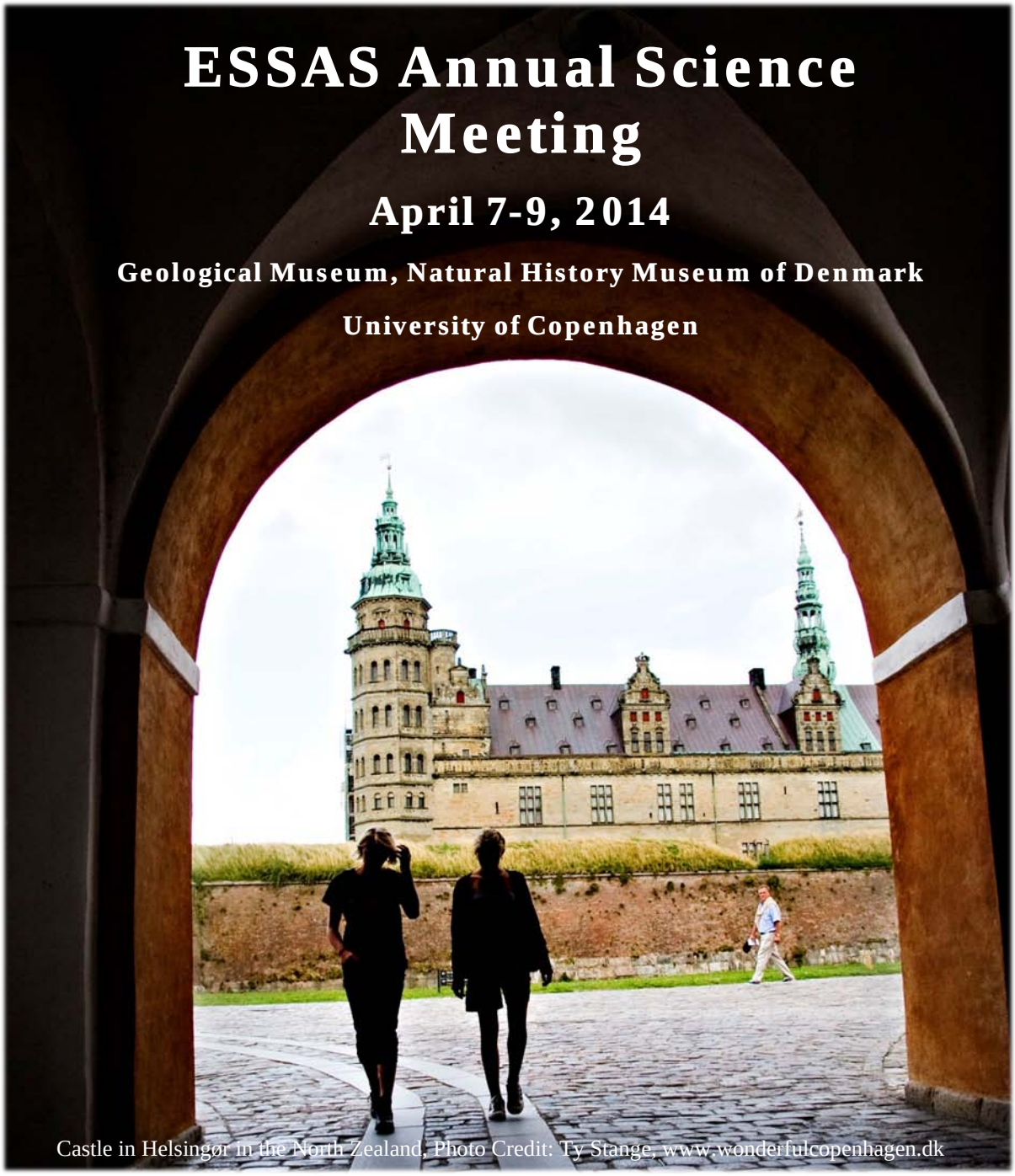
ESSAS Annual Science Meeting

April 7-9, 2014

Geological Museum, Natural History Museum of Denmark

University of Copenhagen



Castle in Helsingør in the North Zealand, Photo Credit: Ty Stange, www.wonderfulcopenhagen.dk

Dynamics of Sub-Arctic Marine Ecosystems

Welcome

On behalf of the symposium conveners, organizers, and the ESSAS Scientific Steering Committee, we welcome you to beautiful Copenhagen, a uniquely northern European city with a great blend of history and modernity. The 2014 Ecosystem Studies of Sub-Arctic Seas (ESSAS) Annual Science Meeting will be held at the Geological Museum, Natural History Museum of Denmark, University of Copenhagen.

We are excited to welcome scientists from at least 7 countries with a range of expertise about sub-arctic and arctic marine ecosystems. As always, the first day of the ASM features a number of presentations from our host country, as well as contributed papers. This will be followed by a workshop on the paleoecology of subarctic seas on Tuesday and a workshop on the ecology of Arctic cods on Wednesday. To our knowledge these are the first international workshops of their kind. We hope the paleoecology workshop will foster discussions about past variability in the subarctic over historical time scales and spur future collaborative work and comparisons among the subarctic seas of both the Pacific and Atlantic. The workshop on the ecology of Arctic cods (particularly polar cod, *Boreogadus saida*) for the first time brings together regional experts on a group of species that are a key trophic link in the Arctic ecosystem and range throughout the Arctic and into all of the subarctic seas.

We look forward to an excellent mix of both oral and poster presentations and encourage all participants to take advantage of this unique opportunity to exchange information, experiences and ideas with fellow marine scientists from around the Arctic. We hope that you will also use the occasion of this ASM as an opportunity to explore Copenhagen, its vibrant culture, architectural delights, and famous Nordic cuisine.

Finally, we thank our Danish hosts for allowing us to use the Natural History Museum and for their generous support of the meeting. We also thank Jared Weems for assembling this abstract book. The ASM was made possible only through the hard work of local and international organizers, your participation, and generous financial support from our sponsors. In particular, we thank the National Science Foundation for sponsoring the Paleoecology workshop and the Research Council of Norway and the International Arctic Science Committee for sponsoring the workshop on Arctic cods. Without those efforts and funds, it would have been impossible to convene a meeting.

To a productive, stimulating and enjoyable meeting!

Ken Drinkwater, Franz Mueter, and Sei-Ichi Saitoh

ESSAS Co-Chairs of the Local Organizing Committee

Morten Meldgaard, Majbritt Betak, Kristian Kjellerup Kjeldsen, Ruth Fernandez Garcia

Local Organizing Committee

NATURAL HISTORY MUSEUM OF DENMARK
UNIVERSITY OF COPENHAGEN

Meeting Information

Location:

The meeting will take place the Natural History Museum of Denmark in the old Geological Museum located on **Øster Voldgade 5-7** (Map 1).

Statens Naturhistoriske Museum (Geological Museum)
Københavns Universitet
Øster Voldgade 5-7
1350 København K

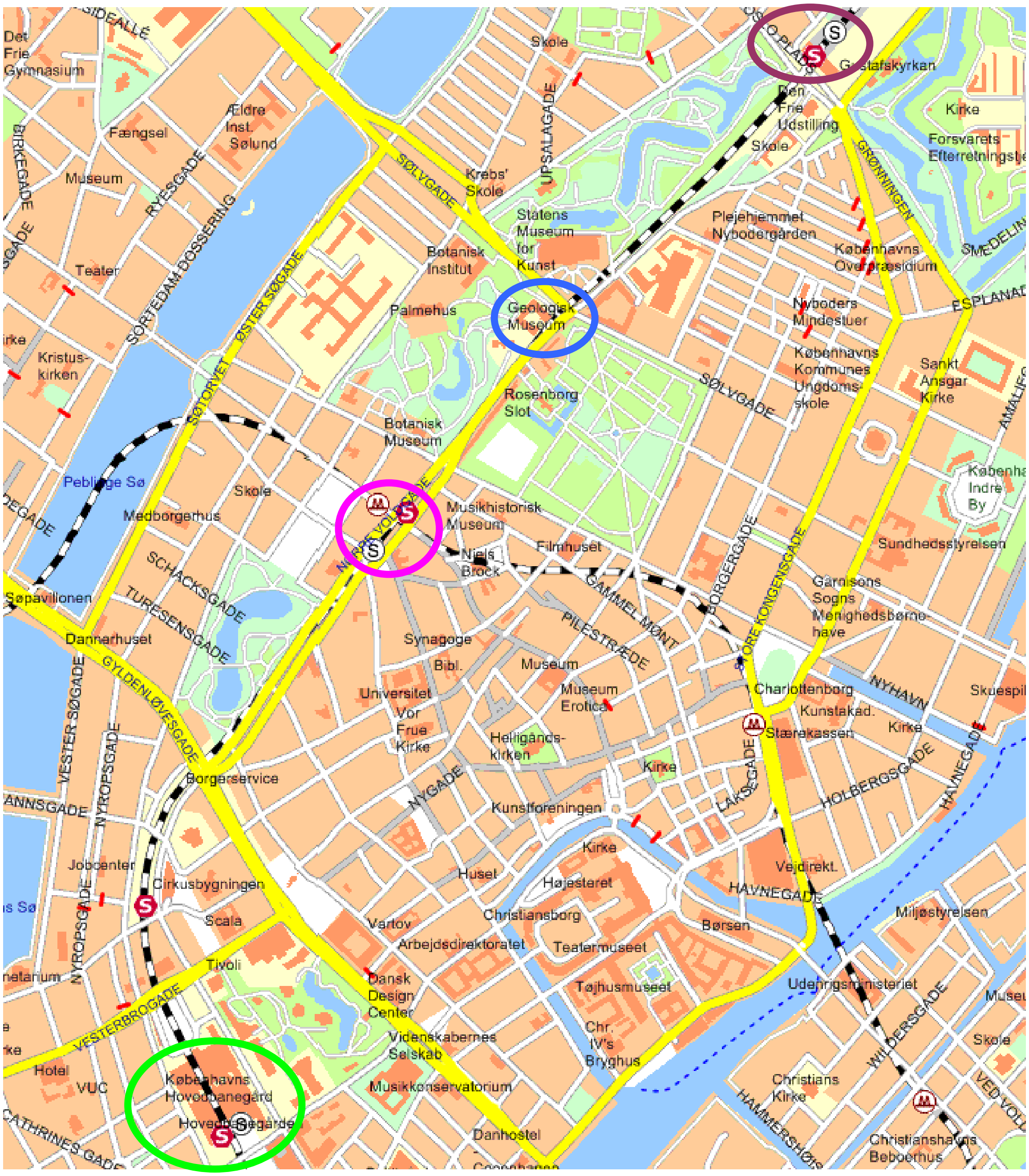
Getting to the Museum:

The Geological Museum is located in central Copenhagen close to Nørreport Metro/Train Station (5 min walk) and Østerport Train Station (10 min walk). The easiest way is walking from Nørreport Station.

From Copenhagen Airport (Lufthavnen) to Nørreport Station there is a direct metro following Metro-line 2 (look for a "M" letter on the Maps 1+2).

Nørreport Station is also a stop on a large number of local Copenhagen S-trains (look for an "S" letter on the Maps 1+2).

Furthermore, a large number of busses also stop at Nørreport Station and busses 6A, 184, and 185 stop close to the museum.



*Map 1: The ESSA meeting will be held at the Natural History Museum (the old Geological Museum) (**Blue circle**). The closest train station is Nørreport Station (**Magenta circle**). Copenhagen Central station is illustrated by the **Green circle** and Østerport Station is illustrated by the **dark purple circle**.*

Map 2: Copenhagen metro-lines. Connections to local trains are indicated by the letter "S".

Registration:

The meeting will start with registration on Monday April 7th at 8am. The registration desk will also be open Tuesday and Wednesday morning (8:00 – 9:00).

Oral presentations:

We kindly ask that you bring your presentation (PowerPoint or PDF) on a USB key.

If you are a MAC-user please make sure that your presentation will work properly on a PC.

Poster presentations:

The maximum size of the poster is A0 vertical (841x1189mm).

Agenda

Day 1 (Monday, April 7)			Day 2 (Tuesday, April 8)			Day 3 (Wednesday, April 9)		
8:00	Registration, coffee		8:00	Coffee		8:00	coffee	
8:50	Introduction		8:30	Introduction	S2	8:30	Introduction	S5
9:00	Tian	S1	8:40	Fitzhugh	S2	8:40	Præbel	S5
9:20	Ribergaard	S1	9:00	de Vernal	S2	9:00	Nelson	S5
9:40	Riisgaard	S1	9:20	Harada et al.	S2	9:20	Astthorsson	S5
10:00	Feirreira	S1	9:40	Nagashima	S2	9:40	Krivosheya	S5
10:20	Coffee Break		10:00	Coffee Break		10:00	Coffee Break	
10:50	Kjellerup	S1	10:30	Finney et al.	S2	10:30	Norcross	S5
11:10	Teglhus	S1	10:50	Misarti & Finney	S2	10:50	Majewski	S5
11:30	Bryndum (MacKenzie)	S1	11:10	Savinetsky	S2	11:10	Geoffroy	S5
11:50	Tsoukali	S1	11:30	Etnier	S2	11:30	David	S5
12:10	Lunch - Museum Cantina		11:50	Hambrecht et al.	S2	11:50	Crawford	S5
13:30	Neuheimer (MacKenzie)	S1	12:10	Allentoft & Lorenzen	S2	12:10	Lunch – off-site or Museum Cantina	
13:50	Payne	S1	12:30	Lunch – off-site or Museum Cantina		13:30	Hop	S5
14:10	MacKenzie	S1	14:00	WG meetings		13:50	Divoky	S5
14:30	Criddle	S6				14:10	Storch	S5
14:50	Kitamura	S6				14:30	Laurel	S5
15:10	Coffee break					14:50	Bouchard	S5
15:40	Heinz	S6				15:20	Coffee break	
16:00	Hunt	S6				15:50	Nahrgang	S5
16:20	Fennel	S6				16:10	Karamushko	S5
16:40	Hansen	S6				16:30	Marsh	S5
17:00	Drinkwater	S6				16:50	Orlova	S5
			18:00	Poster session & Reception		19:30	Group Dinner	

Monday, April 7

08:00 Registration and Coffee

08:50 Welcome — ESSAS Co-Chairs Ken Drinkwater, Franz Mueter & Sei-Ichi Saitoh

Local arrangements and practical information

09:00 Session 1 — *Danish Research in the Sub-Arctic*

Chairs: Ken Drinkwater & Kai Wieland

09:00 Tian Tian and Fredrik Boberg: *The importance of choosing interactive coupling in a regional atmospheric-ocean-ice model in the Baltic Sea*

09:20 Mads Hvid Ribergaard, Jonas Blüthgen Sølvsteen, Stiig Wilkenskjeld, Kristine S. Madsen, Steffen, M. Olsen: *Circulation patterns and shelf/fjord exchanges in a west Greenland sill fjord system, Godthaabsfjorden (Nuup Kangerlua)*

09:40 Karen Riisgaard, Maria Lund Paulsen, T. Frede Thingstad, Torkel Gissel Nielsen: *Importance of deep mixing for initiating the North Atlantic spring bloom*

10:00 A. Sofia A. Ferreira, Hjálmar Hátún, François Counillon, Mark R. Payne, and André W. Visser: *Phytoplankton bloom and subpolar gyre induced dynamics in the North Atlantic*

10:20 ***Break (30 min)***

10:50 Sanne Kjellerup and Torkel Gissel Nielsen: *Population dynamic and life strategies of the dominating copepods in a sub-arctic Greenlandic fjord*

11:10 Frederik Wolff Teglhus, Mette Dalgaard Agersted, Kristine Engel Arendt, and Torkel Gissel Nielsen: *Krill community composition and grazing biology in a sub-Arctic Greenlandic fjord*

11:30 Karoline Minna Bryndum and Brian R. MacKenzie: *Warming impacts on fish species composition in the Kattegat-Belt Sea*

11:50 Stavroula Tsoukali, André W. Visser & Brian R. MacKenzie: *Comparative impacts of temperature and trade-offs on egg ecology of north Atlantic pelagic fish species*

12:10 ***Lunch – Museum Cantina (80 min)***

13:30 Anna B. Neuheimer & Brian R. MacKenzie*: Explaining variation in life history timing across a species range: Effects of climate on spawning time in an exploited marine fish*

13:50 Mark R Payne: *Distributional shifts of species in the North Atlantic: the rule or the exception?*

14:10 Brian R. MacKenzie, Mark R. Payne, Jesper Boje, Jacob L. Høyer & Helle Siegstad: *A cascade of warming impacts brings bluefin tuna to Greenland waters*

14:50 Session 6 — *Contributed: ESSAS relevant themes*

Chairs: Sei-Ichi Saitoh & Ken Drinkwater

14:30 Keith Criddle: *Boom, bust, and boom: the transition from crab to groundfish in the Eastern Bering Sea*

14:50 Minoru Kitamura, Toru Kobari, Rie Nakamura, Kazuhiko Matsumoto & Makio Honda: *Seasonal change of subarctic mesozooplankton community in the western North Pacific with ecological role of the community on biological pump*

15:10 ***Break (30 min)***

15:40 Ron Heintz, Marilyn Zaleski, Elizabeth Siddon and Meghan Garrison: *Nutritional Status and Diets of Juvenile Gadids in the Bering Sea and Gulf of Alaska*

16:00 George L. Hunt, Jr. and Kenneth Drinkwater *:Polar Comparisons: the impact of advection in the Arctic and Antarctic Seas and connections to lower latitudes*

16:20 Wolfgang Fennel: *A nutrient to fish model of the Baltic Sea — A feasibility-study*

16:40 Cecilie Hansen and Mette Skern-Mauritzen: *Atlantis in the Nordic and Barents Seas – vulnerability to tuning*

17:00 Ken Drinkwater, Martin Miles, Iselin Medhaug, Odd Helge Otterå, Trond Kristiansen, Svein Sundby, Yongqi Gao: *The Atlantic Multidecadal Oscillation: its manifestations and impacts with special emphasis on the Atlantic region north of 60°N.*

17:20 ***End of Day Wrap -Up***

Tuesday, April 8

08:00 Registration and Coffee

08:30 ***Session 2 — Paleoecology of the Subarctic Seas: A temporal addition to ESSAS***

Chairs: Ben Fitzhugh & Naomi Harada

08:40 Ben Fitzhugh: *Paleoecology of Subarctic Seas: Inspiration and Goals of a synthetic and comparative perspective on the North Pacific and North Atlantic subarctic.*

09:00 Anne de Vernal: *Paleoceanography-paleoclimatology of the Arctic and subarctic seas based on palynological approaches*

09:20 Naomi Harada, Kota Katsuki, Mitsuhiro Nakagawa, Akiko Matsumoto, Osamu Seki, Bruce P. Finney, Jason A. Addison and Miyako Sato: *Holocene sea surface temperature and sea ice extent in the Okhotsk and Bering Seas*

09:40 Kana Nagashima, Ryuji Tada, and Shin Toyoda: *Westerly jet–East Asian summer monsoon variations during the Holocene*

10:00 ***Break (30 min)***

10:30 Bruce P. Finney, Jason A. Addison, and Naomi Harada: *Comparing Holocene productivity variability in the eastern and western regions of the Subarctic North Pacific Ocean*

10:50 Nicole Misarti and Bruce Finney: *From Fish to Humans; the paleoecology of higher trophic level species in the Gulf of Alaska*

11:10 Arkady Savinetsky, Bulat Khasanov, Olga Krylovich, Ekaterina Gorlova, Zhanna Antipushina, Dmitri Vasyukov, Dixie West, Michael Chernyakhovsky: *Dynamics of Coastal and Island Ecosystems of the Bering Sea Region over the Last Millennia*

11:30 Mike Etnier and Catherine West: *Apparent resilience of Late Holocene North Pacific nearshore ecosystems*

11:50 George Hambrecht, Francis Feeley, Ramona Harrison, Seth Brewington, Konrad Smiarowski, Megan Hicks, Sophia Perdikaris, and Thomas McGovern: *The Archaeology of Norse North Atlantic Fisheries – 871 – 1800 C.E.*

12:10 Morten E. Allentoft: *Ancient DNA, what is it and what can it do for you? and* Eline D. Lorenzen: *Biogeographic insights from past and present megafauna DNA*

12:30 ***Lunch – Museum Cantina (90 min)***

14:00 **WG Meetings**

Arctic-Subarctic Interactions

Paleoecology

Bioenergetics

Human Dimensions

18:00 ***Poster Session and Reception***

Wednesday, April 9

08:00 Coffee

08:30 Session 5 — *Biology and Ecology of Arctic Cods*
Co-chairs: Franz Mueter, Jasmine Nahrgang & John Nelson

08:40 Kim Præbel, Matias Langgaard Madsen, Jørgen Schou Christiansen and Svein-Erik Fevolden: *On the doorstep to a deeper understanding of population divergence in highly mobile Arctic gadoids: examples from sympatric* Arctogadus glacialis *and* Boreogadus saida

09:00 R. John Nelson, C. Bouchard, A. Majewski, M. Madsen, J. Reist, L. Fortier, J. Christiansen, S-E. Fevolden, S. Talbot, R. Crawford, D. Archambault, T. Siferd, S. Palsson, G. Rose, K. Dunton, and G. Divoky: *Molecular Genetics of Arctic Cod*

09:20 Olafur S. Astthorsson: *Distribution, abundance, and biology of polar cod,* Boreogadus saida*, in Icelandic Sub-Arctic waters*

09:40 Pavel Krivosheya: *Review of Russian investigations of polar cod (*Boreogadus saida*) and Arctic cod (*Arctogadus glacialis*) in the Barents and Kara Seas*

10:00 ***Break (30 min)***

10:30 Brenda L. Norcross, Brenda A. Holladay, and Lorena E. Edenfield: Boreogadus saida *in the western Arctic: demersal distribution, habitat and biological characteristics*

10:50 Andrew Majewski, Wojciech Walkusz, Jane Eert, James Reist, and Sheila Atchison: *Distribution of Arctic (Polar) Cod,* Boreogadus saida*, in the Canadian Beaufort Sea relative to key prey items and oceanographic parameters*

11:10 Maxime Geoffroy, Andrew Majewski, Stéphane Gauthier, Mathieu LeBlanc, Wojciech Walkusz, James D. Reist, and Louis Fortier: *Vertical distribution and migrations of Arctic cod (*Boreogadus saida*) in the Canadian Beaufort Sea from spring to fall*

11:30 Carmen David, Hauke Flores, Benjamin Lange and Doreen Kohlbach: *Under-ice distribution of polar cod* Boreogadus saida *in the Central Arctic Ocean and its association with sea ice habitats properties*

11:50 Richard E. Crawford: *Occurrence of a gelatinous predator (*Cyanea capillata*) affects Arctic cod habitat utilization in High Arctic coastal waters*

12:10 ***Lunch – off-site or Museum Cantina (80 min)***

13:30 Haakon Hop and Harald Gjøsæter: *Polar cod (*Boreogadus saida*) in a warmer and more competitive Arctic environment*

13:50 George Divoky[1] and Yann Tremblay[2]: *Decadal, annual and seasonal variation in Arctic Cod (*Boreogadus saida*) abundance in the nearshore Beaufort Sea: the effects of decreasing sea ice and increasing SST*

14:10 Daniela Storch, Flemming Dahlke, and Jasmine Nahrgang: *Effects of ocean acidification and warming on the embryonic development of Polar cod* Boreogadus saida

14:30 Benjamin J. Laurel, Mara Spencer, and Louise A. Copeman: *Temperature-dependent growth, condition and behavior of juvenile Arctic cod (*Boreogadus saida*) and co-occurring North Pacific gadids*

14:50 Caroline Bouchard, Salomé Mollard, Dominique Robert, Keita Suzuki, and Louis Fortier: *Comparing the early life history of sympatric* Boreogadus saida *and* Arctogadus glacialis *in the southeastern Beaufort Sea*

15:20 ***Break (30 min)***

15:50 Jasmine Nahrgang, Øystein Varpe, Ekaterina Korshunova, Svetlana Murzina, Ingeborg G. Hallanger, Ireen Vieweg, and Jørgen Berge: *Gender specific reproductive strategies of an Arctic key species (*Boreogadus saida*) and implications of climate change*

16:10 Larisa I. Karamushko and Jørgen S. Christiansen: *Bioenergetic adaptations in polar cod* Boreogadus saida *(Lepechin, 1774)*

16:30 Jennifer M. Marsh and Franz J. Mueter: *Distribution and trophodynamics of Arctic cod (*Boreogadus saida*) in the eastern Chukchi and northeastern Bering Seas*

16:50 Emma V. Orlova, Andrey V. Dolgov, Irina P. Prokopchuk, Valentina N. Nesterova: *Diet of polar cod (*Boreogadus saida*) in the Barents and Kara Seas*

17:10 ***Conference Wrap–Up***

19:00 ***Group Dinner at NYHAVNS FÆRGEKRO (345 kr/person, please register)***

Abstracts
of
Oral Presentations

Session 1, Monday, April 7

Danish Research in the Sub-Arctic

The importance of choosing interactive coupling in a regional atmospheric-ocean-ice model in the Baltic Sea

Tian Tian and Fredrik Boberg

Danish Meteorological Institute, Lyngbyvej 100, 2100 Copenhagen, Denmark, tian@dmi.dk

Sea surface fields in small ocean basins from the global circulation models (GCMs) are often greatly biased due to the coarse resolution. We configured a high-resolution coupled model system, comprising a regional climate model (RCM) and a regional ocean model, for the North Sea and Baltic Sea regions. Here, we assess the bias in the air-sea interface in the Baltic Sea, induced by the GCM boundary forcing in the uncoupled simulation, and improvements by the coupled one. The first experiment is forced by ERA-Interim (ERAI) reanalysis for the period 1990-2010. ERAI overestimates the Baltic ice extent by 72% in winter. The coupled run resulted in a 33% lower value than the uncoupled one, showing the best agreement in daily ice extent to observations. The second experiment is forced by EC-Earth CMIP5 climate simulations, with a focus on the historical period 1986-2005 for assessment. The EC-Earth forcing showed a significant warm bias in winter surface air temperature and hence very low sea ice cover. This bias resulted in poor amplitude of seasonal cycle in surface air temperature and underestimation of sea ice cover in the uncoupled run. A remarkable improvement was found in the coupled run. In both experiments, the coupled simulation tends to mitigate the effects of bias induced by the forcing. In the presentation, we will also show some results from scenario projections for the atmospheric surface and ocean in the Baltic region.

Circulation patterns and shelf/fjord exchanges in a west Greenland sill fjord system, Godthaabsfjorden (Nuup Kangerlua)

Mads Hvid Ribergaard[1], Jonas Blüthgen Sølvsteen[2], Stiig Wilkenskjeld[3], Kristine S. Madsen[1] Steffen M. Olsen[1]

[1] *Danish Meteorological Institute, Centre for Ocean and Ice, Denmark, mhri@dmi.dk*
[2] *University of Copenhagen, Denmark*
[3] *Max Planck Institute for Meteorology, Germany*

A high resolution setup of the Godthaabfjord and Fylla Bank shelf is used to study the general circulation pattern within the fjord and to study the exchanges between the fjord system and the outer shelf in a fjord with high tidal forcing. The model is forced by realistic atmospheric forcing from a high resolution atmospheric model. The model is simulation includes Aug. 2004 – May

2010 with climatological fresh water discharge. Additional scenarios apply with 2x and 4x discharge.

The major fjord circulation characteristics found is a (partly) renewal of the bottom waters during late winter/early spring at the time when the presence of Irminger Water west of the shelf is highest. The bottom water renewal is seem as either a "warm" inflow of waters with a high fingerprint of Irminger Water entering the fjordsystem through the bottom of the deep narrow Godthaabfjord channel or a "cold" inflow consist waters formed in the narrow Godthaabfjord channel during winter as a mixture of waters with a high imprint of IW but also shelf waters which is being cooled and convected to the bottom of the Godthaabfjord channel. During summer/autumn, an upper estuarine circulation is formed with an outflow within the upper ~30 meters and a compensating intermediate inflow of warmer and more saline waters below to ~130 meters throughout the fjord system. The intermediate water mass is formed within the Godthaabfjord channel by tidal mixing. The vertical extend of this intermediate inflow is remarkable stable within the fjord system.

Importance of deep mixing for initiating the North Atlantic spring bloom

Karen Riisgaard[1], Maria Lund Paulsen[2], T. Frede Thingstad[2], Torkel Gissel Nielsen[1]

[1] *National Institute of Aquatic Resources, DTU-Aqua, Section for Ocean Ecology & Climate, Denmark, krii@qua.dtu.dk*
[2] *Department of Biology, Marine Microbiology Department, University of Bergen, Norway*

The phytoplankton spring bloom is one of the most important recurrent events in the sup-polar part of the Atlantic Ocean. The classical idea is that the bloom is controlled by nutrients and light, but recent observations challenge this hypothesis. During repeated visits to stations in the deep Icelandic and the Norwegian Basins and the shallow Shetland Shelf (26 March to 1 May 2012), we investigated the succession and growth dynamics of microscopic grazers prior to the bloom. We demonstrate that deep mixing of the water column play an important role for predator-prey interactions and that a released grazing pressure could initiate the bloom.

Phytoplankton bloom and subpolar gyre induced dynamics in the North Atlantic

A. Sofia A. Ferreira[1], Hjálmar Hátún[2], François Counillon[3], Mark R. Payne[1,4], and André W. Visser[1]

[1] *Centre for Ocean Life, National Institute of Aquatic Resources, Technical University of Denmark, Denmark, sofer@aqua.dtu.dk*
[2] *Faroe Marine Research Institute, Nóatún 1, P.O. Box 3051, FO 110 Tórshavn, Faroe Islands*
[3] *Nansen Environmental and Remote Sensing Center, Thormøhlensgate 47, Bergen, Norway*
[4] *Environmental Physics, Institute of Biogeochemistry and Pollutant Dynamics, ETH Zürich, Universitätsstrasse 16, 8092 Zürich, Switzerland*

Several hypotheses have been promoted for phytoplankton bloom onset in the North Atlantic. First we show that the bloom dynamics in the northeastern corner stand out from the rest of the subpolar Atlantic, and thus warrants focused attention. We hypothesized that, for this region, late and weak blooms are expected in years of a strong subpolar gyre, *i.e.* strong atmospheric forcing, and cold and low saline conditions. We apply novel phenology algorithms to satellite ocean colour data, and analyse the outcome together with the subpolar gyre index.

We find that the relationship between the bloom dynamics and the subpolar gyre is complex, showing no clear spatial pattern. Our hypothesis is therefore partly refuted, probably due to the disparity in the temporal and spatial resolutions of the subpolar gyre index, compared to indices describing spring bloom dynamics. The annually averaged gyre index represents the integrated oceanic dynamics over the Northern North Atlantic, while the timing of the spring bloom is more governed by direct atmospheric forcing during the pre-bloom weeks.

We, therefore, further investigate which published theories (Sverdrup [1953], Siegel et al [2002], Huisman et al [2002], Townsend et al [1994], and Taylor and Ferrari [2011]) for bloom onset are suited for this region. We construct indicator fields and time series which in various combinations provide models consistent with the principle dynamics proposed in these theories. Using a multi-model inference approach, we investigate the spatially dependent ranking of these models. It appears that that different theories apply at different regions within the North-East Atlantic, depending on the local physical dynamics.

Population dynamics and life history strategies of the dominant copepods in a sub-arctic Greenlandic fjord

Sanne Kjellerup[1,2] and Torkel Gissel Nielsen[1,2]

[1] *Greenland Climate Research Centre, Greenland Institute of Natural Resources, PO Box 570, 3900 Nuuk, Greenland, skh@aqua.dtu.dk*

[2] *National Institute of Aquatic Resources, DTU Aqua Section for Ocean Ecology and Climate. Technical University of Denmark, DTU, Kavalergården 6, 2920 Charlottenlund Denmark*

Investigations of the Arctic and Sub-Arctic pelagic food web have previously focused on the copepod genus *Calanus*, as they often dominate the mesozooplankton community and serve as a lipid rich food source for higher trophic levels. However, if night samples are considered a different food web might emerges with the omnivorous copepod *Metridia* spp. in a major role. Biology of *Metridia* is practically unknown but deviates from *Calanus* e.g. *Metridia* does not hibernate but stays active yearlong benefiting from being omnivore. In the present study abundance, depth distribution, and egg and pellet production of two *Calanus* species and *Metridia longa* was monitored weekly from March-August. *M. longa* performed diel vertical migration of up to 200 meters and was the dominating larger copepod species. Weekly lipid measurements of *M. longa* showed a similar buildup of lipids during late summer as the

hibernating *Calanus*. *M. longa* might thereby also have a central role in the lipid rich food chain which is a distinct feature for Arctic and Sub-Arctic ecosystems.

Krill community composition and grazing biology in a sub-Arctic Greenlandic fjord

Frederik Wolff Teglhus[1], Mette Dalgaard Agersted[1], Kristine Engel Arendt[2] & Torkel Gissel Nielsen[1,2]

[1] *National Institute of Aquatic Resources, Section of Oceanography and Climate, Technical University of Denmark, Kavalergården 6, 2920 Charlottenlund, Denmark, fred.teglhus@gmail.com*
[2] *Greenland Climate Research Centre, Greenland Institute of Natural Resources, Kivioq 2, PO Box 570, 3900 Nuuk, Greenland*

Several studies have described the role of copepods in Arctic marine food webs. However, knowledge about larger zooplankton organisms like krill are very limited. Krill is an important food source for many marine animals and they are potentially a significant contributor to the vertical flux of organic material, i.e. the biological pump. Our aim is to improve the understanding and knowledge about the role of krill in a sub-Arctic fjord. During multiple cruises in the Godthåbsfjord, Southwest Greenland, krill abundance, distribution and grazing biology have been investigated trough field and laboratory experiments. *In situ* gut fluorescence experiments have been conducted to estimate gut evacuation -and ingestion rates of the dominating species *Thysanoessa raschii* and *T. inermis*. Furthermore, the functional biology of *T. raschii* on the diatom *Thalassiosira weissflogii* has been examined. The present novel knowledge about krill abundance and grazing biology will provide the basis for a discussion of the role of krill in the pelagic food web of the sub-Arctic Godthåbsfjord.

Warming impacts on fish species composition in the Kattegat-Belt Sea

Karoline Minna Bryndum[1] & Brian R. MacKenzie[1, 2]

[1] *Centers for Macroecology, Evolution and Climate*
[2] *Ocean Life, National Institute for Aquatic Resources, Technical University of Denmark (DTU-Aqua), Kavelergården 6, DK 2920, Charlottenlund, Denmark, brm@aqua.dtu.dk*

Sea temperatures have been rising in the waters near Denmark during the past 1-2 decades and are expected to affect marine populations, species, communities and foodwebs. Here we investigate whether and how the species richness and composition of the marine fish community in the Kattegat and Belt Sea have been influenced by these changes. We hypothesize that the recent warming has led to an increase in species richness of the local community and that this increase is due to immigration of species from warmer areas. We use spring and fall survey data collected by DTU Aqua during the years 1994-2013 and bottom temperature data (observed and model outputs from a regional phyical oceanographic model) to test these ideas. Species richness has increased significantly during the time period in both seasons of the year, and the increases

were significantly correlated with bottom temperatures. Analysis of the southern range limits of all species captured in the surveys shows that the mean southern latitudinal limit of the fish community has been decreasing and is also corrrelated with bottom temperatures; these patterns are consistent with immigration of fish from southerly zoogeographic regions. Warm-adapted species also increased their distributional area (i. e., probability of occurrence) in the sampling region and some cold-adapted species became rarer and more narrowly distributed. Similar results were generally obtained using both observed and modelled temperature data. The changes reported in this study contribute to a growing documentation of how climate variability and changes are affecting marine communities and biodiversity.

Comparative impacts of temperature and trade-offs on egg ecology of north Atlantic pelagic fish species

Stavroula Tsoukali[1, 2], André W. Visser[2], Brian R. MacKenzie[1, 2]

1 Center for Macroecology, Evolution and Climate, National Institute for Aquatic Resources (DTU Aqua), Technical University of Denmark, Kavalergården 6, DK 2920 Charlottenlund Denmark, stts@aqua.dtu.dk

2 Center for Ocean Life, National Institute for Aquatic Resources (DTU Aqua), Technical University of Denmark, Kavalergården 6, DK 2920 Charlottenlund, Denmark

The early life history stages of fish are considered the most vulnerable and can be strongly affected by environmental variability, leading to population fluctuations. Temperature has a major role on development and mortality rates, with consequences for recruitment and overall stock productivity. We collated development and survival data from publications on laboratory egg incubation experiments to investigate and compare the development, daily mortality and survival of fish eggs from pelagic species in the north Atlantic at different temperatures, and to investigate whether trade-offs exist between these traits at the population and species level and between habitat types (pelagic and demersal). While differing in magnitude, the response of these traits exhibited similar trends with respect to temperature, regardless of species, population or habitat type. A trade-off appears between rapid development and high mortality or slow development and low mortality, resulting in similar survivorship percentages across species. These results quantify physiological effects of temperature on the eggs and are a major factor in yielding a close correspondence between the physiological optimum temperature for survivorship and observed temperature at spawning sites. Temperature during egg development may be a key evolutionary force affecting spawning time and location.

Explaining variation in life history timing across a species range: Effects of climate on spawning time in an exploited marine fish

Anna B. Neuheimer[1,2] & Brian R. MacKenzie[1]

[1] *Centers for Macroecology, Evolution and Climate, and Ocean Life, National Institute for Aquatic Resources, Technical University of Denmark (DTU---Aqua), Kavelergården 6, DK 2920 Charlottenlund, Denmark, abneuheimer@gmail.com*

[2] *Department of Oceanography, School of Earth and Ocean Science and Technology, University of Hawai`i at Manoa, 1000 Pope Road, Marine Sciences Building, Honolulu, HI 96822, U.S.A.*

The capacity of a species to tolerate and/or adapt to environmental conditions will shape its response to future climate change including climate extremes. Of the many life-history processes affected by climate change, timing of reproduction greatly influences offspring success and resulting population production. Here we explore temporal and spatial changes in spawning time for Atlantic cod (*Gadus morhua*) across the species' range (4 to 80°N). We estimate spawning time using a physiologically relevant metric that includes information on fish thermal history (degree days, DD). First, we estimate spawning DD among years (within populations) to show recent changes in spawning time can be explained by local changes in temperature. Second, we employ spawning DD to identify temperature independent trends in spawning time among populations that are consistent with the evolutionary history of the species. Combined, these results shed light on the adaptive capacity of the species in the face of changing climate. We use our results to estimate expected spawning time under future climate regimes, and discuss the implications for codecology and management across the species' range, and in the greater ecosystem.

Distributional shifts of species in the North Atlantic: the rule or the exception?

Mark R Payne[1]

[1] *Center for Ocean Life, National Institute of Aquatic Resources (DTU-Aqua), Technical University of Denmark, 2920 Charlottenlund, Denmark, mpa@aqua.dtu.dk*

This work addresses recent shifts in the distribution of marine pelagic fish in the northern North Atlantic and attempts to set them in the context of climate variability, climate change, population dynamics and migration processes. Shifts in the distribution of North-east Atlantic mackerel, and the associated political dispute over fishing rights, has drawn much attention in recent years. However, a closer examination of spatial distributions of pelagic fish in this region suggests that such shifts are not by any means unique: several other examples, both well- and less-well-known, are presented and discussed here. These examples are then used to illustrate the potential importance of various mechanisms that can control the distribution of these species, such as climate variability and change, and population and migration dynamics. A set of simple analytical approaches is demonstrated that can be used to assess the relative importance of each of these mechanisms. Finally, these observations are drawn together to reveal a picture of a dynamic ecosystem in a constant state of flux and to emphasis the necessity.

A cascade of warming impacts brings bluefin tuna to Greenland waters

Brian R. MacKenzie[1, 2], Mark R. Payne[2], Jesper Boje[3], Jacob L. Høyer[4], Helle Siegstad[5]

[1] *Center for Macroecology, Evolution and Climate, National Institute for Aquatic Resources (DTU Aqua), Technical University of Denmark, Kavalergården 6, DK 2920 Charlottenlund Denmark, brm@aqua.dtu.dk*
[2] *Center for Ocean Life, National Institute for Aquatic Resources (DTU Aqua), Technical University of Denmark, Kavalergården 6, DK 2920 Charlottenlund,Denmark*
[3] *National Institute for Aquatic Resources (DTU Aqua), Technical University of Denmark, Kavalergården 6, DK 2920 Charlottenlund, Denmark*
[4] *Danmarks Meteorologisk Institut, Lyngbyvej 100, DK 2100 Copenhagen Ø, Denmark*
[5] *Greenland Institute for Natural Resources, Postboks 570, 3900 Nuuk, Greenland*

Rising ocean temperatures are causing marine fish species to shift spatial distributions and ranges, and are altering predator-prey dynamics in food-webs. Most documented cases of species shifts so far involve relatively small species at lower trophic levels, and consider individual species in ecological isolation from others. Here we show that a large highly migratory top predator fish species has entered a high latitude sub-polar area. Bluefin tuna, *Thunnus thynnus* Linnaeus 1758, were captured in waters east of Greenland (65o N) in August 2012 during exploratory fishing for Atlantic mackerel, *Scomber scombrus* Linnaeus 1758. The bluefin tuna were captured in a single net-haul in 9-11o C water together with 6 tonnes of mackerel, which is a preferred prey species and itself a new immigrant to the area. Regional temperatures in August 2012 were historically high and contributed to a warming trend since 1985, when temperatures began to rise. The presence of bluefin tuna in this region is likely due to a combination of warm temperatures that are physiologically more tolerable and immigration of an important prey species into the region. We conclude that a cascade of climate change impacts is restructuring the food web in east Greenland waters.

Session 6, Monday, April 7

Contributed papers: ESSAS relevant themes

Boom, bust, and boom: the transition from crab to groundfish in the Eastern Bering Sea

Keith R. Criddle[1]

[1] *Fisheries Division, University of Alaska Fairbanks, 17101 Point Lena Loop, Juneau, AK 99801, USA., kcriddle@alaska.edu*

The U.S. groundfish fishery off Alaska emerged from the ashes of a crab boom gone bust. Fisheries off Alaska are at once ancient and recent in origin. Although Pacific salmon and Pacific herring were heavily utilized by pre-contact native Alaskans and Pacific salmon, Pacific herring, Pacific halibut, and Pacific cod were heavily exploited by commercial fishermen beginning in the late 1800s, flatfish, rockfish, Alaska pollock, and king and Tanner crab were but lightly harvested before the 1960s. This paper presents a political economic analysis of the role that created and rendered redundant by the boom and bust in the crab fishery played in fueling an Americanization of the groundfish fisheries.

Seasonal change of subarctic mesozooplankton community in the western North Pacific with ecological role of the community on biological pump

Minoru Kitamura[1], Toru Kobari[2], Rie Nakamura[3], Kazuhiko Matsumoto[4] and Makio Honda[4]

[1] *Institute of Biogeosciences, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima, Yokosuka, Kanagawa 237-0061, Japan. E- mail: kitamura@jamstec.go.jp*
[2] *Faculty of Fisheries, Kagoshima University, 4-50-20 Shimoarata, Kagoshima 890-0056, Japan.*
[3] *Graduate School of Fisheries, Kagoshima University, 4-50-20 Shimoarata, Kagoshima 890-0056, Japan.*
[4] *Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima, Yokosuka, Kanagawa 237-0061, Japan*

The subarctic northwestern North Pacific is considered to be one of the most productive areas in the global ocean, with an extremely large biological drawdown of surface layer pCO_2. To understand ecological impact of mesozooplankton on the biological pump in this area, we investigated seasonal change of community structure (standing stock, vertical distribution, major taxa composition, dominant species and diversity) with estimation of carbon demand and vertical carbon transport by them. Zooplankton samplings were conducted in the time-series station K2 (47°N, 160°E) during seven cruises from 2008 to 2012. Bulk mesozooplankton biomass integrated through 0−1000 m ranged from 5.32 to 7.85 g C m^{-2}. Prominent biomass peaks were

observed 0−50 m layer during night and 200−300 m layer during day and night. Ontogenetic migratory copepods (*Neocalanus* spp. and *Eucalanus bungii*) contributed the latter peak. Copepoda was predominant except nighttime surface layer in autumn and winter where Euphausiacea was most dominant. Diversities (using Simpson's index) based on major taxa biomass during the night were high in 50−200 m and low in 200−1000 m while those changed seasonally at the surface layer. Carbon demand at 0−150 m layer (annual average: 204 mgC m^{-2} day^{-1}), downward fluxes of CO_2 (3.1 mgC m^{-2} day^{-1}) and DOC (0.9 mgC m^{-2} day^{-1}) by mesozooplankton were also estimated using empirical allometric relationships. The carbon demand was roughly equal to 65% of primary productivity, the downward carbon flux at 150 m was equivalent to 9% of POC flux.

Nutritional Status and Diets of Juvenile Gadids in the Bering Sea and Gulf of Alaska

Ron Heintz, Marilyn Zaleski, Elizabeth Siddon, and Meghan Garrison

Auke Bay Laboratories, National Oceanic and Atmospheric Administration, 17109 Pt. Lena Loop Road, Juneau, AK 99801, US, ron.heintz@noaa.gov

Physiological studies demonstrate increased lipid storage among gadids at cool temperatures. Fishery independent surveys in the north Pacific indicate gadids also enjoy improved food availability and quality at cool temperatures. These factors combine to increase energy reserves in juvenile gadids prior to their first winter, enhancing their survival. However, the relative importance of these factors is unclear. We compared the size, growth, energy reserves and diet of age-0 Pacific cod (*Gadus macrocephalus*) and walleye pollock (*Gadus chalcogrammus*) sampled in the southeastern Bering Sea with those from the Gulf of Alaska. Samples were collected contemporaneously in 2012 allowing a comparison of conspecifics in two different ecosystems located at approximately the same latitude. Gadids collected in the Bering Sea were smaller and in poorer condition than those in the Gulf of Alaska. In addition, gadids in the Gulf of Alaska consumed more lipid in their diet than those in the Bering Sea. Analysis of the temperatures at which these fish were sampled are pending. However, a late ice retreat from the Bering Sea in 2012 suggests low temperatures there. If so, these data would suggest food quality is a more important determinant of body composition than temperature. Most efforts to consider the impacts of climate change on juvenile fishes focus on physical features of the water column. These data and others demonstrate that the most profound effects of climate on fish populations may result from changes in the quality and availability of food to recruiting year classes.

Polar Comparisons: the impact of advection in the Arctic and Antarctic Seas and connections to lower latitudes

George L. Hunt, Jr. [1], Kenneth Drinkwater[2]

[1] *School of Aquatic and Fishery Sciences, University of Washington, Seattle WA 98195, USA, glhunt@uci.edu*
[2] *Institute of Marine Research, Bjerknes Centre for Climate Research, University of Bergen, Norway*

Ocean currents play a major role in the ecology of polar and sub-polar ecosystems and their component species in both the Northern and Southern Hemispheres. In the Arctic, northerly flows of Pacific Water through Bering Strait are important for advecting heat, nutrients and plankton from the Bering Sea into the Chukchi Sea, and eventually, the Arctic Basin. The advected phytoplankton and resulting primary production supports an extraordinarily rich benthic fauna in the Chukchi Sea, and the advected zooplankton is critical for the support of planktivorous cetaceans and seabirds there in summer and fall. In the Atlantic Arctic, the northeastward advection of heat, nutrients and zooplankton in Atlantic water into the Barents Sea supports rich fisheries, and large populations of cetaceans and seabirds there. Outflows of Arctic Water replete with large calanoid copepods are important for supporting planktivorous seabirds along the east coast of Greenland and in the waters between northwest Greenland and Elsmere Island. In the Antarctic, wind-driven currents coarse around the continent, and tend to isolate the southerly portions of the Southern Ocean from the Sub-Antarctic waters to the north. A result is that meridional transport of zooplankton is limited, except for a few areas such as in the Ross Sea and the Scotia Sea, where transport of krill from the Peninsula region and northern Weddell Sea is critical for supporting the vast numbers of seabirds and pinnipeds inhabiting South Georgia.

A nutrient to fish model of the Baltic Sea — A feasibility-study

Wolfgang Fennel

Leibniz Institute for Baltic Sea Research (IOW), See Str. 15, 18119 Rostock, Germany, wolfgang.fennel@io-warnemuende.de

Some example scenarios of the dynamics of fish stock and catches are calculated with the aid of a nutrient-to-fish-model for the Baltic Sea with two-way interaction between a biogeochemical and a fish model. The model approach demonstrates the feasibility of a consistent coupling of the upper and lower parts of the food web. The Baltic fish stock is dominated by two prey species (sprat and herring) and one predator (cod). The fish model is driven by mass-class dependent predator–prey interactions while the interaction between the biogeochemical and Fish model is established through feeding of prey fish on zooplankton and recycling of fish biomass to nutrients and detritus. The scenarios are characterized by time variations in the fishing mortality of cod, in reproduction of cod and changing nutrient loads. The reproduction of cod depends on the oxygen conditions in the spawning areas in the central Baltic, where anoxic conditions are

frequently observed. During anoxic condition the reproduction of cod tends to zero. The choices are motivated by the observed interannual variations of catches in the Baltic Sea. Moreover, some aspects of the coupling of the fish model to an advanced three dimensional biogeochemical model (ERGOM, Neumann et al., 2002, Radtke et al. 2013) are highlighted and issues of connectivity and examples of biogeochemical processes affected by fish are addressed.

Atlantis in the Nordic and Barents Seas – vulnerability to tuning

Cecilie Hansen and Mette Skern-Mauritzen

Institute of Marine Research, Bjerknes Centre for Climate Research, University of Bergen, Norway, cecilie.hansen@imr.no

The end-to-end model Atlantis has been set up for the Nordic and Barents Seas, covering an area of totally 4 million km^2. The model has been under extensive tuning, as it is the first time it has been adapted to such high latitudes. To represent the ecosystem in the area, 52 functional groups and species have been parameterized, covering all trophic levels from bacteria, phytoplankton, zooplankton and fish to marine mammals. Through the tuning process, there has been made a lot of "guesstimates" and approximations. We will present the vulnerability of the model to some of these, such as mortality rates, feeding rates and growth rates. The difference between making guesstimates on growth and mortality rates in comparison with feeding interactions will be presented for a few chosen species. In addition to direct effects, the indirect effects due to feeding interactions will be explored. Through the study we will identify important areas where more information and research is needed, with focus on both commercially important species, but also on vulnerable species. Differences between boreal and arctic species will especially be emphasized.

The Atlantic Multidecadal Oscillation: its manifestations and impacts with special emphasis on the Atlantic region north of 60°N.

Ken Drinkwater[1], Martin Miles[2], Iselin Medhaug[1], Odd Helge Otterå[1], Trond Kristiansen[1], Svein Sundby[1], Yongqi Gao[1]

[1] *Institute of Marine Research and Bjerknes Centre for Climate Research, Bergen, Norway, ken.drinkwater@imr.no*
[2] *Uni Research and Bjerknes Centre for Climate Research, Bergen, Norway*
[3] *Geophysical Institute and Bjerknes Centre for Climate Research, University of Bergen, Bergen, Norway*
[4] *Nansen Environmental and Remote Sensing Center and Bjerknes Centre for Climate Research, Bergen, Norway*

Observations, modelling and paleo data provide evidence of a strong link between the atmospheric and physical oceanographic variability in the northern North Atlantic and the Arctic with Atlantic sea surface temperatures farther south as expressed by the Atlantic Multidecadal

Oscillation (AMO). Air and sea temperatures reveal cool periods in the late 1800s to early 1900s and in the 1970s to 1980s with warm periods during the 1920s to 1960s and from the 1990s through to the present, similar to the variability in the AMO index where a positive (negative) AMO index represents warm (cold) periods. Sea-ice extent in the north has also varied at multidecadal scales with the ice retreating during the above warm periods and expanding during the cold periods. The presence of multidecadal variability is also suggested from marine sediment paleo data as well as ice-core oxygen isotope data. Observations of biological impacts of the multidecadal variability in the northern regions include a general increase in plankton and fish productivity, as well as expansion of the species distributions northward, in conjunction with the AMO warm periods and the opposite during AMO cold periods. In addition, a review of the mechanisms responsible for the AMO and a brief discussion of the linkages between the multidecadal variability in the northern and southern hemispheres, including between the Arctic and Antarctic, are presented.

Session 2, Tuesday, April 8

Paleoecology of the Subarctic Seas: A temporal addition to ESSAS

Paleoecology of Subarctic Seas: Inspiration and Goals of a synthetic and comparative perspective on the North Pacific and North Atlantic subarctic.

Ben Fitzhugh

Quarternary Research Center, Department of Anthropology, University of Washington, Seattle, fitzhugh@u.washington.edu

Whether they had been there before but all traces are lost, archaeological evidence indicates that humans persistently settled the shores of the North Atlantic and North Pacific between the late Pleistocene and mid Holocene. Subsequent adaptations to the subarctic marine ecosystem included the development of sophisticated knowledge, skills, and technologies for subarctic maritime travel and the extraction of food and raw materials from the near-shore and deep marine ecosystems. From subarctic platforms, subsistence hunter-gatherers learned to live on sea ice and eventually expanded into and across the high arctic (twice). In the later Holocene socially complex hierarchical and state societies expanded their influence or even their colonies along these shores, interacting more intensively in the exploitation of marine resources for trade in regional to global commodity markets. The ecosystems supporting these phases of human occupation of the subarctic seas was itself dynamic, changing in relation to climatic and geophysical forces, ecological dynamism, and (at differing spatial scales relative to the intensity of exploitation) human extractive pressures and habitat modifications. This talk will establish a broad scale climatic, oceanography, ecological and human foundation for the interdisciplinary synthesis of Subarctic Ecology, including the proposal of a selection of hypotheses that could guide efforts of the working group.

Paleoceanography-paleoclimatology of the Arctic and subarctic seas based on palynological approaches

Anne de Vernal

GEOTOP & Département des sciences de la Terre et de l'atmosphère Université du Québec à Montréal, devernal.anne@uqam.ca

The analyses of organic-walled microfossils in marine sediment provide information on paleoecology in several manners. Pollen and spores can be used to document land-sea linkages and the terrestrial vegetation of adjacent lands whereas dinocyst assemblages permit to

paleoceanographical inferences. The establishment of databases documenting the distribution of dinocysts in relation to sea-surface conditions led to develop approaches for estimating past sea-surface temperature, salinity, sea ice cover extent, and productivity. Such approches were applied to Holocene sedimentary sequences from the Arctic and subarctic seas pointing to large amplitude changes close to the Atlantic and Pacific gateways of the Arctic Ocean.

Holocene sea surface temperature and sea ice extent in the Okhotsk and Bering Seas

Naomi Harada[1], Kota Katsuki[2], Mitsuhiro Nakagawa[3], Akiko Matsumoto[3], Osamu Seki [3], Bruce P. Finney[4], Jason A. Addison[5], Miyako Sato[1]

[1] *Japan Agency for Marine-Earth Science and Technology, Japan, haradan@jamstec.go.jp*
[2] *Korea Institute of Geoscience and Mineral Resources, Korea*
[3] *Hokkaido University, Japan*
[4] *Idaho State University, USA*
[5] *USGS Menlo Park, USA*

Accurate prediction of future climate requires an understanding of the mechanisms of the Holocene climate; however, the driving forces, mechanisms, and processes of climate change in the Holocene associated with different time scales remain unclear. In order to understand the mechanisms by which the distribution of sea surface temperature (SST) and sea ice extent across the subarctic North Pacific responds to climatic forcing, an external trigger (orbital forcing), and atmosphere–ocean teleconnection, we investigated the drivers of Holocene SST and sea ice extent in the North Pacific Ocean, and the Okhotsk and Bering Seas, as inferred from sediment core records, by using the alkenone unsaturation index as a biomarker of SST and abundances of sea ice–related diatoms (*Fragilariopsis* spp.) as an indicator of sea ice extent to explore controlling mechanisms in the high-latitude Pacific. The Holocene variations of alkenone-SSTs show that at sites near Kamchatka in the Northwest Pacific, as well as in the western and eastern regions of the Bering Sea, and in the eastern North Pacific they track the changes of Holocene summer insolation at 50°N, but at other sites in the western North Pacific, in the Okhotsk Sea, and the eastern Bering Sea they do not. In addition to insolation, other atmosphere and ocean climate drivers, such as sea ice distribution and changes in the position and activity of the Aleutian Low, may have systematically influenced the timing and magnitude of warming and cooling during the Holocene within the subarctic North Pacific. Periods of high sea ice extent in both the Okhotsk and Bering Seas corresponded to periods of frequent or strong winter–spring dust storms in the Mongolian Gobi Desert during three time intervals: 9–8.5, 6.5–6, and 4–3 thousand years before present (kyr BP). The Mongolian dust in Pacific seafloor sediment may be a proxy to reconstruct the frequency or strength of winter–spring storms in the Mongolian Gobi Desert and Siberia, eastward migration of the Aleutian Low and Siberian High, or changes in the relative strengths of the Aleutian Low and Siberian High. Eastward displacement or increased intensity of the Aleutian Low and Siberian High likely became dominant during these three Holocene intervals, increasing the extent of sea ice in the western Okhotsk Sea and eastern Bering Sea.

Westerly jet–East Asian summer monsoon variations during the Holocene

Kana Nagashima[1], Ryuji Tada[2], and Shin Toyoda[3]

[1] *Japan Agency for Marine-Earth Science and Technology, Japan, kanagashima@yahoo.co.jp*
[2] *University of Tokyo, Japan*
[3] *Okayama University of Science, Japan*

The nature and causes of spatial and temporal changes in East Asian summer monsoon (EASM) precipitation on millennial timescale during the Holocene have not yet been resolved. Here we examine the relationship between spatial variations in EASM precipitation and the westerly jet path over East Asia during the Holocene using the provenance of eolian dust in Japan Sea sediments, which we interpret to reflect changes of the westerly jet path over East Asia (Nagashima et al., 2013, G-cubed, 14, doi:10.1002/2013/GC004931). The contribution of dust from the Mongolian Gobi Desert relative to that from the Taklimakan Desert shows millennial-scale minima at 11.5–10, 7–5, and 3.5–1.5 kyr BP, which we attribute to earlier seasonal northward progression of the westerly jet. These dates correlate with precipitation maxima along the present northwestern EASM margin and minima in eastern Northeast China and the Yangtze River Basin, suggesting that the westerly jet shifted northward earlier in the year, allowing earlier northward migration of the EASM rainband and generating abundant precipitation in the northwestern EASM margin. Therefore, during the Holocene, changes of the westerly jet path probably contributed to the millennial-scale EASM precipitation changes and its northwest–southeast contrast within China. The changes of the seasonal northward progression of the westerly jet path also have a potential to change ecosystem of the North Pacific.

Comparing Holocene productivity variability in the eastern and western regions of the Subarctic North Pacific Ocean

Bruce P. Finney[1], Jason A. Addison[2], and Naomi Harada[3]

[1] *Idaho State University, USA, finney@isu.edu*
[2] *USGS Menlo Park, USA*
[3] *Japan Agency for Marine-Earth Science and Technology*

Recent observations indicate that climate and marine ecosystems in the North Pacific Ocean vary strongly over multi-decadal changes, with regionally consistent patterns. Paleoclimate, paleoceanographic and paleoecologic archives can be used to describe temporal and geographic changes in this system prior to historical records. We present high-resolution marine sediment core data from the Kuril Islands in the Sea of Okhotsk and temperate fjords of the Gulf of Alaska (GoAK). These distant sites are located along the western (Kuril) and eastern (GoAK) boundaries of the Subarctic North Pacific Ocean, where micronutrient-rich coastal waters interact with North Pacific high-nutrient-low-chlorophyll (HNLC) waters to drive highly productive marine ecosystems. Opal concentrations and the $\delta^{13}C$ of organic matter (proxies for past primary productivity) increase significantly during the middle Holocene ~4,000 – 6,000 yrs ago in both regions. In the Kuril region alkenone-based warm season SST proxies either decline

or remain relatively constant during this transition, while proxies for sea-ice intensity generally decline. The middle Holocene increase in inferred productivity in the GoAK occurs during an interval of declining warm season coastal SAT as inferred from pollen transfer functions. Declining summer solar insolation during the middle Holocene can explain the overall decline in warm-season SST in both the Sea of Okhotsk and the Gulf of Alaska. However, the increase in productivity, which likely reflects an improvement in growing conditions during the spring/summer bloom season, is unlikely to be related directly to summer insolation. A middle Holocene intensification of the Aleutian Low (AL) pressure cell and concomitant changes in North Pacific circulation best explains the changes in productivity, SST and sea-ice. In both regions, several potential mechanisms related to an intensified AL could result in greater productivity including: (*i*) increased advection fluxes of HNLC macronutrients into coastal areas; (*ii*) greater winter vertical mixing due to elevated storm activity; and (*iii*) enhanced coastal euphotic zone stratification from increased precipitation and fluvial discharge. Long-term changes in sea-ice distribution in the Sea of Okhotsk may also influence productivity locally, though this relationship is complicated by interactions between the Siberian High and the AL, as well as Amur River freshwater discharge.

From Fish to Humans; the paleoecology of higher trophic level species in the Gulf of Alaska

Nicole Misarti[1] and Bruce Finney[2]

[1] *Water and Environmental Research Center, University of Alaska Fairbanks, USA, nmisarti@alaska.edu*
[2] *Idaho State University, USA*

Paleo data from ocean and lake sediment cores has been used to describe decadal and multi-decadal variability in the Gulf of Alaska. Much of that data has centered on climate indicators and/or productivity of lower trophic level species such as phytoplankton. However the use of fish scales from ocean sediment cores, $\delta^{15}N$ records from sockeye salmon lake sediment cores, and archaeological data can provide additional information on long-term ecosystem variability. Abundance indices, human population data and stable isotope data of several species found in archaeological middens indicate variability over time, with shifts often concurrent with changes in the climate-ocean system. Records will include $\delta^{15}N$ from several sockeye spawning lakes, $\delta^{15}N$ and $\delta^{13}C$ and abundance indices data of salmon (*Oncorhynchus sp.)*, Pacific cod (*Gadus macrocephalus*), sea otter (*Enhydra lutris*), and human population data from the Alaska Peninsula. These records reveal differing interspecies relationships during some prehistoric periods relative to observations of current variability such as the Pacific Decadal Oscillation; evidence for different climate-ecosystem modes in the past. Human population trends along the coast appear to correspond with productivity levels and relative numbers of returning sockeye salmon. There is evidence of both bottom-up and top-down forcing mechanisms in the records.

Dynamics of Coastal and Island Ecosystems of the Bering Sea Region over the Last Millennia

Arkady Savinetsky[1], Bulat Khasanov[1], Olga Krylovich[1], Ekaterina Gorlova[1], Zhanna Antipushina[1], Dmitri Vasyukov[1], Dixie West[2], Michael Chernyakhovsky[3]

[1] *Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, arkadybs@rambler.ru*
[2] *Biodiversity Institute and Natural History Museum, University of Kansas, Lawrence, KS 66045, USA*
[3] *Moscow State Pedagogical University, Moscow, Russia*

The dynamics of climate, sea level, vegetation, sea mammal and bird populations, and invertebrates of the Bering Sea region over the last several millennia are reconstructed. We identify osteological material and invertebrate remains from the cultural layers of ancient sea-mammal hunter settlements as well as natural deposits in Chukotka, Kamchatka, and the Aleutian (Western and Central) and Commandor Islands. Climatic changes are reconstructed from complex investigations of peat and coastal deposits in Chukotka and the Aleutian Islands. All material was radiocarbon dated (more than 500 dates). Besides osteological, spore-pollen, and radiocarbon methods, we widely use the analysis of stable isotopes – 13C/12C and 15N/14N of collagen of mammal, bird and fish bones and organic matrix of bivalves, and 18O/16O of shells for identifying the dynamics of trophic position, location of feeding sites of animals and climate changes.

Apparent resilience of Late Holocene North Pacific nearshore ecosystems

Mike Etnier[1] and Catherine West[2]

[1] *Western Washington University, Washington, USA metnier@uw.edu*
[2] *Boston University, Massachusetts, USA*

Analysis of faunal records from Late Holocene archaeological sites in the Kuril archipelago (n = 10), the Aleutian archipelago (n = 28), and the northern Gulf of Alaska (n = 63) shows a high level of consistency through time, in spite of well-documented global and regional climatic anomalies during that time period. Of all of the sites and time periods analyzed, the only hint of a climate-related change in species distribution/abundance is a strong pulse of the ice-adapted ringed seal (*Phoca hispida*), which is reported to have expanded its breeding distribution into the eastern Aleutian Islands ca. 4700 – 3500 BP. Curiously, invertebrate faunas, and other classes of vertebrate faunas (e.g., fish and birds) from the same deposits show no ice-related changes in distribution or abundance. Furthermore, other proxies such as marine cores do not indicate strong cooling in this area during this time frame. Future research hopes to evaluate this inconsistency by measuring ^{18}O concentrations in shellfish dating to the period during and after the purported ice incursion into the eastern Aleutian Islands.

The Archaeology of Norse North Atlantic Fisheries – 871 – 1800 C.E.

George Hambrecht[1], Francis Feeley[2], Ramona Harrison[3], Seth Brewington[2], Konrad Smiarowski[2], Megan Hicks[2], Sophia Perdikaris[4], and Thomas McGovern[3]

[1] *University of Maryland, College Park, ghambrecht@gmail.com*
[2] *Graduate Center of the City, University of New York*
[3] *Hunter College, CUNY, NY*
[4] *Brooklyn College, CUNY, NY*

For the past 30 years the NABO (North Atlantic Biocultural Organization) research and education cooperative has been engaged in the archaeology of fisheries from the Viking Period through to the Early Modern across the North Atlantic from Norway to Greenland. Numerous sites from Norway through to Greenland have been excavated and their faunal assemblages analyzed. This paper will be a digest of the results of this research up to this time. Two main themes will be covered; 1) the origins of the trade in dried Gadidae in the North Atlantic, 2) the potential for combining zooarchaeological, archaeometric, isotopic, and genetic analysis to reconstruct population structures of Gadidae over the past 1100 years.

Ancient DNA, what is it and what can it do for you?

Morten Allentoft

Biogeographic insights from past and present megafauna DNA

Eline Lorenzen

Session 5

Biology and Ecology of Arctic Cods

On the doorstep to a deeper understanding of population divergence in highly mobile Arctic gadoids: examples from sympatric *Arctogadus glacialis* and *Boreogadus saida*

Kim Præbel[1], Matias Langgaard Madsen[1,2], Jørgen Schou Christiansen[1], Svein-Erik Fevolden[1]

[1] *Faculty of Biosciences, Fisheries and Economics, UiT the Arctic University of Norway, Tromsø, Norway, kim.praebel@uit.no*
[2] *Akvaplan-niva AS, Fram Centre, 9296 Tromsø, Norway*

There is strong theoretical and empirical evidence that glacial signatures, environmental clines, and ecological processes are among the major forces driving population divergence in northern systems. Detailed knowledge already exists about the underlying mechanisms for the diversification processes into discrete habitats for the northern freshwater systems. However, surprisingly little is known about the molecular ecology and the major responsible driving forces in the marine systems. Here, we will briefly outline the present status of genetic, ecological and environmental knowledge important for understanding the divergence process within and among populations of sympatric *Arctogadus glacialis* and *Boreogadus saida*. We will then use recent genetic evidence to illustrate the potential role of oceanic clines and ecology in the divergence process in *Boreogadus saida*. Finally, we contrast these findings with expectations for the sympatric species pair and outline our perspectives and ideas for future studies within northern regions.

Molecular Population Genetics of Arctic Cod

R. John Nelson[1], C. Bouchard[2], A. Majewski[3], M. Madsen[4], J. Reist[5], L. Fortier[2], J. Christiansen[6], S-E. Fevolden[6], S. Talbot[7], R. Crawford[8], D. Archambault[9], T. Siferd[3], S. Palsson[10], G. Rose[11], K. Dunton[12], and G. Divoky[13]

[1] *University of Victoria, Victoria, British Columbia, V8W 3N5, jnelson@uvic.ca*
[2] *Université Laval, Québec, Québec, G1V 0A6*
[3] *Fisheries and Oceans Canada, Winnipeg, Manitoba, R3T 2N6*
[4] *Akvaplan-niva AS, 9296 Tromsø*
[5] *Fisheries and Oceans Canada, Winnipeg, Manitoba, R3T 2N6*
[6] *University of Tromsø , N-9037 Tromsø*
[7] *USGS, Anchorage, AK 99508-4626*
[8] *Eastern Carolina University, Greenville, North Carolina, 27858-4353*
[9] *Fisheries and Oceans Canada, Mont-Joli, Québec G5H 3Z4*

[10] *University of Iceland, 101 Reykjavík*
[11] *Memorial University, St. John's, Newfoundland A1C 5R3*
[12] *University of Texas, Port Aransas, TX 78373-5015*
[13] *Friends of Cooper Island, Seattle, Washington 98112*

Understanding genetic population structure provides a foundation that informs many other types of research. Here we use analysis of microsatellite DNA to reveal population structure of *Boreogadus saida*. Population structure is clearly detected at both regional and pan-Arctic scales. This population structure has a geographical basis. However, as would be expected for a pelagic fish with very large population sizes, population differentiation is not strong even across large distances with an overall F_{ST} of 0.01. A North American Atlantic-Arctic group is detected which includes populations ranging from the Gulf of St Lawrence to Baffin and Resolute bays. A North American Pacific – Arctic group is also detected including samples from the North Bering, Chukchi and the US Beaufort seas. This collection of samples appear to be distinct from samples collected further east in the Canadian Beaufort Sea and Amundsen Gulf suggesting that within this region there is a biogeographical boundary. Ongoing follow up work will increase sample coverage across the N. Bering-Beaufort-Amundsen Gulf corridor to pin-point this boundary. Samples collected from the East Greenland and Laptev seas grouped with the samples from the North American Pacific – Artic but support for this group wasn't strong. Samples from Iceland did not group decisively with any other group. Population structuring of Artic Cod from Iceland to the East Siberian Sea will benefit from increased sample coverage and further genetic analysis. Using genetic analysis we discovered many specimens of *Arctogadus glacilis* in our *B. saida* samples highlighting the need to further understand the ecological relationship of these two species.

Distribution, abundance, and biology of polar cod, *Boreogadus saida,* in Icelandic Sub-Arctic waters

Olafur S. Astthorsson

Marine Research Institute, Skulagata 4, PO Box 1390, Reykjavik, Iceland, osa@hafro.is

Distribution, abundance, and biology of polar cod, *Boreogadus saida,* was studied in the waters around Iceland based on material sampled during demersal fish surveys in March 1985-2011 and in pelagic 0-group surveys in August-September 1974-2003. Demersal polar cod was confined only to the Sub-Arctic waters around Iceland and were most often caught on the outer the shelf to the northwest of Iceland but during the years of highest abundance and widest distribution it was also caught on the north and northeastern shelves. Pelagic 0-group polar cod were only caught sporadically and confined to the Sub-Arctic waters over outer part of the northwestern shelf and the east Greenland shelf. Both distribution and abundance showed variations related to bottom temperature. Demersal polar cod were most widely distributed and peaks in abundance highest in the cold years of 1989-1999, 1994-1995 and 2002. A fourth peak in both abundance and distribution was observed during the somewhat warmer period of 2007-2009. On average highest numbers of polar cod per haul were caught at temperatures of 1.4° C and 0.14° C, and at depth ranges 55-100 m and 300- 400 m, respectively. The length of demersal

polar cod ranged from 5-32 cm while the fish caught in the pelagic trawl ranged from 2.2-19 cm. The polar cod in north Icelandic waters most likely originate from east Greenland or even possibly Svalbard waters.

Review of Russian investigations of polar cod (Boreogadus saida) and Arctic cod (Arctogadus glacialis) in the Barents and Kara Seas

Pavel Krivosheya

Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Knipovich St., 6, Murmansk, 183037, Russia, kpv@pinro.ru

In the last few years intensive warming in the Russian Arctic has been observed, with significant impacts on cold-water species including polar and Arctic cods. A review of the Russian literature on the distribution, ecology and biology of polar cod is provided. Two separate groups of polar cod with different spawning areas occur in the Barents Sea - near Spitsbergen archipelago and in the eastern Barents Sea and probably in the Kara Sea. PINRO in cooperation with IMR (Norway) have conducted assessments of polar cod in the Barents Sea since 1986. Data on the spatial (horizontal and vertical) distribution of the eastern Barents sea polar cod during the ice-free season were collected, along with length, age and sex structure of the stock, spawning, distribution of eggs and larvae, fecundity and maturity. During 2007 and 2013 PINRO also carried out similar surveys the Kara Sea. Data on the age and sex structure of the polar cod stock in the Kara Sea and estimates of the abundance and biomass of polar cod were obtained. Data obtained since 2004 on the spatial distribution of Arctic cod in the Barents and Kara Seas during the ice-free season, along with date regarding length structure and maturity will also be presented.

***Boreogadus saida* in the western Arctic: demersal distribution, habitat and biological characteristics**

Brenda L. Norcross[1], Brenda A. Holladay[1], Lorena E. Edenfield[1]

[1] *Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Fairbanks, Alaska 99775-7220, bnorcross@alaska.edu*

Boreogadus saida is a key Arctic species that has a circumpolar distribution. As such, it is important to understand the underlying relationships within the habitat it occupies and to investigate associated biological characteristics. The western Arctic is interesting as there is a wide shallow shelf in the Chukchi Sea and a narrow shelf with a steep slope in the US Beaufort Sea, affording an excellent opportunity to examine *B. saida* distribution in relation to depth and distance from shore. We used a 3 m plumb staff beam trawl to collect demersal fishes from the Russian section of the Chukchi Sea (170^{o} E) throughout the US Chukchi Sea across the US Beaufort Sea and into the Mackenzie River delta in the western Canadian Beaufort Sea (136^{o} W). The highest concentrations of *B. saida* were found east of Pt. Barrow, Alaska (70^{o} – 71^{o} N, 153^{o}

– 155° W) on the Beaufort Sea shelf and at the shelf break; density decreased eastward then increased somewhat at the Mackenzie River delta. Concentrations of *B. saida* were high in isolated catches on the Chukchi shelf north of the Bering Strait (67° – 69° N, 168° – 172° W). Not only was there a geographical break in density between the Chukchi and Beaufort Seas, but diets of *B. saida* >60 mm differed between seas. Overall *B. saida* from 20 to 250 mm were captured, however fish >200 mm were not commonly caught. Ages ranged 0 – 4 years with an occasional age-5 Arctic cod.

Distribution of Arctic (Polar) Cod, *Boreogadus saida*, in the Canadian Beaufort Sea relative to key prey items and oceanographic parameters

Andrew Majewski[1], Wojciech Walkusz[1], Brittany Lynn[1], Jane Eert[2], James Reist[1] and Sheila Atchison[1]

[1]*Fisheries and Oceans Canada, Freshwater Institute, 501 University Cres., Winnipeg, MB, Canada R3T 2N6, andrew.majewski@dfo-mpo.gc.ca*
[2]*Fisheries and Oceans Canada, Institute of Ocean Sciences, 9860 West Saanich Road, PO Box 6000, Sidney, BC, Canada V8L 4B2*

Arctic (or Polar) Cod (*Boreogadus saida*) is a keystone species in Arctic marine ecosystems, understood to be a significant consumer of zooplankton and key prey for marine mammals and birds. *Boreogadus saida* occurs throughout the circumpolar north; however, distributions at localized regional scales are less understood. Habitat associations and diet preferences across life-history stages are also poorly known, thereby impeding effective regulatory efforts in support of conservation objectives. The distribution of *B. saida* in the Canadian Beaufort Sea was assessed using bottom trawling in shelf and slope habitats between 20 and 1000m depths during August. Highest catch biomasses occurred along the Mackenzie Shelf-Slope, generally at 200 and 350m depth stations, and in Amundsen Gulf at stations deeper than 200m. Oceanographic profiles indicate that these depths coincide with the thermohalocline between Pacific and Atlantic water masses. Plankton species composition, relative biomasses and size fractions were documented within and across depth strata using horizontal and vertical tows to assess associations with water column habitats and fish assemblages. Herein, we examine 1) relative biomasses of *B. saida* in relation to the broader demersal fish community within and across depth strata, and 2) associations among catch biomasses of *B. saida*, oceanographic parameters, and catch biomasses of key prey items determined from gut content analyses. Habitat and diet associations presented here will inform knowledge of structural and functional relationships in Arctic marine ecosystems, aid in mitigation and conservation efforts and will enhance our ability to predict the effects of climate change on the distribution of this pivotal marine fish species.

Vertical distribution and migrations of Arctic cod (*Boreogadus saida*) in the Canadian Beaufort Sea from spring to fall

Maxime Geoffroy[1], Andrew Majewski[2], Stéphane Gauthier[3], Mathieu LeBlanc[1], Wojciech Walkusz[2], James D. Reist[2] and Louis Fortier[1]

[1] *Canada Research Chair on the response of Arctic marine ecosystems to climate change, Québec-Océan, Département de biologie, Université Laval, 1045 avenue de la Médecine, Québec, QC, Canada G1V 0A6, maxime.geoffroy.1@ulaval.ca*
[2] *Fisheries and Oceans Canada, Freshwater Institute, 501 University Cres., Winnipeg, MB, Canada R3T 2N6*
[3] *Fisheries and Oceans Canada, Institute of Ocean Sciences, 9860 West Saanich Road, PO Box 6000, Sidney, BC, Canada V8L 4B2*

Arctic cod transfers up to 75% of the energy between lower trophic levels to the top predators of the Arctic marine ecosystem. In the Canadian Beaufort Sea, recent studies documented dense aggregations of Arctic cod in the Atlantic waters, over the slope and under the ice-cover from December to April. However, few studies have documented the offshore vertical distribution and migrations of Arctic cod from spring to fall. The timeline and patterns of vertical migrations remain unknown. Hydroacoustic surveys were conducted in the Beaufort Sea from 2006 to 2012 with multi-frequency echosounders and a fisheries sonar, to test the hypothesis that adult Arctic cod school near the surface during summer and fall. Instead, an ontogenetic segregation between young-of-the-year (YOY) and Age 1+ Arctic cod was observed. YOY remained in the epipelagic zone (< 100 m) and Age 1+ aggregated in a distinct mesopelagic layer over the continental slope at depth ranging from 200 to 400 m. The epipelagic layer appeared in June and most YOY migrated at depth in October. The biomass of fish within the mesopelagic layer diminished in June, most likely as Arctic cod larger than 10 cm migrated towards the seafloor. Arctic cod >10 cm started returning in the mesopelagic layer in August to feed on the descending YOY and *Calanus hyperboreus*. Age-1+ and YOY Arctic cod performed diel vertical migrations from spring to fall. Understanding the ecology of Arctic cod is critical to anticipate the combined effects of climate change and anthropogenic activities on the marine ecosystem.

Under-ice distribution of polar cod *Boreogadus saida* in the Central Arctic Ocean and its association with sea ice habitats properties

Carmen David[1,2], Hauke Flores[1,2], Benjamin Lange[1,2], Doreen Kohlbach[1,2]

[1] *Alfred Wegener Institut, Am Handelshafen 12, 27570 Bremerhaven, Germany, carmen.david@awi.de*
[2] *University Hamburg, Zoological Institute, Martin-Luther-King Platz 3, 20146 Hamburg, Germany*

In the Arctic Ocean, sea ice habitats are undergoing rapid environmental change. Because sea ice constitutes an important habitat for numerous species, these changes have a significant impact on ecosystem functioning, species distribution, and population sizes. In the Arctic Ocean, polar cod

is an ecologically key species known to be associated with the underside of pack-ice. In spite of numerous studies in coastal shelf habitats, the under-ice distribution of polar cod in the Central Arctic Ocean has received little attention in the past. During 2012, we sampled polar cod and other under-ice fauna with a novel under-ice trawl for the first time, covering large parts of the Eurasian deep-sea basins of the Arctic Ocean. To model the relationship of polar cod with sea ice habitat properties, we used a bio-environmental sensor array during under-ice fishing. The parameters measured included sea ice thickness, roughness and spectral light transmission of sea ice. The sensors enabled a real-time characterization of sea ice habitat properties over large (1-5km) distances. Statistical modeling techniques (GLMs, GAMs) were used to model the association of polar cod with these habitat properties. We will present the progress of our group in linking biological and physical sea ice data as a tool to understand, and ultimately predict, ecological responses to a rapidly changing Arctic Ocean.

Occurrence of a gelatinous predator (*Cyanea capillata*) affects Arctic cod habitat utilization in High Arctic coastal waters

Richard E. Crawford

Department of Biology, East Carolina University, Greenville, NC 27858, crawfordr@ecu.edu

Although the Arctic cod (*Boreogadus saida*) has a Pan-Arctic distribution, little is known about its utilization of habitat in near shore waters where this species is the principal prey for seabirds, marine mammals and other fish. This talk presents results of long-term investigations using active hydroacoustics to study its behavior and seasonal movements in open water and under land-fast ice in the Canadian High Arctic archipelago. Generally, the fish exhibits three patterns of distribution: densely aggregated, loosely aggregated, or sparsely distributed, although density distribution (fish/m^3) is highly variable, revealing surprising complexities in behaviors. Echo target strength determinations and groundtruthing indicate size segregation exists between shoals. Horizontal and vertical fish distribution reveals habitat selection by fish size and temperature preference, although predator avoidance is a stronger cue. Arctic cod subjected to gale force winds for 12+ hours aggregated near shore in some of the highest densities recorded in this study. Movement into the shallows was apparently due to avoidance of *Cyanea capillata*, an Arctic cod predator. Many other instances of avoidance in both horizontal and vertical planes have been detected. In one case, a population explosion of jellies led to complete exclusion of Arctic cod from a bay. This fish also avoids disturbance by vessels. Finally, the existence of two morphs, characterized by differences in the hepatosomatic condition factor in fish in several small bays, two separated by less than 15 km, reveals the existence of additional complexities in the life history of the Arctic cod that remain to be unraveled.

Polar cod (*Boreogadus saida*) in a warmer and more competitive Arctic environment

Haakon Hop[1] and Harald Gjøsæter[2]

[1] *Norwegian Polar Institute, Fram Centre, N-9296 Tromsø, Norway, Haakon Hop@npolar.no*
[2] *Institute of Marine Research, PO Box 1870, N-5817 Bergen, Norway*

The polar cod (*Boreogadus saida*) is associated with cold water masses and sea ice in the Arctic. In relation to climate warming and poleward expansion of boreal species, the polar cod could be negatively affected. This species has overlap in distribution with capelin (*Mallotus villosus*) in the Barents Sea, and other fish species, such as Atlantic cod (*Gadus morhua*), haddock (*Melangrammus aeglefinus*) and even mackerel (*Scomber scombrus*) occur sympatrically with polar cod in Svalbard. In fjords in Greenland, polar cod overlap with the ice cod (*Arctogadus glacialis*). This potentially results in competition for food resources, indicated by dietary overlap. Polar cod is considered a specialist adapted to live at sub-zero temperatures, often in contact with ice, and it tends to feed more on amphipods than the other species. In prey selection experiments, with choice of two prey species presented simultaneously to individuals, its preference was *Themisto* sp. > *Calanus* sp. > *Mysis* sp., which concurs with the dietary information. Recent changes in the distribution of Atlantic cod and mackerel may cause increased predation on polar cod. Plans to develop commercial trawlers for targeted fishing of polar cod along the ice edge could further increase the exploitation pressure on this species. Population decline has been shown in the Barents Sea, with reduction from 1-2 million tonnes during the period 1999-2010 to 0.3 million tonnes since 2011. Climate warming with expansion of boreal species, increased competition and predation, and industrial fishing could affect the pivotal role of polar cod as key species in the Arctic marine food web.

Decadal, annual and seasonal variation in Arctic Cod (*Boreogadus saida*) abundance in the nearshore Beaufort Sea: the effects of decreasing sea ice and increasing SST

George Divoky[1] and Yann Tremblay[2]

[1] *Friends of Cooper Island, 652 32nd Ave East, Seattle, WA 98112, USA, divoky@cooperisland.org*
[2] *Institut pour la Recherche et le Développement (IRD), UMR EME 212 - Exploited Marine Ecosystems, Centre de recherche halieutique méditerranéenne et tropicale, Avenue Jean Monnet CS 30171, 34203 Sète Cedex, France.*

The Arctic Cod (*Boreogadus saida*) is the most abundant forage fish in the Arctic Basin and the major link in the transfer of energy to upper trophic levels in arctic marine ecosystems. A four-decade study of the feeding ecology and breeding biology of the Black Guillemot (*Cepphus grylle mandtii*), a diving seabird specializing in Arctic Cod, provides a unique and long-term data set on the availability of Arctic Cod in nearshore waters during the period of summer ice retreat. From 1975-2002 guillemot nestlings were fed Arctic Cod almost exclusively, but in the last decade increasing SSTs (>4°C) and decreasing sea ice cover have greatly decreased cod availability. Analysis of oceanographic conditions (SST and distance to sea ice) in the

guillemot's foraging area identified regime shifts coinciding with observed annual changes in Arctic Cod availability. Temperature/depth loggers deployed on foraging parent guillemots demonstrate a seasonal shift in cod spatial distribution with adult cod taken in the water column and under sea ice in June and early July with a rapid shift to first-year cod in benthic habitats in late July and August as sea ice retreats and SST increases. In recent years Arctic Cod have disappeared from the diet completely when ice retreat has been extreme. Anticipated continuing decreases in summer sea ice extent and increasing SSTs throughout the Arctic Basin will affect a large number of upper trophic level marine predators dependent on Arctic Cod.

Effects of ocean acidification and warming on the embryonic development of Polar cod *Boreogadus saida*

Daniela Storch[1], Flemming Dahlke[1], and Jasmine Nahrgang[2]

[1] *Alfred Wegener Institute for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany, Daniela.Storch@awi.de*
[2] *University of Tromsø, Norges Fiskerihøgskole, Tromsø, Norway*

Marine species are facing increasing seawater temperatures accompanied with a decrease in seawater-pH. Species' abundance and biogeography are mainly driven by the survival and performance of their early life stages. The early life stages are predicted to be the most sensitive to environmental perturbations. The understanding of the underlying physiological mechanisms shaping embryonic survival is thus necessary to forecast the consequences of environmental change. Within the German joint research project BIOACID the impact of projected ocean acidification and warming (OAW) on the embryogenesis of Polar cod (*Boreogadus saida*) and Atlantic cod (*Gadus morhua*) was investigated.Acidifying oceans might have an impact on acid-base regulation of fish embryos because the developing eggs are freely floating in the ocean. An increase in acid-base regulation might result in increased metabolic rates. Regarding the thermal sensitivity of virtually all physiological processes, it can be expected that ocean acidification and warming act synergistically to influence crucial developmental processes during early life history especially at the temperature limits of the embryos.Artificially fertilized eggs of polar cod were incubated under different temperature and PCO_2 conditions simulating future environmental conditions according to climate projections until year 2100. We measured fertilization success, rate of development and embryonic survival to determine whole animal performance. We further analysed metabolic parameters such as egg respiration and embryonic heart beat rates. Finally, the results will be compared with experiments conducted on Atlantic cod to identify differences in OWA sensitivity between both species co-occuring around Svalbard.

Temperature-dependent growth, condition and behavior of juvenile Arctic cod (*Boreogadus saida*) and co-occurring North Pacific gadids

Benjamin J. Laurel[1], Mara Spencer[1], Louise A. Copeman[2]

[1] *Fisheries Behavioral Ecology Program, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Hatfield Marine Science Center, Newport, OR 97365, USA, ben.laurel@noaa.gov*
[2] *College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Hatfield Marine Science Center, Newport, OR 97365*

Climate change impacts on Arctic fish communities will largely be determined by way of temperature-dependent vital rates of resident and invading species. In this study, we experimentally measured growth, condition and activity in the juvenile stage of two Arctic gadids (Arctic cod, *Boreogadus saida* and saffron cod, *Eleginus gracilis*) and two North Pacific gadids (walleye pollock, *Gadus chalcogramma* and Pacific cod, *Gadus macrocephalus*). Experiments were conducted over a 6-wk growth period across 4 temperatures (0, 5, 9 and 16°C) at the Hatfield Marine Science Center in Newport, OR USA. Results indicated clear physiological and behavioral differences among species. Arctic cod demonstrated a cold-water, stenothermic response in that there was relatively high growth at 0°C, limited growth beyond 5°C and negative impacts on condition, activity, growth and survival at 16°C. In contrast, saffron cod demonstrated a warmer-water, eurythermic response with vital rates increasing with temperature up to 16°C. However, despite these distinct thermal responses, walleye pollock and Pacific cod grew 2 – 3 times faster than Arctic gadids across a relatively broad temperature range i.e., 5 – 12°C. These results, coupled with evidence of northward expansion by both Pacific cod and walleye pollock, suggest Arctic cod are highly vulnerable to continued climate change in the Arctic, especially in coastal areas of the Beaufort and Chukchi seas where temperatures already exceed 14°C in the summer growth period.

Comparing the early life history of sympatric *Boreogadus saida* and *Arctogadus glacialis* in the southeastern Beaufort Sea

Caroline Bouchard[1*], Salomé Mollard[1,2], Dominique Robert[1α], Keita Suzuki[1#], Louis Fortier[1]

[1] *Québec-Océan, Département de Biologie, Université Laval, Québec, QC, Canada, G1V 0A6, caroline@marice.is*
[*] *Present address: MARICE, Faculty of Life and Environmental Sciences, University of Iceland, Askja, Sturlugata 7, 101 Reykjavik, Iceland*
[2] *Labex MER, Université de Bretagne Occidentale, Brest, France, 29238*
[α] *Present address: Centre for Fisheries Ecosystems Research, Fisheries and Marine Institute, Memorial University, St. John's, NL, Canada A1C 5R3*
[#] *Present address: Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto, Japan 606-8501*

Early life-history stages of *Boreogadus saida* and *Arctogadus glacialis* co-occur on Arctic shelves and are morphologically undistinguishable. The two species were sampled in the

southeastern Beaufort Sea from April to August of 2004 and 2008. A subset of the 10587 gadids collected was identified to species by genetics and/or otolith nucleus size. Based on size in the month of capture, 5.8% of the cods were assigned to *Arctogadus* in 2004 and 5.1% in 2008. Identified *Arctogadus* were longer than *Boreogadus* from hatching to metamorphosis. Both species shared the same hatching season from March to July, peaking in April-May during maximum production of ice microalgae. Under the ice in April and May, *Arctogadus* was associated with the ice-water interface while *Boreogadus* distributed mainly over the top 40 m. This depth segregation coincided with a remarkably higher feeding occurrence in *Arctogadus* (88%) than in *Boreogadus* (14%) of similar size ranges. At lengths <15 mm, *Boreogadus* preyed primarily on *Pseudocalanus* nauplii and *Arctogadus* on cyclopoid nauplii. At lengths >25 mm, both gadids shared the same wide spectrum of prey, the large calanoids *Calanus glacialis* and *C. hyperboreus* providing >50% of the carbon intake. From June to August, *Boreogadus* and *Arctogadus* had a similar three-dimensional distribution, occurring together at 76% of 96 stations, generally over the top 40 m. The estimated mortality rate of *Arctogadus* was about half that of *Boreogadus*. A larger size and the capacity to occupy the near-surface diluted layer immediately under the ice-water interface may provide *Arctogadus* with some survival advantage over *Boreogadus*.

Gender specific reproductive strategies of an Arctic key species (Boreogadus saida) and implications of climate change

Jasmine Nahrgang[1,2], Øystein Varpe[2,3], Ekaterina Korshunova[1,3], Svetlana Murzina[4], Ingeborg G. Hallanger[1], Ireen Vieweg[1], Jørgen Berge[1,2]

[1] *Department of Arctic and Marine Biology, University of Tromsø, N-9037 Tromsø, Norway*
jasmine.m.nahrgang@uit.no
[2] *Akvaplan-niva, Fram Centre, N-9296 Tromsø, Norway*
[3] *University Centre in Svalbard, Pb 156, N-9171 Longyearbyen, Norway*
[4] *Institute of Biology of the Karelian Research Centre, RAS, 185910 Petrozavodsk, Russia*

The Arctic climate is changing at a unprecedented rate. What consequences this may have on the Arctic marine ecosystem depends to a large degree on how its species will respond both directly to elevated temperatures and more indirectly through ecological cascading effects. But despite an alarming recent warming of the Arctic with accompanying sea ice loss, reports evaluating ecological impacts of climate change in the Arctic remain sparse. Here, based upon a large-scale field study we first of all present basic new knowledge regarding the life history traits for one the most important species in the entire Arctic, the polar cod (*Boreogadus saida*). Furthermore, by utilizing regions of contrasting climatic influence (domains), we present evidence as to how its breeding stock and reproductive success is impaired in regions of strong warming. As the future Arctic is predicted to resemble today's Atlantic domains, we forecast changes in growth and life history characteristics of polar cod that will lead to alteration of its role as an Arctic keystone species. This will in turn affect community dynamics and energy transfer in the entire Arctic food chain.

Bioenergetic adaptations in polar cod *Boreogadus saida* (Lepechin, 1774)

Larisa I. Karamushko[1] and Jørgen S. Christiansen[2]

[1] *Murmansk Marine Biological Institute, Kola Science Centre, Russian Academy of Sciences, 183010 Murmansk, Russia*
[2] *Department of Arctic and Marine Biology, UiT The Arctic University of Norway, 9037 Tromsø, Norway, jorgen.s.christiansen@uit.no*

Bioenergetic rates, i.e. feeding, growth and metabolism, are generally considered low among polar ectotherms compared to temperate and tropical counterparts. Polar cod (Gadidae, *Boreogadus saida*) is abundant and widespread throughout the Arctic Ocean where it serves as the key link in the transfer of bioenergy from zooplankton to marine top predators. Therefore, it is essential to investigate the bioenergetic relationships for this particular species to understand the flow of energy and prey associated pollutants in the marine Arctic. For several years, we conducted series of experiments with polar cod at ambient temperatures 0 - 10 ºC and developed a comprehensive database on the energy budget for juvenile, adult and senile polar cod (body size range: 11-138 g). As an example, the overall effect of temperature (t, ºC) on the resting metabolism (Q, $mgO_2\ g^{-1}\ h^{-1}$) for polar cod with a standardised body size of 100 g could be described by the exponential equation: $Q = \exp[(-3.142 \pm 0.015) + (0.0697 \pm 0.008)\ t]$, $r^2=0.97$, $p<0.01$. The Van't Hoff temperature coefficient Q_{10} was 2.0 and constant across the investigated temperature interval. Our data do not support the concept of "metabolic cold adaptation" in fishes. On the other hand, the data clearly indicate less overall energy costs per unit growth and, thereby, match the observations of enhanced energy efficiency in metabolism. In other words, the net growth efficiency (NGE or coefficient of assimilation efficiency K_2 (Vinberg, 1986)) may be considerably higher among polar fishes than in fishes at lower latitudes.

Distribution and trophodynamics of Arctic cod (*Boreogadus saida*) in the eastern Chukchi and northeastern Bering Seas

Jennifer M. Marsh and Franz J. Mueter

University of Alaska Fairbanks, School of Fisheries and Ocean Sciences, Juneau Center, jmmarsh@alaska.edu

As the most abundant forage fish in the Chukchi Sea, Arctic cod play an integral role linking lower to higher trophic levels in a relatively simple food web. During the 2012 and 2013 Arctic Ecosystem Integrated Survey (Arctic Eis) in the eastern Chukchi and northeastern Bering Seas, Arctic cod were surveyed and collected via surface, midwater and bottom trawls. We present an overview of age-0 and age-1+ Arctic cod distribution and abundance from Arctic Eis and prior surveys. In addition, we examine the variability in distribution in southeastern Bering Sea from survey 1982-2013, relative to the extent of the Bering Sea cold pool. To further explore Arctic cod's ecosystem role, we assess the ontogenetic and spatial variability in their trophic role (trophic level and diet source), using C and N stable isotopes. Generalized additive models were used to detect possible variation in the relationship between length and either $\delta^{13}C$ or $\delta^{15}N$

among regions (or other environmental variables) letting either $\delta^{13}C$ or $\delta^{15}N$ co-vary with length for each fish species. Preliminary results indicate that smallest Arctic cod (5 cm) fed at about 1 trophic level higher than *Calanus* spp., a primary consumer, and larger Arctic cod (15-20 cm) fed up to a trophic level of 4. Examining how spatial gradients in trophic levels and distribution are linked to environmental drivers can provide insight into potential shifts in Arctic cod with a changing climate.

Diet of polar cod (Boreogadus saida) in the Barents and Kara Seas

Emma V. Orlova, Andrey V. Dolgov, Irina P. Prokopchuk, Valentina N. Nesterova

Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Knipovich St., 6, Murmansk, 183037, Russia, dolgov@pinro.ru

A literature review (focus on Russian literature) on diet composition and feeding intensity of polar cod in the Barents and Kara Seas is provided. Based on actual quantitative data of PINRO peculiarities of polar cod diet under recent warming period in Arctic are considered – in the Barents Sea (2004-2012) and in the Kara Sea (2007, 2010). It was shown that during the last decade the most important prey of polar cod juveniles were copepods, while hyperiids and euphausiids were the main prey for moderate size and large individuals, as well as other plankton groups (pteropods, appendicularia, etc). In some case cannibalism was also observed in polar cod populations. Feeding relations of polar cod with other planktivorous fishes and their role in trophic webs in the Barents Sea were also considered.

Abstracts
of
Poster Presentations

Polymorphism of *Arctogadus*, an alternative point of view: *A. borisovi* is a valid species

Natalia V. Chernova

Zoological Institute Russian Academy of Sciences, Saint-Petersburg, Universitetskaya emb. 1, 199034, Russia, nchernova@mail.ru, chernova@zin.ru

Arctogadus includes 4 nominative species: *A. glacialis* (NE Greenland), *A. borisovi* (Kolyma estuary), *A. pearyi* (Lincoln Bay, N. Greenland) and *A. megalops* (NW Greenland). A taxonomic revision suggested that *A. pearyi* and *A. borisovi*, *A. megalops* and *A. glacialis* were synonymous (Nielsen, Jensen, 1967). Two valid species, *A. borisovi* and *A. glacialis*, have been distinguished based on the length of the barbel (developed/absent), gill raker number, forehead width, and orbit diameter. The mitochondrial gene cytochrome b was studied in four *Arctogadus* specimens*:* one *A. glacialis* (lacking barbel) from the slope off Baffin Island and 3 specimens from Uummannaq Fjord, West Greenland, which were determined to be *A. borisovi* based on the length of the barbel (3.9, 3.7 and 0% SL) and on their large size (260, 380, 385 mm); minimal differences suggest these forms are conspecifics (Møller et al., 2002). To support this conclusion, it was shown that allometric morphological characters (mentioned above) cannot be used as diagnostic, and *A.borisovi* was put in synonymy of *A.glacialis* (Jordan et al., 2003). My study is based on collections of the Zoological Institute and the Zoological Museum, Moscow State University, as well as on new materials. Characters of *A.glacialis* and *A. borisovi* from type localities are detailed. The results show that *A. borisovi* is a valid species; both young and adults differ well from *A. glacialis*. It inhabits coastal freshened areas of Siberian seas to 65 m depth and spawns in winter. Presumed *Arctogadus borisovi* and *A. pearyi* from Greenland are not A. *borisovi*. Moreover, *A. glacialis* is a complex, and some other (cryopelagic) forms should be separated. Typical *A. glacialis* is demersal and lives along the continental slope (91-491 m).

Food supply of polar cod in the Barents Sea in recent warming period - changes in the meso- and macroplankton communities

Emma V. Orlova, Andrey V. Dolgov, Valentina N. Nesterova, Anna S. Orlova, Irina P.Prokopchuk, Aleksander N. Bensik

Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Knipovich St., 6, Murmansk, 183037, Russia. dolgov@pinro.ru

This study, based on PINRO data, demonstrating changes in the zooplankton community in the Barents Sea, which forms a food supply for polar cod in this recent period of warming in the Arctic region in 2000-2012. Distribution, abundance and species composition of mesoplankton (copepods) and macroplankton (euphausiids, hyperiids, chaetognaths) are considered. Increasing of water temperature in the Barents Sea during the last decade, resulted in northward shifts of cold-water arctic species (*Calanus glacialis*, *C.hyperboreus*, *Themisto libellula*) distribution , higher abundance and wider distribution of warm-water atlantic species (*Calanus finmarchicus*, *Meganyctiphanes norvegica*), and a generally higher proportion of warm-water species in zooplankton community.

Population dynamics modelling of polar cod (*Boreogadus saida*)

Pedro Duarte[1], Haakon Hop[1], Harald Gjøsæter[2], Jasmine Nahrgang[3]

[1] *Norwegian Polar Institute, Fram Centre, N-9296 Tromsø, Norway. Pedro.Duarte@npolar.no*
[2] *Institute of Marine Research, PO Box 1870, N-5817 Bergen, Norway*
[3] *Faculty of Biosciences, Fisheries and Economics, UiT-The Arctic University of Norway, N-9037, Tromsø, Norway*

A structured population dynamics model for polar cod (*Boregadus saida*) is proposed based on vital rates gathered from the literature and available data bases: growth, survival/mortality, offspring production and recruitment. The model will represent the population divided in age- and in length/weight-classes. Transitions between age-classes will be driven by survival rates, whereas transitions between weight-classes will be driven by growth and survival rates. Variability of vital rates will be used to generate a large number of stochastic simulations that will allow us to predict possible population trajectories over time and estimate the probability of population growth/decline. Model sensitivity to the various vital rates will be tested. A weight versus age-class matrix will be used to keep track of the age of individuals distributed among the different weight-classes and vice versa. This will permit obtaining weight/age curves that may be compared with available data to evaluate model realism. If possible, the model will be applied to local populations (e.g. Svalbard fjords, Barents Sea, Amundsen Gulf) to look for spatial heterogeneity on polar cod population dynamics. This model may serve as a basis for a meta-population model of polar cod based on data applicable to population distributions and connectivity. Furthermore, the model will be set up for coupling with a physiological model for bioenergetics of individuals, where the vital rates will be treated as variables.

Seasonal change of subarctic mesozooplankton community in the western North Pacific with ecological role of the community on biological pump

Minoru Kitamura[1], Toru Kobari[2], Rie Nakamura[3], Kazuhiko Matsumoto[4] and Makio Honda[4]

[1] *Institute of Biogeosciences, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima, Yokosuka, Kanagawa 237-0061, Japan. kitamura@jamstec.go.jp*
[2] *Faculty of Fisheries, Kagoshima University, 4-50-20 Shimoarata, Kagoshima 890-0056, Japan.*
[3] *Graduate School of Fisheries, Kagoshima University, 4-50-20 Shimoarata, Kagoshima 890-0056, Japan.*
[4] *Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima, Yokosuka, Kanagawa 237-0061, Japan*

The subarctic northwestern North Pacific is considered to be one of the most productive areas in the global ocean, with an extremely large biological drawdown of surface layer pCO_2. To understand the ecological impact of mesozooplankton on the biological pump in this area, we investigated seasonal change of community structure (standing stock, vertical distribution, major taxa composition, dominant species and diversity) by estimation of their carbon demand and vertical carbon transport.. Zooplankton sampling was conducted at the time-series station K2

(47°N, 160°E) during seven cruises from 2008 to 2012. Bulk mesozooplankton biomass integrated through 0−1000 m ranged from 5.32 to 7.85 g C m^{-2}. Prominent biomass peaks were observed in the 0−50 m layer during night and 200−300 m layer during day and night. Ontogenetic migratory copepods (*Neocalanus* spp. and *Eucalanus bungii*) contributed the latter peak. Copepoda were predominant except in the nighttime surface layer in autumn and winter where Euphausiacea was most dominant. Diversities (using Simpson's index) based on major taxa biomass during the night were high in 0−200 m and low in 200−1000 m and changed seasonally at the surface layer. Carbon demand at 0−150 m layer (annual average: 204 mgC m^{-2} day^{-1}), downward fluxes of CO_2 (3.1 mgC m^{-2} day^{-1}) and DOC (0.9 mgC m^{-2} day^{-1}) by mesozooplankton were also estimated using empirical allometric relationships. The carbon demand was roughly equal to 65% of primary productivity, the downward carbon flux at 150 m was equivalent to 9% of POC flux.

Why is a Sea Cow like a Pacific Cod? Stable isotopes analysis of Steller's Sea Cow and Pacific Cod Holocene remains from Commander-Aleutian Island arch.

Olga Krylovich, Bulat Khasanov and Mitya Vasyukov

Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, okrylovich@gmail.com

Analysis of stable carbon and nitrogen isotopes of Steller's Sea Cow (Hydrodamalis gigas) and Pacific Cod (Gadus macrocephalus) bone collagen was made. Bones of Sea Cow originated from coastal deposits of the Bering Island (n = 31) and their dates range from 2000 to 200 years BP. Remains of Pacific Cod (n = 68) originated from archaeological site accumulated from 800 to 200 years BP on Adak Island (central part of the Aleutian Islands). Values of bone collagen δ13C of both species were more or less stable in the time, while δ15N of both species synchronously decreased around 600-500 years BP. The reason for such simultaneous changes in δ15N signature for two species totally different in ecology could be found in global ecosystem shift associated with Little Ice Age and possible variation of nitrogen cycle in the northern part of the Pacific Ocean.

Effects of ocean acidification and warming on growth and food consumption of juvenile Polar cod, *Boreogadus saida*

Kristina Kunz[1], Rainer Knust[1] and Felix C. Mark[1]

[1] *Alfred Wegener Institute Bremerhaven, Germany, Kristina.Kunz@awi.de*

Concomitant with increasing ocean temperatures, a northward distribution shift of several temperate fish species has been recorded, with some of them invading the southern habitat of Polar cod (*Boreogadus saida*). This can potentially elicit ecosystem changes by direct and indirect competition. Besides an ongoing warming trend, *P*CO2 levels are increasing especially in cold Arctic waters. However, impacts of the combined stressors ocean acidification and

warming (OAW) on species composition are unknown as yet. Species inhabiting extreme environments tend to be well adapted to the conditions they face in their distribution area, including local natural oscillations, and thereby exhibit narrow thermal windows, which increase their susceptibility to changing abiotic factors. Thus, changing environmental conditions may cause shifts in the energy allocation of organisms due to an increase in the metabolic energy demand at the expense of the evolutionary driving forces growth and reproduction. In this context, the current study focusses on the growth performance and food consumption of juvenile Polar cod under four different temperatures (0, 3, 6, 8 °C) combined with three *P*CO2 conditions (390, 780, 1170 ppm) over a total period of 130 days. Preliminary results revealed a distinct temperature effect on growth and food consumption of Polar cod, whereas the evaluation of a potential hypercapnic impact requires further analysis. The collected data indicate a temperature optimum of this species between 3 and 6 °C. Little growth was observed at 8 °C despite comparable food consumption rates; this may be attributed to a higher metabolic energy demand at this temperature, whereas a low growth rate at 0 °C may be referable to reduced food consumption. These findings will be discussed in the light of further studies considering metabolic rates during rest and activity.

Distribution of fish in Kongsfjord, Svalbard during polar night

Lars-Henrik Larsen[1,2], Sam Newby[3], Torstein Pedersen[2], Morgan Bender[2], Stig Falk-Petersen[1,2]

[1] *Akvaplan-niva, Framcentre, 9296 Tromsø, Norway,* lars@akvaplan.niva.no
[2] *University of Tromsø, The Arctic University, 9037 Tromsø, Norway*
[3] *The University Centre in Svalbard, 9171 Longyearbyen, Norway*

The University of Tromsø, The University Centre in Svalbard and Akvaplan-niva conducted an extensive survey of the marine ecosystems in Kongsfjorden (79°N), Svalbard. The polar night survey was conducted from RV Helmer Hanssen in early January 2014. Nine trawl hauls (6 pelagic, 3 demersal) were undertaken to map species distribution and abundance of fish and large crustaceans. The pelagic trawl was taken in the high biomass Sound Scattering Layer recorded between 90 and 130m water depth. Kongsfjorden has been regarded as a high Arctic Fjord with dominance of arctic fish as polar cod (*Boreogadus saida*) and arctic carnivorous zooplankton as *Themisto libellula.* Interestingly, the fish fauna in January 2014 was dominated by Atlantic cod, (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*) and herring (*Clupea harengus*), all typical boreal species. Polar cod was only found in numbers at the glacial front in an enclosed bay in the inner part of the fjord. Krill (*T. inermi*s) made up the bulk of the pelagic catches, while the deepwater prawn *P. borealis* dominated the demersal hauls. This indicates a transformation from an Arctic to a Boreal marine ecosystem in Kongsfjorden.

Spatial distribution and abundance of *Arctogadus glacialis* and *Boreogadus saida* in NE Greenland

Matias Langgaard Madsen[1,2], Raul Primicerio[2], Michael Greenacre[3], Kim Præbel[2], Svein-Erik Fevolden[2], Oleg V. Karamushko[4], Jørgen Schou Christiansen[2]

[1] *Akvaplan-niva AS, Fram Centre, 9296 Tromsø, Norway. matias@akvaplan.niva.no*
[2] *Faculty of Biosciences, Fisheries and Economics, UIT the Arctic University of Norway, Tromsø, Norway*
[3] *Department of Economics and Business, Universitat Pompeu Fabra, Barcelona, Spain*
[4] *Murmansk Marine Biological Institute, Kola Science Centre, Russian Academy of Sciences, 183010 Murmansk, Russia*

The gadoids (Gadidae), *Arctogadus glacialis* and *Boreogadus saida,* are endemic to the Arctic seas. Both serve as key links in the transfer of bioenergy from lower trophic levels to top predators such as seabirds and marine mammals and, therefore, the pattern of spatial distribution and abundance for these gadoids is of utmost ecological significance for Arctic marine wildlife. Depth and temperature are main factors which affect spatial structuring in fishes. Consequently, data on the distribution and abundance of *Arctogadus* and *Boreogadus* were collected from several bottom trawl surveys conducted in the fjords an on the shelf in NE Greenland during TUNU-Expeditions, 2002-2013. Diagnostic models (GAM, Generalized Additive Models) were used to explore nonlinear relationships between environmental variables (depth, temperature, fjord-shelf) and abundance for each species. This was followed by selection of a set of Generalized Linear Models (GLM), including nonlinear terms when suggested by the diagnostic analysis. Overall, *Boreogadus* was by far the most widespread and abundant species of the two. The occurrence of *Arctogadus* was always accompanied by *Boreogadus* but not vice versa. The two gadoids often coexist (i.e. sympatric) in NE Greenland waters.

Growth and production of polar cod *Boreogadus saida* (Lepechin) in the Barents and Kara Seas

Evgeniia Raskhozheva[1]

[1] *Murmansk Marine Biological Institute Kola Scientific Centre Russian Academy of Sciences, 17 Vladimirskaya str., Murmansk, 183010, Russia, raskhozheva@mmbi.info*

The annual production of polar cod *Boreogadus saida* (Lepechin) is estimated by the increment summation method using original and newly available published data on abundance, biomass, fecundity, and size-at-age and sex structure in 1969–1981 and 1986–2008 in the Barents Sea, and in September-October 2012 in the Kara Sea. The total production of polar cod in the Barents Sea ranged from 0.004 to 0.925 million tonnes in 1969-1981 and from 0.103 to 2.049 million tones in 1986-2008. The average value of the *P/B* coefficient varied from 0.6 to 1.3. The *P/B* coefficient increases at the proportion of younger fishes in the population increases, and decreases with increases in individual average weight in the population. The inverse relationship between the *P/B* ratio and age is described by the equation:
$y = -0.15x + 1.26$ (x = age in years, $R^2 = 0.93$). The relative growth rate of polar cod from the Barents Sea became in three times lower. The contribution of young fish (age-1 and -2) to total production increased on average from 35% to 74%, whereas the percentage of generative production decreased on average from 40 to 17. The average length of polar cod from the Kara Sea in different age groups was as follows: 6.7 cm in year class I, 11.4 cm (II), 13.8 cm (III),

16.2 cm (IV), 19.2 cm (V), 23.2 cm (VI). The relationship between length and weight could be described by the equation: $W = 0.005 \cdot L^{3.15}$ ($R^2 = 0.99$).

Effects of ocean acidification and warming on the behaviour of Polar cod *Boreogadus saida*

Matthias Schmidt[1], Christian Bock[1], Hans-Otto Pörtner[1], Daniela Storch[1]

[1] *Alfred Wegener Institute for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany, Matthias.Schmidt@awi.de*

The currently ongoing increase of CO_2 in the atmosphere causes continuous warming and acidification especially in the polar ocean of the northern hemisphere. While the impact of warming on polar fish was extensively studied during the last decades, the potential effects of ocean acidification, as well as the effect of a combination of both stressors on polar fish are less known. Even though fish are able to effectively counteract a CO_2-induced extracellular acidosis by the accumulation of bicarbonate ions, it was recently found that tropical fish exhibit severe behavioural disturbances under future ocean acidification scenarios which may result from a disturbed neuronal processing of sensory information due to altered neuroreceptor functioning. Information about the behavioural effects on temperate species is very scarce and nothing is known about how polar fish are able to cope with the predicted increase of ambient CO_2. Also, CO_2-induced neurological impairments may interact with a change of temperature. In my talk, I will show preliminary results indicating that acidification affects behavioural laterality in *Boreogadus saida.* Other possible CO_2-induced behavioural changes with respect to activity and aggression are currently under investigation. Furthermore, I will discuss possible combined effects of temperature and CO_2. Our results form the basis for further physiological studies analysing how acidification and warming interfere with the nervous system of *Boreogadus saida.*

***Gadimyxa sphaerica*, a myxosporean parasite found in Polar cod (*Boregadus saida*) and its life cycle in Billenfjorden, Svalbard**

Tomáš Tyml[1,2] and Oleg Ditrich[1]

[1] *Faculty of Science, University of South Bohemia, Branišovská 31, 370 05, České Budějovice, Czech Republic. tomastyml@gmail.com*
[2] *Laboratory of Fish Protistology, Institute of Parasitology, Biology Centre ASCR, Branišovská 31, 370 05, České Budějovice, Czech Republic*

Myxosporeans are microscopic metazoan parasites relatively recently classified to cnidarians. They are widespread in both freshwater and marine habitats. All species probably alternate between two different hosts during their life cycle. In the vertebrate host (mostly fishes) the myxospores are formed. Actinospore, a spore of the second life cycle stage, occurs in invertebrate hosts (mostly annelids) and it is infectious for vertebrate hosts. Until now, only a few life cycles are known in marine environment. Here we reveal a novel one from Billefjorden, Svalbard. Polar cod (*Boreogadus saida*) and Atlantic cod (*Gadus morhua*) were found to be

infected with a member of genus *Gadimyxa*, a myxosporean parasite known from the renal system of cods. Moreover, the actinosporean stage was recorded in a tubeworm *Circeis spirillum*. Morphology of spores and phylogenetic analysis based on SSU rRNA gene sequences assigned all our findings to *Gadimyxa sphaerica*, for which was known only myxosporean stage in urinary system of Atlantic cod *Gadus morhua*[1]. Distinct seasonal dynamic has been observed in the life cycle of *G. sphaerica*. Whereas the actinospores in *C. spirillum* were fully mature in the middle of July in cods at the same time we found developmental stages only. Fully mature myxospores were not present before the middle of August.

[1]Køie M, Karlsbakk E, Nylund A (2007) A new genus *Gadimyxa* with three new species (Myxozoa, Parvicapsilidae) parasitic in marine fish (Gadidae) and the two-host life cycle of *Gadimyxa atlantica* n. sp. J Parasitol 93:1459–1467

Comparative transcriptomics in *Gadus morhua* and *Boreogadus saida* under different temperatures and PCO_2 levels

Heidrun Windisch[1], Magnus Lucassen[1], and Stephan Frickenhaus[2]

[1] *Alfred Wegener Institute Bremerhaven, Germany, Heidrun.Windisch@awi.de*
[2] *Hochschule Bremerhaven, Germany*

Geographical distribution patterns of Atlantic cod, *Gadus morhua,* and Arctic cod, *Boreogadus saida,* have altered during the last decades to a large degree, driven mainly by warming of water masses. Projections of increasing habitat temperature as well as PCO_2 concentrations may lead to stronger adverse effects to their abundance in the future. In general, a species' fitness at a certain condition could best be monitored through the physiological parameter of growth. However, as this fitness parameter is a sum of net free energy, a basic understanding of which process may ultimately limit a species' performance remains obscure. Within our study we aimed to characterize the molecular basis through gene expression patterns, that become effected at optimum conditions or critical limits. Further, we aim to identify gene networks that may contribute to species robustness or sensitivity. To this end we set up a basis for comparative gene expression analyses by sequencing normalized transcriptomic cDNA libraries for both species. In total, we determined 11,901 orthologous sequences constituting a segment of a shared core-transcriptome. In addition, we found unique sequences that may be responsible for species specific varying phenotypic plasticity. Based on all sequences we will build a microarray to analyse transcriptomic patterns under different temperatures and PCO_2 concentrations. By combining gene expression data with physiological parameters we aim to provide a comprehensive view on molecular mechanisms that shape species' vulnerability.

Notes:

POLARISATION

The Research Council of Norway

NATURAL HISTORY MUSEUM OF DENMARK
UNIVERSITY OF COPENHAGEN

Design and Layout: Jared Weems, UAF