ESSAS Report Series **Number 4**

Report of the

2009 ESSAS Annual Science Meeting

With Workshops on

Gadoid-Crustacean Interactions in Sub-Arctic Seas

Advection and Its Effects in Sub-Arctic Ecosystems

Comparisons of Approaches to End-to-End Modeling of Marine Ecosystems

And Updates on

Regional Climate Prediction

Bio-Physical Coupling

Modeling Ecosystem Response

Seattle, Washington, USA
18-19 June, 2009

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1.0 Background

The 2009 ESSAS Annual Science Meeting (ASM) was convened in Seattle, Washington, USA (18 – 19 June), and hosted by the School of Aquatic and Fisher y Sciences at the University of Washington. An annual meeting of the ESSAS Science Steering Committee (SSC) was held concurrently (June 17th and 20th). These meetings were scheduled in conjunction with the 3rd Global Ocean Ecosystem Dynamics (GLOBEC) Open Science Meeting which took place the following week in Victoria, BC, Canada (22 – 26 June). The ASM was opened with welcoming remarks from ESSAS Co-Chair, Professor George Hunt George (University of Washington). Seventy-one scientists from ten countries participated: Canada - 4; Denmark - 1; Faeroes – 1; Iceland - 1; Japan – 5; Korea – 2; New Zealand – 1; Norway – 6; USA – 50 (Appendix 1).

The meeting agenda (Appendix 2) was divided into three workshops to present ongoing research of ESSAS working groups, and reflected the goal of the ESSAS project — *to compare, quantify and predict the impact of climate variability on the productivity and sustainability of Sub-Arctic marine ecosystems* (Appendices 3-6).

Workshop 1 — "*Gadoid-Crustacean Interactions in Sub-Arctic Seas*" — was convened by Franz Mueter (University of Alaska, Fairbanks) and Earl Dawe (Fisheries and Oceans Canada), Co-Chairs of the newly established ESSAS working group on "Climate Effects on Upper Trophic Levels". This working group is undertaking comparative studies between different subarctic seas to elucidate the processes that lead to shifts between demersal fish, especially gadoids such as cod and pollock, and crustaceans, such as shrimp and crabs. The half-day workshop reviewed the dynamic processes that lead to shifts between demersal gadid fish (particularly cod and Pollock) and crustaceans such as shrimp and crabs. The workshop began with two keynote presentations: the first, by David Armstrong of the University of Washington, on crab dynamics with special emphasis on the Bering Sea stocks; the second, by Svein Sundby of the Institute of Marine Research, Bergen, on cod dynamics in the North Atlantic. These were followed by regional overviews of gadoid-crustacean dynamics, environmental conditions, and the effects of targeted fisheries for several ESSAS areas including the Oyashio, Bering Sea, Newfoundland and Labrador, West Greenland, Iceland and the Barents Sea.

Workshop 2 — "*Advection and Its Effects in Sub-Arctic Ecosystems*" — was convened by Ken Drinkwater (ESSAS Co-Chair) to examine the relative contribution of advection to temperature changes and biochemical processes in different Sub-Arctic ecosystems. . This workshop was a follow-up to one on advection held at last year's ESSAS meeting in Halifax, Canada. This year's workshop was conducted jointly with scientists from the Arctic Sub-Arctic Ocean Fluxes (ASOF) program and was used to explore possibilities for greater collaboration between ESSAS and ASOF in the future. Nine presentations were made on various aspects of transport and their effects, including the physical oceanographic dynamics of circulation patterns and flows.

Workshop 3 — "*Comparisons of Approaches to End-to-End Modeling of Marine Ecosystems"* — was convened by Co-Chairs Shin-ichi Ito (Tohoku National Fisheries Research Institute, Fisheries Research Agency, Japan), Bernard Megrey (National Oceanic and Atmospheric Administration, Alaska Fisheries Science Center, USA), and

Kenneth Rose (Louisiana State University, USA) of the ESSAS Working Group on “Modeling Ecosystem Response” to examine different approaches to the development of End-to-End fully integrated models of marine ecosystems.

In a separate session on day-two, updates on recent activities were given by all but the newest working group. Also, in the afternoon of day-two ESSAS working groups held closed sessions to discuss future directions and plan activities for 2010.

This ASM’s focus on planning future directions is particularly relevant in view of the unanimous decision made by the ESSAS Scientific Steering Committee to become a part of Integrated Marine Biochemistry and Ecosystem Research (IMBER) when its current parent organization — the Global Ocean Ecosystem Dynamics (GLOBEC) program — sunsets at the close of 2009.

2. Workshop Reports

2.1. Workshop 1

Effects of Climate Variability on Upper Trophic Levels

Conveners:
Earl Dawe[1] and Franz Mueter[2]
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[2] School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Juneau, AK

Rationale

The Working Group on Effects of Climate Variability on Upper Trophic Levels was formally accepted as an ESSAS working group in 2008. This followed an initial planning meeting on December 12, 2007 in Anchorage, Alaska with 7 participants from the eastern Bering Sea and Newfoundland-Labrador shelf. The goal of this working group is to assess the effects of ocean climate variation and fishing on the interactions between gadoid fishes and crustaceans by conducting a comparative study across multiple sub-arctic marine ecosystems. The primary working hypothesis is that gadoid fishes and crustaceans respond in opposite ways to variability in ocean climate and that such variation results in differences in productivity and abundance between gadoids and crustaceans.

The membership for ESSAS working group 4 (WG4) was finalized at the Sept. 2008 annual meeting in Halifax. At that time, plans were made to meet during the June 17-19, 2009 ESSAS annual meeting in Seattle to review available data, facilitate further data exchanges from all ecosystems, discuss methods and approaches to subsequent data analysis, and plan future activities, in particular the role of WG4 at the 2011 ESSAS Open Science Meeting (OSM). As the first full meeting of WG4, with all ecosystems represented, the Seattle workshop was intended to introduce the working group to the broader scientific community and to review the current state of knowledge regarding gadid-crustacean interactions in general as well as within each ecosystem.

Objective

The objective of the half-day workshop was to deliver a series of presentations that would collectively provide a thorough overview of the current state of knowledge on crustacean-gadid interactions, including effects of ocean climate variation and 'top-down' processes such as predation and fishing. These presentations would include perspectives from renowned gadid and crustacean researchers and specific overviews of each ESSAS sub-Arctic ecosystem by WG members.

Presentations

David Armstrong (School of Aquatic and Fisheries Science, University of Washington) was invited to present an overview of crustacean dynamics from the perspective of a crab researcher. He illustrated how studies of cod stomachs can provide information on the early life history of snow crab (*Chionecetes opilio*) in the eastern Bering Sea. Svein Sundby (Institute of Marine Science, Bergen, Norway) provided an invited perspective on Atlantic cod dynamics from an oceanographic perspective. He provided an overview of historical variability in both climate and cod populations and showed how early Atlantic cod (*Gadus morhua*) survival, and subsequent recruitment, is related to the advection of *Calanus finmarchicus* into the Barents Sea.

The invited talks were followed by five region-specific overviews. Yasunori Sakurai described abundance trends and biological information for Pacific cod (*Gadus macrocephalus*) and major crustacean stocks in Japanese waters. Fishery trends provided little evidence of top-down control by Pacific cod on shrimp and crab stocks in Japanese waters. Franz Mueter and Shareef Siddeek reviewed cod-crustacean interactions in the eastern Bering Sea and Gulf of Alaska. They showed large variability in crustacean stocks in both of these systems and a pronounced shift from a crustacean dominated community to a community dominated by gadids and other large predatory fishes following the well-documented 1976/77 climate regime shift. In the Gulf of Alaska, the available evidence suggests that both increased mortality from predation after the 76/77 regime shift and high fishing mortalities contributed to the collapse of shrimp and crab fisheries. In the eastern Bering Sea, large variability in abundance is driven by high variability in recruitment. While predation is an important component of mortality for young crab, the role of predation on stock fluctuations remains poorly understood. Earl Dawe reviewed cod-crustacean interactions on the Newfoundland-Labrador shelf, where there was a major shift in the fishery to crustaceans following the collapse of Atlantic cod and groundfish stocks in the early 1990's. He showed that abundance of snow crab is likely regulated primarily by the thermal regime during early life history, whereas processes controlling northern shrimp (*Pandalus borealis*) abundance are unclear. Kai Wieland described the ocean climate and interactions between Atlantic cod, northern shrimp and Greenland halibut (*Reinhardtius hippoglossoides*) at West Greenland. He concluded that a recent increase in northern shrimp biomass has resulted from favorable conditions for growth and survival of the juveniles due to enhanced plankton production rather than release from predation pressure. Olafur Astthorson described climatic influences on cod-northern shrimp interactions in the offshore waters north of Iceland. He concluded that reduced stock size of northern shrimp has been attributed to increased predation pressure by cod but could possibly be caused by reduced recruitment due to recent warming. Carsten Hvingel described shrimp-cod interactions in the Barents Sea. He concluded that inverse relationships between Atlantic cod and northern shrimp stock sizes were more likely due to opposing responses to environmental variation rather than the control of shrimp by predatory cod.

Outcomes

The workshop provided an overview of crustacean-gadid interactions and guidance for future comparative analyses across all ecosystems. For example, commonalities and differences across regions led to the idea that it might be useful to develop a framework of basing comparisons on groups that have common associations; for example shrimp-cod interactions that are positive vs. those that are negative. The workshop also highlighted that more attention must be paid to spatial processes within each region, in particular the spatial overlap between gadid and crustacean stocks. Moreover, the importance of diet data for gadids was emphasized by several speakers and in discussions. There was strong evidence from several systems that the availability of alternative prey, for example capelin, may have a large influence on gadid-crustacean interactions. The WG aims to prepare a review paper based on the workshop results.

Action Plan

The WG will continue compiling data, and a spreadsheet with the complete data series will be shared among working group members. It was agreed that we would first compile an inventory of available data before deciding which data series, and at what level of aggregation, can be used for meaningful analyses. As a basis for a review paper, the WG will compile a list of relevant literature including overviews of the oceanography of each system, overviews of the major gadid and crustacean fisheries, and key papers on the biology and dynamics of gadids and crustaceans in these systems. To clarify the importance of crustaceans in cod diets, we will attempt to estimate the "average" diet composition of cod from each region, which should include information on seasonal differences, inter-annual trends, and spatial differences to the extent feasible.

The WG agreed to organize a session on gadid-crustacean interactions for the 2010 annual meeting in Iceland. It was suggested that WG 4 sponsor a joint 1-day session with WG 5, a new working group (Jim Overland, chair) that will focus on issues including climate change and thresholds). We would also hold a half-day closed working session in parallel with other WGs).

Finally, we agreed to sponsor a session on gadid-crustacean interactions in subarctic seas for the 2011 ESSAS OSM. This may be a half-day session, but it will depend in large part on level of interest and number of contributions. Franz Mueter and Earl Dawe volunteered to co-chair the session.

2.2. Workshop 2

Advection and Its Effects in Sub-Arctic Ecosystems

Convener:
Ken Drinkwater
Institute of Marine Research, Bergen, Norway

The ESSAS Working Group on Bio-physical coupling convened a workshop on “Advection and Its Effects in Sub-Arctic Ecosystems” led by Ken Drinkwater (ESSAS Co-Chair). This was a follow-up workshop on advection to one held at last year’s ESSAS meeting in Halifax, Canada. This year’s workshop was conducted jointly with scientists from the Arctic Sub-Arctic Ocean Fluxes (ASOF) program and was being used to explore the possibility of greater collaboration between ESSAS and ASOF in the future. ASOF has been involved in the measurements of volume, heat, and salt exchanges between Arctic and Sub-Arctic regions over the last 5 plus years and recently published a book entitled on the results of their findings. ASOF is moving into phase two of their research program during which they wish to establish closer ties to the effects of these exchanges on the flora and fauna through collaboration with ESSAS.

A total of 9 presentations were made on various aspects of transport and their effects, 3 by ESSAS and 6 by ASOF. Dr. Phyllis Stabeno (USA, ASOF) described the general circulation patterns in the Bering Sea. The northward flows through the numerous passes between the Aluetian Islands are important sources of heat, salt and nutrients to the Bering Sea and Shelf. Currents between 1-3.5 ms^{-1} result in strong mixing in the passes and high chlorophyll concentrations, especially on the Bering Sea side of the passes. Once inside the Bering Sea, the surface flows tend to turn eastward towards and then along the Bering Slope. Cross-shelf advection of these waters occur through a number of processes including eddies and meanders along the slope, wind-induced advection, and the tides. These carry nutrients and zooplankton onto the shelf. She then described the role of advection on transporting eggs and larvae of snow crab, flatfish and Greenland halibut from their spawning sites towards their nursery areas. Dr. Rebecca Woodgate (USA, ASOF) then discussed the flows through the Bering Strait. Although relatively small, the Strait is very important as it connects the Bering Sea and the Arctic Ocean. The primarily northward flows dominate the oceanography of the Chukchi Sea, are an important source of Arctic nutrients, provide a third of the freshwater flux entering the Arctic, and are a significant source of oceanic heat. The variable flows through the strait are driven by a combination of sea level gradients, local winds and possibly other mechanisms. She also described recently deployed mooring array in the Strait as part of an International Polar Year project. Dr. Yugo Shimizu (Japan, ESSAS) described the role of advection in the transport large grazing copepods from the Oyashio area off Japan to the mixed water region (MWR) by the coastal Oyashio intrusion. The transport to the MWR was estimated to be $5.3x10^{11}$ g C over approximately 2 months. This transport of organic carbon is larger than the amount of large zooplankton consumed by Pacific saury, one of the dominant copepod predators in this region. Dr. Humio Mitsudera (Japan, ESSAS) then discussed overturning in the Sea of Okhotsk and the advection of iron into the Northwest Pacific. Dense bottom water is formed in the Sea due to brine rejection with the formation of sea ice. This is mixed by the winds and tides as it flows out in the North Pacific at depths between about 250-600 m. This flow carries with it high concentrations of iron, which when mixed into the surface layers, promotes high primary production. A numerical model of the processes has been developed that agrees reasonably well with the observations. Ms. Eleanor Williams (USA, ASOF) discussed the role of advection of low salinity waters off the West Greenland shelf on the initiation of primary production in the northeastern Labrador Sea. Using an autonomous underwater vehicle equipped with hydrographic — bio-optical and oxygen sensors, high temporal and spatial resolution observations were described in two separate blooms, one in the central Labrador Sea and one to the north. Dr. Peter Rhines (USA, ASOF) discussed the variability in the subpolar gyre in the North Atlantic. He first discussed some of the new technologies used by ASOF scientists to measure the water properties and flows between the Arctic and the sub-Arctic such as profiling moorings, ice-capable shelf moorings, autonomous gliders, the global ARGO float program. He also noted that the future of ASOF will include significant interaction with broad ecosystem research, and with focused biological programs. In regards to the subpolar gyre, mixing and circulation driven by winds and wintertime cooling at the sea-surface, i.e. deep-water convection, play major roles in both water-mass transformation and the gyre circulation. The NAO also plays a role. Models of the gyre circulation were discussed, including their present problems including under-representation of the dense northern overflow waters. Dr. Hjalmar Hatun (Faroe Islands, ASOF) discussed the role of subpolar variability on blue whiting distributions and recruitment. As the subpolar gyre becomes weaker, the transition zone between the subarctic and subtropical water masses shifts. When the subpolar gyre is strong and spreads cold and fresh water masses east, the spawning of blue whiting is constrained along the European continental slope and in a southerly position near the Porcupine Bank. When the gyre is weak and conditions are relatively saline and warm, the spawning distribution moves northwards along the slope and especially westwards covering the Rockall Plateau. Dr. Craig Lee (USA, ASOF) described the 2008 North Atlantic Spring Bloom Experiment that employed a system of drifting floats, mobile gliders and ship-based measurements to resolve patch-scale physical and biological variability over the 3- month course of an entire bloom. The experiment site was southeast of Iceland in a region of swift, heterogeneous velocities. Measurements indicated energetic small-scale exchange process (such as vertical or lateral mixing) and fast-acting biological processes. In mid-April, a period of calm weather, rapid re-stratification and exponentially growing chlorophyll fluorescence marked the start of a bloom. Although diapycnal mixing and solar warming clearly played roles in producing the spring bloom, the rate and vertical extent of upper ocean re-stratification indicate that lateral mixing was more important role in re-stratifying the upper ocean. Harald Loeng (Norway, ESSAS) discussed the exchanges with the Arctic in the Barents Sea. Current measurements have been carried out at the western entrance to the Barents Sea since 1997. Atlantic inflow occupies most of the section but with large variability driven mainly by local winds. Most of the Atlantic Water flowing through the Barents Sea reaches the Arctic Ocean.

Following the presentations, a discussion of potential future collaborations between ESSAS and ASOF was held. Possibilities included: the use of biological sensors on ASOF moorings; the calculation of biological fluxes using ASOF transportation estimates; the development of joint proposals for new field research aimed at determining the processes through which advection influences the biota; and cooperative modeling studies. These possibilities will be explored further during the coming year.

2.3. Workshop 3

Comparisons of Approaches to End-to-End Modeling of Marine Ecosystems

Conveners
Shin-ichi Ito[1], Bernard Megrey[2], and Kenny Rose[3]
[1]Fisheries Oceanography Division, Hokkaido University, Japan

[2]NOAA Alaska Fisheries Center, USA
[3]Louisiana State University, USA

This workshop was convened by the ESSAS Working Group on Modeling Ecosystem Response to discuss development of different end-to-end models and explore ways to compare and contrast them. Presentations were given on three different types of end-to-end models:

1. The first was on a model for the Bering Sea called FEAST (Forage and Euphausiid Abundance in Space and Time) that is an upper trophic level model, including zooplankton and fish, and connects to a lower trophic model. It also will provide input to a fisheries and economic model.

2. The second model is being developed by the ESSAS Modeling Working Group in conjunction with others. They are designing and constructing a fully integrated, biophysical ecosystem model that will be coupled to a hydrodynamic model using the Regional Ocean Model System (ROMS), include biogeochemical cycles that support biological production (nutrient dynamics) and primary/secondary production using multiple functional groups (NPZ) and a spatially explicit, individual-based model to represent upper tropic level (UTL) functional groups, which initially will be fish but could be extended to include birds and marine mammals.

3. The third model is ATLANTIS, an end-to-end model developed in Australia by Dr. Beth Fulton. This model includes physics to fish as well as fisheries and economics. It has been applied throughout Australia and in several locations around the world. ESSAS was informed about the use of ATLANTIS in the California Current and its use to explore different fisheries management scenarios. A second presentation was made on the development of an ATLANTIS model for the Barents Sea, what it will be used for and the challenges in implementing it.

   Finally, a presentation was given on minimal ecosystem models to remind us that sometimes simple models may be the best way to go to answer some fishery questions. The presentations were followed by a lively debate on various aspects of ecosystem modeling and how to carry out comparative modeling studies.

3.0 Working Group Updates

3.1 Regional Climate Prediction (WG-1)

Climate Forcing of Marine Ecosystems

James E. Overland
NOAA Pacific Marine Environmental Laboratory, USA

Dr. Overland updated ASM participants on activities of the ESSAS Working Group on Regional Climate Prediction. He described large-scale climate variability for several marine ecosystems and suggested types of ecosystem responses to climate change. Analyses of observations and model results for the Pacific and Atlantic Oceans support the conclusion that most regional climate variability is accounted for by the combination of intermittent 1–2 year duration events, e.g. the cumulative effect of monthly weather anomalies or the more organized El Niño/La Niña, plus broad-band "red noise" intrinsic variability operating at decadal and longer timescales. While ocean processes such as heat storage and lags due to ocean circulation provide some multi-year memory to the climate system, basic understanding of the mechanisms resulting in observed large decadal variability is lacking, and forces the adoption of a "stochastic or red noise" conceptual model of low frequency variability at the present time. Thus, it was concluded that decadal events with rapid shifts and major departures from climatic means will occur, but their timing cannot be forecast.

The responses to climate by biological systems are diverse in character because intervening processes introduce a variety of amplifications, time lags, feedbacks, and non-linearities. Decadal ecosystem variability can involve a variety of climate to ecosystem transfer functions. These can be expected to convert red noise of the physical system to redder (lower frequency) noise of the biological response, but can also convert climatic red noise to more abrupt and discontinuous biological shifts, transient climatic disturbance to prolonged ecosystem recovery, and perhaps transient disturbance to sustained ecosystem regimes. All of these ecosystem response characteristics are likely to be active for at least some locations and time periods, leading to a mix of slow fluctuations, prolonged trends, and step-like changes in ecosystems and fish populations in response to climate change.

Climate variables such as temperatures and winds can have strong tele-connections (large spatial covariance) within individual ocean basins. However, between-basin tele-connections, and potential climate-driven biological synchrony over several decades, are usually much weaker, and they are a highly intermittent function of the conditions prevailing at the time within the adjoining basins. As noted in the recent IPCC 4th Assessment Report, a warming trend of ocean surface layers and loss of regional sea ice is likely before 2030, due to addition of greenhouse gases. Combined with large continuing natural climate variability, this will stress ecosystems in ways that they have not encountered for at least 100s of years.

Jim Overland (USA), Chair of the ESSAS Working Group on Regional Climate Prediction, presented the final report of this working group, which was charged with exploring which of the IPCC Global Circulation Models (GCMs) would be most useful to downscale to regional models of the Sub-Arctic seas. Based on well the GCMs performed in hind-casting recent climate, a list of GCMs was published for several subarctic seas with the selected GCMs differing between regional seas (Overland and Wang, 2008). It was also suggested that several GCMs should be used when downscaling to regional models. A "best practices" manual for downscaling is also being written. Following the report, Dr. Mike Wallace of the University of Washington gave an open lecture entitled "Global Modes of Climate Variability on Regional Ecosystems". The global modes he discussed included the Northern and Southern Annular Modes that are centered over the Arctic and Antarctic, respectively, as well as the El Nino-Southern Oscillation (ENSO) and the Pacific-North America (PNA) mode. These modes were shown to be strongest in winter and impact regional coastal systems such as the subarctic season annual time scales and longer through their effects on winds, precipitation and temperature patterns.

Impacts of Global Modes of Climate Variability on Regional Ecosystems

Professor John Michael Wallace
Atmospheric Sciences, University of Washington, USA

Professor Wallace shared his insights on global climate and how its year-to-year and decade-to-decade variations impact regional ecosystems. He posed a series of questions asking: 1) Do global modes exist? 2) If so, how many? 3) What are they? and 4) Do they impact regional ecosystems?. His research making use of observational data has contributed to the identification and understanding of a number of atmospheric phenomena, including the vertically propagating planetary waves that drive the quasi-biennial oscillation in zonal winds in the equatorial stratosphere, the 4-5-day period easterly waves that modulate daily rainfall over the tropical oceans, and the dominant spatial patterns in month-to-month and year-to-year climate variability, including the one through which the El Nino phenomenon in the tropical Pacific influences climate over North America. Research findings have contributed to documenting the existence of El Nino-like variability on a decade to decade time scale (the so called 'Pacific Decadal Oscillation'). He also described current investigations of two analogous patterns of weather and climate variability: the Northern and Southern Hemisphere 'annular modes' which have played a prominent role in the climatic trends of the past 30 years. Professor Wallace concluded his presentation by saying that global modes of climate variability do exist, primarily during winter. These global modes include: the North Atlantic Oscillation/Arctic Oscillation/Northern Annular Mode (NAO/AO/NAM); Pacific North America (PNA); the El Niño–Southern Oscillation (ENSO); and the South American Monsoon / Antarctic Oscillation (SAM/AAO). These global modes impact coastal regional systems during winter on annual time scales, and on longer time scales when they project on “ad hoc” patterns.

3.2 Bio-Physical Coupling (WG-2)

Professor George Hunt (Chair)
Aquatic & Fishery Sciences, University of Washington, USA

George Hunt provided an update on work initiated at annual ESSAS meetings in Hakodate, Japan during 2007 on biological hotspots in sub-Arctic seas, i.e. areas of high biomass concentrations. George is leading development of a paper on where biological hotspots are located and the physical/biological processes that determine them. He reported that the paper is underway and should be completed by next year’s meeting. Dr. Mike Sigler (USA) then presented a paper on forge fish hotspots in the southeastern Bering Sea and their influence on Stellar Sea Lions. He showed that geographical persistence of the prey may be just as important as density of prey aggregations to predators; particularly for predators that do not have the ability to search large areas efficiently.

Persistence of forage fish ‘hot spots’ and its association with foraging Steller sea lions in southeast Alaska (Eumetopias jubatus) in southeast Alaska

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Whereas primary and secondary productivity at oceanic ‘hotspots’ may be a function of upwelling and temperature fronts, the aggregation of higher-order vertebrates is a function of their ability to search for and locate these areas. Thus, understanding how predators aggregate at these productive foraging areas is germane to the study of oceanic hot spots. We examined the spatial distribution of forage fish in southeast Alaska for three years to better understand Steller sea lion (Eumetopias jubatus) aggregations and foraging behavior. Energy densities (millions KJ/km2) of forage fish were orders of magnitude greater during the winter months (November–February), due to the presence of schools of overwintering Pacific herring (Clupea pallasi). Within the winter months, herring consistently aggregated at a few areas, and these areas persisted throughout the season and among years. Thus, our study area was characterized by seasonally variable, highly abundant but highly patchily distributed forage fish hot spots. More importantly, the persistence of these forage fish hot spots was an important characteristic in determining whether foraging sea lions utilized them. Over 40% of the variation in the distribution of sea lions on our surveys was explained by the persistence of forage fish hot spots. Using a simple spatial model, we demonstrate that when the density of these hot spots is low, effort necessary to locate these spots is minimized when those spots persist through time. In contrast, under similar prey densities but lower persistence, effort increases dramatically. Thus an important characteristic of pelagic hot spots is their persistence, allowing predators to predict their locations and concentrate search efforts accordingly.

3.3 Modeling Ecosystem Responses (WG-3)

A regional ecosystem modeling inter-comparison project

Masahiko Fujii (Invited)
Associate professor, Graduate School of Environmental Science
Hokkaido University, Japan

Dr. Fujii described ongoing disputes about the needed level of complexity in ecosystem models, and the need to strike a balance between unwanted detail and unjustified simplification in models. He detailed the experimental design used in comparisons of simple and complex ecosystem model that were carried out to determine how much complexity is warranted. Results indicated that models with greater phytoplankton complexity were generally more portable (and realistic). Complex models did not necessarily outperform simple models with regards to zooplankton dynamics. The implication is that both simple and complex models can fit data similarly well, but do so via very different element-flow pathways. This highlights the need for more comprehensive data sets that uniquely constrain pathways of observable rates (e.g. phytoplankton nutrient uptake rates, zooplankton grazing rates) as well as bulk concentrations (e.g. Chl. and nutrients).

Appendix 1:

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Appendix 2:

Agenda / Schedule of Activities

ESSAS

Annual Science Meeting

18 - 19 June 2009

University of Washington
Fisheries Science Building
1122 NE Boat Street
Auditorium, Room 102
Seattle, WA, USA

DRAFT AGENDA

Thursday 18 June

08:00: Registration

08:20: Welcome from George Hunt (ESSAS Co-Chair, USA)

Workshop 1
Gadoid-Crustacean Interactions in Sub-Arctic Seas
(Conveners: Franz Mueter & Earl Dawe, Workgroup Co-Chairs)

08:30 David Armstrong (Invited, USA)
General overview of crab dynamics
09:00 Svein Sundby (Invited, Norway)
General overview of cod dynamics

Regional Overviews
09:30 Yasunori Sakurai (Japan)
Abundance trends and biological information of Pacific cod and major crustacean stocks in Japanese waters

09:50 Siddeek Shareef (USA) / Franz Mueter (USA)
Gadid-crustacean interactions in the Eastern Bering Sea and Gulf of Alaska

10:10 ***Break***

10:30 Earl Dawe (Canada) / Don Stansbury (Canada)
Cod-crustacean interactions on the Newfoundland-Labrador Shelf

10:50: Kai Wieland (Denmark), Kaj Suenksen (Greenland), and Nikoline Ziemer (Greenland)
Ocean climate and interaction between Atlantic cod, Northern shrimp and Greenland halibut West Greenland
11:10 Olafur Astthorsson (Iceland)
Climatic influences on cod-northern shrimp interactions in the offshore waters north of Iceland
11:30 Carsten Hvingel (Norway)
Shrimp-cod interactions in the Barents Sea – an example of ecosystem complexity"
11:50 Synopsis / Discussion

Lead by Franz Mueter & Earl Dawe (Conveners / Workgroup Co-Chairs)

12:10 ***Lunch***

Workshop 2
Advection and Its Effects in Sub-Arctic Ecosystems
(Convener: Ken Drinkwater, ESSAS Co-Chair)

13:30 Introduction: Ken Drinkwater
The Role of Advection in Sub-Arctic Ecosystems
13:40 Phyllis Stabeno (Invited, USA)
Effects of *Advection in the Bering Sea*
14:00 Rebecca Woodgate (Invited, USA)
Flow through the Bering Strait
14:20 Yugo Shimizu (Invited, Japan)
Transport of subarctic large copepods from the Oyashio area to the mixed water region by the coastal Oyashio intrusion
14:40 Humio Mitsudera (Invited, Japan)
Overturning circulation in the Sea of Okhotsk and the western North Pacific and its potential impacts on biogeochemical processes

15:00 ***Break***

15:30 Eleanor Williams (Invited, USA)
Advection off the West Greenland Shelf and Its Effect on Bloom Dynamics in the Labrador Sea
15:50 Peter Rhines (Invited, USA)
Variability in the Sub-Polar Gyre
16:10 Hjálmar Hátún (Invited, Faroes)
Sub-polar Gyre Variability and Its Effects on Blue Whiting
16:30 Craig Lee (Invited, USA)
Atlantic Bloom Experiment South of Iceland
16:50 Harald Loeng (Invited, Norway)
Exchanges between the Barents Sea and the Arctic
17:10 Discussion of ASOF-ESSAS Cooperation

18:00 ***Adjourn***

19:00 ***Banquet at Ivar's Salmon House***

<u>Friday 19 June</u>

Updates

ESSAS Working Group 1 — Regional Climate Prediction
08:00 James Overland (Chair, USA)
Climate Forcing of Marine Ecosystems
08:15 Mike Wallace (Invited, USA)
A Conceptual Model of Climate Variability (AO/PNA and other indices)*

ESSAS Working Group 2 — Bio-Physical Coupling
09:00 George Hunt (Chair, USA)
Hotspots and Thresholds

09:10 Mike Sigler (Invited, USA)
Persistence of forage fish 'hot spots' and their importance to foraging Steller sea lions in southeast Alaska

ESSAS Working Group 3 — Modeling Ecosystem Response

09:30 Masahiko Fujii (Invited, Japan)
A regional ecosystem modeling inter-comparison project

Workshop 3

09:50 ***Comparisons of Approaches to End-to-End Modeling of Marine Ecosystems***
(Conveners: Bernard Megrey, Kenneth Rose, and Shin-Ichi Ito)

10:00 Ivonne Ortiz (Invited, USA)
FEAST: Zooplankton to top predator dynamics on a fine scale in the Eastern Bering Sea

10:20 ***Break***

10:40 Enrique Curchister (USA)
End-to-end Marine Ecosystem Models: Strategies, Applications, and Future Directions
11:00 Isaac Kaplan (Invited, USA)
ATLANTIS Modeling in the California Current Ecosystem
11:20 Erik Olsen (Invited, Norway)
ATLANTIS Modeling in Norway
11:40 Kenneth A. Rose (USA)
End-to-End: Can the people and biology keep up with the computers?
12:00 Tim Essington (Invited, USA)
Minimal models for understanding ecosystems: How many parameters are too many?

12:20 ***Lunch***

13:50 Round Table Discussion on End-to-End Approaches to Ecosystem Modeling

15:00 ***Break***

15:30 Working Group Closed Sessions — Future Directions, Planning Activities, Etc.

18:00 ***Adjourn***

Appendix 3:

Extended Abstracts

Workshop 1
Gadoid-Crustacean Interactions in Sub-Arctic Seas

Conveners: Earl Dawe[1] and Franz Mueter[2]
[1]Department of Fisheries and Oceans, Northwest Atlantic Fisheries Centre in St. John's, Newfoundland
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General overview of crab dynamics

Immature snow crab in the eastern Bering Sea: learning from predatory cod

David A. Armstrong[1], Julián Burgos[1], Billy Ernst[2], Pat Livingston[3] and J.M. (Lobo) Orensanz[4]
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The snow crab (*Chionoecetes opilio*) fishery from the eastern Bering Sea (EBS) shelf, which has been in the past one of the largest and most lucrative crab fisheries in the world, is illustrative of problems faced by many high-latitude fisheries affected by climatic change (Perry et al., 2005). Over the last two decades landings have declined dramatically, from a maximum of nearly 150,000 metric tons in 1991 to historical lows on the order of 12,000 metric tons in 2000 (Armstrong et al, in review). The EBS snow crab stock was declared “overfished” in 1999 because the survey estimate of mature biomass was below the minimum stock size threshold. A rebuilding plan was implemented in 2000; model estimates of the biomass of commercial size males continued to decline through 2003, then increased after 2006 (NPFMC, 2007)

Compared to the situation three decades earlier, the current geographic range of the snow crab spawning female stock has contracted dramatically to the north (Zheng et al., 2001), presumably in relation with warming of the EBS during the late 1970s. This phenomenon has been addressed by the Environmental Ratchet Hypothesis (ERH) (Orensanz et al., 2004), a conjecture claiming that the contraction is a process difficult to reverse, resulting from a combination of circulation patterns, the spatial dynamics of benthic stages in relation to near-bottom temperature (NBT), and fish (mostly cod, *Gadus macrocephalus*) predation.

The contraction of the reproductive female stock has been punctuated by four pulses in the strength of recruitment of primipara (first time breeders) to the female reproductive pool, with core years in 1981, 1987, 1994 and 2001 (Orensanz et al., 2007; Parada et al.,

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in press). Remarkably, the pulses were approximately seven-years apart, that period matching the average age at maturity of an individual female between egg extrusion by her mother and terminal molt. That correspondence suggests dynamic linkage between the pulses, with each one in the sequence becoming the parental stock for the subsequent (Parada et al, in press).

One major problem in the elucidation of this intriguing dynamics has been the virtual absence of extensive information on the early years of snow crab life history in the EBS. Summer trawl surveys capture few crabs smaller than 30 mm in carapace width (CW), which have settled years earlier. Information retrievable from cod stomach contents may provide a window into earlier benthic life history stages. The Food Habits Sampling Program (Livingston, 1989; Livingston et al., 1993; Lang et al., 2006), conducted as part of the NMFS summer survey, started in 1984. Additional information was obtained as part of the observer program, but these were excluded from the analyses because spatial and temporal coverage is too patchy for our purposes. As of November 2007, the database contained information on 44,412 cod stomachs. Of these, 5,958 cod stomachs contained 18,511 snow crabs. For consistency we utilized only data collected in the course of the surveys during June and July.

The use of cod stomach contents has some obvious limitations: [i] geographical coverage has the intrinsic limitations imposed by the variable range of spatial distribution of the cod population; [ii] precision of the measurements is insufficient for the estimation of parameters of size-at-instar of immature crab due to the inevitable deterioration of the specimens; [iii] foraging cod select a size window, and thus size frequency distributions (SFD) based on samples from stomach contents are biased or truncated at both ends; [iv] size selectivity by fish predators is a function of fish size and of the availability of alternative prey. Yet, even with those acknowledged limitations, patterns of cod predation are highly informative about key aspects of early snow crab life history.

Snow crabs were found in cod ranging in length between 17 and 110 cm. Crabs < 25 mm CW were found in cod between 17 and 92 cm length. There was a significant relationship between cod length and the size of their crab prey ($r^2 = 0.62$; Fig. 1a), although plots of stomach fullness are best interpreted in terms of ceiling functions. The pattern reported here is remarkably similar to that found in the Gulf of Saint Lawrence (Chabot et al., 2008, their Fig. 2a), where the predatory cod species is *Gadus morhua*. Most of the snow crabs sampled from cod stomachs were in 10–35 mm CW range (Fig. 1b), which matches primarily Instars iv-vii. The aggregated SFD shows three well-defined modes, two of which are recovered also from the log-transformed data. The smallest mode corresponds to a mixture of Instars iv and v; the data do not have enough resolution to discriminate components in their size range. The other two (larger) modes correspond to Instars vi and vii.

The number of crabs per cod stomach (CCS) ranged between 1 and 53, although 95% of the stomachs had 9 crabs or less. CCS varied between years (Fig. 2) in all sectors of the EBS, but was highest in regions of the Middle Domain north of the Pribilof Islands (Fig. 2: G, D).

The absence of crab in cod stomach may be as informative as its presence. Immature crabs are distributed primarily throughout the Middle Domain, spreading also eastward over fringe areas of the Coastal Domain and (in smaller numbers) in areas of the Outer Domain west of 174°W and north of St. Matthew Island (Orensanz et al., 2004; their Fig. 5). Occurrence of immature crab in stomach contents of cod from expanses of the Coastal Domain to the SE of Nunivak Island and Bristol Bay was minimal, which is consistent (even if not conclusive) with a marginal significance of the Coastal Domain for snow crab recruitment in the EBS; expanses to the N and NW of Nunivak are outside the sampling frame and remain undocumented.

The geographic pattern of CCS has changed over time in a consistent way (Fig. 3). Information has been arranged in Figure 3 so that core years of pseudo-cohort recruitment pulses II-IV (1987, 1994, 2001) are located in the central column, highlighting the 7-year cycle. Going from left to right, notice that one year later there were minima in the occurrence of immature crab in cod stomachs, reflecting that by that time, most immature crab contributing to the pulses had escaped the size range most vulnerable to cod predation. Pulse spawning peaked around core years and at least part of those eggs hatched and larvae settled by the next year, becoming available to cod two or three years later. The result was a sudden increase in CCS two years after pulse-core-years (1989, 1996, 2003).

CCS is also informative about the thermal habitat of immature snow crab (Fig. 4). As before, the pattern has to be taken cautiously because it is the result of immature crabs' thermopreferenda, cod distribution, and foraging selectivity. Cod with crabs in their stomachs were captured mostly at bottom temperatures between -1.8^{o}C and 6^{o}C. CSS for crab < 25 mm CW (generally in their second and third years of post-settlement life) is centered around 2 ºC near bottom temperature (NBT), ranging mostly between 0 ºC and 4 ºC. The NBT range was displaced downwards if the NBT considered was that of the previous year, closer to the time of settlement and earliest instars. This is consistent with the thermopreferenda inferred experimentally by Dionne et al. (2003) in eastern Canada.

The analysis of cod stomach contents is central in two different ways: first, because of the dynamic consequences of cod predation, and second because predatory cod offer a unique window into the early life history of snow crab, valuable even if the image seen through it is distorted by a number of biasing factors.

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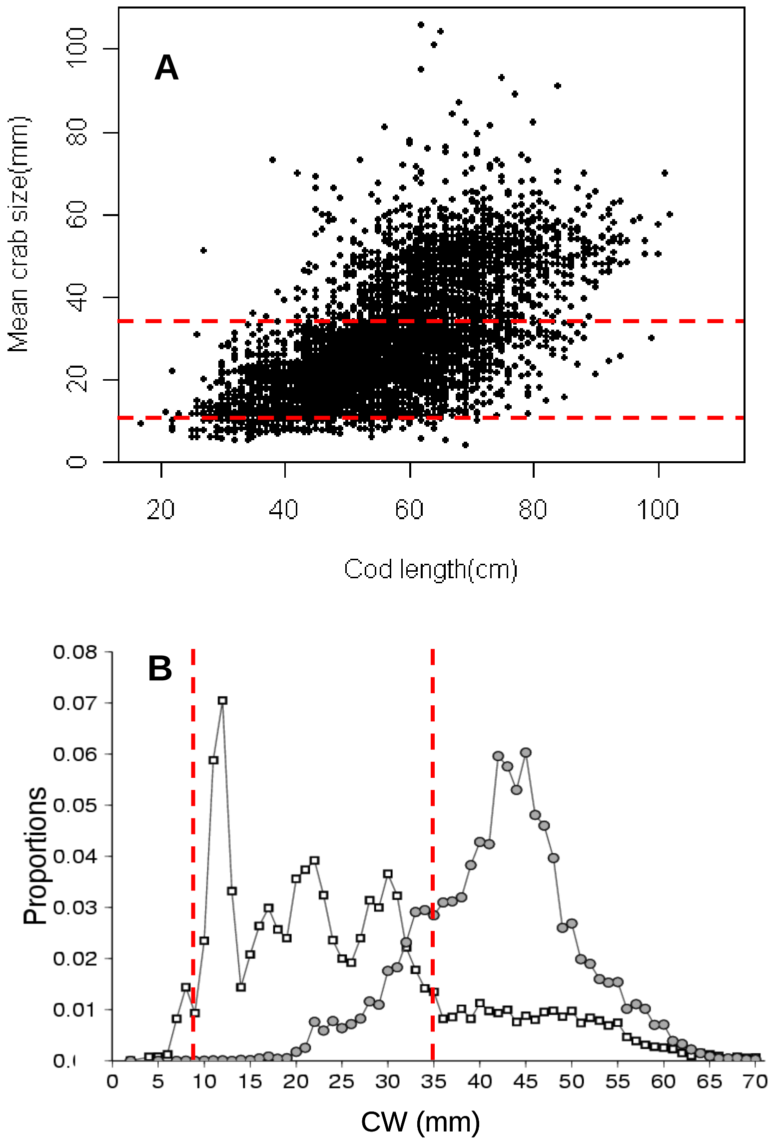

Figure 1.Size range of snow crab sampled from cod stomachs. A: Relation between size of predatory cod (length, in cm) and crab in stomach contents (Carapace width (CW), in mm). Dashed lines correspond to a size range shown in B (from Armstrong et al., MS). B: Aggregated size-frequency distributions (SFDs) of immature females sampled during the surveys (all years pooled): (□) pooled cod stomach samples, (○) pooled trawl samples (from Ernst et al., MS). Dashed lines bound the crab size range that is best represented in stomach samples.

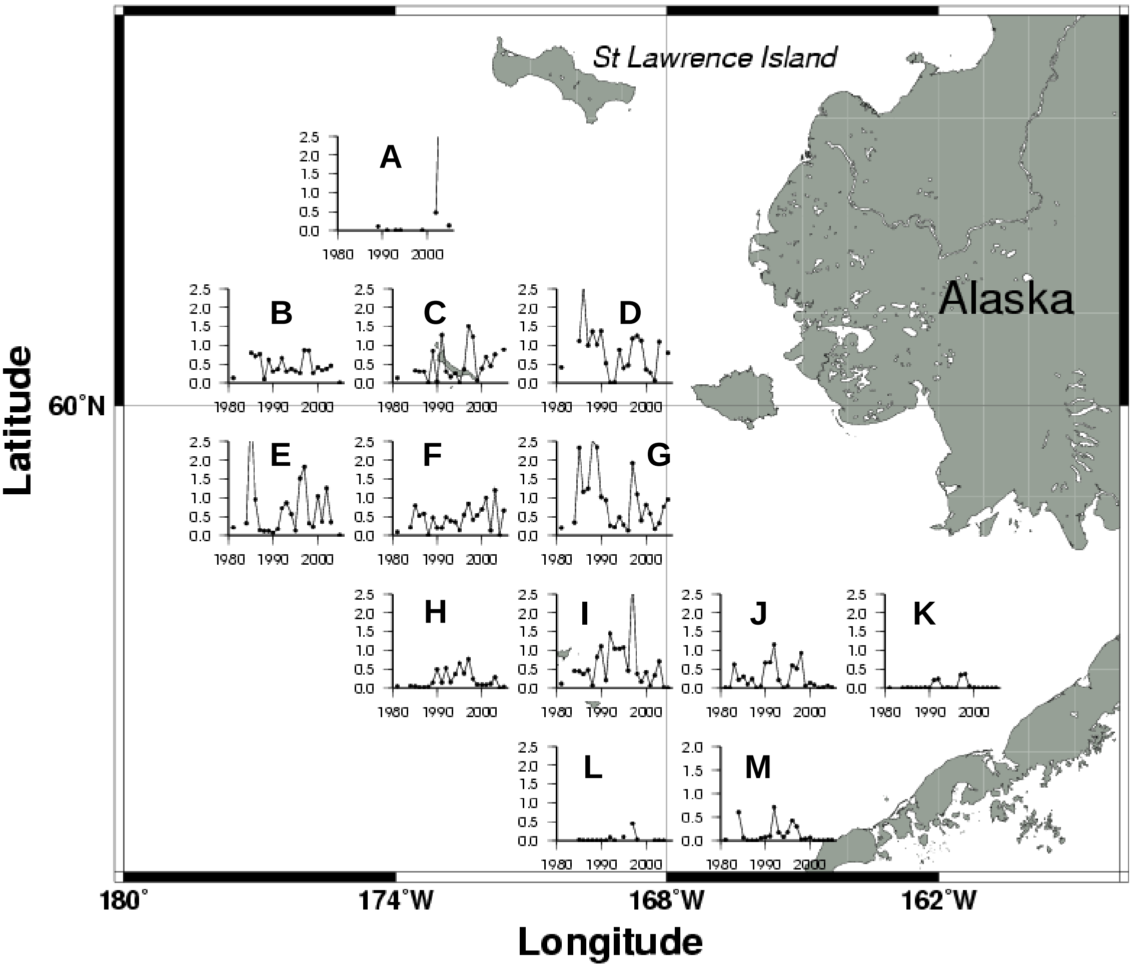

Figure 2. Average number of immature snow crab (CW < 35 mm) per cod stomach in the eastern Bering Sea Shelf, by quadrant, 1981 and 1984-2005 (from Armstrong et al., MS). Quadrants are the same used in other studies of snow crab dynamics in the EBS (Orensanz et al., 2007).

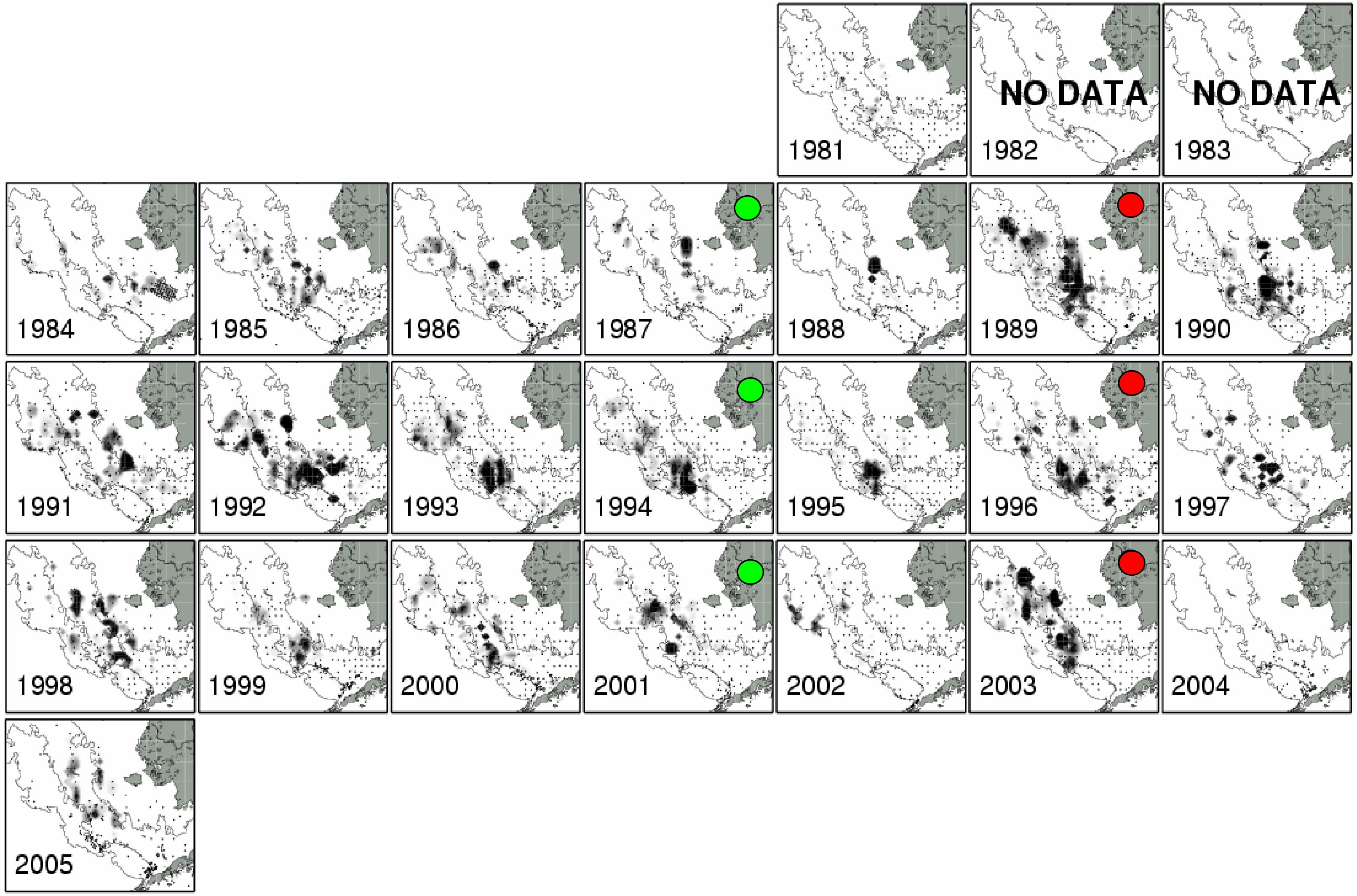

Figure 3. Geographic distribution of average number of immature crab (CW < 35 mm) per cod stomach (CCS) in the eastern Bering Sea Shelf, 1981 and 1984-2005 (shade intensity is proportional to average CCS). Green dots: core years of pseudo-cohort recruitment; red dots: maxima of extension of CCS. (From Armstrong et al., MS).

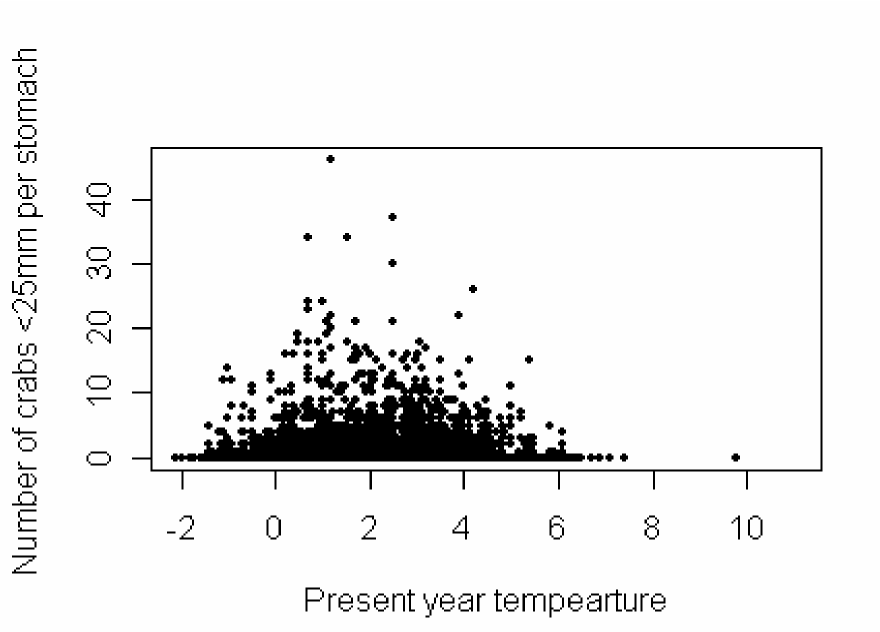

Figure 4. Near bottom temperature and number of immature snow crab (CW < 25 mm) per cod stomach. (From: Armstrong et al., MS).

Aspects on the effects of climate variability and change on high-latitude marine ecosystem

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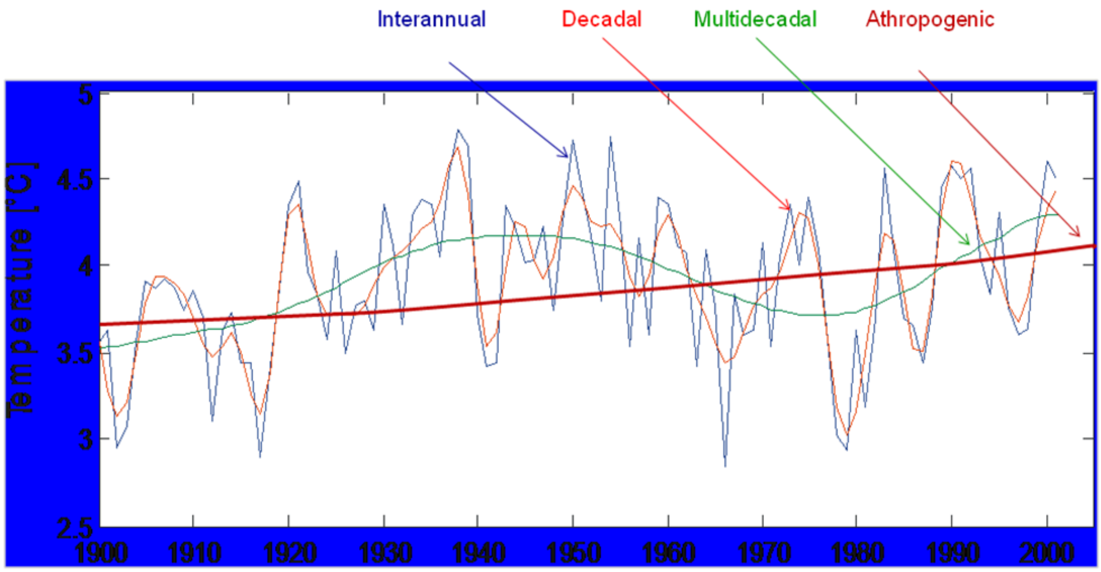
Over recent years, the anthropogenic component of global climate change issues has been the focus of the scientific development on global change. However, climate impacts on marine ecosystems are not caused by anthropogenic climate change alone, but on climate variability under anthropogenic climate change. Reproduction, growth and mortality of marine organisms are influenced by climate fluctuation on a range of various frequencies from seasonal to inter-annual, decadal and multi-decadal scales, and longer-terms such as climate change. The amplitude of temperature change, for example 1^oC, impacts marine ecosystems very differently at inter-annual compared to multi-decadal time scales, as the persistence of the climate signal is also important for climate impacts. Shorter-term fluctuations impact growth and recruitment in high-latitude fish and plankton communities, while multi-decadal fluctuations have more pronounced effects on species distributions in general and on higher trophic levels.

The anthropogenic global climate change component has been less pronounced in the oceans than over land, causing natural climate variability to be more dominant in the ocean than over land. During the 20th century, the North Atlantic Ocean went through a multi-decadal temperature oscillation termed The Atlantic Multi-decadal Oscillation (AMO) (Sutton and Hodson 2005). This resulted in a warm period during the 1930s to 1950s with northward displacement of Atlantic fish species (Drinkwater 2006), a return to a cool period during the 1960s and 1970s, and subsequently the recent warming, which has resulted in a new northward displacement of habitat extents from zooplankton species (Beaugrand et al. 2002) to pelagic, demersal and top-predator fish species (Sundby 2009). The historically and presently largest Atlantic cod stock, the Arcto-Norwegian cod, has oscillated in biomass accordingly to the AMO. The spawning areas are displaced northwards along the Norwegian coast during warm periods and the biomass increases, while a southward shift in spawning habitats is observed during cool period with a reduction in biomass (Sundby and Nakken 2008). A similar oscillation has been observed in spawning stock biomass for the Norwegian spring-spawning herring (Toresen and Østvedt 2000).



Data source: PINRO, Murmansk

Figure 1. Climate periods in the Russian Kola Section in the eastern Barents Sea.

Hence, the major climate impacts on the North Atlantic marine ecosystems during the 20th century have primarily been caused by natural climate oscillations. This is in contrast to the prevailing opinion that the warming over the recent decades is mainly caused by anthropogenic climate change. Since the mechanisms behind the AMO are unclear, it is not possible to predict its development. However, under the assumption that the periodicity of approximately 60-70 years is repeated, it is possible that the present warm phase of the ocean climate is reaching an end resulting in a more moderate increase in the ocean temperature, or even a slight cooling over the next couple of decades. On the other hand, towards the mid-term of this century, it to be expected that the anthropogenic climate change component will completely dominate over the multi-decadal oscillations. The impacts experienced through multi-decadal climate oscillations can give us an indication of what will happen to marine ecosystems under anthropogenic climate change. However, since the anthropogenic climate change signal is expected to become considerably larger than that experienced from the multi-decadal oscillations, non-linear and irreversible ecosystem responses cannot be overlooked as a result of anthropogenic climate change towards the second half of the 21th century.

The temperature itself plays an important role in impacting high-latitude marine ecosystems as it strongly influences vital rates in poikilothermic organisms. But also other climate variables as light, turbulence and salinity influence the vital processes and behavior of individuals. Advection, spreading, and turbulent mixing are climate processes that influenced the marine ecosystems on the population level, particularly the plankton populations. As climate variables and processes partly co-vary, the causal link between an ecosystem state and the climate can be complicated. Particularly, interpretations of correlations between temperature and ecosystem states should be done with care.

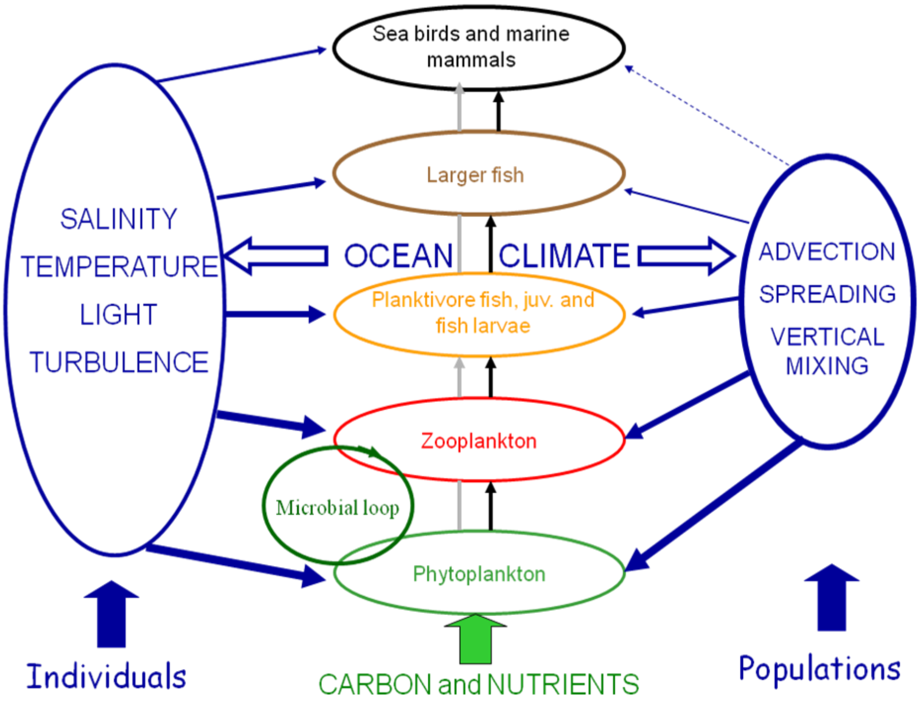


Figure 2. Impacts on climate variables and processes on the marine food web

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Regional Overviews

Abundance trends and biological information of Pacific cod and major crustacean stocks in Japanese waters

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[2]Hokkaido University, Japan

Three gadoid species occur in the subarctic waters of the Japanese EEZ: Pacific cod (*Gadus macrocephalus*), saffron cod (*Eleginus gracilis*) and walleye pollock (*Theragra chalcogramma*). Of these, the distribution and standing stock of saffron cod is very limited, therefore it was excluded from the present analysis. Walleye pollock depends exclusively on pelagic prey, whereas Pacific cod (PC) depends on decapod crustaceans to a considerable extent. Therefore, we examined the abundance trend of the latter species, which has a potential to interact with commercial decapod crustaceans. The diets of Pacific cod consisted of crustaceans, octopus, and fish; therefore we examined abundance trends of PC and commercial crustaceans in different areas off northern Japan.

No estimate of standing stock has been available in the Japanese waters for PC, so we used annual catches as a proxy. Along the Japan Sea coast of the Hokkaido Island, annual catch of PC has fluctuated between 3.5 and 11 kt since 1981, with a declining trend in the last 15 yrs (Fig. 1). The catch of pink shrimp in the same area declined from >4 kt to approximately 5kt by the mid-1990s, and has fluctuated between 1.5 and 3 kt since then. When the catch of PC was plotted against pink shrimp, no relationship was found, suggesting no apparent interaction between these species. Similarly, no relationship was found between catches of PC and pink shrimp along the Japan Sea coast of Honshu.

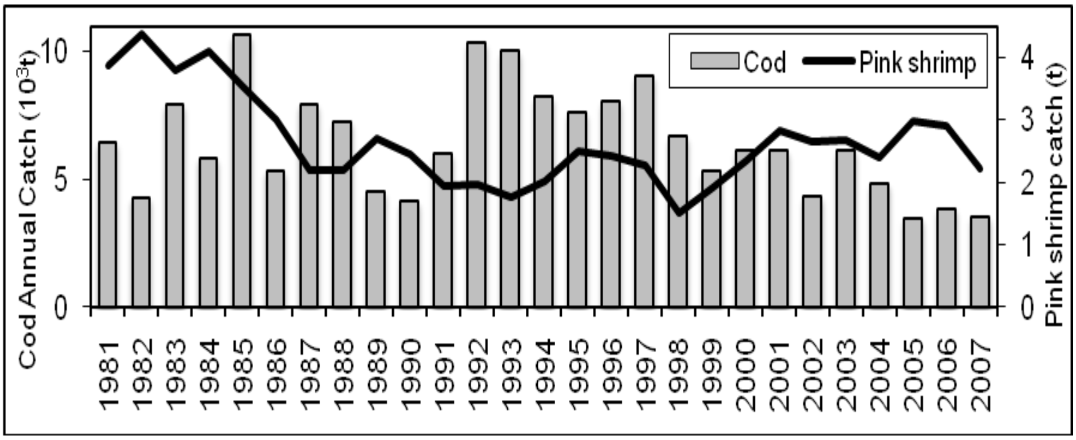

Figure 1. Catches of Pacific cod and pink shrimp off the Japan Sea coast of Honshu.

On the Pacific coast of Hokkaido Island, catches of PC have fluctuated between 3 and 25 kt since 1981. The catches of hair crab (*Erimacrus isenbeckii*) and humpback shrimp

(*Pandalus hypsinotus*) ranged from 0.5 to 1.4 kt and 0.1 to 0.9 kt, respectively (Fig. 2). While the statistics of the former species are less reliable due to poaching and a fishing moratorium enforced in certain areas and years, the latter species showed a weak but significant negative relationship with cod abundance, suggesting weak top-down control (Figure 3). Thus, we found little evidence of top-down control on commercial crustaceans in Japanese waters. This may reflect: 1) high diversity in PC diets, 2) limited density of PC and crustaceans, 3) a long history of severe exploitation, and 4) habitat segregation between PC and crustaceans.

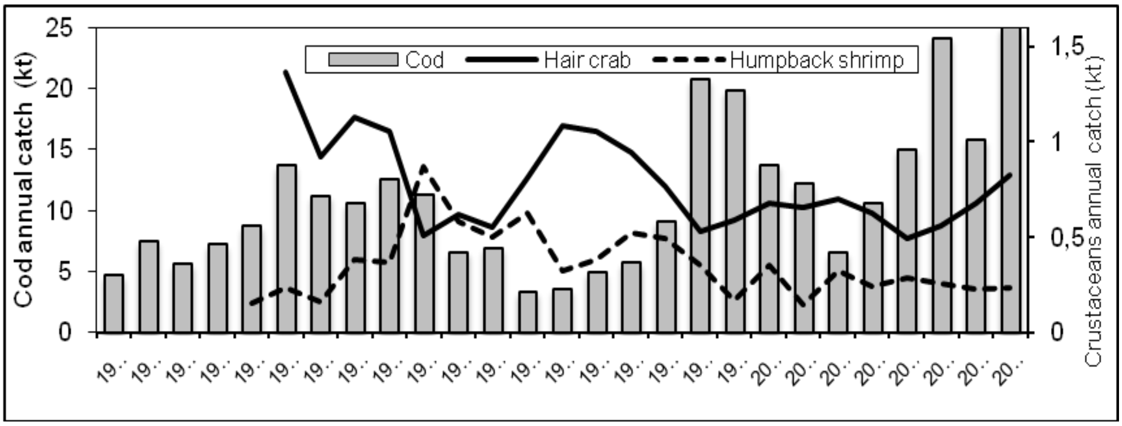

Figure 2. Catches of Pacific cod, hair crab and humpback shrimp of the Pacific coast of Hokkaido.

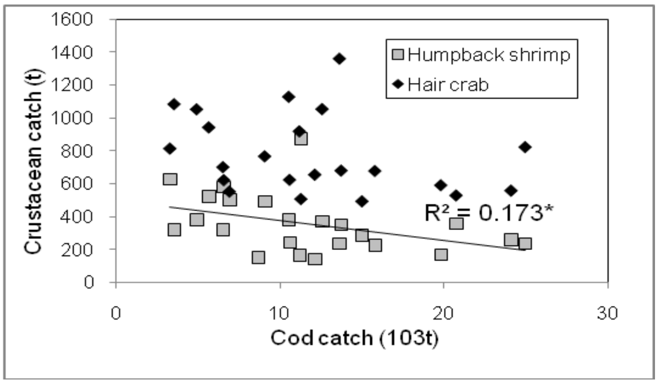

Figure 3. Regressions of hair crab and humpback shrimp catches on the catch of Pacific cod in Pacific waters off Hokkaido.

Gadid-crustacean interactions in the Eastern Bering Sea and Gulf of Alaska

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We compared trends in major gadid and crustacean stocks between two subarctic systems in the Northeast Pacific, the Gulf of Alaska (GOA) and the Eastern Bering Sea (EBS). Walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus* *macrocephalus*) are the only gadid species of commercial importance in both systems. Both species have been harvested since the early 1900s, but major commercial fisheries did not develop until the 1960s (pollock in the EBS) or the late 1970s (cod and pollock in the GOA). Major commercial fisheries for crab and shrimp likewise developed in the 1960s and 1970s, including red king crab (*Paralithodes camtchaticus*), Tanner crab (*Chionoecetes bairdi*), and snow crab (*C. opilio*) in the Bering Sea; and red king crab, Tanner crab, and shrimp (Pandalidae) in the Gulf of Alaska. Catches of most crustacean stocks have undergone large "boom and bust" cycles as a result of both fishing and changes in productivity.

Increased catches of cod and pollock in the late 1970s and early 1980s were associated with large increases in the biomass of these species, as estimated from age-structured assessment models (Fig. 1A, NPFMC 2008a, b). At the same time, sharp decreases in the biomass or catch of a number of important crustacean stocks led to the collapse of major fisheries in both the GOA (shrimp and red king crab) and the Bering Sea (red king crab and Tanner crab) (Bechtol and Kruse 2009, Orensanz et al. 1998, Rugolo et al. 2008, Zheng and Siddeek 2008). These wide-spread changes followed a pronounced climate regime shift in the Northeast Pacific in 1976/77 (Hare and Mantua 2000), suggesting that environmental changes associated with the climate regime shift played a major role in the rise of gadid populations and in the simultaneous decline of crustacean stocks. For example, average recruitment of red king crab decreased substantially after 1976 (Fig. 1B) (Zheng and Siddeek 2009), whereas average recruitment of cod and pollock (Fig. 1B), as well as the recruitment of other demersal and pelagic fish stocks, increased after the 1976/77 regime shift (Mueter et al. 2007).

Pronounced changes in community composition have been well documented in the near-shore communities of the GOA (Anderson and Piatt 1999, Litzow 2006) and have been attributed to a combination of bottom-up processes changing the relative productivity of cold-water and warm-water species (Anderson and Piatt 1999), increased predation mortality of shrimp and forage species from expanding predator populations such as cod, pollock and arrowtooth flounder (*Atheresthes stomias*) (Mueter and Norcross 2000), and the serial depletion of numerous regional stocks (Orensanz et al. 1998). Bottom-up processes, predation by cod, and fishing have also been implicated in the rapid decline of red king crab in the EBS around the same time (Dew and McConnaughey 2005, Zheng and Siddeek 2008). More recent declines in snow crab (Fig. 1), a species requiring cooler bottom waters for successful recruitment, have been attributed to a general warming trend in the EBS combined with increasing predation by cod as the cod population expands into more northern areas ("Environmental ratchet" hypothesis, Orensanz et al. 2004).

Available diet information also suggests that there is a potential for strong trophic interactions between Pacific cod and crustacean stocks. In the EBS, crab and shrimp comprised 30-40% of Pacific cod summer diets by weight from the 1980s to 2005, with a slightly increasing trend over time (Fig. 2). Similarly, crab and shrimp accounted for 40-60% of cod diets in the GOA during the 1990s and 2000s. In contrast, walleye pollock consume very few crabs in either system, although shrimp were an important component of their diet in the 1990s (~ 5% in the EBS, ~ 20% in the GOA, Fig. 2, Aydin et al. 2007).

We conclude that both climate variability and groundfish predation affect the year-class strength and distribution of snow crab, Tanner crab, and red king crab in the Eastern Bering Sea through bottom-up and top-down processes. Similarly, the 1976/77 climate regime shift, the associated increase in predator biomass, and high fishing mortalities contributed to the sharp decline in shrimp and king crab populations in the Gulf of Alaska in the late 1970s, and to the pronounced shift in near-shore community composition.

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Cod-crustacean interactions on the Newfoundland-Labrador Shelf

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The Newfoundland and Labrador continental shelf represents the western margin of the Labrador Sea (Fig. 1). A prominent oceanographic feature of this area is the southward flowing Labrador Current which includes a strong flow of relatively warm saline water of Atlantic origin along the shelf slope, and a weaker diffuse flow of cold, fresher water of Arctic origin over the shelf.

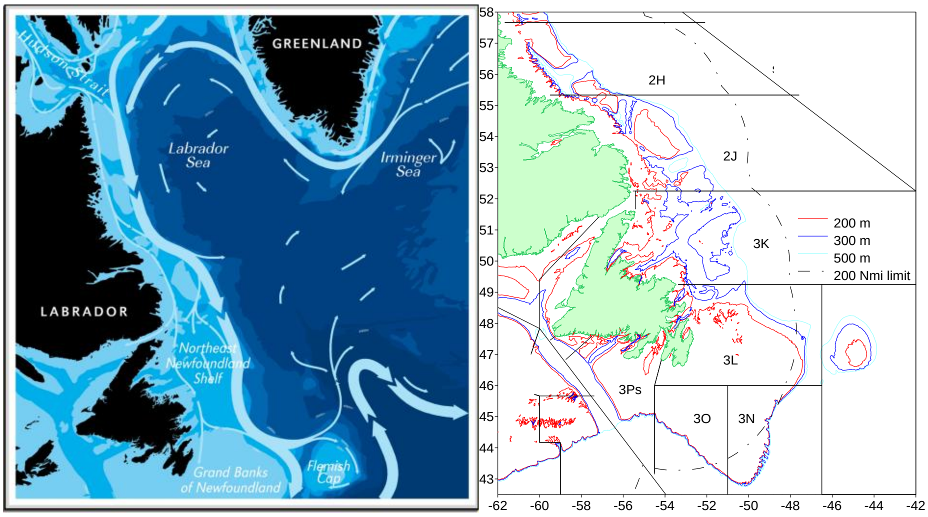

Figure. 1. Maps of the study area showing general circulation pattern (left) and local bathymetry with NAFO Divisions (right).

This overview focuses on the shelf region from the southern Labrador shelf to the northern Grand Bank, NAFO (Northwest Atlantic Fisheries Organization) Divisions 2J3KL (Fig. 1). This region features a spatially variable bathymetric and hydrographic regime; bottom temperatures are lowest within the cold intermediate layer (<1 C) on the shallow northern Grand Bank and warmer (2-4 C) in deeper waters of Atlantic origin to the north. Recent trends in ocean climate include a warm period from the 1950s to the early 1980s, followed by a cold period until the mid-1990s, and a subsequent period of warming to the present (Colbourne at al. 2009). This region has seen a pronounced shift in fisheries during the late 1980s-early 1990s (Fig. 2), from one dependent on Atlantic cod (*Gadus morhua*) to one dependent on crustaceans, specifically northern shrimp (*Pandalus borealis*) and snow crab (*Chionectetes opilio*). The collapse of the northern (NAFO Div. 2J3KL) cod stock, and most other groundfish species, has widely been attributed exclusively to excessive exploitation (Hutchings and Myers 1994). However some researchers believe that the extended cold period at the time (Fig. 2) may have also contributed to the collapse. It is also widely believed that the increase in crustacean landings has been primarily due their increased biomass as a consequence of their release from predation by cod and other groundfish species (Worm and Myers 2003; Frank et al. 2005). However, there is some evidence that abundance is related to temperature conditions during early life (Parsons and Colbourne 2000; Dawe et al. 2008; D. Orr, unpublished data).

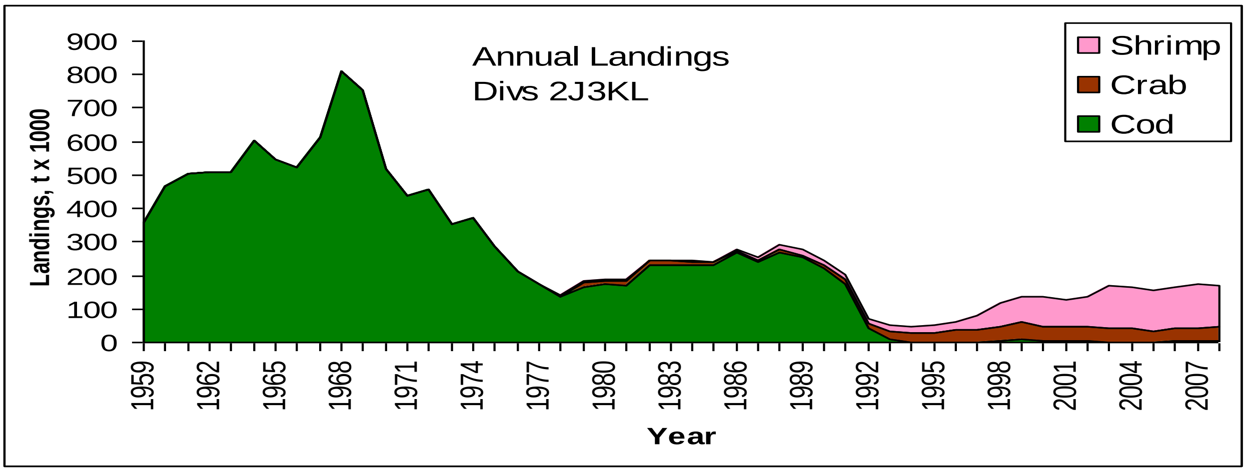

Figure 2. Trends in annual landings of northern cod, snow crab and shrimp from the southern Labrador shelf to the northern Grand Bank.

The increase in crustacean landings since the mid-1990s was in part due to a shift of fishing effort to shrimp and snow crab following the collapse of the cod resource. Long-term trends in abundance of shrimp and crab are uncertain because survey data are available only since 1995, after the cod collapse. Therefore only fishery-based catch per unit effort (CPUE) indices are available for the crustaceans to explore the relative importance of ocean climate versus predation in controlling their abundance.

Atlantic cod was the most important predator in this region prior to its collapse. Its principal prey was capelin (*Mallotus villosus*), and other fishes, with shrimp representing a consistent but less important component of the cod diet, and crabs playing a more minor role than shrimp (Lilly 1991). Capelin population trends are unclear, and there are no detailed data on cod diet since the mid-1990s. Therefore it is not possible to determine any changes in the cod diet in recent years.

The relationship of snow crab CPUE with annual sea ice extent and bottom water temperature, lagged 6-10 years (Fig. 3), showed consistent relationships among the three NAFO Divisions, suggesting that cold conditions in early life history were favorable for snow crab production and subsequent recruitment to fisheries. The unlagged relationship of snow crab CPUE with cod biomass is less convincing because the cod biomass trend is unidirectional. The relative effects of ‘bottom-up’ versus ‘top-down’ processes are even more unclear for northern shrimp than for snow crab because of fewer areas for comparison and a more limited time series of shrimp CPUE data.

It can be concluded that any effects of predation on northern shrimp or snow crab that existed historically have not been important for the past two decades. Fisheries may have played a more important role in controlling these crustacean populations in recent years, especially in the case of snow crab. Exploitation rates on northern shrimp have been consistently low and the fishery is believed to have had little effect on the population.

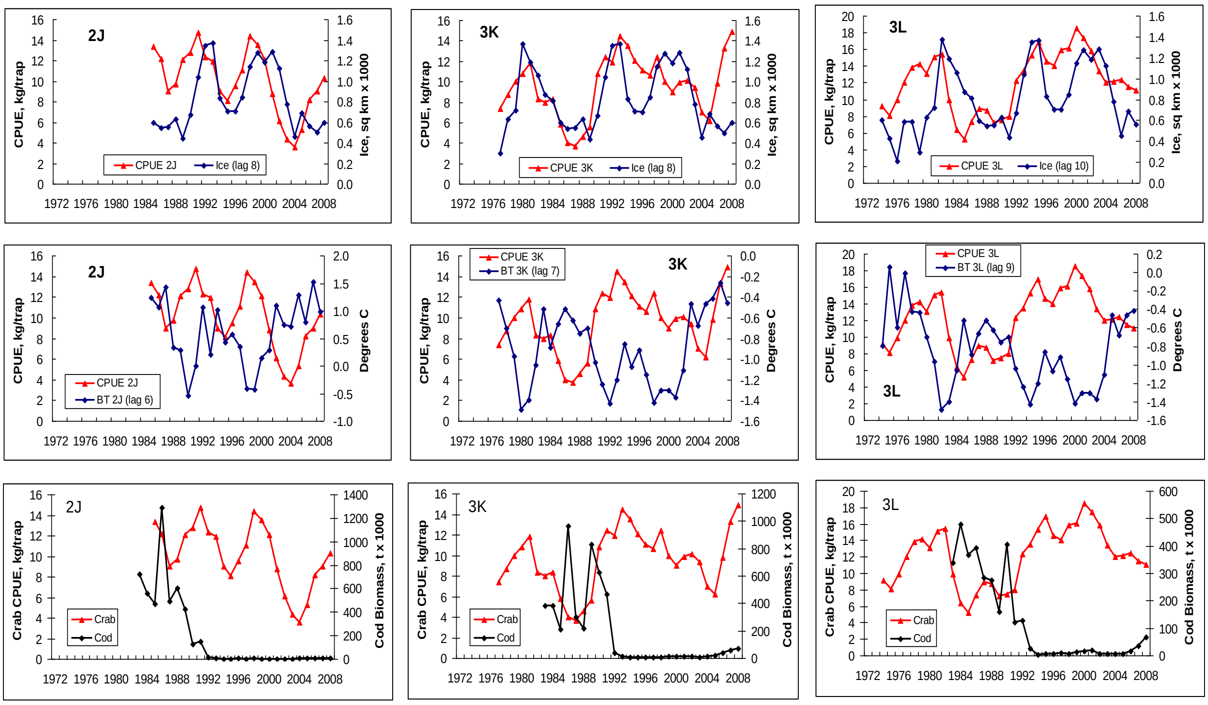

Figure 3. Relationships of snow crab CPUE with annual sea ice extent lagged 8-10 years (top) and with bottom temperature lagged 6-9 years (centre), and with cod biomass, unlagged (bottom), by NAFO Division.

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Ocean climate and interaction between Atlantic cod, Northern shrimp and Greenland halibut

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Changes in ocean climate and potential relationships between stock size of northern shrimp (*Pandalus borealis*) and its main predators, Atlantic cod (*Gadus morhua*) and Greenland halibut (*Reinhardtius hippoglossoides*), in West Greenland waters were examined. In the analysis, changes in spatial overlap between the species were taken into account in the analysis of the impact of predators on the stock size of northern shrimp.

A warming in the beginning of the 20th century was accompanied with the establishment of a self-sustaining and very abundant Atlantic cod stock at West Greenland, which through the 1930s and 1960s frequently produced rich year-classes. However, a prolonged period of decline in stock biomass was observed in 1950 to 1975, which can be attributed to excessive fishing, and the stock collapsed completely in the beginning of the 1990s. Warm conditions returned in the mid 1990s with record high air and ocean temperatures, but not until 2005 was a clear sign of new cod recruitment detected. These recruits remained at Southwest Greenland and did not spread out towards the north, which is in contrast to what was observed in the 1920s and 1930s.

Commercial CPUE of northern shrimp was negatively correlated with Atlantic cod biomass lagged by one and two years until the beginning of the 1990s. Thereafter, the Atlantic cod stock in West Greenland offshore waters collapsed, but there was no immediate response in the stock of northern shrimp, although the estimated predation by Atlantic cod in the preceding period was of the same magnitude as the commercial catch. Recruitment, and subsequently stock biomass, of northern shrimp first increased about 10 years after the collapse of the Atlantic cod stock. The increase in northern shrimp biomass resulted from favorable conditions for growth and survival of the juveniles due to enhanced plankton production, rather than from a release in predation pressure. After a record high level in 2000, survival of juvenile northern shrimp, i.e. the number of recruits at age 2 per unit of spawning stock biomass, decreased drastically. At the same time, the stock disappeared from the southern most areas. The northward shift of the stock distribution was likely an effect of the relatively high bottom temperatures found at Southwest Greenland in the past decade. No link between Atlantic cod biomass and the survival of juvenile northern shrimp was detected, which was mainly due to the very limited spatial overlap between the two species in the recent years.

In contrast, statistical analysis suggests that predation by Greenland halibut may have had some impact on the recruitment of northern shrimp. However, the duration of egg development in northern shrimp is adapted to the long-term average of bottom temperature and bottom-up processes such as a mismatch between the timing of larval hatch and the occurrence of the phytoplankton bloom, which is indicated by a considerable variation in the difference between surface layer and near bottom temperature in the past two decades, may have played a more important role than predation by Greenland halibut. Catches of northern shrimp have exceeded the recommended TAC's for several years, and this has likely contributed to the steep decline in the survey biomass recorded in the most recent years. Hence, mechanisms concerning cod-shrimp interactions and effects of changes in temperature on the recruitment of the two species previously reported for other areas in the North Atlantic do not apply for the actual situation in West Greenland waters.

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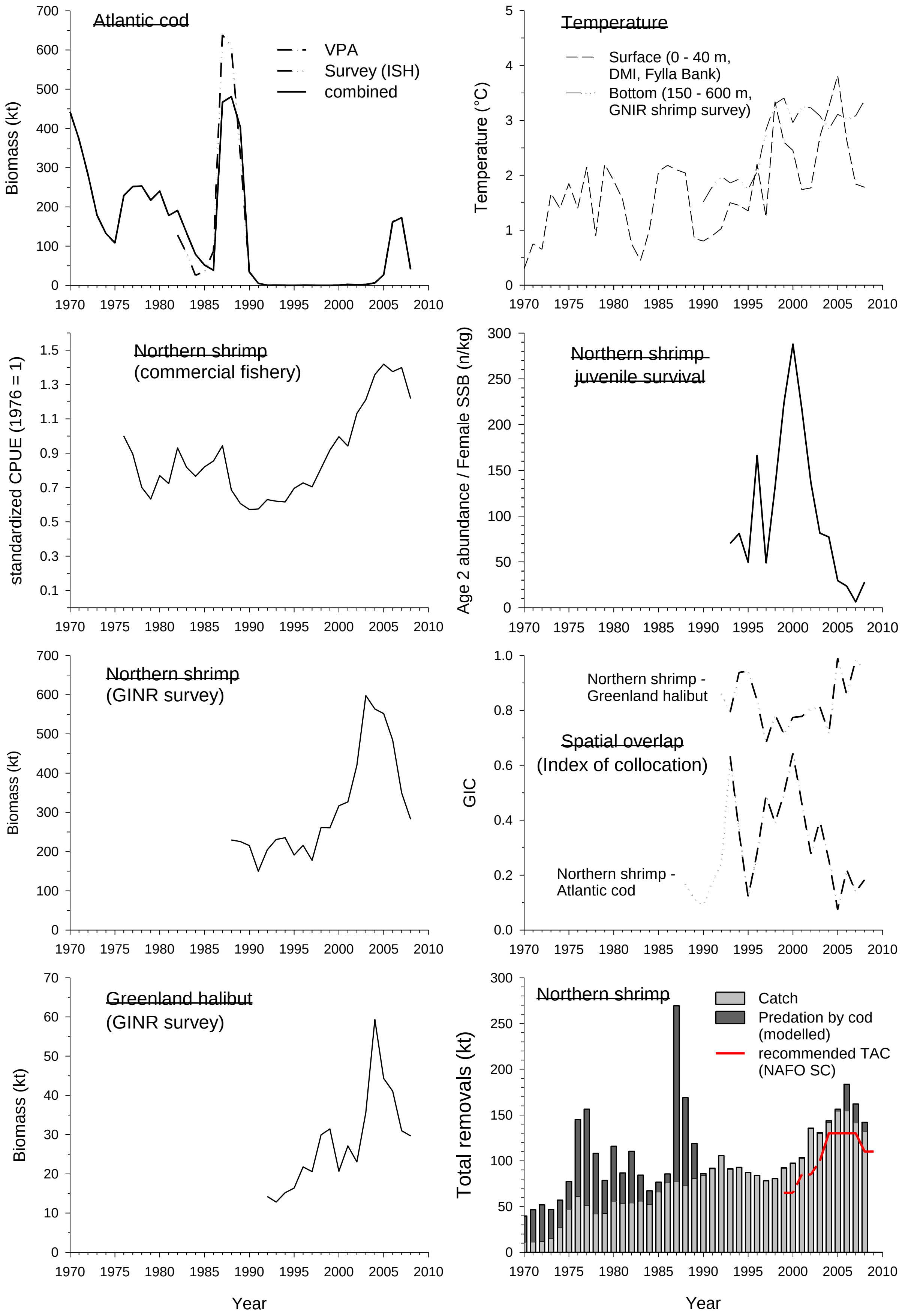
~~Atlantic cod~~
VPA
Survey (ISH)
combined
Biomass (kt)
0
100
200
300
400
500
600
700
~~Temperature~~
Surface (0 - 40 m, DMI, Fylla Bank)
Bottom (150 - 600 m, GNIR shrimp survey)
Temperature (°C)
0
1
2
3
4
5
~~Northern shrimp~~
(commercial fishery)
standardized CPUE (1976 = 1)
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
~~Northern shrimp juvenile survival~~
Age 2 abundance / Female SSB (n/kg)
0
50
100
150
200
250
300
~~Northern shrimp~~
(GINR survey)
Biomass (kt)
0
100
200
300
400
500
600
700
Northern shrimp - Greenland halibut
~~Spatial overlap~~
(Index of collocation)
Northern shrimp - Atlantic cod
GIC
0.0
0.2
0.4
0.6
0.8
1.0
~~Greenland halibut~~
(GINR survey)
Biomass (kt)
0
10
20
30
40
50
60
70
~~Northern shrimp~~
Catch
Predation by cod (modelled)
recommended TAC (NAFO SC)
Total removals (kt)
0
50
100
150
200
250
300
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
Year

Climatic influences on cod-northern shrimp interactions in the offshore waters north of Iceland

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The southern and western parts of the Icelandic marine ecosystem are more or less continuously bathed by warm and saline Atlantic water while the northern and eastern areas are more variable and influenced by Atlantic, Arctic and even Polar water masses to a various degrees. The Icelandic marine ecosystem is highly sensitive to climate variations, as demonstrated by the abundance and distribution changes of many species during the warm period in the 1930s, the cold period in the late 1960s and warm period since 1996. The main spawning grounds of most of the exploited fish stocks are in the Atlantic water south of the country, while nursing grounds are off the north coast. During the late 20th century, the catch of fish and invertebrates has been in the range of 1.6-2.4 million tons. During recent warming, the catch of capelin (*Mallotus villosus*), the most important pelagic stock, has decreased markedly, and similarly to total catch, which in most recent years has been around 1.2 million tons.

The most important gadid species in Icelandic waters are cod (*Gadus morhus),* haddock (*Melanogrammus aeglefinus)*, saithe (*Pollachius virens*) and blue whiting, *Micromesistius poutassou*. The most important exploited crustacean species are northern shrimp (*Pandalus borealis)*, which constitutes an offshore stock and 8 inshore fjord units, and Norway lobster (*Nephrops norvegicus*). Norway lobster is confined to the south coast of Iceland and does not seem to be an important prey of the gadid species in Icelandic waters.

Capelin is the most important prey of most of the demersal fish stocks in Icelandic waters. However, consuption of capelin by other stocks may vary considerably depending on its stock size. During years of low capilin abundance, the weight of adult cod has been found to decrease and it seems as though cod cannot fully compensate for the lack of capelin by converting to other food. When the capelin stock is of moderately large size, about 50% of the food of cod may be capelin (weight average for all size classes). Similarly crustaceans constitute about 10% of the food of cod. Of the crustaceans, shrimps (mainly northern shrimp) are the most important prey (ca. 5%) (Fig. 1). Fish (mainly capelin) are also the main prey of haddock (ca. 50%), while crustaceans are of second importance (ca. 15%). Shrimps constitute about 3-4% of the food of haddock, and of those, northern shrimp is most important or ca. 2.5% (Fig. 2). It is important to have in mind that these are averages for all length classes and covering extensive areas. For certain length classes and on a smaller geographical scale, the consuption of cod (and other gadoids) of particular crutacean species may higher. Thus the amount of crustacean prey in the stomach of cod from the shrimp ground in the offshore waters of the north coast of Iceland may be higher than demonstrated here.

Extensive fisheries-related data are available on both cod and northern shrimp from Icelandic waters. For cod these include: stock abundance index groundfish survey in March (1985-present) and October (1996-present), stock abundance in shrimp survey (1987-present), recruitment (3 yr) and stock size since early 20th century.

For northern offshore shrimp these include: CPUE, 1974-present, stock index, 1988-present, recruitment (2 yr), 1988-present.

The shrimp fishery in Icelandic waters developed initially as an inshore fishery amounting to a few thousand tons per year. During the late 1980s, an offshore fishery developed on the outer part of the northern shelf. The offshore fishery reached a peak of about 65 thousand tons during the late 1990s, while since then it has declined markedly. Reduced stock size has been attributed to higher predatory pressure by cod, but could possibly be caused by reduced recruitment due to recent warming, as the main distribution of northern shrimp is typically in the colder water on the shelf north of Iceland. Finally, in addition to decreasing stock, low market prices have also contributed to the very limited fishing during most recent years.

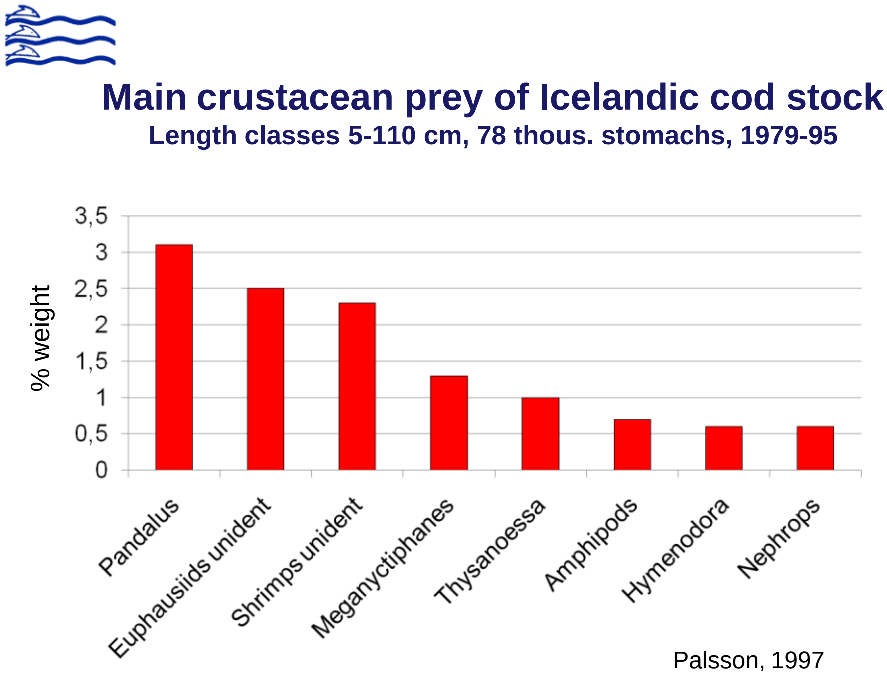
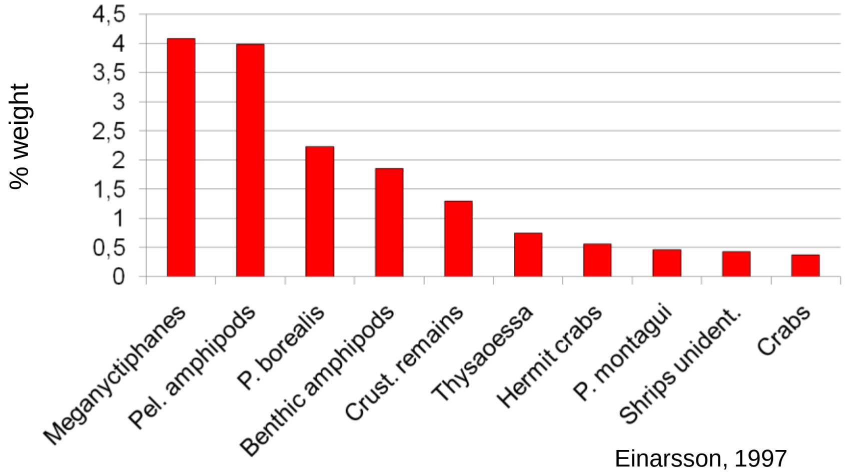


Figure 1. Of the crustaceans, shrimps (mainly northern shrimp) are the most important prey (ca. 5%)

Main crustacean prey of Icelandic haddock stock

Length classes 5-110 cm, 78 thous. stomachs, 1979-95



Einarsson, 1997

Figure 2. Shrimps constitute about 3-4% of the food of haddock, and of those, northern shrimp is most important or ca. 2.5%

Main gadid and crustacean fisheries off Iceland

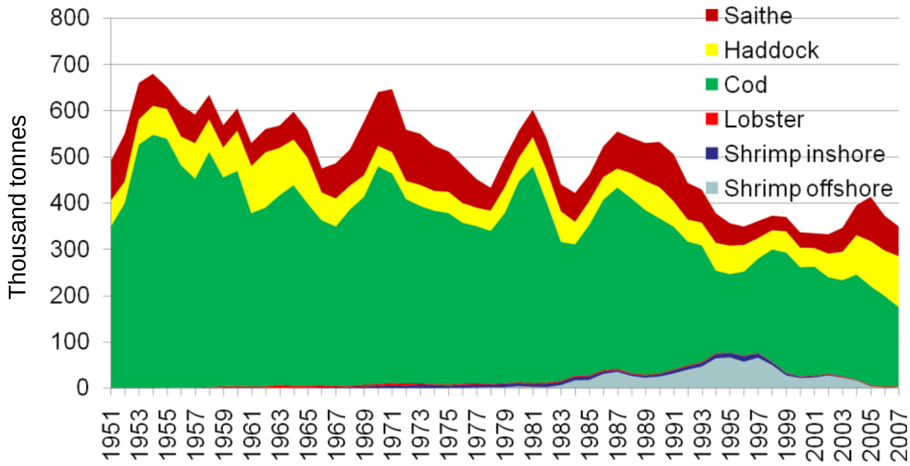


Figure 3.

Shrimp-cod interactions in the Barents Sea – an example of ecosystem complexity

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Inverse relationships between cod (*Gadus morhua*) and shrimp (*Pandalus borealis*) stock sizes have been observed throughout the North Atlantic. While catches of cod have declined, catches of shrimp have increased from 50 ktons in 1970 to more than 400 ktons annually in 2000 (Figure 1).

Cod is considered an important predator on shrimp (Hvingel and Kingsley 2006 and references therein), and predation could potentially be a major driver of the observed inverse relationship between their abundances. However, opposite responses of these species to ocean climate fluctuations might yield a similar pattern (cf. Lilly et al 2000). Likely, both processes (and others see Parsons 2005a+b) are in effect, their relative importance varying between ecosystems.

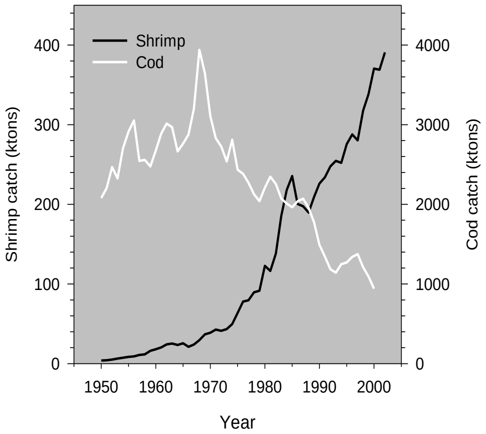

Figure 1**.** Annual landings of cod, *G. morhua*, and shrimp, *P. borealis*, in the North Atlantic (from Hvingel 2006).

Ocean climate variations in the Barents Sea may be summarised by time series of temperature cross sections – e.g. the Kola section (Bochkov 2005). These series show a strong decadal periodicity. Similar patterns can be seen in the trajectories of cod and shrimp stock dynamics (Figure 2).

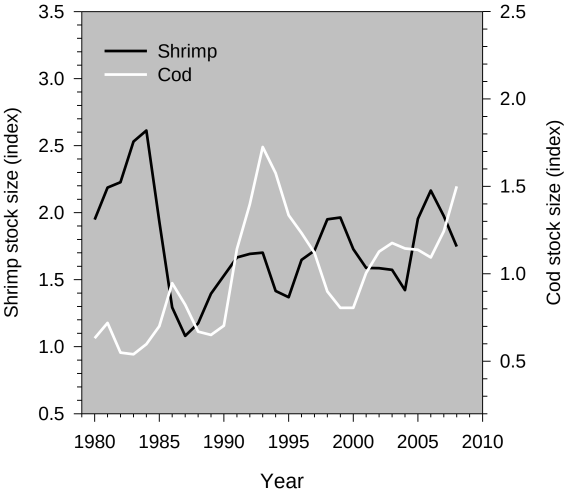

Figure 2**.** Stock biomass trajectories of cod, *G. morhua*, and shrimp, *P. borealis*, in the Barents Sea.

If predation by cod is important in driving the shrimp stock, a negative correlation between the cod and shrimp stock biomass – as suggested in Fig. 1. – would be expected. However, in the Barents Sea, no correlation was seen when overall cod biomass was related to shrimp stock biomass 1-3 years later. With further lags, a positive correlation developed with a maximum when cod was related to shrimp 6 years later Fig (3 *left*). When similar analyses were done correlating shrimp with cod, a maximum negative correlation was found also around lag 6 (Fig. 3 *right*). I.e. there is a tendency of the stocks within this relative short time-series to cycle half a wavelength (5-7 years) apart (see also Figure 2). Thus this analysis may indicate that it is the periodicity of the environmental signal that shows up in the dynamics of both stocks and that the predation effect of cod on shrimp is less conspicuous.

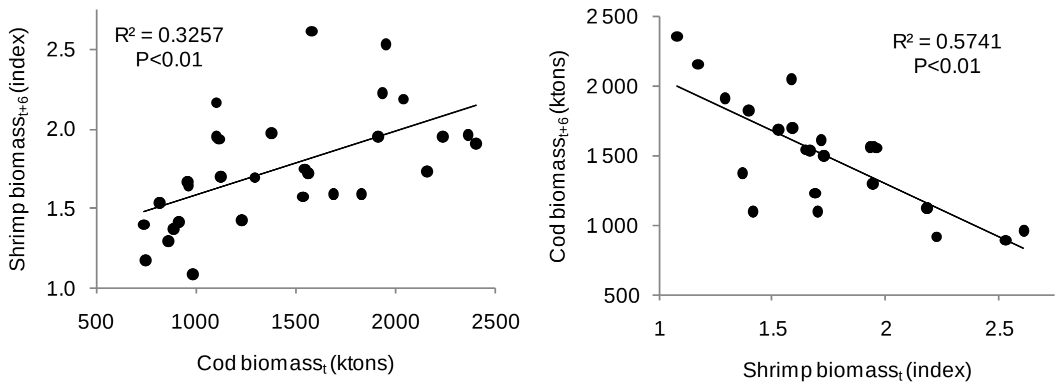

Figure 3. *Left*: Correlation of cod stock biomass in year t *vs.* shrimp stock biomass in year t+6; *right*: Correlation of shrimp stock biomass in year t *vs.* cod stock biomass in year t+6.

A Cod effect on shrimp might, however, be more complicated than a linear one as investigated above. Shrimp is usually not the favourite food of cod and the availability of alternative prey is thus important. In the Barents Sea 'alternative prey' would in particular mean capelin (Figure 4).

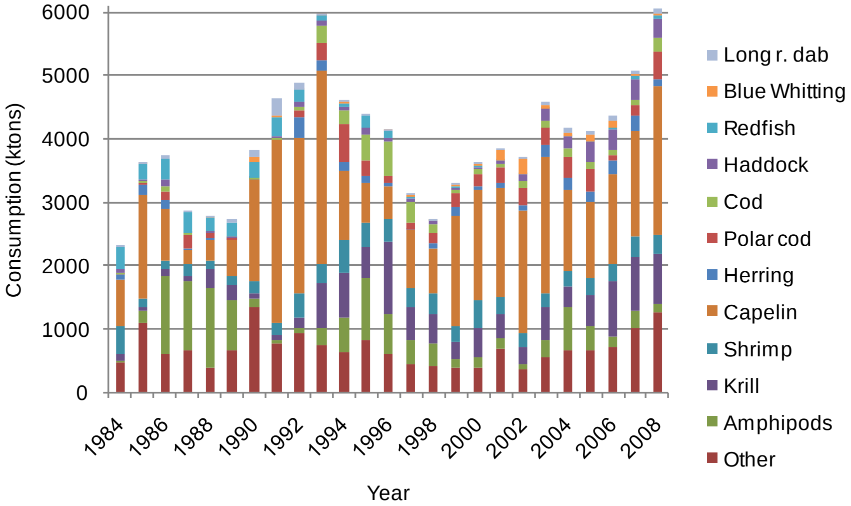

Figure 4. Estimates of annual consumption by cod, *G. morhua*, in the Barents Sea (based on data from Anon. 2009).

Cod do eat more shrimp when the shrimp stock is large although the exact shape of the functional response is not obvious (Fig. 5). Two outliers (years 1984 and 2004) could be identified (Fig. 5) when a unit cod ate more shrimp than would be expected from the shrimp density alone. This could potentially be a signal of a capelin influence: if the abundance of the favourite prey, capelin, was low in these two years this could explain the excessive consumption of shrimp. However, this was not the case and the cause of these 'outliers' remains unclear.

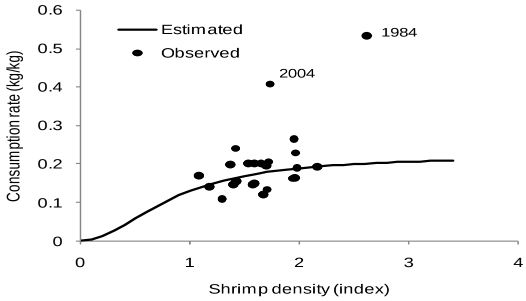

Figure 5. Functional response of cod, *G. morhua*, predation rate to shrimp, *P. borealis*, density in the Barents Sea based on data on

Direct estimates of consumption are available based on stomach analyses (Anon 2009). However, there were no correlation between the estimated consumption in a year and the change in the shrimp stock size from that year to any of the following 6 years. However, doing a similar analysis using an alternative consumption series (Johannesen E. pers. comm.), which to some extent takes more into account the spatial structure of the stomach sampling data, a negative correlation was found between consumption and the change in the shrimp stock 3-6 years later. This might imply that predation by cod does indeed affect shrimp stock dynamics, but also that the spatial scale on which these data are analysed is important.

In conclusion: The cod and shrimp stock size in the Barents Sea tend to cycle half a wavelength (5-7 years) apart. This periodicity is more likely to be driven by opposite responses to the same environmental conditions rather than by the shrimp stock responding to predation pressure proportional to a fluctuating cod stock. However, while initial analyses did not show correlation between cod consumption and shrimp stock dynamics, consumption estimates treating data on a finer spatial scale did. Thus a predation signal may also be hidden in the data, which might be revealed in analyses using a finer spatial resolution and taking into account alternative feeding opportunities for cod.

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Workshop 2
Advection and Its Effects in Sub-Arctic Ecosystems

Convener: Ken Drinkwater (ESSAS Co-Chair)
Institute of Marine Research, Bergen, Norway

Effects of *Advection in the Bering Sea*

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Pioneering work on the Bering Sea shelf described a shelf system dominated by tidal diffusion and lacking in mechanisms for cross-shelf advection of salts and carbon (Coachman 1986). In contrast to these earlier hypotheses, it is now clear that advection plays an important role on the Bering Sea shelf (Schumacher and Stabeno 1998; Stabeno et al 1999) and Stabeno et al. (2001)). Eddies, meanders of the slope flow, and topographic steering are all important mechanisms that introduce nutrient-rich slope water onto the shelf (Schumacher and Stabeno, 1994; Stabeno and van Meurs 1999). While eddies and meanders are both episodic, the interaction of the slope flow with both Bering Canyon and Pribilof Canyon replenishes the shelf with nutrients in both winter and summer (Stabeno et al. 2002a).

Once on the shelf, nutrients can be advected across it. During winter, strong winds break down the frontal structure of the Bering Sea shelf and replenishment of nutrients and salt occurs (Stabeno et al. 2001). During summer, the existence of frontal structure and weaker winds reduces, but does not completely halt, cross-shelf fluxes. While the existence of flow along the 50 m isobath paralleling the Alaska Peninsula and along the 100 m isobath were known earlier, the existence of an eastward flow north of the Pribilof Island was made using observations collected in the last decade (Reed and Stabeno 1996). This current both supplies new nutrients to the middle shelf at the latitude of the Pribilof Islands during summer (Stabeno et al. 2002b), and separates the northern cold pool from the southern cold pool (Wyllie-Echeveria and Wooster, 1998). Although the middle shelf generally has weak flow during summer, on time-scales of a few days to weeks, non-tidal currents can be significant (>10 cm s^{-1}). Thus, contrary to earlier findings, the middle shelf of the Bering Sea is not static, and it is not necessary to postulate large tidal diffusivities for replenishment of the shelf with nutrients and salts (Coachman, 1986).

The generally northward flow over the eastern shelf results in a net flux of carbon and nitrogen into the Arctic, although the magnitude of export is highly variable. Satellite images of the coccolithophore blooms (e.g., Fig. 3 in Stabeno, 1999) reveal the distinctive color of the coccolithophore bloom extending into the Arctic. The advection of warm water from the Bering Sea into the Arctic could play a role in the melting of the ice cap, which has occurred in recent years.

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Changes in the Bering Strait: Pacific Gateway to the Arctic Ocean

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Polar Science Center, University of Washington, USA
Collaborators: Knut Aagaard, Tom Weingartner, Terry Whitledge, Ron Lindsay
John Calder, Kathy Crane, Mikhail Kulakov, Valerian Golavsky

The Bering Strait, ~ 85 km wide and 50 m deep, is the only oceanic gateway between the Pacific and the Arctic Ocean. The flow through the strait, though small in the annual mean (~ 0.8 Sv), has many local and far-field influences. It provides a drain for the Bering Sea shelf to the south, and it dominates the oceanography of the Chukchi Sea to the north [Woodgate et al., 2005b]. The Pacific waters entering the Arctic through the Bering Strait are an important source of Arctic nutrients. They also provide ~ 1/3rd of the freshwater flux entering the Arctic, and are a significant source of oceanic heat (see [Woodgate and Aagaard, 2005; Woodgate et al., 2006] for discussion). The flow through the strait is highly variable in volume, temperature and salinity on a range of timescales [Woodgate et al., 2005a], and is believed to be driven by some combination of a pressure head acting from the Pacific to the Arctic, opposed by local wind effects, although the exact mechanisms are still unclear (see [Woodgate et al., 2005b]) for a discussion.). As part of an International Polar Year (IPY) study funded by NSF and supported with ship-time from NOAA, we have deployed an 8-mooring array in the Bering Strait (Figure 1) to study the physics of the driving mechanisms and to aid design of a monitoring system for the Strait region. Near-bottom moorings have been deployed in the Strait almost continuously since 1990. This new array (deployed for the first time in 2007) aims to provide the first year-round measurements of not just the near bottom water properties and flow, but also of the upper layers, which are believed to contribute significantly to the fluxes of heat and freshwater through the strait.

For more details, please see publications listed below, and our website http://psc.apl.washington.edu/BeringStrait.html

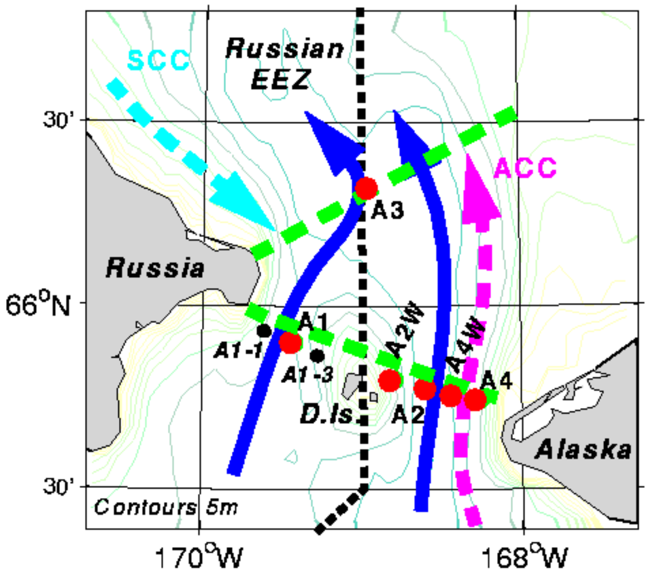

Figure 1: Detail of Bering Strait, with schematic flows, mooring locations (red and black dots) and proposed CTD lines (green). The main northward flow passes through both channels (dark blue arrows). Topography diverts the western channel flow eastward near site A3. The warm, fresh Alaskan Coastal Current (ACC) (pink dotted arrow) is present seasonally in the east. The cold, fresh Siberian Coastal Current (SCC) (light blue dotted arrow) is present in some years seasonally in the west. All these currents reverse on time scales of days to weeks. D.Is.= Diomede Islands. Black dotted line = EEZ (Exclusive Economic Zone).

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Transport of subarctic large copepods from the Oyashio area to the mixed water region by the coastal Oyashio intrusion

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The lateral transport of organic carbon in large grazing copepods (*Neocalanus cristatus*, *Neocalanus flemingeri*, *Neocalanus plumchrus* and *Eucalanus bungii*) from the Oyashio area to the mixed water region (MWR) by the coastal Oyashio intrusion was estimated using the data of VMPS (vertical multiple plankton sampler) and 1500 dbar-referred geostrophic transport from the CTD data of five cruises during June 2001 to April 2002 on a repeat observation section OICE (Oyashio Intensive observation line off Cape Erimo), which extends southeastward from Hokkaido Island, Japan. The transport to the MWR by the coastal Oyashio intrusion was estimated to be 5.3x10^{11} g C for the four species. Data from profiling floats also indicated that the copepods were advected from OICE to MWR by the coastal Oyashio intrusion within about 2 months. This transport is considered to be one of the significant sources of organic carbon in MWR, as it is larger than the amount of large zooplankton consumed by Pacific saury (*Cololabis saira*) in the MWR, one of the dominant copepod predators in this region. More detailed descriptions can be referred to Shimizu et al. (2009, *Fisheries Oceanography*, 18, 312–327).

Overturning circulation in the Sea of Okhotsk and the western North Pacific and its potential impacts on biogeochemical processes

Overturning circulation in the Sea of Okhotsk and the western North Pacific, and its potential impacts on biogeochemical processes

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Dr. Mitsudera presented a 3-dimentional model used to study overturning circulation in the Sea of Okhotsk and the western North Pacific, and variability within Dense Shelf Water (DSW) in this region. He explained the background and motivation for developing this model to incorporate the Intermediate-layer Iron Hypothesis. He described the phenomenon of the overturning, and presented results of experiments that help to understand what causes the intermediate layer variability. The Sea of Okhotsk is known to have the southernmost sea ice extent in the Northern Hemisphere; this is because the world coldest region is located just upstream of the Sea of Okhotsk. Ice formation there results in the heaviest water formed in the northern hemisphere. This water is ventilated to the intermediate layer at depths from 200m to 800m; it is called North Pacific Intermediate water, and drains and transports heat and materials to the deep ocean. Monsoon winds blow from the continent to the ocean. Therefore, even ice produced in the coastal area is transported offshore. The sea surface is always open in the coastal area contributing to the occurrence of polynyas, where sea ice is continuously produced. Because the sea ice is made of fresh water, the condensed salty water is rejected when sea ice is produced; this is called brine — dense cold water which settles over the continental shelf and forms DSW which then sinks to become intermediate water. In the Sea of Okhotsk this water is ventilated to 400 m depth. This causes overturning circulation between the surface layer and the intermediate layer, and DSW in the polynya is the driving force. A lot of iron is transported by DSW to the intermediate layer (200m to 500m deep) ~~by the DSW~~ along the western boundary. The intermediate layer is observed to be warming; this temperature increase (about 0.8^{o} C) is greatest at the western boundary of the Sea of Okhotsk. This increase in temperature in the intermediate layer is the greatest in the world. Large intermediate-layer iron transport was found in the Sea of Okhotsk. Dr. Mitsudera concluded that: large intermediate-layer iron transport was found in the Sea of Okhotsk; that wind forcing and buoyancy forcing (i.e. brine rejection & tidal mixing) are strongly coupled to form the overturning circulation in the Sea of Okhotsk; and that material circulation (CFC) is well reproduced in the model.

Advection off the West Greenland Shelf and Its Effect on Bloom Dynamics in the Labrador Sea

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The 2005 spring phytoplankton bloom in the Labrador Sea was investigated using Seaglider — an autonomous underwater vehicle equipped with hydrographic — bio-optical and oxygen sensors. The Labrador Sea blooms in distinct phases, two of which were observed by Seaglider: the north bloom and the central Labrador Sea bloom. The dominant north bloom and subsequent zooplankton growth are enabled by the advection of low-salinity water from West Greenland in the strong and eddy-rich separation of the boundary current. The glider observed high fluorescence and oxygen super-saturation within haline-stratified eddy-like features; higher fluorescence was observed at the edges than at the centers of eddies. In the central Labrador Sea, the bloom occurred in thermally stratified water. Two regions with elevated subsurface chlorophyll were also observed: a 5 m thin-layer in the southwest Labrador Current, and in the Labrador shelf-break front. The thin layer observations were consistent with vertical shearing of an initially thicker chlorophyll patch. Observations at the front showed high fluorescence down to 100 m depth and aligned with the isopycnals defining the front. The high-resolution Seaglider sampling across the entire Labrador Sea provides the first estimates of the scale-dependence of coincident biological and physical variables.

Variability of the Atlantic Sub-Polar Gyre

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The subpolar (SP) Atlantic is a fertile part of the global climate system and the global biosphere. To quote Bob Dickson, it is the ‘headwaters of the global overturning circulation’. It is an interface between Arctic and Atlantic oceans, yet the water-mass transformations within the subpolar band of latitudes between 50N and 65N are significant in themselves, in both the upper, buoyant waters and the dense deep overflow waters. Many global climate models are exceedingly sensitive (maybe too much so) to deep convection in the Labrador Sea, which plays a strong role in the global overturning circulation.

The SP latitudes contain some of the most intense primary productivity in their spring phytoplankton blooms, and an exceptionally active food chain. Connections between primary productivity and ocean physics are many and diverse. Surface, low-salinity waters stream south from the Arctic in boundary/shelf currents on both sides of Greenland (very roughly 100 milliSverdrups each of fresh water referenced to 34.8 ppt). The buoyant stability of these layers promotes rapid, short-lived spring blooms, notably the dominant bloom in the Labrador Sea southwest of Greenland (Williams, Rhines & Eriksen, *Deep-Sea Res.* 2009). This bloom feeds the dominant zooplankton growth (*Calanus finmarchicus*) of the region (Head *et al., Prog. Oceanogr.* 2003). Large decadal variability of the blooms and the fresh-water layers is observed (by satellite ocean color and *in situ* sampling, including recent Seaglider sections). Global warming is expected to continue increasing the supply of surface fresh water both locally and from Arctic export, and this is likely to have strong impact on upper ocean biology.

In the deep water, dense northern overflows in the Denmark Strait, Iceland Faroe Ridge, Faroe-Bank Channel and Wyville Thompson Ridge have been observed with increasing accuracy and coverage, and their variability traced throughout the subpolar gyre (e.g., Yashayaev, *Prog. Oceanogr.* 2007).

The ASOF (Arctic Subarctic Ocean Flux) program has focused on documenting passage transports and decadal variability of the ‘stable’ SP water masses, which relate to the fresh-water budget. Quantitative results remain difficult to obtain, yet great improvement in our knowledge of both the modes of transport and the transport numbers themselves continues to be made, with major mooring arrays in Davis Strait, Nares Strait, Fram Strait, the Norwegian Current, Barents Sea entrance, Faroe Bank Channel, Faroe-Shetland Channel, and Denmark Strait. In the Canadian Archipelago itself, several passages have been monitored for many years. The challenge of maintaining adequate observations into the future remains. Exploratory arrays have occupied Hudson Strait. Radically new technologies have been developed and proven in these passages and boundary currents: profiling moorings, ice-capable shelf moorings, 1st generation gliders measuring hydrography, oxygen and bio-optics, and now 2d generation gliders capable of working under sea ice with acoustic navigation, reaching full-ocean depths (6000m), having long duration (greater than 12 months), measuring turbulent microstructure and ADCP current shear. The global ARGO float program reached full strength (3000 floats) in 2007, and exploratory ARGO floats with nitrate sensors, improved oxygen and bio-optics probes have been deployed, including sites under sea-ice in Antarctica. 101 authors contributed detailed studies of the SP ocean to the 2008 volume: *Arctic-Subarctic Ocean Flux: defining the role of the northern seas in climate.* R.R. Dickson, J. Meincke & P.B. Rhines Eds., Springer, 736 pp.

The future of ASOF will include significant interaction with broad ecosystem research, and with focused biological programs. Examples of fruitful interaction of the physics and biology communities are already numerous, for example the Atlantic Bloom Experiment 2008 (C. Lee, this meeting), and the investigations into the rapidly changing provinces of the blue whiting fishery (Hatun, this meeting). Both of these programs use the new physics-based technologies of ASOF, and satellite sensing of altimetric upper-ocean currents, SST and ocean color.

Variability of physical circulation and ecosystems is strongly affected by advected low-salinity layers, whose origins include local run-off, sea-ice melt and the Arctic itself. Book-keeping of fresh water transport from the Arctic in the past 50 years has been possible from the dense hydrographic database (Curry & Mauritzen, *Science,* 2005). The effects extend to carbon uptake in the SP Atlantic from the atmosphere, if indications of the massive reduction in that uptake, coinciding with the increased advection from subtropics to SP gyre in the late 1990s, are an indication (Schuster & Watson, *J. Geophys. Res.,*2007).

Two prominent trends have been the strong decline in salinity in dense waters (Labrador Sea Water) from the 1970s to 1995, which involved an initial Great Salinity Anomaly and several later incursions of low-salinity waters from the Arctic. However mixing and circulation driven by winds and wintertime cooling at the sea-surface played a major role in both water-mass transformation and subpolar gyre circulation. The North Atlantic Oscillation (NAO) is prominent, yet by no means a complete, descriptor of atmospheric forcing.

The NAO index took on strongly positive values (strong northwest winds carrying cold air over the subpolar gyre from Arctic Canada), until 1996. Subsequent winters were much milder, and both deep convection and the surface gyre circulation relaxed. The second trend developed when Arctic dominance was replaced by subtropical dominance as warm, saline waters invaded the SP gyre from the south. As documented by Holliday *et al. Geophys. Res. Lett.* (2008), the upper few hundred meters of the eastern SP gyre were affected and time-series of the Atlantic Water entering the Nordic Seas, Barents Sea and Arctic Basin famously exhibited this warming (from the mid 1990s, continuing until recently). Hatun *et al., Science* (2005) argue that weakening of the cyclonic SP gyre was accompanied by a shrinkage westward, so that the ‘window’ for subtropical waters to flow northward was opened. Häkkinen & Rhines (*Science, 2004; J Geophys. Res.* 2009) show how sea-surface drifters and satellite altimetry support this chain of events.

The connection of these events with variability of the Atlantic Meridional Overturning Circulation (AMOC) is not yet well known. Many circulation and models exhibit a connection between Labrador Sea wintertime convection, SP gyre circulation and the AMOC. Yet, the competing, denser northern overflow waters are often under-represented in the climate-model AMOCs, so this connection remains tentative. Models need to be tested by comparing their full potential-temperature/salinity/meridional transport diagrams, including water-mass transformation and diapycnal transports, with observations (e.g., Bailey *et al., Climate Dyn.* 2005). Assimilation of data from the global ARGO and satellite altimetry observation network may make this possible.

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Sub-polar Gyre Variability and Its Effects on Blue Whiting

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Pronounced changes in marine fauna, extending from the English Channel in the south to the Barents Sea in the northeast and off Greenland in the northwest, have occurred in the late 1920s, the late 1960s and again in the late 1990s. We attribute these events to exchanges of subarctic and subtropical water masses in the north-eastern North Atlantic Ocean, associated with changes in the strength and extent of the subpolar gyre. These exchanges lead to variations in the influence exerted by the subarctic or Lusitanian biomes on the intermediate faunistic zone in the north-eastern Atlantic. This strong and persistent bottom-up bio-physical link is demonstrated using a numerical ocean general-circulation-model and data on three trophically connected levels in the food chain - phytoplankton, zooplankton and blue whiting.

We here show that the previously reported steady decline in phytoplankton abundance south of Iceland, interrupted only by a peak in the early 1980s (Reid et al. 1998), abruptly reversed in 1995. The phytoplankton abundance shifted back to the 1960s levels within only three years, and in the long-term perspective, the mid-1990s phytoplankton shift and increase was a remarkable event. Subtropical and subpolar water masses meet and mix in the waters west of Ireland. In terms relating to primary production, this region is a transition zone between the *seasonally mixed subtropical gyre biome* and the *subpolar biome* (Sarmiento et al. 2004). Somewhere along the transition zone between these biomes, there is a favourable compromise (corresponding to an appropriate mixed-layer depth) between nutrient and light limitation which causes increased mean primary production. As the subpolar gyre weakens, the confluence of the subarctic and subtropical water masses, and thus the transition zone, will shift northwards and westwards.

The abundance of *C. finmarchicus* in the waters south of Iceland generally increased from the early 1960s to 1995, only interrupted by a strong decline around 1980. After 1995, there was a marked reduction. The reduced Arctic-boreal influence after 1995 (weakening of the gyre) opened the way for an increase in the influence of subtropical water and its associated zooplankton fauna. The abundance of the *cold-temperate species assemblage* of indicator species (Beaugrand et al. 2002), extracted from a region between Ireland and Iceland (30°W-10°W, 54°N-63°N) covaries with the sub-polar gyre dynamics, showing very high values in the early 1960s, an intermediate peak around 1980 and very low values in the early 1990s followed by a subsequent increase. Furthermore, the abundances of ecologically important copepod species such as *Pseudocalanus, Acartia*, and *Oithona* in the region south of Iceland mentioned above are all significantly correlated to the gyre index. The effect of the gyre circulation on zooplankton has several possible explanations (Hátún et al. 2009a).

The spawning stock of blue whiting, an economically important pelagic gadoid in the North Atlantic Ocean, increased threefold after 1995. The reproductive success of the stock is largely determined during the very early stages of life, but little is known about the spawning dynamics of this species. We here show that the spawning distribution of blue whiting is variable, regulated by the hydrography west of the British Isles (Hátún et al. 2009b). When the North Atlantic subpolar gyre is strong and spreads its cold and fresh water masses east over the Rockall Plateau, the spawning is constrained along the European continental slope and in a southerly position near the Porcupine Bank. When the gyre is weak and conditions are relatively saline and warm, the spawning distribution moves northwards along the slope and especially westwards covering the Rockall Plateau.

The abundance of blue whiting in the Iceland-Faroe region is highly variable and this variability is also correlated with the gyre index (Hátún et al. 2005). The likely causes underlying this linkage are the variable total stock size and shifts in the migration pattern. The subpolar gyre can influence both processes either i) directly by regulating the currents and/or hydrographic conditions that influence behaviour and migration routes, or ii) indirectly via tropho-dynamics. These are discussed in Hátún et al. 2009a. The apparent link between the blue whiting stock dynamics (spawning distribution, stock size and migration pattern) and the subpolar gyre is the first step towards understanding the reproduction variability, which currently is the main challenge for appropriate management of this fish stock.

Recent advances in simulating the dynamics of the subpolar gyre suggests a potential for predicting the distribution of the main faunistic zones in the north-eastern Atlantic a few years into the future, which might facilitate a more rational management of the commercially important fisheries in this region.

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Autonomous Measurements of the 2008 North Atlantic Bloom

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The 2008 North Atlantic Spring Bloom Experiment (NAB08) employed a system of drifting floats, mobile gliders and ship-based measurements to resolve patch-scale physical and biological variability over the 3- month course of an entire bloom. Although both autonomous and ship-based elements were essential to achieving NAB08 goals, the autonomous system provided a novel perspective by employing long-range gliders to repeatedly survey the volume surrounding a drifting Lagrangian float, thus characterizing patch- scale bloom evolution. Integration of physical and biogeochemical sensors (temperature, conductivity, dissolved oxygen, chlorophyll and CDOM fluorescence, light transmission, optical backscatter, spectral light, and nitrate) and development of in situ calibration techniques were required to support this new autonomous approach. Energetic, small-scale eddy activity at the experiment site (southeast of Iceland, near the Joint Global Ocean Flux Study and Marine Light Mixed Layer sites) produced a swift, heterogeneous velocity field that challenged the gliders' operational abilities and drove refinements to the piloting techniques used to maintain float-following surveys. Although intentionally deployed outside of energetic eddies, floats and gliders were rapidly entrained into these features. Floats circulated within eddies near the start and end of the experiment, drifting generally northwest, across the basin, in-between. An eddy sampled late in the deployment provided particularly interesting signatures, with elevated biological signals manifest consistently in one quadrant. As measurements were collected in a parcel-following Lagrangian frame, this suggests energetic small-scale exchange process (such as vertical or lateral mixing) paired with fast-acting biological processes capable of modifying the newly entrained water as it navigates its path around the eddy. Despite this energetic kilometer-scale heterogeneity, broadly distributed platforms appeared to experience similar broad, long-timescale trends. Initial mixed layer depths exceeded 200 m, with gradual shoaling punctuated by periods of rapid, storm-driven deepening. In mid-April, a period of calm weather, rapid re-stratification and exponentially growing chlorophyll fluorescence marked the bloom's start. Although one-dimensional processes (e.g. diapycnal mixing and solar warming) clearly play important roles in producing the spring bloom, the rate and vertical extent of upper ocean re-stratification indicate that lateral mixing, perhaps wind- or eddy-driven exchange or the slumping of lateral density contrasts, play a more important role in re-stratifying the upper ocean. These important trigger events present a severe observational challenge as they take place at small (kilometers) spatial scales, are fully three-dimensional and episodic in time. The NAB08 efforts demonstrate how mobile, autonomous platforms can be exploited to resolve these events and their impact over the course of an entire bloom cycle.

Exchanges between the Barents Sea and the Arctic

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Current measurements have been carried out in a section between Norway and Bear Island where inflow of Atlantic Water has occurred since August 1997. The monitoring program has received financial support from different EU-projects: Variability of Exchanges in the Northern Seas (VEINS); Monitoring the Atlantic Inflow toward the Arctic (MAIA); Arctic-Subarctic Ocean Flux Array for European Climate - North (ASOF-N); and Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES). Most of the Atlantic Water flowing through the Barents Sea reaches the Arctic Ocean.

The mean velocity field shows the Atlantic inflow as a wide core that occupies most of the section, but the general picture is a velocity field that is dominated by large and frequent fluctuations. The key parameter — that to a large degree determines the spatial distribution of the velocity field — is change in sea level within sections that is induced by the local wind field. The main process is Ekman transport, through its ability to accumulate water thereby creating strong gradients of barotrophic pressure and associated currents. Southwest winds along the Norwegian coast will, in general, create wide inflows, while northeast winds will result in wide outflows, mainly in the northern parts. These flow regimes may be persistent for up to 2-3 weeks, and are related to the relative strength and lateral extension of the Icelandic low and the Arctic high, although the alignment of the local isobars must be considered to describe details of the flow.

The seasonal cycle of Atlantic inflow to the Barents Sea has also been investigated. Other than during the first year of measurements, higher transport during winter than summer is observed; this is related to barotrophic currents forced by sea level changes within the section induced by a shear in the cross-section wind stress. It is possible that variations in the remotely forced Norwegian-Atlantic Current also contribute. Seasonal variation within a section is not uniform, and the strongest seasonal signal is found in middle and northern parts.

Mean transport of Atlantic Water is estimated to be 1.7 Sv during winter and 1.3 Sv during summer, but there is a pronounced minimum in Atlantic inflow (or even outflow) in spring due to an annual event of northerly winds.

Workshop 3

Comparisons of Approaches to End-to-End Modeling of Marine Ecosystems

Zooplankton to top predator dynamics on a fine scale in the Eastern Bering Sea (FEAST)

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Dr. Ortiz presented the Bering Sea Model called FEAST (Forage and Euphausiid Abundance in Space and Time) — an upper trophic level model that includes zooplankton and fish. FEAST is a vertically-integrated model that connects to a lower trophic model, and also provides input to a fisheries and economic model. The flow of energy through forage fish is poorly understood; however, evidence suggests that the competition of forage fish for food, particularly for euphausiids, may be a key structural element to understanding upper trophic level variation in the Bering Sea (Napp; Aydin et al. 2006), and the connection between components at this level may be extremely tightly (Aydin and Mueter in press). ROMS accommodates the addition of biologically active state variables; these have served as a convenient point of departure for the creation of new biological models. FEAST implements a spatially-explicit forage fish/pollock model based within ROMS, which communicates directly with the NPZ model and allows for behaviors such as aggregation at fronts. This approach allows for depletion of primary and secondary production by all higher trophic levels, hence a simultaneous treatment of both top-down and bottom-up effects in the ensemble runs with euphausiids and pollock as the key interface between controlling mechanisms. The scale of 10km with 2km nested resolution for hotspots is critical to understanding foraging responses along fronts and for central-place foragers, and indices of prey patchiness have been developed from field data to examine finer scales of foraging. The FEAST model has several sub-components, developed separately and but then integrated:

1) The forage species component — models pollock with age structure, size structure, and bioenergetics applied to track both abundance, growth, and condition as state variables in each grid cell of the model. Key corroboration and tuning for FEAST was provided from the bioenergetics modeling and fieldwork. Other forage species (capelin, eulachon, sand lance, myctophids, squid and shrimp) abundances included multi-frequency differencing of acoustic surveys and functional foraging responses measured on these surveys. These latter species will be modeled using gradient movement and prey search rules, calibrated against field data.

2) The cod/ATF/salmon component: Pacific cod, arrow tooth flounder, and Pacific salmon are important predators of forage in the Bering Sea. Predation fields will be modeled from these species based on the functional foraging response component of this project, and scenarios of changing predator biomass will be incorporated into management evaluations. *Bird/mammal component*: the specific bird and mammal foraging retrospective analyses and fieldwork will be used to predict bird and mammal foraging success based on the forage fields produced by FEAST, and the direct measurements of bird and mammal diets will be used to calibrate/corroborate FEAST predictions of forage fields during the study years.

3) The economic component**:** Dynamic economic model components for pollock and cod has been implemented directly within the ecosystem model to provide a 2-way coupling that links fishing effort to abundance of target species. This coupling is used to simulate rates of fishing mortality, a critical feedback. This economic component forms a set of decision rules that depend on ex-vessel prices, input costs, stock dynamics, regulations, and climate. Catchability coefficients and other parameters in the decision rules are estimated from logbook data and biological

surveys. Trends in global prices for seafood, fuel, and other inputs are based on the IPCC climate scenarios. These dynamic models link variables that measure abundance/concentration of target species to fishing effort, and simultaneously, determine feedback rates of fishing mortality for the corresponding ecological model. Estimates of catch and landings from the integrated economic-ecological models are used to assess impacts of climate change on individual ports and sectors using a regional economic model for Alaska. An emphasis is placed on externalities specific to modeled carbon emission scenarios; for example, in relation to rising fuel costs in the future.

Improvements to the model include: predation by jellyfish; vertical movement; transition from passive to active movement; seabirds and marine mammal in coarse detail

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End-to-end Marine Ecosystem Models: Strategies, Applications, and Future Directions

Enrique Curchister, Institute of Marine and Coastal Sciences, *Rutgers* University (USA)

Dr. Curchister characterized the need for end-to-end models to help explore the relative roles of fishing and natural variability in the describing the current state of the world’s fisheries. One view is that many fisheries are teetering at the breaking point following dramatic declines resulting from overfishing. In 1950, 15% of the fish stocks were harvested to their maximum sustainable limits, while 95% were fished sustainably. In 2003, 32% of fish stocks had collapsed; while 39% were overfished; the remaining 29% were at the limit of sustainability. However, underpinning these declining fish stocks were natural phenomena such as the North Pacific regime shift — reflected in the catch composition during the 1970s — related to the Pacific Decadal Oscillation. These circumstances made clear the need for end-to-end models of marine ecosystems with earth system models as the overarching objective. The belief is that this can now be accomplished because the necessary components exist — improved numerical algorithms and computer power has encouraged assembling a multi-scale physics-to-fish-to-fishers model that includes 1) multi-scale ocean and atmospheric physics; 2) community-based lower trophic level biology; and 3) spatially explicit, full-life cycle individual-based higher trophic level biology. He described a general approach that uses tightly coupled models of circulation and biology — global circulation will be depicted using NCAR-CCSM; regional circulation will be depicted using ROMS. In terms of biological models: NEMURO will be used to depict lower trophic levels; multispecies IBM will be used to depict higher trophic levels. He then presented examples of coupled bio-physical models used to examine the California Current system. Curchister concluded by saying that a suite of physical models have been developed for the North Pacific Ocean that address the various scales of interest, from the sub-mesoscale to climate. These physical models are being tightly coupled with ecosystem models that include fish and fishers. The higher trophic levels (above zooplankton) are individual based. Links between regional and global climate are now being explored, including ecosystems models and the relative effects climate and fishing have on ecosystems.

Atlantis Ecosystem Models for the California Current

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The Atlantis California Current ecosystem model is built to address the impacts of climate, oceanography, nutrient dynamics, and spatial effects on a dynamic food web. The model extends from the US/Canada Border to Point Conception, California, and out to the 1200 m isobath. The trophic dynamics represent 55 functional groups in the food web, using nitrogen as a common currency between groups. Functional groups are typically comprised of pools of 1 to 10 species with similar ecological roles. General classes of functional groups include habitat-forming species like kelp, corals and sponges, as well as vertebrate consumers, benthic invertebrates, zooplankton, phytoplankton and detritus. The model is divided into 62 spatial zones, each with up to seven depth layers. This allows us to explicitly test hypotheses regarding migration, movement behavior, and spatial variation in productivity. The model is forced with daily hydrodynamic flows, salinity, and temperature outputs from a high-resolution Regional Ocean Modeling System (ROMS), allowing us to test the impacts that climate-driven changes in upwelling or coastal currents have on nutrients and primary productivity. Separate sub-modules simulate the dynamics of 32 fishing fleets or gear types. The generic Atlantis code is well developed at this time, and Fulton et al. (2003a, b, 2004a, b) have parameterized it for several systems in Australia. The parameterization for the California Current will be published as a NOAA Technical Memorandum and as a paper for *Ecological Modeling*.

As with any complex simulation model, Atlantis is not intended for making short-term tactical decisions (e.g. annual fishing mortality rates). However, Atlantis is an ideal operating model to be used in MSE, since it reproduces qualitative behavior of the system and exhibits a realistic range of dynamic responses. The ecosystem model can serve as a filter to identify which policies (e.g. decision rules based on ecological indicators) and methods (e.g. stock assessments that incorporate ecological indicators) are robust and which are flawed. Atlantis has been used to successfully identify ecological indicators for the SE Australian coast and a large bay near Melbourne, Australia (Fulton 2005).

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ATLANTIS Modeling in Norway - The Menu II Project

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There is a commitment by the Norwegian government to implement ecosystem-based management by developing management plans for marine ecosystems, and several multispecies models set up for (parts of) Norwegian marine ecosystems (MULTSPEC, Gadget, Ecopath). Through the MENU II project we will set up an ATLANTIS ecosystem model for the Barents and Norwegian seas with the aim to *Conduct a comparative modeling study of the structure, function and variability of marine ecosystems of Norway and the United States.* The sub-goals of this project are to: 1) Set up and parameterize different ecosystem models, 2) Develop ecosystem indicators for management and comparison, 3) Compare models output from within each ecosystem, 4) Compare the structure, function and variability of Norwegian and US ecosystems to determine what processes are fundamental to these ecosystems, 5) Improve our understanding of ecosystem processes, productivity and resilience to anthropogenic forcing such as climate change and fishing activities.

The MENU II project will run from 2009-2011, but the Northeast Atlantic ATLANTIS model will be a long-term tool for ecosystem-based advice and management in Norway.

End-to-End: Can the people and biology keep up with the computers?

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Dr. Rose posed the question: “Why physics to fishers or end-to-end models now?” and explored the issues and challenges related to this state-of-the-art approach to ecosystem modeling. He reported on the results of a recent workshop on this topic “Bridging the gap between lower and higher trophic levels”, and shared a few his professional insights. Physical models coupled with nutrient, phytoplankton, and zooplankton (NPZ) models and fish population models were developed separately and advances in each seemed out-of-phase over the past 50 years. However, the dynamics for these different components of the ecosystem converge at the level of zooplankton. Reasons why 'Physics to Fishers' modeling is now made possible include: advances in data collection to include spatially-detailed data, behavioral measurements, and continued increases in computing power. Parallel advances have been made in modeling, including: physics (meso-scale features in decadal runs); and fish behavior (individual-based, fine-scale observations). Documented phenomena within fishery science have illustrated the complexity of fish population dynamics, thereby further justifying the end-to-end modeling approach. Other papers have documented the seriousness of the recent declines in fish populations, such as "*Extinction on the High Seas*" (Malakoff 1997) and "*Fishing Down Aquatic Food Webs*" (Pauly et al. 2000). Rose cited several papers that suggest that part of the perceived crisis in fisheries management is due the reliance on the single-species approach and that an ecosystem-based approach to research and management should be pursued (whatever that means). Rose offered as one possible long-term solution the approach of using end-to-end modeling: such models would allow for bottom-up, top-down, and side-ways trophic controls; and allow for the effects of climate change on fish to be directly simulated. Dr. Rose concluded that: 1) marine ecosystem do not stop at zooplankton, nor can fish be modeled without considering what happens below; that 2) physics-to-fishers modeling can (should) be done, but only as a long-term solution; and that 3) technical (computing and biological), human, and institutional challenges will be involved.

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In Praise of Minimal Models of Fishery Ecosystems

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Dr. Essington posed the question: "Why and how do we model?" He then reviewed various applications of minimal models, and presented some of the challenges facing the development and functionality of "end-to-end" models. He offered a number of quotes that convey minimalistic thought: "*Art is a lie that makes us realize the truth, at least the truth that is given to us to understand"* — Pablo Picasso; "*Convenient approximations often bring you closer to comprehending the true nature of things*" — Murakami H. 1985; "*All models are wrong, but some are useful*" — Box, G. E. P. 1979; "*The value of modeling in fields like biology has not been to make precise predictions, but rather to provide clear caricatures of nature against which to test and expand experience*." — Walters, C.J. 1986.

He cited studies to emphasize that even as adults, we tend to learn best through oversimplified models. He went on to describe steps in the Minimal Modeling Approach: 1) Identify crucial process(es) using pattern recognition; 2) identify intended use and purpose of the model; and 3) develop the simplest possible model that incorporates the breadth (extent of interacting components) and depth (detail with which components are represented) of the system being modeled. He gave examples of minimal models used to model resilience in terrestrial landscapes for management purposes. End-to-end models are useful to examine the duality of anthropogentic impacts (such as climate and fisheries), while offering a unified treatment of both. They can also represent tactically operational models. The goals and fundamental challenges of developing minimal end-to-end modes are to: link ecosystem processes and population/community dynamics while incorporating human behavior and economics factors; and to understand how the population communicates with the ecosystem — this represents a fundamental challenge for ecologists (Levin 1998).

He stressed that even if the model physics are correct: 1) it is difficult to model complex adaptive ecosystems — where interactions are local, non-linear, and system dynamics are history-dependent; and 2) the system being modeled may also be influenced by human systems which introduce factors related to fleet dynamics, markets, and "surprises". A few of the complexities within "Simple Problems" can be observed by just considering predator prey interactions such as: switching response; behavioral mediated interactions; size based interactions; functional response; and energetic information relative to interaction strengths. Dr Essington concluded by pointing out that key uncertainties may be introduced as a function of ecological (spatial scale of food web connectedness or the strength of species interactions) and human/social factors (fleet behavior, socio-economic constraints, local vs. global market controls).

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