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

# U.S. GLOBEC NEWS

Number 14 September 1999

## Physical Oceanography: GLOBEC's LTOP in the NEP

*by Robert Smith, Michael Kosro, Adriana Huyer and Jack Barth*

Regular sampling of the marine ecosystem off Oregon under the pilot GLOBEC Northeast Pacific Long-Term Observation Program (LTOP) began in November 1997. The cornerstone of this monitoring effort is a section, extending due west from Newport, Oregon along latitude 44.6 N for 160 km, with a historical data base from 1961. As a result of the prompt detection of a major El Niño in the spring of 1997, and with the help of colleagues, we were able to "jump-start"observations (CTD casts and ADCP profiles) along this section in July 1997. By July 1999, we had made 12 cruises, most of which also included sections off southern Oregon and northern California

A compact overview of our observations of the evolution of El Niño is provided by profiles of the dynamic height of the sea surface extending offshore from Newport along the east-west section (Figure 1). The variations in dynamic (steric) height represent the variation in sea level due to density differences integrated over the upper 500 m of the water column; the dynamic height has been extrapolated into shallower water by the method of Reid and Mantyla (1976; JGR 81:3100). The slope of the sea surface across the east-west section is proportional to the north-south (along coast) geostrophic current at the surface; the steeper the slope up (down) toward the coast, the faster the northward (southward) current. Changes in dynamic height at a location indicate changes in temperature and salinity of the underlying water. The historical data base contains at least six sections for each month during 1962-1971, allowing us to compare our observations (thick lines) with the mean during "normal" times (thin lines). The monthly sea level anomalies measured at the coast (from tide guage at 42N) were above normal from May 1997 to July 1998, with maximum anomalies of 15 and 16 cm in November 1997 and February 1998, in very good agreement with those inferred from our dynamic height computations.

The surface layer off Oregon was already warmer than normal when we began in July 1997; the largest anomalies (>4C) were more than 60 km offshore, but upwelling had been occurring and the southward currents were typical for the upwelling season. In September 1997, the largest anomalies were inshore 60 km and the surface layer was everywhere warm (>17C); the sea surface sloped up toward the coast indicating northward current. In November 1997 the subsurface waters over the slope were even warmer than in September and the steric height rose steeply toward the shore over 60 km, indicating strong northward flow over the shelf and slope. Sections were also made at several latitudes between Newport and San Francisco in November 1997; these sections all showed the steric height of the sea surface rising steeply toward shore (~20 cm in ~60 km), giving a northward geostrophic current of about 30 cm/sec along the continental margin. The directly measured currents from the acoustic Doppler profiler showed the

*(Cont. on page 2)*

***Editor's note:*** *This is the first of three articles in this issue that are related to GLOBEC studies in the Northeast Pacific. The others begin on pages five and seven.*

### *In this issue...*

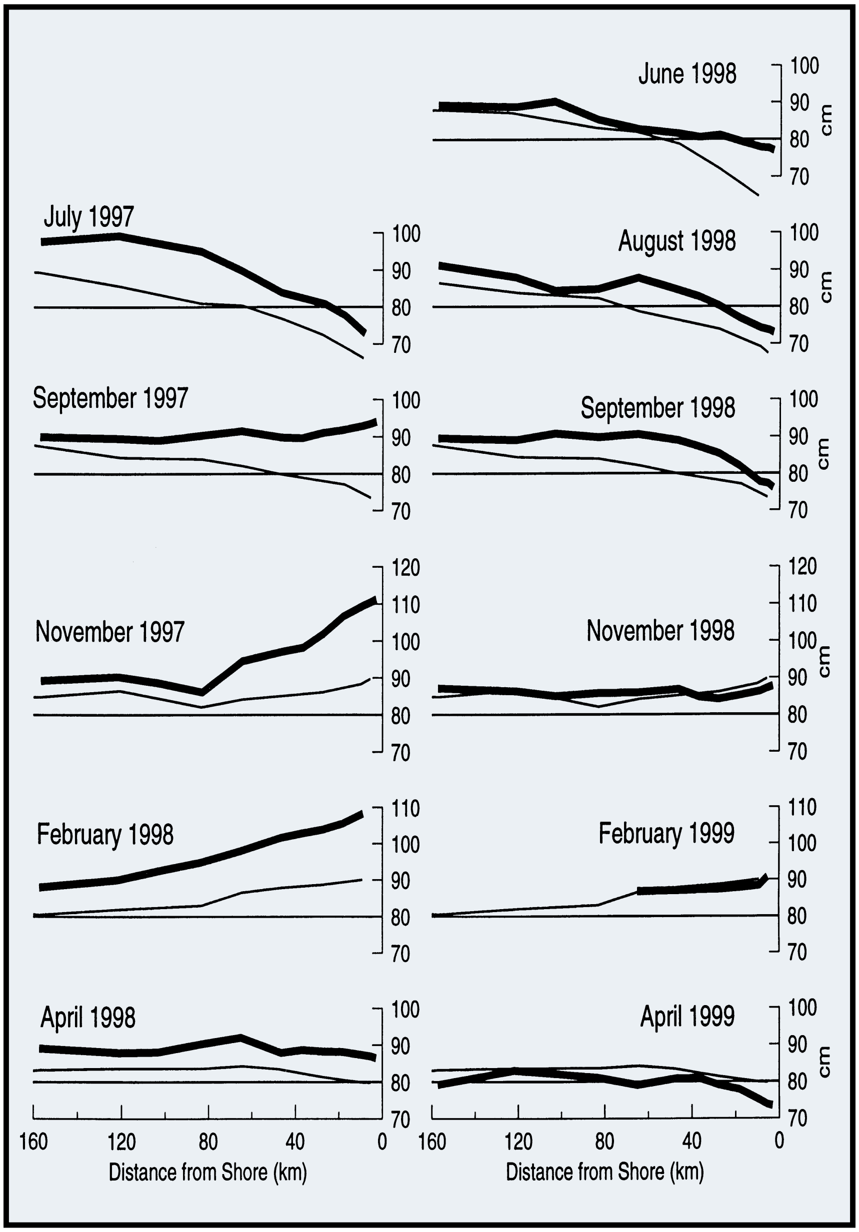


*Figure 1: Offshore profiles of the steric height of the sea surface relative to 500dbar, off Newport, Oregon. Heavy lines were observed during the indicated month; thin lines represent the long term average (1961-1971) for the same month.*

northward flow extending to at least 500 m depth and from at least 38.5 N off California to Newport at 44.6 N (Figure 2). This northward flow maintained the relatively warm ocean temperatures through the Winter of 1997-8.

El Niño conditions continued in the eastern tropical Pacific into early May 1998 and upwelling favorable winds returned to Oregon in June, but subsurface waters off Oregon remained anomalously warm through September 1998. "Normal" conditions were observed in November 1998 - and El Niño was over. The April temperature sections (Figure 3, pg. 3) tell the story and provide the clearest contrast: April 1998 closely resembled April 1983, the year of the previous major El Niño, and both were considerably warmer than April 1999, which resembles the mean of seven Aprils during 1962-1971. Cruises from July, September and November 1999 will help to answer: What will La Niña bring?

Finally, one may ask whether the section off Newport really is "connected" to the larger California Current. To elucidate the connection we deployed satellite-tracked drifters (drogue at 15 m) on the January, April, June, August and September 1998 cruises. The drifters were released between 18 and 120 km from the

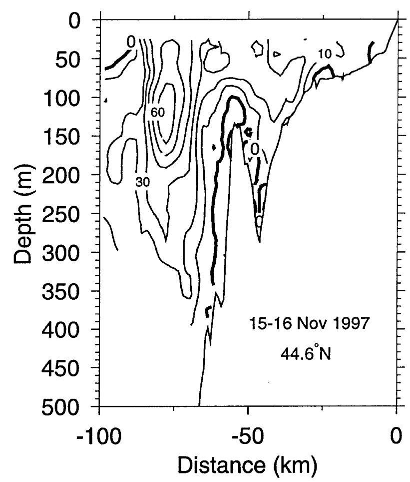


*Figure 2: Shipboard acoustic Doppler measured northward currents over the continental margin in November 1987 off Newport, Oregon (44.6N).*

coast; trajectories of the drifters from their release until Spring 1999 are shown in Figure 4 (pg. 4). The eight drifters released off Newport in January 1998 initially moved coherently to the north, with strongest northward flow (60 cm/sec) near the continental shelf break, consistent with the ADCP measurements and geostrophic current estimates during Winter 1997-8. Five of these drifters eventually beached between 47 and 56 N, two not until September 1998 and January 1999; the other three

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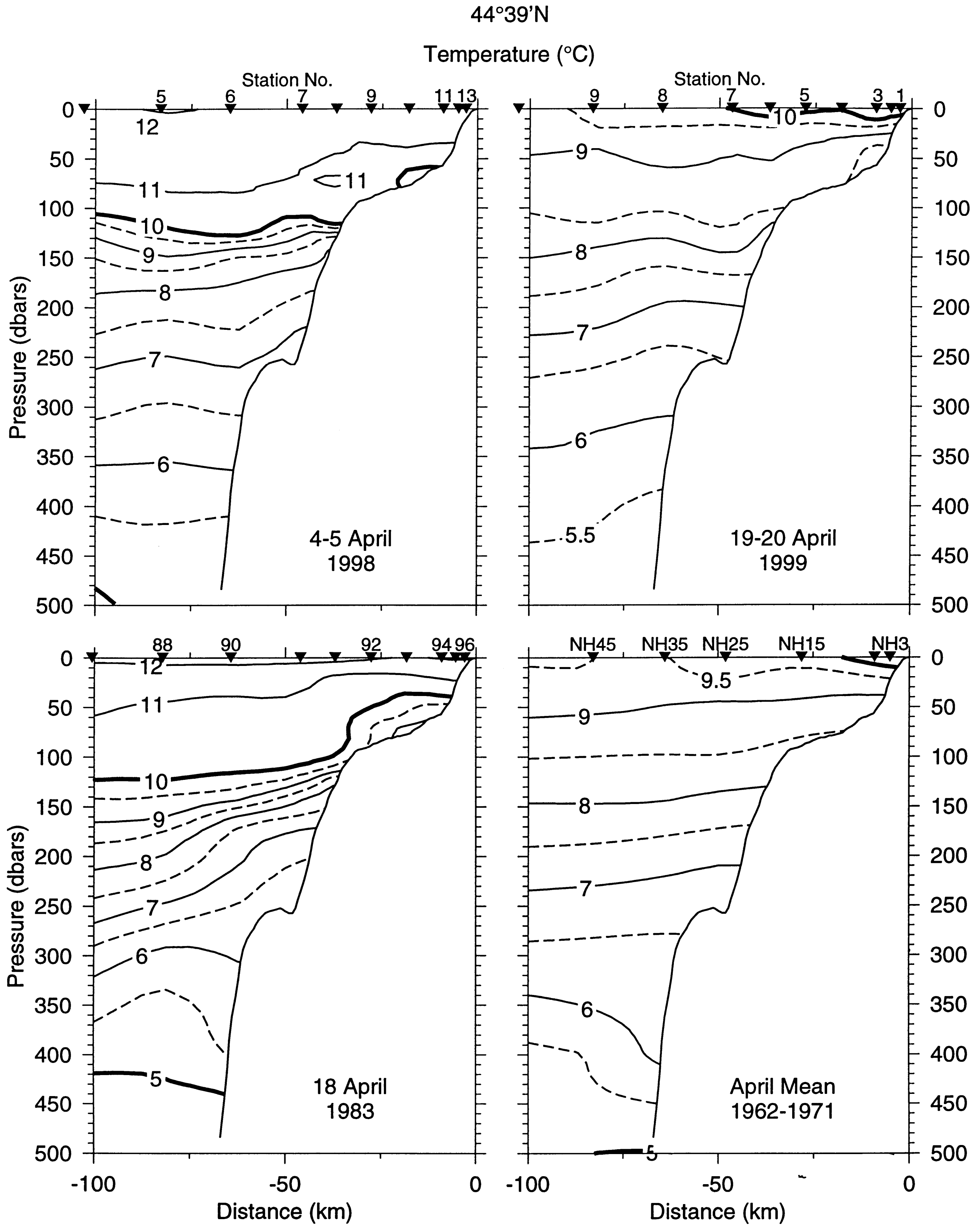


*Figure 3: Temperatures over the continental margin off Newport, Oregon observed in April 1998 (El Niño), 1999, 1983 (El Niño) and the historical average (1962-1971).*

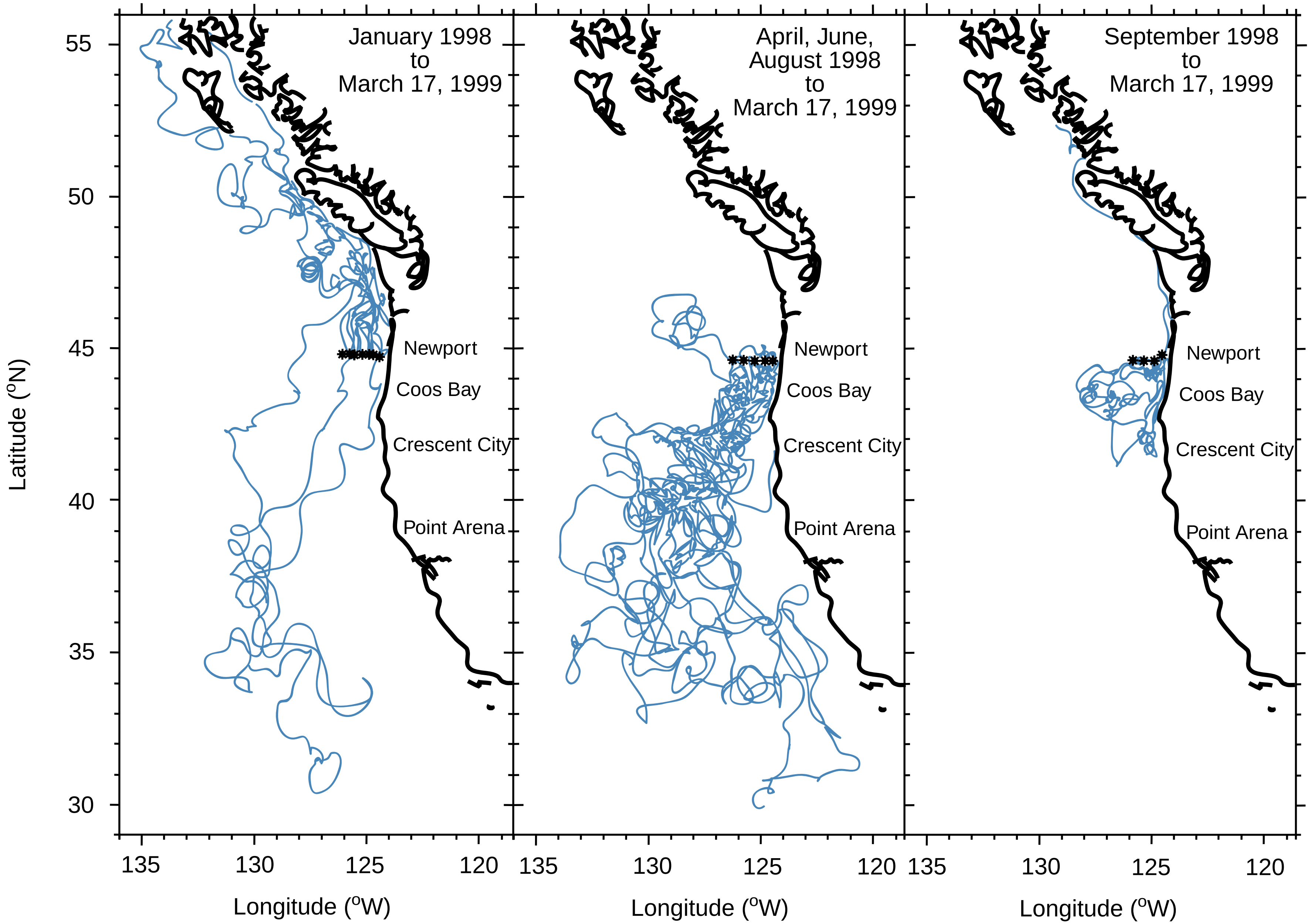


*Figure 4: Trajectories of satellite-tracked WOCE-type drifters deployed off Newport, Oregon in January 1998 (left panel); April, June, and August 1998 (center panel); and late September 1998 (right panel).*

*NEP Posts—(Cont. from page 2)*

turned southward in spring and were south of 35 N in March 1999. Some of the drifters released in April initially moved northward, but from then through September 1998 most drifters moved southward and offshore, delineating the meandering jets of the California Current. By October, some drifters from the January, April, June and August releases were between 35 and 39 N. The drifters released in late September 1998 initially moved offshore and southward but, with the onset of fall storms, moved back toward the coast and all eventually beached; the last came onto the continental shelf in severe storms during February 1999 near 43.5 N and moved northward over the mid- and inner-shelf for more than 100 km before beaching near 44.5 and 46.5 N. The drifter observations in 1998 were consistent with the limited previous drifter studies in 1994 and 1995 (Barth and Smith, 1998; S. Afr. J. mar. Sci. 19:5-14). Drifters released over the continental margin off Oregon during the upwelling season (April-September) move offshore and southward into the California Current, but drifters released too late to move south of about 40 N before fall and winter storms eventually reach the beaches of Oregon, Washington, and British Columbia.

For a more complete discussion and figures, see the *Monitoring the Coastal Ocean off Oregon: El Niño and beyond* web site: http://www.oce.orst.edu/po/coastal.html

The GLOBEC-processed CTD files are on our public ftp site. The ftp site address is ftp.oce.orst.edu (login as anonymous, with your email address as your password), then cd to /dist/globec/ -- the files are under their respective cruise names. The contact is Jane Fleischbein (flei@oce.orst.edu).

**RS/et al**

# Changes in Zooplankton Abundance and Species Composition in the Oregon Coastal Zone

*by Bill Peterson and Julie Keister*

Zooplankton abundance and species composition mirrored the physical observations discussed by Smith et al. The two copepod species which are most abundant in the Oregon upwelling zone, *Pseudocalanus mimus* and *Calanus marshallae*, began to decline in numbers commensurate with the positive sea level anomalies in May 1997. Numbers remained low throughout that summer. The populations did not begin to increase until the following summer, in August 1998, when sea level returned to normal (Figure 1, pg. 6, *Pseudocalanus mimus*). Thus, densities of the common coastal copepod species were anomalously low during both the summers of 1997 and 1998. We attribute reduced numbers in 1997 to a combination of reduced upwelling and reduced secondary production. The failure of the populations to respond in 1998 may have been due to very low initial numbers in spring caused by removal of most individuals from the coastal zone by strong northward transport that persisted through the winter and spring of 1997/98. We hypothesize that when normal transport patterns were established in summer 1998, then members of the *P. mimus* and *C. marshallae* populations were returned to the Oregon upwelling zone and began to increase in numbers.

The El Niño also resulted in the appearance of a large variety of zooplankton species that ordinarily reside well offshore of Oregon and/or to the south. Copepods that became common in the coastal zone during the 15-month El Niño of 1997/98 included *Calanus pacificus*, *Eucalanus californicus*, *Mesocalanus tenuicornis*, *Clausocalanus paululus* and *parapergens*, *Ctenocalanus vanus*, *Paracalanus parvus* and *Calocalanus styliremis*. Unusual mollusks included *Corolla spectabilis* and *Carinaria.* Perhaps the most striking differences were seen in the euphausiid species complex: the coastal species *Nyctiphanes simplex,* which is common off southern and Baja California, appeared commonly in plankton samples collected between January and September 1998. This species was also common off Oregon during the 1982-83 El Niño. Three other euphausiid species were collected that have NEVER been reported for coastal or oceanic waters off Oregon — *Euphausia recurva*, *E. mutica* and *E. gibboides*. These species are usually restricted to the northern portion of the north Pacific Central gyre and to a zone several hundred miles offshore in the California Current south of 40 N.

All of these observations indicate (a) reduced production during the summer of 1997 and (b) strong poleward and/or onshore flows during autumn-spring 1997/98 which transported the common species out of the area (and to the north?) and offshore and southern oceanic species into the area. See Gomez-Gutierrez and Peterson (1999) for a description of how anomalous conditions during the summer of 1997 affected copepod egg production.

*Literature Cited:*

*Gomez-Gutierrez, J. and W. T. Peterson. 1999. Egg production rates of eight calanoid copepod species during the summer of 1997 off Newport, Oregon, USA. J. Plankton Res. 21:637-657.*

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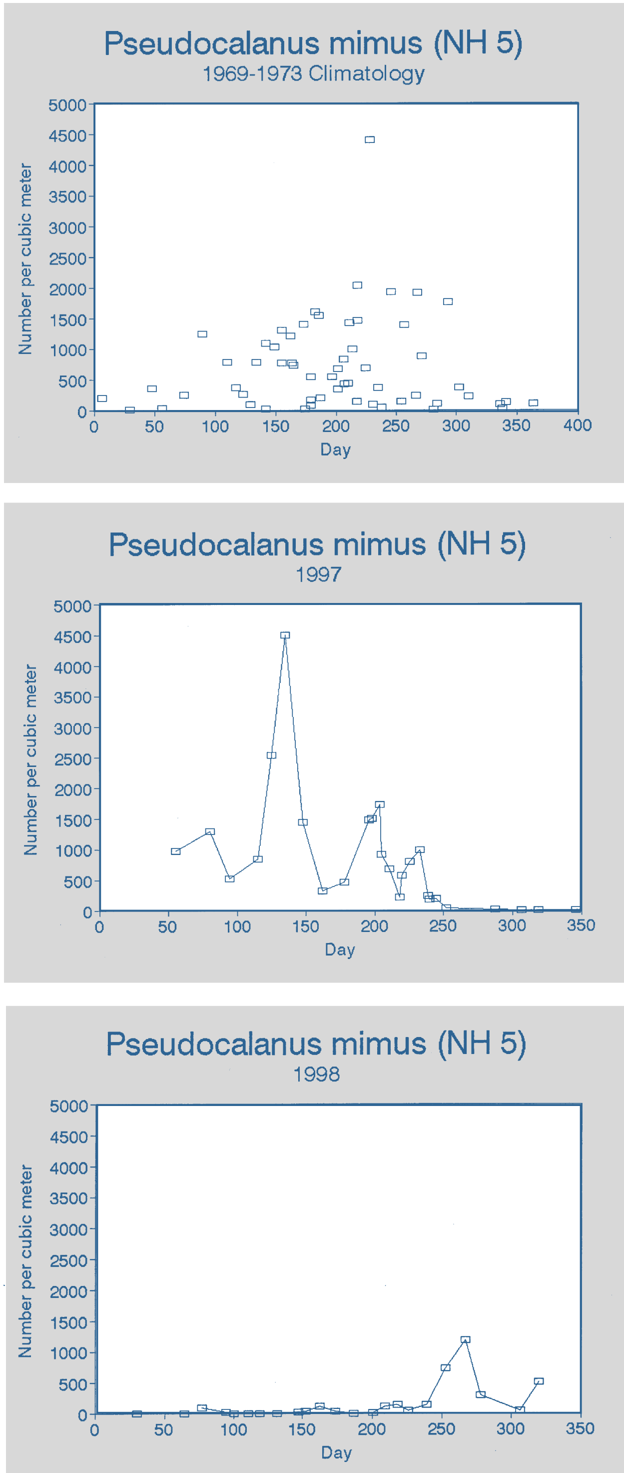


*Figure 1: Density of the* <u>*Pseudocalanus mimus*</u> *population at a station five miles off Newport, OR, in 1997 and 1998, compared to a five-year climatology. In a "normal" year, numbers of 2000 per cubic meter can be expected anytime between June and September (day 150-273).*

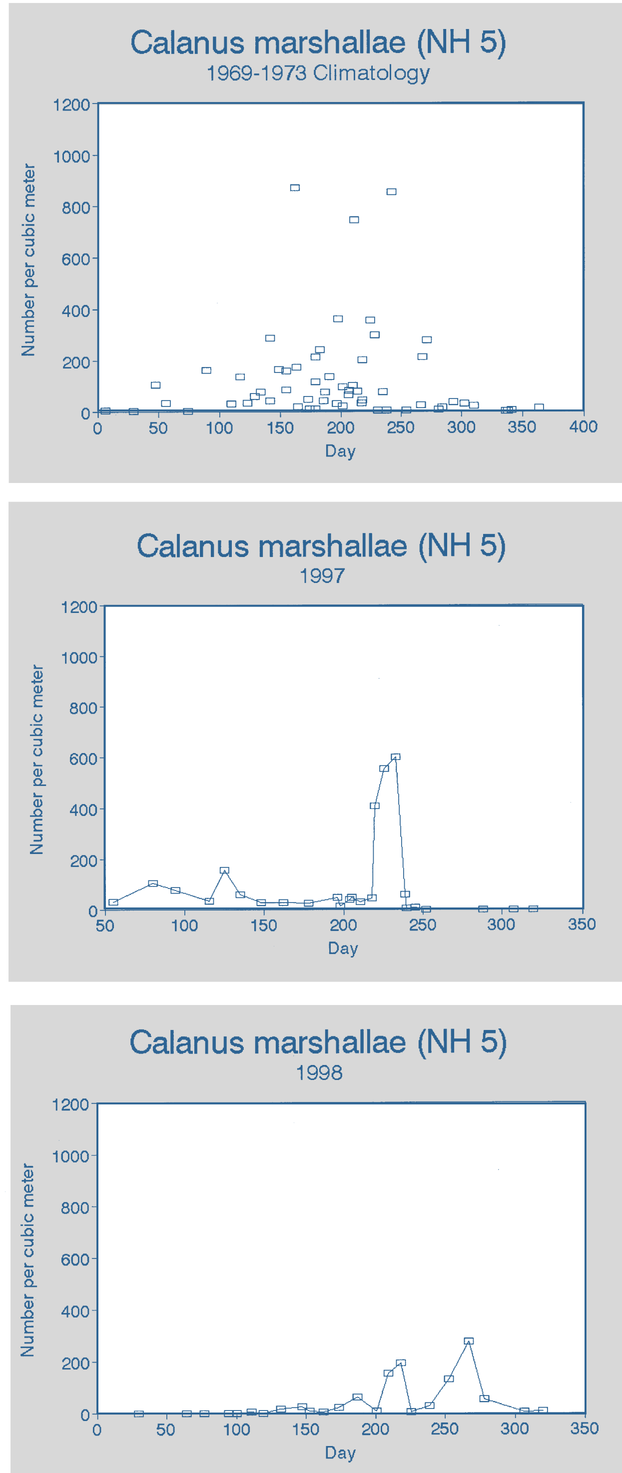


*Figure 2: Density of the* <u>*Calanus marshallae*</u> *population at a station five miles off Newport, OR, in 1997 and 1998 compared to a five-year climatology. In a "normal" year, numbers of 200-400 per cubic meter can be expected anytime between April and September.*

# Effects of the 1997-98 El Nino on Marine Nekton Off Oregon

*by William G. Pearcy*

The 1997-98 El Niño, like the 1982-83 event, was a very strong El Niño. Both of these El Niños had dramatic effects on the physical oceanography and biology along the Oregon coast, but the biological response to the 1997-98 event was very different from the earlier El Niño.

During the late summer and fall of 1997, warm-water, oceanic fishes were commonly caught or sighted off the Oregon coast. The first record was of a dorado, *Coryphaena hippurus*, in late July, followed by yellowtail, *Seriola lalandi*, and yellowfin tuna, *Thunnus albacares*, and striped marlin, *Tetrapturus audux*, in September. In addition, albacore, *Thunnus alalunga*, were caught in commercial quantities in the warm water very close to shore, and some individuals were exceptionally large, over 50 pounds. Pacific markerel (*Scomber japonicus*) and jack mackerel (*Trachurus symmetricus*) were other warm water species found close to shore and even in estuaries along the coast. All of these fishes are strong migrators that are usually associated with warm surface waters.

The most unusual nektonic animal that invaded Oregon waters was the jumbo squid, *Dosidicus gigas.* This large, voracious squid has been reported off California during previous large El Niños, but this is the first record as far north as Oregon. It was so common off Oregon during September through December of 1997, that commercial trawlers were targeting it for a lucrative squid market in southern California.

Except for a striped marlin, epipelagic nekton were not reported during 1998. Instead, several species of coastal and demersal fishes were caught from April through June. These species included the lumptail searobin, *Prionotus stephanophyrs*, the popeye catalufa, *Pseudopriacanthus serrula*, and the California barracuda, *Sphyraena argentea*.

Based on these observations of nektonic animals, the influx of large oceanic fishes and squid from July through September 1997 was related to the advection of warm oceanic waters from offshore due to atmospheric forcing rather than coastally-trapped Kelvin waves along the coast, which did not arrive until later in the year, as indicated by the deep pool of warm water and northward advection (see Smith et al., this issue). The coastal and benthic fishes found in 1998, as well as the occurrence of the euphausiid, *Nyctiphanes simplex* (see Peterson this issue), however, could be the result of coastal transport from California waters.

These observations for the 1997-98 El Niño are quite different than those for the 1982-83 event. During 1982-83 most of the unusual animals, including eight of nine range extensions, were for coastal, epibenthic animals presumably transported by coastal currents from the south (Pearcy and Schoener 1987). In contrast, in 1997-98 most of the unusual sightings were of large migratory, offshore, epipelagic animals that moved into coastal waters that were exceptionally warm because of onshore transport and lack of effective coastal upwelling.

During the 1983 El Niño, unprecedented mortality of coho salmon occurred off Oregon and California, and the mean size of adult salmon was markedly reduced. Such dramatic changes were not obvious during 1998. Ocean survival of hatchery coho salmon from Oregon has been very

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# GLOBEC Studies in the Coastal Gulf of Alaska

*By Hal Batchelder*

The U.S. GLOBEC Northeast Pacific Program (NEP) comprises subprograms in the California Current System (CCS) and in Coastal Gulf of Alaska (CGOA). The question of phase relationships between the production of marine populations in the CCS and CGOA in relation to climatic forcing is central to the NEP efforts. The NEP program emphasizes studies on the biology and ecology of juvenile salmon, the dominant euphausiids, several large copepods, and forage fish (salmon prey) in coastal regions of the North Pacific; and how these populations are controlled by physical and biological processes at large- to meso-scales. Process-oriented studies are slated to begin in 2000 in the California Current System (see U.S. GLOBEC News Number 13). Process studies in the Coastal Gulf of Alaska are planned to start in 2001. Here, the overall goals of the Coastal Gulf of Alaska studies are described. An announcement of opportunity for U.S. GLOBEC studies in the CGOA will be released this fall.

The Northeast Pacific CGOA study will focus on the continental shelf, but where appropriate, also encompasses the processes and phenomena of the larger oceanic boundary region that affect the CGOA. Process studies in 2001 and 2003 will focus on the effects of nearshore transports and cross-shelf exchange on the population dynamics of the target organisms in the northern Gulf of Alaska. Emphasis is on understanding the conditions that favor rapid growth and survival of juvenile pink salmon, so will involve examining both bottom up (productivity) and top-down (predation) processes. Where feasible (where timing and geography overlap), parts of the field and LTOP programs may be carried out in coordination with other research programs in the region. Links to other programs currently underway with important connections to GLOBEC goals and objectives are provided in the accompanying box on this page.

U.S. GLOBEC research in the NEP began in 1997, with integrated, multi-investigator, interdisciplinary programs of modeling, retrospective analysis, and pilot-scale monitoring (henceforth referred to as the Long-Term Observation Program or LTOP). Synthesis and new understanding of the large-scale and meso-scale forcing and responses in the NEP ecosystem will require integration of observations, models, and field experiments from the CCS and CGOA, and the design of observational programs, experiments and process studies that will enable such comparisons between these two ecosystems of the NEP is critical to the success of the overall program.

Ultimately, the U.S. GLOBEC effort in the Northeast Pacific has an overall goal of improving predictability and management of living marine resources of the region through improved understanding of ecosystem interactions and the coupling between the physical environment and the living resources.

***U.S. GLOBEC and Related Programs in the North Pacific***

1) the GLOBEC NEP web site is: http://www.usglobec.berkeley.edu/nep/index/html

2) the Pacific component of Canada GLOBEC (project descriptions available at http://www.globec-canada.mun.ca/globec/projects/index.html);

3) the Ocean Carrying Capacity program (http://www.afsc.noaa.gov/abl/OCC/ablocc.htm) of the National Marine Fisheries Service and the North Pacific Anadromous Fisheries Commission;

4) the Fisheries Oceanography Coordinated Investigations (FOCI) (http://www.pmel.noaa.gov/foci/);

5) the North Pacific Marine Science Organization (PICES) Climate Change and Carrying Capacity (CCCC) Program (http://pices.ios.bc.ca/cccc/ccccf.htm)

6) the Exxon Valdez Oil Spill (EVOS) Trustee Council (http://www.oilspill.state.ak.us/exxon.html) and SEA Program (http://www.pwssc.gen.ak.us/sea/sea.html).

## Program Goals:

The over-arching goals of the Northeast Pacific studies are:

*(a) To determine how biological processes and characteristics of zooplankton populations are affected by mesoscale features and dynamics in the Northeast Pacific;* and

*(b) To quantify the biological and physical processes that determine growth and survival of juvenile salmon in the coastal zone.*

Within the overall goals outlined above, the NE Pacific/CGOA process-oriented field program has four general goals:

*(l) To determine how changing climate, especially its impacts on local wind forcing, freshwater runoff, mixed layer depth, and basin-scale currents, affect spatial and temporal variability in mesoscale circulation and vertical stratification.*

*(2) To quantify how physical features in the Coastal Gulf of Alaska impact zooplankton biomass, production, distribution, and the retention and exchange of zooplankton between coastal regions and oceanic waters, with particular emphasis on the targeted euphausiid and copepod species (see below). In turn, how do the zooplankton distributions influence the distributions of higher trophic level organisms (fish, seabirds, marine mammals)?*

*(3) To quantify the importance of (a) local primary and secondary production, and (b) imported secondary production (e.g., cross-shelf import of large-bodied zooplankton [copepods and euphausiids] from deeper offshore waters in spring) for providing rapid growth and/or high survival of juvenile pink salmon in coastal waters of the Gulf of Alaska.*

*(4) To determine the extent to which high and variable predation mortality on juvenile pink salmon in the coastal region of the Gulf of Alaska is responsible for large interannual variation in adult pink salmon populations, and the factors responsible for the variable predation intensity.*

Toward these ends, the Northeast Pacific field program has two years (2001, 2003) planned of intensive study in the Coastal Gulf of Alaska. The geographic domain of the study is centered on the coastal shelf region SW of Prince William Sound (off Seward, AK), but generally extends from approximately Shelikof Strait (in the west) to Yakutat Bay (in the east; approx. 143°-155°W). This is a major corridor for juvenile salmon migrations in the CGOA, both for pink salmon exiting from Prince William Sound, and for pink, sockeye and chum salmon from SE Alaska stocks. Three-dimensional mesoscale surveys (via ship, drifter, mooring and satellite observations) and process studies will be conducted over a seven-month period (ca. April - October) in each of the two intensive, process-study years. Mesoscale surveys of physical conditions and biological distributions in spring and fall will augment the less spatially-extensive LTOP observations, which will occur during all years (2001-2004) of the study. The surveys will provide the short-term spatial context for the focused process studies, and will provide 3-dimensional data to supplement the predominantly 2-dimensional LTOP data.

Key target species for U.S. GLOBEC process-oriented field studies in the CGOA are euphausiids, calanoid copepods (*Neocalanus*, *Calanus*), and juvenile pink salmon. The most abundant euphausiids on the shelf in the Gulf of Alaska are *Euphausia pacifica*, *Thysanoessa spinifera*, *T. inermis*, and *T. raschii*. Of these, *T. inermis* is the most abundant in spring and summer, while *T. raschii* is distributed more inshore. *Euphausia pacifica* and *T. spinifera* are also common species in the CCS studies of the NEP, and are important subjects of study for developing comparisons between the two regions.

The primary focus of process studies will be on (a) physical (e.g., stratification intensity; transport patterns in space and time; effect of freshwater runoff in buoyancy-driven flow; downwelling-favorable winds) and biological (e.g., prey and predator abundance, distributions, and productivity) factors influencing the population dynamics and vital rates of juvenile pink salmon and other target taxa in the coastal region; and, (b) the importance of bottom-up (primary and secondary production processes) and top-down (predation) processes in controlling juvenile salmon survival. Physical variability in the marine environment (e.g., number and distribution of fronts, mesoscale eddies, vertical stratification and mixed layer depth) may have an impact on salmon growth and survival through either bottom-up, top-down or both mechanisms simultaneously.

## Structure of the CGOA Research Program:

The large range of spatial and temporal scales of important forcing processes and responses in the NEP requires a nested sampling approach (and some associated trade-offs), which is reflected in the descriptions of the LTOP, mesoscale surveys, and process-studies below.

## Long-Term Observation Programs (LTOP):

Long-Term Observation Programs have been established by U.S. GLOBEC at two NEP sites: one along the Gulf of Alaska (GAK) transect extending offshore from Seward, AK, and the second encompassing several

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CGOA—(Cont. from page 9)

offshore extending transects off Newport and Coos Bay, OR, and off Northern California. In both regions, the programs are sampling ocean physics, nutrients, and biology at approximately bimonthly intervals (LTOP projects are described on the NEP web site). Although GLOBEC focuses on zooplankton and juvenile salmon in the NEP, we encourage sampling of phytoplankton, nutrients, and higher trophic levels. The LTOPs provide the fundamental seasonal description of the physical, chemical and biological environment required to complement the mesoscale surveys and process studies. Moreover, U.S. GLOBEC LTOPs, in conjunction with observations at other sites by other programs (Canada GLOBEC, CalCOFI, Ocean Carrying Capacity (OCC), and EVOS) will document the low-frequency, large amplitude signals (e.g., regime shifts, El Niños) that occur at the largest spatial scales in the Pacific.

Mesoscale surveys (described below) conducted 2-3 times during spring to fall during process-study years will provide the spatially-resolved 3-dimensional data required to evaluate how well local LTOP data generalize to a broader region. Data from the mesoscale surveys will be used to bridge the gap between the low spatial (2-D), but annual and long-term coverage of the LTOPs, and the intensive, but spatially-limited process-studies. LTOP projects may make use of multi-disciplinary moorings, long-term drifter deployments, and analysis of satellite data, in addition to seasonal ship observations. There is a continuing need for long-term mooring- and drifter-based observations and interpretation of regional satellite data, which provide the broadest temporal (moorings, drifters) and spatial (satellites) resolution and coverage.

LTOP activities in other regions of the CGOA (e.g., Shelikof Strait or SE Alaska) might be considered if the observations are deemed critical to understanding the connection between large-scale atmospheric and ocean forcing and ecosystem responses, particularly of the target organisms.

### *Three-Dimensional Mesoscale Surveys:*

Ship surveys are needed to determine the distribution and abundance of the target species in relation to their physical and biological environment during the period of euphausiid recruitment and juvenile salmon entry into the ocean, and during the period of possible onshore transport of large, oceanic copepods (March to September). Surveys would be desirable in April (period when large calanoid copepods are advected onshore), July, and September-October. The latter two periods correspond with the anticipated times of juvenile salmon trawling (see next paragraphs). The ship-based mesoscale sampling should encompass the nearshore Alaska Coastal Current region (driven primarily by freshwater input distributed along the coast, along with downwelling-favorable winds), and extend offshore beyond the shelf-edge break, to investigate potential exchanges of shelf and deep ocean waters. High priority will be given to proposals that would survey a region extending from approximately Kodiak Island to Yakutat Bay, i.e., about 500-600 km alongshore, and extending from nearshore to 200-250 km offshore. The fundamental importance of the mesoscale studies is to provide the basis for comparisons of population processes and their coupling to the physical structure and variability of the environment. The mesoscale studies will provide a regional context for the *in situ*, process studies (described below) and provide data for evaluating the environment for juvenile salmon. Mesoscale studies will complement and be complemented by LTOP characterizations and descriptions of the physical and biological conditions of the nearshore and offshore ocean environment. Surveys will provide data required to evaluate coupled circulation-ecosystem models being developed for the NEP study sites, and for assimilation of data into these models. It is anticipated that the mesoscale surveys will be conducted at a given site only in years of process-studies and that three mesoscale surveys per year focused on critical periods in the life history of the target species (April, July, Sept.-Oct.) will be done. Mesoscale surveys will augment, and must coordinate with LTOP observations and salmon trawling, as appropriate.

Trawling and gillnet sampling of juvenile salmon and multifrequency hydroacoustic assessment of both salmon and zooplankton has been conducted in the summers of the past three years as part of a pilot LTOP program on the GAK line. Trawling of juvenile salmon in the broader region described above is a critical addition to the CGOA component of the NEP program, since it will help to identify potentially critical regions supporting the rapid growth and/or high survival of salmon in the coastal corridor. Trawl spatial surveys will document habitat utilization by juvenile salmon, and their competitors and predators, in relation to physical dynamics and structures, and provide samples for dietary and genetic studies. Salmon sampling in this region will complement existing efforts (e.g., Ocean Carrying Capacity coastwide surveys) at larger spatial scales.

Sampling is planned at the time of ocean entry of pink salmon from Prince William Sound (July) and at the end of the first summer in the ocean (approx. September-October). These cruises would also collect salmon from other source regions that are transported through the coastal corridor, and will be useful for examining (a) trophic relationships in

**Research Questions for Process Studies in the *CGOA:***

(a) What is the time-dependent three-dimensional circulation associated with the buoyancy-driven coastal current, and the fronts associated with this feature in the CGOA?

(b) How do mesoscale transport processes affect the recruitment, vital rates, and other measures of population dynamics of the target species?

(c) What are the exchange rates, due to frontal processes, of water properties and the target species between the coastal corridor and offshore waters? What are the consequences for individual and population growth rates of these exchanges?

(d) How do biological and physical processes interact to control cross-shelf exchange of target organisms?

(e) Does strong seasonal variation in freshwater input and buoyancy-driven nearshore flow cause frontal movement, and what are the effects on the exchange of water and organisms across the fronts?

(f) How does distribution, growth and survival of juvenile pink salmon (assessed using otolith marked fish) depend on the timing and intensity of cross-shelf import of large zooplankton (e.g., copepods and euphausiids), either directly (as salmon prey) or indirectly (as alternative prey for juvenile salmon predators)?

(g) How are salmon distributed in relation to mesoscale physical features, and what are the mechanisms responsible for the observed patterns?

(h) What are the dominant predators, how are they distributed, and what are their feeding rates and impacts on juvenile salmon during the period they transit the coastal zone of the CGOA?

the nearshore ecosystem, and (b) genetic structure/stock identity of the salmonids. Highest priority will be given to salmon sampling in the field during process-study years, but contingent on the availability of funding and perceived program needs, salmon sampling in "off" years might be supported as well.

### *Process Studies:*

Buoyancy-driven coastal currents, such as the Alaska Coastal Current, are often relatively narrow, fast, seasonal, and typically have a strong front along their seaward edge. Thus, they may act as a rapid conduit for alongcoast flow and as a barrier for cross-shore transport. The conduit along the coast is potentially a major route for many of the salmon stocks entering the ocean in the NEP. Mesoscale features are important to biological processes in many other regions, and the eddies which occur in this region are likely to be important to production processes and in modifying residence times in the CGOA. Detailed investigations of mechanisms linking biological response to physical forcing at the meso- and other scales is the goal of process-study cruises. Specifically, the physical and biological processes that control the population dynamics of the target species will be examined in process studies. Process studies will occur during the spring-setup and productive summer seasons (March-October), preferably in conjunction with other program activities (mesoscale surveys, fish trawling). From previous studies on the ecosystem of Prince William Sound, it is known that many fishes of the pelagic food web (salmon, herring, pollock) rely directly on zooplankton (copepods and euphausiids) and each other as prey. Moreover, there may be ecologically significant indirect effects, such as the import of oceanic zooplankton to the nearshore providing an alternative prey field to otherwise piscivorous species, reducing the mortality on some of the fish species. The continental shelf outside Prince William Sound is identified for detailed process studies because it is a region that has a large influx of hatchery released juvenile pink salmon. The thermal marks carried by these salmon provide advantages in tracking mortality of the juveniles in their first summer nearshore. It is strongly suspected, but not certain, that most of the "surviving" juvenile salmon entering the coastal ocean are swept westward in the general transport of the Alaska Coastal Current. A large fraction of the juvenile salmon do not survive, but the exact agent of their mortality is not known. A goal of the CGOA process studies will be to track the progression of an entering cohort in the western flow, and identify the agents of mortality (starvation, vagrancy, predation by birds, mammals, other fish, etc.). The exchange of physical and biological properties across the frontal zones associated with the coastal buoyancy flows, and downwelling-favorable winds, can influence the supply of nutrients for primary production, the retention (loss) of the target species and their prey in (from) the coastal zone, and interactions between the target species, their prey, and their predators; this will be studied in process-oriented cruises.

Cross-frontal exchange is influenced by physical processes which determine the location, deformation, and movement of the front including tides, winds, seasonal heating/cooling, offshore forcing, and freshwater runoff, and by biological characteristics and behavior which may enhance or minimize exchange. Fronts often are regions of aggregation for marine plankton, both because of physical processes such as divergence or convergence and biological responses such as enhanced production or behavior (i.e., depth-keeping swimming). Such aggregations of plankton may provide an enhanced

*(Cont. on page 13)*

# The GEM Program

*by Robert B. Spies*

The *Exxon Valdez* Trustee Council voted unanimously in March of this year, shortly before the 10-year anniversary of the spill, to fund a long-term monitoring and research program in the northern Gulf of Alaska (GOA). Using the interest from approximately $115 million that will be set aside in the Restoration Reserve for this purpose by 2002, the program is slated to last 100 years or more. The mission of the Gulf Ecosystem Monitoring (GEM) program is to foster a healthy, biologically diverse marine ecosystem in the northern Gulf of Alaska through greater understanding of how its productivity is influenced by human activities and natural changes. Goals of the program will include: 1) tracking lingering effects from the spill;
2) detecting annual and long-term changes in the marine ecosystem;
3) improving fish and wildlife management through developing new information and technologies;
4) providing integrated and synthesized information on the status, trends and health of fisheries, sea birds, marine mammals and other marine populations over the long-term; 5) providing continuing information on the fate and effects of contaminants on marine animals and human consumers; and
6) helping to identify important marine habitats, basic life history and habitat requirements of marine animals. Nearshore populations in the spill area will be emphasized, but the processes influencing these populations over a wider geographic portion of the GOA will be included.

While this program is still being formulated, it is envisioned that about $5-6 million will be expended annually. This will be split between monitoring for long-term trends ($2-3 million); shorter-term, focused research ($2 million); fostering local stewardship; science management; and synthesis and public information.
As the program matures, studies of lingering spill recovery will continue to decrease and those of natural, climatic and other anthropogenic changes will grow. Monitoring is being designed to test a conceptual model of processes controlling salmon, seabird and marine mammal populations. The model is currently under development and has been greatly influenced by current thinking on long-term climate change. Since there is not enough money to track important processes in the Gulf, GEM must take advantage of existing, ongoing programs and projects. So, for example, existing seabird population and productivity monitoring by the U.S. Fish and Wildlife Service in the western Gulf of Alaska and Aleutian Islands could be complemented by adding several spill-area sites in the northeast Gulf to provide a comprehensive long-term record for the northern GOA. To amplify this example, important controlling factors in sea bird populations would include the quantity, quality, location, and timing of available forage fish populations; production and distribution of nekton zooplankton and phytoplankton to support the fish populations; and the underlying oceanographic features that control such pelagic production and distribution. Periodic cross-shelf oceanographic cruises, fixed moorings, satellite-based measures and coastal meteorology stations will help identify long-term change in wind patterns; rainfall; temperature; the position, strength and speed of the Alaska Coastal and Alaska Currents; and nutrient supply and water column stratification as important controls on seabirds and other Apex predators. Bird tissues themselves could provide insights into sources of production through analyses of their natural isotope ratios and ratios of fatty acids, or the possible influence of contaminants by chemical and biochemical analyses. To extend this example even further, research on sea birds could include a short-term project to investigate feeding congregations at shelf frontal systems and the subsequent success of colonies that obtain this source of production. Or, it could fund the development of new technology for satellite tracking of seabirds.

The results of monitoring and research activities will be synthesized and integrated into refining predictive models of the ecosystem. Synthesized results of the monitoring program will be shared with stakeholders through periodic workshops, newsletters and on the world wide web. The GEM program design will initially be reviewed by the National Research Council, and subsequently at five-year intervals by an independent peer reviewer panel.

GEM program design is underway. A draft for wider scientific review should be available following review by the Trustee Council in late October. The GEM program description will be submitted to the NRC sometime in early 2000. Further revisions are expected before implementation in FY2003. In the current Trustee Council program for FY2000 there are five projects being funded to help lay the foundation for the monitoring program. They will identify cost-effective and meaningful ways to carry out long-term monitoring using the wealth of data gathered over the last 10 years. Our current challenge is to identify a suite of core monitoring measures that can be taken annually or every several years at a cost of several

*(Cont. on page 20)*

CGOA—(Cont. from page 11)

food source for predators, including juvenile salmon. Fine-scale description of the physical and biological fields comprising fronts may reveal aggregations of phytoplankton and zooplankton associated with specific physical (e.g., density, temperature) structures. Determination of the population structure of target organisms within the study area is further identified as an area of critical research.

Because of the movement and migratory patterns of juvenile salmon, process studies of pink salmon may require work outside the domain highlighted above, perhaps to regions extending further to the west (beyond Kodiak Island) to ensure success. Proposals that focus in geographical locations outside the principal study area should closely consider the availability of complementary sampling programs to provide a broader geographical context for their studies. Proposers should recognize that process studies that address relevant issues within the specific region described above will have higher funding priority than projects aimed at peripheral goals or targeted at other geographic regions. Proposers seeking additional information concerning related NEP programs should contact the U.S. GLOBEC Northeast Pacific Coordinating Office.

## Modeling:

The research conducted during the CGOA study will result in a significant archive of data concerning abundance and distribution of the target species, source regions, vital rates, and trophic interrelationships. Inverse modeling will provide specific estimates of population vital rates. These archives and tools will provide significant opportunities for hypothesis testing concerning biophysical processes. The program is expected to progress toward a data-assimilative capability, wherein LTOP and mesoscale survey data are incorporated into coupled biophysical models. In addition, process-oriented model studies are encouraged. The field research supported by U.S. GLOBEC on euphausiids, copepods, and salmon in the CGOA, together with already funded research in the CCS, provide opportunities for larger (basin) scale modeling of coupled biological/ physical dynamics.

We solicit additional modeling proposals that complement existing projects (described on the GLOBEC NEP web site), that provide additional breadth to the program by examining responses at additional trophic levels, and that explore processes in other targeted regions of the northeast Pacific. Proposals responding to this request for additional modeling activities in the NEP may deal with either the CGOA, the CCS, or both. Priority will be given to projects that complement or significantly augment ongoing modeling efforts -- for example, evaluating the impact of other prey (e.g., forage fish) on salmon survival and distribution.

## Retrospective/Comparative Analysis:

A number of retrospective projects in the NEP were funded by earlier RFPs (see summaries on the NEP web site). Projects proposing retrospective analysis should document or address population variability of key species (see U.S. GLOBEC Report No. 17) in NEP ecosystems on several different time and space scales. These studies should also examine linkages between physical and biological processes on these different scales. NEP retrospective analysis should attempt to test the core GLOBEC NEP hypotheses relating to the linkage between climate and ocean variability and population variability. Previous U.S. GLOBEC reports (see esp. U.S. GLOBEC Report Nos. 11 and 15) review some of the kinds of data sets and research approaches suitable for examining links between climate variability, ocean physics and marine animal populations in the NEP. Other research approaches and examination of other existing data sets may be appropriate for retrospective analyses provided that they address the critical NEP GLOBEC mandates highlighted above.

With the funding of the CGOA field work in this notice, U.S. GLOBEC will have funded ecosystem studies in the Northwest Atlantic (a tidally and event dominated shelf bank), in the California Current (wind-driven upwelling and advective system), and the CGOA (a buoyancy-driven downwelling system). Comparative studies among these coastal ecosystems and with others (Benguela, North Africa, Bering Sea, California Bight, Southern Ocean) across the globe are feasible and could be undertaken. Moreover, recent studies of *Calanus* in the North Atlantic and of *Euphausia superba* in the Southern Ocean provide opportunities for broader, global-scale comparisons of biophysical/population dynamics among congeners.

*This summary of GLOBEC NEP's CGOA research program represents a combined effort. As coordinator of the NEP program, I am grateful to those scientists from academic and government institutions across the U.S. who contributed their expertise and time to the development of the research program for the Northeast Pacific.*

**HB**

# GLOBEC - Gulf of Mexico

## *Report of a U.S. GLOBEC Workshop held January 13-15, 1999*

*by Michael Dagg*

Coastal regions dominated by large rivers are important to the biological production of the world's oceans for several reasons:

*large rivers are distinctly different from smaller ones because their productive influences extend well out over the continental shelf;*

*many of the world's large rivers discharge high nutrient loads into otherwise oligotrophic regions;*

*boundaries/fronts associated with large river plumes are important micro- and meso-scale regions for biological production, animal aggregation, and fisheries recruitment;*

*new nitrogen associated with riverine discharge generally supports the classic NPZ food web, resulting in high fisheries production.*

These systems are good indicators of global change because they quickly respond to variations in weather and climate.

*Climatic or anthropogenically caused changes of small magnitude throughout the drainage basin of a large river can result in a large response in the coastal shelf environment because of the magnifying or concentrating effects associated with drainage; characteristics of discharged river water result from an integration of processes that occur over broader time and space scales. As a result, riverine discharges of freshwater and nutrients are responsive to changes in rainfall in the drainage basins, and riverine discharge of nutrients is responsive to anthropogenic activities in the drainage basin.*

*Buoyant plumes are quickly responsive to wind. The processing and fates of plume materials are dependent on plume location (over deep vs. shallow water), so a change in the wind regime can significantly alter the ultimate fate of discharged materials.*

In the U.S., the Mississippi River is the major large river, with discharge equal to approximately 2.2 x that of the Columbia River and 2.9 x that of the Yukon River. The Mississippi River supports much of the biological production in the northern Gulf of Mexico. There is a direct relationship between the flux of inorganic nitrogen into the northern Gulf of Mexico via the Mississippi River and the primary production observed within a 6900 km area around the delta. High rates of primary production stimulate and support high rates of zooplankton production. There is a characteristic group of copepod species in the vicinity of the Mississippi River plume which is numerically dominated by *Temora turbinata*, *Eucalanus pileatus*, *Centropages furcatus*, *Paracalanus* spp., and in the lowest salinity waters, *Acartia tonsa*. In higher salinity waters directly beneath the river plumes, a more oceanic community dominates, including *Eucalanus attenuatus*, *Calanus tenuicornis*, *Phaenna spinifera* and two *Candacia* species. Fish production is high in the northern Gulf of Mexico, a region that supports approximately 20 percent of the U.S. commercial fishery landings by dollar as well as major recreational fisheries. Approximately 90 percent of the commercial fisheries from the Gulf of Mexico come from the "fertile crescent," the area affected directly by the Mississippi River. Fisheries data suggest that an ecosystem shift towards a system more dominated by pelagic fish species (the gulf menhaden, *Brevoortia partonus*, vs. the demersal Atlantic croaker, *Migropogonius undulatus*) may have occurred in the northern Gulf of Mexico, possibly associated with increased nutrient input to the region. This may have implications for the commercially valuable shrimp fisheries in this region.

A workshop supported by NOAA - COP and GLOBEC was held at the Louisiana Universities Marine Consortium (LUMCON) on January 13-15, 1999 to identify and explore the relationships between large rivers and marine populations and how these relationships might be affected by climate changes. Twenty-seven scientists from the U.S. and Canada attended .

Topics discussed in the workshop include:

### I. Scales of Impacts (Temporal And Spatial)

**(a) <u>nutrients</u>.**
We know that the Mississippi River contributes more than 90 percent of the riverine fresh water input to the northern Gulf of Mexico, but assessing the importance of the associated nutrient input to the ecosystem, and specifically to fisheries recruitment, requires information on other nutrient inputs. A more refined N-budget is required.

**(b) physical and biological properties.**
We know that dissolved inorganic nitrogen in river plumes is taken up by phytoplankton within 100-200 km from point of discharge and within time scales of days to weeks but responses in copepod and fish populations occur over significantly broader temporal and spatial scales. It is important to more rigorously define the scales of both primary and secondary impacts.

**(c) hypoxia.**
We know that bottom-water hypoxia, ultimately fueled by riverine nutrients, develops on the shelf almost every summer and that there are temporal lags and spatial offsets between nutrient inputs and hypoxia that need to be better understood.

## II. Processes And Mechanisms

**(a) distribution of plumes and associated materials.**
Processing and fates of riverine materials are dependent in part on where the river plumes flow. Processes occurring in and beneath plumes over deep water are different from processes occurring in and beneath plumes over shallow coastal water. We need to know more about the physical and meteorological processes affecting the transport, retention and mixing of discharge plumes and their associated suspended sediments and nutrients.

**(b) biological responses.**
We know discharges of fresh water, dissolved nutrients and suspended sediments are highly variable but non-linearly related with precipitation in the drainage basin. Water column stratification is affected by patterns of fresh water discharge and meteorological conditions significantly affect the transport of discharged water and associated materials. We need to know more about responses in animal populations to these highly variable forcings.

**(c) pelagic – benthic coupling, vertical flux and hypoxia.**
The shelf of the northern Gulf of Mexico is broad and shallow, implying important linkages between the pelagic and benthic environments. Increased nutrient inputs to the northern Gulf of Mexico have resulted in increased biological productivity (eutrophy), and some fraction of this water column production sinks to the bottom, supporting benthic production and creating an oxygen demand. We need to know more about coupling between the productivity and structure of the pelagic community, vertical flux, and hypoxia. We need to know more about the ratio of benthic to pelagic production on the shelf, and the volume and quality of fish habitat.

**(d) small scale frontal processes.**
We know that frontal boundaries are regions of enhanced biological processes. We need to know more about the significance of the high gradient environments between river plumes and receiving waters to the overall enhancement of biological production, especially fisheries recruitment, in the northern Gulf of Mexico.

**(e) transport and fisheries recruitment.**
Understanding recruitment processes requires knowledge of physical transport. In the northern Gulf of Mexico, transport refers to at least four distinguishable processes: transport within the plume itself; cross-shelf transport; alongshore transport within the Louisiana Coastal Current; and transport from the inner shelf into estuarine juvenile habitats. Depending upon the life history of the particular species of interest, one or more of these processes must be quantitatively understood to predict recruitment pathways.

## III. Links To Climate And Global Change

**(a) climate shifts.**
We know that river plumes, coastal transport processes, and shelf-slope exchanges are all sensitive to local wind regimes that could change with climate shifts. There is evidence that precipitation within the drainage basin has increased over the past two decades and global models indicate this pattern will continue. There is also evidence that climate change can directly affect processes in the open gulf. We need to know how climate change will modulate the characteristics of river forcing and influence the physical – biological couplings of the shelf environment, and how large-scale climatic processes, through their effects on the timing and/or scale of the Mississippi River input, will affect the population dynamics of zooplankton and fish.

**(b) anthropogenic adjustments.**
Changes to characteristics of the river discharge can be anthropogenically induced. Dissolved inorganic nitrogen has increased dramatically in recent decades because of the application of nitrogenous fertilizers within the drainage basin. Patterns of river discharge have been altered by the construction of a river levee system that effectively (with rare and highly visible exceptions) prevents river flooding. There is consideration being given to mechanisms for reducing nitrogen inputs as a means of reducing hypoxia in the northern Gulf of Mexico. We need to know more about the relationships between nutrient loading, food web structure and hypoxia in the northern Gulf of Mexico.

## IV. Target Taxa

Gulf menhaden, *Brevoortia patronus*, and Atlantic croaker, *Micropogonius undulatus*, can serve as target fish species to address these questions in the northern Gulf of Mexico. Both

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# GLOBEC TechnologyTransfer:
## Biological-Physical Modelling of Sea Scallop Fishery Closures

*by Craig V. W. Lewis*

Numerical models developed for the Northwest Atlantic GLOBEC circulation and hindcasting research are beginning to see application in areas of fisheries research well beyond the initial focus on Cod and *Calanus*. In a collaboration between the National Marine Fisheries Service, the University of Maryland and Dartmouth College, researchers are using climatological circulation models with simple population and behavioral models to estimate transport and recruitment of Sea Scallop larvae on Georges Bank. This work synthesizes the results of ongoing modelling studies focused on hydrodynamics (Naimie, 1996) and *Calanus* (Miller 1998).

The simulations identify source and sink regions for the areas of fishery closure and provide simple predictions of their long-term effects on bank-wide population dynamics. Individual scallop larvae are transported for 40 days using a 2-D vertical average of the top 25 meters of Dartmouth's GLOBEC Georges Bank climatological circulation archive. These larvae settle, grow, and spawn further generations, allowing patterns of population density to develop. The rate of population growth and relative sizes of the population in closed and open areas is then used to compare the effects of the closures under various levels of fishing pressure and background mortality.

Initial results have been presented at the 1999 Santa Fe ASLO meeting and summarized for a March Sea Scallop Working Group meeting in Buzzards Bay, Massachusetts. Animations and graphics of results and ongoing work are being communicated and served via a Dartmouth web site (http://mallebarre.dartmouth.edu/~cvl/closed_areas).

The results provide some insight into how these closed areas function. The climatological flowfields suggest that the two closed areas feed larvae to large regions of the bank; they also tend to resupply themselves due to interaction of the 40 day planktonic duration and the anticyclonic gyre (Figure 1). In linear population models, reduction of mortality in closed areas has an immediate effect on population levels within the protected area, and the unprotected areas benefit in turn from the increased supply of larvae flowing to them.

Reduction of fishing mortality within the fishable regions has a dramatic effect on the overall distribution and population growth rate of scallops on the bank. As might be expected, these effects are most strongly felt in those cases where total mortality is assumed to be high and where mortality is believed to be dominated by fishing mortality. These results provide a sense for how some of the products of GLOBEC research may begin to flow into the field of applied fishery management. While the work is still in its infancy, the reception has exceeded expectations. Requests for extensions and clarifications of the work have arrived from fishermen, aquaculturists, scientists and managers. The number and nature of these requests (some of which exceed our current capability)

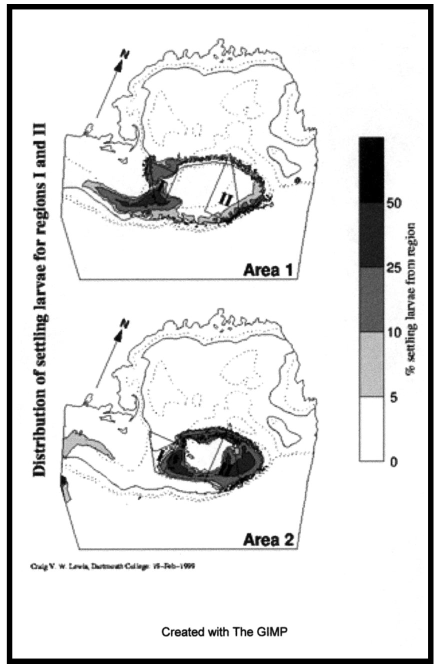


*Figure 1: Map of percentage of larvae in a given region that were spawned in closed areas I (top) and II (bottom). Polygons with identifying roman numerals indicate closed areas.*

indicates a robust demand for continued research and development of reliable management-oriented models.

These models represent an initial foray into a field of work that will require extensive further research. Significant refinement is necessary in a number of areas before even a qualitative predictive system can be contemplated. Inclusion of density dependence, predation, interannual variability and larval behavior are necessary to increase our understanding of this system. On the other hand, some insight into the dynamics of the system can be gained from the simple models presented here.

*(Cont. on page 20)*

# Calendar

## Upcoming Meetings of Interest: 1999 - 2000

### 1999

**7th International Conference on Artificial Reefs and Related Aquatic Habitats** (CARAH) - San Remo, Liguria, Italy; October 7-11, 1999. Contact: Dr. Antony Jensen (England)

**North Pacific Marine Science Organization (PICES)** - Eighth Annual Meeting. Vladivostok, the Russian Federation; October 8-17, 1999. Contact: PICES Secretariat (Canada)

**17th Lowell Wakefield Fisheries Symposium** - "Spatial Processes and Management of Fish Populations." Anchorage, AK, USA; October 27-30, 1999. Contact: Breda Baxter, Univ. of Alaska Sea Grant, Fairbanks

**U.S. GLOBEC Scientific Steering Committee Meeting** - Scripps Institution of Oceanography, Martin Johnson House, La Jolla, CA; November 4-5, 1999. Contact: Mike Fogarty, Chair, Scientific Steering Committee fogarty@cbl.umces.edu

**MEDCOAST '99/EMECS Joint Conference** - "4th International Conference on the Mediterranean Coastal Environment/Environmental Management of Enclosed Coastal Seas." Antalya, Turkey; November 9-13, 1999. Contact: MEDCOAST Secretariat, Middle East Tech. University, Ankara, Turkey

**Young Scientists Conference on Marine Ecosystem Perspectives** - Gilleleje, Denmark; November 20-24, 1999. Contact: Dr. Peter Gronkjaer (Canada) ices.info@ices.dk

### 2000

**AGU/ASLO - 10th Biennial Ocean Sciences Meeting** - San Antonio, TX, USA; January, 24-28, 2000. Contact: AGU Meetings Services, Washington, DC; meetinginfo@agu.org

**18th Lowell Wakefield Fisheries Symposium** - "Herring 2000 - Expectations for a New Millenium." Anchorage, AK, USA; February 23-26, 2000. Contact: Breda Baxter, Univ. of Alaska Sea Grant, Fairbanks

**North Pacific Marine Science Organization (PICES) Conference** "Beyond El Niño: Pacific Climate Variability and Marine Ecosystem Impacts From the Tropics to the Arctic." La Jolla, CA, USA; March 23-26, 2000. Contact: PICES Secretariat (Canada) pices@ios.bc.ca

**ASLO 2000 Annual Meeting** - "Aquatic Sciences: Research Across Boundaries." Copenhagen, Denmark; June 5 - 9, 2000. Contact: Dr. Bo Riemann, NERI, Roskilde, Denmark, and Dr. Morten Sondergaard, FBL, Univ. of Copenhagen, Denmark

**ICES Symposium** - "One Hundred Years of Science Under ICES." Helsinki, Finland; August 1-3, 2000. Contact: Dr. Emory Anderson, NOAA / NMFS, Silver Spring Emory.Anderson@noaa.gov

*For more information and additional calendar listings, visit the U.S. GLOBEC web site (http://www.usglobec.org)*

# Where Are We in the ICES/GLOBEC Cod and Climate Change (CCC) Programme?

*By Keith Brander*

The first meeting of the ICES/International GLOBEC Working Group on Cod and Climate Change took place in 1993. Much of the plan produced then has been carried out and has resulted in a number of reports (the more recent of which can be downloaded from the web site: http://www.ices.dk/globec/globec.htm). The program also acted as a catalyst and focus for a great deal of related work by individuals and research teams. A new five-year plan (http://www.ices.dk/globec/wgccc.htm) was approved by ICES in September.

### Objectives of the CCC 5-year plan

The seven objectives outlined in the new plan are:

- To incorporate environmental information in a quantitative manner into fisheries management strategies and planning;
- To examine past events or periods as a means of better understanding the links between changes in the environment and fisheries;
- To understand the relative importance of zooplankton in determining the variability in cod abundance and production;
- To undertake comparative studies of life history strategies and interannual variability in growth, distribution, and abundance between cod stocks around the North Atlantic;
- To understand and predict climate variability and it's associated ecosystem response;
- To ensure that environmental and fisheries data are easily and widely available;
- To provide a synthesis of the research information obtained on cod stocks.

The word "environment" appears in three of the seven objectives and the preamble to the plan states that it "... refers to the biological (e.g. plankton, food and predators), as well as the physical and chemical characteristics of the water." In fact the environmental information for CCC also includes meteorological and ecosystem variability in addition to these proximate factors.

The CCC program has already brought together much relevant information about the physical and biological environment of cod, but so far it has proved difficult to apply this information in a way which achieves the first objective. This is probably the major scientific and organizational challenge for the new plan. The same may be true for the U.S. GLOBEC program on Georges Bank, where a huge amount has been learned about the physics and the coupled population dynamics of many prey and predator species of cod and haddock, yet the way in which this knowledge will be applied to improve our assessment of the fisheries is not clear.

### Cod Growth Workshop

One CCC activity in 2000 which will tackle the issue of how to apply information about the physical and biological environment is a workshop on the Dynamics of Cod Growth. Further details about the aims and background of this workshop can be viewed at http://www.ices.dk/globec/wkgrowth.htm.

The ICES/GLOBEC office has been trying to design and implement web-based systems for collaborative science and the cod growth workshop will use these for international exchange of ideas, information and data

#### 1999 ICES Working Group Reports

The most recent reports of ICES working groups and workshops which are relevant to GLOBEC can be downloaded from the directory http://www.ices.dk/reports/occ/1999/ . Apart from the 1999 CCC report (wgccc99), these include Zooplankton Ecology (wgze99), Phytoplankton Ecology (wgpe99), Recruitment Processes (wgrp99) and Shelf Seas Oceanography (wgsso99).

The report of the CCC Workshop on Gadoid Stocks in the North Sea during the 1960's and 1970's, the Fourth ICES/GLOBEC Backwards-Facing Workshop, will be available there shortly.

and bibliographic references. New software and rapid communication open up many possibilities for remote collaborative scientific work, but putting these together in a form which people feel comfortable with still poses some challenges.

Much of the preparation of data, graphs and references for the growth workshop website was carried out by Dave O'Brien from the Chesapeake Biological Laboratory, during a month he spent at the ICES/GLOBEC office in Copenhagen, funded by U.S. GLOBEC. Thanks Dave! The U.S. GLOBEC community has always been closely involved with the CCC program and has provided a great deal of much appreciated scientific, financial and organizational support for activities within ICES.

## The Backward Facing Workshops

Retrospective analysis is a very productive component of the CCC program and has resulted in some valuable new understanding of the causes of past events. At the first Backward Facing (BF) Workshop, information about biological events (the change in cod distribution off New England in the late 1870's and the great tilefish kill in 1882) was used to identify a period with unusual ocean climate and hence to develop a better understanding of ocean physics and the effects of the Labrador Current. The traffic of information is not always one way between physics and biology.

The third BF workshop in May 1998 dealt with Ocean Climate of the NW Atlantic during the 1960s and 70s and Consequences for Gadoid Populations and was described by Mike Fogarty in *U.S. GLOBEC News 13*. Since then a parallel workshop in March 1999 looked at Gadoid Stocks in the North Sea during the 1960s and 1970s and we are still in the process of digesting the findings and comparing the two areas. A follow-up workshop is planned to continue with these comparisons.

Although the term "gadoid outburst" has been used to describe the increase in recruitment (and catches and spawning biomass) which took place in the North Sea during the 1960s, the phenomenon lasted for a much longer period.

Both cod and haddock stocks show coherence in recruitment between Georges Bank and Browns Bank (Figure 1), possibly reflecting common environmental forcing or drift of eggs and larvae between them. The spawning areas of cod in the North Sea are spread over 800 km, but are treated as one stock, whereas the spawning areas of cod on Georges and Browns Bank are less than 100 km apart, but they are assessed separately. This probably tells us more about political than about biological or physical reality and one wonders how many cod stocks there would be in the North Sea if every country had its own fishing zone.

## Other National Programs

It is not easy to identify all the GLOBEC-related research around the North Atlantic because the range of subject matter is so wide and encompasses many activities which are relevant, but are not in any formal sense

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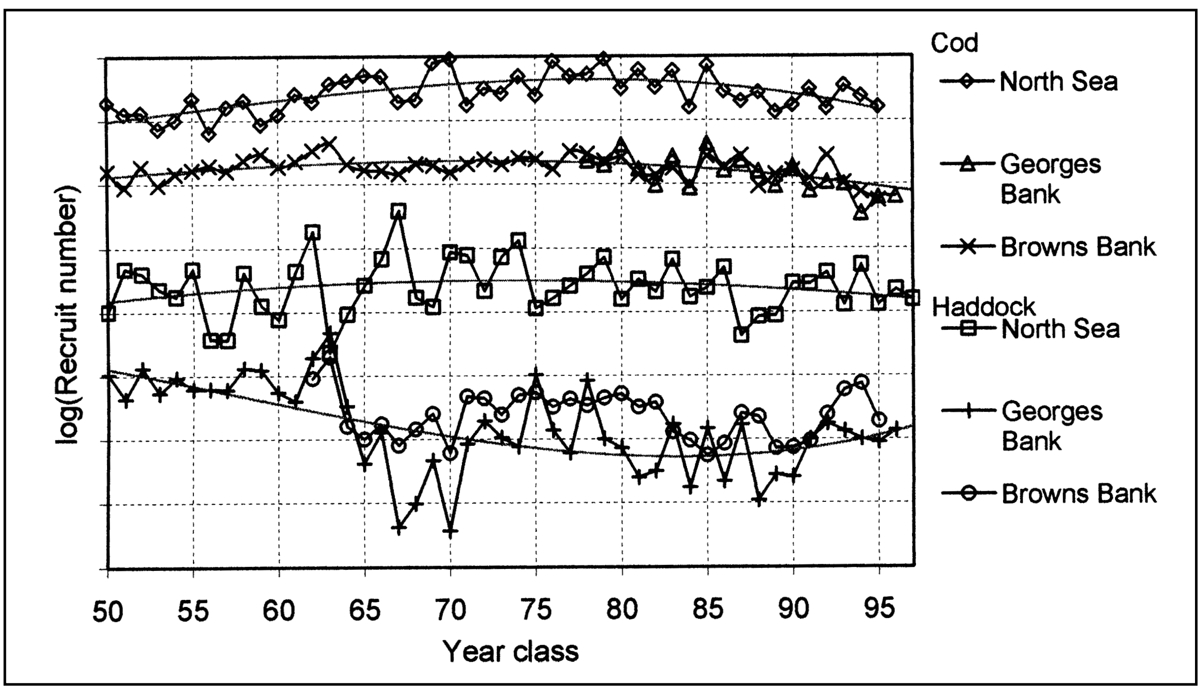


*Figure 1: Cod and haddock recruitment (log scale) for the North Sea, Georges Bank and Browns Bank.*

CCC—(Cont. from page 19)

part of GLOBEC. Apart from the U.S., only Canada has a funded GLOBEC science plan. Other countries have national programs, which are sometimes described as GLOBEC, or they are beginning to put such programs together. The EU has a GLOBEC Science Plan, but it does not have its own funding.

Nevertheless, there are several mature and highly relevant research programs of which participants in U.S. GLOBEC should be aware, notably the French PNDR program, which started in 1992 and held its final symposium in 1998, and several past and ongoing international programs in the Baltic. Some information on other national GLOBEC activity is given in the fourth ICES/GLOBEC Newsletter http://www.ices.dk/globec/globec.htm.

**KB**

The **ICES Annual Science Conference** this year takes place in Stockholm from 27 September to 2 October. Among the sessions which may be of interest to GLOBEC scientists are:

- Plans for Major International Programmes in the North Atlantic Region over the Next Decade: Should ICES Be Involved?
- Application of Coupled Bio-Physical Models in Studies of Zooplankton and Ichthyoplankton Advection and Dispersion
- 4-D Sampling of the Oceans at Micro- to Mesoscales
- Cod and Haddock Recruitment Processes - Integrating Stock and Environmental Effects

Full details about the conference can be obtained from the web site: http://www.ices.dk/asc/1999/asc.htm

SALMON—(Cont. from page 7)

low (<1%) since 1993, which is even lower than the rate of ocean survival for 1983. The mean length of Oregon coho salmon was low in 1983 and 1992 and has increased in recent years, suggesting density-dependent growth.

*REFERENCE*

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**WP**

SCALLOPS—(Cont. from page 16)

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**CVWL**

GEM PROGRAM—(Cont. from page 12)

million dollars annually that capture the important components of long-term ecosystem change.

It is anticipated that the first invitation for GEM monitoring and research proposals will be issued in the spring of 2002. Competition for funds will be open and awarded on the basis of merit-based review and compatibility with program goals. Projects will last one to five years, subject to availability of funds and evaluation of progress toward objectives.

Coordination and communication between GEM and GLOBEC is a very important part of our program strategy. Trustee Council representatives have attended several of the GLOBEC coordination meetings and Hal Batchelder of GLOBEC's NEP regional office has graciously participated in several of our planning group meetings in Anchorage this year. In addition, we anticipate that GEM will play a long-term role in fostering coordination of ecosystem monitoring and research. We fully expect other initiatives to coalesce around GEM objectives, hypotheses and models, so as to achieve a comprehensive network of data gathering and evaluation that truly serves the conservation objectives we all share for the Gulf of Alaska.

Questions about the GEM program can be addressed to Dr. Phil Mundy, trustee council science coordinator, at phil_mundy@oilspill.state.ak.us or to Dr. Robert B. Spies, trustee council chief scientist, at spies@amarine.com.

There are no printed materials or a web site yet available on the program, but we anticipate these soon.

**RBS**

# Toward A U.S. Plan For An Integrated, Sustained Ocean Observing System

*by Thomas Malone*

In August 1998, Congressmen Curt Weldon (R-PA) and James Saxton (R-NJ) requested Secretary of the Navy John Dalton and Undersecretary of Commerce for Oceans and Atmosphere D. James Baker (chair and vice chair, respectively, of the National Ocean Research Leadership Council – NORLC ) to "propose a plan to achieve a truly integrated ocean observing system." Dr. Baker agreed to take the lead in forming a team to draft an initial plan for developing an integrated, sustained ocean observing system to submit to Congress in early 1999. The task team was chaired by Worth Nowlin of Texas A&M University, chair of the steering committee for the international Global Ocean Observing System (GOOS), and co-chaired by Thomas Malone from the University of Maryland Center for Environmental Science, chair of the international Coastal GOOS Panel. The team consisted of both federal and non-federal scientists who have familiarity with related efforts already underway. Advice was obtained from the U.S. GOOS Steering Committee, co-chaired by Nowlin and Malone. The resulting report, "*Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System,*" was reviewed by the NORLC's Ocean Research Advisory Panel (ORAP) to the National Oceanographic Partnership Program (NOPP), and transmitted to Congress on April 20, 1999. The full plan is posted on the NOPP website at:
http://core.cast.msstate.edu/NOPPobsplan.html

A subcommittee of the ORAP has been established to elaborate on this document and submit an updated plan to Congress in 2000.

## A. Goal

The goal is to design and implement an integrated ocean observing system to detect, track and predict changes in the marine environment that affect the safety and well being of people. The integrated ocean observing system (IOOS) will provide the data and information required to significantly enhance our ability to:

- document patterns of change in key properties of marine systems;
- forecast the weather, predict global climate change, and anticipate the regional and local impacts of such meteorological variability; and
- assess and predict the effects of human activities and climate change on marine ecosystems and the living resources they support.

The implementation of the IOOS will improve U.S. capabilities in the following areas: (1) detecting and forecasting the oceanic components of climate variability; (2) enabling safe and efficient marine operations; (3) ensuring national security; (4) managing living resources for sustainable use; (5) preserving healthy marine ecosystems and restoring those that are degraded; (6) forecasting and mitigating natural hazards; and (7) protecting public health. These goals will be achieved by integrating and enhancing current measurement and data management programs for a more cost-effective program of monitoring and research that is locally relevant to multiple user groups and nationally coordinated.

The design and implementation of the IOOS will address the two major impediments to the development of a predictive understanding of environmental variability:

- the scarcity of observations of sufficient duration, spatial extent and resolution and
- the lack of real-time data telemetry, assimilation and analysis.

An integrated system will enable the development of a comprehensive system of observations through shared use of infrastructure from measurement systems, platforms, and communication systems to data management, assimilation techniques, and modeling.

## B. Critical Features

### 1. Integrated and Sustained

Historically, programs were largely developed independent of each other on a case-by-case basis, and by different groups for different purposes. Consequently, there are a plethora of programs that employ different methods and platforms, make measurements on different time and space scales, and employ different data management schemes. As the multi-disciplinary, multi-dimensional nature of environmental issues became apparent, efforts to collate and integrate data from many different sources have increased. Under current conditions, this is a time consuming and expensive process that inhibits timely analysis of data and severely limits the development of predictive capabilities. This problem is especially acute in the coastal zone where the interests and missions of at least eight federal agencies overlap and the environmental issues are multiple and complex.

Observations must be sustained to capture episodic events, low frequency variability and long terms trends and to provide the data required for nowcasts, forecasts and predictions of the status

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of systems and likely changes in their status. To date, there are no programs that are both integrated and sustained. For example, numerical weather predictions and sea level measurements are sustained but narrow in scope. IGBP programs such as JGOFS, LOICZ and GLOBEC are integrated in that they are multi-disciplinary and multi-dimensional, but they are not sustained. Projects such as GODAE, the JGOFS time series, and LEO represent emerging efforts that have the potential of being both.

To achieve its goals, the observing system must be integrated and sustained. The system must be integrated from measurements to analysis.

• The IOOS will integrate measurement programs that are narrow in scope to develop an observing system that is multi-disciplinary (synoptic measurement of key physical, chemical and biological properties) and multi-dimensional (integration of remote and *in situ* measurement made on different time and space scales). A system of integrated data management must be developed that will allow a diversity of user groups to exploit data sets from different sources rapidly through one-stop shopping. Data acquisition and integration from disparate sources is internal to the IOOS and transparent to data providers and users.

• Observations must be sustained in perpetuity to capture the full spectrum of variability of natural and anthropogenic forces and the environmental responses to them. Once begun, measurements must continue into the foreseeable future. Continuity in the observed quantities is sought rather than in the methods used, as it is anticipated that more effective methods will become available with time.

**2. Operational**

In addition to being sustained and integrated, the observing system must be operational. That is (1) it must be responsive to user needs; (2) the measurement program must be sustained and systematic to capture the temporal and spatial dimensions of relevant environmental patterns; (3) measurements must be routine with known precision and accuracy; (4) data must be transformed into products in a timely fashion; and (5) the entire system from measurements to products must be cost effective.

## C. Rationale for Oceanic and Coastal Subsystems

The IOOS must encompass both oceanic and coastal systems (as well as climate and terrestrial systems). Coastal waters include the EEZ, estuaries, bays, sounds and the Great Lakes. Physical processes are of fundamental importance to the ocean-climate system and to the ecology of aquatic systems in general. Thus, the requirements for data on physical processes are similar for oceanic and coastal systems (i.e., temperature and salinity; fluxes of heat, water and momentum; wind stress, waves and circulation patterns) except that variability must be resolved on smaller temporal and spatial scales in coastal systems. The interdisciplinary importance of physical processes provides a framework for the fully integrated ocean observing system.

The oceanic component of the observing system that addresses the role of the ocean in climate change is much closer to being operational than is the coastal component. This reflects several important realities that underscore important differences between oceanic and coastal ecosystems:

(1) In contrast to the open ocean where air-sea interactions are the primary source of environmental variability and the coastal ocean is a boundary condition, coastal waters are a transition region where inputs of materials and energy from terrestrial, oceanic, atmospheric and anthropogenic sources converge.

(2) The coastal zone is a complex mosaic of interacting terrestrial and marine systems that include drainage basins with heterogeneous and changing land cover, tidal wetlands, estuaries, bays, sounds, and open waters of the EEZ.

(3) As a consequence of the diverse nature of external forcings, spatial heterogeneity, the proximity of the benthos to the air-sea interface, and the constraints of coastal geomorphology, coastal marine ecosystems are also characterized by a broad spectrum of variability from the low frequency variability of oceanic systems to the higher frequencies of variability unique to coastal waters. Populations and processes in coastal ecosystems are more variable on smaller space and shorter time scales than is typical of either the open ocean or terrestrial ecosystems.

(4) The spatial and temporal complexity of the coastal zone, and the rapid increase in the number of people living, recreating and working in the coastal zone, have created a complex diversity of related environmental problems from the susceptibility of people to natural hazards and safe navigation to the sustainability of living resources and ecosystem health.

(5) Ecosystem goods and services are concentrated in the coastal zone where the combined effects of climate change and human activities are likely to be most pronounced.

Thus, the spectrum of issues that must be addressed in coastal waters is more diverse in terms of the nature of environmental problems that must be addressed, the range of biological and chemical properties that must be measured, and the scales of variability that must be captured. These realities suggest an approach to the design of an IOOS that is based on a system of infrastructure that is common the oceanic and coastal subsystems with each subsystem enhanced for particular purposes.

## D. Findings and Recommendations

### 1. The Oceanic Subsystem

#### a. Findings

The oceanic component of the IOOS should meet national needs in the areas of national defense, climate and marine commerce. Nearly all the information required to determine the ocean's circulation and associated distribution of properties is originally communicated through the air-sea interface, so estimates of ocean surface fields and air-sea fluxes are fundamental requirements of the IOOS. The upper ocean functions as a buffer to the exchange of heat, carbon dioxide and other properties between the atmosphere and the interior of the ocean. It is the first level of "memory" for the ocean-atmosphere system. The interior of the ocean has an enormous capacity to store heat, carbon and other chemicals that influence climate, productivity and nutrient cycles on a global scale. In terms of capturing the scales of environmental variability that are relevant to the issues of defense, climate and commerce, the major challenge is the problem of undersampling.

#### b. Recommendations

Following the structure of the ocean observing system for climate, the open ocean component of the IOOS should be organized in terms of (1) surface fields and fluxes, (2) the upper ocean (to 1000 m), and (3) the interior ocean (below the permanent thermocline and including the sea floor). The emphasis is on increasing the density and quality of measurements in space and/or time. The appropriate mix of ship-board measurements (VOS, RVs), drifters, fixed platforms, remote sensing, and improved measurement technologies should be developed and maintained to enhance current observing systems as follows:

- More accurate estimates of changes in the distributions of surface properties and fluxes across the air-sea interface require more measurements and higher quality of data on near surface meteorology (wind vectors, temperature, humidity) and sea surface temperature, salinity, waves, sea level, phytoplankton production and carbon dioxide.
- For the upper ocean, sustain an operational ENSO array; develop the Pilot Research Array in the Tropical Atlantic (PIRATA) into a pilot observing system; and continue to implement the Array for Real-time Geostrophic Oceanography (ARGO).
- For the interior ocean, global surveys will be needed at about 10-year intervals to obtain comprehensive global inventories of heat, salinity and carbon; sustained time series measurements of surface to bottom distributions should be established at selected locations; and sustained observations from space (altimetry), combined with the establishment of about 30 geocentrically located precision tide gauges, will be needed to obtain more accurate estimates of sea level change.

### 2. The Coastal Subsystem

#### a. Findings

The purpose of the coastal subsystem is to (1) quantify inputs of energy and materials from land, air, ocean and people and to (2) detect and predict the effects of these inputs on people living in the coastal zone, on coastal ecosystems and living marine resources, and on coastal marine operations. The coastal subsystem must address a broad spectrum of changes that are related to a complex interaction between natural perturbations and anthropogenic stresses (Table 1). As human populations and activities increase in the coastal zone, the combined effects of global climate change and human alterations of the environment are expected to be especially pronounced in coastal areas. It is here that the problems of sustaining living resources, protecting and restoring ecosystem health, mitigating natural disasters, and protecting public health will become most pronounced over the next one to two decades. The perturbations, stresses, and indicators of change listed in Table 1 (pg. 26) are occurring on local to regional scales in coastal waters world-wide. They are globally ubiquitous; they indicate profound changes in the capacity of coastal ecosystems to support living resources; and they are making the coastal zone more susceptible to natural hazards, more costly to live in, and of less value to the national economy.

In the absence of scientific understanding of coastal ecosystems and how they are changing in response to both anthropogenic and natural forcings, it will become more difficult to solve environmental problems as the formulation and implementation of environmental policies becomes increasingly controversial. The challenges of sustaining living marine resources, protecting and restoring ecosystem health, mitigating natural disasters, and safeguarding public health require substantial advances in our basic understanding of how such perturbations are expressed within and propagated among coastal ecosystems. Clearly, substantial advances cannot be achieved in the absence of regional to global perspectives. Hypothesis-driven, mechanistic studies are especially valuable when done in the context of sustained, long-term observations. The changes occurring in local ecosystems must be studied in the context of larger scale changes in ocean circulation, climate, and land-use practices if the effects of natural perturbations and anthropogenic activities are to be resolved and a

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predictive understanding of the causes and consequences of environmental variability and change is to be achieved.

In this regard, the design and implementation of the coastal subsystem of the IOOS must address several major challenges including undersampling, the lack of *in situ* technologies for real-time measurements and telemetry of chemical and biological data, and the reality that integrated data management will be particularly difficult. In addition, the observing system must be locally relevant and nationally coordinated.

**b. Recommendations**

Given the characteristics of coastal ecosystems discussed above, the coastal subsystem should be organized in terms of (1) the open waters of the EEZ (the coastal ocean) and (2) inland seas (estuaries, bays, sounds, the Great Lakes). The system should consist of five key elements: (1) remote sensing (aircraft, satellite and shore based), (2) *in situ* measurements (ships, moored instruments, ROVs, AUVs), (3) real-time data telemetry and assimilation, (4) index sites and pilot projects, and (5) data management that accommodates a diversity of data types and is designed to meet the needs of user groups as well as data providers.

Although the list of indicators of environmental change in coastal waters is long, they are related in terms of ecosystem dynamics, suggesting that there is a common set of key properties that, if measured with sufficient resolution over long enough periods and large enough areas, will serve many needs and can be used to detect long-term environmental trends, forecast environmental changes, and predict the consequences of human activities and climate on coastal ecosystems and the quality of life. Table 2 (pg. 27) gives a consolidated list of key properties that can be measured reliably now, and which are related to most of the indicators of environmental change (Table 1).

High priority issues to be addressed were identified as follows:

- Improve nowcasts and forecasts of marine meteorological conditions, natural hazards, water levels, surface waves, and currents;
- More accurate and timely documentation of changes in shoreline topography and shallow water bathymetry;
- Improve scientific information in support of fisheries management;
- Improve predictions of environmental change and human impacts, especially as related to public health, quality of life, ecosystem health, and living resources;
- Improve assessments of the efficacy of management actions to protect the environment and sustain living resources.

In this context, major recommendations for the design and implementation of the coastal subsystem are as follows:

- Enhance current programs to measure inputs of water, sediments and chemicals to coastal waters from terrestrial and atmospheric sources;
- Develop an integrated approach to remote sensing and *in situ* measurement of key variables (e.g, Table 2);
- Develop a system of *in situ* sensors by expanding and enhancing selected moored instrument networks to address problems of undersampling and synoptic sampling of physical, biological and chemical variables;
- Develop a network of coastal index sites and pilot projects;
- Establish a coastal data and information system that leverages existing capabilities and which can accommodate the anticipated high volume of coastal ocean data.

## U.S. Coastal-GOOS Workshop:
### *Challenges and Promise of Designing and Implementing an Ocean Observing System for U.S. Coastal Waters (May 23-26, 1999)*

In May 1999, a workshop was conducted to begin the process of designing the coastal subsystem of the IOOS. Objectives were to (i) initiate the next iteration of "*Toward a U.S. Plan For an Integrated, Sustained Ocean Observing System*" with particular reference to coastal issues; (ii) acquaint state managers with the potential of *in situ* and remote sensing as a source of information upon which to base management policies, plans, and decisions; and (iii) acquaint scientist with the needs and perspectives of coastal managers responsible for the stewardship of coastal environments and the living resources they support.

The workshop brought together representatives from government (state and federal) and academia who have direct, hands-on experience with and responsibility for *in situ* sensing (platforms or sensors), remote sensing, real-time telemetry, systems modeling, data assimilation, and the stewardship of coastal environments and living resources. The goal was to evaluate requirements for and the ingredients of an integrated coastal ocean observing system. Participants were asked to address three related issues:

- detecting and predicting change in coastal ecosystems;
- monitoring capabilities and information needs; and
- the design and implementation of an integrated, multidisciplinary coastal observing system.

**<u>CONCLUSIONS AND RECOMMENDATIONS</u>**

## Coordination and Focus

Environmental problems of immediate concern include improved predictions of natural hazards and seasonal and interannual changes in regional weather patterns and their economic and ecological effects; physical restructuring of the environment; nutrient mobilization and enrichment of coastal waters; chemical contamination of air, soil and water; exploitation of living resources; and introductions of nonindigenous (exotic) species. Climate change and its consequences are, of course, the principal long-range concerns that must be addressed by the observing system. In these regards, the next iteration of the U.S. plan should include better definition of objectives and products; effective interagency collaboration from design to implementation; identification of pilot projects and research and development priorities for multidisciplinary sensor systems; and the development of a regional approach to full scale implementation.

It is also clear that the objectives and products will change with increasing knowledge and technical capabilities and that hypothesis-driven, mechanistic research studies are of limited value unless they are done in the context of sustained, long-term observations. Thus, **the design of an integrated observing system must incorporate an interactive program of research, modeling and observation to insure accurate documentation of patterns of variability, quantitative understanding of causes and effects, and predictions of known certainty**.

Although research and monitoring have improved our understanding of coastal ecosystems, and management actions to mitigate the effects of human activities have achieved some successes, important challenges remain and new challenges have emerged in recent years. Meeting these challenges will require fundamental changes in the traditional approaches used in the environmental sciences and in the management of living resources and the environmental impact of human activities. An unprecedented level of coordination and collaboration among government agencies and the scientific community will be required to design and implement the regional and comparative ecosystem approaches needed not only to enable more effective monitoring, analysis and prediction of environmental change in local ecosystems, but also to achieve economies of scale.

An overriding operational objective of C-GOOS must be to promote synergy among local and regional programs for the establishment of a locally relevant, nationally coordinated and credible observing system. Critical information from local-regional, issue-driven programs should be integrated into a national framework. The goal is to provide, with due consideration of larger scale (e.g., global) influences, the context required to assess and predict local changes in U.S. coastal waters. This can only be achieved through the development of an integrated, comprehensive, and readily accessible description of ocean circulation and the distributions of physically and ecologically relevant properties.

Many of the observations required to address issues in coastal ecosystems (e.g., Table 1) are not operational and much work is needed to determine those products that will be most useful. In this context, pilot projects, index sites, and test beds are needed to serve at least one of the following purposes: (i) demonstrate the usefulness of the end-to-end approach (proof of concept);
(ii) develop the understanding and capability to predict patterns and change in coastal ecosystems; and
(iii) incorporate research and development programs needed for an integrated, multidisciplinary observing system that incorporates synoptic measurements of biological and chemical variables, as well as physical and meteorological variables.

## A Regional Context

Biological and physical processes in nature exhibit characteristic scales that are related in a multidimensional continuum of time, space and ecological complexity, i.e., large spatial scales tend to be associated with long time scales and with greater ecological complexity, and small scales tend to be associated with short time scales and with less ecological complexity. Small and large scales of variability are linked on regional scales via hierarchies of physical and biological interactions. In this context, the purpose of regional research and monitoring is to understand how energy and matter are propagated to larger or smaller scales of organization, e.g., how events and processes at higher levels of organization and larger scales influence local systems of concern. Here, "regional marine research" is used in a relative sense and to emphasize its importance in bridging the gap between locally, highly resolved research (e.g., COP, LMER, LTER, CoOP, LOICZ, JGOFS, GLOBEC) and larger scale observations (e.g. CEOS, GOOS, GCOS, GTOS).

**<u>First Steps</u>**

Improve the description of the physical environment including the lower atmosphere, the pelagic environment and the benthos:
- establish an *in situ* sensor network;
- improve modeling and assimilation technologies;
- make better use of remote sensing and insure sustained observation from space.

Improve estimates of inputs of freshwater, sediments, nutrients and chemical contaminants:

*(Cont. on page 26)*

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• increase the number of gauging stations;
• add appropriate measures of sediment load and chemical constituents.

Establish a hierarchical observing system from local index sites to regional networks of index sites and observing systems (e.g., ports-estuary-open shelf-open ocean) and a national network of regions:
• link federal programs with local-regional partnerships to insure that programs are relevant;
• establish reference sites that provide for comparative analysis on regional to national scales and for the assessment of status and long-term trends.

Establish a national data and information management system consisting of regional synthesis centers:
• provide regional resources for the storage and retrieval of environmental data and information;
• insure national coordination of data for the purpose of assessing larger scale changes and commonalities (e.g., the ubiquitous nature of local changes, temporal coherence of changes).

Promote, coordinate and communicate locally relevant observations collected by regional partners:
• establish regional teams of stakeholders to establish priorities and coordinate the development of regional observing systems;
• promote technology transfer and demonstration sites. **TM**

*Table 1: Prominent natural perturbations and anthropogenic stresses and associated changes occurring in coastal marine ecosystems.*

| **Perturbations & Stresses** |
|---|
| •Climate change |
| •Exploitation of living resources |
| •Physical restructuring of habitats |
| •Introductions of nonindigenous species |
| •Chemical contamination of air, soil & water |
| •Natural hazards & variations in weather cycles |
| •Nutrient mobilization & enrichment of coastal waters |
| **Indicators of Change** |
| •Diseases and accumulations of chemical contaminants in marine organisms |
| •Excessive accumulations of algal biomass & harmful algal blooms |
| •Increase frequency of mass mortalities of fish, birds, and mammals |
| •Increase susceptibility to natural hazards, public health risks |
| •Temperature increase, sea level rise, and salt intrusions |
| •Habitat loss, erosion & oxygen depletion |
| •Loss of biodiversity & living resources |
| •Growth of nonindigenous species |
| •Sea state & sea ice |

GULF—(Cont. from page 15)

species of fish mature rapidly, reaching sexual maturity within two years, making them highly responsive to processes affecting physical-biological coupling. Recruitment of gulf menhaden, a planktivorous fish, has apparently increased significantly with increasing nutrient input to the northern Gulf. In contrast, populations of croaker, a demersal species, have declined dramatically over the same period. This suggests a shift in community structure has occurred, a shift involving a decline in demersal production and an increase in pelagic production. Commercially, the most important demersal species (three species of shrimp) do not appear to have been affected but data are incompletely analyzed at this time.

## V. Conclusions And Recommendations

The workshop attendees were in agreement that GLOBEC and NOAA should be encouraged to develop a full science plan on the themes discussed in this workshop. **MD**

***Editor's note:*** *A GLOBEC workshop report is being prepared by M. Dagg, P. Ortner and J. Torres and is expected to be published within the next several months.*

*Table 2: Key properties and processes.*

| Property or Process | Time Scale | Platform |
|---|---|---|
| air: winds, pressure, temp[1] surface waves | hourly | moored systems[2] |
| freshwater inputs | continuous | fixed platforms |
| sea ice/icebergs | continuous | ships, remote |
| ambient noise | continuous | moored systems |
| atmospheric deposition[3] | daily – weekly | moored systems |
| water level[4] | continuous | fixed platforms, remote |
| bathymetry | decadal | ships |
| currents | continuous | moored systems, remote |
| temp & salinity | continuous | moored systems, AUVs, remote |
| color (phytoplankton biomass) | continuous - daily - monthly | moored systems, AUVs, remote, ships |
| nutrients[5] | hourly - weekly - monthly | moored systems, ships |
| suspended solids, turbidity | continuous - daily - monthly | moored systems, remote, ships |
| $pCO_2$, $O_2$ | continuous - monthly | moored systems, ships |
| plankton species | weekly - monthly | ships |
| zooplankton biomass | continuous - monthly | moored systems, ships |
| benthic species, biomass | yearly | ships, AUVs |
| recruitment indices | seasonally | ships |
| stock assessment | seasonally | ships |
| chemical contaminants | annually | ships, mussel watch |

[1] Measurements over water;
[2] Includes surface (buoys) and bottom mounted instrumentation;
[3] Wet and dry deposition of nitrate, nitrite, ammonium;
[4] Currently measured by NOS and USGS;
[5] Dissolved inorganic nitrate, ammonium, phosphate and silicate.

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