the ice pack and in the thin ice cover. Within a month, ice algae in the thin lead ice reached a biomass (up to 2.31 mg Chl *a* m^{-2}) similar to the older thick ice. We discuss the light response of algae and potential reasons for why biomass in the thin ice did not exceed the thick ice despite higher light availability. Growth in the young ice was likely delayed by the time needed for recruitment and photoacclimation to the high-light environment. Modeling results indicate that nutrient limitation is more severe in the thin ice. In addition, algae in the thin ice had high concentrations of intracellular UV-protecting compounds (mycosporine-like amino acids, MAAs), which could imply an additional metabolic cost. Also, the concentration of photoprotective carotenoids increased over the sampling period, indicating high-light acclimation. In unacclimated cells however, photoinhibition could have hampered growth. Our results thus indicate that high-light environments, such as young ice, enable greater productivity below the icescape, but might not necessarily become oases for ice algal production.

WKS2 - Climate change impacts on nearshore fish habitats in the Arctic

W2-P1

*Trophic vulnerability of 0-group Atlantic cod (*Gadus morhua*) and saithe (*Pollachius virens*) A case study investigating the juveniles' feeding pattern and identifying valuable nursery habitats in the Icelandic Westfjords*

Anja Nickel

Rapid environmental change due to anthropogenic impacts currently threaten marine ecosystems and increase the pressure on the vulnerable early life stages of many marine organisms. In this study, I examine trophic vulnerability of 0-group Atlantic cod (*Gadus morhua*) and saithe (*Pollachius virens*) during late summer and fall. This period coincides with the Atlantic cod juvenile settlement from the pelagic to the benthic habitat in the northwest of Iceland. It is a critical period for both species as growth in the first summer and fall may determine winter survival. Results from previous studies have identified clear habitat preferences of juvenile gadoids for structured habitats such as maerl beds and macro-algae. In Iceland, both habitat types are exploited and affected directly and indirectly by anthropogenic activities. In the current study, I investigate the diets of 0-group cod and saithe juveniles and discuss the relevance of trophic preferences and trophic competition for nursery ground conservation and management. The feeding patterns of the 0-group juveniles revealed that both species are opportunistic feeders with a wide range of prey organisms. Despite that, there is high overlap in the foraging niche of cod and saithe, suggesting the potential for trophic competition between and within the two species. Juveniles of both species exhibited similar feeding patterns during most of the study time. During the sampling period from late July until November, the proportion of benthic prey items gradually shifted until the diet mainly contained pelagic organisms. From late October on, cod and saithe feeding patterns started to diverge, which indicates more specialized foraging habits. 0-group saithe were larger throughout the sampling period. The results of the current study emphasize the need for further research investigating the early life stages of exploited fish species and the implementation of management measures for their nursery grounds in coastal waters.

W2-P2

*Overwinter growth and condition of juvenile Atlantic cod (*Gadus morhua*) in subarctic coastal Newfoundland*

Emilie A. Geissinger, Robert S. Gregory, Paul V.R. Snelgrove, and Benjamin J. Laurel

Atlantic cod (*Gadus morhua*) typically experience high mortality rates during their first year of life. Atlantic cod in subarctic Newfoundland settle into coastal habitats in several recruitment pulses throughout summer and fall, resulting in broad length-frequency distribution prior to their first winter. The first winter is thought to represent critical period in cod survival, ultimately determining cohort strength. We examined the effect of fish size and food availability on overwinter growth and condition of 0-year-old Atlantic cod. Demersal 0-year-old Atlantic cod were collected from the wild in Newman Sound, Newfoundland in November 2016 and brought to the laboratory for feeding trials at ambient overwinter sea temperatures. We conducted our experiment trials on two size classes of juvenile Atlantic cod, from January 2017 to April 1 2017, under four daily ration levels (0%, 0.5%, 1%, and 2%). Preliminary data suggest that dietary levels at 0% of body weight result in higher mortality in small juvenile cod. We then evaluated condition using Fulton's K condition factor and liver condition to infer the role of food availability on juvenile Atlantic cod survival during the overwinter period.