U.S. GLOBEC: A Component of the U.S. Global Change Research Program

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Exploring Climate Change and Carrying Capacity in the North Pacific

by Anne Hollowed

U.S. GLOBEC recently convened a workshop to discuss a future research program on Climate Change and the Carrying Capacity (CCCC) of the North Pacific. The workshop was held at the Battelle Conference Center in Seattle, Washington, April, 19-20, 1995, and over 75 scientists attended. The need for the workshop stemmed from the development, in October 1994, of a Science Plan for coordinated research on Climate Change and the Carrying Capacity by the North Pacific Marine Science Organization (PICES). In response to the PICES Science Plan, the U.S. GLOBEC Scientific Steering Committee agreed to support a community-wide workshop to explore U.S. GLOBEC-relevant issues of the oceanic and coastal domains of the subarctic Pacific Ocean, and the Bering Sea.

PICES is an intergovernmental organization established in 1992 to promote and coordinate marine scientific research in the temperate and subarctic region of the North Pacific and its adjacent seas. PICES' member countries are Canada, China, Japan, Korea, Russia, and the United States. The PICES Second Annual Meeting (1993) authorized the preparation of a draft Science Plan for what was called the PICES GLOBEC-International Program on Climate Change and Carrying Capacity (CCCC). The Plan was then discussed at a workshop and approved at the PICES Third Annual Meeting (1994) where it was agreed to establish a Scientific Steering Committee (now called Implementation Panel) to initiate development of an implementation plan. An Executive Committee met in May 1995 to prepare a draft for review and revision during the summer. A preliminary draft of this implementation plan was available to the participants of the Seattle workshop.

Central Questions

The PICES/GLOBEC CCCC Science Plan emphasizes activities at two spatial scales:

- Basin-scale studies to determine how plankton productivity and the carrying capacity for higher trophic level, pelagic carnivores in the North Pacific change in response to climate variations.

- Regional scale ecosystem studies comparing how variations in ocean climate affect species dominance and fish populations in the coastal margins of the Pacific Rim.

The Key Scientific Questions postulated in the Science Plan have since been consolidated into the following set of so-called Central Scientific Issues:

• Physical forcing: What are the characteristics of climate variability, can interdecadal patterns be identified, how and when do they arise?

(Cont. on page 2)

In this issue...

CCCC—(Cont. from page 1)

• Lower trophic level response: How do primary and secondary producers respond in productivity, and in species and size composition, to climate variability in different ecosystems of the subarctic Pacific?

• Higher trophic level response: How do life history patterns, distributions, vital rates, and population dynamics of higher trophic level species respond directly and indirectly to climate variability?

• Ecosystem interactions: How are subarctic Pacific ecosystems structured? Do higher trophic levels respond to climate variability solely as a consequence of bottom-up forcing? Are there significant intra-trophic level and top-down effects on lower trophic level production and on energy transfer efficiencies?

Key research activities related to these issues will include retrospective analyses, development of models, process studies, development of observational systems, and data management. The next steps in developing the CCCC implementation plan on the regional scale are expected to include efforts to design the proposed comparison of ecosystem properties and responses to climate variability in cooperation with national GLOBEC programs. On the basin scale, a more comprehensive effort to develop an international cooperative program will be required.

Program Rationale

The North Pacific is an attractive site for a GLOBEC program for many reasons. Many commercial industries in the Pacific Northwest and Alaska are heavily dependent on natural resources. For example, approximately half of the total U.S. fisheries catch is removed from waters off the coast of Alaska. Studies have shown a strong connection between climatic variables and indices of fish abundance and distribution in the North Pacific (see collection of papers Beamish 1995, and Beamish and McFarlane 1989). These strong responses to climatic change translate into direct impacts on the efficiency and sustainability of the region's fishing industry. Elucidation of long term influences of climate change on these natural resources could have important benefits to the nation by improving our knowledge of functional relationships between climatic conditions and biological production that would allow for the development of long range plans for resource conservation and management.

The North Pacific is the location of one of the major storm tracks in the northern hemisphere. Models suggest that the southern side of the Arctic front will be the region of greatest alteration due to global climate change. The storm track responds to two global teleconnections patterns, the West Pacific oscillation that influences the location of storm generation and the Pacific-North American pattern that influences the track of storms across the subarctic Pacific. The Pacific-North American pattern is often considered the major mode of planetary variability of the atmosphere. We can hypothesize the shift in storm frequency and track due to climate change and its potential impact on the physical environment (see Climate Change scenarios box). At present, considerab le natural variability exists on time scales from seasonal to decadal. This variability has a profound impact on circulation, mixed layer depths and the extent of ice coverage, all of which influence the rich biological resources of the subarctic Pacific.

U.S. GLOBEC and PICES are now poised to take advantage of newly developed tools that will enable us to examine the carrying capacity of the subarctic Pacific. These include measurement technologies and complex computer models. The vast time-space scope of the environmental questions requires application of technologies such as remote sensing via aircraft and satellite, shipboard data acquisition systems such as those employing acoustic sampling of currents and biota, and moored platforms to collect time series of biological and physical observations. Advances in computer technology now permit using large-scale models that assimilate field observations and integrate biological and physical processes.

A U.S. GLOBEC program in the North Pacific would benefit from parallel development of complementary research programs of other nations through the PICES-GLOBEC CCCC program. International cooperation on a common research program will inevitably enhance our national research efforts. In the case of coastal programs, Japanese and Russian studies in the Bering Sea, and Canadian research off British Columbia will augment U.S. investigations of ecosystem responses to climate variability.

U.S. GLOBEC research in the North Pacific would complement proposed research on the influence of climate variability on marine ecosystems in the California Current (U.S. GLOBEC Report 11). Coordination with the California Current program is highly desirable because large scale forcing for both regions could be modeled simultaneously, and because of earlier suggestions that the physical and biological systems of the two regions—California Current and Alaskan Gyre—operate oppositely in phase (Chelton and Davis ref).

Linkages to Other Field Programs

There are opportunities for U.S. GLOBEC research in the North Pacific to coordinate with other existing process oriented research programs: Fisheries Oceanography Coordinated Investigations (FOCI), Bering Sea FOCI, Exxon Valdez Oil Spill Trustees, and NMFS Ocean Carrying Capacity studies (OCC). FOCI, and Bering FOCI are NOAA programs

(Cont. on page 3)

CCCC—(Cont. from page 2)

focussing on the biological and physical processes that influence survival of walleye pollock (*Theragra chalcogramma*). FOCI is comprised of scientists at the Pacific Marine Environmental Laboratory, the Alaska Fisheries Science Center, and several other institutions. The biotic and abiotic environment, including processes within larval patches, have been examined during the past decade through integrated field, laboratory and modeling studies. The original focus of FOCI was recruitment to the pollock population spawning in Shelikof Strait. Bering Sea FOCI, a component of NOAA's Coastal Ocean Program, has been studying production of walleye pollock in the Bering Sea since 1991. The Bering Sea FOCI program is investigating stock structure of pollock in the Bering Sea, and recruitment of walleye pollock in the southeastern Bering sea, where significant spawning takes place. The Exxon Valdez Oil Spill Trustees support research leading to the development of an integrated science plan for restoration of species potentially injured by oil spills in Prince William Sound, Gulf of Alaska. Currently, the trustees are sponsoring the Apex Predator Ecosystem-Experiment (APEX) and the Sound Ecosystem Assessment (SEA) programs. SEA is an interdisciplinary, multi-component program designed to understand factors constraining pink salmon and herring production in Prince William Sound, Alaska. The NMFS Auke Bay laboratory initiated the OCC study on Pacific salmon in the Gulf of Alaska in 1995. The OCC study is focused around cooperative Canada-U.S. research surveys on the marine phase of the life history of Pacific salmonids and will include studies of: age-at-maturity, modeling and diet studies, and retrospective studies of salmon growth. These process oriented research programs will provide: a) estimates of many of the critical biological parameters required to develop a coupled bio-physical model, and b) spatially explicit physical models for the region.

Canadian scientists also have a long history of fisheries oceanographic research in the Pacific. The Canadian La Perouse program provides a continuous time series of biological and physical oceanographic conditions off the outer coast of Vancouver Island since 1985.

The FOCI and the Canadian La Perouse programs are among the most mature fisheries oceanography programs in the world. Very few fisheries oceanography programs have been able to maintain continuous coordinated research for more than a decade. The results from these two programs provide many of the critical parameters for the development of the larger scale ecosystem models necessary to study climate change and carrying capacity. For example, the FOCI program has enumerated abundance trends at various life stages of early development; examined processes affecting life stages; mapped horizontal, vertical, and temporal distributions; described the oceanic and atmospheric environment; developed coupled bio-physical models of the Gulf of Alaska, and developed techniques to examine recruitment-process hypotheses.

Regional Boundaries

For the purposes of the workshop, the Bering Sea included all regions north of the Aleutian Islands (Figure

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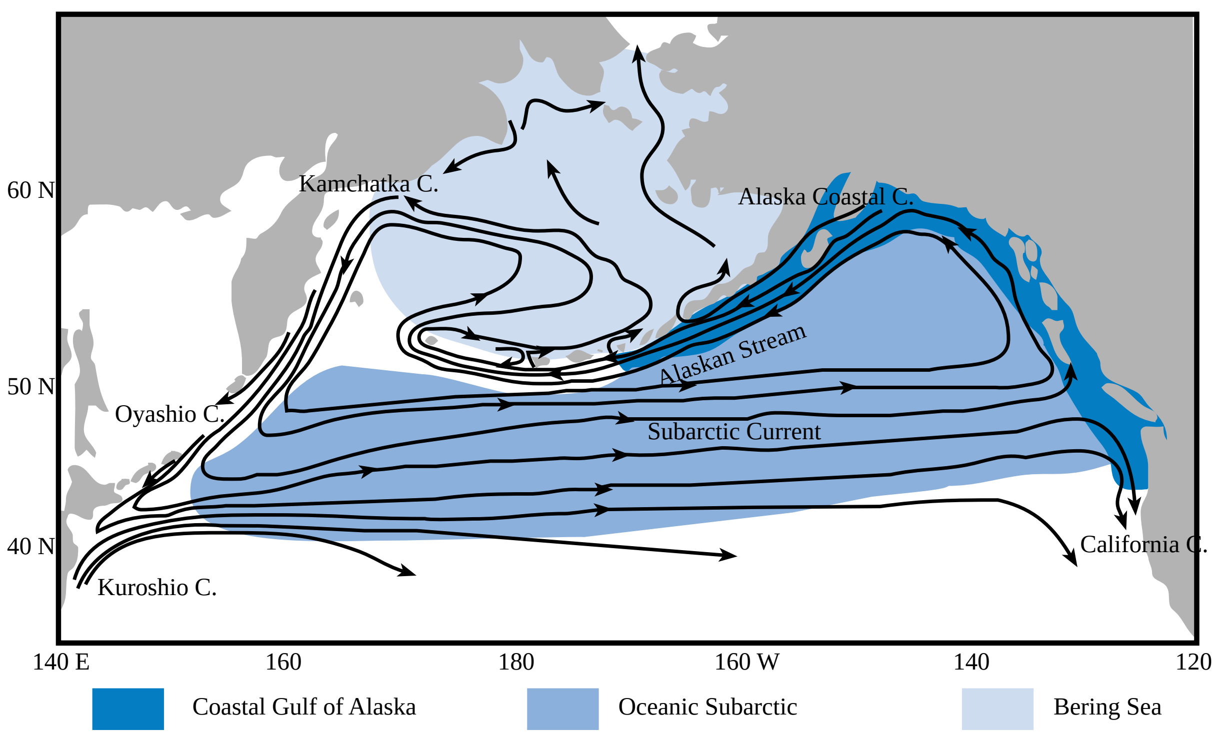

Integrated Assessment of Climate Variability, Impacts and Policy Response in the Pacific Northwest

by Edward L. Miles

This article describes a project concerned with the human and ecological implications/responses to two sources of global and regional climate variability. At the global scale, the focus is on anthropogenically-induced climate change as a result of the increasing concentration of greenhouse gases in the atmosphere (IPCC 1990, 1992, 1994). The principal forcing function is represented by increasing emissions of CO_2 and other greenhouse gases and the timescale of change is on the order of decades to centuries and perhaps millennia (Broecker, 1987).

At the regional scale, the focus is first on the projected regional climate response to anthropogenic greenhouse forcing and the impacts of such forcing on natural ecosystems, natural resources, and human activities. The timescale of change is on the order of decades to centuries. Secondly, however, we consider naturally-occurring climate variations on the regional scale in which the principal forcing functions are fluctuations in the coupled atmosphere/ocean/land system. The timescale of change here is seasons to decades.

In the Pacific Northwest (PNW), the dominant regional climate signal is linked to the large-scale, interannual climate phenomenon called El Niño-Southern Oscillation (ENSO) (Battisti and Sarachik, 1995). ENSO has been shown to have strong Pacific-wide effects with direct connections to regional climate anomalies over Australia, the Indian Ocean, and South America on seasonal/interannual timescales and with mid-latitude Northern hemispheric teleconnections on seasonal to decadal timescales (Graham 1994; and Trenberth 1994).

Since the ENSO phenomenon occurs on a much shorter timescale than the anthropogenic contribution to greenhouse forcing, we, like U.S. GLOBEC (U.S. GLOBEC 1994), choose to treat ENSO and its impacts as a model experiment of how global climate variability might affect natural ecosystems, natural resources, and human activities on a regional scale. In this connection, we are ultimately most concerned with the sensitivities and vulnerabilities of ecosystems, resources, and human activities to climate variability/change of all types and with what kinds of response strategies may make the most sense on different timescales.

Defining Integrated Assessment

Global climate variability generates pervasive, multi-dimensional effects. The prospect of human-induced global climate change necessitates the development of response strategies at a variety of time and space scales. Details of the effects expected as a result of human-induced global climate change are still poorly understood and there is still substantial uncertainty embedded in the predictions generated by general circulation models (GCMs). Since the resolution of the GCMs is poor, our understanding of the regional-scale effects of global climate change (GCC) is as yet rudimentary. It would not be advisable simply to parameterize the GCMs downwards to regional scales because such an approach could yield spectacular errors. Therefore, we will take a bottom-up approach, matching data on regional characteristics to those processes and dynamics of global climate variability, e.g., the ESNO cycle, which are fairly well understood.

Working through the causal chain from climate dynamics to climate impacts to policy response strategies is what we mean by providing integrated assessment. This means that in the PNW, we shall try to link the dominant climate signal, i.e., ENSO, to regional climate variability impacts; and secondly to link the regional climate impacts to response strategies. Care must be taken to estimate the level of uncertainty attached to predictions of specific impacts. Presently, we focus on climate dynamics in relation to water resources, forest resources, marine ecosystems, and coastal activities. In the future, we propose to add energy, urban centers, agriculture, and human health.

There is no one way of doing integrated assessment. Since we are concerned principally with natural climate variability on the regional scale, we begin with the phenomenon itself and the capability to predict its occurrence. In this context, vertical or end-to-end prediction and assessment consists of the following elements (Sarachik, unpub. MS 1995):

- A model to make the predictions.
- Data: Must be quality controlled, ingested and assimilated into a form the model can accept.
- Initialization: The data and the model must be combined to provide an optimal estimate of the state of the coupled system.
- Large Scale Prediction: One, and perhaps an ensemble of predictions must be run.
- Evaluation: The data must be used to see how good the forecast was and to provide an objective measure of skill.
- Assessment: Look at the impacts of seasonal-to-interannual variability and decide on the appropriate regional site and scale.
- Regionalization: Regional data and models must be combined to provide regional data products.
- Regional Forecasts: The regional data products are combined with the large scale forecast to provide a regional forecast.
- Applications: The regional forecasts are applied to differ-

(Cont. on page 5)

Integ. Assess.—(Cont. from page 4)

ent sectors of usability.

- Effectiveness of Applications: Understanding and implementing appropriate ways of distributing and communicating information (including uncertainties) about seasonal-to-interannual variability, prediction, and applications to a broad user community.
- Evaluation of Applications: The impact of the applications and the effectiveness of whatever actions are taken are evaluated.

We note also the following point made by Dowlatabadi and Morgan (1993):

Whereas the arguments for integrated assessment are intellectually compelling, current understanding of the natural and social sciences of the climate problem is so incomplete that today it is not possible to build traditional analytical models that incorporate all the elements, processes, and feedbacks that are likely to be important....The result has often been that the policy discussion has focused on what we know, rather than what is important....it will be necessary to evolve a new class of policy models that allows an integration of subjective expert judgment about poorly understood parts of the problem with formal analytical treatments of the well-understood parts of the problem.

The UW Project on Integrated Assessment for the Pacific Northwest (PNW)

Based on the reasoning outlined above, this project incorporates two foci: a) applying predictions of PNW climate; and b) an integrated assessment of climate variability impacts in the PNW, both as a model for potential climate change and as an economically practical use of current scientific knowledge of seasonal to interannual climate variability.

The state of the art in air/sea interaction studies offers substantial promise for improving long-range climate forecasts, particularly on the seasonal/interannual time scale. These forecasts can encompass precipitation, run-off patterns, sea-surface layer conditions, the frequency and/or probability of storm surges, and changes in the ocean environment of relevance to fisheries.

The ability to offer seasonal/interannual climate forecasts of increasing accuracy implies that the scientific community and the user community of the forecast products must be linked dynamically. Such linking will facilitate reciprocal understanding of the needs, resources, and limitations of both communities; influence design of forecast products which are clearly tailored to **the needs of the user community**; and expand the research community's capabilities to conduct integrated assessment of the probable impacts of global climate change on the Pacific Northwest.

A Workshop

NOAA/OGP organized a one-day workshop held at NOAA/Pacific Marine Environmental Laboratory (PMEL) on February 1, 1995 to discuss what we know about regional-scale climate change, its impacts on the PNW, and new types of forecasts. The workshop brought together climate diagnosticians from NOAA and JISAO and representatives of the user community in Washington and Oregon.

From the perspective of climate diagnostics, the point was made that while it would not be possible to predict what would happen in a particular month or variability over several years, it was possible to predict seasonal and interannual climate fluctuations. We defined the region of the PNW as the entire Columbia Watershed and focused on the relationships between ENSO variability, precipitation, temperature, and snowpack. Temperature is strongly correlated with ENSO in the PNW and temperature predicts to snowpack. New technology is yielding better understanding of the ENSO phenomenon and gives promise of better resolution (smaller scale) in prediction and more lead time in the forecasts.

Anticipated forecast products, based on the new technology, include: a) monthly seasonal forecasts out to one year lead time; b) monthly coupled dynamical model forecasts for Tropical Pacific SSTs out to one year; and c) monthly 9-member ensemble/2-season atmospheric GCM forecasts using either observed or tropical model forecast SSTs.

Who are the users of climate prediction data and what are their needs? Potentially, they are the 1) Washington Dept. of Fish and Wildlife (salmon stock management), 2) Washington Department of Ecology (monitoring and management of eutrophication; habitat management; flooding and coastal erosion hazards), 3) Seattle City Light, Bonneville Power Authority, and Tacoma Power and Light (hydroelectric power generation; monitoring and regulating watersheds; runoff), and 4) the National Marine Fisheries Service (ocean conditions, circulation, fisheries management in face of uncertain climate change). There are many others. Forecasts of the spatial and temporal patterns of temperature, precipitation, stream flow and runoff are needed to enable these agencies (users) to more efficiently and economically manage resources (e.g., water, fisheries). For example, the U.S. Bureau of Reclamation/Yakima has a focus on managing water for multiple uses. They need specific predictions rather than loose statements like "above or below normal." At minimum, they would like a forecast for a range of expected climate conditions. The runoff forecast is their critical management tool, therefore temperature and precipitation are the most important variables. 60% of their summer water comes from snowpack. Most agencies operate on the basis of historical data, i.e., ca. 30 years. They need to understand what is normal in the PNW and how to predict

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Southern Ocean Work Begins

contributed by Polly Penhale and Eileen Hofmann

The long-range goal for the U.S. GLOBEC program is to understand the interactions between physical processes and marine animal populations with an emphasis on predicting the effects of global change on population abundance and variability in marine ecosystems. Long-range goals for the U.S. JGOFS program are to evaluate and understand on a global scale the processes controlling the fluxes of carbon and associated biogenic elements in the ocean and to develop a capability to predict the response of oceanic biogeochemical processes to climate change. The Southern Ocean provides an opportunity to combine the goals of these two programs to address issues of climate change effects on biogeochemical cycling and marine food web processes and how these interact to control and regulate biological production. Modeling provides one apporach for addressing many of the issues related to the long-term goals of both programs. Consequently, the decision was made to issue a joint request GLOBEC-JGOFS request for proposals for modeling work in the Southern Ocean.

The Southern Ocean activties planned as part of the U.S. Global Ocean Ecosystems Dynamics (U.S. GLOBEC) and the U.S. Joint Global Ocean Flux Study (U.S. JGOFS) programs are proposed to begin in the late 1990s. As part of starting these activities, the United States National Science Foundation's (NSF) Office of Polar Programs and Division of Ocean Sciences announced in early 1995 a call for proposals for modeling studies related to the developing science programs in the Southern Ocean. The purpose of the announcement was to encourage modeling studies that will advance the understanding of the biogeochemistry and the interactions between marine populations and physical processes in Southern Ocean ecosystems. In particular, modeling studies were encouraged that would advance the planning and design of multidisciplinary field programs. The goal was to develop the capability to predict the response of oceanic biogeochemical processes and marine animal populations to, as well as their influence upon, climatic change.

Following the recommendations of the national and international workshops and those from the Scientific Steering Committees for U.S. GLOBEC and U.S. JGOFS, proposals for modeling studies were solicited in advance of field programs in the Southern Ocean. It was hoped that modeling studies would provide guidance for the design and implementation of the field programs, both by addressing issues of sampling strategy, and by highlighting key processes and measurements necessary to understand the coupling among physical and biogeochemical processes. Modeling studies were solicited in the areas of (but were not limited to):

- trace metal controls on primary production,
- sea-ice and biological interactions,
- mixed layer and biological interactions,
- biological and physical controls on air-sea carbon exchange,
- aggregation dynamics and the role of patchiness,
- top predator population dynamics and control,
- behavioral responses of predator and prey,
- paleoclimate and paleoceanographic processes,
- microbial controls on material cycling,
- coupled large and regional scale physical-biological models, and
- models as the primary tool for historical data analysis.

In addition, studies that addressed issues that could advance the state of knowledge of modeling as well as provide understanding of the Southern Ocean system were encouraged. Such studies might include ecological models for data assimilation and management, and modeling techniques for matching scales between models.

The Southern Ocean modeling request for proposals resulted in submission of twenty-two proposals, which were split between GLOBEC and JGOFS studies. Of these proposals, three GLOBEC-related proposals were funded from fiscal year 1995 funds. It is anticipated that additional proposals from this competition will be recommened for funding from fiscal year 1996 funds. Below are the abstracts for the funded GLOBEC proposals.

Aggregation Dynamics of Antarctic Krill, *Euphausia superba* Dana (Mark E Huntley, Scripps Institution)—Patchiness of zooplankton and micronekton is a feature of central importance in marine ecosystems. In the Southern Ocean, aggregations of krill (*Euphausia superba*) are of particular interest. The distribution and dynamics of such aggregations are critical to determining the transformation of organic matter (e.g. carbon flux) and the fate of populations in the sea. These phenomena are especially important in the mesoscale and sub-mesoscale domains, where patchiness is most strongly expressed. If the means to predict patch dynamics is lacking, then so is the means to adequately predict carbon flux and population dynamics at these scales. Traditional models of zooplankton patch dynamics generally treat animals as Lagrangian particles whose aggregations are determined solely by processes of advection and diffusion. This approach ignores behavior induced by biotic and abiotic forces and manifested as purposeful motion—motion that

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Southern Ocean—(Cont. from page 6)

clearly is not governed by advection and diffusion. Attempts to acknowledge behavior in models of plankton motility have been successful at the level of the individual animal, but even the most powerful computers cannot run individual-based models to predict aggregation dynamics of n individuals. This proposal takes a new approach to modeling aggregation dynamics, based on "bio-continuum" theory, and provides for model verification against benchmark field data. Rather than relying on traditional advection-diffusion equations, which ignore behavior, the bio-continuum theory recognizes behavioral forces in the context of statistical mechanics. Model output provides information on animal behaviors, manifest as swimming velocities, that are absent from other models of patch dynamics. All key model variables are measurable using common sampling techniques, such as acoustic Doppler and multiple net systems. The proposed research consists of studying both the internal and external forces that act on aggregations of *Euphausia superba*. First, the internal forces of autocoherence (that act between animals to maintain patch integrity) will be measured in krill aggregations observed in the Gerlache Strait region in 1992. Our database consists of more than 20 such aggregations observed by ADCP and MOCNESS. Second, the effect of external physical forcing on krill aggregations will be studied by embedding krill swarms of typical scales in numerically modeled flow regimes that are typical of the Gerlache Strait region, by combining the Princeton circulation model with our aggregation model. This research provides a novel, dynamic theory of animal aggregations in the sea. A study of the fundamental theory, coupled with model realizations that can be compared to observed aggregations of *Euphausia superba*, may lead to more realistic predictions of krill patch dynamics in the Southern Ocean. Such predictions are critical to more accurate measurements of carbon flux and the population dynamics of krill.

Modeling the Transport and Exchange of Krill between the Antarctic Peninsula and South Georgia (Eileen E. Hofmann and John M. Klinck, Old Dominion Univ.)—Increasing evidence indicates that krill populations surrounding South Georgia are supplied by krill exported from the Antarctic Peninsula region. However, little knowledge of the potential krill transport pathways exists. General circulation patterns for the Antarctic Peninsula and Scotia Sea regions are known. However, recent observations have shown considerable mesoscale structure to the flow on the continental shelf west of the Peninsula, in Bransfield Strait, around Elephant Island and in the Scotia Sea, which potentially influences krill transport and retention. Moreover, local hydrographic and current conditions have considerable influence on the development and growth of krill. Hence, understanding and elucidating krill transport pathways or possible retention regions requires knowledge of the mesoscale current and water mass distributions. The overall goal of the research is to investigate transport of krill between the Antarctic Peninsula region across the Scotia Sea to South Georgia. To accomplish this general objective the following specific research objectives will be pursued: (1) implement a circulation model for the Antarctic Peninsula-Scotia Sea region; (2) interface an energetically based model for the development of krill from larva to adult with the circulation model; and (3) use the circulation-krill model to investigate the retention and/or transport of krill in the Antarctic Peninsula to South Georgia. This modeling study is a joint effort between E. Hofmann and J. Klinck at Old Dominion University and Dr. Eugene Murphy at the British Antarctic Survey (BAS) in Cambridge, England. It will provide a framework for analyzing, synthesizing and integrating the large environmental and krill data sets collected by BAS around South Georgia with those from the Antarctic Peninsula region that have come from historical sources (e.g., BIOMASS) and the Palmer Long Term Ecological Research (LTER) Program and those from the Bransfi eld Strait and Elephant Island regions from the U.S. Antarctic Marine Living Resources (AMLR) program. Moreover, the proposed modeling studies are relevant to the key science questions set forth by U.S. GLOBEC (GLOBEC, 1990) and International GLOBEC (GLOBEC, 1993) for the Southern Ocean. In particular, it addresses issues related to the role of circulation and biological processes in structuring Antarctic krill populations. Also, quantifying the krill transport (flux) between the Peninsula and Scotia Sea has been identified as a high priority issue by the Convention for Conservation of Antarctic Marine Living Resources (CCAMLR).

Physical-Biological Interactions Controlling Larval Krill Development and Early Survival: Implications for Population Recruitment and Demography of *Euphausia superba* Dana (Peter J. Franks, Scripps Institution)—This project will investigate how spatial and temporal variability in physical-biological features affects the development, condition and survival of Antarctic krill larvae (*Euphausia superba*). It is believed that adult spawning behavior and regional differences in primary productivity and temperature are significant forces controlling krill mortality, population demography and recruitment. Using a modified stage-structured larval population model, the effects of spawning behavior and variations in stage durations and mortalities on demography and recruitment will be examined. The model results will be compared with observed larval distributions to determine which processes best account for the observed population structures. Using a detailed metabolic

(Cont. on page 13)

U.S. GLOBEC Calendar

1996

22-25 January: 9th Western Groundfish Conference, Newport OR, USA. Contact: Elaine Stewart; ODFW, 2040 SE Marine Science Drive, Newport OR, USA 97365

12-16 February: AGU/ASLO Ocean Sciences Meeting, San Diego CA, USA. Contact: AGU - Suzette Kimball, Deputy Associate Regional Director, Science and Natural Resource Management, National Park Service, Southeast Region, 75 Spring Street, S.W., Suite 1092, Atlanta, GA 30303 (Phone: 404-331-4916; FAX: 404-331-4943; Internet: suzette_kimball@nps.gov) or ASLO - Polly A. Penhale, Office of Polar Programs, National Science Foundation, 4201 Wilson Blvd., Suite 1092, Arlington, VA 22230 (Phone: 703-306-1033; FAX: 703-306-0139; Internet: ppenhale@nsf.gov)

5-8 March: Oceanology International 96, Brighton, UK. Contact: Angela Pederzolli, OI96, Spearhead Exhibitions Ltd, Ocean House, 50 Kingston Rd., New Malden, Surrey KT3 3LZ, UK; (Phone: 0181-949-8186/8193; FAX: 0181-949-8186; Internet: oi96@spearhead.co.uk)

20-22 March: Estuarine and Ocean Survival of Pacific Salmonids, Newport, OR. Convened by NMFS and Oregon State University. Contact: Bob Emmett (Internet: emmettb@ccmail.orst.edu)

21-23 March: Second ICES/GLOBEC Backward-Facing Workshop, Bergen, Norway. Contact: R. Dickson and K. Frank (Internet: k_frank@bionet.bio.dfo.ca)

25-27 March: ICES/GLOBEC Working Group on Cod and Climate Change, Bergen, Norway. Contact: Svein Sundby (Internet: sveins@sentral.imr.no)

10-11 April: U.S. GLOBEC Scientific Steering Committee meeting, Washington, DC, USA. Contact: H. Batchelder, Department of Integrative Biology, University of California, Berkeley, CA 94720-3140 (Phone: 510-642-7452; FAX 510-643-6264; Internet: halbatch@violet.berkeley.edu)

8-11 July: Scientific Meeting on Marine Environment and the Global Change Programs. The Oceanography Society (TOS) in cooperation with WCRP, IGBP, HDP and SCOR, Amsterdam, The Netherlands. Contact: TOS, 4052 Timber Ridge Dr., Virginia Beach, VA, USA (Phone: 804-464-0131; FAX: 804-464-1759; Internet: jrhodes@ccpo.odu.edu)

28 July-2 August: 2nd World Fisheries Congress: Developing and Sustaining World Fisheries Resources: The State of Science and Management, Brisbane, Australia. Contact: Secretariat, P.O. Box 1280, Milton Brisbane, Queensland 4064, Australia (Phone: 617-3369-0477; FAX: 617-3369-1512; Internet: fish96@sunray.im.com.au)

27 September-1 October: 1996 ICES Annual Science Conference, Reykjavik, Iceland Contact: ICES, Palaegade 2-4, DK-1261 Copenhagen K, Denmark (Phone: +45 33 15 42 25; FAX: +45 33 93 42 15; Internet: postmaster@server.ices.inst.dk)

14 October - (tentative): PICES 5th Annual Meeting, Nanaimo BC, Canada. Contact: PICES Secretariat, c/o Institute of Ocean Sciences, P.O. Box 6000 Sidney BC, Canada V8L 4B2 (Phone: 604-363-6366; FAX: 604-363-6827; Internet:pices@ios.bc.ca)

29 October-1 November: CalCOFI Conference, Asilomar Conference Center, Pacific Grove, CA, USA. Contact: George Hemingway or Mary Olivarria, MLRG, Scripps Inst. of Oceanogr., La Jolla CA, USA 92093-0227 (Phone: 619-534-4236/2868; FAX: 619-534-6500; Internet: ghemingway@ucsd.edu; Internet: molivarria@ucsd.edu)

13-15 November: International Symposium on the Role of Forage Fishes in Marine Ecosystems, Anchorage AK, USA. Contact: Brenda Baxter, Alaska Sea Grant College Program, Univ. of Alaska, PO Box 755040, Fairbanks AK, USA 99775-5040 (Phone: 907-474-6701; FAX: 907-474-6285; Internet: fnbrm1@aurora.alaska.edu)

22-24 November: Symposium on Seabird Ecology and Distribution in Relation to the Marine Environment, Glasgow, Scotland. Contact: ICES, Palaegade 2-4, DK-1261 Copenhagen K, Denmark (Phone: +45 33 15 42 25; FAX: +45 33 93 42 15; Internet: postmaster@server.ices.inst.dk)

25-27 November: International Symposium on Benguela Dynamics: Impacts of Variability on Shelf-Sea Environments and their Living Resources, Cape Town, South Africa. Contact: The BEP Symposium Secretariat, Dept. of Zoology, Univ. of Cape Town, Rondebosch 7700, South Africa (FAX: 27-21-685-3937; Internet: bep@ucthpx.uct.ac.za)

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GLOBEC Activities in ICES

ICES has continued to develop a firm role in GLOBEC, and looks forward to a continued close collaboration with IOC, SCOR and PICES on GLOBEC issues. During 1995 it hosted a meeting in its Copenhagen Headquarters aimed at finalising the GLOBEC Science Plan for the approval of the IGBP. ICES has also now received funding from the USA and Norway to allow for the establishment of a North Atlantic Regional Office of GLOBEC and plans are currently underway to recruit a suitable marine scientist to man this Office. It is hoped that the Office will be opened in early 1996. Oversight and direction for this Office will be provided by a newly-established ICES/GLOBEC North Atlantic Regional Co-ordinaton Group. This Group will also seek to integrate national activities into a co-ordinated GLOBEC implementation plan, provide scientific direction for liaison with other regional bodies (e.g. PICES) and the relevant global organisations (IOC, SCOR, IGBP), develop plans for the design and implementation of an integrated data management system for the North Atlantic, and identify and direct the GLOBEC Office to implement appropriate ways to engage the widest possible involvement in scientific development and communication through workshops, the ICES Annual Science Conference, and special sessions at other scientific meetings.

In 1995 ICES/GLOBEC meeting activities have very much focused on Cod and Climate Issues which have been steered by the ICES Consultative Committee and the ICES/GLOBEC Working Group on Cod and Climate Change. Two substantive workshops assessing the state of knowledge of the interactions between the environment and various life stages of cod have so far been held. The first of these, the AGGREGATION Workshop was held in late 1994 and examined such issues as the statistical relationships between oceanographic models and cod growth and recruitment, mesoscale transport models, retentive circulation patterns, plankton production, and turbulence and feeding. Some of these issues were developed further at the Theme Session on the Influence of Intermediate-Scale Physical Processes on the Transport and Food Environment of Fish which was held at the 1995 ICES Annual Science Conference.

A second Workshop, the Backward Facing-Workshop, was held in early 1995 and examined past analogues for present and recent conditions of excessive cold from West Greenland to the Middle Atlantic Bight. This was undertaken using data from the early 1880s onwards in order to isolate the effects of fishing which dominate current data sets. A follow-up Workshop, focusing on the Barents Sea, is planned for early 1996.

Plans for a Workshop on Cod and Climate Database issues have been made for some time, but this workshop will not meet until November 1995. This Workshop will consider current and past analyses of the interrelationships between cod and the environment and will consider the data structures that are necessary to allow for a wide variety of analysis options. The Workshop will also consider a potential data management plan for GLOBEC, including investigating the pros and cons for distributed and centralised databases. *(Harry Dooley of ICES provided this information, extracted from the 1995 ICES report to SCOR)*. ΔΔΔ

Ann Durbin

Ann Durbin, a former U.S. GLOBEC SSC member, passed away in July following a long and courageous struggle with cancer. Paul Smith, a long-time friend and colleague, spoke of Ann's influence on the oceanographic community and his remembrances of her at our October SSC meeting at the University of Rhode Island, where Ann was on the faculty until her death. Paul recalled how Ann held her work to the highest standards, and expected no less of others; she was critical of less than excellent work. Her "toughness" and "thoroughness" will be missed by her friends and by the ocean science community.

GLOBEC and The International Whaling Commission—Complementary Interests in the Southern Ocean Marine Ecosystem

by Eileen E. Hofmann

Introduction

In 1992 the International Whaling Commission (IWC) passed a resolution calling for research to address questions related to the potential impact of environmental change in the Antarctic and elsewhere on whale stocks. As part of this resolution information was requested on international programs that are directed at understanding environmental change and its effect on marine animal populations, especially in the Southern Ocean. GLOBEC International is coordinating the development of a program to investigate the dynamics of Southern Ocean organisms and the interactions of key populations with each other (predation, competition) and with their physical environment, especially with sea ice dynamics and water circulation. Both of these are susceptible to climate change. An implementation plan for a Southern Ocean GLOBEC program should be available from the GLOBEC International Secretariat by the time you read this article. This article is a synopsis of a lengthier paper prepared for the 47th Annual Meeting of the IWC, recently held in Dublin, Ireland. It focuses primarily on the mutual interests of the IWC and GLOBEC and potential interaction of the two programs.

The Antarctic marine food web is unique among ocean ecosystems in that 1) it is characterized by dependence largely on a single key species, Antarctic krill (*Euphausia superba*), and 2) many species of the food web are dependent on sea ice during some or all of their life history. For these reasons the Southern Ocean marine ecosystem may be especially vulnerable to perturbations caused by changes in environmental conditions (e.g., climate), pollution stress, or exploitation of natural resources. Consequently, documentation of natural population fluctuations and understanding of the mechanisms underlying this variability is critical if prediction of the effects of natural or anthropogenic changes on the Antarctic marine ecosystem is a goal.

The Antarctic marine food web is more complex than the simple linear food chain (phytoplankton-krill-higher consumers) that has often been described for this system (Marchant and Murphy, 1994). However, linkages in the Antarctic food web can be short and may be dominated by few species. The short trophic connections arise because the basic prey types (e.g., Antarctic krill) available to predators are limited and because among the basic prey types, predators tend to concentrate on core groups of species, such as the abundant euphausiids and fish near the base of the food chain. It has been suggested that because of the apparent close coupling between trophic levels, long-term studies focusing on these predator-prey relationships and their environment will not only be critical to understanding variability in the Southern Ocean ecosystem in general, but may ultimately form the basis for monitoring the effects of man-induced perturbations on the system (see Sherman (1994) for a discussion).

Long-term fluctuations in krill abundance are well documented and years of low krill biomass have been attributed to krill redistribution by physical process (Priddle et al., 1988). However, the mechanisms controlling the abundance and recruitment of Antarctic krill are not well known. Similarly, long-term fluctuations in the abundance of top predators have been documented and have been attributed to habitat modifications brought about by changes in environmental conditions (e.g., Fraser et al., 1992), as well as biological interactions. As with krill, the processes underlying the observed changes in top predators are not well understood.

The strong coupling between the Antarctic marine food web and the physical environment, especially the dependence on sea ice, makes the Southern Ocean an ideal environment to test many of the GLOBEC core hypotheses on the role of physical variability on marine animal population dynamics. Many of the scientific concerns and objectives of this program are relevant also to those of the International Whaling Commission.

Linkages Between Southern Ocean GLOBEC and IWC

Much of the early study of the Southern Ocean marine ecosystem was initiated as a result of whaling activities and was directed at understanding the factors controlling the food supply of whales, namely krill. The large supply of krill was assumed to be a result of high transfer efficiencies of a short and simple food chain in which much of the primary production went to krill: whales-krill-diatoms. This conceptual model was accepted until the 1980s when sufficient data become available to show that primary production in the Southern Ocean is low, diatom blooms are not ubiquitous, and that the phytoplankton populations tended to be composed of small cells (Marchant and Murphy, 1994). As a result, the environmental and biological processes that maintain a large krill stock are still unknown.

In the 1980s Southern Ocean research shifted to attempting to understand the processes that controlled primary production. Programs (e.g., JGOFS) have been undertaken to determine the role of circulation, mixed layer depth, stratification, micronutrient (especially iron) limitations, and grazing by protozoa and

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Whaling—(Cont. from page 10)

metazooplankton on limiting primary production in the Southern Ocean. Also, the ecology of sea ice and the impact of seasonal ice advance and retreat on water column biology have received attention. The importance of sea ice as a winter refuge for many pelagic organisms, including krill, as a component of the survival of certain top predators (e.g., Adelie and Chinstrap penguins) and as a productive region during periods of ice melt has become apparent. Also, in addition to krill, copepods and salps are now recognized as important metazoan grazers in the Southern Ocean. The results from recent multidisciplinary Antarctic programs indicate that the pelagic ecosystem is far more complex than the diatom-krill-whale paradigm. Moreover, considerable regional and interannual variation has been observed in the Antarctic marine food web which appears to result from environmental effects (Fraser et al., 1992; Murphy et al., in press).

Studies on krill distribution and population dynamics to date have not resolved the factors enabling maintenance of the enormous krill stock. Various hypotheses have been put forward to explain this unique feature of the Southern Ocean. The hypotheses are not mutually exclusive and none of them alone is sufficient to account for the available observations of krill occurrence. It appears that krill are capable of exploiting a wide variety of food resources in habitats ranging from open water to sea-ice and benthos. The regions where high krill concentrations have been frequently observed share common features, for instance their proximity to frontal zones separating major water masses. However, the reasons why krill congregate there and the underlying mechanisms of swarm formation and dispersal remain obscure.

Food supply is a major factor regulating the abundance and productivity of top predators in the Southern Ocean. For many of these species krill is the primary food source, and despite ecological segregation of many of these species competition for this resource potentially exists. It has been suggested that changes in abundance and population characteristics of some top predator species have come about as a result of food (krill) made available by the reduction in whale numbers (Laws, 1985). For example, Figure 1 shows estimated krill consumption by Antarctic predators before and following an approximately 90% reduction in baleen whale biomass. However, the evidence in support of this hypothesis is inconclusive (Kock and Shimadzu, 1994).

While whaling did no doubt produce changes in the Southern Ocean marine food web, the role of environmental conditions in either mitigating or exacerbating these changes cannot be dismissed (Kock and Shimadzu, 1994). Long term changes have been documented in sea ice cover, atmospheric systems, and current systems. These potentially affect all parts of the Antarctic marine food web through regulating food sources, changing patterns of dispersal, or changing habitat characteristics, for example. To simply attribute changes in prey availability to increases or decreases in predator stocks (e.g., the whale reduction-krill surplus hypothesis) ignores evolutionary processes that have produced strong linkages between the components of the Antarctic marine food web and their environment.

The inability of current hypotheses, such as whale reduction-krill surplus, to adequately explain observed changes in Southern Ocean top predator stocks suggests that the processes responsible for these changes have not been represented in current thinking about this system. The complex nature of the Antarctic system argues for a holistic and integrated approach for studying its response to changes. It is through a research program that includes studies of the environment as well as the organism that the cause and effect underlying changes in the Southern Ocean marine ecosystem will be understood.

GLOBEC-IWC Connections

Southern Ocean GLOBEC differs from GLOBEC programs in other regions in that there is greater emphasis on top predator species such as birds and seals. Historically, top predator research has been usually conducted independently of studies of lower trophic levels. However, in recent years the application of new technology has resulted in rapid advances in understanding of bird and seal ecology and it is now feasible to integrate studies of plankton ecology with those of their predators (e.g., Hunt et al., 1992). The study of top predator/pelagic interactions is a major goal of Southern Ocean GLOBEC (U.S. GLOBEC, 1991; GLOBEC, 1993; GLOBEC, in press).

At a Southern Ocean GLOBEC

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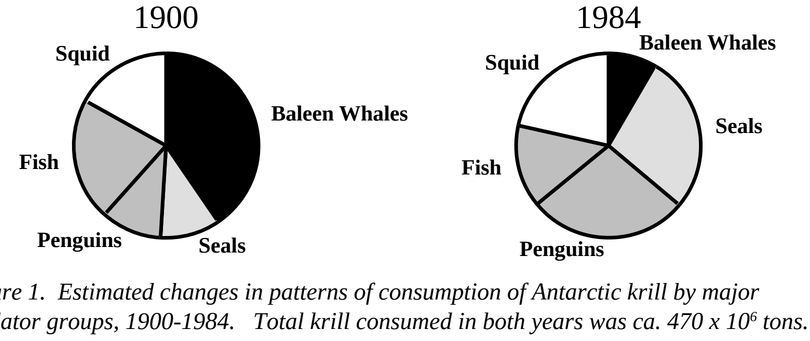

Figure 1. Estimated changes in patterns of consumption of Antarctic krill by major predator groups, 1900-1984. Total krill consumed in both years was ca. 470 x 10^6 tons. (Plotted from data in Table 5.2 of Lalli and Parsons, 1993)

Whaling—(Cont. from page 11)

workshop held in June 1993, criteria were set forward for selection of top predator target species. The criteria were:

• degree of association of the target species with ice cover or the ice edge;

• the degree of dependence of the predator on krill;

• the availability of data on the species from existing and historical studies; and

• the feasibility of studying the target species.

Several of the whale species that are found in the Southern Ocean, such as the minke whale, fit these criteria and were discussed at the workshop as possible target species for U.S. GLOBEC studies. However, at that time, the decision was made to exclude whales as target top predator species because it was believed that the IWC was developing a program for monitoring and studying whales in the Southern Ocean.

Nevertheless, the importance of whales in the Southern Ocean food web has been recognized in Southern Ocean GLOBEC planning. As a result, it was recommended that Southern Ocean GLOBEC develop and maintain ties with the IWC (GLOBEC, 1993). The goal put forward by the IWC of understanding the processes that regulate whale populations in the Southern Ocean makes interfacing with Southern Ocean GLOBEC desirable, as many of the scientific issues are of mutual interest to both programs.

To begin discussions between GLOBEC and IWC it is recommended that a joint GLOBEC-IWC working group be established. This group would be tasked with:

• reviewing the Southern Ocean GLOBEC top predator key questions to determine how these might be modified (if necessary) to include issues related to environmental and biological effects on whales;

• providing input and recommendations on Southern Ocean study sites that will satisfy GLOBEC and IWC scientific interests; and

• providing input for topics to be discussed at the IWC intercessional workshop on cetaceans and environmental change.

The report from the joint GLOBEC-IWC working group could provide the basis for determining future directions for collaborative international research in the Southern Ocean.*(Eileen Hofmann is at the Center for Coastal Physical Oceanography at Old Dominion University. She is a member of the U.S. GLOBEC Scientific Steering Committee and Chairperson of the U.S. GLOBEC Southern Ocean Working Group.)*

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Whatever became of...

Bill Peterson has left the U.S.GLOBEC Interagency Program Coordination Office and returned to private life. He is currently working for the National Marine Fisheries Service, Northwest Fisheries Science Center at their newly-opened Newport OR field station. His new e-mail is petersbi@ccmail.orst.edu; phone is 541-867-0201; fax is -- 0379. What is he up to there? Drop him a note or give him a call.

Where is he now...

Third International Benguela Ecology Program Symposium

The 3rd International Symposium, BENGUELA DYNAMICS. Impacts of Variability on Shelf-sea Environments and their Living Resources, is being organised under the auspices of the Benguela Ecology Programme (BEP), and will take place at the University of Cape Town, South Africa, from 25-27 November 1996. Established in 1981, the BEP is an interdisciplinary, multi-institutional marine research programme, concerned with the shelf and adjacent offshore waters of southern Africa.

The Symposium will follow the 9th Southern African Marine Science Symposium (SAMSS) on 21-23 November, and will form a climax to the Gilchrist Centenary Celebrations of 1995-96. These are planned to celebrate the one-hundredth year since the appointment in 1895 of Dr John D. Gilchrist as the first Government Marine Biologist in South Africa.

The Symposium theme is: Assessments of variability and change in shelf-sea environments, and forecasts of the impacts on marine resources and their management.

The Symposium objectives are:

- to assess variability and change in shelf-sea environments;
- to evaluate the impacts of such change on marine resources;
- to examine the management-, economic and social implications of resource variability;
- to disseminate the results of the BEP to local and international research communities;
- to provide impetus and direction for future research and monitoring in the broader Benguela region.

The symposium will address the following broad categories:

- past, present and future environmental variability;
- intra-annual variability impacting resources;
- inter-annual variability impacting resources;
- long-term variability impacting resources;
- social and economic implications of resource variability;
- management of varying resources.

For correspondence and enquiries about the Symposium, contact:

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Southern Ocean—(Cont. from page 7)

model with stage structure and realistic external forcing, we will determine how much of the variability in stage durations and mortalities can be explained by the effects of food availability and temperature. Larval lipid metabolism will be incorporated into the model for elucidating the influences of physical and biological variability on larval krill condition. Models will integrate the effects of multiple parameters and will intimately coupled to field observations and laboratory experiments. This study will provided a valuable contribution to the understanding of interactions between marine populations and physical processes in the Southern Ocean ecosystem. The results from this study will be applicable to concurrent research investigating the physical-biological interactions affecting *Euphausia superba* in the Southern Ocean, and *Euphausia pacifica* in the California current. The ultimate intent is to quantify the impact of physical-biological patchiness associated with physical features and phenomena on larval condition, demography and recruitment in euphausiid populations. Understanding species' responses to physical perturbations will elucidate how environments have evolutionarily constrained life-history patterns to maximize survival in inherently patchy and variable systems. Through this understanding, this study will provide insights into the potential effects of climatic change on euphausiid populations and their ecosystems. *(Polly Penhale is manager of the Polar Biology & Medicine Program of the Office of Polar Programs at NSF. Eileen Hofmann is at Old Dominion University and is Chairperson of the U.S. GLOBEC Southern Ocean Working Group).* ΔΔΔ

Integ. Assess.—(Cont. from page 5)

and understand regime shifts.

Based on these views, expressed at the workshop, the project will focus on:

- Climate variability and the ENSO phenomenon on seasonal/interannual and intra-decadal/decadal time-scales and their impacts on the PNW, in particular on the relationships between precipitation, temperature, and snowpack.
- Describing and evaluating the policy framework on the basis of which management decisions are made with respect to multiple uses of freshwater resources, salmon production/survival, agriculture, energy, coastal zone utilization and development. Part of the evaluation will assess the prospects for a more holistic approach.
- Changes in and upgrades of climate information systems in the context of understanding which players are sensitive and vulnerable to climate variability.
- Improved communication and public education as a result of the above; the Internet provides a means of information exchange; and encouraging and providing a mechanism for feedback between climate diagnosticians and the user community.
- Implications for the PNW's ability to adapt to human-induced climate change that may result from anthropogenic greenhouse gas emissions.

Table 1. Concept of Integrated Assessments

Time Scales: seasonal/interannual; intradecadal/decadal; centenial/millenial

Space Scales: subnational; national; regional (international); global

A. CLIMATE DYNAMICS
All time scales: primarily global space scales currently (GCM's). Limited regional capacity (patchy).

B. IMPACTS: BIOGEOCHEMICAL SYSTEMS (BGS)
1) Climate impacts on BGS.
2) BGS impacts on climate.
3) Feedback loops and natural variability (mediated via the ENSO cycle).

C. IMPACTS: SOCIOECONOMIC/POLITICAL SYSTEMS (SS)
1) Climate impacts on SS (focus on sensitivity and vulnerability).
2) Anthropogenic impacts on climate.
3) Feedback loops and time lags (mediated via the ENSO cycle).

D. THRESHOLD EFFECTS: BGS/SS
1) Climate on BGS/SS.
2) BGS/SS on climate.
3) Rates of change.
4) Ecosystemic and distributional effects.
5) Sensitivities and vulnerabilities (mediated via the ENSO cycle).

E. SOCIOECONOMIC/POLITICAL RESPONSE STRATEGIES
1) Type and value of forecast products.
2) Timing of forecasts (will vary by type of use).
3) Institutional contexts and constraints.
4) Planning, adaptation, & mitigation strategies.
5) Probable outcomes and effects for forecast scenarios.

Human Dimensions of Climate Variability

The last four foci (above) relate to the human dimensions of climate variability in the PNW. Human activities in fact provide part of the context into which climate variability is introduced. The other part of the context consists of the natural ecosystems and natural resources which constitute the objects of use. In the first instance, therefore, we are concerned to describe the social organization of the various user communities, their relative capabilities, and how they interact with each other.

Perhaps the central components of the social context relate to institutional arrangements for managing patterns of use. Institutional arrangements include the legal frameworks underlying the resource use, defining ownership and use rights, defining authority relationships, and the right to manage. In addition, the degree of centralization/fragmentation of authority is critical to effective performance and relates to patterns of inter-organizational relations and the potential for coordinated responses across multiple uses. Such patterns include both conflict and cooperation and the capacity to mobilize organizational constituencies and resources.

Patterns of information flow and communication capabilities are important. To what extent, for instance, do patterns of social organization permit the user community to respond to and make use of climate forecasts. In part, the response will be determined by the value to the user of the information embedded in the forecast, but responses can also be facilitated or hindered by legal frameworks defining ownership/use rights and by highly fragmented managerial authority. Who has the authority to make resource decisions is therefore a

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Integ. Assess.—(Cont. from page 14)

question of particular importance.

We shall therefore seek to understand which players are most sensitive and vulnerable to climate variability in the PNW and assess how the new information should be conveyed to maximize its value. The Internet will be important in linking the climate diagnostic community dynamically with the user community.

Finally, response strategies will include a focus on adaptation to climate variability to reduce vulnerabilities. Consequently, we are concerned with thresholds of effects and rates of change as constraints to adaptation. The intent is to determine how to best use more accurate climate forecasts to reduce socioeconomic vulnerability and enhance economic planning.

An Approach

Our analytical approach to the overall integrated assessment is based on the concept outlined in Table 1. We conceive of a four-dimensional space/time matrix in which we attempt to link climate dynamics with its impacts on biogeochemical systems and socioeconomic political systems. The relationship is reciprocal rather than a one-way flow.

Since we wish to determine the sensitivities and vulnerabilities of biogeochemical systems and socioeconomic/political systems in the Pacific Northwest to climate variability/change, we are concerned with threshold effects and rates of change, which could lead to catastrophic changes, e.g., fishery collapses. The final step in the causal chain will be to link our understanding of climate dynamics/impacts/threshold effects to socioeconomic and political response strategies. Up to this point, quantitative modeling will play a large part in our analysis. When we focus on response strategies, however, the analysis must be largely qualitative since the case study material available suggests the crucial importance of institutional arrangements as constraints on or facilitators of response strategies.

The questions which our analytical approach lead us to ask are:

- What is the natural climate variability in the PNW?
- How are the effects of natural climate variability related across dimensions in time and space (hydrology, forests, marine ecosystems, and coastal activities)?
- What are the sensitivities and vulnerabilities of the various social and ecological dimensions to global climate change at rates of 0.2-0.35°C per decade (i.e., 1-2°C by 2050) (IPCC/95)?
- What are the impacts of climate variability/change on biogeochemical systems and on social systems? Are there feedback loops which connect BGS and SS?
- Are there thresholds? If so, what?
- What makes the human systems associated with the Columbia Watershed vulnerable to climate variability? How can improved climate forecasting capabilities be used to reduce vulnerability and enhance economic planning by users?
- What are probable mitigation/adaptation response strategies and what changes/innovations in institutional design are required to facilitate implementation?
- Do scientists know enough about the climate system to provide accurate predictions of climate variability for the PNW at seasonal to interannual leadtimes?

(Dr. Miles is Virginia and Prentice Bloedel Professor of Marine Studies and Public Affairs and Senior Fellow at the Joint Institute for the Study of Atmosphere and Oceans (JISAO) of the University of Washington.)

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1). The geographic boundary between the coastal regions of the Gulf of Alaska and the open sub-Arctic was not defined by the PICES/CCCC working group. The following working definition is offered by U.S. GLOBEC:

The open sub-Arctic region will include Pacific waters north of the position of the isohaline of 34.0 psu in the upper mixed layer, with the exception of the coastal regions over the continental shelf and slope (to depths of 1000 m).

Coastal regions of the subarctic Pacific will include all waters over the continental shelf and slope to depths of 1000 m. This region will include areas south of the Aleutian Islands to the western boundary of U.S. waters at 173 E.

Some species, such as salmon, undertake seasonal migrations that cross both the coastal Gulf of Alaska and the open subarctic. In such situations, it may be necessary to include processes from adjacent regions (such as the coastal Gulf of Alaska or Bering Sea), if they significantly affect the physics, chemistry or biology of the subarctic gyre.

Workshop Structure and Breakout Session Summaries

The workshop began with background briefings on U.S. GLOBEC planning and research activities, and an introduction to the PICES Climate Change and Carrying Capacity Science Plan. Participants were then divided into six multi-disciplinary breakout groups. These six breakout groups covered issues that were relevant to the development of a research plan designed to address the impact of climate variability on biological systems: climate change, regime shifts, carrying capacity, modeling, technology, spatial and temporal scales. The following day, participants were divided into groups to discuss specific recommendations for future research in three geographic regions: oceanic subarctic, Bering Sea and coastal Gulf of Alaska. The following summaries provide a synopsis of the discussions and recommendations made in each of the breakout sessions.

Breakout Session 1. Climate Change: What are the likely scenarios for climate change in the North Pacific and how would they influence the ecosystem?

This group discussed the potential impact of climate change caused by increased CO_2 and other greenhouse gases from anthropogenic sources. Climate change would influence North Pacific ecosystems primarily through four physical factors: mixed layer depth (MLD), volume and location of marine habitat, sea ice, and river flows. Time variation in late spring/summer MLD is the physical oceanographic measurement which may correlate most highly with primary and secondary productivity in the coastal Gulf of Alaska and Bering Sea shelf. Changes in marine habitat, thus the zoogeographic distribution of marine species, are expected to accompany ocean warming, with particular impacts on species at the edge of their ranges. Sea ice is foreseen to decrease both in space and seasonal duration, with effects on the Bering Sea's primary productivity and distribution of many marine mammals. The overall magnitude and seasonal cycle of river flows may change significantly, with implications for coastal currents and freshwater habitats for salmon.

Breakout Session 2. Regime shifts: Can they be detected, what is their impact, are they predictable?

Long term variations in ocean conditions appear to occur at two different time scales and the biological responses appear to differ in magnitude. The temporal periods most commonly mentioned are: 1) decadal and bi-decadal scale shifts, including 6-12 year warm and cool eras and the 18.6 year cyclic phenomenon (Trenberth and Hurrell 1994; Hollowed and Wooster 1992; Royer 1993), and 2) regime shifts that are 30-60 year cycles and appear to generate measurable ecosystem responses (Francis and Hare 1994; Baumgartner et al. 1992; Kawasaki 1992). There is compelling evidence of interdecadal changes in the physical environment of the North Pacific and Bering Sea. The most recent regime shift occurred in the late 1970s. The changes appear to be linked to large scale shifts in atmospheric processes. Marine organisms seem to respond to these decadal scale changes in the physical environment. The group acknowledged that research is required to improve our understanding of the mechanisms underlying the response of marine organisms to shifts in physical conditions. North Pacific basin modeling shows promise in simulating and explaining decadal fluctuations of the ocean over coarse scales. Regional and mesoscale oceanographic models exist for the Gulf of Alaska and need to be developed for other regions. Several physical and biological variables were identified that could be used as diagnostic indicators of regime shifts.

Breakout Session 3: What is carrying capacity?

This group discussed the concept of carrying capacity and methods of measuring it. The group adopted the following definition of carrying capacity: "Carrying capacity is a measure of the biomass of a population that can be supported by the ecosystem. The carrying capacity changes over time with the abundance of predators and resources (food and habitat). Resources are a function of the productivity of the prey populations and competition. Changes in the biotic environment affect the distributions and productivity of all populations involved." Rather than measuring carrying capacity as an absolute value, or providing a rigorous definition, the group discussed indices of carrying

(Cont. on page 17)

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capacity that could be used to assess relative changes in the status of a population. The group noted that size spectrum theory, which relates rates of productivity to the size class of organisms in the ecosystem, is a potentially valuable conceptual framework for examining carrying capacity questions.

Breakout Session 4: What is required to model the impact of climate change on the carrying capacity of the region?

Participants discussed a variety of modeling approaches and suggested that different types of models be nested spatially, temporally and trophically. Physical models of the North Pacific and Bering Sea already exist and could be utilized in the U.S. GLOBEC program. While the formulation of governing equations and choice of parameters for biophysical models is difficult, reasonable choices can be made. Encouraging results have been obtained from the application of coupled biophysical models in other areas of the world (such as the North Atlantic).

Breakout Session 5: What are the technological impediments to measuring the effects of climate change on the carrying capacity?

Climate change by definition is a large scale, long term process (decadal) and will require ample measurements collected over a large geographical area for a long duration. A successful program will require careful selection of study sites at key or pulse points where the variance is minimized and the effects of climate change on carrying capacity are indicative of large scale change. A variety of technological issues were discussed and the disadvantages and advantages of each were identified. The group encouraged efforts to measure sea-surface salinity from satellites to map the large-scale distribution of this variable which can be dynamically more important than temperature in the Gulf of Alaska and Bering Sea. They also noted that deep ocean currents could be monitored using electro-magnetic observations from submarine telephone cables and identified the Kamchatka Current and Alaskan Stream as possible pulse points. Finally they noted the need for research on non-commercial species such as jellyfish or forage fish. These species may play a critical role in determining the carrying capacity of oceanic systems, and at least in the case of the "jellies" require specialized sampling.

Breakout Session 6: What are the spatial and temporal scales required to resolve questions concerning climate change and the carrying capacity?

This group concluded that the spatial scale of climate forcing is large—basin scale at least. The group noted that while considerable attention has been devoted to interannual variations, decadal and longer time scales may be more important for resolving issues of climate forcing and its impact on marine ecosystems. Participants acknowledged that the response time to climate change differs among species, which complicates the interpretation of biological/ecological systems to climatically driven physical changes. Criteria for selecting specific time and space scales for a future U.S. GLOBEC study must include: 1) important sources of variability must be concentrated, 2) relationship to plausible mechanisms of interaction, and 3) related to applied problems.

Coastal Gulf of Alaska Breakout Session

Participants were asked to define research questions that should be investigated to improve our understanding of the impact of climate change on: physical forcing, lower trophic level species, and higher trophic level species. Forcing questions focused on four forcing factors: atmospheric forcing, interactions between the Alaska Stream and Alaska Coastal Currents, the influence of bottom topography on coastal circulation, and tidal influence on nutrient flux. These four large scale factors influence important physical processes such as: mixed layer depth, mixed layer temperature, retention times (eddies), turbidity, and cross shelf transport. Research on the functional relationship between large scale forcing and local conditions will be required. Lower trophic level questions focused on five research topics: the effect of ocean transport on the composition and production of plankton communities, the role of grazing and predation on the structure of plankton communities, trophic phasing, climate change effects on over wintering plankton communities, and freshwater influences on plankton communities. Potential research topics relevant to higher trophic levels focussed on identifying climate change effects upon: a) the spatial distribution of predators, b) prey abundance, c) species composition of fish communities, and d) seasonality of resources to apex consumers.

In the Gulf of Alaska, bio-physical models have been developed for British Columbia, Prince William Sound and Shelikof Strait. Efforts to nest regional models into a large-scale biophysical model of the Gulf of Alaska were recommended. A broad-scale biological model of the Gulf might include the following: phytoplankton, protozoa, euphausiids, copepods, jellyfish salmon, herring, and pollock.

Oceanic Subarctic Breakout Session

Three subgroups formed to discuss projects relevant to 1) physical forcing/ lower trophic level response, 2) higher trophic level response, and 3) ecosystem interactions. The first group identified three projects for future study: a program to document changes in standing stocks of plankton, a project to distinguish the effects of iron,

(Cont. on page 18)

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Ekman pumping, cloud variation, and other factors on primary production, and a test of the Chelton hypothesis on the split of the west wind drift as it nears North America. Five questions were identified for future research of higher trophic level responses. These questions focused on mechanisms responsible for sustained high biomass of higher trophic level species since 1976-77, identifying historical biomass levels, studies to examine the coherence between the eastern and western gyres, bio-physical interactions, and regulatory factors controlling the carrying capacity of salmon. The ecosystem subgroup identified four research topics: effects of Kuroshio/ Oyashio currents on coastal ecosystems of Asia and the deflection of these currents into the eastern subarctic, effects of subarctic currents and ENSO events on the subarctic coastal ecosystem, effects of the transition zone on the subarctic ecosystem and the effect of deep water species on near surface ecosystems. Retrospective, monitoring studies, process oriented and modeling projects were identified to address each of the research topics.

Bering Sea Breakout Session

The Bering Sea is possibly the most productive of the northern high latitude seas. The group noted that a first order understanding of the Bering Sea has been obtained and that a U.S. GLOBEC program should focus on studies aimed at elucidating the mechanisms linking environmental change to responses of the system. Four specific research topics were identified by the group: 1) what is the relation of the range of storm activity to the annual production budget and food web dynamics of the mixed layer?; 2) What is the relation of the sea ice melt-back bloom to total annual production?; 3) How does the nature (esp. timing) of the spring bloom determine the partition of energy between the pelagic and benthic ecosystem components?; and 4) Will climate change alter habitat/domain volumes and how will this influence recruitment? Retrospective, modeling, process oriented studies, and monitoring activities designed to answer these four questions were identified.

Products

Contributions of a U.S. GLOBEC CCCC program might include:

- The development and/or refinement of coupled bio-physical models that could be used to examine hypotheses regarding potential impacts of climate variability on marine ecosystems.
- Improved knowledge of the impact of climate variability on marine ecosystems of the North Pacific. Specifically, the program could elucidate mechanisms controlling marine populations (including commercially important fish species) and provide quantitative information that would improve the assessment, conservation and management of our nations valuable marine resources.
- Data sets will be assembled during the program that will provide the basis of future research activities in the region.
- The program will advance our ability to make predictions on the future composition of marine communities which could be utilized in simulation models to assess the impact of human activities in the region.

Recommendations for Initial Activities

Workshop participants focused on the four broad research questions proposed by PICES. These questions could form the basis of Announcements of Opportunity for research at a later date. A first AO would probably emphasize retrospective data analysis, modeling, and monitoring studies.

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