ESSAS Report Series Number 3

Report of the 2008 ESSAS Annual Science Meeting

With Sessions/Workshops on

Results from the 2007 Hokodate Workshops and Planning: Hotspots, Thresholds and Ice Models

The Importance of Advective Processes in Sub-Arctic Seas

Climate Forcing of Marine Ecosystems

And

Modeling Ecosystem Response

Halifax, Nova Scotia, Canada

15-19 September 2008

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November 2008

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1. Background

The 2008 ESSAS Annual Science Meeting (ASM) was held in Halifax, Nova Scotia, Canada from 15 to 17 September, and hosted by the Bedford Institute of Oceanography (B.I.O.). An annual meeting of the ESSAS Science Steering Committee (SSC) followed on September 18th and 19th. The annual science meeting was opened with welcoming remarks from Erica Head (Department of Fisheries and Oceans, B.I.O.) and ESSAS Co-chair (Professor George Hunt, University of Washington). A round of self-introductions by participants followed. Fifty-six participants attended from seven countries: Canada - 29; Denmark - 1; Iceland - 1; Japan – 4; Korea - 1; Norway – 5; Russia - 1; UK – 1; USA - 9) (Appendix 1).

Consistent with the goal of the ESSAS program — *to compare, quantify and predict the impact of climate variability on the productivity and sustainability of Sub-Arctic marine ecosystems* — the meeting agenda (Appendix 2) was divided into different sessions to present ongoing research efforts of ESSAS working groups (Appendices 3-6). Session 1 was convened by Professor Hunt to review results from workshops during the 2007 ESSAS Annual Science Meeting in Hakodate, Japan "*Hotspots, Thresholds, and Ice Models".* This included results from: long-term simulations of ice and ocean climate in the Bering Sea; examinations of thresholds in warming Sub-Arctic Seas; and delineations of hotspots of biodiversity and aggregation in Sub-Arctic Seas. Session 2 was a workshop convened by Ken Drinkwater to examine the importance of advective processes in Sub-Arctic Seas. Session 3 was a workshop convened by James Overland to examine climate forcing of marine ecosystems, and was a follow-up to one held in 2007 in Hakodate; it was designed to consider types of ecological responses to future climate change, to review IPCC models and their relevance to Sub-Arctic Seas, and to discuss down-scaling the results of these models to regional models. Session 4 was a workshop on modeling ecosystem response using ECOPATH. (Appendix 1, Schedule of Activities).

During the 2007 annual meeting in Hakodate, Japan, WG-3 decided to build the agenda for its workshop at the 2008 annual meeting around its work using a single model (ECOPATH) to compare a number of Sub-Arctic ecosystems. The rationale is that differences that emerge using a single model will more likely reflect differences in the systems being modeled than differences in the architecture of the model used. Consequently, the 2008 annual meeting workshop for WG-3 presents ECOPATH modeling results from: the Sea of Okhotsk, Oyashio Current, eastern Bering Sea, Labrador Shelf, West Greenland Sea, Icelandic Sea, and the Norwegian/Barents Sea. As well as comparisons of ECPATH modeling results from the Marine Ecosystems of Norway and the United States (MENU) project, and comparisons of downscaled climate change response for Sub-Arctic Seas.

The near-term objective is to apply a number of models to one or more system to examine differences in their ability to capture effects of climate forcing. The overarching goal for ESSAS is to develop predictive models of the response in Sub-Arctic marine ecosystems (WG-3) to the climate scenarios developed by the Regional Climate Prediction Working Group (WG-1), given the mechanisms believed to link ecosystem components (WG-2).

2. Session Reports

2.1. Session 1

Results from the 2007 Hakodate Workshops and Planning: Hotspots, Thresholds and Ice Models

Convener: George Hunt
University of Washington School of Aquatic and Fishery Sciences, USA

WG-2 on Bio-physical coupling held a half-day Workshop in Halifax, Nova Scotia, Canada in September 2008. The Workshop was intended to reprise progress on the "Thresholds" paper headed up by Dr. John Bengtson and the "Hotspots" paper headed up now by Dr. George Hunt as agreed to in Hakodate, in June 2007. We also had an invited presentation by Dr. Boris Worm of Dalhousie University on his work on biodiversity hotspots in lower latitude oceans. A rough draft of the hotspots paper is well underway. Also, as a follow-up to the Halifax meeting, Dr. Enrique Curchitser presented a talk on progress in the modeling of sea-ice cover in the Sub-Arctic Seas.

2.2. Session 2

The Importance of Advective Processes in Sub-Arctic Seas

Convener: Ken Drinkwater
Institute of Marine Research, Norway

At the 2007 ESSAS Meeting in Hakodate in Japan, plans were made for a workshop on the role of advection in Sub-Arctic Seas at the 2008 meeting. Its purpose was to review the various ways that transport processes affect marine ecosystems through presentations on the topic covering several different Sub-Arctic regions. These would also allow a comparison of advective processes between regions. In addition, and in line with continuing efforts to carry out comparisons between the Sub-Arctic and Antarctic regions, Dr. Sally Thorpe of BAS in Cambridge in the UK was invited to make a presentation on the role of advection in Antarctic waters. The workshop was held at the Bedford Institute of Oceanography in order to allow more Department of Fisheries and Oceans scientists to participate in the workshop with the hope that some of them will become involved in ESSAS activities in the future.

The meeting was opened with a few words of welcome by Dr. Mike Sinclair, director of the Bedford Institute followed by the convener, Dr. Ken Drinkwater of Norway, who outlined briefly the objectives of the workshop. Before addressing advection per se, the first presentation was that of Dr. Ken Frank (Canada) of the Bedford Institute, who discussed comparative studies giving results from recent work he and his colleagues have carried out primarily in the Northwest Atlantic. Such comparative studies focusing on finding large-scale patterns and then developing explanations or mechanisms have been labeled as macroecology. He presented results from several studies in the Pacific and Atlantic showing relationships between phytoplankton productivity and fish production suggesting bottom-up forcing. He also noted the problem of top down forcing citing the large declines in several size classes of fish on the Scotian Shelf off Nova Scotia. Finally he discussed results from a comparative study of the correlations between trophic levels for 47 regions in the Northern Hemisphere. The results show a positive latitudinal gradient with negative correlations (indicating top-down control) in the more northern regions and positive correlations (indicating more bottom-up control) in the south. Causes of this pattern were attributed to both decreasing temperatures and reductions in the number of species (biodiversity) northwards.

Dr. Thorpe (UK) discussed the role of advection on Antarctic krill, the dominant food source in the Southern Ocean. She began by discussing the physical oceanography whose main features are the clockwise Circumpolar Current, an anticlockwise coastal current, and eddy features largely associated with the geography and topography of the region. Seventy percent of the krill population around Antarctica is found in the southwest Atlantic sector and advection and retention of krill into this area play an important role in this distribution, shown from results in the vicinity of the island of South Georgia. Modeling efforts undertaken were then presented including physical models of advection and sea ice and biophysical models examining the advection and growth of krill. They have also included krill behavior in the models through random swimming. She finished with a brief description of the new ICED (Integrating Climate and Ecosystem Dynamics in the Southern Ocean) program within IMBER that is a follow on from the GLOBEC Southern Ocean program.

Dr. Andrew Pershing (USA) examined the advection of *Calanus finmarchicus* in the North Atlantic with special emphasis on different scales, spatially from patches to entire shelves and temporally from seasonal to inter-decadal. High concentrations of *C. finmarchicus* or patches are needed for whales to feed successfully with examples given from the Gulf of Maine off the northeast US. Internal waves and Langmuir circulation are possible physical mechanisms contributing to these patches. Within the Gulf of Maine, advection of zooplankton by the currents was shown to be important at spatial scales of kilometers and weeks but at the larger Gulf scale production seemed to dominate over advection. Strong correlations in zooplankton on the scale of the NW Atlantic shelves were found indicating common responses. There is also some evidence for propagation (advection?) of zooplankton within the Gulf of Maine and into the Middle Atlantic Bight. Examination of initial boundary conditions, sea surface temperatures and surface chlorophyll levels on inter-annual variability of *C. finmarchicus* within the Gulf indicated that the first two factors had the strongest influence.

Dr. Orio Yamamura (Japan) discussed the role of tidal currents in supplying prey to the offshore Oyashio Shelf Region off northern Japan. Walleye pollock spawn in the inshore regions (Funaka Bay) of Hokkaido and then feed in the offshore regions off the east coast of Hokkaido. Biophysical models indicated that the zooplankton populations in these offshore regions would be depleted by the feeding of the pollock and the pollock would subsequently crash without a continual supply of zooplankton. This led to investigations into possible advective mechanisms that could supply the zooplankton. Field surveys coupled with modeling pointed out that tidal exchange due to cross shelf currents and tidal mixing were sufficient to transport zooplankton from off the shelf into the feeding areas of the pollock. Dr. Yamamura's talk was not presented at BIO but rather on Wednesday at the Lord Nelson due to his flight being delayed by a day because of poor weather.

Dr. George Hunt (USA) presented examples of the role of advection on the Bering Sea. Of particular importance are the inflows to the Bering Sea through the Aleutian Passes. In those such as Amukta Pass that are not too deep or too shallow the strong current shears mix nutrients vertically. This results in high nutrient concentrations near the sea surface that are advected into the Bering Sea where they promote increased primary production. High zooplankton concentrations near the passes also attract huge concentrations of feeding seabirds as well as whales. Advection northward through the Bering Sea is important as a source of both nutrients and freshwater to the Arctic. Tides generate residual currents such as around the Pribolof Islands that can lead to longer than usual residence times for the local biota. Inter-annual changes in wind induced circulation patterns were shown to account for difference in larval drift, which in turn lead to significant differences in recruitment levels of flatfish species.

The final three papers dealt with egg and larval drift. Dr. Kai Wieland (Denmark) discussed the effects of the drift of cod eggs and larvae between Iceland and Greenland in a presentation delivered by K. Drinkwater. Surveys have shown that eggs spawned off SW and western Iceland drift towards East Greenland. Those that take a more westerly route towards Greenland as opposite to a more northern path are more likely to survive. While eggs and larvae have been shown in past studies to drift northwards along West Greenland, in recent years few eggs or larvae have been observed past 62°N. Modeling advection of shrimp larvae suggested northward drift by the residual currents but this would require s southward back-migration of the adults, which has not been observed. Dr. David Brickman (Canada) presented studies of the drift of cod eggs and larvae around Iceland. Based on genetics and otolith shape, the cod from the south side of the island are different than those in the north. Cod spawned in the south, however, drift to the north side where they reside as juveniles. A bio-physical model of the drift of cod eggs and larvae was described that is able to recreate the observed drift and distribution patterns. Dr. Trond Kristiansen (Norway) emphasized the importance of vertical structure in modeling the drift of cod eggs and larvae based on studies off Norway. Cod mainly spawn in the Lofoten area off Western Norway and drift northward into the Barents Sea. The individual based model used examined the effects of temperature, prey concentrations and light levels on the drift and growth of the cod larvae. The vertical location of the larvae is a balance between high food concentrations but high predation near surface and lower food but less predation deeper in the water column. Larval behavior will have to be incorporated in drift studies in order to adequately represent reality.

It was clear from the presentations that advection strongly influences the biota in all of the regions discussed. Special attention was paid to the transport of fish eggs and larvae by the residual circulation and for inter-annual variability due to changes in the winds. Advection also was shown to affect nutrient levels, heat and freshwater content, and zooplankton concentrations. The relative importance of advection on zooplankton depends upon both the spatial and temporal scales one is looking at. Further comparison of advection and advective processes and their effects should be carried out between different Sub-Arctic regions and between the Sub-Arctic and Antarctic regions.

2.3. Session 3

Climate Forcing of Marine Ecosystems

Convener: James Overland
NOAA Pacific Marine Environmental Laboratory, USA

The morning session was devoted to the application of future climate projections from International Panel on Climate Change (IPCC AR4) models to ESSAS regions. Ken Drinkwater set the context with a talk on ecosystem responses to climate forcing in North Atlantic Sub-Arctic Seas. He showed examples where the type of ecosystem response to increased temperature is location-dependent. Different seas are nearer or further in time from potential threshold limits of major bio-geographic or food web changes for specific species.

During the balance of the morning, James Overland and Vladimir Kattsov gave presentations related to the Report from Working Group I on climate model selection. Based on multiple analyses, WG1 has concluded that the IPCC 4th Report models have utility for climate projections out to 2050 for ESSAS seas. The projections, however, vary based on model, location, variable, and evaluation metric. WG1 concluded that there is no one best model. An approach is to determine whether certain models represent outliers when compared to observational data from the 20th century, and then to excluded them from further analysis. It is important to develop observational constraints based on how model hind-casts compare with late twentieth century data in terms of matching means, inter-annual variance, and annual cycles of temperature and pressure. A meta-analysis (comparison of independent studies) was conducted to recommend a subset of models for regional climate projections. Rather than relying on a single model, at least 3-5 models should be considered in any climate projection to account for model-to-model uncertainty. This is the major source of uncertainty in projections out to 2050. Out to 2100, the choice of which economic/social scenario for different greenhouse emissions is the major source of uncertainty.

Loss of sea ice — 38% of summer-sea ice in the central Arctic during 2007 and 2008 — is occurring faster than expected from IPCC projections. This results from the influence of natural variability, in addition to emerging climate forcing from anthropogenic activities, and ice/ocean feedbacks. ESSAS seas, however, which respond to winter and spring ice growth, are mostly decoupled from this summer loss of Arctic multi-year sea ice. In upcoming decades, ESSAS seas will still be dominated by multi-annual to decadal natural variability in sea ice, temperature, winds and related variables.

The afternoon was devoted to the related issue of downscaling, i.e. how to infer local scale 0(10 km) climate impacts based on the large scale 0(200 km) projections from IPCC models. Two approaches noted by John Walsh are: 1) a statistical fit of observational data to IPCC and NCAR reanalysis fields of variables; and 2) the use of high resolution numerical ocean models driven by boundary conditions from IPCC projections (dynamical downscaling). Foreman presented an application of statistical downscaling for coastal winds. Enrique Curchitser, Simon Prisensberg, and Paul Budgell discussed regional ocean models, and approaches to dynamical downscaling. A final discussion by Mike Foreman concluded that for ESSAS purposes the dynamical downscaling approach is necessary to capture local oceanographic features such as fronts, current jets, and eddies.

2.4. Session 4

Modeling Ecosystem Response

Conveners:

Bernard Megrey[1], Shin-ichi Ito[2], and Kenneth Rose[3]
[1]NOAA Alaska Fisheries Science Center, USA
[2]Tohoku, National Fisheries Research Institute, Japan
[3]Louisiana State University, USA

Rationale

The charge of WG3 is to model marine ecosystem response. Understanding must be achieved, however, before modeling can begin. A necessary first step toward understanding any marine ecosystem (and its response) is to determine its community structure and function and its variability. Obtaining such understanding has proved difficult because of the complexity of marine ecosystems and its many interacting components

Testing hypotheses by conducting in situ *manipulative experiments at the scale of ocean basins is impractical and conclusive cause-and-effect evidence of underlying mechanisms is not possible. The comparative approach is useful in such situations. Comparisons can identify the main internal and external variables of the system, potential gaps in knowledge in one system compared to others, comparable key species or species assemblages, and comparable trophic levels and food-web structures.*

Comparisons allow the opportunity to take a broad perspective which provides the ability to draw generalizations, determine what is fundamental to ecosystems in general and what is unique to particular ecosystems, and provide new insights into mechanisms through which ecosystems respond to physical forcing

Objective

The objective of the workshop was to take a very basic first level approach. We began WG3 activity by comparing Sub-Arctic marine ecosystems by applying one common modeling approach to multiple ecosystems using the Ecopath modeling paradigm (EwE).

An ecosystem/Ecopath presentation rubric was supplied to presenters to help facilitate comparisons among the various ESSAS ecosystems. This included items such as the physical background and setting, geography (latitude and longitude boundaries, surface area, and average depth), climate (major seasonal, multiyear and decadal influences), hydrography and bathymetry (major currents and circulation patterns and significant aspects of bathymetry), the role of ice? (is ice important? what role does it play?), biological background and setting, nutrients (major nutrients, limiting nutrients, range or annual average levels), primary producers (community composition/dominate taxa, annual production cycle, maximum/average production rates, total primary production etc), zooplankton (community composition/dominate taxa, maximum/average production rates etc), benthos (community composition/dominate taxa, biomass estimates or trends), fish (community composition/dominate taxa, biomass estimates or trends, catch trends of top 5 species, total catch over past 5 years), seabirds (community composition/dominate taxa, biomass estimates or trends), marine mammals (community composition/dominate taxa, biomass estimates or trends, catch trends of top 5 species), trophic interactions (major energy/mass pathways, trophic bottlenecks, etc), a trophic food web connection diagram from Ecopath software, fisheries and management systems, major natural and anthropogenic drivers, critical factors that cause ecosystem change, and preparation of a trophic linkage diagram. Presenters were also requested to deliver a version of their Ecopath model so that it could be archived within the ESSAS website.

Presentations

Regrets: Several participants that were scheduled to appear had to offer their regrets. These included co-chairs Shin-ichi Ito and Kenneth Rose as well as Vladimir Radchenko, Kerim Aydin, and Astrid Jarre. WG3 did have the benefit of unanticipated presentations from Orio Yamamura and Yasunori Sakurai. The workshop agenda is presented in End Note I.

Since WG3 was at the end of three days of workshops, the agenda was dynamic as we tried to accommodate unanticipated presentations as well as carryovers from the previous two days. The following description does not follow the organized agenda in Endnote I because of the reason mentioned earlier.

Presentations started with Orio Yamamura’s report on “Advective supply of offshore prey into the continental shelves in the Oyashio area: the role of tidal currents”. This was followed by an analysis by Michio J, Kishi on the application of different lower tropic levels marine ecosystem models, results from a side-by-side comparison of various ecosystem configurations and conclusions about the benefits of comparative analysis. After these, Bernard A. Megrey gave a presentation on lessons learned from the ESSAS-sponsored Marine Ecosystems of Norway and the US (MENU) project.

These were followed by individual Ecopath presentation on various ESSAS ecosystems including the Norwegian/Barents Sea (Skaret), eastern Newfoundland Shelf (Bundy), eastern Bering Sea (Aydin – delivered by Bernard A. Megrey), Icelandic Sea (Astthorsson), western Greenland Sea (Jarre – delivered by Kai Weiland), and the Oyashio-Kuroshio current region (Hakamada). These were followed by a presentation by Budgell on a comparison of ice dynamics using two versions of the ROMS model for the Barents and eastern Bering Sea and an unanticipated presentation by Yasunori Sakurai on the effects of sea ice on the fate of walleye pollock. For the most part, all presenters on ESSAS ecosystems using EwE conformed to the suggested presentation rubric to varying levels depending on the information they had at hand.

The workshop ended with a discussion session focused on the following questions designed to stimulate discussion.

Q1: What is similar?

Q2: What is different?

Q3: Which systems should be considered for comparison?

Q4: Should other approaches, other than Ecopath or the meeting template, be considered?

Q5: Is it possible to compare ecosystem models without considering decisions made by the modeler? How does that impact interpretation or ability to compare?

Q6: Are results from EwE, as a first step, sufficient to effectively compare ESSAS ecosystems – considering Q5 and consequences for the number of species and metrics derived from them?

Q7: How do we foster multidisciplinary and international collaborations required to carry out comparisons?

The consensus from the audience was that the session was received well and moved forward the goals of ESSAS as they concerned ecosystem comparisons.

Outcomes and Action Plan

Plans were discussed to take the workshop results and prepare a manuscript to submit for publication in a peer-reviewed publication. A follow-up meeting was scheduled for the following morning. At this meeting, it was decided to prepare a data catalogue to determine if sufficient information was available to prepare a paper on comparisons of ESSAS ecosystems for submission to a peer-reviewed publication outlet. Megrey will prepare a template of available information products useful for comparisons and distribute it to representatives from individual ecosystems. From the catalogue, an evaluation will be made as to the likelihood of a suitable publication arising from the information gathered. Plans are in place for Megrey and Hunt to meet with Radchenko at the October PICES in Dalian China to gauge the Russian interest to include the Sea of Okhotsk ecosystem in the comparison.

Finally, WG3 prepared a proposal to GLOBEC to fund an inter-sessional workshop to coordinate the preparation of an end-to-end marine ecosystem model (see End Note II).

3. References

Hunt, G. L., Jr. and K. Drinkwater (Compilers) 2007. Report of the ESSAS Workshop: Development of Methods for Comparisons of the Sub-Arctic Seas, St. Petersburg, Russia, 12-14 June 2006. ESSAS Report Series 1, 47pp.

4. Acknowledgments

We thank the attendees at the ESSAS Halifax Workshops for their active participation in discussions and for their comments on earlier drafts of this report. Special thanks go to the Bedford Institute of Oceanography (B.I.O.) for hosting this meeting — including an informative visit to the Institute followed by a delightful reception for participants — and to Dr. Erica Head (Department of Fisheries and Oceans, B.I.O.) for her support and efforts in arranging the venue and meeting logistics. We thank the North Pacific Research Board, PICES, and the GLOBEC International Project Office for their financial support of the workshop. The Research Council of Norway and NESSAS supported several of the Norwegian participants, and the U.S. National Science Foundation, Office of Polar Programs supported participation by scientists from the Bering Ecosystem Study (BEST) program.

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Appendix 2: Agenda / Schedule of Activities

2008 ESSAS Annual Science and SSC Meetings

15 - 19 September 2008

Lord Nelson Hotel, Halifax, Nova Scotia, Canada

Monday 15 September

Admiral Room

09:00 Welcome from Erica Head (Department of Fisheries and Oceans, Canada, Bedford Institute of Oceanography) Local Host

09:10 Welcome from George Hunt (University of Washington, USA)

09:15: **SESSION 1: Results from the 2007 Hakodate Workshops and Planning: Hotspots, Thresholds and Ice Models** (**Convener - George Hunt)**

09:15: Enrique Curchitser (Rutgers University, USA) - *A 50-year simulation of ice and ocean climate in the Bering Sea*

09:45: John Bengtson (NOAA National Marine Mammal Laboratory, USA) - *Thresholds in warming Sub-Arctic Seas*

10:15: George Hunt - *Hotspots of biodiversity and aggregation in the Sub-Arctic Seas*

10:45: Break

11:15: Invited Speaker – Boris Worm (Dalhousie University, Canada) – *Marine biodiversity hotspots: What have we learned so far*?

11:45: Discussion

12:00: Lunch Break

13:00: Bus from the Lord Nelson Hotel to the Bedford Institute of Oceanography (B.I.O.)

B.I.O. Main Auditorium

13:45: Welcome to the B.I.O.

14:00: **SESSION 2: Workshop on the Importance of Advective Processes in Sub-Arctic Seas** (**Convener - Ken Drinkwater, Institute of Marine Research, Bergen, Norway)**

14:00: Ken Drinkwater - Introduction

14:05: Invited Speaker - Ken Frank (Department of Fisheries and Oceans, B.I.O., Canada) - *Comparative ecology of marine ecosystems*

14:35: Invited Speaker - Sally Thorpe (British Antarctic Survey, UK) - *Modeling the life cycle of Antarctic krill: the importance of advection*

15:05 **Break**

15:25 Invited Speaker - Andrew Pershing (University of Maine, USA) - *Influence of advection on Calanus finmarchicus abundance across multiple scales*

15:45: Invited Speaker - Orio Yamamura (Hokkaido National Fisheries Research Institute, Japan) - *Advective supply of offshore prey into the continental shelves in the Oyashio area: the role of tidal currents*

16:00: Invited Speaker - George Hunt, Phyllis Stabeno (Pacific Marine Environmental Laboratory, USA) and Rebecca Woodgate (Applied Physics Laboratory, University of Washington) – *Advective processes in the Bering Sea*

16:15: Invited Speaker - Kai Wieland (Technical University of Denmark/Danish Institute for Fisheries Research, Denmark) (given by Ken Drinkwater) – *Effects of advection on the West Greenland Shelf*

16:30: Invited Speaker - Dave Brickman (B.I.O., Canada) - *Larval drift of the Icelandic cod*

16:45: Invited Speaker - Trond Kristiansen (Institute of Marine Research, Norway) - *Larval drift into the Barents Sea of NE Arctic Cod*

17:00: Ken Drinkwater - Concluding Remarks

Following the Workshop there will be a RECEPTION at B.I.O. in the “Iceberg” area

Tuesday 16 September

Admiral Room

SESSION 3: Workshop on Climate Forcing of Marine Ecosystems. Convener: James Overland (NOAA Pacific Marine Environmental Laboratory, USA)

09:00: Introduction to Workshop – Jim Overland

09:30: Invited Speaker - Ken Drinkwater - *Ecosystem responses to climate forcing in the Barents and other North Atlantic Sub-Arctic Seas*

10:00: **Break**

10:30: Invited Speaker - Vladimir Kattsov (Voeikov Main Geophysical Observatory, Russia) - *Climate prediction: IPCC 4th Assessment Report and beyond*

11:10: James Overland, John Walsh (University of Alaska, USA) and Vladimir Kattsov - *Results of the ESSAS Panel on climate model selection*

11:40 Open Discussion

12:00-13:30 Lunch

13:30: Invited Speaker - John. Walsh (given by James Overland) – *Review of statistical downscaling to regional and local scales*

14:00: Invited Speaker - Mike Foreman (Department of Fisheries and Oceans, Canada) - *Statistical and dynamical downscaling: examples and strategies for the Northeast Pacific*

14:30: **Break**

15:00: Invited Speaker - Enrique Curchitser - *Downscaling climate simulations using a fully-coupled global/regional model*

15:30: Invited Speaker - Simon Prinsenberg (Department of Fisheries and Oceans, B.I.O., Canada) - *Physical oceanographic modeling the Canadian east coast shelves*

16:00: Invited Speaker - Paul Budgell (Institute of Marine Research, Norway) - *Validation of climate downscaling scenarios for the Nordic and Barents Seas*

16:30: Invited Speaker - Mike Foreman - Summary and discussion: *Strengths and weaknesses in recent regional ocean modeling*

17:00: **Adjourn**

19:00: Group Dinner at the **Tap Room** (lobster, mussels and other local delicacies)

Wednesday 17 September

Admiral Room

SESSION 4: Workshop on Modeling Ecosystem Response (Conveners: Bernard Megrey, NOAA Alaska Fisheries Science Center, USA; Shin-ichi Ito, Tohoku, National Fisheries Research Institute, Japan; and Kenneth Rose, Louisiana State University, USA)

09:00: Bernard Megrey and Ken Rose - Introduction

09:10: Invited Speaker - Michio J. Kishi, (Hokkaido University, Japan) - *Comparison of Simulated Particle Fluxes using NEMURO and other ecosystem models in the western North Pacific*

09:40: Bernard Megrey - *MENU ECOPATH comparisons: What did we learn?*

10:00 Kenneth Rose - *Can we compare models without also considering the modeler?*

10:20: **Break**

11:00: **ECOPATH Regional Presentations**

11:00: Invited Speaker - Georg Skaret (Institute of Marine Research, Bergen, Norway) – *ECOPATH analysis of the Barents Sea Ecosystem*

11:20: Invited Speaker - Alida Bundy (Department of Fisheries and Oceans, B.I.O., Canada) - *ECOPATH analysis of the Labrador Shelf ecosystem*

11:40: Invited Speaker - Kerim Aydin (NOAA Alaska Fisheries Science Center, USA) - *ECOPATH analysis of the Eastern Bering Sea ecosystem*

12:00-13:30: Lunch

13:30: Invited Speaker - Vladimir Radchenko (Sakhalin Research Institute of Fisheries and Oceanography (SakhNIRO), Russia) - *ECOPATH analysis of the Okhotsk Sea ecosystem*

13:50: Invited Speaker - Olafur S. Astthorsson (Marine Research Institute, Iceland) - *ECOPATH analysis of the Iceland Sea ecosystem*

14:10: Invited Speaker - Astrid Jarre (University of Cape Town, South Africa) (given by Kai Wieland) - *ECOPATH analysis of the West Greenland ecosystem*

14:30: Invited Speaker - Takashi Hakamada (Institute of Cetacean Research, Japan) - *ECOPATH analysis of the Oyashio Current ecosytem*

14:50: Invited Speaker - Enrique Curchitser and Paul Budgell - *A comparison of sea ice conditions in Sub-Arctic Seas over the last 50 years*

15:10: **Break**

15:40: Open Discussion - *What is similar? What is different? Which systems should be considered for comparison? By what method?*

16:40: Summary of ESSAS Annual Science Meeting and closing remarks (George Hunt, Ken Drinkwater)

Thursday, 18 September

Belle Isle Room

09:00: **Discussion Session for WG-3, Modeling Ecosystem Responses: Future Directions of ESSAS WG-3 (Moderators: Bernard Megrey and Kenneth Rose)**

10:30: **Break**

12:30: **Adjourn**

Thursday and Friday, 18 and 19 September

Vanguard 1 Room

09:00: **ESSAS SSC and invited guests**: Agenda to be provided
10:30: Break
12:30: Lunch
14:00: Reconvene
15:30: Break
17:30: Adjourn

Appendix 3: Extended Abstracts of Presentations

Session 1

Results from the 2007 Hakodate Workshops and Planning: Hotspots, Thresholds and Ice Models

Convener: George Hunt
School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA.

A 50-year simulation of ice and ocean climate in the Bering Sea

Enrique Curchitser
Rutgers University, USA

Thresholds in warming Sub-Arctic Seas

John Bengtson
NOAA National Marine Mammal Laboratory, USA

Hotspots of biodiversity and aggregation in the Sub-Arctic Seas

George L. Hunt, Jr.

School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA

The Sub-Arctic Seas support some of the greatest aggregations of marine birds and mammals in the Northern Hemisphere. In most cases, the distribution of breeding colonies, rookeries and haul-out sites are well documented. However, the information on the distribution and abundance of top predators at sea is scattered. Thus, it is of value to both review the mechanisms responsible for these aggregations, and to summarize what is known about the most important sites of aggregation in the Sub-Arctic Seas.

The identification of conservation hotspots in marine habitats has lagged those in the terrestrial realm. Among the first mention of biodiversity hotspots in marine environments, were tropical reefs and equatorial waters where biodiversity of large predatory fishes was high. However, in the high-latitude seas, biodiversity is most often low, but those species that are present can be in found in immense numbers in restricted areas, thus increasing their vulnerability to a variety of environmental insults.

The idea that aggregations of top predators should be considered as hot spots in the ocean was first broached by Cairns and Schneider (1980). The concept of aggregation hotspots in ocean environments was further explored by Sydeman et al. (2006) in a special issue of Deep-Sea Research Part II that was devoted to aggregation hotspots in the North Pacific Ocean. They, and several other authors in the volume, discussed the importance of areas where top predators concentrate to forage. These hotspots of trophic transfer vary in spatial scale from oceanic fronts crossing large portions the North Pacific, to eddies, heads of submarine canyons, and features where forage fish concentrate on a predictable basis.

There is a need to identify areas of high trophic transfer, *aggregation hotspots*, in the Sub-Arctic Seas, as these may be important for the support of the large colonies and rookeries of breeding marine birds and mammals. In addition, major portions of the world population of several species of seabirds and marine mammals that breed in the low latitudes or the Southern Hemisphere migrate to high latitude waters in the Northern Hemisphere to forage in the austral winter. Aggregation hotspots provide the chance to investigate the mechanisms essential for supporting trophic transfer to marine animals with high metabolic demands, and their vulnerabilities to disruption (e.g., Table 1). When marine conservation efforts include the establishment of marine protected areas, identification of hotspots, whether they are areas of enhanced species richness or of aggregations of foraging predators, must be a first step.

In this paper, I examine the mechanisms that result in aggregation hotspots, the spatial and temporal scales at which the various types of aggregation hotspots exist, and the distribution of different types of aggregation hotspots in the Sub-Arctic Seas.

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Cairns, D.K. & Schneider, D.C. 1990. Hot spots in cold water: feeding habitat selection by Thick-billed Murres. Studies in Avian Biology 14: 52-60.

Sydeman, W.J., Brodeur, R.D., Bychkov, A.S., Grimes, C.B., McKinnell, S.M. (eds.), 2006. Top predator “hotspots” in the North Pacific. Deep-Sea Research Part II 53 (3-4).

Table 1. Small-scale, process-oriented studies of seabird foraging in the Bering Sea and Aleutian Islands

Species or species group	Location	Physical Mechanism	Prey	Reference
Multiple species	Pribilof Islands	Tidal front	Unknown	Kinder et al., 1983
Multiple species	SE Bering Sea	Oceanographic fronts	Unknown	Schneider et al., 1987
Murres	St. Matthew Island	Tidal flow over a reef	Euphausiids	Hunt et al., 1988
Least auklets	Chirikov Basin	Front	Copepods	Hunt & Harrison, 1990
Multiple species	Pribilof Islands	Tidal Front	Euphausiids, and other	Schneider et al., 1990
Least auklets	St. Lawrence Island	Tidal front and pycnocline	Copepods	Hunt et al., 1990
Multiple species	Chirikov Basin	Grey Whale mud plumes	Benthic amphipods	Obst & Hunt, 1990
Murres	St. George Island	Tidal flow over a reef	Euphausiids	Coyle et al., 1992
Auklets	Bering Sea & Aleutian Is.	Various (a review)	N/A	Hunt et al., 1993
Murres	Pribilof Islands	Tidal front	Forage fish?	Decker & Hunt, 1996
Shearwaters	Pribilof Islands	Basins in reefs	Euphausiids	Hunt et al., 1996
Least auklets	Bering Sea	Various (a review)	N/A	Hunt, 1997
Least, crested & parakeet auklets	Delarof Islands, Aleutian Archipelago	Tidal flow over reef; convergence front	Copepods, euphausiids, other	Hunt et al., 1998
Multiple species	Anadyr Current, Chirikov Basin	Convergence fronts & passage over a bank	Copepods, euphausiids	Russell et al., 1999
Murres	Pribilof Domain	pycnocline	Forage fish?	Swartzman et al., 1999
Multiple Species	Central & eastern Aleutian passes	Tidal currents impinging on reefs; convergences	Copepods, euphausiids	Ladd et al., 2005
Multiple species	Central and eastern Aleutian passes	Tidal currents impinging on reefs; convergences	Copepods, euphausiids	Jahncke et al., 2005b
Shearwaters, fulmars	Eastern Aleutians	Tidal currents, convergences	Euphausiids	Vlietstra et al., 2005
Shearwaters	Inner front, EBS	Structural front	Euphausiids	Jahncke et al., 2005a
Multiple species	Eastern & central Aleutian Islands	Tidal currents, fronts	Copepods, euphausiids, other	Renner et al., 2008

Marine biodiversity hotspots: What have we learned so far?

Boris Worm
Dalhousie University, Canada

Session 2

Workshop on the Importance of Advective Processes in Sub-Arctic Seas

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

Modeling the life cycle of Antarctic krill: the importance of advection

Sally Thorpe
British Antarctic Survey

The Southern Ocean is a key component of the global ocean circulation system. It connects the three major world oceans transferring between them heat, salt and nutrients. This physical connectivity has ecological importance in terms of population connection and distribution. The food webs in the Southern Ocean are typically short, often relying on one particular key species to provide the link from primary production to higher predators. The species varies according to location - here we focus on the food web centered on Antarctic krill, *Euphausia superba* Dana. A relatively small, long-lived (up to 7 years) crustacean, it forms a key prey item of many higher marine predators particularly in the southwest Atlantic sector of the Southern Ocean where a large proportion of the circumpolar population of krill is found (Atkinson et al, 2008). Antarctic krill are vulnerable to physical forcing, particularly in the early life stages where not only the ocean but also sea ice provides a critical habitat. Field studies around South Georgia, an island in the north-east Scotia Sea, have shown that krill can be concentrated in frontal jets (Murphy et al, 2004). A comparison of the krill influx into the region with predator consumption and krill growth data demonstrated that the krill influx can at times match the local production and thus advection can be important for sustaining the local ecosystem (Hofmann & Murphy, 2004). Modeling studies have examined the temporal variability in the advection pathways to South Georgia; the probability and timing of krill reaching South Georgia can show large fluctuations particularly when the sea ice habitat is included (Thorpe et al, 2007). At a circumpolar scale, the association of the early life stages of krill with sea ice can substantially alter the oceanic advective pathways creating areas of retention and regions of more rapid transfer (Fig. 1).

We are currently developing a coupled life cycle model for Antarctic krill in which functions for egg development, growth and spawning will be embedded into our advection model. This will allow us to identify key regions in the circumpolar Southern Ocean for the life stages of krill and provide further insight into the importance of advection on the distribution of the species.

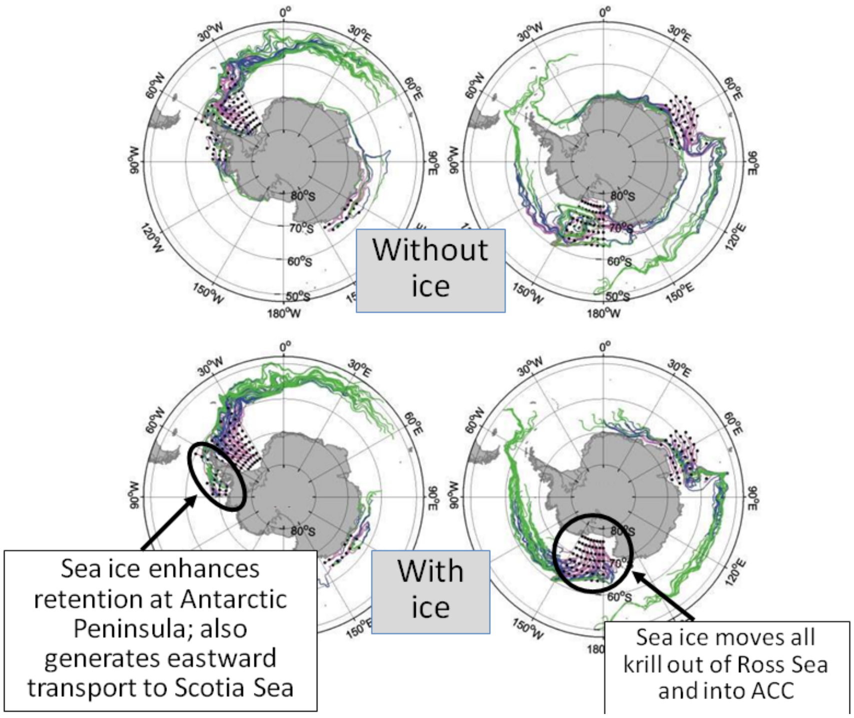

Fig.1. Near-surface advection pathways in the Southern Ocean illustrating the effect of including the sea ice habitat. Particles were released at the black dots and tracked for 3 years. Trajectories are color-coded according to age (Pink: 0-1 yr, blue: 1-2 yr, green: 2-3 yr). Two scenarios are shown: upper panel trajectories were generated using ocean velocity fields from OCCAM general circulation model; bottom panel trajectories were generated using the same OCCAM ocean velocities combined with satellite-derived sea ice motion fields. For further details, please see Thorpe et al (2007).

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Influence of advection on *Calanus finmarchicus* abundance across multiple scales

Andrew J. Pershing
University of Maine and Gulf of Maine Research Institute, USA

By definition, the distribution of zooplankton is strongly influenced by physical processes. However, the role of advection changes as we move from fine to coarse scales. I reviewed the physical and biological processes influencing the copepod *Calanus finmarchicus* change across scales and how these patterns affect predators such as the endangered North Atlantic right whale. At scales of a few meters and a few hours, fine scale physical processes such as internal waves and boundary layer phenomena like Langmuir circulation can create patches of *C. finmarchicus*. However, the behavior of the copepods is essential in determining when and where a patch will form. At scales of a few kilometers and a few days, copepod swimming is too weak to affect the distribution. The time scale is also too short for changes in population growth rates to play a role. Thus, physical processes such as wind and tidal currents and the position of density fronts will have the strongest influence on copepod distribution. At scales on the order of a hundred kilometers and over several weeks, population dynamics can play a larger role. I explored the relative influence of growth rates (determined by temperature and chlorophyll) and circulation using a coupled physical-biological model of *C. finmarchicus*. Experiments with the model suggest that changes in initial or boundary conditions are overwhelmed by variability in growth rates after approximately 50 days. Temperature has the largest effect on growth rate. Elevated chlorophyll during the late winter can lead to increased *C. finmarchicus* abundance during the spring, but the effect of variations in chlorophyll concentrations is secondary to the other inputs. At the largest scale considered, hundreds of kilometers and years, I found evidence for large scale coherence in abundance anomalies in regions ranging from the Mid Atlantic Bight to the Grand Banks.

Advective supply of offshore prey into the continental shelves in the Oyashio area: the role of tidal currents

Orio Yamamura, Akira Kusaka, and Tsuneo Ono
Hokkaido National Fisheries Research Institute, Fisheries Research Agency

Walleye pollock is the one of the key species in the Sub-Arctic NPO. Age-0 pollock settling in the Doto area, where is strongly affected by Oyashio current, attain a substantial density sometimes exceeding 100 individuals m-2. Such an extremely high density would suggest prey depletion because of high grazing impact, and is likely to be a constraint for growth and survival. Furthermore, reduced abundance of zooplankton prey would result in increased mortality because of cannibalism. A tropho-dynamic model was constructed to analyze the bottom-up and top-down controls (Yamamura, 2004). In the course of model construction, prey (euphausiids) population crashed immediately after the onset of simulation due to the predation impact of pollock. By assuming advective supply of offshore prey, the system showed a stable behavior. The

annual predation on euphausiids (22.5±5.3gm-2) exceeded the annual production (17.2±0.1gm-2) indicating that an advective supply of prey is essential to support the pollock population.

To elucidate the mechanism of offshore prey supply, a biophysical coupling survey has been carried out in the Oyashio area. An ADCP observation continued for 24.8 h revealed that the variance in cross-shore component of water flow in the bottom layer (30cms-1) was comparable to the surface velocity of Oyashio current (0.6 kt = 31cms-1). This result indicates that tidal current is capable of transporting meso-zooplankton prey from the offshore into the coastal waters in the Oyashio area.

Advective processes in the Bering Sea

George L. Hunt, Jr. [1], Phyllis J. Stabeno[2] and Rebecca Woodgate[3]

[1] School of Aquatic and Fishery Sciences, University of Washington, USA

[2]NOAA Pacific Marine Environmental Laboratory

[3]Applied Physics Laboratory, University of Washington, USA

The eastern Bering Sea is a seasonally ice-covered, high-latitude shelf sea, dependent on advection for heat and for replenishment of nutrients on its shelf. Water from the North Pacific Ocean enters the Bering Sea via passes through the Aleutian Islands (Figure 1). Water from the Alaska Coastal Current, enters the Bering through passes in the eastern Aleutian Islands, in particular through Unimak Pass and Samalga Pass. Water from the Alaskan Stream enters the Bering Sea farther west, primarily through Amukta and Amchitka Passes, both of which are broad (>50 km) and deep (>400 m). Water entering through Unimak Pass either flows along the 100 m isobath to the northwest, or along the 50 m isobath (Inner Front) to the east. Water entering the Bering between Unimak Pass and Amchitka Island mostly turns eastward to form the Aleutian North Slope current. As this current encounters the southeastern shelf just northwest of Unimak Pass, it turns northwest to form the Bering Slope Current that eventually turns west and then south to form the Kamchatka Current that exits the Bering Sea through Near Pass. Water also exits the Bering Sea through Bering Strait (Figure 2). Flows entering the Arctic from the Bering carry fresh water, salt, and heat, and thus impact the hydrography of the Arctic Ocean. In winter, flows through Bering Strait can reverse, with the result that Arctic ice may be advected into the northern Bering, although it is believed that by the end of the winter, the net flux of ice is northward.

In the southeastern Bering Sea, most on-shelf flows are weak, and cross-shelf currents are dominated by the tidal signal. The exception to this is the weak (~5 cm s-1) flow along the 50-m isobath which transports water from area around Unimak Pass towards Bristol Bay. Cross-shelf flows are further inhibited by the presence of bathymetrically-fixed fronts along the 50 m (inner Front), 100m (Middle Front) and 200 m (Shelf-edge Front). Farther north, off-shelf fluxes of fresh water have been detected north of Nunivak Island, whereas in the vicinity of St. Lawrence Island, on-shelf fluxes of nutrient-rich water from the outer shelf and slope are transported both through Anadyr Strait to the west of St. Lawrence Island, around St. Lawrence Island and thence northward east of the island to Bering Strait (Figure 2).

Strong tidal currents in the vicinity of the Pribilof Islands are rectified, and result in both the advection of outer shelf and shelf-edge waters to the Pribilof Islands, and the subsequent retention of these waters within the Pribilof Domain (Figure 3). These processes are important for the presence of nutrient-rich water and new production in the Pribilof Domain throughout the post-bloom summer season, when elsewhere on the southern shelf, strong stratification inhibits mixing of nutrients into the upper mixed layer, which has little post-bloom new production.

Advection of zooplankton that originates in the basin occurs at the heads of canyons, in the vicinity of the Pribilof Islands, and in the northern Bering to the southwest of St. Lawrence Island. These on-shelf fluxes of zooplankton are important for supporting large colonies of planktivorous seabirds on the Pribilof Islands and at St. Lawrence Island, as well as on islands to the north as far as Bering Strait. When zooplankton-rich waters are unavailable near the Pribilof Islands and St. Lawrence Island, planktivorous birds nesting there may experience reproductive failure.

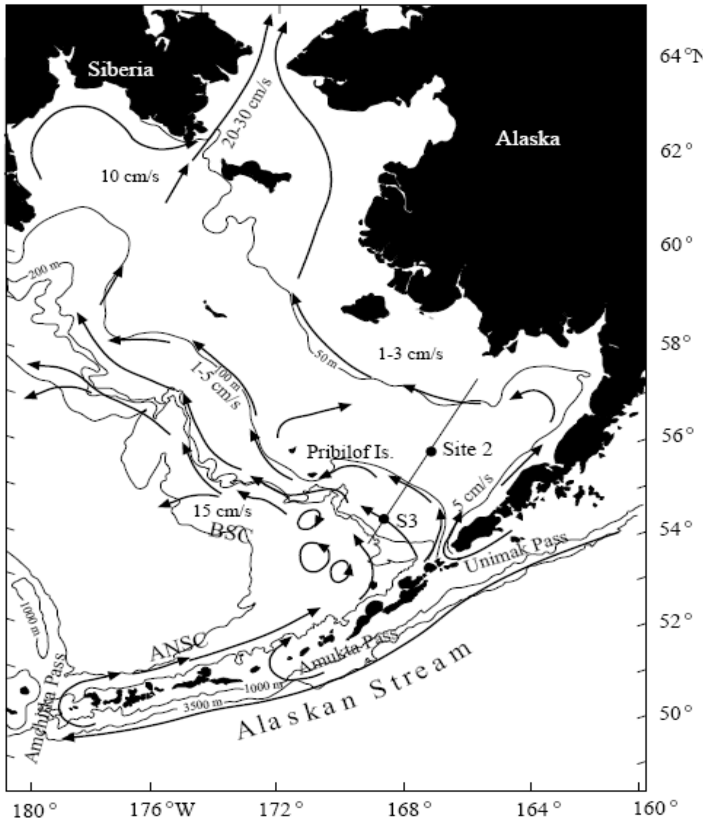

Figure 1. General circulation patterns in the eastern Bering Sea. (From Stabeno et al., 2001, Fisheries Oceanography 10: 81-98).

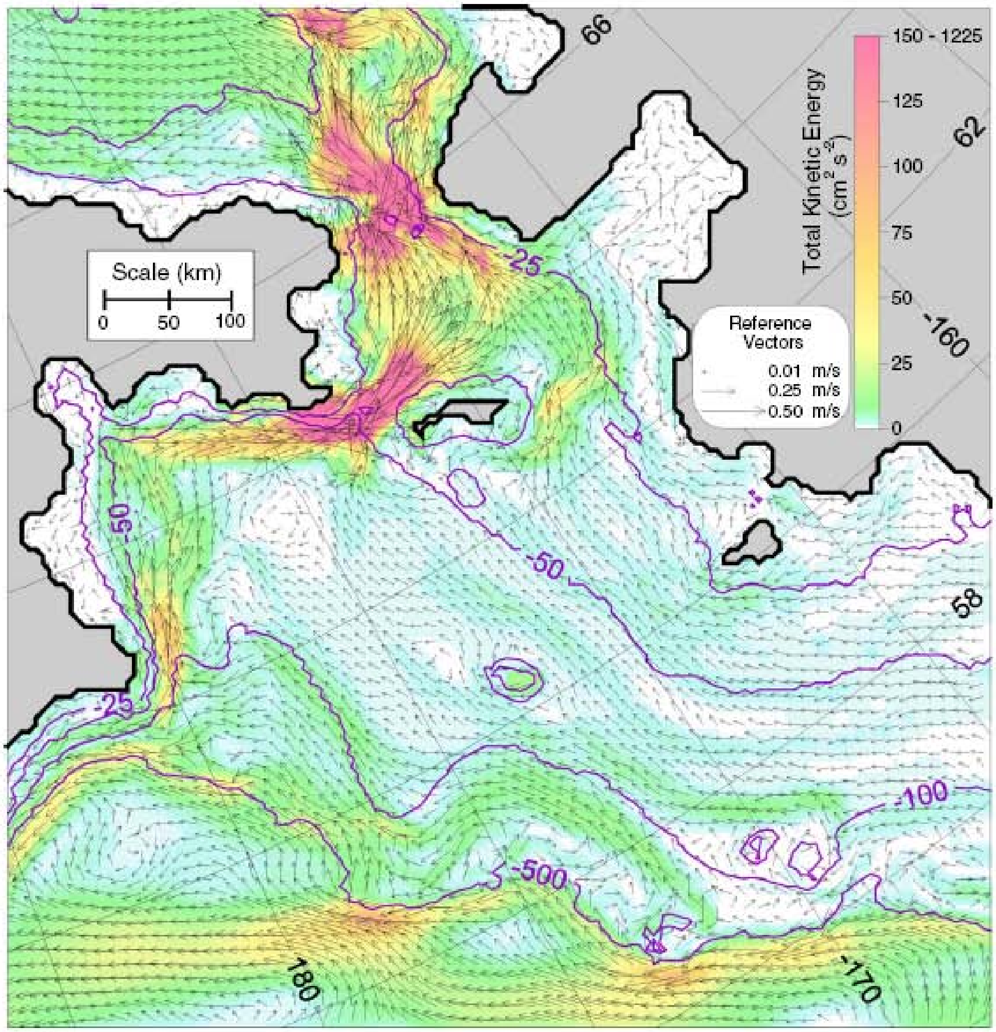

Fig. 2. Twenty-three-year mean velocity averaged over the upper 50 m. Twenty-five percent of vectors are shown. Color shading represents the total kinetic energy (cm^2 s^{-2}) calculated as $0.5*(u^2+v^2)$.

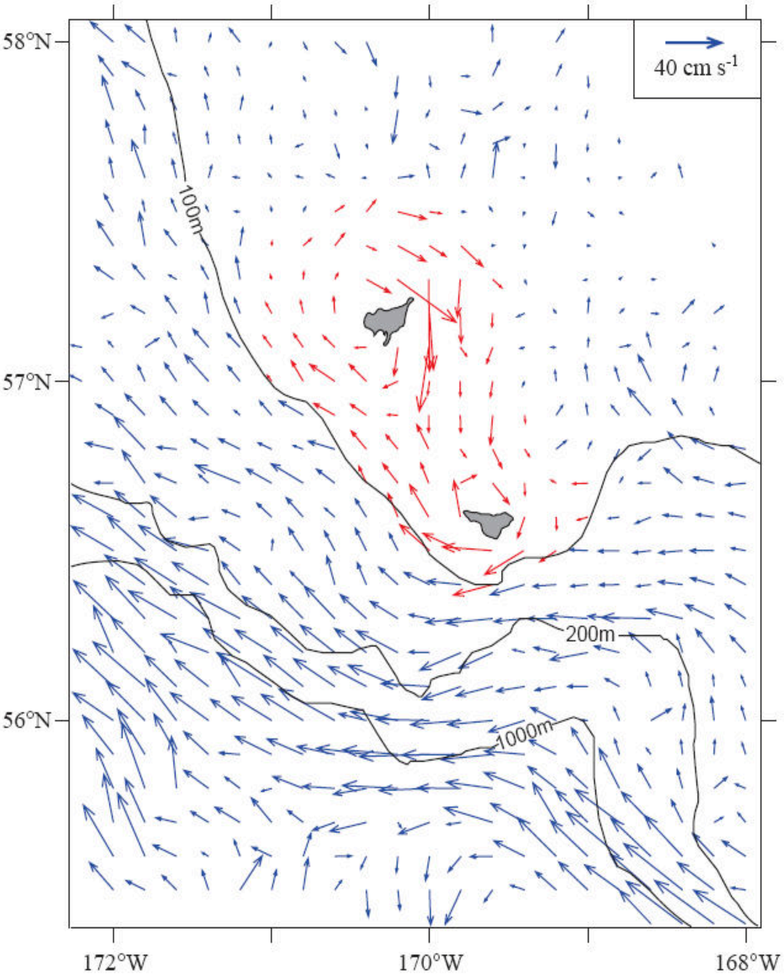

Figure 3. Rectified tidal circulation around the Pribilof Islands creates a region with enhanced nutrient and zooplankton concentrations that can be physically defined as the Pribilof Domain (From Hunt et al., 2008, Deep-Sea Research II, 55: 1919-1944).

Effects of advection on the East and West Greenland shelf: Implications of transport for the recruitment of Atlantic cod and Northern shrimp in Greenland waters

Kai Wieland
National Institute of Aquatic Resources, Technical University of Denmark

Transport of early life stages by ocean currents is an essential process for many marine fish and shellfish species. This is also the case for Atlantic cod and Northern shrimp in Greenland waters. For cod, active migration back to the original spawning areas is well documented and hence larval transport may occur over larger distances than it is likely for shrimp as intensive spawning migration against the currents is probably not possible for this species.

Direct observation on cod eggs and larvae are scarce in the East Greenland area, and the only sample series with intensive area coverage were the international NORWESTLANT surveys in 1963. In addition, information on the distribution of pelagic juveniles is available from Icelandic 0-group surveys. Results derived from these surveys indicate that cod eggs drift from SW Iceland towards Denmark Strait and that a part of larvae in some years continue to drift across the Denmark Strait and settle on the East Greenland shelf. Cod eggs spawned at Southeast Greenland are transported around the southern tip of Greenland and settle on the West Greenland shelf. Results from plankton surveys conducted by Greenland and the former GDR in the 1960s and 1970s suggest that the offspring from cod spawning grounds at Southwest Greenland are transported northward along the shelf but a considerable portion may also end up in the western part of the Davis Strait becoming lost for recruitment of the West Greenland cod stock. Back migration of maturing cod is documented based on tagging experiments while correspondence between the output from particle tracking models and observed 0-group distribution and recruitment is poor. The latter is most likely due to inappropriate assumptions concerning the biological part in the model.

Hatching areas of shrimp larvae are not well known but bottom trawl survey give indication for the location of settling areas. Mean currents suggest transport of shrimp larvae over large distances. However, back-migration of adults to keep the population ‘in balance’ has not been observed. Vertical distribution of shrimp larvae changes during larval phase and is temperature-dependent (about 80 to 120 days at West Greenland). Realistic representation of the change in vertical distribution may result in considerably shorter transport paths than actual model results suggest as it has been seen e.g. for the Barents Sea. However, the necessary input data for such model runs do not exist for West Greenland to date.

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Session 3

Workshop on Climate Forcing of Marine Ecosystems
Convener: James Overland
NOAA Pacific Marine Environmental Laboratory, USA

The Ecosystem Response to Future Climate Change in the Sub-Arctic Atlantic

Ken Drinkwater
Institute of Marine Research, Bergen, Norway

Under future climate change due to anthropogenic sources, it is projected that temperatures will warm throughout the globe with the maximum warming in the Polar Regions and only slightly less in Sub-Arctic regions. Precipitation as well will change with expected increases in many of the Sub-Arctic regions although with high spatial variability in the amplitude of change. Ice coverage will shrink and fronts between Arctic and Sub-Arctic waters will likely shift northwards. These changes in the physical environment will have important impacts on the ecology of the Sub-Arctic regions.

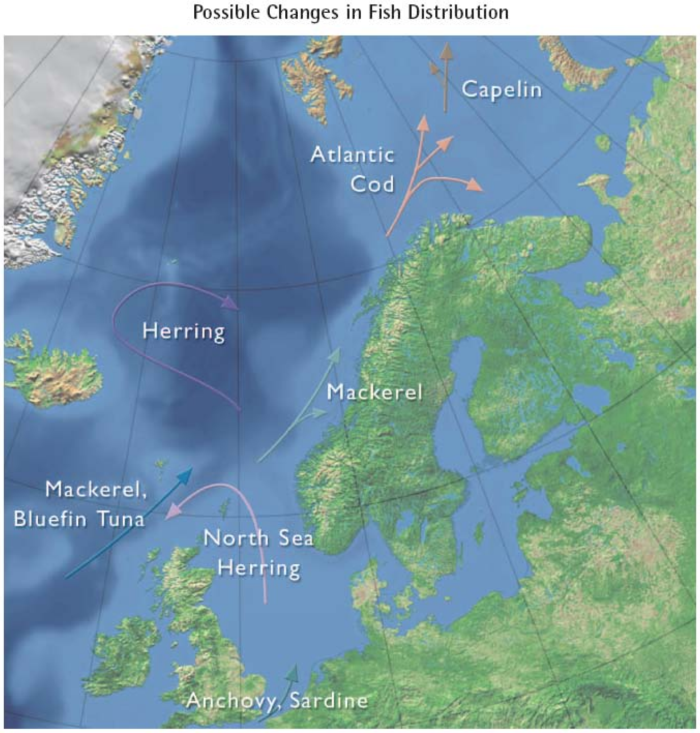
Possible Changes in Fish Distribution

Fig.1. The arrows indicate the predicted distributional shifts in several of the major fish species in the NE Atlantic (taken from the chapter on marine systems (Loeng et al., 2005) in the ACIA report). Note that all of these changes have been observed during the last few years due to the recent warming, well in advance of the full extent of climate change.

In Sub-Arctic areas where ice coverage will be reduced, there will likely be increased primary production due to increased light conditions over a longer period of time. Distributional shifts in zooplankton are expected with Arctic species retreating northward while temperate species will expand to the north (Fig. 1). The timing of seasonal migrations is expected to change with earlier arrival and later departures. The changes in standing stocks and production of zooplankton are more difficult to predict. Where Arctic Waters are replaced or diluted, the Arctic zooplankton species such as *Calanus glacialis* and *C. hyperboreous* will likely decrease, on the other hand *C. finmarchicus* that is associated more with Atlantic waters will likely increase while the overall effect is uncertain. Distributional shifts northward of fish are expected. Based on temperature changes alone, Atlantic cod is expected to extent farther north (and in the Barents Sea farther eastward; Fig. 1) than at present while polar cod may disappear from the Sub-Arctic regions and retreat into the Arctic Ocean. Proportionately more spawning will occur in northern regions for some species such as cod and new spawning sites may be established. The latter is likely to occur in those areas where spawning habitat is available and where the species has to move farther north to follow their prey. Ocean habitat is expected to decrease for some species such as Atlantic salmon off eastern North America, while for others it will increase such as Norwegian spring-spawning herring in the Norwegian Sea. Fish abundance is expected to increase for species like herring and cod due to improved growth rates under warmer conditions and improved recruitment. On the other hand, at the southern limit of their distribution, some species will likely decline due to lower growth rates and declining recruitment. There will be invasions of new southern species into the Sub-Arctic regions with the potential to change substantially trophic interactions through predator-prey relationships and even community structure. For example, Atlantic mackerel have been moving northward during recent years and could soon enter the Barents Sea. This fish could change the interactions between the present three major species there, i.e. the cod, capelin and herring. For example, they might begin to feed on cod eggs and larvae significantly reducing their numbers as have been seen in other Sub-Arctic regions. In some Sub-Arctic regions such as the Barents Sea, the Arctic ecosystems where diatom blooms lead to *C. glacialis* production that in turn are feed upon by numerous seabirds such as dovekies and little auks could be replaced by diatom and flagellate blooms leading in succession to *C. finmarchicus*, forage fish such as herring, up through to whales. Ice-dependent marine mammals such as some species of seals, walruses and polar bears will suffer as the ice disappears. The changes due to climate change will, in addition, depend upon the level of fishing intensity and must be considered in developing future scenarios for fish populations. The ecological responses to climate change will in some cases be are likely to be non-linear therefore adding to the complexity. For example, thermal thresholds may be passed that either will prevent a species from inhabiting a region or, for other species, allowing it to survive where previously it could not. While we may be able to make reasonable estimates on what may happen to a particular functional group, projections for specific species will be much more uncertain. One thing for certain is that we can expect many surprises.

To improve our ecological scenarios, we need improved regional models with projections of what will happen in regards to the physical oceanography of the regions. We also need improved understanding of the processes linking climate variability and changes to ecosystem responses, including threshold limits. Biophysical models that include the high trophic levels (above zooplankton) are needed. While such models are beginning to appear much more work is needed in this area. Finally, more research into the interactions of fishing (top-down) and climate (bottom-up) on the ecology of Sub-Arctic ecosystems is needed.

Climate prediction: IPCC 4th Assessment Report and beyond

Vladimir Kattsov
Voeikov Main Geophysical Observatory, St. Petersburg, Russia

An unprecedented model experiment was undertaken in the course of preparation of the IPCC 4th Assessment Report: climate simulations and projections using 23 models from 11 countries were provided for a comprehensive international analysis – under about 1200 diagnostic projects. The geographical pattern of projected global warming has not changed qualitatively since 1970s. However, encouraging improvements can be noted in the state-of-the-art climate models themselves; computational strategies; methods of model evaluation; understanding of climate processes and feedbacks; and therefore the credibility of the projections. In spite of the evident progress, uncertainties of climate projections are still very significant. Major sources of the uncertainties remain: (1) uncertainties in future emissions of GHG and aerosols, and their conversion to atmospheric concentrations, and further – to radiative forcing of the climate; (2) uncertainties in the global and regional climate responses to a radiative forcing in different GCMs; (3) uncertainties due to insufficient resolution of AOGCMs and different methods of downscaling AOGCM results; (4) uncertainties due to forced and unforced natural variability. Varying sets of strengths and weaknesses that models display lead to the conclusion that no single model can be considered "best"; it is important to utilize results from a suite of models. Improved computational strategies, e.g. larger ensembles of simulations, and multi-model ensembles have started to play an increasingly important role in addressing unforced variability, as well as in understanding processes responsible for the range of model results. Having the large inter-model differences in sensitivity to external forcing, a quantitative likelihood weighting of different models in multi-model ensembles should improve credibility of the climate projections. The possibility that metrics based on observations might be used to constrain model projections of climate change has been explored in the IPCC AR4 for the first time, through the analysis of ensembles of model simulations. "Nevertheless, a proven set of model metrics that might be used to narrow the range of plausible climate projections has yet to be developed" (IPCC, 2007). While it has become evident that future progress in ensemble climate prediction requires an objective discrimination of models, it is not quite clear how such discrimination can be made. There is emerging evidence that model selection (metrics) for an ensemble, as well as an "optimum" size of the ensemble may be problem-/region-/variable-dependent. Some of the results presented here were obtained within the Russian Federal Targeted Research Program "World Ocean" and under projects supported by the US NSF via IARC/UAF and by the RFBR. The modeling groups are acknowledged for making their simulations available for analysis, the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) for collecting and archiving the CMIP3 model output, and the WCRP's Working Group on Coupled Modeling (WGCM) for organizing the model data analysis activity. The WCRP CMIP3 multi-model dataset is supported by the Office of Science, US Department of Energy.

Statistical and Dynamical Downscaling: Examples and Strategies for the Northeast Pacific

Mike Foreman
Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney BC

This presentation briefly described projects and plans for statistical and dynamical downscaling in the Northeast Pacific by Fisheries and Oceans Canada (FOC). Those interested in more details should view the online version of the presentation or contact the author.

The primary reason for downscaling is that the resolution of most global climate models is too coarse to capture regional climate effects. In continental shelf waters of the Northeast Pacific, the most notable feature requiring better resolution is upwelling. To that end, a collaborative project between FOC and the Canadian Centre for Climate Modelling and Analysis has been undertaken to statistically downscale winds off the coast of British Columbia (Merryfield et al. 2008). Time series of up to fifty years exist at fifteen offshore weather buoys and first used to evaluate the accuracy of eighteen global model winds through comparisons over periods of up to 12 years. Results from the Canadian Regional Climate model (45 km resolution at 60°N) and a 15km resolution regional climate model from the University of Washington (Salathé et al, 2008) were also included in some of these evaluations. Not surprisingly, the UW model was the most accurate in the Strait of Georgia, a roughly 30 km wide channel that is flanked by mountains to both its east and west. It generally did the best job in reproducing average monthly wind magnitudes and directions and capturing the seasonal cycle. Though future projections for the regional climate models are yet to be examined, those for the eighteen global models on average only showed about a 5% increase in wind magnitude and a 2° clockwise rotation in direction.

FOC has recently provided funding for two projects that will employ atmospheric forcing from the foregoing global or regional climate models to drive regional ocean climate models. The first is the “Strait of Georgia in 2030”, a project whose primary goal is to better understand and anticipate changes in the marine ecosystem of the strait. A one-km, ROMS-based, circulation model coupled to a NPZD biological model is being developed and will be linked to one or more higher level trophic models. More information can be obtained from http://www-sci.pac.dfo-mpo.gc.ca/sogeri/default_e.htm.

The second project is the development of a 3-km regional climate model for the shelf and near offshore region extending from the Columbia River to the Alaskan Panhandle. This model will also be ROMS-based and may provide oceanic boundary conditions to the Strait of Georgia model. Oceanic boundary conditions for this larger model will either be taken from the nested Northeast Pacific regional climate model under development by Enrique Curchitser and colleagues at Rutgers University and NCAR, or down-scaled values from global climate models. Given the importance of river discharges and estuarine flows within both model domains, it will also be important to incorporate projected changes in those phenomena, probably via statistical downscaling techniques similar to those described in Morrison et al. (2008).

To summarize, both statistical and dynamical downscaling efforts are underway as part of FOC climate change projects in the waters off British Columbia.

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Physical and Biological Oceanographic modeling of the Canadian East coast and Arctic shelves

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Personnel at the Bedford Institute of Oceanography (BIO) use coupled physical-biological oceanographic models validated by observations to simulate the processes in the marine and pack ice ecosystems. The model domains range from the Arctic and North Atlantic and include sub-grid models of the Canadian Arctic Archipelago (CAA), the Baffin Bay – Labrador Sea region, Gulf of St. Lawrence and the Nova Scotia coastal waters. The ESSAS presentation will concentrate on three models: the finite element model with an example from the CAA where the model is used to simulate locations of sensible polynyas, the large and regional OPA model and the POM east coast model forecasting both ice and ocean fields. The coupled ice-ocean POM model is used by the Canadian Ice Service to forecast ice conditions and iceberg populations along the Labrador and Newfoundland coasts. It also is used determine the phytoplankton bloom depth by assimilating surface chlorophyll distributions determined by remote sensing data.

The finite element in the Arctic started as a tidal model and was connected to other models to form a seamless tidal height and tidal current forecast-hind cast model that is being run by BIO personnel on the DFO-Maritimes Website. It was used to explain the location of tidally-driven sensible polynyas in the CAA, based on two parameters: tidal mixing and tidal upwelling to bring the warm deeper water to the surface to prevent ice formation. The OPA model simulations were compared within the CAA to 8-year of mooring data collected in western Lancaster Sound, the centre of the NW Passage. The model simulates the seasonal and inter-variability of the observed fluxes. The fluxes have a max in the summer, a min in the fall and second minor max in late winter. Analysis determined that the flux variability is generated by the far-field wind stress in the Beaufort Sea some 100km away that sets ups the sea level gradient along the NW Passage within the CAA. In contrast, the variability of the east-to-west location of the ice-arches within Lancaster Sound is generated by local atmospheric conditions (temperature and wind). Since the ice arches are locations of high biological production, models are being developed to simulate the present ice arch locations and possibly the expected general westwards shift due to climate warming.

Validation of Dynamical Downscaling of Ice and Ocean Conditions in the Barents and Nordic Seas

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Results from the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) are being downscaled to examine projected changes in ocean and ice conditions in the Barents and Nordic Seas. The GISS AOM (NASA Goddard Institute for Space Studies Atmosphere-Ocean Model) results are being downscaled using the coupled ice-ocean Regional Ocean Modeling System (ROMS). Before future climate scenarios are considered, we wished to assess the realism of downscaled present-day results. Original and downscaled results from the climate of the twentieth century (20C3M) scenario are compared with available observations of ocean and ice conditions in the Barents and Nordic Seas. We wish to determine how well the downscaled results represent twentieth century climate and whether the downscaling improves (provides added value to) the IPCC model results.

Although the spatial resolution of the GISS AOM model, at 4° X 4°, is very coarse, the model was selected for downscaling because it was found by Overland and Wang (2007) to be one of only three models in the IPCC that provided realistic descriptions of sea ice in both the Barents sea and Arctic Ocean as a whole for the twentieth century. Interestingly, the GISS AOM seems to produce a realistic basin-scale wind-stress curl for the North Atlantic, since the downscaled Atlantic Meridional Overturning Circulation (AMOC) at 14.2 sievert (Sv) is in good agreement with the observed 16 Sv. Recently, Sandø and Furevik (2008) have shown that it is the large-scale wind stress curl in the North Atlantic that largely determines the Atlantic inflow to the Nordic Seas. Thus, the coarse resolution of the atmospheric fields from the GISS AOM should not seriously impact the quality of the downscaled ocean circulation fields.

In general, it was found that where the GISS AOM produced realistic results, the downscaled results were also in good agreement with observations. Conversely, when the GISS AOM results were of poor quality, the downscaled results tended to be in poor agreement with observations. The major exception to this tendency is where the higher spatial resolution of the downscaling regional model permitted the resolution of topographic effects and representation of finer-scale circulation features that were not present in the coarse-resolution climate model. In particular, the regional model produced a very accurate estimate of net Atlantic Water inflow to the Barents of 1.8 Sv. This enhanced transport produced more accurate descriptions of sea ice distribution (less ice) and ocean temperature (warmer) than the climate model in the eastern Barents.

While the downscaled Barents inflow is in good agreement with observations, the Atlantic inflow to the Nordic Seas is underestimated by 50%. This appears to be attributable in equal parts to too weak wind forcing and too strong topographic blocking of the inflow by ridge topography. A parallel experiment using ERA40 atmospheric forcing instead of that from the GISS AOM showed a 25% increase in the inflow. Another experiment with NCEP forcing and smoother topography and coarser resolution produced excellent agreement with observations. We hypothesize that the topographic blocking of the inflow is likely due to the fact that while the topographic length scale is resolved by the regional model, the eddy dynamics are not. Thus, an enhanced potential vorticity barrier is produced at the ridges by the higher spatial resolution, but the resolution is still not high enough to permit exchanges by eddy fluxes across the ridges.

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Strengths and Weaknesses in Recent Regional Ocean Modeling: Summary and Discussion

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As the title suggests, this presentation was intended to summarize some of the attributes and pitfalls of regional climate modeling that were given earlier in the session. The convenor started things off by reviewing a few practical issues that must be addressed in developing and running regional climate models (RCMs). These include:
a) One or two-way nesting?
b) A coupled atmosphere-ocean-ice model or only ocean?
c) Sensitivities to the RCM domain and location

d) Lateral boundary conditions (with 1-way nesting)
e) “Big-brother” sensitivity experiments to determine the extent to which results are due to higher resolution.

He then followed with a summary of some limitations/caveats of regional modelling that were pointed out in a paper by Leung et al. (2003).

These are:

a) Global Climate Model (GCM) parameterizations may not be valid for RCMs
    a. Need to determine what processes should be resolved and what should be parameterized.
b) Does climate variability increase with spatial resolution?
    a. Maybe, but only to a point
    b. More ensemble runs are needed to improve the signal-to-noise ratio
c) What aspects of large–scale conditions need to be correctly simulated in order to enable successful downscaling?
d) We should use multiple GCMs with multiple ensembles to force multiple RCMs
    a. Yes but making all these runs may exceed available computer capacity
e) Many CGMs ignore important processes like land use change and biogeochemical effects of CO_2
    a. Most next generation IPPC models will have CO_2 cycle

Finally, he summarized a recent paper by Laprise et al. (2008) that challenges some popular tenets of RCMs. These tenets, and the *answer* to whether or not each is true, are given as follows:

a) RCMs are capable of generating small-scale features absent in the driving fields supplied as lateral boundary conditions. *Yes*
b) The small scales that are generated have the appropriate amplitudes and climate statistics. *Yes, for mid-latitude climate statistics but a minimum domain size needed*
c) The generated small scales accurately represent those that would be present in the driving data if it were not limited by resolution. *Except for short time scales when these scales are in boundary and initial fields, no. But that may not matter as it is statistics, not event sequence that matters, and those are good.*
d) In performing dynamical downscaling, RCM generated small scales are universally defined for a given set of lateral boundary conditions. *No*
e) Opposing views of large scale features:
    a. They are unaffected in the RCM domain. *No*
    b. They may be improved due to reduced truncation and explicit treatment of meso-scale resolution. *Maybe (this has been demonstrated in weather prediction)*
    c. Scales larger than the RCM domain are degraded. *Yes*

Interested readers were referred to the Laprise et al. (2008) and Leung et al. (2003) papers for further details.

A broader discussion involving many in the audience then followed. Some of the important points raised were as follows:

1. Enrique emphasized the importance of two-way coupling with his example for upwelling off the California and Oregon coasts. The more highly resolved cold

upwelled waters in the RCM will feed back to produce fog in the atmosphere, which will then shade solar radiation and cause further cooling. Coarser GCMs couldn't be expected to get the magnitudes and spatial extent of these feedbacks correctly.

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Session 4

Workshop on Modeling Ecosystem Response
Conveners: Bernard Megrey, NOAA Alaska Fisheries Science Center, USA
Shin-ichi Ito, Tohoku, National Fisheries Research Institute, Japan &
Kenneth Rose, Louisiana State University, USA

A Comparison of Simulated Particle Fluxes Using NEMURO and Other Ecosystem Models in the Western North Pacific

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This is a result from Kishi et al. (2004) and Okunishi et al. (2007). In Kishi et al. (2004) they pointed out that JGOFS revealed the importance of marine biological activity to the global carbon cycle. Ecological models are valuable tools for improving our understanding of biogeochemical cycles. Through a series of workshops, the North Pacific Marine Science Organization (PICES) developed NEMURO (North Pacific Ecosystem Model Understanding Regional Oceanography, Kishi et al. (2007)) a model, specifically designed to simulate the lower trophic ecosystem in the North Pacific Ocean. Its ability to simulate vertical fluxes generated by biological activities has not yet been validated. Here compare NEMURO with several other lower trophic level models of the northern North Pacific. The different ecosystem models are each embedded in a common three-dimensional physical model, and the simulated vertical flux of POM and the biomass of phytoplankton are compared. The models compared are: (1) NEMURO, (2) the Kishi and Nakata Model (Kishi *et al*., 1981), (3) KKYS (Kawamiya, *et al*., 1995, 2000a, 2000b), and (4) the Denman model (Denman and Peña, 2002). With simple NPZD models, it is difficult to describe the production of POM (Particulate Organic Matter) and hence the simulations of vertical flux are poor. However, if the parameters are properly defined, the primary production can be well reproduced, even though none of models we used here includes iron limitation effects. On the whole, NEMURO gave a satisfactory simulation of the vertical flux of POM in the northern North Pacific.

Okunishi et al. (2007) described that they applied a three-dimensional ecosystem-physical coupled model including iron the effect to the Okhotsk Sea. In order to clarify the sources of iron, four dissolved iron compartments, based on the sources of supply, were added to (Kawamiya et al. 1995) an ecological-physical coupled model applied to Station Papa. (Journal of Oceanography, 51, 635-664) model (KKYS) to create our ecosystem model (KKYS-Fe). We hypothesized that four processes supply iron to sea water: atmospheric loadings from Northeastern Asia, input from the Amur River, dissolution from sediments and regeneration by zooplankton and bacteria. We simulated one year, from 1 January 2001 to 31 December 2001, using both KKYS-Fe and KKYS. KKYS could not reproduce the surface nitrate distribution after the spring bloom, whereas KKYS-Fe agreed well with observations in the northwestern Pacific because it includes iron limitation of phytoplankton growth. During the spring bloom, the main source of iron at the sea surface is from the atmosphere. The contribution of riverine iron to the total iron utilized for primary production is small in the Okhotsk Sea. Atmospheric deposition, the iron flux from sediment and regeneration of iron in the water column play important roles in maintaining high primary production in the Okhotsk Sea.

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MENU ECOPATH comparisons: What did we learn?

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Results from the ESSAS-sponsored project Marine Ecosystems of Norway and the US (MENU), a collaborative project between NOAA/NMFS and Norway's Institute of Marine Research, were reviewed. Special emphasis was devoted to lessons learned from a detailed comparative analysis of ecosystem structure and function. Information projects from the Northern Hemisphere marine ecosystems including eastern Bering Sea, Gulf of Alaska, Gulf of Main/Georges Bank, and the Norwegian/Barents Sea ecosystems were compared with respect to the environment, biota, fisheries, tropho-dynamics, common features, unique features, fundamental features, important drivers, and controlling processes. The wealth of data permitted several avenues for performing comparisons. Some comparisons that were examined included comparisons between geographically adjacent ecosystems (i.e. between the eastern Bering Sea and Gulf of Alaska), between ecosystems (i.e. eastern Bering Sea and Barents Sea), and cross-basin (Atlantic vs. Pacific) comparisons. One outcome was the conclusion that large multi-national collaborations are almost essential to conduct similar comparisons since local experts are needed to supply data, interpret results, and provide perspective.

Summary of the presentation 'Ecosystem modeling of the Norwegian Sea and the Barents Sea'

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The Norwegian and Barents Sea ecosystems are different in many aspects; the Norwegian Sea is basically a basin area (average depth ca. 1800 m) whereas the Barents is a shelf area (average depth ca. 230 m). Moreover, large parts of the Barents are heavily influenced by the dynamics of seasonal ice cover. Still, there are good reasons for treating the two systems as one in an Ecopath with Ecosim modeling approach. Firstly, the two ecosystems are tightly linked together through the Atlantic current and the Coastal current which again largely affect the biota of both systems. Huge amounts of plankton, in particular Calanus and krill, are advected into the Barents with the Atlantic current, whereas larvae from some of the most important fish stocks including Norwegian spring spawning herring (NSS-herring; *Clupea harengus*), North East Arctic cod (NEA cod; *gadus morhua*) and saithe (*Pollachius virens*) drift from the spawning areas in the Norwegian Sea into the nursery areas in the Barents with the Coastal current. In addition, the large whales migrate freely between the Norwegian Sea and the Barents during the summer feeding season.

With both the Barents and the Norwegian Sea included, the total modeling area constitutes 3.116 million km^2 and the area stretches from latitude N 63 to 81° and longitude W 11 to E 68°. There are three main current systems of different origin dominating the ecosystems; the Arctic, Atlantic and Coastal currents. The water masses of the currents differ in quality and provide different conditions for production. These water masses meet in several fronts of high productivity. Whereas the Norwegian Sea is ice free around the year, large parts of the Barents are covered with ice in winter time. Specifically adapted plankton, fish and mammals are linked to the ice, and the withdrawal of the ice edge during spring creates a particular dynamic with an early plankton bloom, providing food for ice amphipods which again provide food for pelagic fish, in particular capelin, and fish larvae.

The primary production in both the Norwegian Sea and the Barents Sea is characterized by pronounced peaks in production during late spring and a less pronounced peak during autumn. The average production in the Barents has been estimated to 90 g C m^{-2} $year^{-1}$. The zooplankton community both in the Norwegian Sea and the Barents is dominated by three groups: *Calanus finnmarchicus* which is totally dominating both the Norwegian Sea and the Barents in terms of biomass, krill following second in terms of biomass and pelagic amphipods following third. *C. finnmarchicus* is essential in the diets of all the big pelagic fish populations like NSS-herring, capelin and mackerel *(Scomber scombrus)*. The dominant krill species are *Thysanoessa inermis, T. longicaudata* and *Meganyctiphanes norvegica.* They occur in all water masses in the Nordic Seas and are important in diet of NSS-herring, mackerel, blue whiting (*Micromesistius poutassou),* NEA cod, haddock *(Melanogrammus aeglefinus),* redfish *(Sebastes spp.),* and salmon *(Salmo salar).* The dominating amphipods in the Barents are the *Themisto abyssorum* and *Themisto libellula.* They are important in the diet of capelin (*Mallotus villotus*), but also of NEA cod in years when capelin and herring are scarce. In addition, they are important in the diet of polar cod, harp seal and different seabirds.

The benthic community in these ecosystems is poorly known, in particular in the Norwegian Sea. In the Barents the bentho-pelagic coupling is probably strong in some areas, and a time series on benthos is starting to build up showing that both temporal and spatial variability in the benthic communities is strong.

Among the fish there are a few dominating pelagic groups in terms of biomass: The population of NSS-herring constitutes a biomass of more than 10 million tons. It spawns along the Norwegian coast, feeds in the Norwegian Sea and has its main nursery areas in the Barents. The blue whiting and Atlantic mackerel stocks are also seasonally highly abundant in the Norwegian Sea. The mackerel competes with herring for Calanus in the upper pelagic whereas blue whiting has a more semipelagic distribution. In the Barents, the capelin plays a fundamental role. It is a major consumer of plankton and essential as food for NEA cod and marine mammals. The NEA cod is economically the most important stock, and is an important consumer of capelin and other young fish. In the Norwegian Sea there is a community of mesopelagic fish that play an important role in terms of biomass. In the Barents the polar cod is important in association with the ice, with a biomass estimated to 1.5 to 2 million tons.

The most important seabird species in the Norwegian Sea In terms of abundance and consumption, is the Atlantic puffin (*Fratercula arctica*) consuming an estimated 300000 tons of fish. Second follows the Northern fulmar (*Fulmarus glacialis*) consuming an estimated 165000 tons of which 2/3 are invertebrates. In the Barents the Brünnich’s guillemot (*Uria lomvia*) is by far the most important consuming an estimated 550000 tons of which 50 % is estimated to be fish and the rest invertebrates.

The most important whales in terms of biomass and consumption are the minke whales *(Balaenoptera acutorostrata)* with an estimated consumption of about 1.8 million tons. The main prey is krill, young herring and young cod. It is present during summer time in the Norwegian Sea and the Barents. Other important whales when considering consumption are the sperm whale and the fin whale. The most important seal in terms of biomass and consumption and probably the most important top predator in the Barents is the harp seal. It is separated into three populations with two of them feeding in the Barents: The Greenland Sea population with an estimated number of 600000 ±200000 adults and 100000 ±35000 pups and the White Sea population with 2 million ±600000 adults and 360000 ±60000 pups. Only the consumption of the White Sea population is estimated to lie between 2.7 and 4 million tons, consisting mostly of amphipods, capelin, polar cod, and herring.

The sum of fisheries in the Barents and Norwegian Sea catches a total of about 5-7 million tons. NSS-herring dominates the catch in the Norwegian Sea with 1.5 million tons followed by blue whiting with 1.25 million tons and saithe with 200000 tons. In the Barents there has historically been a huge fishery after capelin peaking at around 3 million tons in the late 70ies. The catch of NEA cod is at present around 430000 tons and of haddock around 100000 tons. 90 % of the fishery resources in Norwegian waters are shared with other nations. Typical is also the fact that many of the important fish stocks are migratory and distributed between several EEZ. All advice to management goes through the ICES.

Ecosystem Modelling of the Newfoundland-Labrador Shelf (NAFO Divisions 2J3KLNO)

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The Newfoundland-Labrador Shelf is located in the northwest Atlantic and extends from the Hudson Strait in the north (latitude 60°00') to the Grand Banks (46°00') in the south, encompassing the North Atlantic Fisheries Organization (NAFO) management divisions 2GHJ3KLNO (Figure 1). Sea-ice begins to form by December in the north and by March has reached its maximum spread south to the northern Grand Bank (Prinsenberg *et al*., 1997). In the southern regions, ice usually lasts from 1-2 months whereas at the northern end of the Labrador Shelf it lasts for an average of around 8 months. There are strong annual cycles in the water mass properties due to seasonal variations in atmospheric forcing, while decadal changes are linked to the NAO which can account for between 40-50% of the variance in sea-ice, ocean temperatures and shelf stratification off Labrador and Newfoundland. There are many shallow offshore banks separated by a series of channels and gullies and the circulation pattern over the shelf is dominated by the southward flowing Labrador Current (for further details of the oceanography of the Newfoundland-Labrador shelf, see the Appendix to the ESSAS Science Plan[1]).

A defining species of the Newfoundland-Labrador shelf, from a fisheries perspective, is Atlantic cod (*Gadus morhua*), which was exploited for over 500 years before it collapsed in the early 1990s in NAFO Divisions 2J3KL and 3NO. A moratorium on cod was imposed in 1992, and other than a recreational fishery, a stewardship fishery, and a food fishery, there has been no legally directed fishing for cod since then. The collapse of cod was accompanied by other ecosystem changes, such as the colder water temperatures and large increases in the abundance of harp seals (*Phocus groenlandica)*, snow crab (*Chionoecetes opilio*) and shrimp (*Pandalus borealis*). The non-recovery cod on the Newfoundland-Labrador shelf and in eastern Canada has, in general, been the subject of much enquiry.

The Newfoundland–Labrador fishery was modeled for the period 1985–1987 in North Atlantic Fisheries Organization (NAFO) Div. 2J3KLNO to a depth of 1000 m (Bundy et al. 2000) using the mass balance model Ecopath with Ecosim (Christensen et al. 2005). An analysis of the relative roles of fishing and predation indicated that harp seal predation and cod predation accounted for a greater part of the total mortality on all fish groups than the fishery. However, for mature fish of species such as cod, American plaice, and Greenland halibut, the effects of fishing mortality were much greater than predation mortality. These results indicate that fishing mortality was a major determinant in the population dynamics of some of these commercial species.

Model results indicate that the main energy pathway in the ecosystem is through phytoplankton – small zooplankton – large zooplankton – capelin – cod – harp seals. Keystone species in the system were identified as cetaceans, capelin, harp seals and hooded seals, using the method of Libralato et al. (2006). Keystone species are species which have a strong role in the structure and function of ecosystems, despite having a relatively low biomass and low food intake (Power et al., 1996). These species are comparable to keystone species in other Canadian northwest Atlantic ecosystems (Bundy et al, *in press*). For more details about input data and results see Bundy et al. 2001, Bundy 2001 and Bundy et al, *in press.*

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[1] http://web.pml.ac.uk/globec/structure/regional/essas/essas_appendix_web.pdf

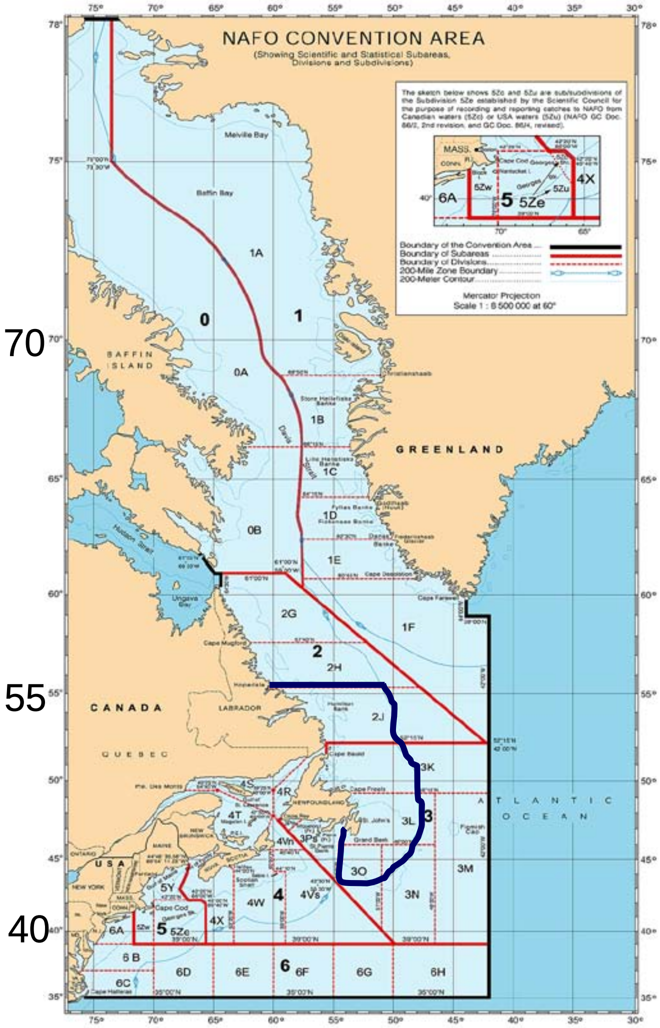

Figure 1. NAFO convention area. Blue line represents the Ecopath model area (NAFO Divisions 2J3KLNO), taken from http://sattrax.ca/marine/map_nafo.html

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The Icelandic EEZ: background information of relevance for ecosystem comparison.

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The Mid-Atlantic or Reykjanes ridge and the Greenland-Iceland-Scotland ridges influence the ocean ciculation and distribution of water masses and thus also biological production around Iceland. The GIS ridge is of particular importance as it separates the flow between the warm water of the North Atlantic and cold Arctic deep water of the Iceland and Norwegian Seas. The Icelandic shelf is narrowest of the south coast while off the west and north coast it is much broader. Most of the commercially exploited fish stocks spawn in the Atlantic water off the south and west coasts while nursing grounds are off the north-west, north and north-east coasts. The Icelandic EEZ covers an area of 758 thousand km^2 while only about 220 thousand km^2 is over the self and where depth is less than 500 m.

To the south and west of Iceland relatively warm Atlantic is brought to the coast by the Irminger Current or the North Atlantic Irminger Current as it reaches the northwestern self of Iceland. From north along the east coast of Greenland flows the Polar East Greenland Current and the Arctic/Sub-Arctic East Icelandic Current flows southeastwards off the northeast Icelandic shelf. On the north and eastern shelves the Arctic/Sub-Arctic watermass is formed by mixing and local modifications of the water transported by the main currents. Close to the coast there is low saline Coastal Current formed from Atlantic/Sub-Arctic water diluted by fresh water from land.

Monitoring of temperture and salinity of Icelandic waters demonstrates four main periods or regimes north of Iceland during past 100 years or so. Prior to 1965 there was a warm period which started around 1920, 1965-1971 was a cold period with polar influence over the whole north Icelandic shelf area, between 1972-1997 warm and cold years alternated and from around 1998 until present warm years have prevailed.

Most of the sea ice that reaches Iceland originates from the Arctic Ocean and is transported with currents southwards along the east coast of Greenland. Southwesterly winds reduce the southwards flow and direct the ice eastwards on to the northwest and north Icelandic shelf. Records of sea ice incidences reflect the hydrographic climate periods mentioned above.

Winter concentrations of main nutrients (nitrate, phosphate and silicate) are higher in the Atlantic water than in the Arctic water. Partly this relates to greater winter mixing in the Atlantic water. The seasonal cycle of nutrients is similar to that observed in other cold temparate waters. Nutrient depletion starts along with spring growth in April-May, nutrients are low in surface layers during summer and increase again with autumn mixing in September-November.

Primary production is higher over the shelves than farther out. Over the shelf the production is also higher in the Atlantic water to the south and west than in the mixed Atlantic/Sub-Arctic waters to the north and east. Further, in the waters to the north productivity is higher in water where salinity is >34.5 – that is water where Atlantic influence is pronounced – compared to water where salinity is <34.5 - water influenced by Arctic Water. High primary production is also observed in frontal zones to SE and NW due to increased mixing. Main phytoplankton genera/species are the following. Spring: Diatoms, *Thalassiosira*, *Chaetoceros*, while in the spring bloom north of Iceland a Prymnesiophyte (*Phaeocyctis pouchetti*) may also be important. Summer: Dinoflagellates (*Ceratium*, *Protoperidinium*). Autumn: Diatoms (*Thalassiosira*, *Chaetoceros*) and Dinoflagellates (*Ceratium, Protoperidinium*).

Zooplankton investigations in spring shown that Copepods dominate by abundance, usually ~60-80% to the south and ~20-80% to the north. *C. finmarchicus* is usually by far the most common zooplankton species. Euphausiids are clearly an important component of the plankton community but valid information on abundance and biomass is limited. Long term observations on zooplankton biomass show that it is generally higher in the Atlantic water to the south than in the Sub-Arctic water to the north. Highs and lows in biomass have been found to alternate at 6-11 year intervals. To the north of Iceland the variations in biomass are related to variations in temperature (or distribution of water masses). When tempertures are high the zooplankton biomass tends aslo to be higher.

Information on the benthic invertebrate communities in Icelandic waters is limited except for the exploited species. Five species (shrimp (offshore/inshore), scallop, lobster, quahog, and, to a lesser extent, whelk) constitute the invertebrate fishery. During past 10 years, the invertebrate fisheries have decreased from about 45 thousand tonnes to about 8 thousand tonnes. Mainly this is due to decline in the offshore shrimp fishery but also most of the other fisheries except for lobster have decreased. Partly, this decrease has been attributed to environmental changes.

In recent years the total catch from the main demersal species (cod, haddock, and saithe) has been fairly stable and in fact some increase has occurred for haddock and saithe. Similarly for the main pelagic species, Icelandic herring, Atlanto-Scandian herring and blue whiting the catch has been fairly stalble, while the capelin catch has decreased markedly or from about 1 million tonnes at the turn of the century to about to about 300 thousand tonnes during most recent years. The changes that have taken place with regard to the capelin stock have partly been connected to recent warming in Icelandic waters. Instead of being mainly distributed on the Icelandic shelf and in the Iceland Sea the stock has shifted farther north- and westward into Greenland waters. Co-occurring with the warming in Icelandic waters since 1998 marked changes in distribution and abundance of many other species have also been observed.

There are 23 species of seabirds in the Icelandic bird fauna and the estimated breeding populations are ca. 7 million pairs. Assuming immature birds to be about 40% of the breeding populations then the total seabird populations are ca. 20 million birds. By far the largest seabird population is Atlantic puffin with 2-3 million breeding pairs, and then northern fulmar and common guillimot with more than 1 million.

Whales are an important component of the Icelandic marine ecosystem with about 18 species occupying the waters regularly. Most of the whales are migratory species that stay in Icelandic waters during summer for feeding. Minke whale is by far the largest baleen stock (about 60 thousand individuals), while the stocks of fin and sei whales are also quite large (10 thousand each). Of the toothed whales the long finned pilot whale is most abundant (58 thousand), followed by northern bottlenose and white-sided dolphin (both at around 40 thousand). Seals (gray and harbour) are not an important component of the system Icelandic shelf ecosystem. Harp and hooded seals are found in large quantities in Northern waters but limited information on stocks in the Iceland Sea.

A very preliminary Ecopath model for Icelandic waters was constituted. In several cases basic parameters had to be adjusted in order not to get an Ecotrophic efficiency >1. Further in some cases data on stock sizes and catch did not cover the same period which may lead to an error in cases where there have been marked changes in biomass. The biomass and PB ratios for *Calanus* and krill seem low in the model. More groups should be feeding on these groups but consumption on these species had to adjusted (kept low) otherwise Ecotrophic efficiency would be greater than 1. Several other parameters of the model need also to be looked into further before the model can be used in comparative studies.

The Icelandic fishery is managed through an ITQ system that covers most of the commercial fisheries has been under development for several years. Thus individual vessel quotas represent shares in the total allowable catch and quotas are permanent and fairly freely transferable. TAC is reccommened by the Marine Research Institue but allocated by Ministry of Fisheries.

The major natural and anthropogenic drivers in the Icelandic ecosystem are considered to be the flow of Atlantic water influences production and distribution/abundance of stocks at most trophic levels. In addition, the stock status of capelin influences the condition of most other stocks and too heavy fishing on capelin may inpact stock size and therefore food availability in total system. Finally whales are important predators that must be considered as part of the whole system.

Towards modeling trophic interactions in the ecosystem off West Greenland

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The West Greenland shelf between 59°30’N and 72°00’ N at a depth down to 600 m is relatively narrow in particular in the south and consist of several banks with depths of less than 150 m separated by deep troughs and gullies. It is influenced by subsurface heat transport from the Atlantic in the Irminger current which keeps the shelf waters ice-free up to about 65° N even in severe winters. This also leads to a distinct latitudinal gradient in temperature with almost boreal condition in the south. To contrast boreal and Sub-Arctic food webs, Ecopath models were constructed for the region south of 62° N and for a region between 66 and 69° N excluding fjord and inshore areas in both cases. 34 living groups were considered and the analysis focused on forage fish/shellfish and their predators in the period 1995 to 2002. However, due to some severe uncertainties e.g. concerning the plankton dynamics and the diet of Greenland halibut and seals as well as with respect to abundance estimates for several functional groups the results so far can only be regarded as preliminary. The obtained models regrettably are not suitable as a basis for simulations or comparison with other ecosystems. Nonetheless some sub-system specifics can be inferred. Total production in the Sub-Arctic region was dominated by Northern shrimp (*Pandalus borealis*) followed by polar cod (*Boreogadus saida*) and cephalapods whereas capelin (*Mallotus villosus*) and sand eels (*Ammodytes sp.*) were most important in the southern region. Seals and Greenland halibut were the most prominent predators in the north. In contrast, predation on forage groups was attributed to more than 75 % to seals alone in the southern region. Atlantic cod did not play any role because this species had disappeared from the system in both regions since the collapse of the stock in the late 1980s.

Air temperature as well as surface layer temperature and in particular bottom temperature increased considerably in the mid 1990s. In contrast to previous warm periods, this was not accompanied by a recovery of the Atlantic cod stock so far suggesting that once the ecosystem structured has severely been altered a return to the previous state may not be possible, at least not in a short term. Along with the warming biomass of Northern shrimp and Greenland halibut on the shelf increased in the late 1990s. In this period, Northern shrimp moved gradually northward and the spatial overlap between Greenland halibut and Northern shrimp increased. Indications were found that predation by Greenland halibut on recruits of Northern shrimp have contributed to a drastic decline of the shrimp stock in the most recent years.

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ECOPATH model of the Western North Pacific (Oyashio – Transition – Kuroshio Region)

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Our objective of building an Ecopath with Ecosim (EwE) model in the western North Pacific region is to evaluate the potential impact of whales migrating to the western North Pacific off Japan on Japan’s fisheries resources. From 1994 to 1999, a survey called JARPN (Japanese whale research program under special permit in the western North Pacific) has been carried out mainly in this region, and from 2000 to 2007, the second phase of this survey (called JARPN II) has been carried out. The survey has collected information on whale abundance, prey preferences, diet composition, rates of consumption for predator and prey, and oceanography. Based mainly on these collected data, we are currently building an EwE model. Here, we focus on briefly introducing physical and biological backgrounds of such Ecopath model.

The modeled area is east of northern Honshu Island, north of 35ºN, and west of 170ºE, south of Hokkaido (excluding Russia’s EEZ), which corresponds to sub-areas 7,8 and 9 for the North Pacific IWC minke whale management area. The area covers part of the Oyashio and Kuroshio region and the transition zone between the two currents. Several environmental factors are thought to affect the distribution and dynamics of the species in the modeled area. One is the southern limit of the Oyashio current. The southern limit of Oyashio varies by season and year. When the southern limit is towards the north side, suitable fishing area of Pacific saury becomes near shore, and when the southern limit is towards the southern side, suitable fishing area of pacific saucy becomes offshore, and often when it is too south, poor harvesting of fisheries is expected. Another important factor to consider is the pattern of the pathway of the Kuroshio Current. The pathway of Kuroshio varies by year and there are mainly three pathways.

There are some other environmental factors that are thought to affect the dynamics of the species considered in the model. In the western North Pacific, 'fish species alteration' has been observed. The abundant species has altered from sardine to anchovy to mackerel then again to sardine then anchovy. Both biomass and catch of sardine drastically declined in the end of 1980s. Possible environmental factors that affect this phenomenon are thought to be, for example, strength of the ALPI (Aleutian Low Pressure Index) and the PDO (pacific decadal oscillation). When the strength of ALPI is weak, it is thought that the condition is not suitable for sardine, and when the strength of ALPI is strong, it is though that it brings good condition for sardine. Also, surface water temperature of the Kuroshio Extension area may be affecting the dynamics of the species in this area. When the surface water temperature of the Kuroshio Extension is low, it is thought to bring good condition for sardine, and when the surface water temperature of the Kuroshio Extension is high, it is thought to bring poor condition for sardines. However, the detailed mechanism of fish species alteration in the western North Pacific is not yet well known, and is currently under investigation.

The Ecopath model consists of 31 species (or groups) and the modeled year is around 2006-2007. As for primary producers, phytoplankton is considered. As for zooplankton, we considered three groups; one is euphausiids, another is 'copepods eaten by whales' and the other is 'other copepods'. Major euphausiid species in the area are *Euphausia pacifica*, *Thysanoessa inspinata*, and *Nyctyphanes difficillis*. As for 'copepods eaten by whales', we considered mainly three species which are *Neocalanus cristatus*, *N. plumchrus*, and *N. flemingeri*. Biomass of these species is estimated from net-sampling and echo-sounder data obtained from JARPNII. As for fish and squids, we considered 11 fish species and four squid species or groups, totaling 15 species/groups. Among the 15 species/groups considered, six species are at high biomass level (which are albacore, skipjack tuna, blue shark, spotted chub mackerel, anchovy and Pacific saury), two species are at middle biomass level (which are sword fish, large surface squid), and three species are at low level (which are neon-flying squid, chub mackerel and sardine). As for the trend of biomass, most of the species are stable in recent years, except that biomass of blue shark and chub mackerel is increasing currently, and biomass of spotted chub-mackerel and anchovy is slightly decreasing. Among these species, lanternfish has the largest biomass. Neon-flying squid, mackerel, sardine, anchovy and pacific saucy are important Japanese fish resources. Among these five fish/squid species, catch and biomass of sardine drastically decreased from the end of 1980s to the 1990s and currently is at very low level. Also, catch and biomass of mackerel also decreased at the end of 1970s. For other species such as pacific saucy, neon-flying squid and anchovy, no obvious trend in catch and biomass can be seen for the past 40 years. Total catch of Pacific saury is the highest among these five species resulting in approximately 2 million tons/year, followed by that of anchovy of 1.5 million tons then mackerel of about 1.2 million tons. Total catch of sardine and neon-flying squid is about 450 thousand tons/year.

As for marine mammals, since we are focusing on these species and its interactions, groups are classified in quite details and we considered nine whale species or groups, and one fur seals. Whale species considered included: minke; Bryde's; sei; sperm; Baird's beaked; and short-finned pilot whale. We also considered other baleen whales, ziphiidae, and other toothed whales. Among the marine mammals, sperm whale has the largest biomass. Biomass estimates, Q/B and diet composition data are mainly obtained from JARPNII.

As for trophic interactions, from JARPNII, we found that minke whales mainly feed on Pacific saury and anchovy, Bryde's whales and sei whales also mainly feed on anchovy. The diet of sperm whales was different from other species and they feed mainly on mid-deep water sea squid. When relative consumption on Pacific saury and anchovy by predators is compared, consumption by mackerel and whales is relatively high; the largest predation on anchovy (mature component) is by whales; followed by skipjack tuna, mackerel, and neon-flying squid. Thus, whales seems to be important predators for Pacific saury and anchovy, and this is the reason why we are focusing our research on this point which is the impact of whale's consumption on Japan's fisheries resources.

As for fisheries and management systems, catches of mackerel, sardine and Pacific saury are controlled by TAC system in Japan. Current stock assessment indicates that F of chub-mackerel and sardine, especially F on the immature component, needs to be reduced below the current level. For other species, no major limit on catch is set. For baleen whales, management procedure was agreed by IWC. But it has not been implemented yet in this area.

Finally, as for major natural drivers or critical factors that cause ecosystem change in a several decadal scale, possible environmental factors are strength of ALPI, PDO, surface water temperature of the Kuroshio Extension area, and for yearly or monthly change, southern limit of Oyashio or pattern of the pathway of Kuroshio affects distribution of fishes, and also to some extent, we believe that predator-prey interactions and fisheries are affecting the dynamics of the species.

Projected Changes in the Physical Environment of Four Sub-Arctic Seas under Climate Change

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Results from the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) were downscaled to examine projected changes in ocean and ice conditions in four Sub-Arctic Seas under climate change. The GISS AOM (NASA Goddard Institute for Space Studies Atmosphere-Ocean Model) results were downscaled using the coupled ice-ocean Regional Ocean Modeling System (ROMS) for two scenarios: the climate of the twentieth century (20C3M) and potential future conditions with CO_2 stabilized at 720 ppm (SRES A1B). Conditions during the period 1985-2000 in the 20C3M scenario are contrasted with those during the period 2051-2065 in the SRES A1B scenario for four Sub-Arctic Seas: the Barents, Nordic, Labrador and Bering Seas.

The responses to projected climate change of the Barents and Bering Seas are similar and the response of the Nordic Seas is similar to that of the Labrador Sea. The strongest responses are those of the Barents and Bering Seas, with substantial warming and winter ice reduction in the eastern Barents and north-eastern Bering. The responses of the Nordic and Labrador Seas are relatively weak. There is a projected slight cooling on the continental shelves of Iceland and south-eastern Greenland due to a reduced Atlantic inflow to the Nordic Seas. Warming in the Labrador Sea is restricted to the continental shelf break and (in summer) to western Baffin Bay.

Appendix 4: Terms of Reference ESSAS WG-1

Terms of Reference

ESSAS Working Group 1: Regional Climate Prediction (WGRCP)

28 February 2007

Introduction

A major goal of ESSAS is to predict the potential impacts of climate variability on the sustainable use of the Sub-Arctic Seas. ESSAS has elected to employ a comparative approach, investigating in each of the Sub-Arctic Seas which energy pathways appear particularly vulnerable to decadal and longer-term climate change. The ecosystem response to climate can be non-linear with thresholds, have complex interactions between species, and different species impacts from similar climate fluctuations. Reducing uncertainty about the future states of ESSAS ecosystems depends on knowledge of the response of the ecosystem to changes in climate and a quantitative ability to project future climate states. The first task represents understanding and modeling the complex linkages between climate variables and species distributions and is a primary focus of the other two ESSAS Working Groups (ESSAS Working Group 2: Biophysical Coupling Mechanisms and ESSAS Working Group 3: Modeling Ecosystem Responses).

A Goal of the Working Group on Regional Climate Prediction (WGRCP) is to provide quantitative estimates of the magnitude and uncertainty of future climate change for the ESSAS regions, and the frequency distribution of natural variability, such as the well known ecosystem reorganization of the North Pacific in the mid-1970s and historical interdecadal variability in the marginal seas of the North Atlantic. Climate elements known to be crucial to ESSAS ecosystems include sea ice cover, ocean temperature, circulation, and stratification.

A major resource for the development of future climate scenarios is the recently available results from 22 state-of-the art coupled atmosphere-ocean climate models which are part of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). A preliminary investigation has shown that a subset of these models represents the physical forcing in several ESSAS ecosystems reasonably well based on comparison with *in situ* data for the late 20th century. There are several factors that lead to the perceived credibility of future climate scenarios from climate models, including the differences between models, validation exercises for different physical variables, and matching the spatial scales that are important to ecosystem biology.

Tasks

1. Evaluate the credibility of the 22 IPCC models as applied to each of the different ESSAS regions based on comparison of 20th century hindcasts with data, and model

to model consistency and physical reliability in their forecasts. Produce a report which provides recommendations on which models perform well for each region.

2. Working within the larger ESSAS framework, establish which seasons, regions and variables are most important to potential ecosystem shifts and provide report on future scenarios and confidence estimates of these conditions for different future time horizons. Assess the contributions from intrinsic climate variability and external anthropogenic forcing.

3. Recommend IPCC models and procedures for downscaling of the model output for use in regional ocean/ecosystem models.

4. Be a community resource on retrospective and future climate change issues.

Implementation

1. The Working Group on Prediction shall exist for a period of three years, ending six months after the 2009 annual meeting of ESSAS.

2. Six to eight members will be chosen from the fields of climate science and numerical modeling. Input from experts on ecosystem processes will be sought through collaboration with ESSAS WG 2 and 3.

3. The development of the proposed products includes conducting workshops held at the annual ESSAS meetings and will require inter-sessional work. The purpose of the workshops is to vett and reach consensus on information made available prior to the workshops from the published IPCC Reports and from direct model evaluations provided by members.

Expected Results

To ensure the perceived credibility of future regional climate scenarios, we will develop a white paper after the ESSAS Workshop in 2007 that examines the differences between IPCC models, identifies the spatial scales and variables that are of relevance to ecosystem-effects of climate change, and delineates further validation exercises for different physical variables that have been performed.

After the ESSAS Workshop in 2008, we plan to have a set of climate predictions for the major ESSAS ecosystems, based on the IPCC climate models. These regional climate scenarios will have sufficient credibility that they can be used by other ESSAS Working Groups as the basis for their ecosystem modeling efforts.

Initial Membership

James Overland	Acting Chair, USA	Lennart Bengtsson	Germany
Paul Budgell	Norway	Vladimir Kattsov	Russia
Ken Drinkwater	Norway	Mike Foreman	Canada
Hisashi Nakamura	Japan	John Walsh	USA

Appendix 5: Terms of Reference ESSAS WG-2

Terms of Reference

ESSAS Working Group 2: Bio-Physical Coupling (WGBPC)

28 February 2007

Introduction

A major goal of ESSAS is to predict the potential impacts of climate variability on the sustainable use of the Sub-Arctic Seas. ESSAS has elected to employ a comparative approach, investigating, in each of the Sub-Arctic Seas, which energy pathways appear particularly vulnerable to decadal and longer-term climate change. The ecosystem response to climate can be non-linear with thresholds, have complex interactions between species, and feature different species responses to similar climate fluctuations in different ecosystems. Reducing uncertainty about the future states of ESSAS ecosystems depends on developing the ability to project future climate states as well as predicting the response of the ecosystem to changes in climate. Predicting future climate states is the primary focus of ESSAS Working Group I on Regional Climate Prediction. This requires quantitative estimates of the magnitude and uncertainty of future climate change for the ESSAS regions, and the frequency distribution of natural variability, such as the well-known ecosystem reorganization of the North Pacific in the mid-1970s and historical inter-decadal variability in the marginal seas of the North Atlantic. Predicting ecosystem response requires both understanding and modeling the complex linkages between climate variables and species distributions. This represents the primary focus of two ESSAS Working Groups (ESSAS Working Group 2: Biophysical Coupling Mechanisms and ESSAS Working Group 3: Modeling Ecosystem Responses).

A Goal of the Working Group on Bio-Physical Coupling (WGBPC) is to determine how climate-driven variability in physical conditions and processes in the ocean will affect the organisms that make up marine ecosystems and thus the transfer of energy and material through Sub-Arctic marine ecosystems. Physical aspects of the ocean thought to be crucial to ESSAS ecosystems include sea ice cover, ocean temperature, circulation, and stratification.

A great deal is already known about the responses of organisms to physical variability in the ocean, but the literature is scattered and there is need to summarize what is known specifically about the responses of populations and the ecosystem as a whole in the Sub-Arctic Seas and how information gathered in one basin may be applied to ocean regions elsewhere in the Sub-Arctic. Thus a major task for the WGBPC will be to provide the modelers in the ESSAS WGMER with realistic values for parameterizing predictive models of ecosystem response to climate variability.

Tasks

1. Summarize and evaluate the available information on the responses of marine organisms of the Sub-Arctic Seas from phytoplankton to marine mammals and seabirds to variability in physical attributes of the ocean such as seasonal sea ice cover, ocean temperature, stratification, and circulation.

2. Working within the larger ESSAS framework, provide the WGMER with a realistic set of values with which to model organism responses to climate-driven variability in the physical attributes of the Sub-Arctic Seas.

3. Be a community resource on retrospective and future climate change issues.

Implementation

1. The Working Group on Bio-Physical Coupling shall exist for an initial period of three years, ending six months after the 2009 annual meeting of ESSAS. At this time, the ESSAS SSC will evaluate whether the WG should continue, be revised slightly or dissolved.

2. Eight to ten members will be chosen from the fields of biological and fisheries oceanography. Input from experts on future climate variability and the needs of ecosystem modelers will be sought through collaboration with ESSAS WG 1 and 3, respectively.

3. The development of the proposed products includes conducting workshops held at the annual ESSAS meetings and will require inter-sessional work. The purpose of the workshops is to review information on how changes in various physical attributes of the ocean will affect important ecosystem components. Foci of workshops will include the roles of: seasonal sea ice cover, temperature, stratification and circulation.

Expected Results

Workshop products will be one or more review papers based on comparative studies, to be published in the refereed literature, that summarize the important mechanisms whereby the changes in the physical attribute under discussion affect biological constituents of Sub-Arctic ecosystems and their inter-relationships. Where possible, these papers should provide the information necessary for parameterizing the biophysical coupling parameters in ecosystem models of the Sub-Arctic Seas. Where sufficient data are lacking to accomplish this task, there should be a clear statement concerning the lack of specific data that could guide fieldwork during ESSAS.

Initial Membership

George Hunt	USA, Acting Chair	Earl Dawe	Canada
Elena Dulepova	Russia	Erica Head	Canada
Franz Mueter	USA	Emma Orlova	Russia
Vladimir Ozhigin	Russia	Vladimir Radchenko	Russia
Marit Reigstad	Norway	Sei-ichi Saitoh	Japan
Egil Sakshaug	Norway	Yasunori Sakurai	Japan
Paul Wassermann	Norway	Kai Wieland	Denmark

Appendix 6: Terms of Reference ESSAS WG-3

Terms of Reference

ESSAS Working Group 3: Modeling Ecosystem Response (WGMER)

28 February 2007

Introduction

A major goal of ESSAS is to predict the potential impacts of climate variability on the sustainable use of the Sub-Arctic Seas. ESSAS has elected to employ a comparative approach, investigating in each of the Sub-Arctic Seas which energy pathways appear particularly vulnerable to decadal and longer-term climate change. Ecosystem-level response to climate can vary spatially, geographically, and ontogentically. It can manifest itself locally (i.e., be non-linear with threshold responses), involve complex species-to-species interactions (i.e. ecosystem reorganization in response to climate change, and/or demonstrate different within-species responses between different regional geographic locations within the same ocean basin, all originating from similar climate fluctuations.

Reducing uncertainty about the future states of ESSAS ecosystems depends on knowledge of the response of the ecosystem to changes in climate and a quantitative ability to project future climate states. The first ESSAS goal of prediction requires a fundamental understanding of climate-biological interactions. With understanding comes the ability to model the complex linkages between climate variables and species distributions, which are the primary focus of the other two ESSAS Working Groups (ESSAS Working Group 1: Regional Climate Prediction and ESSAS Working Group 2: Biophysical Coupling Mechanisms).

The goal of the Working Group on Modeling Ecosystem Response (WGMER) is to develop conceptual, mechanistic/process, statistical/empirical, and simulation models to facilitate comparison of ESSAS ecosystems and to forecast the impacts of climate change on ecosystem structure and function in multiple ESSAS ecosystems.

Much data has already been collected in ESSAS ecosystems. Thus a major task of WGMER will be to inventory these data and evaluate the suitability of using these data in comparative analysis, modeling and forecasting climate impacts.

Tasks

Identify modeling methodologies that will facilitate comparison of the biological, physical, and trophodynamic aspects of the ESSAS ecosystems across regions. Identify and suggest suitable conceptual, mechanistic/process, statistical/empirical, and simulation models to examine for potential application.

1. Assemble existing biophysical datasets and time series from ESSAS ecosystems to facilitate joint comparative studies.

2. Apply the identified candidate models and modeling techniques to ESSAS ecosystems and ecosystem data sets to describe and validate the models.

3. Evaluate ESSAS modeling proposals and offer recommendations to the SSC.

Implementation

1. The Working Group on Modeling Ecosystem response shall exist for a period of three years, ending six months after the 2009 annual meeting of ESSAS.

2. Six to eight members will be chosen from the fields of quantitative ecology and fisheries oceanography. Input from experts on future climate variability and ecosystem process will be sought through collaboration with ESSAS WG 1 and 2, respectively.

3. The development of the proposed products will include conducting workshops held at the annual ESSAS meetings and also inter-sessional workshops as required. The purpose of the workshops will be to review candidate modeling methodology, to facilitate ecosystem comparisons, and the identification of suitable data sets. Inter-sessional work will involve pre-workshop preparation, data analysis, model coding, model application post-workshop report preparation, and the preparation of peer-reviewed manuscripts.

Expected Results

Workshop products will be one or more review papers, to be published in the refereed literature, that summarize the important ecosystem features that facilitate comparison.

Other products will include short position reports on the models evaluated, strategies for implementing the models, recommendations on future data collection and on synthesis of existing data, and methodological recommendations for ensuring appropriate among and between ecosystem comparisons. Joint efforts on these and other specific topics will be done in collaboration with the WG 1 and WG 2.

Initial Membership

Bernard A. Megrey	USA, Co-Chair	Shin-ichi Ito	Japan, Co-Chair
Kenneth Rose	USA, Co-Chair	Paul Budgell	Norway
Lorenzo Ciannelli	USA	Masahiko Fujii	Japan
Gennady Kantakov	Russia	Franz Mueter	USA

Appendix 7: Terms of Reference ESSAS WG-4

Terms of Reference

ESSAS Working Group 4: Gadoid-Crustacean Interactions (WGGCI)

Ecosystem Studies of Sub-Arctic Seas (ESSAS)
25 March 2008

Introduction

A major goal of ESSAS is to predict the potential impacts of climate variability on the sustainable use of the Sub-Arctic Seas. ESSAS has elected to employ a comparative approach to investigate, in each of the Sub-Arctic Seas, which energy pathways appear particularly vulnerable to decadal and longer-term climate change. The ecosystem response to climate change can be non-linear with thresholds, have complex interactions between species, and feature different species responses to similar climate fluctuations in different ecosystems. Reducing uncertainty about the future states of ESSAS ecosystems depends on developing the ability to project future climate states as well as predicting the response of the ecosystem to changes in climate. Predicting future climate states is the primary focus of ESSAS Working Group I on Regional Climate Prediction. Understanding and modeling the complex linkages between observed and projected climate variability and species distributions is the primary focus of two ESSAS Working Groups (ESSAS Working Group 2: Biophysical Coupling Mechanisms and ESSAS Working Group 3: Modeling Ecosystem Responses).

Goals

The main goal of Working Group 4 on Gadoid-Crustacean Interactions (WGGCI) 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.

Approach

Gadoid fish and crustaceans are important components of the benthic food web in most Sub-Arctic ecosystems and are often among the most important commercial fisheries in these systems. Much is already known about the responses of gadoid fish and crustaceans to physical variability in the ocean. However, there is a need to summarize what is known specifically about the responses of these populations in Sub-Arctic Seas to climate variability in the context of fishery takes and to contrast and compare these responses among different ecosystems. This working group deliberately focuses on a small set of interacting species to identify consistent associations between the major, commercially important, gadoid fish and crustacean species in each system and to evaluate their responses to observed climate variability. Identifying associations will improve our understanding of ocean climate effects or ‘bottom-up’ processes that are important in regulating these populations. Our working hypothesis is that gadoid fish and crustaceans respond in opposite ways to ocean climate variation and that such variation results in differences in productivity and abundance between gadoids and crustaceans.

The physical aspects of the ocean that may be crucial in regulating these responses in the ESSAS ecosystems include sea ice cover, ocean temperature, circulation, and stratification. Our approach is consistent with the ESSAS approach of making comparisons across multiple ecosystems. It is recognized that population responses may not be consistent across all Sub-Arctic ecosystems, but similarities and differences will help identify ecosystem features that are related to the functional mechanisms governing gadoid – crustacean interactions and dynamics. These mechanisms may operate at the adult stages (e.g. through predation or variations in reproductive success), during early life history stages (e.g. through effects on survival of larval or early benthic/demersal stages) and/or at lower trophic levels (variations in food availability). This study is intended to complement other studies of effects of ocean climate on productivity at low trophic levels (e.g. BSIERP/BEST in the Bering Sea, ESSAS Working Group on Biophysical Coupling) to elucidate how bottom-up processes function in regulating ecosystem structure.

To achieve its goals the working group will engage experts from as many Sub-Arctic ecosystems as possible to obtain the best available datasets on variability in abundance of gadoids and crustaceans, as well as relevant ocean climate indices and fisheries takes from each system. Data analyses will be conducted within and across ecosystems to identify important associations and to examine similarities and differences among ecosystems. Results from these analyses should lead to a better understanding of the functional relationships between gadoid and crustacean populations and between climate variability and these populations.

Tasks

1. Summarize and evaluate the available information on the responses of gadoid fish and crustaceans in the Sub-Arctic Seas to variability in physical attributes of the ocean (such as seasonal sea ice cover, ocean temperature, stratification, and circulation). This includes: compilation of relevant literature, and compilation of relevant datasets. For each ecosystem, these datasets should include: annual estimates of abundance or biomass of important gadoid and crustacean populations; annual estimates of recruitment to these populations where available; total annual harvests from these populations; and ocean climate indices thought to be relevant to the populations by local experts.

2. Conduct statistical analyses of relevant data sets from each ecosystem, including: correlation analyses; multivariate analyses of within and between-system patterns of variability; and models of species interactions

3. Serve as a resource to other working groups within ESSAS, to the larger ESSAS community, and to other researchers on retrospective and future climate change issues in regards to gadoid and crustacean resources.

Implementation

The Working Group on Gadoid-Crustacean Interactions shall exist for an initial period of three years, ending six months after the 2011 annual meeting of ESSAS. At that time, the ESSAS Scientific Steering Committee will evaluate whether the WG should continue as is, continue under revised terms of reference, or be dissolved.

Twelve to fourteen members will be chosen from the fields of gadoid and crustacean biology, as well as physical, biological and fisheries oceanography. Input from experts on future climate variability, bio-physical coupling, and the needs of ecosystem modelers will be sought through collaboration with ESSAS WG 1, 2, and 3, respectively.

Development of the proposed products includes:

- Conducting a workshop to be held at one of the annual ESSAS meetings. The purpose of the workshop will be to review information on how changes in climate will affect gadoid and crustacean populations
- Literature searches and data compilation with help from local experts in each of the regions; a student will be recruited to assist with these tasks (funds for a M.S. student for 2 years have been secured)
- Conducting data analyses (student, with help from working group members)
- Preparing presentations for workshops, preparing manuscripts
- Conducting e-meetings as necessary to review progress and coordinate tasks

Expected Results

We anticipate one or more comparative papers based on a review of the literature and new data analyses to summarize important associations between climate variability and the relative productivity of gadoid and crustacean populations in Sub-Arctic ecosystems. Where possible, the paper(s) should provide the information necessary for parameterizing relevant relationships between gadoid and crustacean populations in ecosystem models of the Sub-Arctic Seas. Where sufficient data are lacking to accomplish this task, there should be a clear statement concerning the lack of specific data that could guide future fieldwork.

Initial Membership

Boris Berenboim	Russia
Ann Dorte Burmeister	West Greenland
Earl Dawe	Canada (Co-chair)
Franz Mueter	USA (Co-chair)
Vladimir Ozhigin	Russia
Yasunori Sakurai	Japan
Shareef Siddeek	USA
Don Stansbury	Canada
Jan Sundet	Norway
Dan Urban	USA
Jie Zheng	USA

Regions of study (tentative):
Barents Sea
East Greenland / Iceland
West Greenland
Labrador/Newfoundland
Eastern Bering Sea
Gulf of Alaska
Oyashio Current region

Appendix 8:

ICED – Integrating Climate and Ecosytem Dynamics

A program overview by Rachel Cavanagh[1], ICED Program Officer
Interim Steering Committee led by Eugene Murphy[1] and Eileen Hofmann[2]
[1]British Antarctic Survey, [2]Old Dominion University

Results from the past two decades of Southern Ocean research clearly demonstrate that integrated multidisciplinary approaches are required to improve understanding of the circumpolar ecosystem and the response of this system to variability and change. This is key to predicting impacts of climate and harvesting, improving sustainable management, and elucidating the role of the Southern Ocean in the Earth System. However, ecosystem modeling for the region is in its early stages and tends to be restricted in geographic and/or trophic scope. Integration of relevant data resources, field efforts, and experimental studies is vital to improving models. Circumpolar data collation and rationalization are required to identify gaps in coverage and knowledge, and to address these through coordination of international fieldwork.

Acknowledging these challenges the recently adopted Integrating Climate and Ecosystem Dynamics in the Southern Ocean program (ICED) will cross traditional disciplinary boundaries to integrate research on ecosystems, biogeochemistry and climate at the circumpolar scale. The ICED Science Plan and Implementation Strategy has recently been approved and is about to be published. This document serves as a framework to guide the ICED program in generating circumpolar datasets, undertaking coordinated field activities, and developing integrated models to determine the process interactions underlying Southern Ocean ecosystem variability and change. ICED will run for a decade under the joint guidance of IMBER and GLOBEC.

It is becoming increasingly apparent that links need to be strengthened between those working in Antarctic and Arctic regions. Some of the strongest regional expressions of global climate change have occurred in the Polar Regions and are predicted to continue. Comparative views of marine ecosystem operation in both Polar Regions are essential to determine the responses to climate change and potential feedback effects. ICED aims to build firm links with ESSAS, particularly to conduct comparative analyses and develop models of polar marine ecosystems.
For more information see http://www.iced.ac.uk