TAKING OCEAN RESEARCH RESULTS TO APPLICATIONS

EXAMPLES AND LESSONS FROM US GLOBEC

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Courtesy of Peter Wiebe, Woods Hole Oceanographic Institution

ABSTRACT. Researchers and funding agencies justify much oceanographic research by characterizing it as useful for better understanding ocean issues of interest to society at large. However, the direct transfer of ocean science to applications in the policy and management context remains a challenge. This paper explores how one large ocean science program, US Global Ocean Ecosystem Dynamics (US GLOBEC), has begun to take research results to applications in fisheries management, ocean observation systems, and applied ocean modeling. We review selected examples of this transition, and examine some characteristics of the program that have facilitated them. We also provide advice for future large oceanographic programs seeking to maximize the utility of their results.

INTRODUCTION

Ocean scientists have direct and personal interests in the preservation and sustainable use of our ocean environment and resources. Whereas early physical oceanographic studies had practical use for the Navy (Munk, 2008), basic oceanographic research has not always been conducted with regard to such benefits. However, now funding agencies are increasingly looking to the "broader impacts" of the research they fund, and almost every oceanographic proposal written contains some indication of potential societal relevance. A report by the Ocean Research and Resources Advisory Panel (ORRAP) of the Office of Science and Technology Policy notes that "America's investment in science and technology has generated a steady stream of new knowledge and technologies, but has failed to develop a network of institutional mechanisms that transition these advances to applications addressing major social and environmental problems" (ORRAP, 2007). The difficulty in translating ocean science results to societal applications has been attributed to differences in culture between scientists and managers, time constraints on both sides, lack of unambiguous scientific results, and difficulties in communication among scientists, managers, and policymakers (National Research Council, 1995).

In a larger sense, many authors have explored issues of disconnect between applied vs. basic research, or mission-driven vs. curiosity-driven research, since the landmark report by Vannevar Bush that led to the establishment of the National Science Foundation (Bush, 1945). Branscomb (1990) provided a useful distinction between research, which has uncertain outcomes and gives the practitioner a high degree of freedom, and development, which has constrained risks and is tightly coupled to a prescribed outcome and timetable. Stokes (1997) argued that the basic/applied dichotomy is too simplistic, and developed a conceptual framework that distinguished research activities among Bohr's Quadrant (searching for fundamental knowledge, with little emphasis on consideration of use), Edison's Quadrant (highly motivated by practical concerns, with little emphasis on exploring universal truths), and Pasteur's Quadrant (involving both practical uses and intellectual curiosity, exemplified by Pasteur's discoveries related to germ theory while investigating practical problems in beer brewing). Holton and Sonnert (1999) categorize Newtonian science (intellectual), Baconian science (practical), and Jeffersonian science (e.g., Jefferson's support of the Lewis and Clark expedition), which they define thus:

> *The specific research project is motivated by placing it in an area of basic scientific ignorance that seems to lie at the heart of a social problem. The main goal is to remove that basic ignorance in an uncharted area of science and thereby to attain knowledge that will have a fair probability—even if it is years distant—of being brought to bear on a persistent, debilitating national (or international) problem.*

We contend that US GLOBEC fits within the Jeffersonian research category. US GLOBEC responded to a lack of information about the dynamics of early life history stages of fish populations and how environmental variability influenced fish recruitment. This gap in understanding limited the ability of fishery managers to plan harvest strategies in a changing oceanic environment. The program was not designed to deliver specific tools for fisheries management, but to advance the science needed to develop those tools. Thus, US GLOBEC sought to respond to recommendations such as this one contained in Briscoe and Evans (1993):

> *[T]here is great merit in the agency telling the basic researcher what its problems are, so that whatever captures the researcher's fancy will have a better chance of actually being applied to the agency's problems. The point is not to require the basic researcher to do applied research, but rather to help the basic researcher do applicable research. The existence and nature of the applied problems can help to stimulate the researcher's curiosity.*

US GLOBEC was designed to examine the potential impact of global climate change and ocean variability on marine animal populations (Fogarty and Powell, 2002). The program has been conducted in phases since 1991 (Table 1), with regional programs in the Northwest Atlantic on Georges Bank, the Northeast Pacific in the northern California current and the coastal Gulf of Alaska, and the Southern Ocean around Marguerite Bay (Figure 1 and Table 2). Each regional study had a subsequent synthesis phase, and the program is currently in a pan-regional synthesis phase. Similar GLOBEC studies have been conducted by several other nations, as well as in a joint international program in the Southern Ocean, under the auspices of the GLOBEC International program.

The transition of results from US GLOBEC science to management use is not complete in most cases, yet information from US GLOBEC and other GLOBEC-like studies is available and used in formulating advice given to fishery management councils. US GLOBEC influence can be seen in the development of forecasts for fisheries management; the way that agencies monitor and assess ocean conditions; the development of regional, integrated ocean observation systems; and enhanced scientific capacity for coupled physical-biological modeling to predict ecological impacts of climate change.

HALLMARKS OF US GLOBEC THAT FACILITATED RESEARCH TRANSITION

Many of the successes in transitioning US GLOBEC research results have come about through the personal initiative of scientists involved in the program. Any transition activity takes time, patience, communication skills, and creativity, and these traits are certainly not unique to scientists involved in the GLOBEC program. Nevertheless, some characteristics of the US GLOBEC program have facilitated the transition of research results into application, including:

- Shared agency funding and academic-federal collaboration
- Long-range view and planning by a scientific steering committee accompanied by a long-term commitment of resources to advance the science and maintain observations
- An international program providing larger context for the national program

Joint Support and Academic-Federal Collaboration

US GLOBEC has been jointly supported by the National Science Foundation (NSF) and the National Oceanic and Atmospheric Administration (NOAA), with support coming from many divisions and line offices within the two agencies. This collaboration between NSF and NOAA resulted in participation by both academic scientists and scientists working in the federal government. Federal scientists often have a closer relationship with end users of the information derived from the research. This connection has proven to be a distinct advantage, with the academic side providing cutting-edge science, and the federal side facilitating communication and adoption of research advances. Management of US fisheries occurs through regional Fishery Management Councils (FMCs). Communication of research results to FMCs has been helped enormously through the direct involvement of NOAA National Marine Fisheries Service (NMFS) scientists in the US GLOBEC program. Many of these NMFS scientists are involved in providing ecosystem advice to FMCs on a regular basis. For instance, NMFS routinely provides FMCs with SAFE (Stock Assessment and Fishery Evaluation) reports, which contain information on the biological condition of stocks and the marine ecosystems in which they live. A specific program within NMFS for Fisheries and the Environment (FATE) was designed to take research results from fisheries oceanography research programs to

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Table 1. Phased timing of US GLOBEC regional research programs.

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<tr><td colspan="3" rowspan="4">Modeling and Retrospective</td><td colspan="7">Northwest Atlantic Field Program</td><td colspan="7">Northwest Atlantic Synthesis</td><td colspan="3" rowspan="4">Pan-Regional Synthesis</td></tr>
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Figure 1. US GLOBEC study areas. *From Fogarty and Powell, 2002, courtesy WHOI Graphics*

stock assessments and other applications in the agency. Many of the indices and models developed through GLOBEC and other research programs are refined and delivered to NMFS and FMCs through the FATE program. In addition, there is often direct communication between the GLOBEC/NMFS scientists and the regional FMC's Science and Statistical Committee.

Joint support and management of the program has not been without challenges. NSF, as a "basic" science agency, and NOAA, as a "mission-oriented" agency, had somewhat different expectations for program success. NOAA was driven more to emphasize research advances that related directly to its missions in fisheries and ocean management, while NSF viewed success through the program's wider influences on biological and physical oceanography and ocean modeling. NSF and NOAA have very different budgetary constraints and grants procedures. In many cases, collaborators on projects had different funding cycles, depending on whether their individual awards came from NSF or NOAA. This discrepancy created difficulties in coordinating research projects with several investigators. In addition, academic and federal scientists have different benchmarks for career success.

Because of these challenges, flexibility and good will on both sides was required. Yet, the advances that US GLOBEC has achieved would not have been possible without the close interaction of federal and academic scientists. The advantages of pooling agency efforts has been recognized nationally, and programs such as the National Oceanographic Partnership Program (see June 2009 special issue of *Oceanography*) and the National Science and Technology Council's Joint Subcommittee on Ocean Science and Technology are furthering and expanding interagency collaborative efforts.

Long-Range Planning and Funding

Since its inception, US GLOBEC has been guided by a Scientific Steering Committee (SSC), which convened planning workshops, developed science and implementation plans, and integrated

Table 2. Characteristics and target species for US GLOBEC study sites. *From US GLOBEC (2007)*

GLOBEC REGION	NORTHWEST ATLANTIC	NORTHEAST PACIFIC		SOUTHERN OCEAN
STUDY SITES	Georges Bank	N. California Current	Gulf of Alaska	Marguerite Bay
SYSTEM TYPE	Seasonally Stratified Bank	Eastern Boundary Current	Buoyancy-Driven Flow	Ice-dominated
TARGET ORGANISMS	Cod, Haddock, Copepods (*Calanus finmarchicus* and *Pseudocalanus* spp.)	Coho and Chinook Salmon, Krill (*Euphausia pacifica, Thyanoessa spinifera*), Copepod spp.	Pink Salmon, Krill (*Euphausia pacifica, Thyanoessa spinifera*), Copepods (*Neocalanus* spp.)	Krill (*Euphausia superba*), Penguins, Crabeater seals, Whales
IMPORTANT PHYSICAL PROCESSES	Stratification, Transport/Retention, Cross-Frontal Exchange	Stratification, Cross-Shelf Transport, Mesoscale Circulation, Upwelling	Stratification, Cross-Shelf Transport, Mesoscale Circulation, Downwelling	Stratification, Transport/Retention, Cross-Frontal Exchange, Cross-Shelf Transport, Sea Ice Dynamics, Mesoscale Circulation

the regional programs into a national strategy. SSC membership included federal and academic scientists with expertise in physical oceanography, marine ecology, population biology, numerical modeling, and fisheries oceanography and management. The SSC met semiannually during the active field years of the program, permitting direct and regular communication between the US GLOBEC science program and its program managers at NSF and NOAA about their expectations for application of research results.

By the time the US GLOBEC program ends in 2011, it will represent more than 20 years of effort in planning, implementing, and synthesizing results. Hundreds of scientists have been involved in the SSC, as funded researchers and as reviewers of proposals and research papers. This long-term funding base and wide visibility in the ocean science community creates an expectation that the research results will do more than just "sit on the shelf."

Because US GLOBEC sought to investigate the effects of environmental variability on ocean ecosystems, the time period of observations had to be long enough to at least resolve interannual variability (Table 1). Resources were dedicated to systematic long-term observations that could place process studies within the context of this variability.

In addition to supporting scientific activities over the long term, US GLOBEC had separate research phases devoted to integrating field data and developing models for specific regions, plus a final pan-regional synthesis to compare across regions and to draw out larger lessons by ecosystem comparisons (Table 1). In some cases, scientists involved in the field research were not necessarily the most appropriate people to take the larger-scale view demanded by synthesis. Separate calls for synthesis proposals permitted the addition of new investigators, who could take innovative approaches to analyzing and synthesizing US GLOBEC data. An example is the Bayesian analysis undertaken in the pan-regional phase by Ralph Milliff and colleagues (see http://www.usglobec.org/funded.php#Milliff for this project's abstract).

Long-term funding was important, allowing enough time for some scientific results to make it to management applications. Data require analysis to become information, which then requires synthesis to become knowledge (sensu Burnett et al., 2002). Taking these steps further, knowledge has to be evaluated in political and social contexts before it can inform action, which can then result in societal benefit. Although some research results can be put to use relatively rapidly, the majority pass through a longer process. This longer time frame can be especially true for ecosystem research, which by its nature is impacted by and impacts a large number of societal issues.

International Context

The GLOBEC International program has provided a wider forum for discussion and dissemination of US GLOBEC research results. It stimulated the international scientific collaboration necessary to examine large-scale issues involved in climate research. International science meetings permitted comparison and extension of national GLOBEC research to basin-scale understanding. Moreover, international bodies such as the International Council for the Exploration of the Sea (ICES) in the Atlantic, and its counterpart in the Pacific (North Pacific Marine Science Organization, or PICES [for "Pacific ICES"]), are conduits of information from ocean scientists to policymakers.

GLOBEC has been a major focus of ICES and PICES activities for the past decade, and GLOBEC scientists have been key players in writing scientific synthesis documents for these groups. An example is the PICES report on fisheries and ecosystem response to recent regime shifts (King, 2005). GLOBEC scientists also contributed greatly to the PICES ecosystem status report (PICES, 2004). These reports provided syntheses of existing information about North Pacific regime shifts, and discussions of how management agencies can incorporate ecosystem conditions into their stock assessments and decisions. International symposia sponsored by ICES and PICES include GLOBEC scientists as key experts on the effects of climate change on fish and fisheries, and allow their science results to be collated into advice to international bodies such as the Fisheries and Agriculture Organization of the United Nations.

EXAMPLES OF RESEARCH TRANSITIONS FROM US GLOBEC

Applications to Fisheries Management

Some of the earliest modeling work supported under US GLOBEC had a direct impact on the management of scallops on Georges Bank. A circulation model developed under the Northwest Atlantic/Georges Bank program (Tremblay et al., 1994; Naimie, 1996; Miller et al., 1998) was used to predict trajectories and settlement patterns of larval scallops. Through the collaborative efforts of NMFS, the University of Maryland, and Dartmouth College, these results were presented to the New England Fisheries Management Council in 1998, and to (then) Secretary of Commerce William M. Daley, to inform decisions on the reopening of closed areas of the bank to scalloping. Key locations within the existing closed areas were identified as important source areas for scallop larvae, including a designated Habitat Area of Particular Concern in Closed Area II (Figure 2). By demonstrating the importance of the closed area through model visualization, US GLOBEC was able to support maintaining the closure in this region.

More recently, analyses of ocean conditions and their impacts on zooplankton and salmon populations undertaken through GLOBEC (Peterson and Keister, 2003; Brodeur et al., 2007) allowed federal fisheries scientists to develop forecasts of coho and Chinook salmon returns using ecosystem-based indicators. With the support of the NMFS FATE program, the forecasts were made available on the Web site of the Northwest Fisheries Science Center, a partner in US GLOBEC research (Figure 3). Environmental factors were implicated as a cause of poor returns of salmon to California and Oregon, and the salmon forecasts were available to inform the Pacific Fishery Management Council's decision to close salmon fishing along the Oregon and California coasts in 2008 and 2009. This project is as an example of the often-long time lag between getting scientific results and applying those results to real problems. The forecast relies on information from many salmon research projects, including those supported by US GLOBEC field studies. The forecast itself was developed during the Northeast Pacific regional synthesis phase, and became available in late 2006. However, its application became more important when salmon returns were seen to decline in 2008. At least 10 years elapsed between the initiation of US GLOBEC research in the Northeast Pacific and the its application.

Although some research results have directly influenced management decisions, other advances have been incorporated into routine agency practices. Many of the long-term observations undertaken by US GLOBEC have influenced the way that fisheries management agencies at the federal and state levels obtain long-term observations to understand the ecosystem context for management.

When the GLOBEC science program ends, many of the long-time-series observations will continue through the support of federal and state agencies. For example, long-term US GLOBEC support was essential for establishing the Southeast Alaska Coastal Monitoring (SECM) project of NMFS Auke Bay Laboratories. SECM focuses on oceanographic and biological factors affecting the growth and survival of southeast Alaska juvenile pink and coho salmon entering the Gulf of Alaska (Orsi et al., 2000, 2006). Scientists from NMFS and the Alaska Department of Fish and Game (ADFG) are now using information from the monitoring program to develop prediction models for pink salmon returns to Southeast Alaska, and ADFG has incorporated SECM data into its current region-wide forecast (Figure 4).

Applications to Ocean Observing Networks

Long-term time series initiated, continued, or resumed by US GLOBEC are important for determining appropriate and cost-effective temporal and spatial scales for sampling within the Integrated Ocean Observing System,

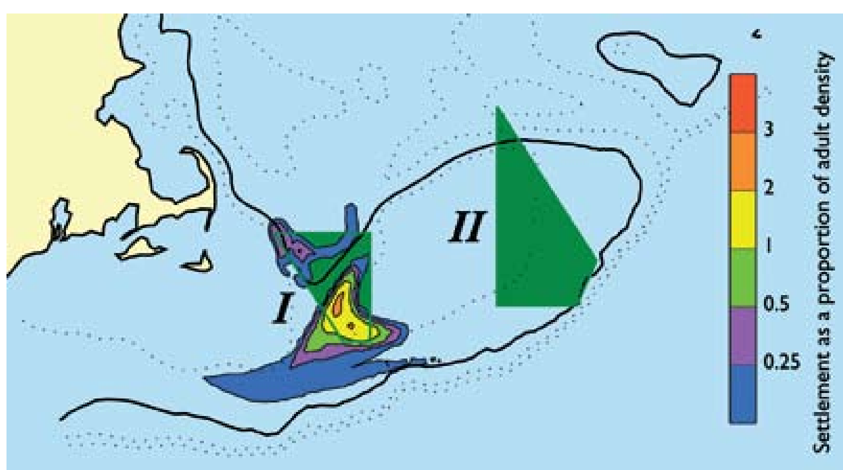

Figure 2. Map of percentage of larvae in a given region that were spawned in Closed Area II (from Fogarty and Botsford, 2007). Scallop settlement trajectories were presented to the Fisheries Management Council, and resulted in the continued closure of Area II.

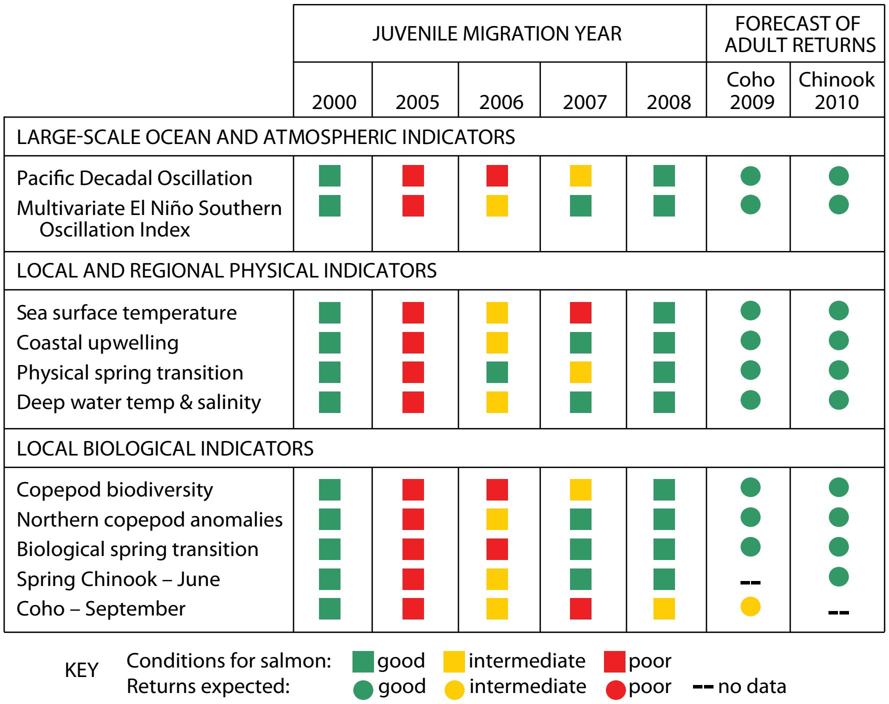

Figure 3. Ocean ecosystem indicators for salmon returns in the Northern California Current. Colored squares indicate positive (green), neutral (yellow), or negative (red) conditions for salmon entering the ocean each year. In the two columns to the far right, colored dots indicate the forecast of adult Coho and Chinook salmon returns in 2009, based on ocean conditions in 2008. The current salmon indicator matrix is available at: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/g-forecast.cfm. *Courtesy of Bill Peterson, National Marine Fisheries Service, Northwest Fisheries Science Center*

and for providing a historic foundation for comparison to current measurements in assessing long-term trends. These data sets provided foundations for the Gulf of Maine Ocean Observing System (GoMOOS), the Pacific Coast Ocean Observing System (PaCOOS), and the Alaska Ocean Observing System (AOOS). GLOBEC scientists serve on steering committees, science teams, and boards of governors for these emerging regional systems. Through their involvement in a long-term major oceanographic program such as US GLOBEC, these scientists are well qualified to assess ecosystem dynamics and the observations needed to analyze them.

Data management and accessibility is as important as data collection. As part of national steering committee activities, US GLOBEC has worked vigorously on data management issues, influencing the direction of data management for many large ocean research programs. All data collected during US GLOBEC studies are available through the US GLOBEC Web site (http://www.usglobec.org/data.php), and US GLOBEC developed a data policy (US GLOBEC, 1994) that has been a model for other large-scale research programs. GLOBEC support built on a foundation established by the Joint Global Ocean Flux Study to help establish the Biological and Chemical Oceanography Data Management Office (Groman et al., 2008), which supports the ocean research community through improved accessibility to ocean science data.

Applications to Multiscale Climate Modeling and Ecological Forecasting

The past two decades have brought unprecedented progress in our ability to model and to forecast marine systems. Although many research programs and funding sources have contributed to this progress, US GLOBEC has made unique contributions. In particular, GLOBEC provided a research context that encouraged an interdisciplinary approach to studying marine ecosystems, and thereby supported the development of a significant-sized community with new interdisciplinary skills. As a consequence, physical-biological research advanced much faster and in a more coordinated manner than it would have otherwise.

Owing to the program's focus on the regional impacts of climate variability on marine processes and populations, GLOBEC scientists have had to contend with two essential and substantial modeling challenges: first, how to bridge the enormous range of spatial and temporal scales separating global climate from regional marine responses, and second, how to formulate coupled physical-ecosystem models capable of predictive application.

The ultimate objective of US GLOBEC research is to understand and predict the effects of climate change and variability on the structure and dynamics of marine ecosystems and fishery production. The prediction of these ecological climate impacts will eventually require that the regional coupled modeling capabilities developed within US GLOBEC, and other programs, be successfully linked within operational global climate models (Mantua et al., 2002). This "downscaling" is necessary because global climate

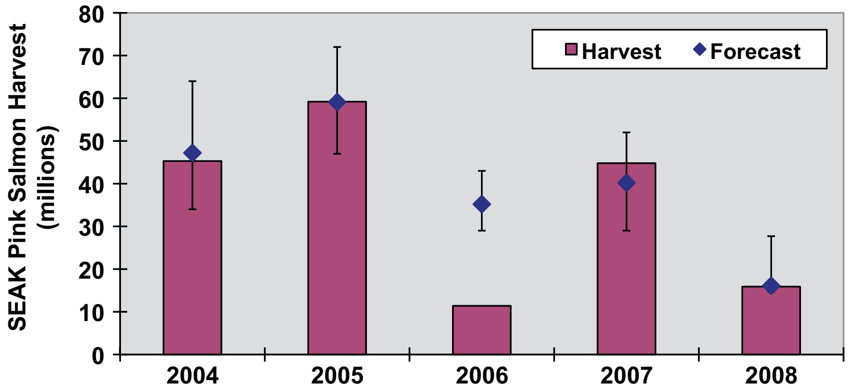

Figure 4. Forecast of adult pink salmon returns to Southeast Alaska (blue diamonds) compared to actual returns (purple bars). Pink salmon forecast available at http://www.afsc.noaa.gov/ABL/MSI/msi_sae_psf.htm. *Courtesy of Alex Wertheimer, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory.*

models do not have the spatial resolution necessary to properly represent processes (both physical and biological) crucial to ecosystem dynamics on a regional level.

An effort to develop such a regional downscaling capability is presently well advanced at the National Center for Atmospheric Research (NCAR). The approach has been to embed the Regional Ocean Modeling System (ROMS) developed within US GLOBEC, and other programs, within the NCAR Community Climate System Model (CCSM). In large measure due to the efforts of US GLOBEC investigators, the ROMS system now incorporates multiple options for ecosystem studies (nutrients-phytoplankton-zooplankton-detritus [NPZD]-type models; e.g., North Pacific Ecosystem Model for Understanding Regional Oceanography [NEMURO]), thus accommodating a range of complexities, as well as bio-energetic models. Individual-based models for higher trophic levels are also currently available within ROMS. The incorporation of ROMS within the CCSM framework thus offers immediate opportunities for regional downscaling of climate scenarios with the explicit inclusion of ecosystem dynamics, realizing a major goal of the GLOBEC program.

US GLOBEC and GLOBEC International have been major sources of funding for the development and use of coupled physical-ecological models to provide predictive capabilities for ocean ecosystems. The concept of ecological forecasting advocates for the use of these coupled models to support ecosystem-based management of the ocean (Clark et al., 2001; Valette-Silver and Scavia, 2003; Murawski and Matlock, 2006; NSTC, 2007). GLOBEC has advanced ecological forecasting approaches in relation to fisheries and protected species management. As an example, GLOBEC scientists identified links among atmospheric conditions, deep-water temperatures in the Gulf of Maine, and the abundance of the Gulf's dominant zooplankton species, *Calanus finmarchicus* (Greene and Pershing, 2004). As an outgrowth of this research, the Gulf of Maine Ocean Observing System (GoMOOS) developed an operational system that predicts ocean temperatures and forecasts *Calanus* abundance (http://www.gomoos.org/environmentalprediction/). Because *Calanus* serves as a dominant food source for right whales, the number of right whale births can also be predicted. Right whales are critically endangered, so being able to better predict the number of calves can assist in protection and recovery efforts for this iconic species.

LESSONS LEARNED

GLOBEC helped plant the seeds from which we expect important scientific developments to grow. It has influenced many subsequent programs such as FATE and CAMEO (Comparative Analysis of Marine Ecosystem Organization) in the United States, and international programs such as Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) and Basin-Scale Analysis, Synthesis, and Integration (BASIN). These programs can take advantage of what was learned through US GLOBEC.

As noted, US GLOBEC was designed as a research program to provide understanding, but not explicitly to deliver specific products for management. That so many applications have resulted from the program so far is a credit to the quality and relevance of the science and the enthusiasm of the scientists involved. Dedicated funding for syntheses allowed many GLOBEC scientific advances to mature and move into use in NOAA (e.g., the indicator-based salmon forecast) and other operational venues (e.g., the right whale forecast through GoMOOS). This separate synthesis phase was very important—but is probably not sufficient for full transition. In the future, to maximize utility of research results, large ocean research programs should consider setting aside specific sources of funding for transition activities, and bring science translators and facilitators into their programs (ORRAP, 2007).

Through the participation of NOAA scientists and the guidance of SSC, US GLOBEC was able to incorporate agency science needs into program planning. But US GLOBEC never explicitly incorporated the idea of developing research "products" into its program planning (ORRAP, 2007). Scientists had to reach a level of understanding of the systems before they could think about how that understanding could be translated in useful ways for management purposes. Perhaps future programs will be able to set more explicit pragmatic goals as well as achieve improved scientific understanding. Certainly, some newer research programs that have been informed by GLOBEC, such as FATE and CAMEO, have incorporated these aspects into program planning. One important issue to consider is matching the scale of the science to the scale of applications. GLOBEC science was done on a regional ecosystem scale before there was any federal mandate to manage in an ecosystem context. Most FMCs are just beginning to grapple with their own transition from single-species management to ecosystem-based approaches. We hope and expect that results from US GLOBEC will continue to stimulate this transition.

Another aspect to consider in future research planning is including social sciences with natural sciences (Smith, 2002; Cheong, 2008). GLOBEC International examined interactions between natural and social systems in a changing climate (Perry and Ommer, 2003), but these activities came at the end of the international program rather than being integrated from the beginning. GLOBEC advanced integration of physical and ecological studies over the past 20 years, and was part of a profound cultural change in the ocean sciences (Powell, 2008), but it did not fully succeed in integrating social sciences. Future programs stand at the cusp of a new scientific culture and should seek to better integrate social and natural sciences.

Finally, the participation of both NSF and NOAA was crucial to the success of US GLOBEC. Interagency programs being developed now as a result of the "Ocean Research Priorities Plan" (NSTC, 2007), such as CAMEO, can build on that success. They would benefit from more explicit definition of what each agency expects from these programs and a clear strategy to reconcile any differences in these expectations.

US GLOBEC PROGRAM LEGACY

GLOBEC influence will continue long after the program officially ends. The comprehensive data sets collected will be analyzed for years to come, will provide a basis for multidisciplinary integration and synthesis of ocean patterns and processes, and will form a foundation for future ocean science. Modeling techniques developed during GLOBEC can be used to plan and evaluate the design of ocean observing systems. The combined use of these models and observing systems will serve as tools for ecosystem-based management of the nation's precious ocean and coastal resources.

Just as important is the human capital developed through GLOBEC. Hundreds of graduate students and postdoctoral scholars received training and support through GLOBEC projects. Some of these scientists are now employed by research institutions and federal laboratories, and will become tomorrow's leaders of oceanographic research. An important legacy of the US GLOBEC program is that these scientists of tomorrow will be trained in observational and modeling techniques that will enable them to make progress on the grand challenges of ocean science, and increase the understanding necessary to sustain and protect our nation's marine resources.

Transitioning results from a research program into products useful for management purposes is never easy, nor is it swift. Certain GLOBEC results are making the transition due to the involvement of agency scientists in the research, broad oversight of the program by a standing body of advisors, international collaborations, long-term commitment of resources by partner agencies, and the personal initiative and dedication of the scientists involved in the program. Future ocean ecosystem programs should plan for research transition as early as practical in the program by involving users of the information in program planning and implementation, including social science considerations into their overall science planning, and devoting a portion of direct funding for synthesis and transition of the science results.

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