ESSAS Annual Science Meeting

Ecological, social, and economic dynamics of high-latitude coastal systems

June 19-22, 2023

Institute of Marine Research, Bergen, Norway

Ecological, social, and economic dynamics of high-latitude coastal systems

Overview and Schedule

The meeting will be held at the Institute of Marine Research (IMR), meeting room *Pynten*, in Bergen, Norway. For details, registration, and accommodations see the ESSAS website. Abstracts are listed by session below.

Monday, June 19

Day: Workshop – AnalogueART: Using natural analogues to investigate the effects of climate change on northern ecosystems; moving from gradient to mosaic approachesers

Eveninng: Reception

Tuesday, June 20

Morning: Session 1: Cooperative studies of coastal ecosystems engaging local communities in the sub-Arctic and Arctic

Afternoon: Session 2: Natural disasters, multiple stressors and cumulative impacts along sub-arctic and arctic coasts

Wednesday, June 21 (morning only)

Morning: Session 3: Blue Carbon, mariculture and climate change mitigation and adaptation in the Subarctic and Arctic

Afternoon: Excursion, possibly followed by group dinner

Thursday, June 22

Day: Session 4: Cod and climate change at the coastal interface

Friday, June 23

ESSAS business meeting

See detailed schedule below

Monday, June 19, 2023

<u>Workshop:</u> Using natural analogues to investigate the effects of climate change on northern ecosystems; moving from gradient to mosaic approaches

Time	*Presenter*	*Abstract title*
9:00	Samuel Rastrick	Workshop Introduction.
9:30	Kumiko Azetsu-Scott	A Tale of Two Fjords, with marine-terminated and land-terminated glaciers
9:45	Agneta Fransson	Western Svalbard fjords as climate change proxies for a changing Arctic: focus on ocean acidification and climate drivers
10:00	Jonaotaro Onodera	Decadal condition changes in material transportation in the southwestern Canada Basin, 2020-2021
10:15	Nina Bednaršek	Natural ocean acidification analogues in the subpolar and polar Northern regions: a synthesis study
10:30	Susen Fitzer (r)	Impacts of climate change on mollusc biomineralisation
10:45	Michael Bank	Using stable isotopes as tracers of pollution in heterogeneous environments
11:00	**Break**	
11:15	Jason Hall-Spencer	An overview of CO2 seep studies and the International CO2 Natural Analogues Network
11:30	Ben Harvey	The simplification of marine ecosystems under ocean acidification – insights from CO2 seeps
11:45	Richard Bellerby	Climate-Smart kelp restoration opportunities for coastal Norway
12:00	Jorge Corrales-Guerrero	Using natural analogues to evaluate the resilience of cold-water coral reefs to changes in environmental conditions
12:15	Antonio Agüera	Seasonal variability of Mytilus spp metabolic rate
12:30	Talia Mullen-Humphreys	Assessing vulnerability to future environmental change based on current habitat preferences along salinity gradients within Kongsfjorden: a case study on marine gammarid amphipods
13:00	**Lunch**	
14:00	Jorge Corrales-Guerrero	Knowledge gaps and future directions; results of a meta-analysis of natural gradient and mosaic studies.
14:15	Samuel Rastrick	Introduction to the group writing activity (5 min)
14:20	All	Group writing activity, split up for group discussions in to Chemistry, Biology, Statistics/experimental design.
15:15	**Break**	

Time	*Presenter*	*Abstract title*
15:30	All	Group writing (cont'd)
17:00	Wrap-up	
18:00	**Reception**	(At venue)

Tuesday, June 20, 2023

<u>Session 1</u>: Cooperative studies of coastal ecosystems engaging local communities in the sub-Arctic and Arctic

Time	*Presenter*	*Abstract title*
9:00	ESSAS co-chairs / Session chairs	Welcome & Introduction
9:10	Malgorzata Smieszek	Understanding risk in ecosystem impact assessments in the Arctic
9:30	Kate Ortenzi	Southern scientists, your data debt's come due.
9:50	Anne Beaudreau	Stewardship, advocacy, and knowledge exchange in coastal resource management: Case studies from Alaska
10:10	Rachael Cadman	Participatory Scenario Planning for Inuit-led Fish Futures
10:30	**Break**	
11:00	David Cote	Integrative and multidisciplinary approach leads to discovery of deep ocean biodiversity hotspot off Labrador, Canada
11:20	Yuki Minegishi	Another role of coastal marine science for making the hope in a local community: a case of sub-Arctic area in Japan
11:40	Caroline Bouchard (r)	Polar cod (Boreogadus saida) in fjord and glacial habitats: a collaborative study with Uummannaq fishers
12:00	Ben Fitzhugh (r)	Stewarding Sugpiaq (Alutiiq) Fisheries through the Millennia: Braiding Knowledge for a Sustainable and Equitable Future
12:20	***Discussion***	
13:00	**Lunch**	

Session 2: Natural disasters, multiple stressors and cumulative impacts along sub-arctic and arctic coasts

Time	*Presenter*	*Abstract title*
14:00	Hideki Fukuda	Recovery process of coastal ecosystem and local communities from the disturbance induced by mega tsunami following the 2011 Tohoku Earthquake off the Pacific coast, northeastern Japan
14:20	Raymond Nepstad	Oil spill modelling for preparedness and potential impacts in the Barents Sea region
14:40	Toru Hirawake	Water mass distribution in the northern Bering and southern Chukchi seas using light absorption of chromophoric dissolved organic matter
15:00	Johanna Myrseth Aarflot	Cumulative impact assessment of four coastal, sub-Arctic regions with contrasting scope of human activities
15:20	James Overland (r)	Catastrophic ecological and human impacts from climate change and diminished sea ice in the northern Bering Sea
15:40	**Break**	

Session 3: Blue Carbon, mariculture and climate change mitigation and adaptation

Time	*Presenter*	*Abstract title*
16:00	Session chairs	Introduction
16:10	Øivind Strand	Perspectives on Mariculture Planning facing climate change
16:30	Navya Vikraman Nair	Linking Blue Carbon Ecosystems And Water Quality In Coastal Wetlands For Viable Small-Scale Fisheries
16:50	Wrap-up	

Wednesday, June 21, 2023

<u>Session 3</u> (cont'd): Blue Carbon, mariculture and climate change mitigation and adaptation

Time	*Presenter*	*Abstract title*
9:00	Ann-Lisbeth Agnalt	Overview of Aquaculture in the North Atlantic from the chair of the ICES Aquaculture Steering Group
9:20	Ramon Filgueira	Bivalve aquaculture in Atlantic Canada: challenges and solutions under a changing climate
9:40	Weiwei Jiang (r)	Effects of Ocean Acidification on Pacific oyster, Crassostrea gigas and Mitigation Approach
10:00	Masahiko Fujii	Assessing impacts of coastal warming, acidification, and deoxygenation on Pacific oyster (*Crassostrea gigas*) farming: A case study in the Hinase Area, Okayama Prefecture and Shizugawa Bay, Miyagi Prefecture, Japan
10:20	Jiaqi Li (r)	Some insight into the influence of ocean acidification on physiology of molluscs
10:40	**Break**	
11:10	Xi Xiao	Climate mitigation and adaptation by large-scale seaweed farming in China
11:30	Nina Bednaršek	Predictable patterns within the kelp forest can indirectly create temporary spatial refugia for ocean acidification
11:50	Yaping Gao (r)	Carbon from kelp and shellfish was captured and stored by both natural and restored seagrass bed in Sanggou Bay, China.
12:10	Samuel Rastrick	Can integrated multi-trophic aquaculture help mitigate the effects of climate change on economically important filter feeders.
12:30	Frithiof Svenson (r)	Interventions for Business Model Change - Building on a Boundary Object Framework
13:00	**Lunch**	
14:00	Afternoon excursion	To be determined
18:00	Group dinner	To be determined

Thursday, June 22, 2023

Session 4: Cod and climate change at the coastal interface

Time	*Presenter*	*Abstract title*
9:00	Session chairs	Introduction
9:10	Svein Sundby	Synthesis on selected recruitment studies in Northeast Arctic and adjacent Norwegian coastal cod stocks
9:30	James Orr	Future projections of potential egg survival for polar and Atlantic cod across the Arctic
9:50	Anja Nickel	Spatial Ecology of Sympatric Juvenile Atlantic Cod and Saithe at Nursery Grounds
10:00	Carlissa Salant	Experimental evidence of the effect of temperature and ration on adult polar cod (*Boreogadus saida*) growth and condition metrics
10:20	Michelle Valliant	Distribution and movement of juvenile Atlantic cod ecotypes in nearshore water
10:40	**Break**	
11:00	Zachary MacMillan-Kenny	Mapping Ogak/Greenland cod (Gadus ogac) habitats in nearshore Nunatsiavut waters using community identified fishing locations
11:20	Pavel Emelin	Dominance transition in the nektonic species structure of the western Chukchi Sea
11:40	Kali Stone	Retrospective look at the growth and condition of juvenile Arctic cod (Boreogadus saida) in a warming Alaska Arctic
12:00	Emilie Geissinger (r)	Overwinter Survival of Juvenile Atlantic Cod (Gadus morhua) in a Coastal Ecosystem
12:20	Robert Gregory (r)	Temperature effects on recruitment of Atlantic and Greenland cod and their predators in Newfoundland coastal waters
12:50	Discussion & closing	
13:00	**Lunch**	

Session 1: Cooperative studies of coastal ecosystems engaging local communities in the sub-Arctic and Arctic

Polar cod (*Boreogadus saida*) in fjord and glacial habitats: a collaborative study with Uummannaq fishers

Authors: *Caroline Bouchard, Patrick Farnole, Kristine Lynge-Pedersen, Parnuna Egede Dahl, Henrik Christiansen*

Greenland Climate Research Centre

Polar cod (Boreogadus saida) are often found in front of glaciers, but this is the least studied of the species habitats. The Uummannaq Fjord in West Greenland provides a unique opportunity to study polar cod in the glacial habitat, as it is the only place with a directed polar cod fishery. Uummannaq fishers regularly catch polar cod as fresh bait for the Greenland halibut (Reinhardtius hippoglossoides) longline fishery, the main economic activity in the region. We collaborated with Uummannaq fishers to learn about polar cod through interviews and collection of fish samples. Ten informants provided information on fishing areas, methods and season, and reported a spawning area near Saattut. The fishers reported a scarcity of polar cod in the Uummannaq region in 2022 compared to prior years and suggested a link with the absence of seals which they also observed. One of the two samples collected contained only 21% males, which were longer, heavier, older and had a higher gonadosomatic index than females. We hypothesize that size-selective predation from ringed seals caused this skewed sex ratio. Collaboration with fishers provided important baseline information on polar cod in fjord and glacial habitats.

Understanding risk in ecosystem impact assessments in the Arctic

Authors: *Malgorzata Smieszek[1], Frode Vikebø[2], Alf Håkon Hoel[1]*

[1] UiT The Arctic University of Norway

[2] Institute of Marine Research, Norway

The Barents Sea is expected to become the first summer ice-free Arctic region by around 2050, if not sooner. As the ice cover is receding fast due to climate change, new areas farther north become increasingly accessible for economic activities such as oil and gas exploration and shipping. Extracting and transporting oil come with the risk of accidental oil spills, including in the areas near ice that are critical to spawning/recruitment of the cornerstone of the Arctic food chain – polar cod. While the negative effects of declining winter sea ice cover on polar cod are partly established, the ACTION project ("Arctic ecosystem impact assessment of oil in ice under climate change") examines the cumulative impacts of climate change and oil pollution on that key species in the Barents Sea ecosystem. The main objective of ACTION is to develop and demonstrate a risk assessment of those cumulative impacts and through that inform relevant policy-making processes.

Whereas results of the project will fill important knowledge gaps in our understanding of mechanisms by which pollutants and climate change interact to affect key Arctic species, there are inherent

limitations in the studies of that kind. Among others, they relate to complexity of investigated processes, nature of obstacles that prevent the filling of knowledge gaps, climate change timescales under examination, and tipping points that – if crossed – might render today´s risk assessments inadequate.

In that context, understanding of risk and related uncertainties becomes of paramount importance, especially among stakeholders with potentially different value perceptions. How is risk conceived by decision-makers and stakeholders in offshore petroleum industry? What is the treatment and communication of uncertainties? What are the implications for decision-making processes? The case presented here raises generic questions of fundamental importance to decision-making under conditions of climate change and increased uncertainty.

Stewardship, advocacy, and knowledge exchange in coastal resource management: Case studies from Alaska

Authors: *Anne H. Beaudreau*

University of Washington, School of Marine and Environmental Affairs, USA

Coastal communities in Alaska are experiencing unprecedented shifts in land and seascapes arising from climate change. These changes in the environment, together with economic and regulatory factors, exert a complex set of pressures on small-scale fisheries and resource-dependent communities. Fishers and fishing communities have responded in numerous ways, such as diversification into new fisheries or seafood industries, development of direct marketing strategies, advocacy in resource management settings, and local stewardship efforts.

I will compare and contrast findings from community-based research on rockfish and salmon fisheries in the Gulf of Alaska, to explore the roles of stewardship, knowledge exchange, and engagement in the public process of management in facilitating resilience in the context of changing coastal ecosystems. Our research highlights existing strengths and opportunities for broader inclusion of fishers' knowledge within state (Alaska) and federa l (USA) fishery management system.

Participatory Scenario Planning for Inuit-led Fish Futures

Authors: *Rachael Cadman, Jamie Snook, Jim Goudie, Keith Watts, Megan Bailey*

Dalhousie University, Canada

In many places across the Arctic and sub-Arctic, commercial fisheries play a vital role in supporting the social, cultural, and economic wellbeing of Inuit communities. Still, many northern communities remain locked out of decision-making processes while the majority of benefits flow south. There is a need for research that can support Inuit governance over their adjacent resources, led by their own priorities. This prompts an important question: what do Inuit want the future of their fisheries to look like? Using an iterative participatory approach, a group of Inuit fisheries stakeholders in Nunatsiavut, Labrador in partnership with university researchers, led a scenario planning process to imagine desirable futures for the Nunatsiavut commercial fishing industry. First, through interviews with fishers and managers, we uncovered a complex system of values that frame the fisheries as a pathway for care in community, a

tool to nurture autonomy, and a space that fosters connection to history and belonging for many. Next, we used these values and characteristics of a "successful fishery" as narrative prompts to build stories of desirable futures for fisheries. The resulting vision represents a future for fisheries that is led by and for Inuit and has implications for how governance is framed in the circumpolar north.

Southern scientists, your data debt's come due

Authors: *Kate Ortenzi, Veronica Flowers*

Dalhousie University, Canada

In the summer of 2022, I co-supervised a master's student from Nunatsiavut in identifying previously collected oceanographic and biological data from coastal Nunatsiavut, Newfoundland and Labrador, Canada. Together, we combed through over 400 research applications that had been approved by the Nunatsiavut Government Research Advisory Committee (NGRAC) over the past 10 years. Just over half the researchers indicated their willingness to share their data with Nunatsiavut, however, very few had. In fact, after months of email exchanges and zoom calls with past researchers, we had only gotten data returned from about 10 percent of projects. When contacted, researchers explained why they weren't able to share their data. Some indicated that their institution's ethics review board didn't allow for data sharing, which they had sought and gotten approved after submitting their NGRAC ethics approval. Others explained that the research was never published, or too much time had passed and the location of the data was no longer known.

This story is illustrative of a larger data sovereignty issue facing Northern communities derived from ethical tension between academic and Indigenous institutions and values, as well as a lack of research process governance. Confronting this tension can help ensure that data ownership resides with communities, and that any ethical impasse on data management between academic institutions and Northern communities doesn't result in researchers withholding data. As researchers, we must recognize that disrespecting data sovereignty is a form of extractive colonialism. We must reflect on the reality that by not returning data to communities, we are creating harm by withholding information that could be used to further self-governance. In this panel, I will reflect on the story outlined above as well as offer recommendations for researchers based on conversations with the individuals engaged in data management in Nunatsiavut.

Integrative and multidisciplinary approach leads to discovery of deep ocean biodiversity hotspot off Labrador, Canada

Authors: *D. Cote, B. M. Neves, J. Angnatok, E. Edinger, L. Gullage, R. Laing, A. Normandeau, V. Hayes, O. Sherwood, M. Geoffroy*

Fisheries and Oceans Canada, Canada

International commitments to preserve global biodiversity target the protection of 30% of marine habitats by 2030. The lack of even basic knowledge for many marine areas, combined with short timelines, requires that integrative knowledge and multidisciplinary techniques are used to efficiently

identify areas worthy of protection. Here we outline a case study of the discovery of the Makkovik Hanging Gardens found in the poorly studied coastal waters of Labrador, Canada. The area is of ecological significance as it supports high densities of Vulnerable Marine Ecosystem Indicator taxa including the gorgonian coral Primnoa resedaeformis on vertical submarine walls spanning depths of 460-700 m . This study illustrates the benefits of integrating local knowledge, scientific models, and a variety of technologies such as Remote Operated Vehicles and multibeam sonar to discover hidden biodiversity.

Another role of coastal marine science for making the hope in a local community: a case of sub-Arctic area in Japan

Authors: *Yuki Minegishi*

Atmosphere and Ocean Research Institute, The University of Tokyo

The Pacific side of the northeastern Japan's mainland, referred as Sanriku Coast, is an area where local communities have been historically tightly linked to seas in various aspects such as natures, marine resources, industries and cultures. However, the values of seas in local communities in the Sanriku area have been diminishing for last several decades due to natural and social issues like serious depopulation, aging population, and drastic decline of local fisheries. The great earthquake and massive tsunami attacked the Sanriku Coast in 2011, which eventually accelerated this deterioration, with resulting in non-negligible physical and psychological separations between human societies and seas, and even between local communities. For futures of communities and generations in this area beyond restoration from the disaster and facing climate change, making hopes in local communities is obviously needed.

In social science, a hope is defined as a wish for something to come true by action, and reconstruction of local identities is required to generate hopes in local communities. In the Sanriku area, local identities are based on seas, and thus it is needed for local communities to arouse interests in seas and to be proud of their local seas. In this context, basic marine science to understand natural/social particularities and diversities may help local communities rediscover the values of local seas/areas through sharing scientific results but also research processes in any ways. Moreover, involvement with various local sectors that have a wide range of aspects and standpoints possibly facilitates engagement of a whole community. This kind of collaborations of basic marine science and communities would work more effectively in the coastal areas, rather than open oceans and urban areas. In the presentation, concrete activities engaging local communities from kids to general public in various ways will be introduced.

Stewarding Sugpiaq (Alutiiq) Fisheries through the Millennia: Braiding Knowledge for a Sustainable and Equitable Future

Authors: *Ben Fitzhugh, Hollis Miller, Dehrich Chya, Courtney Carothers*

University of Washington, USA

Sugpiaq (Alutiiq) people of the Kodiak Archipelago and surrounding coasts have a long history of deep relationships with marine ecosystems. These close relationships are well known in oral tradition and

apparent in archaeological evidence of marine mammal hunting and fishing going back more than 7000 years. Maritime livelihoods are witnessed in the written accounts of the earliest European and Northeast Asian invaders in the late 18th and 19th centuries and persist throughout the Russian and American periods. Fish are and have always been central to Sugpiaq cultural identity and essential to food sovereignty and security in the archipelago. In this talk, we will explore linkages between past, present, and future for Sugpiaq communities drawing on community-centered archaeology and ethnography, traditional place names, and storytelling (oral histories). We will consider the impacts of industrial fisheries management, especially access privatization, on community well-being and argue that a more community-centered approach to resource governance is needed, one that honors the sovereignty and traditional and contemporary rights of Sugpiaq communities to participate equitably in the sustainable management and use of local fisheries.

Session 2: Natural disasters, multiple stressors and cumulative impacts along sub-arctic and arctic coasts

Catastrophic ecological and human impacts from climate change and diminished sea ice in the northern Bering Sea

Authors: *James Overland[1]; Elizibeth Siddon[2]; Thomas Ballinger[3]; Gay Sheffield[4]*

[1] NOAA – Pacific Marine Environmental Laboratory, USA

[2] NOAA – Alaska Fisheries Science Center, USA

[3] International Arctic Research Center, University of Alaska Fairbanks, USA

[4] Alaska Sea Grant, University of Alaska Fairbanks, USA

There was record minimum sea-ice cover during winter 2018 and 2019 in the Bering Sea, with continuing multi-year impacts on the marine ecosystem and human activities. The back-to-back sea-ice minimums during 2018 and 2019 were certainly unexpected, given the normal large year-to-year variability of storms for the northern Bering Sea. Ecological shifts indicated reorganization of the northern marine food web that included loss of sea-ice algae and young crabs, predatory cod and pollock moving north impacting lower trophic levels, and loss of salmon abundance. Direct human impacts included increased seabird and ice-associated seal emaciation and mortality, and increased harmful algal blooms. These changes affected regional food security, human/wildlife health, cultural activities, and marine wildlife conservation. Resulting impacts to livelihoods in the northern Bering Sea included commercial and non-commercial subsistence acquisition of essential marine resources for sale and direct consumption. Global warming initiated these events through a weakened atmospheric Arctic Front that promotes a self-reinforcing cycle of sea-ice loss, warmer temperatures, southerly winds and a wavy jet stream. Interannual variability is still important however; during 2022 the Aleutian Low pressure system was regionally dominant. Projections for the next decades are for an increasing

frequency of low sea-ice years and a continuing ecosystem transition impacting essential marine wildlife resources and residents of the coastal northern Bering Sea.

Variation in Bering Sea snow crab (*Chionoecetes opilio*) lipid dynamics under multiple stressors

Authors: *Erin Fedewa and Louise Copeman*

NOAA-Alaska Fisheries Science Center, USA

Snow crab, Chionoecetes opilio, support a high value fishery in the Bering Sea that topped international news headlines in 2022 when the iconic fishery was abruptly closed following an unprecedented stock collapse. Drivers of the snow crab mass mortality event are still widely unknown, although the collapse of the arctic species notably coincided with record-high recruitment, extreme temperatures, and sea ice decline in the Bering Sea. Declines in juvenile snow crab body condition have previously been associated with warmer temperatures in the Bering Sea, and energetic condition is likely an important determinant of survival to recruitment. Here, we investigate spatiotemporal variation in body condition of juvenile snow crab collected during (2019) and after (2021 – 2022) the Bering Sea snow crab stock collapse. While bottom temperature was a poor predictor of snow crab condition metrics, we present the first evidence that immature snow crab in eastern Bering Sea nursery grounds were in reduced energetic condition in 2019 relative to post-collapse years. Our results suggest that large, immature male snow crab may experience energetic constraints prior to terminal molt and recruitment to the fishery. A complementary objective validated hepatopancreas moisture content as a rapid metric for quantifying energetic condition in field-collected snow crab. We propose that this condition metric may be useful for developing a baseline monitoring program to forecast snow crab recruitment. Overall, we expect that continued data collection on future NOAA surveys will advance our understanding of environmental drivers of snow crab recruitment in a rapidly warming Bering Sea ecosystem.

Water mass distribution in the northern Bering and southern Chukchi seas using light absorption of chromophoric dissolved organic matter

Authors: *Toru Hirawake, Joji Oida, Youhei Yamashita, Hisatomo Waga, Hiroto Abe,*

Jun Nishioka, Daiki Nomura, Hiromichi Ueno, Atsushi Ooki

National Institute of Polar Research, Japan

We used the light absorption coefficient of chromophoric dissolved organic matter (CDOM), aCDOM, as an alternative way to classify water masses. The aCDOM spectra of several water depths were measured in the Northern Bering Sea (NBS), the Gulf of Anadyr included, and the Southern Chukchi Sea (SCS) in July 2017 and 2018, and August 2018. Using optical parameters, aCDOM(350) and spectral slopes (S275–295 and S350–400), waters were classified with cluster analysis. When surface waters in the NBS and SCS are classified using a temperature–salinity diagram, they are mistakenly identified as Alaskan Coastal Water because of warmer temperatures. However, our cluster analysis using CDOM parameters evenly classified seven water masses with reasonable distributions. A water mass with the highest aCDOM(350) and lowest S275–295 was found along the coast of the Gulf of Anadyr and Alaska

mainland, which suggests that freshwater originates from the Anadyr and Yukon rivers and is transported by the Anadyr Current and Alaskan Coastal Current, respectively. A CDOM-based water mass with high S275–295, indicating CDOM degradation by ultraviolet radiation, was present at the sea surface. A water mass with low S275–295 was found at deeper water depths and river mouths. These results suggest that classification with CDOM parameters is consistent with geographical features. Overall, this study reveals that water mass classification using CDOM parameters is useful in coastal sea areas in which water mass mixing is complex.

Oil spill modelling for preparedness and potential impacts in the Barents Sea region

Authors: *Raymond Nepstad, Tor Nordam, Emma Litzler*

SINTEF Ocean, Norway

As petroleum development and shipping activities move further north, the potential for oil spills in Arctic waters is of great concern. As a tool for contingency planning and forecasting during response, oil spill models play a key role. Such models can provide valuable information on how the oil will behave at sea and in coastal areas with e.g., stranding. With the development of new, high-resolution coupled ice-ocean models, better predictions of sea ice are becoming available, and new models for early life stages of, e.g., polar cod, can be combined with oil spill models to give more realistic impact assessments.

Studies in the Arctic indicate that when present, sea ice is very strongly correlated with the fate of an oil spill, highlighting the importance of having accurate ice data available. Both seasonal trends and longer-term climate change can therefore have consequences for how Environmental Risk Assessments should be carried out in the Arctic. The statistical nature of climate change predictions means that ensemble simulations should be used, were oil spill simulations are run with varying inputs to map potential outcomes.

We are currently working on improving a model of oil behavior in the marginal ice zone and ice edge by utilizing data from recent flume experiments, to better reflect oil-ice interactions and to account for oil transport under ice. The model will also account for the changes in the weathering (e.g., biodegradation) of oil due to low ocean temperatures. We will illustrate the model with simulations of spill scenarios at sea and near the coast. As a part of the ACTION project, these improvements combined with coupling of models for ocean currents, sea ice and polar cod will lead to improved understanding of the potential impact of oil spills in the Arctic.

Recovery process of coastal ecosystem and local communities from the disturbance induced by mega tsunami following the 2011 Tohoku Earthquake off the Pacific coast in northeastern Japan

Authors: *Hideki Fukuda*

The University of Tokyo, Japan

The devastating physical disturbance by a mega-tsunami event causes serious and extensive damage to coastal environment and local community. A massive tsunami associated with the 2011 Tohoku Earthquake off the Pacific coast struck the Sanriku ria coast, which is located in the subarctic area of

northeastern Japan. The extent and nature of the damage to coastal biota and its recovery process differed greatly between species, life forms and localities. With the ground subsidence that linked the movement of a plate forming a seabed, the ecotone of Sanriku ria coast was exposed to sudden, irreversible changes. Simultaneously, local communities in the area, where aquaculture (oyster, scallop and seaweed) in a semi-enclosed bay and industries processing marine products caught in the offshore area of the western subarctic Pacific are the main industries, were severely damaged. Although buildings and facilities had been protected by a seawall of several meters height that had been constructed along the coastline, the unexpected mega-tsunami destroyed them and introduced an enormous amount of land-derived debris (soil, wood, houses, cars) to the coastal sea. Part of the land-derived debris was transported to other countries in the northeastern Pacific with associated alien species. Although protective measures were implemented after the tsunami, such as a huge seawall along the coastline and a sluice gate at the river mouth, local communities suffered an increase in shellfish poisoning after recovery of aquaculture facilities. Furthermore, damage to the blue economy and delay in the restoration of communities accelerated a long-lasting trend of population decline in the area. These alterations in the coastal ecosystem and local communities are probably more rapid and more drastic than those due to climate change. However, lessons learned from the disaster may be useful for mitigation of various disaster risks in the coastal zone.

Cumulative impact assessment of four coastal, sub-Arctic regions with contrasting scope of human activities

Authors: *Johanna Myrseth Aarflot, Vilde Regine Bjørdal, Marina Espinasse, Bérengère Husson, Ulf Lindstrøm, Felicia Keulder-Stenevik, Kotaro Ono, Anna Siwertsson, Mette Skern-Mauritzen*

Institute of Marine Research, Norway

Coastal waters are exposed to a range of anthropogenic impacts from multiple sectors operating at sea and on land. Ensuring that the cumulative pressures from human activities do not harm the coastal ecosystems is challenging but crucial for sustainable management of these waters. Linkage frameworks and ecological risk assessments have proved useful tools for holistic evaluations of human pressures as a guide to policy makers for prioritization of risk factors. Here, we present the first holistic assessment of ecosystem risk from human activities in Norwegian coastal waters. Pressures from a range of sectors are identified and weighted by the exposure to and potential impact on ecosystem components following the ODEMM framework. Our analysis focuses on four regions with contrasting scope of human activities, which is reflected in the outcome of the risk assessment. Southern regions with high cumulative activities are associated with higher risks of negative impacts compared to northern areas where the cumulative activities presumably exert a lower imprint on the coastal ecosystems. Pressures associated with ship traffic, imposed by a range of sectors, turn out as dominant risk factors, though also associated with considerable uncertainty. We discuss benefits and challenges with these types of assessments and make suggestions for key next steps to increase the relevance to management.

Session 3: Blue Carbon, mariculture and climate change mitigation and adaptation in the Subarctic and Arctic

Some insight into the influence of ocean acidification on physiology of molluscs

Authors: *Jiaqi Li, Suyan Xue, Yuze Mao, Zengjie Jiang*

Yellow Sea Fisheries Research Institute (YSFRI), Chinese Academy of Fishery Sciences(CAFS), China

pH or pCO2 are usually taken to study the impact of ocean acidification on molluscs. However, we found that seawater carbonate parameters function differently on embryonic development, calcification and haemolymph pH of two molluscs. Early embryonic development was susceptible to elevated pCO2 level, while calcium carbonate (CaCO3) deposition of larval shell was found to be susceptible to calcium carbonate saturation state (Ω) rather than pCO2 or pH. Most larvae incubated in seawater with Ωarag = 1.5 succeeded in shell formation, even when seawater pCO2 level was higher than 3700 µatm and pHT was close to 7.4. Nevertheless, larvae failed to generate CaCO3 in seawater with Ωarag ≤ 0.52 and control level of pCO2, while seawater DIC level was lowered (≤ 852 µmol/kg). Surprisingly, some larvae completed CaCO3 deposition in seawater with Ωarag = 0.6 and slightly elevated DIC (2266 µmol/kg), while seawater pCO2 level was higher than 2700 µatm and pHT was lower than 7.3. The haemolymph pH of molluscs showed a fast response to acidified seawater incubation. However, no significant correlation ($P > 0.05$) was found between haemolymph pH and seawater pCO2 or pH. CO2 excretion occurs in the microenvironment, and CO2 first diffuses to limited amounts of seawater that tightly surround the gills, causing dissolved inorganic carbon (DIC) accumulation in the ventilation sites, which leads to a sharp increase in the pCO2 of the surrounding seawater and hinders the excretion of CO2. Moreover, the pCO2 level increases much faster and more greatly if the environmental seawater is acidified or contains a lower level of TA. In conclusion, different seawater carbonate parameters play different roles in affecting physiology of molluscs and the whole seawater carbonate system should be taken into consideration instead of considering only pCO2 or pH.

Effects of Ocean Acidification on Pacific oyster, *Crassostrea gigas,* and Mitigation Approach

Authors: *Weiwei Jiang, Zengjie Jiang, Samuel P.S. Rastrick, Xiaoqin Wang, Junwei Wang, Yitao Zhang, Øivind Strand, Jianguang Fang*

Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, China

Ocean acidification is predicted to have significant implications for marine calcifying organisms. However, little is known about the physiological responses of Pacific oyster, Crassostrea gigas, to elevated pCO2 under natural fluctuations associated with a farm environment. The present study evaluated the effect of two pCO2 levels (i.e. ambient ~625 µatm and elevated ~1432 µatm) on the physiological processes and growth of C. gigas using patented in situ mesocosms that simulated the farm environment. Results showed that elevated pCO2 levels decreased clearance rate, ingestion rate, absorption efficiency and oxygen to nitrogen ratio (O:N), while increasing oxygen consumption and ammonia-N excretion rates. These physiological responses of oysters spat resulted in a reduction in energy available for growth (scope for growth). Due to the ability of seaweed to absorb dissolved carbon

dioxide from the surrounding seawater through photosynthesis, seaweed has gained theoretical attention as a potential partner of bivalves in integrated aquaculture to help mitigate the adverse effects of OA. Consequently, we further investigated the impact of elevated pCO2 on the physiological responses of Pacific oyster Crassostrea gigas, in the presence and absence of kelp (Saccharina japonica), using in situ mesocosms. Results showed that the presence of S. japonica changed the daytime pHNBS of experimental units by ~0.16 units in the elevated pCO2 treatment, as a consequence, clearance rate and scope for growth significantly increased and oxygen consumption and ammonia-N excretion rates decreased compared to C. gigas exposed to elevated pCO2 without S. japonica. These findings indicate that the presence of S. japonica in integrated aquaculture may help shield C. gigas from the negative effects of elevated seawater pCO2.

Assessing impacts of coastal warming, acidification, and deoxygenation on Pacific oyster (*Crassostrea gigas*) farming: A case study in the Hinase Area, Okayama Prefecture and Shizugawa Bay, Miyagi Prefecture, Japan

Authors: *Masahiko Fujii, Ryuji Hamanoue, Lawrence Patrick Cases Bernardo, Tsuneo Ono, Akihiro Dazai, Shigeyuki Oomoto, Masahide Wakita, and Takehiro Tanaka*

Atmosphere and Ocean Research Institute, The University of Tokyo, Japan

Coastal warming, acidification, and deoxygenation are progressing, primarily due to the increase in anthropogenic CO2. Coastal acidification has been reported to have effects that are expected to become more severe as acidification progresses, including inhibiting formation of the shells of calcifying organisms such as shellfish. However, compared to water temperature, an indicator of coastal warming, spatiotemporal variations in acidification and deoxygenation indicators such as pH, aragonite saturation state (Ωarag), and dissolved oxygen in coastal areas of Japan have not been observed and projected. Moreover, many species of shellfish are important fisheries resources, including Pacific oyster (Crassostrea gigas). Therefore, there is concern regarding the future combined impacts of coastal warming, acidification, and deoxygenation on Pacific oyster farming, necessitating evaluation of current and future impacts to facilitate mitigation measures. We deployed continuous monitoring systems for coastal warming, acidification, and deoxygenation in the Hinase area of Okayama Prefecture and Shizugawa Bay in Miyagi Prefecture, Japan. In Hinase, the Ωarag value was often lower than the critical level of acidification for Pacific oyster larvae, although no impact of acidification on larvae was identified by microscopy examination. Oyster larvae are anticipated to be affected more seriously by the combined impacts of coastal warming and acidification, with lower pH and Ωarag values and a prolonged spawning period, which may shorten the oyster shipping period and lower the quality of oysters. No significant future impact of surface-water deoxygenation on Pacific oysters was identified. To minimize the impacts of coastal warming and acidification on Pacific oyster and related local industries, cutting CO2 emissions is mandatory, but adaptation measures such as regulation of freshwater and organic matter inflow from rivers and changes in the form of oyster farming practiced locally might also be required.

Bivalve aquaculture in Atlantic Canada: challenges and solutions under a changing climate

Authors: *Filgueira R, Clarke S, Talevi J, Comeau LA, Coffin M, Davidson J, Porier L, Sonier, Hori T*

Dalhousie University, Canada

Bivalves are not only relevant species from the economic perspective but also play a crucial role in coastal marine environments as ecosystem engineers, providing multiple ecosystem services. However, the habitat of these species is becoming increasingly compromised due to human activities. In Atlantic Canada, two main anthropogenic drivers constitute the major challenges for developing this industry, eutrophication and ocean warming. Nutrient loading increases the occurrence of eutrophication, leading to hypoxic or anoxic conditions that negatively impact bivalve performance. Further, ocean warming has a double effect by reducing the solubility of oxygen in seawater and increasing the occurrence of heatwaves. Under this future scenario, it is important to understand the behavioural, physiological, and molecular responses of bivalves to these stressors to ensure that aquaculture management and farming practices allow for minimizing the negative effects of climate change. Further, genetic solutions based on breeding programs that allow the generation of heat- and hypoxia-tolerant lines of bivalves that could perform better under climate change conditions become a crucial component of industry adaptation. Transdisciplinary research combining physiology, behaviour and genetics for the early identification of suitable candidate broodstock can accelerate the development of resistant lines, increasing the potential success of hatchery operations. This talk provides a general overview of challenges for bivalve aquaculture in Atlantic Canada and discusses potential solutions for the sustainable management of aquaculture operations under a changing climate.

Carbon from kelp and shellfish was captured and stored by both natural and restored seagrass bed in Sanggou Bay, China.

Authors: *Yaping Gao, Zengjie Jiang, Fan Lin, Weiwei Jiang*

Yellow Sea Fisheries Research Institute, CAFS, China

Sanggou Bay is a typical mariculture bay in China and is also an important seagrass restoration area in northern China. A technique for large-scale artificial cultivation and transplantation of eelgrass (Zostera marina L.) seedlings were used and a 30-ha eelgrass meadow was established. The large-scale multi-species mariculture activities give a special ecological scene of the adjacent culture ecosystem and seagrass beds. Based on stable isotopes, the sources of organic carbon in the sediments of both natural and restored eelgrass meadows were analyzed in Sanggou Bay. The results showed that the isotope δ13C of the eelgrass bed in Sanggou Bay is -20.31~21.99‰, compared with -12.30‰ of the eelgrass itself. The -8.2‰ difference of δ13C showed the typical characteristics of allochthonous organic carbon. The estimation from the mixing model in SIAR (stable isotope analysis in R) showed that the surface organic carbon in the two eelgrass beds was mainly from phytoplankton 34.0%~41.4%. Carbon of biodeposit from cultured bivalve and from cultured seaweed/kelp contributed 23.9%~25.3% and ~25.0%, respectively, while eelgrass itself only contributed about 8.3%~17.1%. The organic carbon storage of 0~30 cm sediment is 2.01 Mg C/ha in natural eelgrass bed and about 0.48 Mg C/ha and 0.50 Mg C/ha from bivalve and kelp was captured and stored in eelgrass bed. Within 2 km of the restored

eelgrass bed, carbon export of eelgrass contributed about 5.2~10.7% in the sediment of shellfish culture area. The results emphasize the synergistic effect between seagrass blue carbon and mariculture.

Linking Blue Carbon Ecosystems And Water Quality In Coastal Wetlands For Viable Small-Scale Fisheries

Authors: *Navya Vikraman Nair; Dr. Prateep Kumar Nayak*

University of Waterloo, Canada

Small-scale fisheries (SSFs) sustain millions of livelihoods worldwide by contributing to food security and income. However, small-scale fishing communities are marginalized and vulnerable due to cumulative impacts of sea-level rise, hydrological changes, hydrodynamic disruptions, overexploitation of resources, aquaculture, coastal and inland habitat loss, overfishing, lack of livelihood alternatives, along with food insecurity, occupational displacement, and outmigration. While most studies on SSF vulnerability have focused on economic, social, and political factors, limited research links these vulnerabilities with changes in water quality. My research addresses this gap by examining the effects of water quality changes on the vulnerability of SSF and using this examination to advance potential approaches for achieving viability. Our findings suggest ways in which SSF communities can respond to these vulnerabilities. Overall, the aim is to foster knowledge on the sustainable management of SSFs by closely linking hydrological changes and the importance of pertaining to sustainable development goals to achieve good water quality management.

Predictable patterns within the kelp forest can indirectly create temporary spatial refugia for ocean acidification

Authors: *Nina Bednaršek, Greg Pelletier, Marcus Beck, Richard Feely, Zach Siegrist, Dale Kiefer, Jonathan Davis, Betsy Peabody*

Marine Biological Stations, National Institute of Biology, Slovenia

Cooperative Institute for Marine Resources Studies; Oregon State University, USA

Macrophytes are recognized for serving multiple functions in coastal areas, including in ocean acidification (OA) mitigation. However, assessing OA modification strength requires an understanding of the multiple parameters effects, especially in highly dynamic systems. We studied the effects of sugar kelp (Saccharina latissima) on an experimental farm at the north end of Hood Canal, Washington—a low retentive coastal system. In this field mesocosm study, benthic calcifiers (Olympia and Pacific oysters) were exposed with or without the kelp's putatively protective proximity at locations in the mid, on the edge, and outside the kelp array. Model outputs were used to identify dominating factors in spatial and temporal kelp dynamics, while wavelet spectrum analyses helped in understanding predictability patterns. We linked these results to biological assessments, including biomineralization, growth, and trophic connectivity of the examined species. We found no measurable alterations of the seawater chemistry at the study site. As such, kelp did not have a direct mitigating effect to provide a refugia for OA but created it indirectly though the autocorrelation signal related to increased predictability. Kelp

also improved habitat provisioning through kelp-derived particulate organic resource utilization. As such, kelp array indirectly created refugia from OA with marine calcifiers showing more favorable responses. Our results shows that a complex combination of physical, chemical and biological processes determines the efficacy of the kelp farms for creating more favorable habitats with respect to OA. This study can serve as a natural analogue for many coastal bay habitats where prevailing physical forcing drives chemical changes. Future macrophyte studies that investigate OA mitigating effects should focus significantly on the importance of predictability patterns, which can additionally improve the conditions for marine calcifiers as well as ecosystem services with important implications for the aquaculture industry.

Interventions for Business Model Change. Building on a Boundary Object Framework

Authors: *Frithiof Svenson*

Norwegian College of Fishery Science, UiT The Arctic University of Norway, Norway

To successfully implement industry-wide climate change mitigation and adaptation, a shift in business model is required. Nonetheless, the effects of climate change on marine life and human wellbeing provide evidence of a growing incoherence between the natural world and human communities. Focusing on the intersection of the three factors cognition, coherence, and business model change is key to overcoming this obstacle. Through business model change the impacts of climate change on ocean life and human well-being can be reduced. This requires human involvement across several platforms using boundary objects. Boundary objects refer to different ways that the human mind processes information. To increase understanding about climate change mitigation and adaptation, grounding abstract concepts in the preferred cognitive mode of managers is vital. Ahead of the envisaged shift towards a conscious integration of climate change issues managers can use boundary objects to inform their decisions about future directions of their business models. The interventions allow a continuous comparison between manager's internal perception and the external perception of what the business model does to the ecosystem of the subarctic and arctic seas. Any lack of coherence between manager's internal perception and the external perception can lay the ground for business model change. The contribution illustrates how boundary objects that consider climate change help to display incoherence of some current business models. By making use of boundary objects, we can encourage entrepreneurial managers to rethink their approaches to problem solving and encourage them to adopt more sustainable business models. We propose an intervention for more climate-resilient business models grounded in our understanding of the interdependence of ecological, social, and economic systems. The overall objective is to come up with climate-aware business models. Through this technique, we help to bring about business model coherence, through considering managerial cognition.

Can integrated multi-trophic aquaculture help mitigate the effects of climate change on economically important filter feeders.

Authors: *Rastrick S.P.S., Jiang Z.J., Wang X.Q., Graham H.E., Collier V., Whiteley N.M., Strohmeier T., Fang J.G., Strand Ø.*

Institute of Marine Research, Norway

Elevated costs of maintaining homeostasis under elevated pCO2 and temperature conditions associated with climate change and ocean acidification (OA) are shown to divert energy away from growth and reproduction effecting the production of filter feeders important to aquaculture (Magallana gigas, Mytilus edulis and Ciona intestinalis). It has been postulated that within an IMTA system increased energetic demand may be met by greater energy availability. However, results show that filter feeders are unable to utilise seston energy due to the effects of elevated pCO2 on absorption efficiency and clearance rate. Suggesting that decreased scope for growth and lower production in the future may occur independently of nutrient availability. Furthermore, when energy is available for growth smaller body size may convey an energetic, and so selective, advantage effecting production.

In some IMTA systems the fixation of inorganic carbon by macroalgae may, in part, mitigate the effects of elevated pCO2 on bivalves. Within field mesocosms supplied with elevated pCO2 water (1000uatm) the introduction of macroalgae (Saccharina japonica) increased pH. This led to increased clearance rate, absorption efficiency, and growth in oysters (M. gigas) incubated with macroalgae compared to oysters incubated alone under predicted OA conditions.

The energetic interactions between species within IMTA systems will change due to climate change. It is unlikely that the elevated costs of maintaining homeostasis can be met by increasing energy availability in the seston. However, fixation of inorganic carbon by macroalgae within some IMTA systems may, in part, mitigate the effects of OA on cultured bivalves.

Perspectives on Mariculture Planning facing climate change

Authors: *Øivind Strand , Hui Liu , Joao G. Ferreira , Jon Grant , Ellen Sofie Grefsruda, Pia Kupka Hansena, Qianwen Sun , Jenny Weitzman*

Institute of Marine Research, Norway

The policy and legal frameworks that regulate expansion of mariculture differs worldwide, and specifically between some of the major players in mariculture development: China, the European Union (EU), Norway and Canada. In China, marine functional zoning (MFZ) is the legal framework regulating use of marine space, while in the other nations marine spatial planning (MSP) is applied.

China, the EU, Norway, and Canada all have governmental visions and objectives to develop their mariculture industries. They have established institutional frameworks for managing aquaculture planning, although these are highly diverse, where a general concern and condition for further development and growth is the interaction between mariculture and the environment.

In the prospects of future increase in competition for space and resources in coastal waters and oceans and consequently the need for efficient governance, the apparent weak or receding position of mariculture in MFZ and MSP processes should be of considerable concern. As mariculture is regarded as the most promising route to achieve a substantial increase in provision of food from the oceans, there is a need for strengthening the position of mariculture and its implementation in maritime spatial planning frameworks like MFZ and MSP. In the time frame of such endeavor mariculture will also be faced by climate change affecting environments that regulate carrying capacities and use of space. We will

present those climate change perspective also recognizing the relationship between food security, intensification of mariculture and environmental sustainability.

Climate mitigation and adaptation by large-scale seaweed farming in China

Authors: *Xi Xiao, Yuzhou Huang, Jiaping Wu, Carlos M Duarte*

Zhejiang University, China

Seaweed farming has been proposed as a strategy for adaptation to ocean acidification, but evidence is largely lacking. Changes of pH and carbon system parameters in surface waters of three seaweed farms along a latitudinal range in China were compared, on the weeks preceding harvesting, with those of the surrounding seawaters. Results confirmed that seaweed farming is efficient in buffering acidification, with Saccharina japonica showing the highest capacity of 0.10 pH increase within the aquaculture area, followed by Gracilariopsis lemaneiformis (ΔpH = 0.04) and Porphyra haitanensis (ΔpH = 0.03). Deficit in pCO2 in waters in seaweed farms relative to control waters averaged 58.7 ± 15.9 µatm, ranging from 27.3 to 113.9 µatm across farms. In addition, China is facing intense coastal eutrophication. We combined estimates of yield and nutrient concentration of Chinese seaweed aquaculture to quantify that one hectare of seaweed aquaculture removes the equivalent nutrient inputs entering 17.8 ha for nitrogen and 126.7 ha for phosphorus of Chinese coastal waters, respectively. Seaweed farming, which unlike natural seaweed forests, is scalable and is not dependent on suitable substrate or light availability, could serve as a low-cost adaptation strategy to ocean acidification, deoxygenation and eutrophication, and provide important refugia from ocean acidification.

Session 4: Cod and climate change at the coastal interface

Experimental evidence of the effect of temperature and ration on adult polar cod (*Boreogadus saida*) growth and condition metrics

Authors: *Salant C, Hicks MBRH, Iseri PJ, Ottmar ML, Laurel BJ, Parrish CC, Copeman LA*

Memorial University of Newfoundland, Canada

NOAA – Alaska Fisheries Science Center, USA

Polar cod (*Boreogadus saida*) are an essential energy source for larger consumers. Due to Arctic ocean warming and expected food-web shifts, individuals may adjust energy allocation to balance immediate needs (growth) with future survival (lipid storage), and reproductive success (gonadal development). To investigate the effects of temperature and food ration on polar cod morphometrics and energetic condition during a simulated fall-early winter, we performed a laboratory experiment from September-December of 2022. We held age-3 polar cod at 0, 3, and 8C for 12 weeks, and fish were fed either a low (1% fish-dry weight/day) or high (4% fish-dry weight/day) ration diet. We measured specific growth rate (SGR; mass% day^{-1}), hepatosomatic indices (HSI), gonadosomatic indices (GSI), as well as lipid metrics in

multiple tissues. A general linear model (GLM) indicated there were significant differences among SGR based on sampling interval ($F_{5,72}$=30.06, p<0.001), temperature ($F_{2,72}$=9.05, p<0.001), and ration ($F_{1,72}$=30.66, p<0.001). Sampling interval interacted with both temperature ($F_{10,72}$=2.18, p=0.028) and ration ($F_{5,72}$=3.17, p=0.012) with the difference in growth between fish at 0 and 8C being most significant in the latter half of the experiment. GLMs indicated HSI decreased significantly by the end of the experiment ($F_{2,36}$=9.95, p<0.001), more quickly at warmer temperatures ($F_{2,36}$=5.3, p=0.01) and with decreased food availability ($F_{1,36}$=4.79, p=0.04). Conversely, female GSI significantly increased as the experiment progressed ($F_{2,30}$=21.17, p<0.001). Overall, these results suggest that adult polar cod demonstrate seasonal energetic patterns characterized by mobilization of lipid energy reserves away from liver storage towards gonad development. Polar cod growth and condition depend on the interactive effects of fall temperature and food availability such that these processes may be significantly affected by ongoing Arctic warming, especially during the fall-to-winter transition.

Overwinter Survival of Juvenile Atlantic Cod (*Gadus morhua*) in a Coastal Ecosystem

Authors: *Emilie Geissinger, Chelsea Bloom, Ben Laurel, Robert Gregory, Paul Snelgrove*

Memorial University, Canada

Juvenile Atlantic cod (Gadus morhua) in coastal Newfoundland settle in nearshore habitats in 3-6 pulsed late summer-fall events each year, creating a broad size-structured age-0 year-class with potentially different survival trajectories entering their first winter. Our primary objectives were to evaluate overwinter size-structured mortality in age-0 cod based on settlement pulses and assess the role body condition, winter duration, and food availability have on survival using long-term monitoring data with support from an experimental study. In addition, we estimated overwinter dispersal and mortality in a field-based capture-mark-recapture study. Our results show that winter survival improved during long winters when body condition was high, with highest survival among the larger, early fall arriving pulses of cod. Late-arriving pulses were smaller at winter onset but had a survival advantage over early-settling cod during short winters and high body condition. However, all settlement pulses had a survival advantage when settlement occurred earlier than average. Our experimental study showed that even small amounts of consumed food (<1% body weight · d-1) maximized winter growth and condition potential of juvenile cod in Newfoundland waters. Lastly, highest fall mortality characterized late settling juveniles relative to early settling juveniles (16.20%·d-1 vs. 4.52-7.72%·d-1), noting unexpectedly low overwinter mortality in the first two groups (0.0052 and 0.0022%·d-1). These combined studies demonstrate potentially low winter mortality in early settling juveniles and emphasize the critical importance of the period leading up to winter for survivorship, with increased resources before and during winter reducing a survival bottleneck. These findings advance understanding of overwinter survival and recruitment in sub-arctic marine ecosystems experiencing changing climate and challenge many assumptions of high overwinter mortality in sub-arctic cod populations.

Retrospective look at the growth and condition of juvenile Arctic cod (*Boreogadus saida*) in a warming Alaska Arctic

Authors: *Kali Stone[1], Thomas Helser[2], Timothy Essington[1], Anne Beaudreau[1], Matthew Baker[3], and Louise Copeman[2]*

[1] University of Washington, USA
[2] NOAA - Alaska Fisheries Science Center
[3] North Pacific Research Board

Arctic cod (*Boreogadus saida*) is a highly abundant fish species in Arctic and sub-Arctic ecosystems and is an integral component of northern latitude food webs. Rapidly changing conditions in the region have made it increasingly important to expand what is known of Arctic cod ecology in the context of climate change. Survival of juveniles through their first winter is likely a crucial bottleneck for Arctic cod population dynamics. Both larger size and increased lipid storage in the fall have previously been demonstrated to increase starvation resistance in overwintering juveniles. However, summer temperatures in the Northern Bering and Chukchi Sea regions are rapidly approaching laboratory-determined upper thermal limits for juvenile Arctic cod growth and energy storage. Yet it is unclear if laboratory measurements of thermal stress (i.e. reduced growth and lipid storage) translates to the same degree of stress in wild fish. To fully realize the value of these laboratory studies, it is important to compare the growth and energy storage of laboratory fish to that of wild fish under comparable thermal conditions. This study retrospectively compares the growth and condition of wild-caught juvenile Arctic cod between recent cool and warm thermal conditions in the US Arctic. Juvenile Arctic cod otoliths were used to estimate daily ages, back-calculate hatch dates, and to evaluate the growth rates and thermography of fish born in thermally distinct years. These age and growth outcomes will ultimately be combined with corresponding lipid data to explore whether the growth and condition of wild Arctic cod respond to temperature in a manner consistent with laboratory findings. Such comparisons will clarify whether and to what extent these laboratory findings provide predictive capabilities for wild Arctic cod populations and enhance our ability to monitor Arctic cod moving forward.

Spatial Ecology of Sympatric Juvenile Atlantic Cod and Saithe at Nursery Grounds

Authors: *Anja Katrin Nickel, Guðbjörg Ásta Ólafsdóttir, Steven Campana*

University of Iceland, Research Centre of the Westfjords, Iceland

Nearshore habitats provide important nursery grounds for juvenile Atlantic cod (Gadus morhua) and saithe (Pollachius virens). Juvenile distribution and migration at nurseries are highly affected by seasonal changes in temperature and photoperiod as well as by individuals' body size and condition. Furthermore, spatial and temporal variation in habitat choice and small scale movement between species, size-classes and individuals can unveil adaptations which allow for the co-existence of congeneric cohorts as well as closely related species, such as the sympatric juvenile cod and saithe.

In this study we used acoustic telemetry to examine inter- and intraspecific differences in activity, mobility and depth distribution of age-group 1 and 2 Atlantic cod and saithe in near-shore nursery grounds. Each movement metric was examined for differences between species, size classes and diel

variation. We further examined the effect of temperature on juvenile movement and distribution. The movement of 53 juvenile cod and 33 juvenile saithe was studied in an array of 33 receivers positioned in 6 gates across a small fjord in the Icelandic North-West. The study period extended from late summer until early winter in 2020 and 2021.

Results highlighted the importance of the shallow coastal waters in their role as juvenile gadoid nursery grounds both during summer and winter. Saithe occupied the shallowest areas (<20m) throughout the study period, whereas cod occupied increasing depths with body size. Significant differences in diel distribution was observed in both species. All cod larger than 22cm left the fjord, presumably to migrate into deeper overwintering grounds. 50% of smaller cod (<20cm) stayed within the shallow waters during early winter with near-freezing surface temperatures. Different effects of temperature and daylight within season and between years suggest that these two factors are not the sole drivers of juvenile distribution and migration.

Synthesis on selected recruitment studies in Northeast Arctic and adjacent Norwegian coastal cod stocks

Authors: *Olav S. Kjesbu, Inken Tiedemann, Maud Alix, Anders Thorsen, Svein Sundby*

Institute of Marine Research, Norway

We present results of selected studies on reproduction and recruitment in cod stocks from the Northeast Atlantic with emphasis on Northeast Arctic and Norwegian Coastal cod stocks. It is based on a comprehensive review in progress on the recent ~ 50 years studies on cod recruitment at Institute of Marine Research (IMR). These studies started with the Cod Larvae Projects (CLP) (1975-1990) inspired by the seminal work of Johan Hjort (1914) and has been subsequently followed up by more than 30 years integrated studies on reproduction and early life growth/survival in a biological-physical modelling framework.

Ocean temperature is the overarching and dominant climate variable in studies on impacts of climate variability and climate change in marine ecosystems in general and in studies of growth and recruitment in fish stocks. Correlation studies between ocean temperature and biotic measures are world-wide used to confirm or reject impacts of climate variability and climate change. Such conclusions may be problematic of multiple reasons: firstly, because ocean temperature is to variable extent positively or negatively co-correlated with other ocean climate variables of importance to ecosystems such as wind mixing, water column stratification, light and advection processes; secondly, because time scales of change among these ocean climate variables vary by several orders of magnitude; thirdly, because ocean climate variables impact a studied target organism both directly and indirectly through higher and/or lower trophic levels of the ecosystem. In addition, marine organisms are variably sensitive to ocean climate variability throughout their life histories. This demonstrates that time series correlation analyses must be supported by process studies in laboratory and the field, in addition to modelling of key ecosystem processes to reveal the underlying mechanisms behind impacts of climate variability and change.

Mapping Ogak/Greenland cod (Gadus ogac) habitats in nearshore Nunatsiavut waters using community identified fishing locations

Authors: *Zachary MacMillan-Kenny, Katleen Robert, Evan Edinger*

Memorial University of Newfoundland

In Canada, northern coastlines are undergoing significant environmental change in response to the rapidly warming climate. Warmer conditions coupled with changes in ocean circulation and ecological processes (e.g., migration periods, prey availability) continue to cause profound changes to the ranges and ecology of northern fish, benthic ecosystems, and ecosystem services. These changes impact the social, cultural, and physiological well-being of Labrador Inuit within Nunatsiavut (Newfoundland and Labrador, Canada) whose livelihoods are intrinsically linked to the coastal marine environment. Ogak (Inuktitut for Greenland cod (Gadus ogac)) is a highly valued demersal marine fish species within the subarctic communities of Nunatsiavut and has been designated as a research priority in a local marine management plan, Imappivut. Ogak have traditionally been a large part of Inuit subsistence, yet the distribution of benthic habitats in Inuit Nunangat (Inuit homeland in Canada) and how these habitats support the species is poorly understood. This research uses nearshore community-identified Ogak fishing locations to map the distribution of benthic habitats in Nain, Nunatsiavut in support of managing one of the most important marine resources in this rapidly changing region. Residents of Nain who fish for Ogak year-round disclosed important locations near the community. These 5 fishing locations, and 70 additional locations within Nain's nearshore benthic environment, were surveyed with 5-minute drift videos. Continuous environmental layers found to influence faunal distribution were derived using a multiscale approach from available bathymetric data. Random Forest was used to model the presence of species assemblages against the acoustic data and derivatives to create a full-coverage habitat map. A total of 68 morphospecies comprised of 29,734 individuals were identified within 75 video drops. By pairing community expertise with habitat mapping, this project supports Inuit research interests, and provides a baseline on the distribution and structure of Ogak habitats in Nain.

Distribution and movement of juvenile Atlantic cod ecotypes in nearshore water

Authors: *Michelle Valliant, Snæbjörn Pálsson, Anja Nickel, Guðbjörg Ásta Ólafsdóttir*

Marine and Freshwater Research Institute, University of Iceland, Iceland

In a changing world it is important to consider intraspecific phenotypic variation in both management and conservation. For Atlantic cod specifically, variation in migration and movement is widely documented between populations and individuals. Maintaining migratory variation in Atlantic cod is therefore critical for stock management. Icelandic Atlantic cod is generally thought to consist of a large migratory component, offshore or frontal cod, and smaller inshore or resident components. These migratory ecotypes are known to differ in many ecologically important genes and inhabit distinct environments, i.e. temperature and depth regimes, as adults. Less attention has been given to the early development of cod migratory ecotypes. In species with partial migration, that is, when part of the population migrates as others remain resident, the "decision" to migrate often depends on interactions

of numerous intrinsic and extrinsic factors. To understand the plasticity or permanence of the Atlantic cod ecotypes it is therefore important to examine the ecotypes during the juvenile phase. Factors of interest include habitat selection before the onset of migration and environmental preferences or avoidance that may trigger movement. Here the results of genetic analysis, behavioral analysis and acoustic telemetry movement analysis of juvenile Atlantic cod in Icelandic nearshore waters are presented. The implication of the results for conservation and management are discussed.

Dominance transition in the nektonic species structure of the western Chukchi Sea

Authors: *Pavel O. Emelin[1], Alexei M. Orlov[2,4]*

[1] Russian Federal Research Institute of Fisheries and Oceanography, Moscow, Russia;

[2] Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia;

[3] A.N. Severtsov Institute of Ecology

Recent studies in the western Chukchi Sea (WCS) in 2003-2020 shown significant alterations of gadids biomass. Walleye pollock total biomass dramatically increased from 10.8 t in 2003 to 157188.8 t in 2020. Indices for polar cod shown reversed trend for the same period: from 117554.9 t (2003) to 3344.0 t (2020). To test the hypothesis of dominance transition in the nektonic species structure, complete data of 7 surveys for 86 fish and cephalopod species was recalculated. To eliminate differences in survey areas, data of species biomass was processed as density per square km. Interannual variability was determined by 23 “core species” which formed from 84.6 to 99.9% of the total nekton biomass. Survey data was divided to 10 spatio-temporal groups: 2003, 2007, 2008, 2010, 2018, 2019, 2020 in the southern area (<71°N), 2019 in the central area (between 71° and 73°30’N) and 2018, 2020 in the northern area (>73°30’N) of WCS. Variability of “core species” biomass in spatio-temporal groups was studied with Multidimensional scaling (MDS) based on similarities matrix of Pianka correlation coefficient. Results of MDS shown several clusters with similar nektonic species community structure. First cluster was formed by 2003 and 2007 data in the southern area of WCS with polar cod as dominant specie. Second cluster consisted of 2018, 2019 and 2020 data in the southern area of the WCS where dominant specie was walleye pollock. Data from northern area of WCS (2018, 2019) shown more similarity with species structure of 2003-2007 than with data from the same years from the southern area by reason of low walleye pollock biomass and dominance of polar cod. Thus, dominance transition in the nektonic species structure of the western Chukchi Sea was observed from 2018 to 2020 for southern area of WCS only.

Temperature effects on recruitment of Atlantic and Greenland cod and their predators in Newfoundland coastal waters

Authors: *Robert Gregory, Coady Fitzpatrick, Courtney King*

Fisheries and Oceans Canada, Canada

Marine coastal nursery habitat is a widely recognized determinant of fish production world-wide, including the northern population of Atlantic cod (*Gadus morhua*) and Greenland cod (*Gadus*

macrocephalus ogac) along the Newfoundland coast of Canada. We used 27 years of coastal zone data in such a nursery habitat to show that eelgrass (*Zostera marina*) determines much of the recruitment variability in juvenile cod abundance, and possibly the offshore adult interannual abundances by extension. Young cod (age 0 & 1) show elevated growth and survival in such coastal nurseries and even though eelgrass occupies only a small proportion of the Newfoundland coast (likely <2%), its presence has been shown to have a stabilizing influence in the coastal fish community, young cod in particular. Increased summer temperatures in Canada's coastal waters represent an additional cumulative stressor negatively effecting recruitment success in these two species.

Future projections of potential egg survival for polar and Atlantic cod across the Arctic

Authors: *Jame Orr, Fanny Dubanton[2], Adèle Besnard[3]*

[1] Laboratoire des Sciences du Climat et de l'Environnement (LSCE), CEA-CNRS-UVSQ, Gif-sur-Yvette, France

[2] Ecole Ploytechnique, Palaiseau, France

[3] PSL Université, Paris, France

As the most vulnerable life stage, embryos of both Atlantic and polar cod have been shown experimentally to be sensitive not only to warming projected over this century in the Arctic Ocean but also to increasing acidity from rising CO2. A previous study assessed thermal habitat suitability based on larval morphometrics at hatch, first by making laboratory experiments at various temperatures and CO2 levels and then by combining those relationships with projections of surface water warming from Earth system models that participated in the previous phase of the Coupled Model international Intercomparison Project (CMIP5). Here we extend such analysis to the entire Arctic Ocean using the same larval morphometric data combined with projections from 18 Earth system models that participated in CMIP6. In addition, we refine estimates of the effect of increasing CO2 by also exploiting model output for the partial pressure of CO2 (pCO2) of Arctic surface waters, which are typically far from equilibrium with atmospheric CO2. For Atlantic cod, despite the general benefit of warming of Arctic, under all future emission scenarios, potential egg survival (PES) never makes it above the critical limit of 90% except in the Barents Sea and Seas of Norden, being reduced by effects from increasing CO2. By 2100, in the high-emission scenario (SSP5-8.5), no Arctic surface waters remain with PES > 90%. Traditional spawning grounds for Atlantic cod off Iceland and Norway become unsuitable above mid-level emissions (SSP2-4.5). For polar cod, negative effects from both warming and rising CO2 reduce habitat suitability below sustainable levels in the Barents Sea even under the high-mitigation scenario (SSP1-2.6), while the Chukchi Sea becomes unsuitable under SSP2-4.5. Under that scenario, suitable habitat for polar cod still remains elsewhere, but such is not the case under higher emissions (SSP3-7.0 and SSP5-8.5).

Workshop: AnalogueART - Using natural analogues to investigate the effects of climate change on northern ecosystems

Using natural analogues to evaluate the resilience of cold-water coral reefs to changes in environmental conditions

Authors: *Jorge Corrales Guerrero, Samuel Rastrick, Melissa Chierici, Tina Kutti*

Institute of Marine Research, Norway

Current knowledge of the response of cold-water coral (CWC) reefs to ocean acidification and warming is limited and based mainly on observations from short-term perturbation experiments on a few coral species. It is difficult to correctly up-scale from these and predict effects of climate change on CWC reefs because laboratory experiments are run on a temporal scale of months to a year, which is unlikely to correctly elucidate how organisms that become several hundreds, if not thousands, of years old will respond to long-term changes in ocean chemistry and temperature.

Here, we present two studies were small-scale vertical and horizontal gradients in carbonate chemistry, temperature and food availability around 5 Norwegian CWC reefs were used to assess how the interaction of multiple drivers affects the structure and functioning of CWC reefs. The first study compares species occurrences and the metabolic cost of survival of key species at the CWC reef at the LoVe Node 7 methane seep, with two near-by reefs. At Node 7 methane has been seeping since the establishment of the reefs 7000-10000 years ago. The second study surveyed the macro-fauna species composition along steep vertical fjord walls with well documented vertical gradients in carbonate chemistry and temperature.

Multivariate statistics demonstrated a dominant role of temperature in structuring the wall reef communities, while carbonate chemistry and food availability only played sub-ordinate roles in this. At lower temperatures scleractinian corals, large sized gorgonians and sponges dominate and were replaced by small gorgonian corals and fan shaped sponges at higher temperatures. Further work has documented the influence of the methane seepage and associated elevated CO2 levels on community structure of CWC reefs and elucidate the critical physiological traits enabling the existence of reefs in environments naturally enriched in CO2.

Using stable isotopes as tracers of pollution in heterogenous environments

Authors: *Michael S. Bank and Samuel Rastrick*

Institute of Marine Research, Norway

Environmental pollution is inherently complex and varies across ecosystem reservoirs and geographical gradients. Increasingly scientists, natural resource managers, and policy makers strive to identify pollution sources at various spatiotemporal scales to support viable solutions. One tool to track pollutants within and among abiotic and biotic matrices is stable isotope source apportionment modeling. Here, using complex systems analyses, contaminant biology, stable isotope tracer models, and Bayesian information theory we discuss new scientific findings. We also propose novel ideas

regarding the complex relationships between global environmental change, planetary boundaries, and ecosystem health in the context of blue food stable isotope tracer and pollution case studies from Norwegian fjords and the open ocean. This presentation will discuss several simple and complex modeling strategies including big data information theory, Bayesian degrees of belief analytics, and risk and decision sciences in the context of contaminants and stable isotope source apportionment applications. We also discuss our results in the context of the relevant UN sustainable development goals and existing and proposed, multilateral, environmental conventions.

The simplification of marine ecosystems under ocean acidification – insights from CO2 seeps

Authors: *Ben P. Harvey, Sylvain Agostini, Shigeki Wada, Ro Allen, Jason M. Hall-Spencer, Linn J. Hoffmann, Koetsu Kon, Marco Milazzo, Tina C. Summerfield, ICONA members*

Shimoda Marine Research Center, University of Tsukuba, Japan

University of Plymouth, UK

Human activities are rapidly changing the structure of coastal marine ecosystems, but the ecological consequences of these changes remain uncertain. Natural analogues of futuristic conditions are increasingly being used to assess the likely effects of rising atmospheric CO2 emissions on marine ecosystems. Here, using a CO2 seep in Japan, we show how ocean acidification causes habitat and biodiversity loss, resulting in the simplification of marine ecosystems. This simplification involves structurally complex habitat-forming species (including corals and larger macrophytes) being replaced by more homogenous and simple turf algal habitats. Such ecological shifts are concerning because they result in habitats that have less ecological and human value. Moreover, once these ecological shifts occur, ocean acidification-driven stabilising feedback loops 'lock-in' these novel turf systems making them particularly difficult to reverse. By understanding the ecological processes responsible for driving community shifts, we can better assess how future communities and ecosystems are likely to be altered by ocean acidification. Taken together, we demonstrate how the simplification of marine habitats by increased CO2 levels will cascade through the ecosystem and will have severe consequences for the provision of goods and services.

Decadal condition changes in material transportation in the southwestern Canada Basin, 2020-2021

Authors: *Jonaotaro Onodera, Eiji Watanabe, Kohei Mizobata, Miaki Muramatsu, Motoyo Itoh, Katsunori Kimoto, Yuichiro Tanaka, Eun Jin Yang, Naomi Harada, Takashi Kikuchi*

Japan Agency for Marine-Earth Science and Technology, Japan

The dynamics of upper ocean circulation and chemical oceanographic condition affect lower-trophic marine ecosystems and basin-shelf interaction such as the transportation of materials. To observe the relationships between particle transportation and oceanographic condition, multi-year observation of setting particles have been conducted by the deployment of time-series sediment traps in the southern Northwind Abyssal Plain (NAP) and north of the Barrow Canyon. The obtained settling particles were mainly composed of lithogenic matter with biogenic matter, suggesting an advection of re-suspended

particles from the shelf to the Canada Basin. The setting particle flux showed maxima in the productive summer season and at the physical oceanographic events like the passing of oceanic eddies over the mooring position. Total mass and particulate organic carbon fluxes at ~200 m depth in the southern Northwind Abyssal Plain for 2018-2021 (median: 101.8 and 5.2 mg m-2 day-1, respectively) were higher than those for 2010-2014 (median: 31.9 and 2.0 mg m-2 day-1, respectively). The settling particle fluxes in the north of the Barrow Canyon also showed an increasing trend for 2015-2019. There were no large changes in the bulk component of trapped materials during the studied period. In the Canada Basin, a southward position shift of oceanic Beaufort Gyre and the intensification of the westward shelf-slope current along the shelf edge were observed after 2017. The physical oceanographic-ecosystem model also showed an increase in the transportation of resuspended matter with the intensified westward current along the shelf slope in 2017. These physical oceanographic changes are the possible main causes of the recent increase in the observed settling particle fluxes. The pH in oxygen minimum layer at NAP temporally decreased from 2013-2014 to fall 2018. These hydrographic changes may have a potential to affect the marine ecosystems and biogeochemical condition in the study area.

An overview of CO2 seep studies and the International CO2 Natural Analogues Network

Authors: *Jason Hall-Spencer and ICONA project partners*

Universities of Plymouth, UK; University of Tsukuba (Japan)

This talk will highlight advanced made over the past 15 years in the use of natural analogues of future ocean conditions, with a focus on CO2 seeps which have been used to assess the combined ecological effects of climate change, such as warming, acidification, hypoxia and increased storminess. The methods we have used to monitor changes in the blue carbon cycle and marine ecosystem services could be applied to areas that have conditions that provide insights into the future of northern marine ecosystems and the opportunities there are for coastal communities to adapt to these changes. The talk will start with a description of how natural analogues have been identified and used to assess the benefits of reductions in CO2 emissions, and the risks of carbon capture storage leaks. It will showcase some examples from around the world and introduce the International CO2 Natural Analogues Network (ICONA) that has been designed to enable international collaborations and to standardize methods. It will finish with some examples of cheap and easy experiments that could be done at high latitudes to assess the likely impacts of climate change.

Assessing vulnerability to future environmental change based on current habitat preferences along salinity gradients within Kongsfjorden: a case study on marine gammarid amphipods

Authors: *T. Mullen-Humphreys, J. Brown, N.M. Whiteley, H. Graham, E. Zandt, and S. Rastrick*

University of Chester, United Kingdom

Climate change is leading to alterations in salinity and carbonate chemistry in arctic/sub-arctic marine ecosystems. However, we have little understanding of the resulting effects on the biology of marine invertebrates living along these salinity gradients, or on their ability to cope with further change. With this in mind, we initially examined nominal populations of the circumpolar arctic/subarctic amphipod,

Gammarus setosus, along a salinity gradient in the Kongsfjorden-Krossfjorden area of Svalbard. Field and laboratory experiments assessed physiological (haemolymph osmolality and gill Na+/K+-ATPase activity, NKA) and energetic responses (metabolic rates, MO2, and Cellular Energy Allocation, CEA). In the field, all populations had similar osmoregulatory capacities and MO2, but lower-salinity populations had lower CEA. Reduced salinity (S = 25) and elevated pCO2 (~1000 µatm) in the laboratory for one month increased gill NKA activities and reduced CEA in all populations, but increased MO2 in the higher-salinity population. Elevated pCO2 did not interact with salinity and had no effect on NKA activities or CEA, but reduced MO2 in all populations. Reduced CEA in lower-rather than higher-salinity populations may have longer term effects on other energy demanding processes (growth and reproduction). Follow-on work has investigated the metabolic rate compensation of the different populations in the field, and after exposure to pCO2 (500 and 1000 µatm) and salinity (S= 35, 25 and 15) combinations in the laboratory. Comparisons will be made between the responses shown by populations in the field and after exposure to the low salinity/high CO2 combinations in the laboratory. Any resulting changes will be related to the survival prospects of the populations to further changes in temperature, salinity and CO2 levels within the Kongsfjorden-Krossfjorden area of Svalbard.

Workshop Introduction: Using natural analogues to investigate the effects of climate change on northern ecosystems; moving from gradient to mosaic approaches.

Authors: *Samuel S P Rastrick, Antonio Aguera, Kumiko Azetsu-Scott, James Brown, Melissa Chierici, Jorge Corrales, Agneta Fransson, Jason Hall-Spencer, Haakon Hop, Tina Kutti. Marco Milazzo, Helen E Rastrick.*

Institute of Marine Research, Norway

Northern oceans are in a state of rapid transition. Still, our knowledge of the likely effects of climate change and ocean acidification on key species in the food web, functionally important habitats and the structure of Arctic and sub-Arctic ecosystems is limited and based mainly on short-term laboratory studies on single species. In tropical and temperate systems natural analogues (Gradients and Mosaics) of carbonate chemistry drivers have been used to further our knowledge of the sensitivity of biological systems to predicted climate change, and thus assess the capacity of different species to show long-term acclimation and adaptation to elevated levels of pCO2. Natural analogues have also provided the means to scale-up from single-species responses to community and ecosystem level responses. However, to date the application of such approaches is limited in high latitude systems. Here we present an overview of work within the Analogues of an Arctic in Rapid Transition WG (AnalogueART) (within ESSAS regional program of IMBeR). Presenting a range of Arctic and sub-Arctic case studies where environmental gradients and mosaics in Carbonate Chemistry (including, CO2 and methane cold seeps, fiords, up-welling areas, exchanges between Arctic and Atlantic water) are being used within AnalogueART to elucidate how future climate change may effect vulnerable systems (including, cold water coral reefs, intertidal invertebrates, and bivalves important to aquaculture. We will also discuss the need for the standardisation of methods across natural analogue research and the method development necessary to move from signal stressor gradient studies to more complex multi-stressor Mosaic studies.

Natural ocean acidification analogues in the Northern subpolar and polar regions: a synthesis study

Authors: *Nina Bednaršek*

Marine Biological Stations, National Institute of Biology, Slovenia

Cooperative Institute for Marine Resources Studies; Oregon State University

The northern subpolar and polar regions are one of the most vulnerable to the effects of ocean acidification (OA), both because of the current OA-related conditions as well as the rate of change, which is one of the fastest globally. These regions also host a variety of small-scale mosaics and larger-scale gradients across spatial and vertical scales that can be considered the natural OA analogues. They offer insights into the mechanisms underlying adaptation and plasticity and potential ecological near-future changes under far greater realism than offered by the lab experimental studies. Variety of natural analogues have complex setting with divergent drivers and variations in natural and anthropogenic signal that requires an integration of chemical-biological observations, tools and metrics across the spatial and temporal scales for improved projections of ecological risks, potential refugia and the consequences for the carbonate pump and carbon sequestration. I will present several case studies across the subpolar estuarine and coastal macroalgae habitats, as well as the polar upwelling settings in the natural OA analogues. For better prediction of biological responses, parameters such as amplitude of fluctuations, frequency, lowest OA conditions, the frequency and cumulative exposure, and as well as the dominant frequencies of variation and amplitude should be studied. The results for example suggests that natural analogues with similar means but different variance will have substantially different exposure, pre-exposing the organisms to lower pH values more frequently and for prolonged cumulative durations. Because of the lower predictability in the northern habitats, the organisms may be less adaptable to predicted change and therefore better suited to sustain future changes related to variability. These implications are crucial for evaluating the suitability of coastal habitats for aquaculture, adaptation and carbon dioxide removal strategies.

Using gradient approaches in experimental design to integrate physiological performance into species distribution models in Canada's Hudson Bay and the Estuary and Gulf of St. Lawrence.

Authors: *Daniel P. Small*

Pêches et Océans Canada, Canada

Institute Maurice Lamontagne, Mont-Joli, Québec, Canada

Elevated temperatures are causing shifts in species distributions, while impacts from heat waves, ocean acidification, and deoxygenation amongst others are imposing extra restrictions on species ranges through physiological tolerance, alterations to energy balance, and mortality events. Northern and Arctic regions are predicted to experience the greatest of these changes in environmental factors, however there are knowledge gaps regarding northern ecosystems and species due to the difficulties of performing research in often remote and challenging environments or transporting those species to southern research centres. Furthermore, factorial laboratory experiments on organism physiology are often narrow in scope with few treatment levels or environmental factors, while the data required to incorporate physiology into species distributions models needs to be more detailed; often being in the form of response curves or bioenergetic model outputs covering the entire survivable range of that

environmental factor. Designing and performing such large scale physiology experiments is technically challenging and costly in terms of time, effort, and resources, thus making this data scarce.

Natural gradients represent an important tool in overcoming these challenges as they allow us to investigate species and communities which have undergone long term acclimatisation to our environmental factor(s) of interest, while doing so in the context of their environment. Furthermore, recent advances in statistics, modelling capabilities, and technical aspects of experimental design and data acquisition will allow us to increase our throughput of physiological measurements, both from field and laboratory based gradient studies, and incorporate this data into species distribution models. In this presentation I will discuss some recent attempts in laboratory based gradient studies and future perspectives on how we can compare these to natural analogues to meet these challenges in Canada's Hudson Bay and the Estuary and Gulf of St. Lawrence regions.

Seasonal variability of *Mytilus* spp metabolic rate

Authors: *A. Agüera, T. Strohmeier, C. Krogness, H. Rastrick, S. Rastrick & Ø. Strand*

Institute of Marine Research, Norway

Blue mussels, Mytilus edulis L., are an important natural and cultured resource in coastal areas around the world. As such, there has been a wide interest in describing the physiological performance of blue mussels in varying environments. However, our understanding of the individual plasticity as environmental conditions change is still limited.

High temporal resolution measurements of feeding physiology and metabolism are necessary to gain further insight on how sensitive blue mussels performance are to natural changes, the potential addaptationss to different seasons or combinations of food and temperature or the variability of individually predetermined physiological performance, among others. We measured growth, feeding physiology (clearance, retention rates) and metabolism (respiration rate) of the same 20 mussels exposed to the natural variation of food, temperature and salinity at a high temporal frequency for a year. An automatised system performed measurements of feeding every 2 hours and respiration every 4 hours.

Over 17000 respirometries and 40000 measurements of clearance and retention were collected over that year. Preliminary results show that mussels exhibit a wide variability in both metabolism and feeding physiology that reflect in growth and overall performance. Individuals could not be classified as either slow or fast growers/feeders but a continuous range of performance was observed that resulted in larger variability of measured growth, feeding and metabolism as the experiment progressed. Food was the main driver of both feeding physiology and metabolism variability during the year, with little effect of temperature in modulating these within the observed temperature range (5 - 18°C).