ESSAS Annual Science Meeting

June 11-14, 2018

Wedgewood Resort

Fairbanks, Alaska

UAF Photo by JR Archeta

Subarctic and Arctic Marine Ecosystems

Welcome

On behalf of the symposium conveners, organizers, and the ESSAS Scientific Steering Committee, we welcome you to Fairbanks. The 2018 Ecosystem Studies of Subarctic and Arctic Seas (ESSAS) Annual Science Meeting will be held at the Wedgewood Resort in Fairbanks, Alaska's second largest city that sits on the banks of the Chena River in the heart of Alaska. The city is steeped in a history of riverboat captains and gold seekers. Its character has been shaped by a large military presence, construction of the Trans-Alaska Pipeline and the continuing oil economy, and its thriving university. It is a city where old quietly blends with new, that maintains its Frontier spirit to this day.

We are excited to welcome scientists representing at least 7 countries with a range of expertise about sub-arctic and arctic marine ecosystems. The first day will feature presentations and a workshop on the use of satellites in studying high-latitude marine ecosystems. This will be followed on day two by presentations and discussions on the promise and challenges of an Integrated Ecosystem Approach to managing Arctic and Subarctic marine ecosystems. Finally, we will explore recent advances in studying the ecology and paleoecology of Arctic gadids, following up on a successful Arctic Gadid workshop held in Copenhagen in April 2014. This session 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 Fairbanks, its wonderful trail systems and its striking modern buildings that sit side-by-side with log cabins built in the early part of the last century.

Finally, we thank session co-chairs for putting together an excellent program, participants from overseas for making the long trip to Fairbanks, and all our sponsors for their generous support. In particular, we thank NASA, the European Space Agency, IMBER (in particular Lisa Maddison) and the Alaska Satellite Facility (in particular Scott Arko) for their generous support. Without those efforts and funds, it would have been impossible to convene this meeting.

Here is to a productive, stimulating and enjoyable meeting!

Franz Mueter, Ken Drinkwater, and Sei-Ichi Saitoh
ESSAS Co-Chairs and Convenors

Franz Mueter, Jen Marsh, Brenda Norcross
Local Organizing Committee

IMBeR

esa
European Space Agency

NASA

UAF ALASKA SATELLITE FACILITY

UAF COLLEGE OF FISHERIES AND OCEAN SCIENCES
University of Alaska Fairbanks

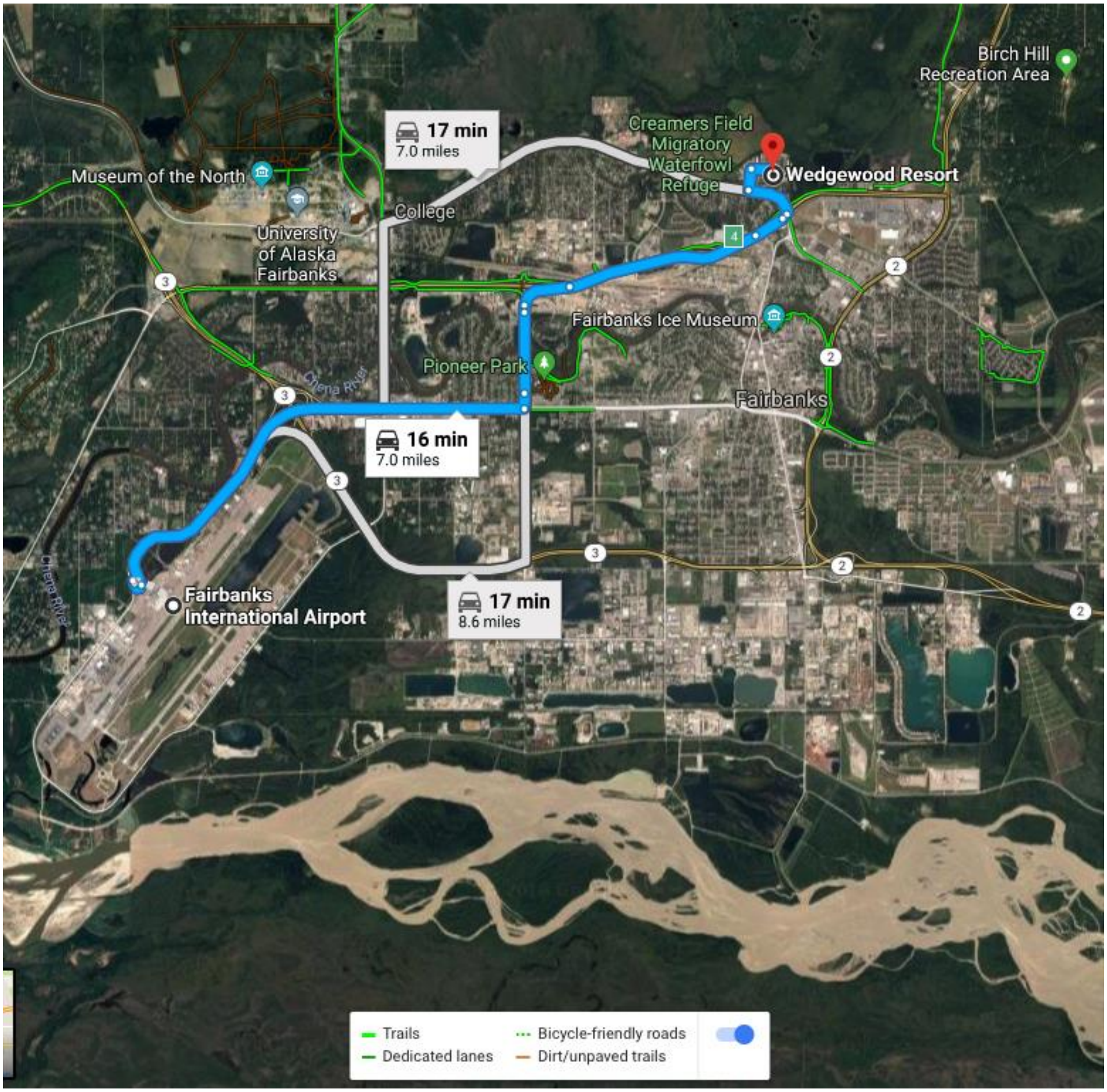
Meeting Information

Location:

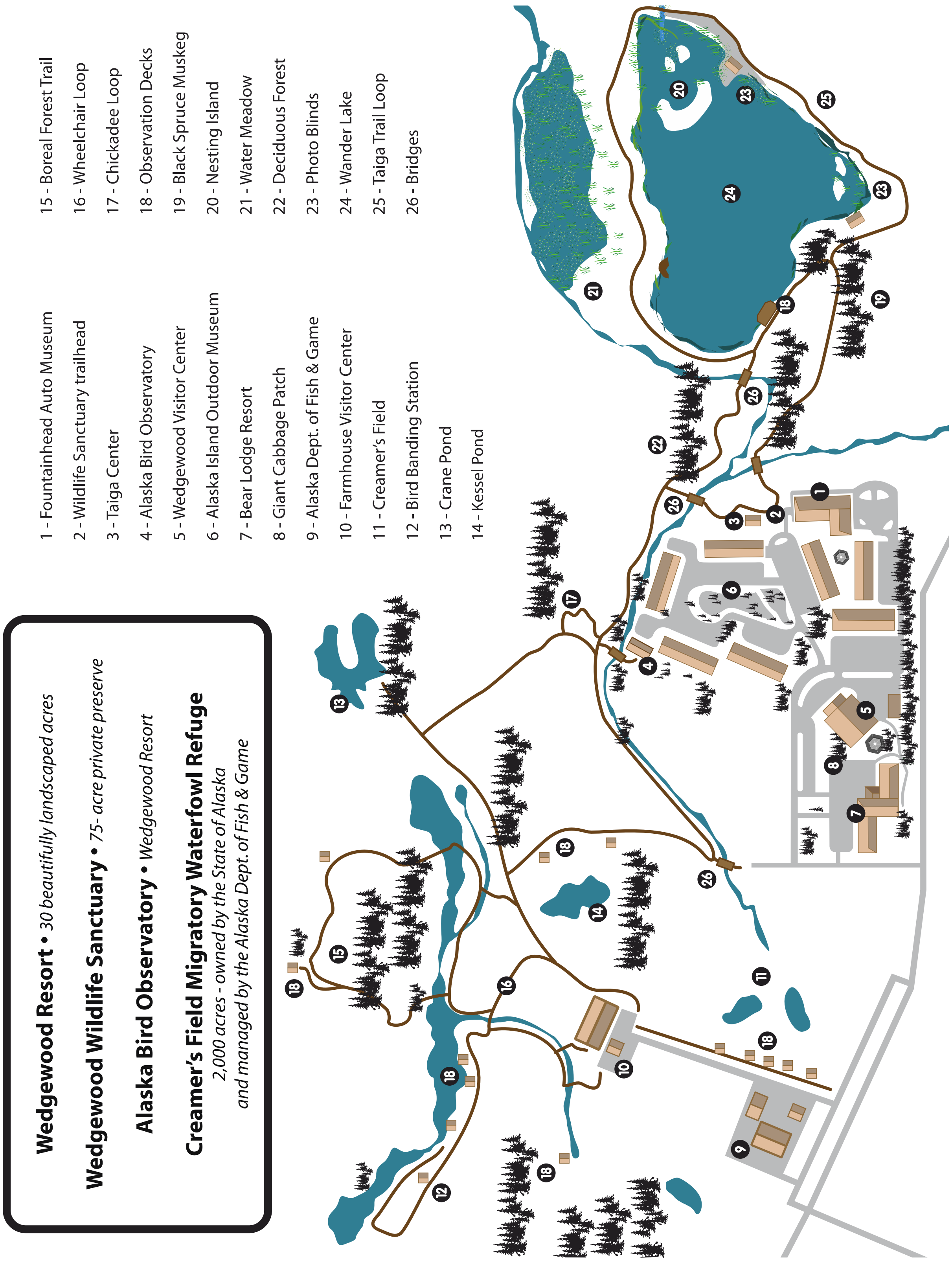
The meeting will take place at the Wedgewood Resort located on 212 Wedgewood Dr
Fairbanks, AK 99701
(Maps 1, 2 and 3).

Getting to the Wedgewood Resort:

The easiest way the get to the Wedgewood Resort from Fairbanks International Airport is to take a Taxi, Uber or Lyft.

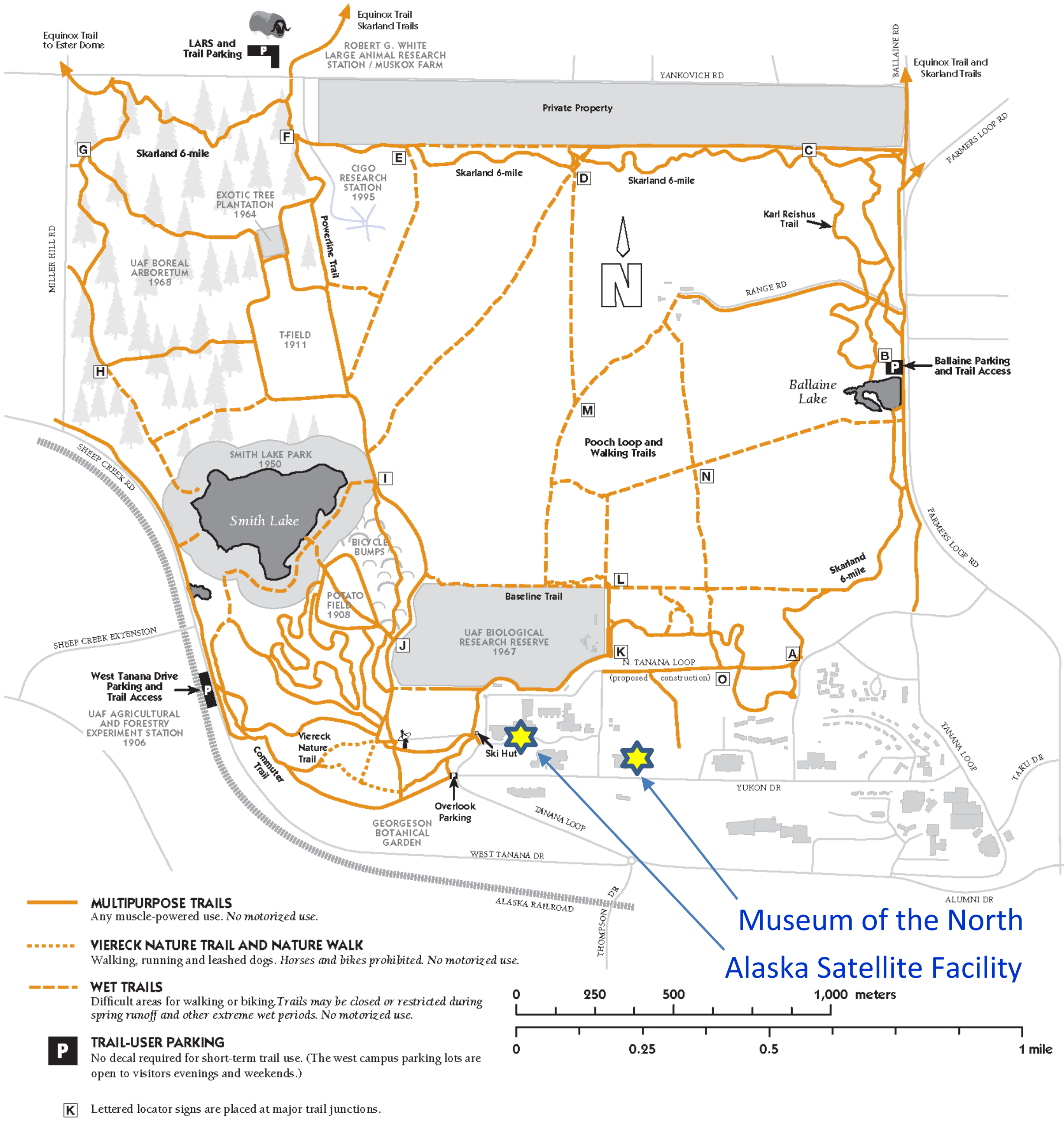


Map 1: The ESSAS meeting will be held at the Wedgewood resort, which is less than 20 minutes away from Fairbanks International Airport.



Map 2: Wedgewood Resort and surrounding property.

Map 3: Wedgewood Resort and surrounding property



Registration:

The meeting will start with a welcome reception on Monday June 11th at 18:00. 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.

Agenda

Tuesday, June 12			Wednesday, June 13			Thursday, June 14		
8:30	Coffee & light breakfast		8:30	Coffee & light breakfast		8:30	Coffee & light breakfast	
9:00	Introduction							
9:10	Mizobata	S1	9:00	Logerwell	S2	9:00	Hop	S3
9:35	Garron	S1	9:25	Planque	S2	9:45	Mueter	S3
10:00	Abe	S1	9:50	Baker	S2	10:10	Marsh	S3
10:25	Waga	S1	10:15	Haynie	S2	10:35	Coffee Break	
10:50	Coffee Break		10:40	Coffee Break		11:05	Laurel	S3
11:20	Saitoh	S1	11:10	Planque	S2	11:30	Logerwell	S3
11:45	Alabia	S1	10:50	Moore	S2	11:55	Priou	S3
12:10	Tibbles	S1	11:10	Hunt	S2	12:20	Levine	S3
12:35	Breed	S1	11:30	Haynie	S2			
13:00	Lunch (provided)		12:50	Lunch (provided)		12:45	Lunch (provided)	
	Workshop & Site Visit: Alaska Satellite Facility		14:00	Facilitated discussion: Arctic IEA	S2	14:00	Huserbråten	S3
						14:25	Bender	S3
14:00	Arko					14:50	Nickel	S3
						15:15	Bouchard	S3
15:30	Coffee Break		15:30	Coffee Break		15:40	Coffee Break	
15:45	Bus to site		16:00	Pilcher		16:10	Vestfals	S3
16:00	Tour		16:25	Azetsu-Scott		16:35	Forster	S3
			16:50	Rastrick				
17:00	Museum or trails		17:15	Misarti				
			18:30	Poster session & Reception		18:30	Group Dinner	

Monday, June 11

18:00 Welcome Reception (Garden Room)

Tuesday, June 12

08:30 ***Coffee and light breakfast***

09:00 Opening Remarks — ESSAS Co-Chairs Ken Drinkwater, Franz Mueter & Sei-Ichi Saitoh

Local arrangements and practical information

09:10 Session 1 — ***Novel applications of remote sensing in Subarctic and Arctic marine ecosystems***

Co-Chairs: Sei-Ichi Saitoh, Hajo Eicken, Taka Hirata

09:10 Kohei Mizobata, Yamamoto-Kawai, M. and Abe, M.: *Improved sea surface salinity in the Chukchi / Beaufort Seas using DINEOF*

09:35 Jessica Garron : *Remote-sensing techniques for oil spill detection under Arctic conditions*

10:00 Hiroto Abe, Sampei M., Hirawake T., Waga H., Nishino S., and Ooki A.: *Spring phytoplankton bloom and sediment resuspension in the Bering Strait*

10:25 Hisatoma Waga and Hirawake,T.: *Satellite-observed phenological shifts in phytoplankton community in the Pacific Arctic Region*

10:50 ***Coffee break (30 min)***

11:20 Sei-Ichi Saitoh, Alabia, I., Igarashi, H., Ishikawa, Y., Kamachi, M. and Imamura, Y.: *Practical procedure for potential fishing zone prediction of neon flying squid (*Ommastrephes bartramii*) in the north western North Pacific*

11:45 Irene Alabia, Jorge García Molinos, Sei-Ichi Saitoh, Takafumi Hirata, Toru Hirawake, and Franz J. Mueter: *Projected distribution and diversity patterns of marine taxa in the Pacific Arctic under future climate*

12:10 Marguerite Tibbles, Falke, J.A., Mahoney, A.R., Robards, M.D. and Seitz, A.C.: *An InSAR habitat suitability model to identify overwinter conditions for whitefishes in Arctic lagoons*

12:35 Greg Breed, Cory J. D. Matthews, Jack Orr, Jeff W. Higdon, Bernard LeBlanc, Stephen D. Petersen, Steven H. Ferguson: *Assessing non-consumptive effects of emerging predator regimes in warming Arctic marine ecosystems*

13:00 ***Lunch break (lunch provided)***

Tuesday Afternoon - Workshop and Site Visit: Alaska Satellite Facility

14:00 Scott Arko*: UAF's Alaska Satellite Facility - Data, Tools & Products*

15:30 ***Coffee break (15 min)***

15:45 Bus to Alaska Satellite Facility

16:00 Tour Alaska Satellite Facility

17:00 Option to visit Museum of the North (open until 19:00) or to explore UAF trails or facilities

Wednesday, June 13

08:30 ***Coffee and light breakfast***

09:00 Session 2 — ***Integrated Ecosystem Assessments (IEA) in the Subarctic and Arctic***

Co-Chairs: Libby Logerwell, Benjamin Planque, and Alan Haynie

09:00 Libby Logerwell: *Ecosystem Approach in the Arctic Council.*

09:25 Arneberg, P., van der Meeren, G. I., Benjamin Planque: *Data, concepts, models and management drivers in the ICES integrated assessment groups for the Norwegian and Barents Seas*

09:50 Matthew Baker, Edward Farley, Seth Danielson, Carol Ladd, Nils Christian Stenseth, Anne Husebekk, Jørgen Berge, Bob Lauth, Aleksey Somov: *Integrated Ecosystem Research in the Pacific-Arctic Interface*

10:15 Alan Haynie,:*Social and natural science integration in IEAs and large interdisciplinary marine science projects*

10:40 ***Coffee break (30 min)***

11:10 Benjamin Planque and Arneberg, P.: *'Letting the data speak' - misleading data exploration in IEAs.*

11:35 Sue Moore, Shuford, R., Gedamke, J., and Hatch, L.: *Including underwater sound in Arctic and Subarctic IEAs: an ecosystem component to link ecological, social, and economic factors in support of holistic decision-making*

12:00 George L. Hunt, Jr., Renner, M., Eisner, L., Kuletz, K., Salo, S., Ressler, P., Santora, J.A., and Ladd, C.: *Seabird abundance in a variable Bering Sea: long and short-term changes in density*

12:25 Alan Haynie, Faig, A., Holsman, K. K., Kasperski, S., and Hollowed, A.B: *Alaska Climate Integrated Modeling*

12:50 ***Lunch break (lunch provided)***

14:00 Facilitated discussion: Artic IEA

15:30 ***Coffee break (30 min)***

16:00 ***Contributed papers and paleoecology of Gadids***

16:00 Darren Pilcher, Naiman, D.M., Cross, J.N., Hermann, A.J., Siedlecki, S.A., Gibson, G.A., and Mathis, J.T.: *Impact of local biogeochemical processes and climate variability on ocean acidification in the Bering Sea*

16:25 Kumiko Azetsu-Scott and Punshon, S.: *Ocean Acidification in the Eastern Canadian Arctic*

16:50 Samuel S.P. Rastrick, H.E. Graham, K. Azetsu-Scott, P. Calosi, M. Chierici, A. Fransson, H. Hop, J. Hall-Spencer, M. Milazzo, P. Thor, T. Kutti *Using natural analogues to investigate the effects of climate change and ocean acidification on northern ecosystems*

17:15 Nicole Misarti, Lester Lembke-Jene, Jason Addison, Naomi Harada, Bruce Finney, Mark Shapely, Ben Fitzhugh, William Brown, Anne deVerna: *Integrating proxy-data of ocean productivity, sockeye salmon and human populations from the mid to late Holocene*

18:30 ***Poster Reception with no-host bar (Gazebo Room)***

Thursday, June 14

08:30 ***Coffee and light breakfast***

08:30 **Session 3 —** ***Biology and ecology of Arctic cods***
Co-Chairs: Franz Mueter, Benjamin Laurel, Caroline Bouchard, John Nelson, Brenda Norcross, Haakon Hop

09:00 Haakon Hop,: *Polar cod (*Boreogadus saida*) revisited in laboratories and the warming Arctic*

09:45 Franz Mueter and Flores, H.: *Current and future research on* Boreogadus saida

10:10 Jennifer Marsh and Mueter, F.: *Influences of temperature, predators and competitors on the southern distribution of Arctic cod (*Boreogadus saida*)*

10:35 ***Coffee break (30 min)***

11:05 Benjamin Laurel and Copeman, L.A.: *Size- and temperature-dependent overwintering success in age-0 juvenile polar cod (*Boreogadus saida*) and walleye pollock (*Gadus chalcogrammus*).*

11:30 Elizabeth Logerwell, Busby, M., Mier, K., Tabisola, H., and Duffy-Anderson, J.: *The effect of oceanographic variability on the distribution of Arctic cod of the Northern Bering and Chukchi Seas*

11:55 Pierre Priou, Chawarski, J., Berge, J., and Geoffroy, M.: *Arctic cod (*Boreogadus saida*) versus boreal fish species in the Barents Sea*

12:20 Robert Levine, Alex De Robertis, Christopher Wilson, Ed Farley, and Daniel Grünbaum: *Field Studies to Investigate the Fate of Juvenile Arctic Cod in the U.S. Continental Shelf Region of the Chukchi Sea*

12:45 ***Lunch break (lunch provided)***

14:00 Mats Huserbråten, Eriksen, E., Gjøsæter, H., Vikebø, F., and Albretsen. J.: *Polar cod at drift in the Barents Sea*

14:25 Morgan Bender, Gossa, J., Laurent, J., Teisrud, R., Jones, C., Frantzen, M., Hansen, B.H., Laurel, B., Meador, J., and Nahrgang, J.: *Effects of increased water temperature and water-soluble crude oil exposure on survival, growth, and feeding success of early life stages of polar cod (*Boreogadus saida*)*

14:50 Anja Nickel and Guðbjörg Ásta Ólafsdóttir: *Trophic interactions of 0-group Atlantic cod and saithe*

15:15 Caroline Bouchard, Ariane Aspirault, Dominique Robert, and Louis Fortier: *Eat BIG: the importance of* Calanus glacialis *for the feeding success of polar cod larvae*

15:40 ***Break (30 min)***

16:10 Cathleen Vestfals, Mueter, F.J., Hedstrom, K.S., Laurel, B.J., Petrik, C.M., Duffy-Anderson, J.T., Danielson, S.L., De Robertis, A., Curchitser, E.N.: *Gender specific reproductive strategies of an Arctic key species (*Boreogadus saida*) and implications of climate change*

16:35 Caitlin Forster, Brenda Norcross, and Franz Mueter: *Assessing spatial patterns of Arctic Cod (*Boreogadus saida*) abundance and distribution in the Chukchi and Beaufort seas*

17:00 ***Conference Wrap–Up***

18:30 ***Group Dinner at TBD***

Friday, June 15

09:00 ESSAS Scientific Steering Committee – Business Meeting (in Board Room)

Abstracts of Oral Presentations

Session 1, Tuesday, June 12

Novel applications of remote sensing in Subarctic and Arctic marine ecosystems

Improved sea surface salinity in the Chukchi / Beaufort Seas using DINEOF

Kohei Mizobata[1], Yamamoto-Kawai, M.[1] and Abe, M.[2]

[1]*Department of Ocean Sciences, Tokyo University of Marine Science and Technology, 4-5-7 Kounan, Minato-ku, Tokyo, JAPAN, mizobata@kaiyodai.ac.jp*
[2]*Graduate School of Fisheries Sciences, 3-1-1, Minato-cho, Hakodate, Hokkaido, JAPAN*

A new physical parameter as a satellite remote sensing product, sea surface salinity (SSS) is currently available. Based on the measurement principle, SSS in the cold area will have many uncertainties, and the validation effort is still needed, especially, in the Arctic Ocean. In this study, we examined Level-2 Aquarius/SAC-D SSS distributed by NSIDC, using in-situ thermosalinograph data obtained by R/V Mirai cruises in 2012 and 2013. There are three different resolutions according to the Beam. The comparison of SSS from each beam and in-situ SSS indicates that Beam 2 is best and somehow Beam 3 is better in the deep ocean. Then we reconstructed Aquarius SSS dataset using Beam 2 and Beam 3 only. After the reconstruction of SSS data, we improved it using the Data Interpolating Empirical Orthogonal Functions (e.g., Alvera-Azcarate, 2016). Original SSS and improved SSS show the error 1.2 psu and 0.7 psu, respectively. While the EOF 1st mode of SSS exhibits activity center over the Hanna Shoal and northern Bering Strait, the EOF 2nd mode of SSS indicates the band-like feature lying around 69oN. Basically, horizontal distribution of SSS depends on wind field. Also improved SSS clearly captured low salinity at the center of the Beaufort Gyre. In August and September in 2014, low salinity field was also observed off the Mackenzie River where high amount of ocean heat content was found during the CCGS Amundsen cruise, implying that salinity stratification will have an impact on effective warming of surface layer.

Remote-sensing Techniques for Oil Spill Detection under Arctic

Jessica Garron

University of Alaska Fairbanks, USA, jigarron@alaska.edu

Driven by decreased persistent Arctic sea-ice cover, increases in shipping, marine tourism, oil exploration and oil development activities, there is an increased likelihood for a marine oil spill in the Arctic. The challenges of detecting and responding to an Arctic marine oil spill are confounded during the winter months by a lack of sun, harsh weather and the presence of sea ice of variable thicknesses. Present oil spill detection methods range from satellite based monitoring, to direct human observation, with a functional middle-ground of remote-sensing technologies

rapidly evolving on a worldwide scale. This presentation will discuss current remote-sensing techniques and their limitations for detecting oil spills under Arctic conditions.

Spring phytoplankton bloom and sediment resuspension in the Bering Strait

Hiroto Abe[1], Sampei M.[1], Hirawake T.[1], Waga H.[1], Nishino S.[2], and Ooki A.[1]

[1] *Faculty of Fisheries Sciences, Hokkaido University, Japan, abe@fish.hokudai.ac.jp*
[2] *Institute of Arctic Climate and Environment Research, Japan Agency for Marine-Earth Science and Technology, Japan*

Bering Strait is one of the most biologically productive regions in the world. To deepen our understanding on biological process including phytoplankton bloom dynamics, time series observations in the Bering Strait are indispensable. This report presents preliminary result of our analysis based on satellite observations and in-situ mooring measurement conducted from 2016 to 2017. Analysis of Aqua/MODIS chlorophyll a concentration and AMSR2 sea ice concentration indicated occurrence of spring phytoplankton bloom at 130 – 135th day of 2017. This was seen when the sea ice concentration rapidly dropped from 50% to 0%, thus this can be regarded as ice edge bloom. This mid May bloom was one month earlier than normal year, which is consistent with the fact that rapid retreat of sea ice is observed in spring 2017. This bloom was also detected by moored chlorophyll fluorescence sensor at 50 m at 120 – 150th day of 2017, which would be the result of newly produced phytoplankton and organic matter sinking from the sea surface. In addition to this downward transport, mooring observation indicated the presence of the upward transport as well. Our time-series analysis showed that high turbidity events near the seafloor occurred through all seasons, which were triggered by strong barotropic currents with the speed of 50 cm s^{-1} – 100 cm s^{-1}. In response to these events, sediment-associated phytoplankton was released from the seafloor. The barotropic currents were driven/modulated by surface winds associated with an intercontinental atmospheric pattern with a 5000 km spatial scale at the time scale of 6 days. The phytoplankton and organic matter charged to the seafloor by spring phytoplankton bloom, are discharged from the seafloor by strong barotropic currents. This charge/discharge process, together with horizontal transport, would play an important role in sustaining biomass in/around the Bering Strait.

Satellite-observed phenological shifts in phytoplankton community in the Pacific Arctic Region

Hisatomo Waga and Hirawake,T.

Hokkaido University, Japan, waga@salmon.fish.hokudai.ac.jp

Phytoplankton blooms in the Pacific Arctic Region (PAR) has been characterized as a huge single bloom in spring when light availability is high, the mixed layer is shallow and nutrients are abundant due to winter deep mixing. However, several studies have reported that recent increases in occurrence of a relatively small but evident second bloom in fall when light availability is still relatively high and storm-driven mixing replenishes nutrients in the upper well-lit layer. Here we explored interannual variations in phytoplankton phenology in PAR by using satellite data, which enable us to derive not only biomass but also size structure of phytoplankton community. In this study, phenology of phytoplankton community was divided

into four types based on time-series chla variations from late spring to fall: second bloom (SB), probable second bloom (PSB), flat high (FH), and flat low (FL). The areas of SB and FL have significantly ($p < 0.05$) increased and decreased in northern PAR (67–70 °N) from 1998 to 2017, while those in northern PAR (62–65 °N) decreased and increased during the period, respectively. As size structure of phytoplankton community was large in SB than that of FL, the efficiency of biological pump in open water period would increase and decrease in northern and southern PAR owing to such phenological shifts in phytoplankton community. Our findings suggest that the spatiotemporal monitoring of phytoplankton community not only in spring bloom period but also after the period is important for understanding of variations in PAR, because even small changes in the phytoplankton community would have cascading effects on the higher trophic levels via the short and efficient energy pathways in this region. Overall, satellite monitoring of phytoplankton community could improve our understanding about processes of marine ecosystem variations which occurred and/or would occur in PAR.

Practical procedure for potential fishing zone prediction of neon flying squid (*Ommastrephes bartramii*) in the north western North Pacific

Sei-Ichi Saitoh[1], Alabia, I., Igarashi, H.[2], Ishikawa, Y.[2], Kamachi, M.[2] and Imamura, Y.[3]

[1] *Arctic Research Center, Hokkaido University, Hokkaido, Japan, ssaitoh@archokudai.ac.jp*
[2] *Data Research Center for Marine-Earth Sciences, Japan Agency for Marine Earth-Science and Technology (JAMSTEC), Kanagawa, Japan*
[3] *Aomori Prefectural Industrial Technology Research Center, Aomori, Japan.*

The neon flying squid (*Ommastrephes bartramii*) has a wide-spread distribution in subtropical and temperate waters in the North Pacific, which plays an important role in the pelagic ecosystem and is one of the major targets in Japanese squid fisheries. We have constructed a habitat suitability index (HSI) model for neon flying squid using the Japanese commercial fishery dataset collected in winter, January-March, during 2001-2011 and 4D-VAR ocean reanalysis data set MOVE. We employed maximum entropy (MaxEnt) as a habitat model. There were two oceanographic conditions, eddy develop and eddy non-develop, during 2001-2011. The predictive performance of models was evaluated based on area under the ROC curve (AUC) computed from independent data projections (January-March 2017, eddy develop year). Mean AUCs obtained for eddy year, non-eddy year, and overall year models, showed that eddy year model was highest. We propose a practical procedure to use synchronize the model for eddy year or non-eddy year. In the case of 2017, eddy year, in advance two months before fishing season, we can identify eddy develop or eddy non-develop, then we can advise fisher to decide to go to off Sanriku to catch neon flying squid, not to go to Japan Sea to catch common flying squid as fishing strategy. This practical procedure could be useful for economic catch planning and tactical fisheries activities management.

Projected distribution and diversity patterns of marine taxa in the Pacific Arctic under future climate

Irene D. Alabia[1], Jorge García Molinos, Sei-Ichi Saitoh, Takafumi Hirata, Toru Hirawake, and Franz J. Mueter

[1] *Arctic Research Center, Hokkaido University, Sapporo, Japan, irenealabia@arc.hokudai.ac.jp*

Future climatic changes are expected to impact species distributions and diversity patterns in marine ecosystems. Here, we investigated possible consequences of changes in habitat and diversity patterns of fish and invertebrate species due to ocean warming and sea ice loss in the Eastern Bering and Southern Chukchi seas, the climate-sensitive regions of the Pacific Arctic. Changes in current species-specific habitat patterns and biodiversity components (e.g. species richness and beta-diversity) were examined under two contrasting CMIP5 climate scenarios (RCPs 4.5 and 8.5). The ensemble models were developed using summer catch data (June-August) from NOAA bottom trawl surveys and several relevant environmental covariates (winter sea surface temperature, sea ice concentration, and depth). These models were then used for predicting species-specific habitat suitability across the study region under present-day and future climatic conditions. Results from these analyses will have clear implications for the management and conservation of marine resources under future climate change.

An InSAR habitat suitability model to identify overwinter conditions for whitefishes in Arctic lagoons

Marguerite Tibbles[1], Falke, J.A., Mahoney, A.R., Robards, M.D. and Seitz, A.C.

[1] *University of Alaska Fairbanks, USA, mtibbles2@alaska.edu*

Lagoons provide critical habitats for many fishes, including whitefishes, which are a mainstay in subsistence fisheries of Arctic Alaska rural communities. Despite their importance, little is known about the overwintering habits of whitefishes in Arctic Alaska due to the challenges associated with sampling during winter. We developed a habitat suitability (HS) model to understand the potential range of physical conditions that whitefishes experience during the Arctic winter, using three indicator lagoons that represent a range of environmental characteristics. The HS model was built using a three-step approach. First, interferometric synthetic aperture radar (InSAR) remote sensing identified areas of floating and bottomfast ice. Second, through in-field groundtruthing, we confirmed the a) presence, and b) quality of liquid water (water depth, salinity, and dissolved oxygen) beneath the ice. Third, we assessed the suitability of that liquid water as habitat for whitefishes, based on published literature and expert interpretation of water quality parameters. To groundtruth the HS model, we sampled the lagoons for fishes in March. InSAR determined that 0, 65.4, and 88.2 % of the three lagoons were composed of floating ice, corresponding with areas of liquid water beneath a layer of ice. The HS model indicated that all three lagoons had reduced suitability as whitefish habitat in winter as compared to summer due to loss of habitat from the presence of bottomfast ice and a reduction of liquid water quality due to cold temperatures, high salinities and low dissolved oxygen levels. However, only the shallowest lagoon had lethal conditions and zero suitability as whitefish habitat. The methods outlined here provide a simple, cost-effective method to allow stakeholders to identify lagoons that consistently provide winter whitefish habitat that are widely

used for subsistence as the Arctic faces an uncertain future with climate change and increased oil and gas exploration.

Assessing non-consumptive effects of emerging predator regimes in warming Arctic marine ecosystems

Greg Breed[1], Cory J. D. Matthews[2], Jack Orr[2], Jeff W. Higdon[3], Bernard LeBlanc[2], Stephen D. Petersen[4], Steven H. Ferguson[2]

[1] *University of Alaska Fairbanks, USA, gabreed@alaska.edu*
[2] *Fisheries and Oceans Canada*
[3] *Higdon Wildlife Consulting*
[4] *Assiniboine Park Zoo*

Predators are widely understood to impact the structure and stability of ecosystems. In the Arctic, summer sea ice is rapidly declining, degrading habitat for Arctic species such as polar bears and ringed seals, but also providing more access to important predators, such as killer whales. Using data from concurrently observed predators (killer whales) and prey (narwhal, bowhead whales) tracked by satellite in the Eastern Canadian Arctic, we show that the presence of killer whales significantly changes the behavior and distribution of narwhal. Similarly, the relationship between tracked bowhead whales and sea ice as observed by satellite is reversed in the presence of Arctic killer whales; bowheads prefer open water well away from the ice edge where there is no predation threat, but prefer dense sea ice when threatened by killer whales. Such non-consumptive predator effects of killer whales on iconic Arctic marine mammals may become a major impact of sea ice loss as the climate warms. Currently, the best approaches for assessing these effects rely heavily on satellite data of animal movement and environmental conditions analyzed with robust, relatively new statistical models of animal movement.

Session 2, Wednesday, June 13

Integrated Ecosystem Assessments in the Subarctic and Arctic

Ecosystem Approach in the Arctic Council

Elizabeth Logerwell

NOAA Alaska Fisheries Science Center, USA, libby.logerwell@noaa.gov

The Arctic Council is a high level intergovernmental forum to provide a means for promoting cooperation, coordination and interactions among the Arctic States, with the involvement of the Arctic Indigenous communities and other Arctic inhabitants. One of the Expert Groups of the Arctic Council is the “Ecosystem Approach (EA) Expert Group”. This Expert Group was formed in 2007 and is currently chaired by a Norwegian and a US scientist. This presentation will describe the goals of the Expert Group and the Arctic Council’s Framework/Guidelines for EA. Information on stakeholder interactions, products and future plans of the EG will also be presented. In addition, a joint Arctic Council/ICES/PICES project: the Working Group on Integrated Ecosystem Assessment of the Central Arctic Ocean (WGICA) will be described.

Data, concepts, models and management drivers in the ICES

Arneberg, P.[1], van der Meeren, G. I., and Benjamin Planque[1]

[1] *Institute of Marine Research, Norway, per.arneberg@hi.no*

Eight regional expert groups on integrated ecosystem assessment are currently operating in ICES. These groups were originally set up within a common framework devised by ICES, but they have operated in semi-autonomous fashion with region specific goals and approaches. We review here the approaches taken by the Barents Sea and Norwegian Sea expert groups. We describe how their activities have developed in the past and will possibly evolve in the coming years. The review focuses on the main concepts, data and models considered by these two groups and how the results of the work can respond to specific management objectives.

Integrated Ecosystem Research in the Pacific-Arctic Interface

Matthew Baker[1], Edward Farley, Seth Danielson, Carol Ladd, Nils Christian Stenseth, Anne Husebekk, Jørgen Berge, Bob Lauth, Aleksey Somov

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Integrated Ecosystem Assessments (IEAs) have emerged as an approach to integrate science and understand complex interactions. Data that inform these assessments are often collected through separate research surveys conducted at multiple temporal and spatial scales. While there are means to account for discontinuities of scale, research efforts are increasingly designed to leverage platforms and surveys and collect data that extend beyond the principle focus of the study. This allows for congruent comparison of data across various part of the ecosystem. Moreover, several large-scale efforts have been designed to deliberately integrate various scientific disciplines to study processes across ecosystem components (e.g., physics, biological production, fishes, humans) to better understand, linkages, interactions, and mechanisms that structure marine systems. Several large-scale efforts are planned or currently underway in the Arctic. In the Pacific Arctic, this includes the North Pacific Research Board Arctic Integrated Ecosystem Research Program (IERP, 2017-21) and NOAA Loss of Sea Ice (LOSI, 2010, 2017-2019). In the Atlantic Arctic, this includes the Nansen Legacy (2018−2023) and Arctic ABC coordinated by the Arctic University of Norway (UiT), Institute of Marine Research (IMR), and Scottish Association for Marine Science. Many other national (TINRO, KOPRI, JAMSTEC) efforts are active in the Arctic. NPRB and NOAA have initiatives to coordinate through the Pacific Arctic Group (PAG) and North Pacific Marine Science Organization (PICES). In particular, efforts are ongoing to integrate with Russian research initiatives, share data with Russian colleagues and host Russian scientists on cruises. Efforts are also underway to share findings and insights between the Pacific and Atlantic initiatives. In this talk, information on the research plans, objectives, and findings from recent cruises will be provided. Information on initiatives to share data, integrate analyses, synthesize findings, and promote comparative studies and inform management will also be detailed.

Social and natural science integration in IEAs and large interdisciplinary marine science projects

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Integrated Ecosystem Assessments (IEAs) attempt to capture and understand the diversity of interactions that occur within an ecosystem. While a core element of IEAs is the characterization of the natural ecosystem, humans are increasingly recognized as being part of the ecosystem, rather than an outside actor impacting the ecosystem. In this talk, we discuss the manner in which human activities are being incorporated into several IEAs. We discuss the current steps underway in Alaska and in the NOAA IEA Program and in ICES through the Strategic Initiative on the Human Dimension (SIHD) and within several ICES workgroups.

Additionally, we characterize lessons learned from a large interdisciplinary project, the Bering Sea Project, which combined the Bering Sea Ecosystem Study (BEST) and Bering Sea Integrated Ecosystem Research Program (BSIERP). We discuss the initial manner in which the economics elements of the Bering Sea Project were developed, challenges that arose, and how the economics components of the project evolved in light of changes and findings from other elements of the project. This experience provides a useful roadmap for how social and natural scientists can more effectively work together in IEAs and in interdisciplinary projects in general.

'Letting the data speak' - misleading data exploration in IEAs.

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Integrated Assessment Working Groups often devote large efforts in the compilation of physical and biological data over multidecadal time scales. These ecosystem time series serve as the basis for describing changes that have occurred in marine ecosystems.

These datasets are complex as they often contain a large number of variables that relate to very different ecosystem components or processes. A common practice is thus to summarise this complexity into few time series that reflect the variations shared by most ecosystem components. Multivariate methods, such as Principal Component Analysis (PCA), are a way to achieve this summary and to let complex data 'speak' to the observer.

Although each individual time-series may provide important information about the state of a marine ecosystem, we show here that the summary provided by PCA analyses can be uninformative or even misleading. We demonstrate this using four case studies in the Northeast Atlantic and a control study in which PCA is performed on independent time series of human and economic indicators worldwide. We conclude by advocating that integrated ecosystem assessments should prioritise model-based integration of complex ecological datasets focused on clearly defined research questions over explorative data summaries.

Including underwater sound in Arctic and Subarctic IEAs: an ecosystem component to link ecological, social, and economic factors in support of holistic decision-making

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Sound is a primary sensory modality for many aquatic organisms because it travels readily through water. With the dramatic reduction in sea ice and warming of Arctic and Subarctic seas, concern is growing regarding the impact of sound from anthropogenic activities on wildlife. This concern is especially focused on marine mammals, which are protected by US and international laws. Furthermore, Native communities rely upon marine mammals for subsistence and cultural wellbeing; a point recognized in the 2009 Arctic Marine Shipping Assessment. Although a key element of the marine environment, sound is not routinely included as a component in ecosystem assessments, due primarily to a lack of standardization in sampling protocols and soundscape metrics. However, increasing use of autonomous recorders has provided rich datasets on seasonal variability of sounds from natural (e.g. wind, sea ice, marine mammal calls) and anthropogenic (e.g. ships, sonars, seismic surveys) sources within high-latitude LMEs offshore the USA-Alaska, Canada, Greenland and Norway-Svalbard. In 2014, a passive acoustic data archive was initiated at NOAA's National Centers for Environmental

Information and, in 2016, sound was included as a core variable for the US Integrated Ocean Observing System. Concurrently, NOAA developed an Ocean Noise Strategy that recommended including acoustics as a fundamental habitat quality, part of a coherent approach to reducing the impacts of anthropogenic sounds on marine life. Integrated Ecosystem Assessments (IEA) provide a framework for an ecosystem-based approach to management of marine ecosystems. Including underwater sound in Arctic and Subarctic IEAs would provide a component to link ecological (ambient sound, marine mammal detection), social (connection to local communities, subsistence food security) and economic (shipping, resource extraction, tourism) factors. The science of underwater sound is now mature enough to warrant inclusion in ecosystem assessments, to underscore its role in marine ecosystems and support holistic decision-making.

Seabird abundance in a variable Bering Sea: long and short-term changes in density

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The long-term impacts of climate change are of immense concern. At present, we know little about the impacts of future climate states on marine ecosystems. However, examination of the impacts of present inter-annual to inter-decadal variability provides the possibility to assess how present-day ecosystems might react to long-term trends. Here we report how seabird densities over the southeastern Bering Sea responded to inter-annual variation in ocean-climate conditions by examining the densities of seabird species in years of early and late sea-ice-retreat. We predicted that, in years when prey resources were expected to be scarce, seabird densities would be lower. We also examined whether there had been a long-term change in the densities of seabird species. We used 40 years of surveys of the summer at-sea abundance of seabirds and recent data on the distribution of zooplankton and forage fish. In years with early sea-ice-retreat, the euphausiid *Thysanoesssa raschii* and the copepod *Calanus marshallae* were scarce and age-0 pollock (*Gadus chalcogrammus*) increased in availability in the upper water column of the middle shelf. We found substantial changes in the densities of seabird species between years with early and late sea-ice-retreat, with 29 of 35 species showing lower densities in years with early sea-ice-retreat. Likewise, significant changes in the densities of seabirds between 1975 and 2014 were observed, with declines in the density of 22 of 35 species, of which 6 showed significant declines. Our data support the notion that densities of many seabird species have declined and are likely to decline further with long-term warming.

Adaptive fisheries management under changing environmental and economic conditions in the Alaska Climate Integrated Modeling (ACLIM) Project

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The Alaska Climate Integrated Modeling (ACLIM) Project is a multidisciplinary effort to examine how different climate scenarios are likely to impact the Bering Sea ecosystem – and to ensure that our management system is ready for these potential changes. ACLIM integrates several climate scenarios and global climate models with a suite of biological models which include different levels of ecosystem complexity and sources of uncertainty. This talk describes the primary elements of ACLIM with an emphasis on coupling the project's bio-physical models with models of fisher behavior and management. The complexity of the economic models varies to match the scale of the biological models with which they are coupled.

We identify groups of economic and management factors that are the core drivers of fisheries. For management, there are many possible future policy choices, such as changes in target and bycatch species allocations or expanded spatial protective measures that can reduce the vulnerability of different stakeholders. Building on shared socioeconomic pathways (SSPs), we define the primary measures that have been shown to impact past fisher behavior in the Bering Sea and define a range of future economic changes and policy interactions under which we predict future integrated modeling outcomes. We demonstrate how different policy tools can have a large impact on how effectively we can adapt to environmental change and variation.

Wednesday, June 13 - Afternoon

Contributed papers and Paleoecology of Gadids

Impact of local biogeochemical processes and climate variability on ocean acidification in the Bering Sea

Darren Pilcher[1,2], Naiman, D.M.[1,3], Cross, J.N.[1], Hermann, A.J.[1,2], Siedlecki, S.A.[4], Gibson, G.A.[5], and Mathis, J.T.[6]

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The Bering Sea is highly vulnerable to OA due to naturally cold, low carbonate concentration waters. Expected negative impacts of OA to marine organisms therefore pose a significant threat to this highly productive marine ecosystem. However, harsh weather conditions within this rapidly changing environment hamper longterm observational monitoring. Well-validated biogeochemical models are a useful tool to help support observational efforts and provide skillful projections of OA on multiple timeframes. We add carbonate chemistry to a regional biogeochemical model of the Bering Sea to explore the underlying mechanisms driving carbon dynamics over a decadal hindcast (2003-2012). The results illustrate that local processes generate considerable spatial variability in the biogeochemistry and vulnerability to OA of Bering Sea shelf water. Substantial seasonal biological productivity maintains highly supersaturated carbonate saturation states (Ω) on the outer shelf, whereas freshwater runoff from major river systems with relatively corrosive water decrease Ω to values below 1 on the inner shelf. Over the model hindcast, annual surface Ω decreases by 0.1-0.3 units due to positive trends in ocean carbon concentration. Variability in this trend is driven by variability in primary productivity occurring during the transition from a relatively warm (2003-2005) to cold (2010-2012) temperature regime. Nonetheless, these trends in seawater chemistry are robust throughout most of the Bering Sea shelf, suggesting that the OA signal may be distinguishable from natural variability on decadal timeframes.

Ocean Acidification in the Eastern Canadian Arctic

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Spatial and temporal variability of the ocean acidification in the Eastern Canadian Arctic and controlling mechanisms are discussed. The Eastern Canadian Arctic is a key region connecting the high Arctic and the North Atlantic, includes the Canadian Arctic Archipelago (CAA), Baffin Bay, the Hudson Bay System and Davis Strait. The Arctic outflow through the CAA has a high content of Pacific Water with an inherently high CO_2 concentration, and is therefore more acidic, compared to the receiving Atlantic Water. The Pacific inflow to Chukchi Sea is further modified with fluvial input, sea ice meltwater, biological activity and uptake of atmospheric CO_2 during the transit through Beaufort Sea and Canada Basin, further increasing its acidity. These waters can be traced along western Baffin Bay to the south of Davis Strait. Temporal variation of the Arctic outflow along Baffin Island Shelf has shown a steady decrease in calcium carbonate saturation state for the past 20 years. In contrast to large-scale spatial and temporal variations, ocean acidification in fjords and coastal regions is strongly influenced by rivers with diverse watershed characteristics (for example, the Hudson Bay system), glacial meltwater and local biological activities, and is more variable in time and space

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

Samuel S.P. Rastrick, Helen E. Graham, Kumiko Azetsu-Scott, Piero Calosi, Melissa Chierici, Agneta Fransson, Haakon Hop, Jason Hall-Spencer, Marco Milazzo, Peter Thor, Tina Kutti

Northern oceans are in a state of rapid transition. Still, our knowledge on the likely effects of climate change and ocean acidification on key species in the polar food web, functionally important habitats and the structure of polar ecosystems is limited and based mainly on short-term single-species laboratory studies. Natural analogues to ocean acidification, such as CO_2 vents, have been used to further our knowledge on the sensitivity of biological systems to this global change driver. Thus, assess the capacity of different tropical and temperate species to show long-term acclimatisation and adaptation to elevated levels of pCO_2. Natural analogues have also provided the means to scale-up from single-species responses to community and ecosystem level responses. A range of Arctic and sub-Arctic sites, including CO_2 vents, methane cold seeps, estuaries, up-welling areas and polar fronts, that encompass gradients of pH, carbonate saturation state and alkalinity, are suggested for future high latitude, in-situ ocean acidification research. It is recommended that combinations of monitoring of the chemical oceanography, observational and experimental (in situ and laboratory) studies of organisms around these natural analogues be used to attain more accurate predictions of the impacts of ocean acidification and climate change on high latitude species and ecosystems.

Integrating proxy-data of ocean productivity, sockeye salmon and human populations from the mid to late Holocene

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Ocean and lake sediment cores from the subarctic NE Pacific Ocean provide the basis for our understanding of long-term fluctuations in both ocean primary productivity and sockeye salmon (*Oncorhynchus nerka*) abundance beyond the modern instrumental record. Sediments from multiple southwest Alaskan lakes yield proxy data on climate and salmon returns over the past 5,000 years, while ocean cores yield information on primary productivity, sea surface temperatures, and species dynamics of phytoplankton groups. Fluctuating numbers of returning sockeye salmon appear to correspond with large scale climate and oceanic change. They also appear to correlate with changes in past human population size on adjacent coastlines, even when the populations in question are not focused on salmon as their major resource. We hypothesize that changes in sockeye salmon stocks can be utilized as a proxy for subarctic NE Pacific upper trophic level productivity, suggesting that a connection exists between large-scale regional ecosystem dynamics and long-term natural climate variability, comprising several trophic levels from photoautotrophic primary producers to top predators (including humans) in the subarctic NE Pacific.

Session 3, Thursday, June 14

Biology and Ecology of Arctic Cods

Polar cod (*Boreogadus saida*) revisited in laboratories and the warming Arctic

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The polar cod has a key role in Arctic marine food webs with regard to channelling the energy flow from zooplankton to a variety of upper-trophic level predators. It is recognized as a keystone species, which implies that the removal of this species from the food web would destabilize the entire marine ecosystem and lead to further loss of other species. Keystone also implies that this species has a larger role than their abundance and biomass would suggest, although the key role of polar cod is based on their large biomasses distributed around the Arctic. Until recently, much of this biomass has been in the hiding below sea ice or in areas that are difficult to access, but recent studies have detected large concentrations of polar cod below sea ice in deep waters (Arctic Canada) as well close to the ice in the Arctic Ocean. Climate change in the Arctic threatens polar cod because of warming of their habitats, reductions in sea ice and increased competition from boreal fish species that have expanded into the Arctic. Multiple stressors from climate change (e.g. temperature, ocean acidification, hypoxia) and industrial development (oil exploration, contaminants) may potentially act synergistically on polar cod. Recent laboratory experiment on such stressors have provided novel insight into e.g. temperature-dependent growth, upper thermal limit and acclimation potential, and effects of crude oil on reproductive development and lipid metabolism. The polar cod has become the choice for Arctic fish experiments, most often performed in facilities outside the Arctic. Applications of lab results to polar cod in their natural habitats have limitations, although are still relevant. Recent field studies have included e.g. gender-specific reproductive strategies, growth patterns, feeding and trophic links, competition with boreal species, and climate-related changes in their distribution and habitats, including sea ice.

Current and future research on *Boreogadus saida* in the Central Arctic Ocean and surrounding shelf seas

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A negotiated agreement on the prevention of unregulated fishing in the Central Arctic Ocean (CAO) was reached in fall 2017 by the five Arctic Coastal States (Canada, Denmark

(Greenland), Norway, Russia, United States) and 5 other non-Arctic jurisdictions (China, Japan, Korea, European Union, and Iceland). The group agreed to not pursue commercial fishing in the High Arctic for 16 years and called for the development of a program to monitor and regulate potential fisheries that could develop in the CAO beyond national boundaries. Parallel to the diplomatic meetings, the Fish Stocks in the Central Arctic Ocean (FiSCAO) working group met to compile a CAO fish synthesis. The 5th FiSCAO workshop identified the need for mapping the distribution of species with a potential for future commercial harvests; understanding their life histories, trophic dynamics and population dynamics; and understanding the linkages between populations in the high seas CAO and adjacent shelf regions. Here we review some of the ongoing and planned efforts to study the distribution, abundance, and dynamics of *Boregadus saida* in the CAO and on the surrounding shelves, and the connections between shelf seas and the CAO.

Influences of temperature, predators and competitors on the southern distribution of Arctic cod (*Boreogadus saida*)

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

Size- and temperature-dependent overwintering success in age-0 juvenile polar cod (*Boreogadus saida*) and walleye pollock (*Gadus chalcogrammus*)

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Overwintering success is a poorly understood process for marine fish species, especially in ice-covered polar regions where fish are logistically difficult to sample. To address this knowledge gap, the NOAA Alaska Fisheries Science Center laboratory in Newport, OR recently expanded cold-water infrastructure and broodstock programs for key Alaskan gadids to examine physiological and behavioral impacts of overwintering stress. In this study, we investigated how summer growth (size) of juvenile fish differentially impacts the survival potential of two important species, Polar cod (*Boreogadus saida*) and walleye pollock (*Gadus chalcogrammus*), under varying winter thermal conditions (-1, 1, 3 or 5 °C). Within each thermal environment, larger juveniles of both species were able to survive longer, suggesting 'bigger is better' in the absence of food. However, polar cod were able to survive 4-5x longer at smaller sizes (<60 mm SL) than walleye pollock at temperatures ≤1 °C. These data suggest polar cod have adaptations (e.g., high lipid density and low-temperature physiology) that compensate for limited summer growth potential in the Arctic. In contrast, walleye pollock were less impacted by changes in overwintering temperature than polar cod, suggesting walleye pollock can occupy a more diverse range of overwintering habitats than polar cod, provided summer conditions are sufficient for high growth and lipid storage preceding winter onset. The complex interaction of summer growth potential and overwintering conditions in the first year of life are likely important mechanisms driving population dynamics and biogeography in these two cold-water marine species.

The effect of oceanographic variability on the distribution of Arctic cod of the Northern Bering and Chukchi Seas

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This work is part of the Arctic Ecosystem Integrated Survey (Arctic Eis) program which is a multi-disciplinary approach to document the state of the ecosystem through oceanography, plankton, and fisheries surveys. Surveys were conducted in the Chukchi and Northern Bering Seas from August to September 2012, 2013 and 2017. Oceanographic conditions were very different between the years. We investigated whether the distribution of Arctic cod pelagic larvae and benthic juveniles and adults reflected these differences. Arctic cod were associated with Anadyr/Bering Sea/Chukchi Sea Water and with Chukchi Winter Water. These water masses had moderate to high nutrient concentrations, elevated chlorophyll and relatively high zooplankton biomass, so we hypothesize that the result was favorable foraging for larval, juvenile and adult Arctic cod. Statistical models were developed to test these hypotheses and to examine the effects of interannual oceanographic variability. Our results increase the knowledge of the mechanistic links between oceanography and the life history of Arctic cod. Ocean processes such as advection and the formation and retreat of sea-ice have been and likely will continue to be impacted by climate change. Because growth and survival of early life stages of fish often drives population change, our results contribute to the understanding of the impacts of climate change on Arctic fish populations.

Arctic cod (*Boreogadus saida*) versus boreal fish species in the Barents Sea

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A shift in the northern range of boreal fish species has been identified as one of the most apparent consequences of climate change. In the European Arctic, north of Svalbard, acoustic-trawl surveys revealed that boreal species dominated the offshore pelagic fish assemblage up to 82°N. In particular, juvenile redfish *Sebastes mentella* represented up to 68 % of the biomass while Arctic cod (*Boreogadus saida*) only represented < 2 %. However, in other regions of the Barents Sea where boreal and Arctic fish co-occur, pelagic boreal species are not feeding during the polar night while Arctic cod actively forage at that time of the year. Hence, the potential for competition seems limited in winter. More knowledge is critically needed to properly assess the overlap of boreal and Arctic fish species. New broadband acoustic technology may provide critical improvements to our understanding of niche overlap of Arctic and boreal species. Promising new research suggests that species-specific frequency response can help distinguish these species during acoustic surveys in the North.

Field Studies to Investigate the Fate of Juvenile Arctic Cod in the U.S. Continental Shelf Region of the Chukchi Sea

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Acoustic-trawl (AT) surveys of Chukchi Sea during summers 2012 and 2013 determined that pelagic fishes were dominated by large numbers of age-0 Arctic cod (*Boreogadus saida*). These and other summer surveys suggested that few adults were present in the region. Thus, survivorship of age-0 fish is likely very low or they emigrate to other areas as they grow. To investigate the role of the Chukchi Sea as a nursery area for juvenile Arctic cod, an AT survey was conducted during August-September 2017 and another is planned for 2019 as part of the Arctic Integrated Ecosystem Research Project. One objective of the surveys is to determine whether the relatively large age-0 abundances observed in previous years is a characteristic feature of the Chukchi Sea. Another objective is to describe seasonal changes in abundance and track the movement patterns of individual Arctic cod to understand the fate of the juvenile fish observed in the summer surveys. We address this objective with three echosounder moorings, which were deployed in 2017 to make continuous acoustic measurements of the fish over two years (2017-2019). Additional work is planned to monitor inter- and intra-annual variability in juvenile Arctic cod abundance, by using autonomous sailing vehicles to conduct multiple acoustic surveys along transects from 67 to 72.5 °N across the Chukchi Sea U.S. continental shelf during a three-month period in late summer 2018. These vehicles will also survey the Beaufort shelf break and Barrow Canyon to examine connectivity between fish populations in the Chukchi and Beaufort Seas. Here, we present preliminary findings from the 2017 summer AT survey, and describe future work to quantify the distribution and movement of pelagic fishes in the Chukchi Sea

Polar cod at drift in the Barents Sea

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The polar cod (*Boreogadus saida*) is assumed to play a key role in the Arctic marine food web, being an important link between the lower and higher trophic levels. Although the main

spawning sites of polar cod in the Barents Sea is distributed in the south-west, a few studies have also suggested a Svalbard component of the Barents Sea polar cod population with spawning sites east of Svalbard–but due to the seasonal ice cover around the archipelago, spawning has never been observed directly. In this project we aimed to build knowledge about the spatial structure of polar cod populations in the Barents Sea. This was done by applying a particle trajectory model with release points (i.e spawning grounds) as suggested in the literature, and comparing the simulated drift end-points with observations of 0-group polar cod in the Barents Sea ecosystem survey in summer. In a pilot study running one year of simulations with release points around the Svalbard archipelago, the relative number of modelled drift end-points present around the sampling stations was significantly correlated with the observed abundance of 0-group polar cod (cor=0.35, z=4.31, p<0.001); which indicates a causal relationship between the hypothesised spawning areas and distribution of 0-group polar cod. The ocean model also facilitated a unique view of the physical conditions under the ice that could potentially be used to quantify vital rates of particles "in drift". Our next step will be to apply the same methods described above but to encompass all potential spawning grounds in Barents Sea over several spawning seasons (e.g. 1990-2016). This may give important answers to how the pelagic habitat of the early life-stages of polar cod has changed during recent warming, as well as look into the degree of mixing among the tentative eastern and western populations

Effects of increased water temperature and water-soluble crude oil exposure on survival, growth, and feeding success of early life stages of polar cod (*Boreogadus saida*)

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This study investigated the physiological sensitivity of early life stages of an Arctic key species, polar cod (*Boreogadus saida*), to changes in water temperature and crude oil exposure from fertilization to exogenous feeding. Wild polar cod were collected from Arctic waters east of Svalbard, Norway and strip-spawned in the laboratory during the onset of natural spawning in January 2018. Polar cod eggs were fertilized under two temperature regimes (0°C and 3°C). Fertilized eggs were then immediately exposed to four graded concentrations of water-soluble crude oil (0, 0.19, 0.75, 3 g crude oil / kg gravel corresponding to control, low, medium, and high oil exposure) through an oiled-rock column at their respective fertilization temperature. Samples for water chemistry, body burden, and lipid concentrations were taken prior to hatch while growth, development, respiration, and feeding success were followed in larvae from each incubator (4 incubators for each combination of crude oil concentration and temperature).

Preliminary data analysis indicated significant effects of temperature, oil exposure, and synergistic effects of both stressors. By 80 days post fertilization (dpf), fish held at 3°C exhibited reduced survival compared to those held at 0°C; furthermore, the fish in the high crude oil treatment at 3°C experienced increased mortality when compared to the 3°C control group. At hatch, the 3°C larvae were significantly smaller (peak hatch at 32 dpf) compared to the larvae held at 0°C (62 dpf). High and medium oil exposure groups for both temperature regimes had reduced growth and feeding. The results of this study illuminate the sensitivity of polar cod early life stages to minor changes in temperature and low concentrations of crude oil. These data add to our limited understanding regarding the impacts of large-scale climatic changes and small-scale pollution events such as oil spills on this endemic Arctic species.

Trophic interactions of 0-group Atlantic cod and saithe

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The settlement of juvenile fish from the pelagic to the shallow coastal waters is described as a critical stage during their ontogenetic shift, as growth in the first summer and fall may determine winter survival. After the settlement, juveniles of different species and size classes commonly share the same nursery grounds which can lead to inter- and intraspecific competition. Under a scenario of food limitation these competitive effects may effect growth, survival and ultimately year-class recruitment. The current study investigated the diet of 0-group Atlantic cod (*Gadus morhua*) and saithe (*Pollachius virens*) during the first six months after settlement. The fish were caught with a beach seine on a rocky shore in the North-West of Iceland during late summer and fall in 2015 and '16. Results from stomach content and stable isotope analysis revealed a high overlap in the trophic niche, indicating that both species are utilizing the same trophic resources. A clear shift in the diet of cod with increasing fish size and time reflect the settlement phase from the pelagic towards the benthic environment during September and October. The habitat choice for saithe, however, seemed to be driven by the size of the prey items. Thus, the prey size increased with increasing fish size, allowing the biggest individuals highest profitabilities in prey selection. The high trophic overlap during the settlement leads to a high potential for trophic interactions between Atlantic cod and saithe.

Eat BIG: the importance of Calanus glacialis for the feeding success of polar cod larvae

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We investigated the relationships between diet and feeding success in polar cod (*Boreogadus saida*) using 1797 larvae and juveniles 4.5 to 55.6 mm standard length collected from 1993 to

2014 in four arctic seas. Ingested prey were identified to the lowest possible taxonomical level, measured, and their carbon content was estimated using taxon-specific allometric equations. Feeding success was defined as the ratio of ingested carbon to larva weight. Larval polar cod fed mainly on *Calanus* spp. nauplii (prosome length 0.2-0.5 mm) and aquired the capacity to catch *Calanus glacialis* copepodites (prosome length 0.8-3.3 mm) at 9.6 mm. From that size up, feeding success was higher in individuals that had ingested one or more *Calanus glacialis* copepodite. For larvae < 15 mm, catching such a big prey is a relatively rare event (6.5% of larvae) but can represent a "jackpot" accounting for up to 80% of a stomach carbon content.

Identifying spawning and hatching locations of Arctic cod and saffron cod in the Pacific Arctic using individual-based, biophysical transport models

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Arctic cod (*Boreogadus saida*) and saffron cod (*Eleginus gracilis*) are the two most abundant and ecologically significant fish species in the Pacific Arctic, serving as an important food source for seabirds, marine mammals, and humans. Despite their importance, little is known about their life history in Alaska's Arctic, especially in regard to their early life stages (ELS), such as spawning locations, larval drift pathways, and nursery grounds. To help fill these critical knowledge gaps, we developed individual-based, biophysical transport models (TRACMASS) for each species coupled to a high-resolution ocean circulation model (PAROMS) to simulate larval growth and transport from hypothesized spawning and hatching locations in the northern Bering and Chukchi seas. Larvae were released at bi-weekly intervals during their respective peak hatching seasons and tracked until September 1st, after which their simulated distributions were compared to summer distributions of age-0 Arctic cod and saffron cod from acoustic-trawl (AT) surveys conducted during the 2012 and 2013 Arctic Ecosystem Integrated Surveys (Arctic Eis). Simulation results suggest that source populations for the Chukchi Sea likely originate from

the northern Bering and southern Chukchi seas, as larvae hatching from more southern locations attained the sizes and spatial distributions observed during the AT surveys, while those hatching from northern locations did not. Furthermore, we found variation between hatch dates and years, with substantially more larvae reaching the appropriate size and location when they hatched earlier in the season and in 2013 compared to 2012, which suggests larval growth and transport are sensitive to environmental forcing. This research provides new insight into potential spawning and hatching locations of Arctic cod and saffron cod and the transport of their ELS in Alaskan waters, and helps to improve our understanding of how their growth and dispersal may respond to variable climate forcing.

Assessing spatial patterns of Arctic Cod *(Boreogadus saida*) abundance and distribution in the Chukchi and Beaufort seas

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As a result of the challenges inherent in sampling the remote Arctic environment, most knowledge of Arctic species' life history is constrained to information collected from opportunistic research efforts. Arctic Cod (*Boreogadus saida*) warrants additional study because it is a key forage fish species and provides a critical energetic link between lower and upper trophic levels in this marine ecosystem. Spatially explicit studies synthesizing Arctic Cod distribution across a multitude of research efforts have not been conducted in the western portion of its range. The need for an initial characterization of the spatial distribution of Arctic Cod is particularly relevant given the 2009 actions of the North Pacific Fisheries Management Council (NPFMC), which closed the U.S. Arctic to commercial fishing until sufficient information is available to sustainably manage a fishery. We used spatial generalized additive models (GAM) to map the distribution of Arctic Cod by size class and relative to environmental variables. By compiling demersal trawl data from 22 research cruises conducted from 2004 – 2017 on the Chukchi and Beaufort seas shelves and investigating size-specific patterns in distribution, we hope to infer the movement ecology of Arctic Cod as they develop from juvenile to adult life stages. Preliminary results suggest modest population structure in the U.S. Beaufort Sea as well as some degree of spatial separation between juvenile and adult life stages. Characterization of this species' distribution not only contributes to general understanding of Arctic Cod life history in the Pacific Arctic, but is also an essential input for any future quantitative ecosystem modeling efforts in this region. An increasing human presence in the Arctic renders this analysis both timely and necessary for responsible decision making regarding this key Arctic fish species.

Abstracts of Poster Presentations

Assessment of biological and biogeochemical feedbacks to the surface ocean radiative heating in the Arctic ocean using satellite remote sensing

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Under the present climate change, atmospheric and ocean heating is a dominant process responsible to reduction of sea ice in the Arctic oceans, causing a positive feedback to the climate change. The heating itself is thermodynamic process, but it is directly associated, in the ocean, with not only physical property of seawater but also non-physical (or biological and biogeochemical) properties of water constituents such as photosynthetic organisms concentrations and the chromophoric dissolved organic matter (CDOM), via their ability to absorb the solar radiation penetrating underwater. Therefore, when the ocean heating induces variations in the sea ice coverage, sea surface temperature, sea water mixing and so on, subsequent changes of the biology (photosynthetic organisms) and biogeochemistry (CDOM), via ecological fluctuations if present, may (1) influence back to the radiative forcing/heating of the seawater through a change in their absorption of the solar radiation underwater (i.e. biogeochemical/biological feedback) and/or (2) alter relative contribution among physics, biogeochemistry and biology to the radiative heating of the ocean. The CDOM and phytoplankton are relatively rich in the high latitudes and coastal waters and over continental shelves, such as those in the Arctic. Using satellite remote sensing data obtained during the Arctic summer over a decade, we show the potential of the biogeochemical/biological feedbacks to the ocean radiative heating and how its mechanism has been fluctuated in the Arctic ocean over different time scales.

Temperature and food availability affect the growth, condition, and survival of larval Alaskan gadids

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Arctic cod (*Boreogadus saida*) is an ecologically significant species in polar food webs, forming a critical link between plankton and upper trophic levels including marine mammals, seabirds, and other fish which Arctic residents depend on. Arctic cod is uniquely adapted to occupy ice-edges, but shrinkage of sea-ice habitat could facilitate potential invasions by North Pacific gadids (e.g, walleye pollock. *Gadus chalcogrammus*). Both Arctic cod and walleye pollock co-occur in the North Bering and Chukchi Sea, but basic understanding of larval physiology is limited by widespread sea-ice cover. Laboratory experiments allow us to assess the sensitivity of these species to controlled environmental conditions which affect larval growth. Experimentally determined physiological rates can be used along with climate models to forecast species-

specific responses to predicted changes in temperature and food availability. These physiological rates will largely dictate the success of species and populations in the face of climate change. In the laboratory, we directly examined larval growth, survival and energetic condition of both gadid species in response to predicted variation in temperature (-1 to 12°C) and food availability (0.5 to 2 prey/mL). Larvae were cultured from eggs in the laboratory and two larval rearing experiments were carried out; one on first-feeding larvae and one for later stage larvae. Results indicate significantly different growth and survival responses between species across the experimental temperature range. Both first-feeding and later stage Arctic cod had higher growth potential at low temperature but survived across a narrower thermal range than walleye pollock, with extremely high mortality rates at temperatures > 5°C. Total lipids and lipid classes were measured using thin-layer chromatography with flame ionization detection (TLC-FID) in larvae at the end of each experimental trial. The triacylglycerol (storage lipid class) to sterol (membrane lipid class) ratio (TAG:ST) was used as an index of larval nutritional condition. An effect of prey density on the TAG:ST condition index of both species was evident at most temperatures, indicating a higher proportion of storage lipids in larvae receiving high food rations. Collectively, these results suggest that Arctic cod larvae are more sensitive to variation in spring temperatures and prey availability than walleye pollock, and consequently, may be more vulnerable to the forecasted warming and sea ice loss at the Pacific-Arctic interface.

Fishing pressure or environmental variability? Clues from size distribution of Pacific cod (*Gadus macrocephalus*) in the North Pacific Ocean over 6 millennia

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Fish size distributions are widely used to understand the role of harvesting and changing environmental conditions on fish population dynamics. In the North Pacific Ocean, contemporary size data are used in stock assessments to determine the health of the Pacific cod (*Gadus macrocephalus*) population and evaluate effects of commercial fishing. Zooarchaeological data are available that track cod size variability over thousands of years, recording the impacts of environmental variability, as well as possible anthropogenic forcing such as climate change and over-fishing. However, this broad measure - mean body size - masks variability across and within cod populations. In this paper, we compile estimates of cod size distributions based on zooarchaeological data and contemporary length-frequency data to look at size composition through time across the North Pacific from the Kuril Islands to Southeast Alaska. The results suggest that while cod length varies in both modern and ancient datasets across this region, this variability and overall cod length have been consistent for 6 ka.

Ontogenetic changes in the buoyancy and salinity tolerance of eggs and larvae of Arctic cod (*Boreogadus saida*) and other gadids

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Climate change in Arctic and subarctic seas is resulting in rapid ice melt and increasing river runoff. Associated salinity changes have the potential to affect the distribution and survival of eggs and larvae of key fish species, such as Arctic cod (*Boreogadus saida*) in the Chukchi Sea and walleye pollock (*Gadus chalcogrammus*) in the Eastern Bering Sea. We conducted a series of laboratory experiments to investigate how salinity impacted the buoyancy and survival of eggs and larvae in these and other gadids from Alaskan waters. Buoyancy of eggs and anaesthetized larvae was determined using a series of calibrated, temperature-controlled salinity gradient columns. Salinity tolerance (% survival) was determined at the larval stage following 48h exposures of cohorts to 0, 1, 2, 3, 5, ~32 (ambient seawater), and 35 ppt. Arctic cod egg density varied among family groups (batches), but eggs were more buoyant than those of walleye pollock overall. Ontogenetically, eggs of both species followed a typical pattern of increasing density early in development. However, Arctic cod eggs became more buoyant prior to hatching whereas walleye pollock continued to increase in density through the egg stage. After hatching, Arctic cod and walleye pollock larvae were similar in density and were notably more buoyant than the larvae of species with demersal eggs (saffron cod, *Eleginus gracilis* and Pacific cod, *Gadus macrocephalus*). Salinity tolerance also differed among species, largely driven by the higher tolerance of the two Arctic species (Arctic cod and saffron cod) to low salinities. These results highlight possible adaptations of Arctic cod to ensure that their eggs are positioned under ice (or near ice) after spawning so that larvae are timed to hatch in nutrient-rich surface waters as ice breaks up, often in regions with significant freshwater input.

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