First U.S. GLOBEC Pan-Regional Synthesis Workshop

Report of the meeting held at the National Center for Atmospheric Research, 27-30 November, 2006.

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I) Executive Summary

This report summarizes the activities at the first yearly U.S. GLOBEC Pan-Regional Synthesis Workshop. The purpose of the Workshop was to discuss the needs of, and the approaches to, Pan-Regional Synthesis as a basis for developing an Announcement of Opportunity for Pan-Regional Synthesis. The meeting was held at the National Center for Atmospheric Research Center Green Facility in Boulder Colorado, and was hosted by Dr. James Hurrell, Director of the NCAR Climate and Global Dynamics Division. The meeting was attended by thirty-eight scientists from the USA (Appendix A). Further information on the U.S. GLOBEC program and its Pan-Regional Synthesis phase can be obtained at: http://www.usglobec.org/ .

The Workshop agenda featured a mixture of plenary talks and discussion, as well as daily Working Group Sessions. The Working Groups were asked to consider several questions of importance to U.S. GLOBEC, now entering its Pan-Regional Synthesis phase. These questions included:

- What are the opportunities for Pan-Regional Synthesis that can be answered by comparing and contrasting systems?
- How are climate effects manifested in the GLOBEC study regions?
- What are three questions that should be in the Pan-Regional Synthesis Announcement of Opportunity?

Responses to the latter question provided guidance on the formulation of the Pan-Regional Synthesis Announcement of Opportunity by the U.S. GLOBEC National Office and Scientific Steering Committee. The reports of the Working Groups and the content of the Pan-Regional Synthesis AO are described below in further detail.

The Workshop was organized by the U.S. GLOBEC National Coordinating Office, with assistance from an Executive Committee consisting of Eileen Hofmann, Cabell Davis, Peter Wiebe and Hal Batchelder.

II) The Role of Pan-Regional Synthesis in U.S. GLOBEC

A higher-order synthesis incorporating basin-scale modeling efforts and comparative analyses among U.S. GLOBEC studies and related national and international programs is required to meet the overarching GLOBEC goal of predicting the effects of global climate change on marine ecosystems.

The goals of the U.S. GLOBEC program are (1) to understand the potential impacts of climate variability and change on the dynamics of shelf ecosystems and on the distribution, abundance and production of several specific target species; (2) to embody this understanding in conceptual and quantitative models capable of capturing population and ecosystem responses over a broad range of spatial and temporal scales; and (3) to improve predictions of U.S. living marine resource populations which can lead to enhanced management capabilities.

The U.S. GLOBEC program has comprised three regional ecosystem programs -- Northwest Atlantic/Georges Bank (NWA), Northeast Pacific (NEP) and Southern Ocean (SO) -- and has supported a series of data collection and process studies in each of the three regions. The focus of the U.S. GLOBEC program is now on comparing and contrasting the results from the prior phases of U.S. GLOBEC, and on extending these results with comparisons to, or tests within, other comparable ecosystems. The priority focus for the Pan-Regional Synthesis phase of U.S. GLOBEC will be to achieve a broader understanding of climate impacts on marine populations and ecosystems employing hypotheses, concepts, methods and/or data derived from the regional studies in the Northwest Atlantic, Northeast Pacific, and Southern Ocean.

The importance of comparative analysis in U.S. GLOBEC for Pan-Regional Synthesis has been recognized from the inception of the program. Comparison of the dynamics of closely related taxa selected as target species in relation to specific **physical processes** (including *stratification*, mechanisms of *retention and loss*, *upwelling and downwelling*, and *cross-front exchange*) must be an integral component of the overall synthesis and integration effort in U.S. GLOBEC. Comparisons of closely related species within regions in relation to these physical processes must also be employed in conjunction with comparisons across system types to examine the effects of climate forcing on marine ecosystem structure and function.

As U.S. GLOBEC studies have progressed, it has become evident that factors such as **top-down vs. bottom-up controls** on productivity, and the importance of **topographic controls** on local and regional circulation patterns, provide important cross-cutting themes and foci for comparative analysis. Bottom-up controls mediated through mechanisms of nutrient exchange have been hypothesized to be critically important in the California Current System and the Coastal Gulf of Alaska, and to be related to the apparent inverse production regimes for salmon in these regions. In contrast, top-down controls by predators on the target species may be of central importance in the Southern Ocean and on Georges Bank. In the former, the relatively simple food web results in strong trophic linkages, while in the latter the direct and indirect effects of over-harvesting have resulted in dramatic changes in community composition. Planktivorous fishes are currently at high levels of abundance on Georges Bank during spring and summer months; these species prey on copepods and larval fish.

The commonality of modeling approaches applied in U.S. GLOBEC regional studies provides opportunity for synthesis and comparison across systems and taxa. The convergence toward application of similar **3-D circulation models** in each of the areas and the recognized importance of applying a common nested modeling strategy in each of the areas at the basin scale will facilitate model intercomparisons of key hydrodynamic forcing mechanisms. Similarly, in each of the U.S. GLOBEC study areas the same general classes of **biological/ecological models** have been applied including individual-based models for target taxa and simple ecosystem models such as NPZ(D) structures. The biological models for the target species employ a "middle-out" (or 'rhomboidal') modeling approach where focus is placed first on the taxa or trophic level of primary interest, with decreasing resolution in detail in the links up to predators and down to prey. This structure relies on providing necessary detail of the model for the target species and requires diminishing detail of neighboring trophic levels. By adopting the rhomboidal modeling structure, a focus on the role of adjacent trophic levels on the dynamics of the target species can be easily accommodated to address issues such as top-down or bottom-up controls.

Consideration of the effects of climate forcing on the major system types represented in U.S. GLOBEC will require comparisons not only among the regional U.S. studies but comparisons and contrasts with results from related national and international programs. The worldwide GLOBEC research effort affords critical opportunities for comparative analyses and for consideration of basin-scale processes. In particular, comparisons with studies of calanoid copepods and gadoids on bank and shelf systems in the North Atlantic and copepods, euphausiids, and salmonids in the North Pacific will be critical. Opportunities exist for intercomparison between U.S. GLOBEC results and those of other national and international research programs concentrating on the role of environmental forcing on the dynamics of selected marine taxa. These programs include:

- GLOBEC Canada,
- Northern Cod Recovery Program,
- ICES Cod and Climate Change (CCC) Program,
- TransAtlantic Study of Calanus (TASC),
- Exxon Valdez Oil Spill (EVOS) Program,
- PICES Climate Change & Carrying Capacity (CCCC),
- Ocean Carrying Capacity (OCC) program,
- Commission for Conservation of Antarctic Marine Living Resources (CCAMLR),
- Southern Ocean GLOBEC Programs, and
- Small Pelagic Fish and Climate Change.

Comparison between the dynamics of cod and haddock populations on Georges Bank can be made with other gadoids (notably other cod populations) derived from GLOBEC Canada conducted on Western and Sable Banks, the Northern Cod recovery program off Newfoundland, and the ICES Cod and Climate program conducted on cod stocks throughout the North Atlantic. The potential for intercomparison with other gadoid stocks in the Pacific exists through the PICES Climate Change and Carrying Capacity Program. The dynamics of calanoid copepod populations can be made with results obtained during GLOBEC Canada and TASC. Opportunities for comparison of the dynamics of salmon stocks exist with the EVOS, CCCC, and OCC programs. Finally, information collected on krill dynamics conducted under CCAMLR provides an important point of comparison with Southern Ocean GLOBEC studies. International GLOBEC programs in the Southern Ocean conducted by other nations both complement the U.S. effort in austral winter and provide another source of important comparisons.

A complete description of the plan for Synthesis in the U.S. GLOBEC program may be found at:
http://www.usglobec.org/workshops/synth07/GLOBEC_Synthesis_Implementation_Plan.doc

IV Narrative of the Workshop

The Workshop had been carefully organized by the Workshop Executive Committee to begin with an invited plenary talk by **Ken Denman** on Monday afternoon (November 27). Unfortunately, Mother Nature had other plans for Dr. Denman, who was stranded in Vancouver by an unusually heavy, and untimely, snow storm. Many thanks to **Thomas Powell** for stepping in at the last minute and delivering Ken's PPT talk entitled "US GLOBEC Pan-Regional Synthesis: An Outsider's View". A copy of the opening talk may be found at

http://www.usglobec.org/workshops/synth06/presentations/Denman-Opening_Talk.ppt

The evening concluded with a reception at the Center Green facility.

The first full day of the Workshop began at 0830 hours on Tuesday, 28 November with welcoming remarks by the Chair of the U.S. GLOBEC Scientific Steering Committee, **Dale Haidvogel**. After introductions around the room, Haidvogel reviewed the agenda (Appendix B) as well as the goals of the Workshop. The latter were:

- To familiarize attendees with the status of the three regional programs as a basis for planning inter-regional US GLOBEC synthesis (**Goal 1**)
- To define pan-regional synthesis in the US GLOBEC context (**Goal 2**), and
- To establish the expected outcomes of the Pan-Regional Synthesis phase to enable the US GLOBEC Scientific Steering Committee to formulate future calls for pan-regional synthesis activities (**Goal 3**).

The remainder of Tuesday morning was spent in plenary session, during which time the participants heard three regional overview talks delivered by **Hal Batchelder** (Northeast Pacific), **Cabell Davis** (Northwest Atlantic / Georges Bank), and **Eileen Hofmann** (Southern Ocean). With **Goal 1** in mind, the three regional talks were asked to provide an overview of regional processes, datasets collected and their status, the modeling systems then in place, and fruitful topics for pan-regional synthesis. The morning concluded with a background presentation on Ecosystems-Based Management, delivered by **Pat Livingston**.

After lunch in the NCAR cafeteria, the Workshop reconvened at 1345 hours. Tuesday afternoon was devoted to the first of three sets of Working Groups. Dale Haidvogel introduced the Working Groups, Group leaders and Rapporteurs, and discussed the charge to the Working Groups. Based upon prior discussion within the Executive Committee for the Workshop, the first three Working Groups were asked to break out by trophic level, as follows:

- Climate/circulation
- Circulation/Primary production/Zooplankton
- Zooplankton/Top predators.

To help address **Goal 2** of the Workshop, the three Working Groups were asked to consider the following over-arching question: **What are the opportunities for Pan-Regional Synthesis that can be answered by comparing and contrasting systems?** After deliberation, the Working Groups reported back in plenary session at 1600 hours. A summary of the findings of these Working Groups is given in the following section, and the resulting Working Group reports can be found in Appendix C. Tuesday concluded with a social hour and poster viewing at 1730 hours.

The morning of the second full day (Wednesday, 29 November) was again devoted to plenary background talks. A total of eight short presentations were given, in the topical areas of **Approaches to Pan-Regional Synthesis**, **Synthesis as seen in other programs**, and **Bridge to future programs**. The speakers included **Bob Groman** (speaking on Data repositories and associated tools), **Dan Lynch** (Skill assessment), **Thomas Powell** (Nested/coupled models) **Ric Brodeur** (Salmon synthesis), **Cisco Werner** (GLOBEC International), **Ann Bucklin** (IMBER), **Kendra Daly** (ORION), and **Tom Malone** (U.S. IOOS). The Wednesday morning session adjourned for lunch at 1200 hours.

The second afternoon session, convened at 1330 hours on Wednesday, again featured Working Groups, but with redistributed membership. This time, all three groups were asked to consider the same question: **How are climate effects manifested in the GLOBEC study regions?** Subsidiary questions addressed to the three new Working Groups included:

- Through what physical mechanisms (stratification, transport/retention, upwelling/downwelling, mesoscale stirring and mixing)?
- Through what biological mechanisms?
- How important are episodic events and “hot spots”? Are other temporal and spatial scales “more” relevant to ecosystem considerations?
- What key attributes characterize systems that vary on these scales? What observing methods/networks would best capture them?

The three Working Groups had the remainder of the afternoon until 1600 hours to consider these questions, and to prepare a report for subsequent plenary presentation and discussion. A summary of the Working Group reports is given below. The plenary session ended shortly after 1700 hours, and was followed by a social hour and poster viewing.

Thursday morning (30 November) was devoted to the important issue of the Pan-Regional Announcement of Opportunity (**Goal 3**). Beginning at 0830 hours, participants were once again re-organized into three new Working Groups. Each was asked to **state three questions that should be in the Pan-Regional Synthesis Announcement of Opportunity**, and to discuss why these three had been chosen. The suggestions of the Working Groups, reported out in plenary session at the end of Thursday morning, are summarized below. These summary recommendations were forwarded to the U.S. GLOBEC SSC, who then formulated, revised and approved the Draft Announcement of Opportunity shown in Appendix D.

Following lunch on Thursday, the participants met a last time in plenary session to summarize the plans for Pan-Regional Synthesis and to identify action items. The Workshop adjourned at 1430 hours.

IV) Summary of Working Group reports

IV.A) Tuesday, 28 November

Three working groups were formed to consider the following over-arching question: **What are the opportunities for Pan-Regional Synthesis that can be answered by comparing and contrasting systems?** In their response, they were asked to consider the following specific questions:

- What are the critical characteristics that make these species useful for pan-regional comparisons?
- How does climate influence the variability of recruitment in these systems?
- What have we learned? What models (or other approaches to synthesis) exist, or are needed, and of what type?
- Where are the data gaps? How might they be filled with existing data taken in other programs?
- What are the effects of the targeted processes (e.g., stratification) on the community structure and dynamics of the systems?
- What is the predictability of this process and the impact of this predictability on ecosystem based management?

The three Working Groups were broken out by trophic level: **Climate/Circulation**, **Circulation/Primary production/Zooplankton**, and **Zooplankton/Top predators**. The members of the three Working Groups are shown in **Table 1**.

Climate/Circulation **WG1.1**	Circulation/Primary Production/Zooplankton **WG1.2**	Zooplankton/Top predators **WG1.3**
Alexander (Chair)	Runge (Chair)	Costa (Chair)
Gangopadhyay (Rapporteur)	Mountain (Rapporteur)	Burns (Rapporteur)
Beardsley	Bisagni	Batchelder
Bograd	Brodeur	Botsford
Bond	Bucklin	Chapman
Haidvogel	Daly	Hofmann
Hurrell	Davis	Livingston
Lynch	Fritsen	McDonald
	Hermann	Miller
	Powell	Teo
	Ross	Tynan
	Turner	Werner
	Wiebe	

Table 1: Members of the Working Groups on Tuesday, 28 November

In response to the over-arching question, the three Working Groups identified many critical research issues which provide opportunities for Pan-Regional Synthesis. Organized into several theme areas, these opportunities include the following:

- Climate forcing mechanisms and physical processes
  - the impact of local forcing vs. remote influences in different regions
  - the role of cross topographic exchange, *i.e.* deep versus shelf sources, in the different regions
  - processes of retention in the different systems
  - freshwater input and the effects on regional stratification and circulation
  - response of shelf systems to climate change
  - inherent variability of the physical and biological systems; causes of hot spots
- Ecosystem responses to climate variability
  - ecosystem/habitat boundaries (What sets them? How will they change?)
  - functional linkages between lower trophic levels and upper trophic levels (how to model?)
- Population dynamics
  - similarities/differences in life history strategies in response to forcing
  - processes driving good/bad recruitment as a function of region
- Management issues
  - the role of human harvesting in the three study regions
  - the data streams and their appropriate spatial and temporal scales that would be most useful for understanding each system
  - the appropriate scales at which to study top predators

Several common themes emerged from the three Working Group reports. The first was the **critical need to identify existing short- and long-term datasets that complement the regional datasets obtained in the U.S. GLOBEC program**. The Circulation/Climate Working Group noted a particular need for assembling state-of-the-art surface fluxes for forcing ocean models (consistent forcing in all regions), which could be achieved by using the large-scale forcing fields from the same data set(s) and then downscaling these fluxes via statistical methods or regional atmospheric models. Working Group 1.2 (Circulation/Phytoplankton/Zooplankton) highlighted a lack of information on the microbial components, nutrient fields, and non-target species (*e.g.*, pterapods), but noted that (limited) datasets do exist from other programs. The third Working Group (Zooplankton/Top predators) underscored the need, and likely availability, of additional information on animal movements and behavior.

The three Working Groups also emphasized the role of models in the Pan-Regional phase of U.S. GLOBEC. For modeling the pelagic ecosystem, the rhomboid or middle-out approach (de Young et al. 2004) offers a way to deal with the complexity of interactions from physics to phytoplankton to zooplankton and ichthyoplankton, including characterization of the life histories of the individual key species in the higher trophic levels. Figure 1 shows one possible configuration for an end-to-end model based upon the rhomboid approach. Within each region, this approach would include nested circulation models coupled to an NPZD model. The output of this (prey availability in space and time) would then be used as input to a coupled physical- ZLCM model (zooplankton life cycle model). The output from the coupled ZLCM model (zooplankton prey fields) would provide input to a coupled physical-larval fish trophodynamic or other higher topic level model. The NPZD models are Eulerian and concentration based. The larval fish/higher trophic level models are Lagrangian and IBM. The intermediate zooplankton model could be either Eulerian/concentration or Lagrangian/IBM.

In the modeling activities currently being done, the coupling between the rhomboids generally is in one direction, from lower to higher levels. There is not included a feedback from an upper trophic level, IBM model to the NPZD model. There may be situations where this type of two-way coupling would prove valuable. An issue to be addressed during synthesis will be determining the advantages and/or necessity of having a fully coupled set of models.

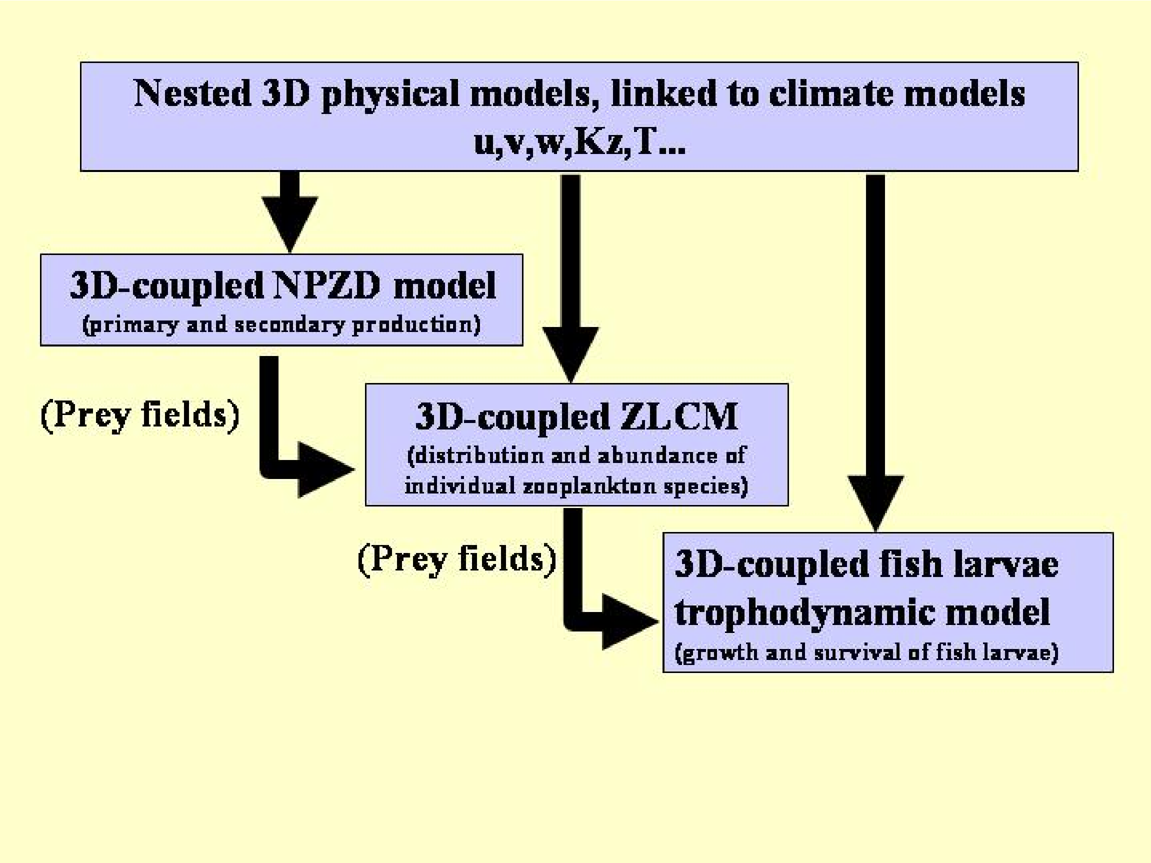

Figure 1. Middle-out model approach for analysis of climate forcing on phytoplankton, zooplankton and ichthyoplankton. Shown is a system of linked coupled models in which population dynamics of target species are parameterised in detail, linked to lower resolution models of describing prey and predator abundance (adapted from Runge et al. 2005).

IV.B) Wednesday, 29 November

Three Working Groups were constituted to consider the same question: **How are climate effects manifested in the GLOBEC study regions?** Specifically,

- Through what physical mechanisms (stratification, transport/retention, upwelling/downwelling, mesoscale stirring and mixing)?
- Through what biological mechanisms?
- How important are episodic events and "hot spots"? Are other temporal and spatial scales "more" relevant to ecosystem considerations?
- What key attributes characterize systems that vary on these scales? What observing methods/networks would best capture them?

The members of the three Working Groups are shown in **Table 2**.

The reports from Working Groups 2.1 and 2.2 present thorough discussions of the physical processes at work in each of the study regions and their relative importance. The processes discussed include:

- phenology/seasonality: The relative timing of physical processes and biological life cycles is critical in each study region.
- freshwater input / stratification: Each study region has important sources of freshwater, though the source details differ.
- advective transport: Changes in circulation and/or water properties being advected are important in all regions.
- retention/loss: All regions have recirculating/retentive sub-regions.
- land-sea temperature contrasts: All regions respond to systematic changes in land-sea temperature contrasts.
- vertical structure: Water column structure is critical to biology in all regions.

Examples of common features that might provide a basis for pan-regional synthesis and comparison are shown in **Table 3**.

All three Working Groups considered the likely biological consequences of climate variability and change. These consequences include:

- Direct effects of changes in T, S, circulation
    - effects on vital rates
    - effects on nutrient supply
    - biogeochemistry (e.g., acidification)

- Ecosystems
    - Ecosystem efficiency
    - Ecosystem productivity

- Species-level changes
  - Species ranges
  - Resiliency
  - Ability to respond to Human Activity

- Life histories
  - Predator/prey relationships
  - Advection-based life history processes
  - Responses to fronts/thin layers
  - Timing of diapause

The Working Group reports note that these considerations have application in all four study regions.

The importance of episodic events and hot spots was also recognized by all three Working Groups. In particular, many (if not all) of the physical and biological processes discussed by the Working Groups feature episodic (that is, non-periodic) responses or local enhancements ("hot spots"). Of note are the following:

- Storms: important in all regions *(e.g.,* storm-driven egg mortality on Georges Bank)
- Hypoxia (*e.g.*, Oregon/Washington)
- Mesoscale eddies / Gulf Stream rings (*e.g.*, Haida eddies)
- Freshwater inputs (*e.g.*, rivers)
- Fronts (tidal mixing, shelf-slope)
- Banks (*e.g.*, Heceta, Portlock, etc.)

Hot spots are by definition where the action is. Indeed, U.S. GLOBEC focused on hot spots by design. (As noted by two Working Groups: Georges Bank is one big hot spot.) This has implications for the observability and predictability of these events. Hot spots are good, in this sense, if they are always located in the same places (*e.g.*, Georges Bank). However, the more episodic in time, and/or variable in location (or fine-scale), the harder the task of monitoring and predicting becomes.

A variety of advanced observing methods are now available that might be employed. These include (*e.g.*) long-term high-frequency moored samplers, satellite-based sensors, species-specific sensors (for taxonomic information), ship-based studies, AUVs, Lagrangian instruments (drifters, floats), electronic tags on top predators. An important outcome of pan-regional synthesis will be to identify harbingers of regime change that could be measured by observing systems to predict change in an ecosystem. Such questions can be answered with the coupled physical/biological models developed within U.S. GLOBEC and other programs.

WG2.1	WG2.2	WG2.3
Botsford (Chair)	Bograd (Chair)	Bond (Chair)
Hermann (Rapporteur)	Bisagni (Rapporteur)	Turner (Rapporteur)
Alexander	Batchelder	Bucklin
Burns	Boeing	Costa
Daly	Chapman	Fritsen
Gangopadhyay	Davis	Haidvogel
Hofmann	McDonald	Livingston
Lynch	Powell	Miller
Mountain	Teo	Ross
Runge	Werner	Wiebe
Tynan	Brodeur	Beardsley

Table 2: Members of the Working Groups on Wednesday, 29 November

Process	NWA/GB	CCS	CGOA	SO
Phenology	Spring bloom	Transition to upwelling		Development of Coastal Current; sea ice
Freshwater	FW input; buoyancy-driven currents	Columbia River plume	FW input; buoyancy-driven currents	FW input; buoyancy-driven currents
Advection	Scotian Shelf cross-overs; Western Boundary Current	El Nino; West Wind Drift	El Nino; West Wind Drift	Western Boundary Current (ACC)
Retention/Loss	Banks; ring-shelf interactions	Banks; mesoscale eddies	Eddies	Interactions with the ACC
Land-sea contrasts	Variations in wind forcing	Upwelling efficiency	Variations in wind forcing	Catabatic winds
Vertical structure	Increased stratification	Increased stratification	Increased stratification	Increased stratification

Table 3: Examples of physical processes influenced by climate variability in each region

IV.C) Thursday, 30 November

Each working group was asked to consider the content of the forthcoming Announcement of Opportunity for Pan-Regional Synthesis. In particular, they were charged to **state three questions that should be in the Pan-Regional Synthesis Announcement of Opportunity**, and to discuss why these three were chosen. Considerations to be taken into account included:

- Multi-region (at least one US GLOBEC study region)
- Can be accomplished in 2-3 years and O($6M)
- Makes practical contributions to Ecosystems-Based Management
- NB: Synthesis efforts in other international programs

Members of the three final Working Groups are shown in **Table 4**.

In a very real sense, this was the defining issue of the entire Workshop – to provide guidance to the U.S. GLOBEC National Office and the Scientific Steering Committee on the focus and content of the Pan-Regional Synthesis Announcement of Opportunity. The fact that the three Working Groups provided extremely complementary responses to their charge shows the high degree of unanimity among the attendees as to the goals of Pan-Regional Synthesis. The Thursday Working Group reports are reproduced in Appendix C (pages 43-48).

With this input from the Working Groups, the National Office together with the SSC synthesized the following three research themes:

- <u>The influence of climate on physical and biological processes</u>: Fundamental to the success of U.S. GLOBEC is the need for synthetic understanding of how changes in climate at basin and global scales force physical processes that determine biological communities at local and regional scale.
- <u>Population dynamics and recruitment of target species</u>: In its final phase, U.S. GLOBEC needs to identify the processes controlling the population dynamics and recruitment of the target organisms as a function of system type, and to ascertain how these processes would be affected by a changing climate. This analysis would be done through comparing/contrasting the different systems being studied.
- <u>Ecosystem structure and function</u>: Taking the knowledge gained in U.S. GLOBEC about target species' physiology, behavior and population dynamics, we must better understand ecosystem response to climate change, particularly in connection with other, anthropogenic forcing. This activity should provide guidance on how to assess ecosystem level questions using GLOBEC concepts, methods and/or data, and on further implications for the management of marine resources in a changing climate.

The Announcement of Opportunity provides examples of research questions and approaches that would be appropriate to each of these research themes. A draft of the AO (awaiting approval by the National Science Foundation) is shown in Appendix D.

Table 4: Members of the Working Groups on Thursday, 30 November

Group 1	Group 2	Group 3
Bucklin (Chair)	Mountain (Chair)	Wiebe (Chair)
Bond (Rapporteur)	Daly (Rapporteur)	Teo (Rapporteur)
Batchelder	Davis	Powell
Bisagni	Fritsen	Ross
Bograd	Gangopadhyay	Runge
Botsford	Haidvogel	Turner
Burns	Hermann	Tynan
Chapman	Hofmann	Werner
Costa		Alexander

V) References

deYoung, B., M. Heath, F. Werner, F. Chai, B. Megrey and P. Monfray. 2004. Challenges of modeling ocean basin ecosystems. *Science* 304: 1463-1466.

Runge, J. A., Franks, P. J. S., Gentleman, W. C., Megrey, B. A., Rose, K. A., Werner, F., E., Zakardjian, B., 2005. Diagnosis and prediction of variability in secondary production and fish recruitment processes : developments in 12 physical-biological modeling. In: The Sea. John Wiley & Sons, New York.

Appendix A. BASIN Meeting Participants

Name	Affiliation	E-mail
Alexander, Michael	NOAA/Earth System Research Laboratory	michael.alexander@noaa.gov
Batchelder, Harold	Oregon State University	hbatchelder@coas.oregonstate.edu
Beardsley, Bob	Woods Hole Oceanographic Institute	rbeardsley@whoi.edu
Bisagni, James	Univ. of Massachusetts, Dartmouth	jbisagni@umassd.edu
Boeing, Wiebke	Atmocean	
Bograd, Steven	NOAA SWFSC	steven.bograd@noaa.gov
Bond, Nick	University of Washington	nicholas.bond@noaa.gov
Botsford, Louis	University of California, Davis	lwbotsford@ucdavis.edu
Brodeur, Richard	NWFSC/NOAA Newport OR	rick.brodeur@noaa.gov
Bucklin, Ann	University of Connecticut	ann.bucklin@uconn.edu
Burns, Jennifer	University of Alaska Anchorage	afjmb4@uaa.alaska.edu
Chapman, Erik	Old Dominion University	chapman@ccpo.odu.edu
Costa, Daniel	University of California Santa Barbara	costa@biology.ucsb.edu
Daly, Kendra	Joint Oceanographic Institutions	kdaly@marine.usf.edu
Davis, Cabell	Woods Hole Oceanographic Institute	cdavis@whoi.edu
Fritsen, Christian H.	DRI	cfritsen@dri.edu
Gangopadhyay, Avijit	University of Massachusetts School for Marine Science and Technology	avijit@umassd.edu
Groman, Robert	Woods Hole Oceanographic Institute	rgroman@whoi.edu
Haidvogel, Dale	IMCS, Rutgers University	dale@imcs.rutgers.edu
Hermann, Albert	JISAO/University of Washington	albert.j.hermann@noaa.gov
Hofmann, Eileen	Old Dominion University	hofmann@ccpo.odu.edu
Hurrell, James	National Center for Atmospheric Research	jhurrell@ucar.edu
Lagle, Linda (Staff)	IMCS, Rutgers University	lagle@marine.rutgers.edu
Livingston, Patricia	Alaska Fisheries Science Center	pat.livingston@noaa.gov
Lynch, Daniel R.	Dartmouth College	daniel.r.lynch@dartmouth.edu
McDonald, Mark	Whale Acoustics	mark@whaleacoustics.com
Malone, Tom	OceanUS	t.malone@ocean.us
Miller, Kathleen	National Center for Atmospheric Research	kathleen@ucar.edu
Mountain, David	NOAA/NMFS	dmountai@whsun1.wh.whoi.edu
Powell, Thomas M .(Zack)	University of California, Berkeley	zackp@socrates.berkeley.edu
Robertson, David (Staff)	IMCS, Rutgers University	robertson@marine.rutgers.edu
Ross, Robin	Marine Science Institute UCSB	robin@icess.ucsb.edu

Runge, Jeffrey	University of Maine/Gulf of Maine Research Institute	jrunge@gmri.org
Teo, Steven	UC Davis	slhteo@stanford.edu
Turner, Beth	NOAA Center for Sponsored Coastal Ocean Research	elizabeth.turner@noaa.gov
Tynan, Cynthia	Assoc. Scientists at Woods Hole	snowpetrel@comcast.net
Werner, Cisco	University of North Carolina	cisco@unc.edu
Wiebe, Peter	Woods Hole Oceanographic Institute	pwiebe@whoi.edu

Appendix B. Agenda of First U.S. GLOBEC Pan-Regional Synthesis Workshop

U.S. GLOBEC Pan-Regional Synthesis Workshop
27-30 November 2006
NCAR Center Green Facility, Boulder CO

Monday, 27 November

1200 Lunch available (NCAR cafeteria)

1300 Meeting rooms available (by arrangement) for pre-Workshop meetings

1500 Executive Committee meets to review program

1600 Opening talk: Ken Denman (followed by discussion)

1730 Reception

Tuesday, 28 November

0830 Welcome / Introductions / Workshop purpose & outcomes (Haidvogel)

0900 Regional (NEP, GB, SO) overviews (plenary talks; ~40 minutes each) (Batchelder, Davis, Hofmann)

- Overview of processes
- Datasets collected and status
- Modeling systems in place
- Pan-regional topics

1130 Ecosystems-Based Management (Livingston; plenary talk and discussion)

1215 Lunch (NCAR cafeteria)

1215 Southern Ocean GLOBEC: meet over lunch

1345 Charges to the Working Groups

1400 Working groups (#1): Break-out by trophic levels

- Climate/Circulation
- Circulation/Primary production/Zooplankton
- Zooplankton/Top predators

1600 Working group reports

1700 End of day

1700 Executive Committee meets to discuss organization of Wednesday session

1730 Social hour and poster viewing

Wednesday, 29 November

0830 Approaches to PR synthesis (plenary; ~20 minutes each)
- Data repositories and associated tools (Groman)
- Skill assessment (Lynch)
- Nested/coupled models (Powell)

Synthesis as seen in other programs (plenary; ~20 minutes each)
- Salmon Synthesis (Brodeur)
- International GLOBEC (Werner)
- IMBER (Bucklin)

Bridge to future programs (plenary; ~20 minutes each)
- ORION (Daly)
- U.S. IOOS (Malone)

Discussion

1200 Lunch (NCAR cafeteria)

1330 Charge to Working groups (#2)

1345 Working groups (#2)

1600 Working group reports (plenary)

1700 End of day

1700 Executive Committee meets to discuss organization of Thursday session

1730 Social hour and poster viewing

Thursday, 30 November

0830 Charge to Working Groups #3

0845 Working groups (#3): Conceptualize priorities/needs for Pan-Regional Announcement of Opportunity:

Come back with three well-crafted questions that you think should appear in the AO

1100 Working group reports

1200 Lunch (NCAR cafeteria)

1215 Executive Committee meets over lunch to draw up action plan

1330 Summarize plan for PR Synthesis; identify action items
(plenary wrap-up and final discussion)

1430 Adjourn

Appendix C. Working Group Reports

Working Group 1.1

Pan-regional cross-cut by trophic levels: Climate/Circulation group

What are the opportunities for Pan-Regional Synthesis that can be answered by comparing and contrasting systems?

Chair: Michael Alexander; Rapporteur: Avijit Gangopadhyay

Participants: Bob Beardsley, Steven Bograd, Nick Bond, Dale Haidvogel, Dan Lynch

We will address this question after addressing the specific questions below.

Some specific questions:

- *How does climate influence the variability of recruitment in these systems?*

Two key ways in which climate could influence recruitment are via: (i) changes in the seasonal cycle that can impact the timing of biological processes (phenology), such as the spring transition. This could lead to mismatches between the environment, the ecosystem in general and recruitment success of a particular species; and (ii) the influence of large-scale forcing on mesoscale variability, as the latter is an important source of nutrients in all of the GLOBEC regions.

In addition, we provide a matrix of climate indices and regions (**Table 1**), which shows whether or not climate phenomena (e.g. ENSO, AO, SAM, Sea Ice index etc.), impact the four US GLOBEC regions (CC, GOA, SO and GB). The grid elements of the matrix will need to be expanded to include characteristic physical and biological processes that are important for each target species and the ecosystem in which they reside.

- *What have we learned? What models (or other approaches to synthesis) exist, or are needed, and of what type?*

We can begin to understand many local and regional processes from the individual basin-scale and regional modeling work for different GLOBEC regions. In the pan-regional synthesis phase, the following modeling activities are needed.

- Regional models embedded in climate models (e.g., ROMS in the NCAR CCSM). Biological models (e.g NEMURO) could be included within the regional models or output from the regional models could be used to drive the biological models off-line. Such a system can simulate global changes, like those associated with ENSO or global warming, and their subsequent impact on the physics/biology of the GLOBEC regions.

- Drive ocean only models off-line
  - Retrospective of GLOBEC years (~1993-2005) -- hindcasts,
  - Choose specific events (striking anomalies), e.g.
    - 1997-98 ENSO event
    - 1997-98 low NAO event in the NWA/GB
    - Biological events (e.g. blooms)
    - Examine predictability for these past events
  - 50-year long climatic simulations to examine
    - the 1976-77 Pacific regime shift
    - low vs. high NAO periods, ie., 1960s vs 1980s
    - phenology – to what extent is the seasonal cycle modified by global change

- Modeling methods
  - Data assimilation will be an integrator of data and dynamics
  - Adjoint methods for sensitivity studies (to initial condition as well as climatic conditions) should be explored. The adjoints can use input on cost function from GLOBEC data sets.
  - Model intercomparisons

- *Where are the data gaps? How might they be filled with existing data taken in other programs?*

Data from other field programs will be very valuable for the pan-regional synthesis effort. For example, previous/ongoing programs that have studied upwelling/eastern boundary currents would be very useful for CC/GOA region. Other regions have similar previous/ongoing efforts, including MARMAP, The Canadian GLOBEC, FRAM, CalCOFI, GODAE and ARGO floats. Data collected from these studies can also be used to validate GLOBEC synthesis modeling efforts.

A particular need was identified for assembling state of the art surface fluxes for forcing ocean models (consistent forcing in all regions), which could be achieved by using the large-scale forcing fields from the same data set(s) and then downscaling these fluxes via statistical methods or regional atmospheric models (e.g. MM5).

- *What is the predictability of this process and the impact of this predictability on ecosystem based management?*

Predictability of a modeling system is scale-dependent. Validating a model and determining its skill should be an important component of the synthesis effort.

To address the **overarching question**: "*What are the opportunities for Pan-Regional Synthesis that can be answered by comparing and contrasting systems?*"

Theme areas where we found opportunities for PRS (stated as questions)

- What is the impact of local forcing vs. remote influences in different regions (will depend on size of the regions)?
- What is the role of cross topographic exchange, i.e. deep verses shelf sources, in the different regions?
- How does climate/circulation set up ecosystem/habitat boundaries and do fluctuations in climate impact these boundaries?
- How does local/remote fresh water input influence (buoyancy) boundary currents and their variability?
- What is the nature of the inherent variability in the atmosphere, ocean, and biology in the absence of the variable forcing? How do nonlinearities in the physics affect ecosystem variability? To address this last question, one might perform ensembles with the same forcing.

Priorities for synthesis: (i) addressing the linkages of the climate-circulation synthesis matrix, particularly using coupled climate/ecosystem models and (ii) investigating how the climate/circulation set up ecosystem/habitat boundaries and how fluctuations in climate impact these boundaries (iii) phenology.

Table 1. Matrix of Climate Phenomena (patterns/indices) and a qualitative assessment of their impact on GLOBEC Regions

	Regions			
Index	GB	CC	GOA	SO
ACW				S
AMO	S			
AO/NAM	S	M	M	
AAO/SAM				S
PDO/IPO		S	S	M
ENSO	W	S	S	S
MJO		M	M	M
NAO	M			
Sea Ice Index				S
WP/NPO		S	S	

S - Strong; M – Medium; W – Weak

Where: ACW - Antarctic Circumpolar Wave; AMO – Atlantic Multidecadal Oscillation; AO – Arctic Oscillation; NAM - Northern Annular Mode: AAO – Antarctic Oscillation; SAM – Southern Annular Mode; PDO - Pacific Decadal Oscillation; IPO – Interdecadal Pacific Oscillation; ENSO – El Niño/Southern Oscillation; MJO – Madden and Julian Oscillation; NAO - North Atlantic Oscillation; WP - West Pacific pattern; NPO- North Pacific Oscillation

Note there is some debate in the climate community about the physical meaning of these modes or indices. For example, some think the NAO and the AO are one in the same.

Additional climate indices could also be developed that are more biological relevant. For example, one could regress climatic fields on variables such as upwelling (particularly in the California Current System), meso-scale activity, productivity, biomass, etc. or use indices based on atmosphere/ocean dynamic measures, such as storm track strength and location or wind stress curl.

Working Group 1.2

Pan-regional cross-cut by trophic levels: Circulation/Phytoplankton Production/Zooplankton group

What are the opportunities for Pan-Regional Synthesis that can be answered by comparing and contrasting systems?

Chair: Jeffrey Runge; Rapporteur: David Mountain

Participants: James Bisagni, Ric Brodeur, Ann Bucklin, Kendra Daily, Cabell Davis, Christian Fritsen, Al Hermann, Zack Powell, Robin Ross, Beth Turner, Peter Wiebe

The Chair recommended that the group address its task by working through the questions one at a time. It was recommended that pages 54-58 of the Pan Regional Synthesis document by Mike Fogarty be used as a reference. The questions are addressed here in the order they were discussed

What have we learned? What models (or other approaches to synthesis) exist, or are needed, and of what type?

For modeling the pelagic ecosystem, the rhomboid or middle-out approach (de Young et al. 2004) offers a way to deal with the complexity of interactions from physics to phytoplankton to zooplankton and ichthyoplankton, including characterization of the life histories of the individual key species in the higher trophic levels. Within each region, this approach would include a physical circulation model coupled to an NPZD model. The output of this (prey availability in space and time) would then be used as input to a coupled physical- ZLCM model (zooplankton life cycle model). The output from the coupled ZLCM model (zooplankton prey fields) would provide input to a coupled physical-larval fish trophodynamic or other higher topic level model. The NPZD models are Eulerian and concentration based. The larval fish/higher trophic level models are Lagrangian and IBM. The intermediate zooplankton model could be either Eulerian/concentration or Lagrangian/IBM (Figure 1).

When the GLOBEC program began, neither the approach nor the modeling capability existed. It represents a major advance that the approach has been 'learned' through the program. Using this approach does require fairly specific knowledge of the various trophic levels and an important consideration – also addressed below – is how much simplification is necessary and/or appropriate.

Each region has the capability to undertake this approach. There are differences between regions in how this modeling approach is implemented for synthesis. For example, in the Antarctic the physical model will include a coupled ocean-ice component and for the biology the top predators will be more of a focus than in the other projects. In the northeast Pacific, the zooplankton (*Pseudocalanus*) population dyanamics is dynamically embedded in the NPZ model.

In the modeling activities currently being done, the coupling between the rhomboids generally is in one direction, from lower to higher levels. There is not included a feedback from an upper trophic level, IBM model to the NPZD model. There may be situations where this type of two-way coupling would prove valuable. An issue to be addressed during synthesis will be determining the advantages and/or necessity of having a fully coupled set of models.

IMBER intends to have a large effort in model development. Depending upon the timing, IMBER's effort may contribute to GLOBEC's modeling needs (especially for development of NPZ models including microzooplankton), or GLOBEC's efforts may contribute to IMBER (especially for characterization of individual key species).

In more general terms of what has been learned, it will be useful for each region to identify ideas or concepts that were thought to be 'conventional wisdom' at the beginning, but through the program results have been shown to be inaccurate.

How does climate influence the variability of recruitment in these systems?

The U.S. GLOBEC programs have focused on climate forcing through bottom up processes, and the approach of linked coupled models described above can address climate influences on recruitment processes.The effects of climate change enter primarily through advection, as opposed through direct, local influence. In the NEP the large scale climate models do capture the changes and deliver them to the coastal region. For Georges Bank the ability of the large scale models to represent the observed changes (e.g., the low salinity event which appears to have originated at high latitude) is not yet clear. On the biological side it will be important to determine whether the biological response to the climate variability also is advected into the region or occurs through local biological processes responding to the advected physical changes.

.There was general consensus that we do have the knowledge and the approaches to answer the effect of climate forcing on recruitment of the target species.

What are the critical characteristics that make these species useful for PRS?

The group felt that this question needed to be restated as: What evidence do we have that knowledge of the life history characteristics and physiological attributes of the individual species is essential to understanding the ecosystem dynamics?

It will be important to determine how much simplification in the life history can be done and still represent the population and ecosystem dynamics. Related questions are:

How can we use the individual species life history information to give us a comprehensive understanding of ecosystem dynamics? This point also applies to modeling issues discussed above.

Can/must we ultimately deal with functional groups of species or will keeping a focus on the identified target species be sufficient? For examination of full ecosystem dynamics, the answer to the latter question is no. The target species may be good to indicate climate sensitivity, but in some cases they are not as critical to the ecosystem as other species, i.e. there are more key species than initially targeted by the GLOBEC.

A fundamental aspect of a species population dynamics that has not been addressed determining knowing what processes or characteristics limit the range of a species. Can we derive and predict distributional limits from our models?

In terms of the rhomboid modeling how much do we need to know about the prey of a target species to successfully model its dynamics? If the prey is sensitive climate change, then including that sensitivity will be important.

Where are the data gaps? How might they be filled with existing data taken in other programs?

The group did not have much time to spend on this question. However a number of data gaps were identified for all of the regions
:

Information on many microbial components
Nutrient data
Information on non-target species (e.g., pteropods)

Existing data does exist from other programs, but it will be limited.

The overarching question: What are the opportunities for Pan-Regional Synthesis that can be answered by comparing and contrasting systems?
.
There are a number of characteristics of the systems that can be compared and contrasted as a basis for Pan-Regional Synthesis:

- Climate forcing mechanisms, for example freshwater effects on density driven circulation and stratification; effects of winds on mixing and on transport of zooplankton and ichthyoplankton. All of the regions have climate forcing issue related to fresh water sources; in the northwest Atlantic, the freshwater forcing is "remote" (originating in the Arctic) whereas they are "local" (melting of glaciers and river discharge) in the Northeast Pacific. For Georges Bank the important wind forcing is mainly local, while for the NEP the important winds are associated with the large scale atmospheric pattern.

- Model approaches: There are common, important and non-trivial technical issues concerned with linking the coupled models (e.g. the prey field output from an NPZ model to a zooplankton life history model). Approaches to model validation with data is also a common pan-regional issue.

- Similarities and differences in life history strategies in response to forcing; for example copepod dormancy responses among species and regions.

- Similarities in geomorphology; eg. The Antarctic and the Gulf of Maine/Georges Bank have much in common in their geomorphology (size and topographic features). GB and Antarctica translate into similarities in forcing and ecosystem responses?

- Georges Bank has physical and biological mechanisms promoting retention, while the California Current is more directly a flow through system.

- The physical and biological processes driving good and bad recruitment of the target organisms can be compared and contrasted between the regions

An important issue discussed by the group on which a consensus was not reached was what expectations should we have for Pan-Regional Synthesis in relation to addressing the population dynamics of the target organisms in a changing climate vs addressing ecosystem dynamics in a changing climate. We need to live up to the goals set out for the program, but not to redefine those goals upward as we approach the end. While we have approaches and detailed knowledge to answer questions of climate forcing on recruitment of the target species, we also need to identify during synthesis how our knowledge can be applied to the broad question of climate forcing on ecosystem and function. To what extent can target species responses represent ecosystem structure and function? Will inclusion of other species now identified as key functional components be sufficient? How much simplification can we re-introduce? A quote from GLOBEC report 6 seemed to capture the relationship between the focus on the population dynamics of the target organisms and the expectations for ecosystem level implications. This issue should be reviewed carefully when the Announcement of Opportunity for Pan-Regional Synthesis is being drafted.

Working Group 1.3

Pan-regional cross-cut by trophic levels: Zooplankton/Top predators group

What are the opportunities for Pan-Regional Synthesis that can be answered by comparing and contrasting systems?

Chair: Dan Costa; Rapporteur: Jennifer Burns

Participants: Hal Batchelder, Lou Botsford, Erik Chapman, Eileen Hofmann, Pat Livingston, Steve Teo, Cynthia Tynan, Cisco Werner

Goal of the group was to identify the most relevant and interesting research questions that were sufficiently broad that they could be moved forward as projects that integrated or compared data across the three programs. These questions must also reflect the needs, interests, and data realities of the predator group.

First the group defined top predators as those large zooplankton, fish, birds, seal, whale species that are /were economically, culturally, and /or ecologically important (critical) to the focal ecosystems and their functioning, as well as to management needs.

Then, the group agreed that it was very important for synthesis and integration within the GLOBEC framework to use GLOBEC data as a basis, but also to include any and all other relevant datasets and study species that could help in furthering an understanding of the systems and questions.

- **To further this goal, it is critical to identify existing short- and long-term datasets that can supplement GLOBEC datasets.** This is especially true since many technologies now used to study top predators were not available when the earliest GLOBEC programs started, and there have been many other 'GLOBEC-like' studies in areas near, or connected to, GLOBEC areas. For example, animal movements and behaviors can now be studied by deploying tags on animals as small as salmon smolt, and satellite tags deployed on larger animals can simultaneously collect information on environmental parameters such as salinity and temperature.

The group decided not to focus on the questions in the handout, but instead worked to identify critical research questions. We identified the following areas:

1. **The role of human harvest on the dynamics of the three GLOBEC systems.** GLOBEC was designed to focus on bottom-up processes in systems that have all experienced exploitation. How much of observed ecosystem dynamics is truly due to climate change and natural fluctuations, and how much is a result of lingering human impacts and/or unbalanced ecosystem structure? This is particularly important in light of continuing &/or increasing harvest pressures in many of these systems. Trophic modeling will be essential to separating top-down and bottom-up effects in these systems.

2. **The causes and consequences of 'hot spots'.** All GLOBEC programs have identified regional hotspots, or local areas within a wider system where predators exist in greater

than expected numbers. What are the physical and biological features that create these 'hot-spots', how general are these processes, and how similar are community structures within these hot spots? Given that climate change may alter the presence and temporal/spatial persistence of prey patches, it is important to understand how robust hotspots are to climate change, and understand how sensitive different species and community assemblages are to the spatial and temporal spacing and persistence of the hotspots. Inherent in this, is the realization that climate changes are likely to impact top predators in ways that are not captured by monitoring changes in mean (physical) parameters. As part of this effort, it would be useful to extrapolate from the fine-scale understanding of the key physical features that lead to the creation of hotspots identified in the GLOBEC studies, to types of information that can be obtained over a broader scale with less effort, such as remote sensing.

3. **Development of functional linkages between climate change / lower tropic level models and upper trophic levels.** While there are well developed models that link environmental conditions to zooplankton abundance and distribution, models that link changes in prey fields to the behavior of upper trophic level species are largely absent. Concentrations, densities, and presence/absence may not be the best way to characterize predators, which demonstrate a variety of behaviors and differ in their ability to respond to changing environmental conditions. To make these linkages, information on preyfield species composition, energetic content, and temporal and spatial variability may need to supplement biomass estimates. The challenge is to find a way to identify and integrate relevant behavioral data into models at appropriate spatial and temporal scales. Models that can be transported across systems by retuning of parameters would be particularly helpful.

4. **Linking GLOBEC regions to the surrounding oceans.** All of the GLOBEC study areas are shelf systems that are influenced by their connections to the surrounding ocean, and where the magnitude of the retentive and flow through processes strongly influenced productivity at the lower trophic levels. In addition, it may be that shelf systems are more sensitive to small changes in climate (temperature) than pelagic systems, such that small climate changes will have much larger impacts on upper trophic levels, possibly through temporal mismatches in key physical and biological processes. Understanding the sensitivities of shelf systems to climate change, as mediated through water mass structure, advection, mixing, etc. will be important to resolving these issues.

5. **Broader Management Implications** GLOBEC has been a large-scale, intensive (and expensive) program that focused on collecting fairly fine scale data on a limited number of target species and parameters. It would now be useful to identify the appropriate scales at which to study top predators, and the spatial and temporal extent of the habitat which must be studied to capture relevant changes in predator populations. Part of this effort should be the identification of the data streams and their appropriate spatio-temporal scales that were /are / would be most useful for understanding the system, and making recommendations about key types of data that could /should be collected in future that would best benefit future synthetic studies and management activities

Working Group 2.1

How are climate effects manifested in the GLOBEC study regions?

Chair: Lou Botsford; Rapporteur: Al Hermann

Participants: Michael Alexander, Jennifer Burns, Kendra Daly, Avijit Gangopadhyay, Eileen Hofmann, Dan Lynch, David Mountain, Jeff Runge, Cynthia Tynan

1 - PHYSICAL MECHANISMS IN EACH STUDY REGION

General Comments

Climate change on broad spatial and temporal scales modulates many smaller scale phenomena, including: stratification, transport/retention, upwelling/downwelling, mesoscale stirring and mixing. In each area there is significant cross-shelf exchange; in the NEP and SO regions deep water flows up onto the shelf through submarine canyons.

Northeast Pacific

The California Current (CC) region experienced significant changes in zooplankton composition and salmon survival around the year 2000. We don't completely understand the mechanism underlying that change, although it appears to be correlated with large (basin) scale changes. Changes in alongshore advection are likely responsible for some of the observed shifts from boreal to subtropical communities. The California Current has experienced increased upwelling in recent years, with the notable exception of the delayed upwelling in 2005.

Southern Ocean

The Southern Ocean (SO) area exhibits many bathymetrically-trapped gyres, as well as random eddies derived from boundary currents, shelf-break currents and the Antarctic Circumpolar Current (AntCC). However, the Rossby Radius of this area is small (~5km) so eddies derived from baroclinic instability can be difficult to observe with standard arrays and surveys. As in the Coastal Gulf of Alaska there are strong buoyancy-driven coastal currents, with freshwater derived from glacial runoff.

Like other GLOBEC regions, the SO area has fronts and strong current systems, but sea ice is its main distinguishing feature. Climate-driven changes in this ice affect the current systems and hydrography. The food web is strongly dependent on this ice and is itself undergoing long-term and seasonal changes driven by climate change.

The Antarctic Circumpolar Current (AntCC) operates much like other Western Boundary Current systems. The AntCC changes its location in synchrony with the Southern Annular mode of the atmosphere, which is in turn correlated with ENSO phenomena.

The West Antarctic Peninsula has many distinct subregions and scenarios. Warm deep water flows up onto the continental shelf in this area; if this warm flow were attenuated, the West Antarctic Peninsula would grow more ice and look more like the Weddell Sea. It is not known whether this would increase or decrease primary production. There are many intriguing possibilities for modeling of this area. Cooler deep flows onto the shelf probably have little effect on the ice dynamics. Climate modelers suspect atmosphere-ocean interactions affect this transport of warm water onto the shelf; however, different models give very different answers. Intruding AntCC water may bring larval krill onto the shelf. The AntCC is iron rich, while the shelf is iron-poor; this contrasts nicely with the Coastal Gulf of Alaska (CGOA), where basin waters have little iron and the shelf waters are iron-rich.

Georges Bank
Fresher water advected from further north, with sources of origin probably in the Arctic, affected stratification in the Gulf of Maine (GOM) and on Georges Bank (GB). 40 years of CPR data in the GOM show order of magnitude decadal changes in the abundance of dominant zooplankton species. The CPR phytoplankton color index has increased, corresponding to greater fall stratification and higher abundance of the fall-spawning copepods. The hypothesis is that remote climate forcing, by advecting fresher water into the GOM, increased stratification in the fall and made it possible to support higher phytoplankton and zooplankton abundance. There is some nutrient input associated with the buoyancy flux, but its effects are uncertain.

Interannual changes in wind-driven advection off of GB have been observed; egg mortality is strongly affected by such washout from one year to the next. Changes in the fall appear especially important. During periods of positive North Atlantic Oscillation, the Gulf Stream migrates northward and hence more Gulf Stream rings impinge on GB and modify its stratification. Saline water in the deep Northeast Channel is derived from such ring impacts. Ring impacts can lead to a net export of larvae and zooplankton from GB.

Common features/comparison among areas
Possibilites for physical comparison of the areas include: 1) deep water effects in each region; 2) iron/nitrogen impacts on production in each region (see above comparison of CGOA vs SO); 3) stratification driven by flow from rivers, as modulated by climate; 4) western boundary influences on GB and SO; 4) recirculation/retention features in each area (e.g. Heceta Bank, Cape Mendocino, Point Reyes in CC, all of GB, Portlock Bank in CGOA, others in SO). Both predators and prey distributions are influenced by these.

2 - BIOLOGICAL MECHANISMS

Northeast Pacific
In the CC system, large scale climate changes have yielded changes in zooplankton from high-lipid, high-latitude to low-lipid, low-latitude species. This transition between communities is probably due to large-scale alongshore advection related to the PDO, but changes in upwelling intensity and MLD may also be important. During the cold phase of the PDO, ENSO impacts are smaller than during the (present) warm phase of the PDO.

Lags in the spring transition (as in 2005) led to lower production, a mismatch with predators, and subsequent negative effects on birds. Some predators move out of the system when conditions are unfavorable, but many others are central place foragers (unable to easily move) and are hence strongly affected. So far as we know there is no interdecadal modulation of the spring transition, but there is strong interannual variability of this feature.

Enhanced spawning of small fish (e.g. hake) off Northern California, rather than their typical spawning sites further south, has recently been observed in the wintertime. This should have significant effects on the local food web.

The CGOA exhibits high iron on the shelf (due to sediments and river runoff) and high nitrogen in the deep basin. The confluence of these two water types at the shelf break, may explain much of observed high production in this downwelling-favorable area. Other phenomena, likely supporting primary production on the CGOA shelf, include tidal mixing and mixing in estuaries.

There is a probable link between primary production in the deep basin and the CGOA salmon life cycle. Upwelling in the central subarctic gyre feeds primary and secondary production; copepods from the deep basin advecting onto the shelf feed salmon. An interdecadal correlation between the PDO/wind stress curl and salmon is likely for this region.

Pollock in the CGOA are believed to be strongly affected by advection off the shelf; washout effects may be important as in the GB for cod.

Georges Bank
Salinity events driven by climate should yield biological changes in the GB area. More stratification probably yields higher chlorophyll values, higher copepods, and hence higher growth rate leading to better survival of cod larvae. There has been a significant recent shift from large to small zooplankton on GB. The timing of diapause for each species affects the response to changes in circulation. The time-dependent feeding of cod larvae is sensitive to the timing of zooplankton (match/mismatch effects). Pseudocalanus (small zooplankton) are an important cod diet item. The greatest advective loss ("washout") of cod larvae from GB occurs during cold months. It may be possible for the larvae to minimize this washout through evolved vertical behaviors.

Overwintering studies in the various regions are needed. The GB lines need to extend into the Gulf of Maine and the Labrodor Shelf. Winter is key time that some species "bulk up". The GB has lowest mortality rates in winter – this could be due to slower metabolism of the organism or slower metabolism of its predator. There is a marked contrast between how warm-blooded and cold-blooded predators respond to the seasonal temperature cycle. As a notable example, seals gain fat in the winter.

GB has low salinity water coming further south, and some cold water species with it. This may have produced a sharpening of zoogeographic gradients in that area.

GB fish recruitment variability has been ascribed to variability in egg loss due to advection off the shelf. (Note the similarity here with pollock in the CGOA; in the CC also have spawning in areas with high retention). Nutrient advection affects may be important, but data suggest wind-driven egg loss (March-April) is the main driver. Cod growth is also affected by copepod abundance. It is likely that many species have evolved to successfully "ride" the alongshore currents.

Southern Ocean
The SO has two fall/winter seasons. There is an apparent link between high chlorophyll values and high recruitment of krill. Larval krill feed on sea ice algae and so should be affected by ice extent; there is a strong correlation of krill with sea ice in Scotian Sea, which may not apply in other parts of the Antarctic. Adult krill spawn near the shelf break, so the AntCC can sweep them into the Scotian Sea. Retention by gyres is important to survival. There is a high abundance of krill larvae off the shelf. Larvae closest to shore are observed to be the oldest; suggesting transport onto the shelf throughout the year.

The SO has a strong prey switching issue – that is, some predators in the AO seem "hard wired" behaviorally for what prey they can use. Adelie penguins exhibit strong seasonal changes in feeding behavior.

Although the SO has evident climate effects, we don't have really long time series to analyze. Indeed, there are no time series longer than 25 years in this area. The Weddell and Ross seas have some longer time series, however.

Common features/comparison among areas
Retention/loss issues are a common thread to all the systems.

3 - EPISODIC EVENTS and HOT SPOTS

Northeast Pacific
Episodic events in the CC include: 1) delayed upwelling in 2005; hypoxia events; strong downwelling events, where the cross-shelf community gradient gets compressed against the shore. In the CGOA, episodic upwelling events may drive higher production in the summer. These may be driven by upwelling favorable winds at the coast, or by wind stress curl events further offshore. Episodic intrusion of 200-km eddies from the deep basin may have profound effects on the shelf biota. Conversely, the export of iron-rich shelf waters by such large eddies detaching from the Eastern Boundary currents may have profound effects on the biota in the deep basin.

Georges Bank
A major episodic event on GB is wind-driven egg mortality due to storms. Eddies at the shelf break may also lead to episodic loss of larvae. The Gulf of Maine has a set of hot spots with aggregation of zooplankton.

Southern Ocean
Polynyas locked to topography are a significant hot spot in the SO. Predators live near such reliable food sources, e.g. those tied to bathymetry or a persistent direction of katabatic winds. Adelie penguins are observed contracting back to higher latitudes recently.

Common features/comparison among areas
Tidal mixing over shallow bathymetry is a variety of hot spot common to all areas, e.g. Heceta Bank in the CC and Portlock Bank in the CGOA. In many ways GB is one big hot spot of enhanced tidal mixing.

4 - KEY ATTRIBUTES/OBSERVING

1) In the SO, new programs could better find hot spots, based on our accumulated research experience.
2) Different seasons are important for different taxa; need for year-round sampling.
3) Fixed stations are highly valuable for year-round sampling.
4) Fine-scale fronts are probably important to biology via convergence effects; note that ephemeral fine-scale features are difficult to measure with fixed arrays.

Working Group 2.2

How are climate effects manifested in the GLOBEC study regions?

Chair: Steven Bograd; Rapporteur: Jim Bisagni

Participants: Hal Batchelder, Erik Chapman, Cabell Davis, Zack Powell, Steve Teo, Cisco Werner

NEP – Northeast Pacific
GOA – Gulf of Alaska
CCS – California Current System
NWA – Northwest Atlantic
GB – Georges Bank
AP – Antarctic Peninsula
SO – Southern Ocean

How are climate effects manifested in the GLOBEC study regions?

(1) Through what physical mechanisms?

The group's approach was to prepare a relatively comprehensive list of dominant physical processes through which climate effects are manifested in each study region, and to compare the relative importance of these processes between regions. The following list was derived:

- Phenology/Seasonality: The relative timing of seasonally driven physical processes and biological life cycles is critical to ecosystem productivity and structure in each study region. CCS: wind forcing, spring transition to coastal upwelling; NWA: spring bloom, retentive closed circulation, wind-forcing; SO: development of Antarctic Peninsula Coastal Current. It will be important to explore climate's role in changing seasonality in each region.

- Freshwater Input: Different sources of FW, but important in each study region. GOA/NWA/AP: seasonal buoyancy-driven coastal currents fed by FW input; CCS: Columbia River plume impacts properties, stratification on upper layer waters in northern CCS.

- Advection: Changes in magnitude of advection, or in water properties being transported is important in each study region. NWA: Scotian Shelf Water Crossovers, low-frequency low salinity anomalies; NEP: anomalous advection associated with El Niño events, bifurcation of the West Wind Drift and relative proportion of transport into the California and Alaska Currents.

- Retention/Loss: Changes in mesoscale circulation patterns will impact the retention or loss of planktonic organisms. NWA: effects of NAO-related shelf-ring interactions; NEP: climate connections to mesoscale variability, including propensity of eddies and fronts, EKE; SO: climate-driven variations in the Antarctic Circumpolar Current (impact on krill).

- Land-Sea Temperature Contrasts: Variation in land and sea heating associated with global warming could lead to variable wind forcing in each study region. NEP: changes in the strength of alongshore wind stress (upwelling – the Bakun hypothesis); NWA: SST changes; SO: changes in catabatic winds.

- Vertical Structure: Water column density structure is critical to biology in all study regions. NEP: effects on upwelling efficiency and nutrient supply; NWA: local heating is critical; All regions: direct effect of rising temperatures on biological rate processes.

(2) Through what biological mechanisms?

The group's approach was to prepare a relatively comprehensive list of dominant biological processes through which climate effects are manifested in each study region. All biological processes were deemed equally important in each of the study regions. The following list was derived:

- Heating Effects on Vital Rates: Most biological rate processes are strongly temperature-dependent, so direct heating effects (global warming) will have a big impact.

- Temperature-driven Range Shifts: Latitudinal shifts in species ranges can occur due to large-scale temperature changes. Shifts in species composition of potential prey items are important to higher trophic levels.

- Predator/Prey Relationships, Ecosystem Structure: Physical changes (temperature, advection, etc.) can cause changes in predator-prey relationships, or changes in ecosystem structure (due in part to range shifts).

- Ecosystem Efficiency: The efficiency at which an ecosystem can convert primary production to upper trophic levels can change due to climate-driven fluctuations in the components of food webs (e.g., food chain length).

- Resilience of Target (and non-target) Species: Some species (target or non-target) may have more resiliency to climate-driven changes than others; would be good to identify the response potential of different ecosystem components.

- Time Scales of Advective-Life History Processes: The relative time scales of advective processes and life cycle strategies could shift. Species have evolved life history strategies to take advantage of known physical processes; changes in these processes could interrupt life cycle closure for some species.

- Fronts/Thin Layers: These are features that are exploitable by "intelligent" organisms (most upper trophics, but also zooplankton); location and intensity of these features will change with climate.

- Biogeochemical Variability: Changes in ocean biogeochemistry (e.g., ocean acidification) will have biological impacts. This is an area where GLOBEC can link to IMBER.

- Interaction between Climate Change – Human Activity: Activities such as overfishing will affect the resiliency of an ecosystem (e.g., its ability to "recover" from a regime shift or other climate perturbation).

(3) How important are episodic events and "hot spots"? Are other temporal and spatial scales "more" relevant to ecosystem considerations?

Depending on the system, episodic events and spatial "hot spots" can be very important. We chose not to rank the relative importance of different time and space scales, since variability on all scales have important impacts. We also noted that the terms "episodic" and "hot spot" are scale-dependent. One could consider the entire Georges Bank a hot spot. However, we identified a number of important processes/features/scales that have different levels of importance in each study region.

- Tidal mixing and shelf-slope fronts are important hotspots of new primary production and biological activity across many trophic levels in the NWA.

- Topographically-controlled hot spots have important consequences for mesoscale circulation and the retention/loss of biogenic material. CCS: Hecata Bank has relatively long residence time on the Oregon shelf, as well as upwelling shadows around capes and headlands in numerous coastal areas; SO: topographically-steered flow of Upper Circumpolar Deep Water onto the shelf.

- Hypoxic events have become chronic on the Oregon/Washington shelf in recent years.

- Long-lived mesoscale eddies can transport significant quantities of coastal water (nutrients, planktonic organisms, other biogenic material) to oligotrophic offshore regions. GOA: Haida eddies are important transporters of nutrients (including iron) to offshore waters, seeding productivity in the open ocean.

- Top predators regularly utilize hot spots (persistent or recurrent features or regions, generally of enhanced productivity) in all study regions. These hot spots can serve a variety of ecological functions (e.g., foraging, migration, reproduction).

- Riverine inputs supply nutrients and freshwater episodically, and can alter stratification. Important in NEP.

- Other episodic events are important: NEP: intraseasonal oscillations (possibly associated with MJO); NWA: Scotian Shelf Water Crossover-related salinity anomalies; All regions: storm events.

- Of equal or greater relevance to these episodic events are lower-frequency climate variations. NEP: ENSO, PDO, AO; NWA: NAO, AO; SO: SAM.

(4) What key attributes characterize systems that vary on these scales? What observing methods/networks would best capture them?

- It was noted that there is low observability and predictability for episodic events and hot spots.

- We must sample appropriately for the process being studied (e.g., intraseasonal resolution is required in the CCS to capture the spring transition).

- What observing methods/networks are needed? We need long-term high-frequency moored samplers, satellite-based sensors, species-specific sensors (for taxonomic information), ship-based studies, AUVs, Lagrangian instruments (drifters, floats), electronic tags on top predators. All these data sources need to be linked to interactive, data-assimilative high-resolution coupled physical-biological models.

- We need to maintain current capabilities in satellite sensors (at least), whose near-term future for ocean observing looks bleak. We also need to maintain and expand our ship resources.

Working Groups 2.3

How are climate effects manifested in the GLOBEC study regions?

Chair: Nick Bond; Rapporteur: Beth Turner

Participants: Ann Bucklin, Dan Costa, Christian Fritsen, Dale Haidvogel, Robin Ross, Peter Wiebe

This group discussed cross-cutting issues that might be profitably addressed in pan-regional synthesis studies. The major topics of discussion included an overarching question, the biological mechanisms relating ecosystem response to physical forcing, the formation of "hotspots", and the relative roles of short, episodic events versus slow changes for the regional ecosystems. The group's perspectives on these topics are fleshed out below.

The overarching question or theme that arose was an evaluation of the relative sensitivity of the different GLOBEC study regions to climate variability. It was felt that the process of carrying out this evaluation would have the useful outcome of identifying the actual elements of the climate forcing (the predictors) and the aspects of the ecosystems of interest and importance (the predictands). One goal of GLOBEC regional synthesis will be to identify relationships between forcing and response for each of the GLOBEC regions individually. This will provide insight into the key mechanisms/interactions for each GLOBEC region in a comparative sense.

The physical mechanisms through which climate impacts are expressed on the GLOBEC ecosystems did not receive much attention. This was a conscious decision by the group, but by no means because the topic lacks importance. It is just that the group felt that these physical mechanisms are already well appreciated (they were identified in the charges to the working groups), if not necessarily quantified, and that the group's time could be most productively spent on consideration of biological mechanisms.

A variety of biological mechanisms were discussed, with the goal of itemizing broad themes amenable to pan-regional analysis. A strong consensus emerged on the importance, and feasibility, of pursuing the general problem of match/mis-match between trophic levels, namely as related to the timing and hence availability of suitable prey. Comparisons on this problem between the GLOBEC regions should help increase our basic understanding of how marine ecosystems react to climate variability, i.e., bottom-up effects. The second idea to receive considerable attention was the concept of the distance between a population and limiting biogeographic boundaries, in that this distance essentially determines the sensitivity of this population to climate-induced shifts in these boundaries. A third theme arose on the concept of complexity, in that there were likely to be payoffs from a comparative analysis of how the diversity of the various GLOBEC ecosystems relate to their resiliency to climate (and other) variations. In some cases, total carrying capacity of an ecosystem may not change, but the individual species present, and their comparative abundances, may differ due to climate forcing, with associated ecosystem effects. There was additional discussion of the life span and migration patterns of organisms and how that might influence adaptation/sensitivity to climate changes.

The concept of "hot spots" was suggested as a topic of consideration, which received much discussion. It was pointed out that GLOBEC focused on hot spots by design, and therefore direct information is scanty on the differences in ecosystem dynamics between productive and nearby less productive environments. The discussion therefore centered on how it would be fruitful to assess the relative importance of the various mechanisms that are potentially responsible for making the GLOBEC regions productive. Because hotspots are by definition regions of high productivity, they are also areas of special emphasis from a management standpoint.

The group had substantial interest in impacts associated with episodic events, as compared with those due to low-frequency variability, expressed as "pulse versus press". While the intensive field operations for GLOBEC were conducted over short time spans relative to slow variations in climate, both data from additional long-term monitoring efforts, and the results from biophysical models, could be used profitably to address this issue. One implication of this pulse versus press concept is predictability, in that if episodic events (slow variations) dominate a system, then that system might be characterized as more stochastic (deterministic).

The group's session ended with a short conversation on future observing networks. While little specific recommendations could be made in this forum, there was no quarrel that GLOBEC synthesis, in general, would help provide guidance for the design of observational arrays for monitoring ecosystem structure and function. An extremely useful outcome of pan-regional synthesis would be to identify harbingers of regime change that could be measured by observing systems to predict change in an ecosystem. The scientific questions involved in identifying these harbingers are at the heart of the issues discussed above.

Working Group 3.1

State three questions that should be in the Pan-Regional Synthesis Announcement of Opportunity.

Chair: Ann Bucklin; Rapporteur: Nick Bond

Participants: Hal Batchelder, Jim Bisagni, Steven Bograd, Lou Botsford, Jennifer Burns, Eric Chapman, Dan Costa

This group briefly reviewed the points made by the working groups on the previous day, and then set to the task of formulating a trio of questions suitable for inclusion in an announcement of opportunity (AO) for pan-regional synthesis in U.S. GLOBEC. While all participants were familiar with the GLOBEC program, the topics addressed, and the questions formulated, were in the spirit of an independent and fresh attempt to provide input for an AO. These questions, with supporting material, are presented below.

Question 1 - Climate Impacts

How does climate forcing affect the target forage species in terms of timing, distribution, abundance, and species composition?

The group felt that this question could be answered through two, related lines of inquiry. One line would involve the assessment of the relative roles of mechanisms of climate forcing (e.g., advection, mixing, stratification, phenology and biogeography) in the various regions. The other line would focus on how the impacts of climate forcing propagate through the food web.

Question 2 - Ecosystem Interactions

What are the functional relationships between climate-driven lower-trophic level variability and higher-trophic level response?

Headway on this question would require bridging a basic knowledge gap on the coupling of lower-trophic level properties to higher-trophic levels, to which GLOBEC can make a significant contribution. The group discussed a variety of specific elements that probably need to be involved in addressing this topic: (1) confirmation that available biophysical models can replicate the observed characteristics of each region, (2) integration of GLOBEC data with relevant non-GLOBEC data bases, (3) consideration of the effects of climate variability on behavior (especially foraging behavior and movement), abundance, and distribution of higher trophic levels, and (4) modulation of climate impacts by top-down effects (e.g., removal of higher-trophic level species).

Question 3 - Management

How can GLOBEC results be synthesized to provide a scientific basis for effective management of harvested and protected species?

The overall goal here would be two-fold and that is to develop ecosystem indicators and their associated uncertainties for use in integrated ecosystem assessments, and to generalize regional results to global management needs. This activity would necessarily require the new understanding that research on the first two questions, or their equivalents, would bring about.

Working Group 3.2

State three questions that should be in the Pan-Regional Synthesis Announcement of Opportunity.

Chair: David Mountain; Rapporteur: Kendra Daly

Participants: Cabell Davis, Christian Fritsen, Avijit Gangopadhyay, Dale Haidvogel, Al Hermann, Eileen Hofmann

Early in a general, introductory discussion it was suggested that we should look back at the overall goals of GLOBEC as originally cast and consider what specific questions would allow us to reach those objectives. Without actually searching out those documents, the group identified and discussed three or four major themes or issues for Pan-Regional Synthesis.

The first concerned identifying the processes controlling the population dynamics and recruitment of the target organisms and how those processes would be affected by a changing climate. This analysis would be done through comparing/contrasting the different systems studied in the program. Modeling – likely coupled bio-physical modeling – would be a primary tool for this effort.

The second theme focused on moving from understanding the response of individual species to climate change to understanding the ecosystem response. What is the role of individual species dynamics in determining ecosystem and food web dynamics? Based on the knowledge we have gained about target species physiology and population dynamics, what can we infer/extrapolate from this knowledge to help us better understand ecosystem response to climate change? This activity could provide guidance on how to assess ecosystem level questions using GLOBEC data (i.e., information on individual species), plus other, ancillary data that might be available.

Both of these issues seemed fundamental to the objectives of the GLOBEC program. It will be important to identify which mechanisms are associated with forcing that would be independent of a changing climate (e.g., tidal forcing) and which would be sensitive to climate change.

The third theme related to determining which aspects of biological systems are predictable and which are not. For the ultimate application of the GLOBEC results – both in terms of understanding the biological systems and of the modeling capabilities that have been developed – predictability is a central issue. The variance of processes, e.g. timing and strength of the spring bloom, could be investigated to determine the level of uncertainty in how well can we model processes and the implications of that uncertainty to the rest of the system. Knowing what aspect of system parameters leads to the largest expansion of uncertainty could focus future efforts and lead to new techniques to address the problem. It also would be important to identify which aspects of uncertainty are inherent and which could be addressed by additional research or improved modeling capabilities.

While investigating what aspects of biological responses are predictable in relation to climate change, various theoretical ecology concepts could be tested: does diversity lead to stability, is the level of connectivity in the system important (does loose connectance lead to higher resilience)? How do food webs adapt – e.g., look at Antarctic food webs and its possible adaptation through alternative food sources as the geographic range of species – e.g., the Adelie penguin – change with changing climate. Perhaps there are not sufficient observations, but one could start investigating through models. Scenarios could be set up to examine the response of different systems to a given change (e.g., an increase water temp of 1 degree). What does that do in each region? In the Antarctic where the normal seasonal range is only -1.8 to 2 degrees C, a 1 degree increase would have a large impact (presumably). On Georges Bank the characteristic seasonal range is 10-15 degrees C and a 1 degree change might not have a large effect on the biology directly, but in the spring might have a significant affect on stratification or some other aspect of the system.

What is the threshold of response for climate change to have a significant effect on each system? This involves knowing how the food web itself might change and in a modeling context, having a dynamic food web (a '3-D ecosystem'). That dynamic nature of the food web might be incorporated in a model through genetic adaptation or phenotypic variation that allows populations to respond.

What are common dynamics in all regions? There are teleconnections between the GLOBEC study areas (AO to NAO and PDO) in climate models. For model evaluation, the specific models used in each region will need to be different, even if they have the same core (e.g., the ROMS used in the North Pacific will be different from the ROMS used in the Southern Ocean since the latter has sea ice and flow under ice shelves). While direct comparisons may not be possible, but the models still will have many commonalities.

Near the end of the discussions two statements of note emerged relating to modeling
:

THE TRUTH IS NOT MODEL DEPENDENT

NATURE IS INSENSITIVE TO MODELING

Out of the above discussions the group developed the following three questions:

1. What are the common mechanisms that control population dynamics and recruitment across/between regions in response to climate change?

2. In what way is our understanding of ecosystem dynamics improved by species specific information?

3. What aspects of population or ecosystem response to climate change are predictable, and what are the key threshold responses?

Working Group 3.3

State three questions that should be in the Pan-Regional Synthesis Announcement of Opportunity.

Chair: Peter Wiebe; Rapporteur: Steve Teo

Participants: Mike Alexander, Zack Powell, Robin Ross, Jeff Runge, Beth Turner, Cynthia Tynan, Cisco Werner

Discussion began with discussion about the ground rules for participants in pan-synthesis. Participants should be encouraged to go beyond US programs and be able to make comparisons with regions outside the US. The questions devised in this working group should include at least one GLOBEC program, but there is a need to include other regions. The three questions should be phrased so that each of the regions can address them. For this purpose, the NEP region is considered a single module and comparisons with this region needs to include other regions.

Before formulating the questions, discussion focused on three major areas for pan-synthesis:

- Population dynamics and recruitment of the target species.

- Ecosystem structure and function in the GLOBEC study areas.

- Linking climate models to coupled physical/biological models at regional to ocean basin-scales.

In addition, discussion also centered on whether it was possible for pan-synthesis to result in the development of an end to end model that works in the various study sites. Associated with this was the view that it would be good to get to a single climate model drives the regional and local models. This would make it possible to compare the regional models without having to worry about larger-scale climate prognostications derived from different climate models influencing or dominating the intercomparison results. It was also decided that ecosystem-based management goals should be integrated into each question, rather than be set as a separate question.

The three major areas of discussion and the questions associated with each area are detailed below:

1) Population dynamics and recruitment of target species

Questions: How has environmental/climate forcing affected population dynamics and recruitment processes in different ecosystems? To what extent do frameworks like ecological theories or simulation modeling provide a basis for determining the differences and commonalities between the systems? What key environmental/ecosystem indicators emerge that can relate these findings to ecosystem-based management needs and do these have commonalities across regions?

There was consensus in the group on the importance of determining and understanding the commonalities between the ecosystems and not just providing a laundry list of the processes in the different ecosystems. One of the ways to do so would be to use frameworks like ecological theories and simulation modeling. It would also be important to relate the findings to ecosystem-based management needs.

2) Ecosystem structure and function in the GLOBEC study areas

Questions: How has climate forcing altered ecosystem structure and function across regions? What are the characteristics that contribute to the resilience and sensitivity of ecosystems? To what extent does the strength of climate effects in systems result from different anthropogenic/historical effects? Are there commonalities between the systems and if so, why? How does climate change impact the range and distribution of predators and their impacts on ecosystems?

In this discussion area, it was suggested that the interactions between top predators and lower trophic levels be explicitly included in the AO. This includes how habitat utilization, ecophysiological, and foraging models of the top predators in different ecosystems change under varying climatic conditions. Since all the systems under US GLOBEC have been affected by direct and indirect human activities in the regions, it would be important to compare and understand these anthropogenic and historical effects.

3) Linking climate models to coupled physical/biological models at regional to ocean basin-scales.

Questions: How will features of global climate (e.g., ENSO, PDO, global warming, acidification) affect physical processes in the ocean (e.g., FW input, seasonality, wind patterns) and subsequently affect different regional ecosystems? Are there common features and effects among the ecosystems?

It is envisioned that these questions can be addressed by linking global climate models to regional oceanographic and ecological models. Development of a global ecological model or model structure for the GLOBEC regions that includes the necessary demographic parameters may be needed.

There was some discussion on whether it would be appropriate to include an explicit modeling question since both previous questions requires modeling as well. However, it was suggested that there is a need for an explicit AO question to link global climate models to regional oceanographic and ecological models. Otherwise, such links are not likely take place spontaneously, to the detriment of the GLOBEC community. The AO should also be careful not to restrict the modeling approach to any one specific type of model.

Appendix D. The U.S. GLOBEC Pan-Regional Synthesis Announcement of Opportunity

Program Title: U.S. GLOBEC - Global Ocean Ecosystems Dynamics: Pan-Regional Synthesis

Synopsis of Program: As the culmination of a series of solicitations for the U.S. Global Ocean Ecosystem Dynamics Program (U.S. GLOBEC), this solicitation seeks a broader understanding of climate impacts on marine ecosystems and embedded populations that builds upon findings from the three regional U.S. GLOBEC studies in the Northwest Atlantic, Northeast Pacific, and Southern Ocean. Science investigators submitting proposals to this solicitation should focus on (1) synthetic activities, including conceptual and analytical modeling activities that capitalize upon and integrate concepts, methods, and/or data from the prior solicitations; (2) broader-scale studies including comparisons across system types, encompassing both GLOBEC and non-GLOBEC study areas; and/or (3) the development of management strategies at the population, community, and ecosystem levels. Participation of investigators new to the U.S. GLOBEC program is strongly encouraged in order to maximize the depth and breadth of the synthesis results.

Cognizant Program Officer(s): Phillip R. Taylor, Program Director, Directorate for Geosciences, Division of Ocean Sciences, National Science Foundation, telephone: (703) 292-8582, fax: (703) 292-9085, email: prtaylor@nsf.gov

Award Information
- Anticipated Type of Award: Standard or Continuing Grant
- Anticipated Duration of Awards: Two or three years
- Estimated Number of Awards: About 5-10 integrated, interdisciplinary projects, some of which will be multi-organizational collaborative projects.

Anticipated Funding Amount: $7,000,000 (total) pending the quality of proposals received and the availability of funds. Please see Section IV. AWARD INFORMATION for details on anticipated funding.

Proposal Preparation and Submission Instructions
A. Proposal Preparation Instructions: Full Proposal Preparation Instructions: This solicitation contains information that supplements the standard Grant Proposal Guide (GPG) proposal preparation guidelines. Please see the full text of this solicitation for further information.

B. Budgetary Information
- Cost Sharing Requirements: Cost Sharing is not required.
- Indirect Cost (F&A) Limitations: Not Applicable.
- Other Budgetary Limitations: Not Applicable.

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C. Due Dates
- Full Proposal Deadline Date(s) (due by 5 p.m. proposer's local time): 1 December 2007

Proposal Review Information
Merit Review Criteria: National Science Board approved

I. Introduction

The solicitation is being issued under the auspices of the U.S. Global Ocean Ecosystem Dynamics (U.S. GLOBEC) program. The goals of U.S. GLOBEC include understanding and ultimately predicting how populations of marine animals (holozooplankton, fish, benthic invertebrates, seabirds, and marine mammals) respond to changes in the global climate. The U.S. GLOBEC program is a component of the U.S. Global Change Research Program. U.S. GLOBEC is also a component of the International GLOBEC program, a core project of the International Geosphere-Biosphere Program (IGBP), with co-sponsorship from the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC), and affiliate intergovernmental programs within ICES (International Council for the Exploration of the Seas) and PICES (Pacific ICES).

Prior phases of U.S. GLOBEC research have been supported jointly by the NSF Ocean Sciences Division and Office of Polar Programs, and the National Oceanic and Atmospheric Administration Center for Sponsored Coastal Ocean Research and the National Marine Fisheries Service (NMFS), with additional participation by NASA. It is expected that NOAA research scientists could participate in Pan-Regional Synthesis as no-cost collaborators.

Specific goals of the U.S. GLOBEC program are (1) to understand the potential impacts of climate variability and change on the dynamics of shelf ecosystems and on the distribution, abundance and production of several specific target species; (2) to embody this understanding in conceptual and quantitative models capable of capturing population and ecosystem responses over a broad range of spatial and temporal scales; and (3) to improve predictions of U.S. living marine resource populations which can lead to enhanced management capabilities. U.S. GLOBEC science and implementation plans and other program reports are available at http://www.usglobec.org/reports.php.

U.S. GLOBEC has comprised three regional ecosystem programs -- Northwest Atlantic/Georges Bank (NWA), Northeast Pacific (NEP) and Southern Ocean (SO) -- and a series of technology and modeling development projects. Data collection and process studies in each of the three regions have been funded through a series of previous solicitations. Publications resulting from these U.S. GLOBEC studies are catalogued at http://www.usglobec.org/papers.php, and the entirety of the data derived from these research programs can be freely accessed at http://www.usglobec.org/data.php (see below for more details).

The focus of the U.S. GLOBEC program is now on comparing and contrasting the results from the prior phases of U.S. GLOBEC, and on extending these results with comparisons to, or tests within, other comparable ecosystems. This solicitation seeks to build upon and support the synthesis and integration of results across the three U.S. GLOBEC study regions. For all three regions, synthesis and comparative analysis efforts are presently underway, as described further below. The priority focus for the Pan-Regional Synthesis phase of U.S. GLOBEC will be to achieve a broader understanding of climate impacts on marine populations and ecosystems employing hypotheses, concepts, methods and/or data derived from the regional studies in the Northwest Atlantic, Northeast Pacific, and Southern Ocean. This solicitation marks the culmination of synthesis in U.S. GLOBEC. The Pan-Regional Synthesis program, its goals, and the research themes of particular interest are each described in the Program Description Section below.

Electronic Data Access: The synthesis and comparative analysis opportunities described in this solicitation are open to scientists without past involvement in U.S. GLOBEC as well as those who have had funding through previous GLOBEC activities. U.S. GLOBEC Data Policy requires that all data collected under the U.S. GLOBEC program and associated documentation be made available to all researchers. The U.S. GLOBEC Data Policy (U.S. GLOBEC Report 10) is available at http://www.usglobec.org/reports/datapol/datapol.contents.html. Again, data for all three U.S. GLOBEC regional programs is available at http://www.usglobec.org/data.php.

II. Regional Program Descriptions and current status

A. U.S. GLOBEC Northwest Atlantic / Georges Bank Program (NWA)

Within the overall U.S. GLOBEC goals, the NWA / Georges Bank Program has the following specific goals:

- To determine the mechanisms by which physical and biological processes control the population dynamics of the target organisms (early life stages of cod and haddock and their copepod prey, e.g., *Calanus finmarchicus, Pseudocalanus* spp., and *Oithona*) in the NWA / Georges Bank area;
- To develop conceptual and quantitative models capable of predicting ecosystem dynamics and responses on a broad range of space and time scales; and
- To understand the effects of climate variability and climate change on the distribution, abundance and production of the target organisms.

The specific objectives and scientific questions related to these goals are described in greater detail in the U.S. GLOBEC NWA Plan (Report No. 6), available at http://www.usglobec.org/reports/nwaip/nwaip.contents.html.

The NWA regional program included modeling studies together with broad-scale and process-oriented field studies on Georges Bank and the surrounding continental margin and shelf, in the context of the larger oceanic boundary region with emphasis on the processes and phenomena that affect the ecosystem of the Bank. Each process-oriented field study focused on a particular physical process and the influence of that process on the bank's biology: Phase I – stratification, Phase II - source/retention/loss of water and organisms from the Bank, and Phase III – cross frontal exchange. The coordinated modeling and field effort was in support of improving the predictability and management of U.S. marine resources through better understanding of the NWA / Georges Bank ecosystem.

The U.S. NWA Program is now nearing completion of its regional synthesis phase (Phase IV). Phase IVa initiated the overall synthesis effort resulting in several data integration and modeling studies. Phase IVb proposals were selected to place the research findings of the Georges Bank program into the context of basin-scale phenomena in the North Atlantic, and to use that knowledge to predict the Georges Bank ecosystem response to future climate variability with international and other U.S. GLOBEC study areas.

B. U.S. GLOBEC Northeast Pacific Program (NEP)

Within the overall U.S. GLOBEC goals, the NEP program has the following specific goals:

- To determine how changing climate, especially its impacts on local wind and buoyancy forcing and basin-scale currents, affect spatial and temporal variability in

mesoscale circulation and water column structure;
- To quantify how physical features in the NEP, and variability related to climate change, impact zooplankton biomass, production, distribution, and the retention and loss of zooplankton from coastal regions, and how these, in turn, influence the distributions of higher trophic levels, such as forage fish, salmon, and marine birds and mammals;
- To quantify the impacts of key coastal physical and biological processes on controlling juvenile salmon growth and survival in the coastal zone of the NEP;
- To determine the extent to which high and variable mortality of juvenile salmon in the coastal regions of the Northeast Pacific is responsible for large inter-annual variation in adult salmon populations, and to determine whether and how the proximate mortality causes (*e.g.*, predation, parasites, starvation, loss by advection) are affected by climate variability; and
- To compare the impacts of climate variability and change (such as El Niño-La Niña cycles and regime decadal variability) on similar marine animal populations (copepods, euphausiids, salmon) across the sub-regions of the NEP.

The specific objectives and scientific questions related to these goals are described in greater detail in the U.S. GLOBEC NEP Implementation Plan (Report No. 17), available at http://www.usglobec.org/reports/rep17/nepip.contents.html.

The NEP regional program has two sub-regions, the California Current System (CCS) and the Coastal Gulf of Alaska (CGOA). Thus far, the NEP program has consisted of regionally combined modeling, retrospective and pilot field studies (Phase I) and separate sub-regional field and model studies (Phase II). These studies have resulted in substantial new data sets and understanding of the physical-chemical-biological interactions in shelf, slope and adjacent deep-ocean habitats in the NEP.

Synthesis (Phase III) in the CCS was initiated with funding in 2004 and in the CGOA in 2005. The objective of Phase III is the integration and synthesis of data collected during the field phases of the NEP program, and the implementation of robust and reliable coupled biophysical models, leading to improved knowledge of, and predictive tools for, the impact of climate variability on specific marine populations and ecosystems of the eastern North Pacific.

C. U.S. GLOBEC Southern Ocean Program (SO)

Within the overall U.S. GLOBEC goals, the SO program has the following specific goals:
- To elucidate shelf-circulation processes and their effect on sea-ice formation and Antarctic krill (*Euphausia superba)* distribution, and
- To examine the factors that govern Antarctic krill survivorship and availability to higher trophic levels, including penguins, seals and whales.

The program also seeks to improve the predictability of living marine resources – including their abundance, distribution and behavior – with respect to local and global climatic shifts. The U.S. SO GLOBEC Implementation plan (International GLOBEC Report No. 7A) may be found at http://www.globec.org.

The goals of the first phase of the US SO GLOBEC program were accomplished through broad-scale synoptic studies and process-oriented investigations, conducted primarily during the austral winter (2001-2002). These studies addressed the following questions:
- What is the physical environment of the Western Antarctic Peninsula shelf and how

does it govern the distribution of and the resources available to krill?
- What physical, chemical and biological factors govern krill recruitment?
- What is the relationship between the physical environment, krill ecology and the success of krill-dependent predators?

The field and process studies undertaken in the first phase of SO-GLOBEC resulted in new data sets and an increased understanding of climatic and geophysical forcing factors that structure ecological communities in the Southern Ocean.

The first SO GLOBEC Synthesis and Modeling activities were initiated in 2005 with goals that included: (1) improved knowledge of the impact of environmental and climate variability on specific marine species, communities, and ecosystems of Antarctic continental shelf waters; (2) circulation, sea ice, ecosystem, and coupled physical-biological models that can be used to examine impacts of environmental and climate variability on Antarctic ecosystems; (3) detailed and quality controlled datasets of physical, chemical and biological conditions that will be used in model validation and can provide a baseline and basis for future research in the region; and (4) new indices or strategies that provide increased understanding of the structure and function of Antarctic marine food webs.

III. Program Description: U.S. GLOBEC Pan-Regional Synthesis (PRS Phase)

This solicitation constitutes the initiation of Pan-Regional Synthesis within U.S. GLOBEC. The objective of Pan-Regional Synthesis is to seek a broader understanding of climate impacts on marine animal populations and ecosystems that will build upon regional studies in the Northwest Atlantic, Northeast Pacific, Southern Ocean, and elsewhere. A higher-order synthesis effort incorporating basin-scale and circum-Antarctic efforts, for example, and comparative analyses among U.S. and International GLOBEC studies and related programs is required to meet the overarching GLOBEC goal of predicting the effects of global climate change on marine ecosystems. A copy of the U.S. GLOBEC Implementation Plan for Pan-Regional Synthesis may be found at: http://www.usglobec.org/.

Proposed projects are sought that compare, contrast, and/or extend the concepts, hypotheses, models and/or data from two or more study regions, the first of which must be one of the three U.S. GLOBEC focus regions (NWA/Georges Bank, Northeast Pacific, or Southern Ocean). The remaining region(s) may be drawn from U.S. GLOBEC, GLOBEC International, or any related program/region. For the purposes of this solicitation, the Northeast Pacific will be considered as a single U.S. GLOBEC region.

Attaining an integrated level of understanding in U.S. GLOBEC depends critically on achieving a synthesis of individual elements within each regional program, as well as on a comparative analysis among GLOBEC programs and other marine ecosystem research programs. The latter is the focus of Pan-Regional Synthesis within the U.S. GLOBEC Program. From its inception, the importance of comparative analysis in U.S. GLOBEC for ascertaining the effects of climate forcing has been recognized. Comparison of the dynamics of closely related taxa selected as target species in relation to specific physical processes (including stratification, mechanisms of retention and loss, upwelling and downwelling, cross-front exchange, and sea ice extent and concentration) must be an integral component of the overall synthesis and integration effort in U.S. GLOBEC. Examples of cross-cutting issues suitable for comparative analysis include top-down vs. bottom-up controls on productivity, and the importance of topographic controls on local and regional circulation patterns. Synthetic studies of population and system states over time in relation to climate forcing must also be undertaken.

Consideration of the effects of climate forcing on the major system types represented in U.S. GLOBEC will require comparisons and contrasts not only among the regional U.S. studies but with results from related national and international programs in other similar systems. The worldwide GLOBEC program and related research efforts afford critical opportunities for comparative analyses and for consideration of basin-scale processes. For example, comparisons with other studies of calanoid copepods and gadoids on bank and shelf systems in the North Atlantic; copepods, euphausiids, and salmonids in the North Pacific; and euphausiids, calanoid copepods, and upper trophic level predators (*e.g.*, seabirds, penguins, seals and cetaceans) in continental shelf waters of the Southern Ocean are desirable.

Models play a central role in U.S GLOBEC in its overarching objective of understanding and eventually predicting long-term variability of target species identified in each of the regional studies. Here, models are broadly defined to encompass validated models of all kinds – conceptual, mathematical, numerical, and statistical.

A. Research Themes and Questions

U.S. GLOBEC held its first Pan-Regional Synthesis Workshop in November 2006. At this Workshop, the science community had the opportunity to discuss and to define the goals and approaches of pan-regional synthesis. A Workshop report can be obtained at http://www.usglobec.org/workshops/synth06/index.php.

Based upon the consensus developed at this Workshop, studies in the Pan-Regional Synthesis phase of U.S. GLOBEC are sought that focus on three research themes. These general themes, and representative research questions appropriate to each, are described below. It is anticipated that proposed work may address more than one of these or other themes.

1. <u>The influence of climate on physical and biological processes</u>: Fundamental to the success of U.S. GLOBEC is the need for synthetic understanding of how changes in climate at basin and global scales force physical processes that determine biological communities at local and regional scale.

   Example questions appropriate to this theme include: How will features of global climate (*e.g.*, the North Atlantic Oscillation (NAO), the Pacific Decadal Oscillation (PDO), global warming, and acidification) that affect physical processes in the ocean (*e.g.*, fresh water input, wind patterns, and circulation) consequently affect different regional ecosystems? Are there common features and effects among the ecosystems? What is the threshold of response for climate change to have a significant effect on each ecosystem? How do climate-mediated changes in physical conditions interact with organism behavior and influence species distributions, trophic interactions, and community structure? How do the effects of climate on primary production and lower trophic levels determine the timing, distribution, abundance, and species composition at higher trophic levels? How does this understanding support, and provide specific strategies for, ecosystems approaches to management? Can models be developed that provide reliable forecasts of end-to-end ecosystem change?

2. Population dynamics and recruitment of target species: This theme seeks to identify the processes controlling the population dynamics and recruitment of the target organisms as a function of system type, and to ascertain how these processes would be affected by a changing climate. This analysis would be done through comparing/contrasting the different systems being studied.

   Example questions appropriate to this theme include: What are the common mechanisms that control population dynamics and recruitment across/between regions in response to climate change? To what extent do frameworks like ecological theories or simulation modeling provide a basis for determining the differences and commonalities between the systems? What key environmental/ecosystem indicators emerge that can relate these findings to ecosystem-based management needs and do these have commonalities across regions?

3. Ecosystem structure and function: Taking the knowledge gained in U.S. GLOBEC about target species' physiology, behavior and population dynamics, the third theme seeks to better understand ecosystem response to climate change, particularly in connection with other, anthropogenic forcing. This activity should provide guidance on how to assess ecosystem level questions using GLOBEC concepts, methods and/or data, and on further implications for the management of marine resources in a changing climate.

   Example questions appropriate to this theme include: What is the role of individual species dynamics in determining ecosystem and food web dynamics? How has climate forcing altered ecosystem structure and function across regions? What are the characteristics that contribute to the resilience and sensitivity of ecosystems? To what extent does the strength of climate effects in systems result from different anthropogenic/historical effects? How does climate change impact the range and distribution of predators and their impacts on ecosystems?

B. Research approaches

This phase of the U.S. GLOBEC program will emphasize synthesis across the U.S. GLOBEC study regions, as well as the comparison with other systems worldwide. The intent is to coordinate activities that collectively address the program goals stated above. Examples of appropriate approaches to be applied are described below. It is anticipated that proposed work may utilize more than one of these approaches.

1. Synthesis of Data Sets across U.S. GLOBEC and other study regions:

   Answering the questions posed above will require a concerted effort to integrate the results of physical observations, estimates of *in situ* animal abundances, the condition and reproductive rates of plankton, and the distributions of predators. Data from multiple disciplines need to be integrated to enable inter-annual comparisons of population processes and their coupling to the physical structure and variability of the environment. Integration of data sets from the long-term observation program (LTOP), process and survey components of the regional programs, remote sensing data, retrospective data sets, and modeling analyses are critical in the development of multidisciplinary synthesis research efforts.

2. Physical/biological modeling:

   The development and use of conceptual and quantitative models to investigate physical and coupled physical/biological processes have been emphasized throughout the U.S. GLOBEC program. Circulation models have been used to explore the influence of wind forcing on alongshore and cross-shelf flow using realistic regional bathymetry and forcing. Ecosystem models have been developed to examine the specific contributions of multiple zooplankton grazers (micro, meso, and macro) to energy transfer from lower trophic levels to higher levels. In Pan-Regional Synthesis, these and other modeling approaches (including both prognostic and data-assimilative) will be encouraged, with the aim of comparing and contrasting responses to climate variability across system types. Effort is also encouraged on the further development of approaches that effectively couple the lower and upper trophic levels. Integration of models and modeling approaches that can be readily adapted and applied to different regions into a comprehensive "toolbox" will be an important activity for advancing and expanding GLOBEC modeling approaches to other areas. This effort will provide predictive tools for advancing understanding of climate-related changes to ecosystems, an important consideration in an ecosystem approach to management.

3. Comparative Regional Studies:

   This solicitation encourages comparative studies of broader nature, including other GLOBEC regions and non-GLOBEC-funded studies in similar shelf systems elsewhere. Comparative studies could include such topics as inter-ocean analyses of target zooplankton or predator taxa with other species having similar (or contrasting) life histories; comparative study of regional circulation and ecosystem responses to basin- and larger-scale climate influences; inter-ocean contrasts of the effects of wind and buoyancy forcing on near-shore retention and loss of pelagic organisms. Comparative studies could employ remote sensing and bio-physical models to analyze ecosystem responses to climate variability in different regions, or develop new indices and measures for comparison. In proposing to compare a U.S. GLOBEC study site to other regions, it is critical that the proposals clearly identify the processes and characteristics that will be better understood through generalizations to and/or contrasts with the other systems. By encouraging proposals that reach beyond the three U.S. GLOBEC study sites, this solicitation does not downplay the value of studies that integrate the data sets, models and understanding gained entirely within U.S. GLOBEC.

4. Scientific development and evaluation of metrics to characterize environmental and ecosystem status and change.

   The more complete understanding of pan-regional ecosystem dynamics gained through the U.S. GLOBEC program should allow for the design of more efficient and more informative monitoring programs in the region. Achieving this improvement will involve determining indices (sets of key parameters) for the physical and lower trophic level system components that best characterize the status of the ecosystem, particularly in relation to potential higher trophic level production. Determining the optimal spatial and temporal scales for sampling and reporting of these key parameters will provide important information for transitioning GLOBEC monitoring activities to long-term monitoring programs. An important goal is for the indices to identify environmental influences on living marine resource variability (*e.g.*, cod and haddock, salmon, and krill) and protected species (*e.g.*, marine mammals) that can be incorporated into the assessment of the status of these resources and populations in the region. Indices may be derived from directly measured parameters (from field observations), remotely sensed parameters, or from output of specific configurations of coupled physical-biological models.

C. Coordination of Pan-Regional Synthesis and dissemination of results

As the culmination of U.S. GLOBEC, the two most important objectives for the Pan-Regional Synthesis program are first to achieve a comprehensive pan-regional synthesis, and second to disseminate the understanding and data/model products thus derived to the fullest extent, to the scientific community as well as to natural resource managers and lay people. The National Office for U.S. GLOBEC will help to coordinate inter-project communication and to facilitate dissemination activities. As part of its coordination activities, the National Office will host yearly (nominally, Fall 2007, 2008 and 2009) Pan-Regional Synthesis Workshops. The Second Pan-Regional Synthesis Workshop will be held the week of 24 September 2007, and will provide an opportunity for interested investigators to form partnerships prior to the submission deadline for this announcement. The Third and Fourth Pan-Regional Synthesis Workshops in 2008 and 2009 will provide an opportunity for communication and coordination among the projects funded under this announcement. Funded investigators will be expected to attend these two Workshops, with support for their participation provided by the National Office.

In addition to hosting the Pan-Regional Workshops, the National Office will request the active participation of Pan-Regional Synthesis investigators in efforts to hold symposia, to contribute to synthesis publications (*e.g.*, books), to transfer knowledge to fisheries managers, and to communicate to the public. Proposals are encouraged that include well-defined dissemination plans that leverage/form partnerships with established outreach programs (*e.g.*, NSF COSEE, NOAA Sea Grant College Programs, non-profit groups, *etc.*), and/or envision novel/integrative techniques to promote dissemination of Pan-Regional Synthesis results.

D. Who may apply

Proposals that undertake synthesis and integration of data sets across species or disciplinary boundaries are encouraged from single investigators as well as integrated multidisciplinary teams. Researchers from NOAA and/or other Federal agencies are eligible to participate as no-cost collaborators, but cannot be lead Principal Investigators. Participation of investigators new to the U.S. GLOBEC program is greatly encouraged. Normal NSF guidelines on eligibility apply as per the Grand Proposal Guide.