The GLOBEC Northeast Pacific California Current System Program

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In the summer of 1775 a lone frigate, commanded by Bruno de Hezeta, sailed southward along the west coast of a land which would eventually become the United States of America. Hezeta, a first lieutenant in the Spanish Royal Navy, had secretly been sent north from California to claim land on the Northwest coast before Russia could claim the land. On the return voyage to Monterey, his diary entry for 18 August 1775 described the coastal region between 44° and 45°N:

> *This land is mountainous but not very elevated, nor as well forested as that from latitude 48°30' down to 46°. In sounding I found considerable difference, for at a distance of seven leagues [about 21 nautical miles] I sounded in 84 varas [vara is the Spanish term for yard, equivalent to 33 English inches, or 0.838 m] but as I approached the coast I sometimes found no bottom. This leads me to believe there are some reefs or sandbanks on this coast, which is also shown by the color of the water. In some places the coast ends in a beach, and in others in steep cliffs. (Beals, 1985, p. 89)*

This was the first reliable European sighting of the central Oregon coast, especially the region near present day Newport and Florence, and the discovery of offshore shoals or banks (present day Stonewall Bank and Heceta Bank, the latter named for Hezeta). Significantly, only a day earlier Hezeta noted in his diary the discovery of the Columbia River, "…with the frigate placed almost midway between the two capes, I sounded in 24 brazas [Spanish term for a fathom, or two varas]. The swirling currents were so swift that despite having a full press of sail it was difficult to get clear...These currents and the seething of the waters have led me to believe that it may be the mouth of some great river or some passage to another sea." (Beals, 1985, p. 86). This was clearly the mouth of the largest river entering the Pacific in these latitudes, which was first entered in 1792 by Capt. Robert Gray, on the American ship *Columbia*, and has since been called the Columbia River.

Thirty years later, Lewis and Clark lived temporarily among the native people in the Pacific Northwest, many of whom depended predominantly on ocean productivity through the great salmon runs on the Columbia and other rivers for survival. Even then, interannual variability in salmon run timing and abundance had substantial effects on human populations, and engendered a strong cultural response (Taylor, 1999).

The California Current program emphasizes studies of processes that occur at peaks in the space-time spectrum of variability.

Now, more than 200 years after Hezeta's discoveries, new explorations of the ocean along this stretch of the west coast and of the impact of ocean conditions on salmon are being conducted by U.S. GLOBEC. These explorations are addressing specific goals and hypotheses as described in Strub et al. (this issue). We hope that our discoveries will not go unrecognized as long as Hezeta's!

Introduction

Flowing southward along the west coast of the U.S., the California Current forms as the eastward flowing North Pacific Current splits at some distance from the west coast of North America near the latitude of Vancouver Island in Southern Canada (45°to 50°N; see Figure 2 of Strub et al., this issue). The California Current flows equatorward from the shelf-break to about 1000 km offshore, with strongest flows at the surface, but with significant currents down to 500 m (Hickey, 1998). A subsurface poleward undercurrent is usually found next to the slope between 100–700 m depths (Pierce et al., 2000), with peak speeds of 0.3–0.5 m s^{-1} at 100–300 m depth (Hickey, 1998). The California Current transports relatively cold, fresh water from the subarctic Pacific along the coast, while the poleward undercurrent transports warm, salty water from the south. Between approximately 35° and 50°N, wind forcing is determined by the positions and intensities of the North Pacific High and Aleutian Low Pressure systems, which produce equatorward winds in spring and summer. The coastline is primarily oriented N-S, so the equatorward winds create net offshore Ekman transport, with upwelling of deeper waters to replace the surface waters displaced offshore. An upwelling front forms where the cold upwelled water meets the warmer offshore water. An equatorward jet develops along the front, in approximate geostrophic balance with the across-front pressure gradient. Currents in the upwelling-front jet are substantially higher (of order 0.2–0.7 m s^{-1}) than the mean California Current flow (0.1 m s^{-1}).

Conditions off Oregon and Northern California are different during winter. Mean monthly winds blow poleward north of 38°N, currents on the shelf are toward the north (Davidson Current) and downwelling conditions prevail, although the core of the California Current still flows to the south further offshore.

Substantial freshwater (maximum in spring) enters the coastal ocean of Oregon and Washington from the Columbia River; in summer, the plume of low salinity water is most frequently found equatorward of its source and offshore; during winter, the plume is poleward of its source and over the shelf and slope, often directly adjacent to the coast. However, the position of the plume on a given day is highly variable and its location is determined by regional winds and ambient currents.

Coastal upwelling replenishes nutrients to the photic zone, where they can result in enhanced and sustained productivity during the spring and summer which supports higher trophic levels. The continental shelf in this region is narrow, of order 10–40 km, with submerged river mouths, canyons and prominent capes at a few locations. Complex bathymetry may enhance deep-ocean-continental shelf exchange and biological productivity. Submerged shelf-banks are not common along the U.S. West Coast, but one does occur off Oregon (Heceta Bank) and has significant fisheries associated with it, suggesting that upwelling and productivity are enhanced near the bank.

Why the California Current System?

The U.S. GLOBEC program seeks to determine how climate change and climate variability affect abundances, distributions and productivity of animals in key ecosystems of the coastal ocean. Scientific and strategic criteria for the selection of GLOBEC study sites include (list not exhaustive): demonstrated connections between ecosystem responses and climate forcing; important zooplankton and fish species as targets for research; a focus on processes and mechanisms; extensive historical database/archives for comparison; and potential for international collaborations. Studies in the California Current System (CCS) are ideally suited because they meet these criteria. It was recognized early in the development of the CCS program that, "The overall goal of GLOBEC data collection is to capture the variability to which the biological system is most sensitive, regardless of the space and time scales at which it occurs." (U.S. GLOBEC, 1992, p. 19). The

California Current program emphasizes studies of processes that occur at peaks in the space-time spectrum of variability (Haury et al., 1978; Mantua et al., this issue) and which may be affected by a changing global climate. Specific study sites and species are selected that best allow exploration of those peaks. Spatial scales in the CCS are partially determined by bottom topography, coastal geometry and the spatial pattern of atmospheric forcing (U.S. GLOBEC, 1994), but are also strongly controlled by the intrinsic scales of hydrodynamic instabilities of the frontal jet (Allen et al., 1991; Pierce et al., 1991; Barth, 1994). Thus spatial scales of interest range from a few tens of kilometers across the frontal jet to several hundreds of kilometers in offshore meanders and eddies. The range of time scales of interest are broad and include upwelling events (days to a week), seasonal changes (months), interannual El Niño occurrences and interdecadal "regime shifts".

Climate variability at interannual and interdecadal time scales significantly affects overall biological productivity, including the abundance, distribution, growth and survival of living marine resources. Although the basic processes, e.g. coastal upwelling, responsible for the generally high production of the California Current are known, the specific mechanisms responsible for interannual variability in primary and secondary productivity are not well understood. The biophysical linkages between lower trophic productivity and production at higher trophic levels are also poorly known. Much of what is understood of atmospheric forcing, ocean structure and dynamics, and the biological response of the California Current System results from a few long-term data sets (CalCOFI, Line P), and from previous process-oriented investigations (e.g. CUEA, CODE, ONR-CTZ, ONR-EBC) in the region. Unfortunately, earlier process studies were of limited duration and none included biological measurements of trophic levels higher than phytoplankton and zooplankton.

Study Site

The region of the CCS selected for study ranges from Crescent City, CA (41°54'N) to Newport, OR (44°39'N) (Figure 1). This spans a 300 km region alongshore that includes a major cape (Cape Blanco; 42°50'N) and a substantial shelf-bank (Heceta Bank; 44°N). Both of these features impact productivity and ecosystem structure. The regions north and south of Cape Blanco differ in several respects. Spring and summer upwelling favorable winds are weaker and more intermittent north of Cape Blanco, compared to the strong, sustained winds near and south of Cape Blanco. Also, interactions of the equatorward alongshore jet with Cape Blanco's coastline geometry result in different ocean responses in the two regions. North of Cape Blanco, and especially north of Heceta Bank, the upwelling front and zone of coldest, nutrient-rich water is restricted to relatively nearshore regions. As

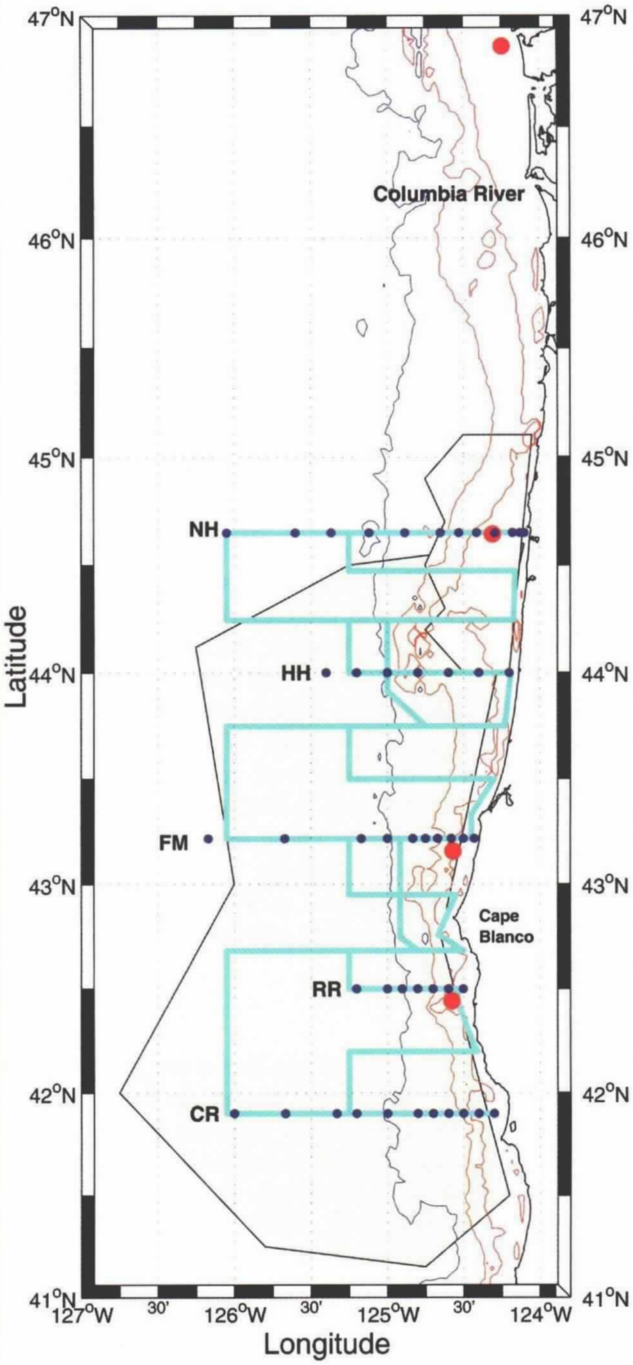

Figure 1. *U.S. GLOBEC NEP sampling off Oregon and Northern California during 1997–2003. Light green and yellow colored regions are the ocean areas sampled by the long-and standard-range high-frequency surface radars, respectively. Small dots are the locations of standard LTOP sampling sites. Red circles are locations of instrumented moorings. Continuous thick lines are sampling lines for mesoscale surveys in summers of 2000 and 2002. Thin colored lines show the 100, 200 and 1000m bottom contours. Major LTOP sampling lines are: NH = Newport; HH = Heceta Head; FM = Five Mile (Coos Bay); RR = Rogue River; CR = Crescent City.*

the jet nears Heceta Bank, the strong flows interact with the topography to divert the jet offshore, around the bank. Further south the jet interacts with Cape Blanco and the poleward undercurrent and is displaced again offshore, so that south of Cape Blanco the jet can be several hundreds of kilometers offshore (Barth et al., 2000). Interactions of the flow with submarine and coastal topography may impact local productivity and the transfer of productivity to higher trophic levels. Moreover, eddies are produced that can persist for sustained periods, and may be sites of high biological growth, while retarding along or cross-shelf transport. As discussed in Strub et al. (this issue), GLOBEC also selected the Northeast Pacific because of the opportunity it affords for making comparisons between the CCS and the Coastal Gulf of Alaska (CGOA; see Weingartner et al., this issue) systems. These two systems have populations and ecosystems responding to different regional forcing—wind-forced upwelling vs. wind- and buoyancy-forced downwelling—yet common large-scale atmospheric forcing.

> *The mechanisms connecting environmental change and population dynamics at present and in the past are assumed to be the important mechanisms operating in scenarios of future climate variability.*

Target Species and Management Implications

Target species in the CCS are copepods of the genus *Calanus*, the euphausiids *Euphausia pacifica* and *Thysanoessa spinifera*, and juvenile coho (*Oncorhynchus kisutch*) and chinook (*O. tshawytscha*) salmon. Coastal ocean conditions and productivity strongly impact the growth and survival of juvenile salmon during their first summer at sea (Fisher and Pearcy, 1988; Pearcy, 1992) and may largely determine subsequent year-class strength.

As in other GLOBEC programs, one of the goals in the NEP is to provide greater understanding of fluctuations in marine resources, thereby reducing the uncertainty that plagues fishery management. However, because salmon are anadromous (i.e. they return to freshwater to reproduce), they are unique among GLOBEC focal species. Resource management decisions on land, such as those involving dams, water diversions and habitat modification often consider the impacts on salmon populations. Throughout the CCS, the question of whether anthropogenic effects on land or natural changes in ocean conditions are responsible for declining salmon populations is at the center of these environmental management decisions. The NEP program will provide a better understanding of the role of oceanic and climatic variability to different salmon populations. This information will help reduce the uncertainty that impairs a variety of environmental management decisions (Botsford and Parma, in press). The combination of the commercial and cultural importance of salmon, coupled with the fact that many stocks are at low levels and listed under the U.S. Endangered Species Act, underscores the potential value of GLOBEC CCS findings.

Although salmon and a few zooplankton species are the target taxa in the CCS for process studies, other species will be studied when they interact as predators, prey or competitors with the key species. Thus, the program is estimating the abundance and impacts of seabirds, marine mammals, sardines, anchovies, and other pelagic fishes on the target species. The program intends to collect sufficient data on species at all trophic levels to enable explicit comparisons with studies from other regional and international GLOBEC programs.

The GLOBEC Approach Applied in the CCS

The NEP-CCS program uses the U.S. GLOBEC approach of examining the effects of past and present environmental variability on population ecology of select marine taxa. The mechanisms connecting environmental change and population dynamics at present and in the past are assumed to be the important mechanisms operating in scenarios of future climate variability. This allows the development of conceptual and computer models to explore population responses to projected future environmental changes. To accomplish this goal, the program uses the strong temporal variability in physical and biological systems to examine biophysical *mechanisms* linking zooplankton and salmon populations and their physical environment. This is accomplished through a combination of research components: long-term observation programs (LTOPs); process studies; spatial surveys of mesoscale features (20–200 km); remote sensing; modeling; and retrospective data analysis (see tables at: http://globec.coas.oregonstate.edu/groups/nep/misc/outreach/ccs_cgoa_table.html).

Observational Program

Variability at annual and interannual time scales is sampled directly through LTOPs, process and mesoscale survey cruises. Beginning in autumn 1997, 4–5 seasonal LTOP cruises per year have been conducted and these will continue through autumn 2003 (see Huyer et al., 2002; Kosro, 2002; Peterson et al., 2002). On spring-summer (March–September) cruises, five transect lines are sampled between Newport and Crescent City; during the winter (November and February) only one line (Newport) is sampled (Figure 1). Table II at http://globec.coas.oregonstate.edu/groups/nep/misc/outreach/ccs_cgoa_table.html summarizes the observations made during LTOP cruises. Moorings at 75–80 m water depth off Grays Harbor, WA, Newport, Coos

Bay, and Gold Beach, OR provide continuous records of currents, hydrography at multiple depths, and fluorescence at a single depth. High-frequency radar measurements provide hourly and daily average surface current maps out to 50 km offshore near Newport, and out to 160 km from shore over a larger longitudinal range with new radar tools (Kosro and Paduan, 2002). Satellite remote sensing (altimeter, SeaWiFS, AVHRR) provide data on sea surface height, chlorophyll biomass and sea surface temperature.

During intensive field years (2000 and 2002) the LTOP, mooring and radar observations are complemented by focused mesoscale survey and process cruises to evaluate the seasonal evolution of the ecosystem during the productive spring and summer months, and to compare this evolution between two years. This requires three vessels operating simultaneously: (1) a mapping vessel to measure the three-dimensional spatial fields; (2) a process-study vessel to conduct quantitative studies for calibrating the acoustical and optical information collected by the spatial surveys and to conduct shipboard incubations of zooplankton; and (3) a chartered commercial fishing vessel to quantitatively sample juvenile salmon and other fish. These surveys provide data describing the physical environment (ocean hydrography, circulation, nutrient concentration) and the biomass of plankton (using remote acoustics, optics and nets). Data from the trawl vessel are used to determine salmon distributions, size, age, diet and condition. The distribution of salmon predators, including birds and mammals, and their potential impact on salmon are also estimated from the surveys. Interactions of juvenile salmon with other fish and invertebrate species, as competitors for prey or alternative prey for predators, are being examined. Experiments conducted on the process study vessel provide information on vital rates for the target copepod and euphausiid species.

Process studies in the NEP focus on the causes of salmon mortality, growth of salmon and on measuring the vital (esp. production) rates of other target taxa in the nearshore region. Process studies are geographically focused on the Heceta Bank and Cape Blanco regions, where strong flow-topography interactions appear to affect the cross-shelf distribution of physical, chemical and biological properties and influence ocean productivity.

Retrospective Analysis

Variability at longer (interdecadal) time scales is being examined by retrospective analysis of existing long-term data sets. Records of salmon catch from the CCS and CGOA suggest that the biological productivity of these ecosystems are negatively correlated with characteristic periods of several decades (see Figure 1 of Strub et al., this issue). The responses of these salmon stocks may reflect fundamental changes in coastal productivity of the two regions to large-scale forcing. Recent reanalysis of the salmon catch data from the NEP by GLOBEC investigators (Botsford and Lawrence, in press) indicates that the response to the ocean changes is species specific (Figure 2). Abundances of sockeye, pink, and coho salmon in Alaska and coho salmon in the PNW have responded strongly to large-scale changes in the marine climate (as evidenced by the Pacific Decadal Oscillation [PDO] index; Mantua et al., 1997). However, chinook salmon populations in both the PNW and Alaska remained nearly constant during 1950–1990, which encompassed the time of the major 1976-'77 shift in ocean conditions. The effects of changing ocean conditions during "regime shifts" in the Northeast Pacific are being examined also using historical ichthyoplankton collections, fish scale data, and the archives of zooplankton collections made during CalCOFI and off Oregon.

Models

Modeling is an important component of the NEP program. Data collected to describe and better understand the effects of climate variability and change on the distribution and production of plankton and fish are being used to build diagnostic and prognostic models of ecosystem dynamics. Several types of coupled models are being developed. First, numerical models of ocean circulation and hydrographic structure are being coupled at basin-, NEP-wide, and regional-scale, with horizontal resolutions of 40, 10 and 3 km, respectively. Second, at the regional and NEP-scale these circulation models are being coupled with Eulerian NPZ+ ecosystem models, and Lagrangian particle tracking models for mesoplankton and fish, some of which include behavior (Batchelder et al., in press). The eventual goal is to simulate "typical" ocean conditions during different recognized regimes in the NEP, and to evaluate how those ocean conditions affect productivity, advection and retention in coastal zones. In addition, simulations will be forced with atmospheric conditions (wind, heating) from specific years to compare with observations from the GLOBEC NEP field years. Modeling is also used to examine how population dynamics and life history contribute to variability in salmon populations and metapopulations (groups of salmon stocks from different spawning streams, linked by straying) in the CCS (Botsford et al., in press; Hill et al., in press).

Scientific Highlights

Most of the results that have been reported to date are the result of the initial monitoring, modeling and retrospective projects begun in 1997. Approximately two dozen papers funded by GLOBEC NEP appear in three special volumes of *Progress in Oceanography*, and additional papers are published or in press in other journals. Scientists who were involved in the cruises of 2000 are actively analyzing their data and preparing for the second year of intensive field studies. Consequently, the results presented below are preliminary.

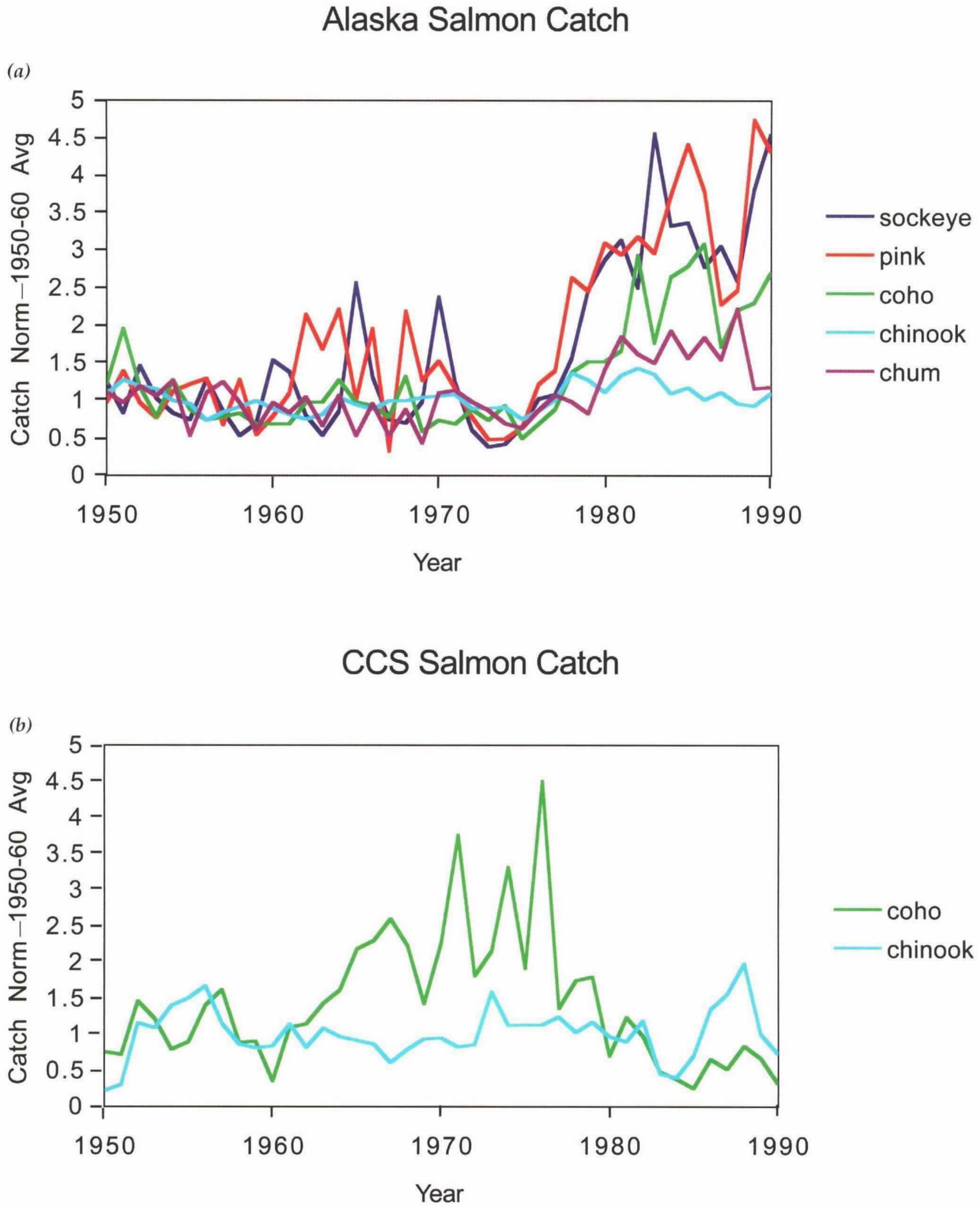

Figure 2. Catches of ***a)*** *salmon species in Alaska and* ***b)*** *coho and chinook salmon in the California Current System. To place all species data on the same scale, each catch series was divided by its mean for the period 1950–1960. Note that there are no comparable catches of salmon in the CCS after 1990 because salmon populations were so low in abundance that commercial harvests were ended or severely reduced. Figure from Botsford and Lawrence (in press).*

Documented Temporal Ecosystem Change

The GLOBEC NEP program has been fortunate to occur at a time when ocean conditions in the Northeast Pacific have experienced strong climate signals—including a strong El Niño of 1997–98, the subsequent La Niña, and perhaps a "regime shift" in late-1998. The species composition of zooplankton ranging from the CalCOFI region (Mark Ohman, pers. comm.) through the GLOBEC CCS region to the shelf off Vancouver Island (Peterson and Mackas, 2001), and the survival rate of coho salmon all indicate a shift from a warm, low-production regime to a cool, highly-productive regime in the CCS (Figure 3). It remains to be determined whether this shift is a manifestation of a low-frequency "regime-shift" or a residual effect of the El Niño-La Niña of 1997–1999. In either case, the GLOBEC NEP sampling has a strong signal to work with, in both physical and biological fields and time series. Early recognition of low-frequency changes in the ecosystems of the CCS, like that postulated to have occurred in 1998, would be particularly valuable for implementing appropriate environmental management decisions-especially if these changes impact upwelling dynamics, stratification intensity or the frequency or intensity of ENSO events.

Strong Flow-Topography Interactions

The field surveys of 2000 occurred during a summer that experienced reasonably typical wind forcing (Figure 4). Winds were primarily from the north (upwelling favorable) through most of the summer. These southward winds were briefly interrupted by short episodes (a few days) of slack or northward winds throughout the summer, except for the latter half of June which was consistently and persistently upwelling favorable. A strong storm with winds from the south occurred during 6–12 June, while the other downwelling periods were less intense. Current meters on the midshelf moorings indicate that near-surface flow was nearly always southward, with a slight offshore mean, as would be expected during upwelling periods (Figure 4). During spring, the deeper flow was also toward the south on average, but weaker and interrupted by periods of flow to the north. In summer, the deeper flow was as likely to be northward as southward. Springtime temperature records from near 20-m depth on the three LTOP moorings show coherent episodes of near-surface warming, associated with wind reversals. Near-surface salinity (not shown) from the moorings decreased during these warming events, suggesting the changes were due to onshore movement of warm, low salinity water from the Columbia River plume.

The coastal ocean off Oregon and northern California responds quickly (within a day) to upwelling and downwelling wind events. Early in the upwelling season during the June 2000 survey (not shown), cold, high-nutrient waters were almost completely confined to the shelf, i.e. waters less than 200 m depth (Barth et al., 2002). Small, localized regions of high chlorophyll (up to 5–7 mg m^{-3}) were found over Heceta Bank and near Coos Bay, Rogue River and Crescent City. During the strong summertime downwelling-favorable wind event in early June, inshore currents flowed poleward at up to 0.5 m s^{-1}, and warm, chlorophyll-poor surface waters were forced back onshore and downward near the coast (Barth et al., 2002). With the return of episodic upwelling-favorable winds separated by relaxation events, the typical coastal upwelling response was re-established.

Figure 5 demonstrates the important role of interactions of ocean currents and shelf topography in determining species distributions and ocean conditions off Oregon and Northern California. These plots show distributions of temperature, chlorophyll concentration, copepod abundance, juvenile salmon, birds and mammals obtained from a three-vessel survey of ocean conditions during August 2000. Near-surface nutrient (silicate, nitrate) distributions (not shown) largely reflect upwelling processes and vary inversely with temperature-e.g. higher nutrient concentrations nearshore where upwelling is strong and temperatures low, and lower concentrations offshore where surface temperatures are higher. There are clear patterns in the distributions, with concentration of salmon, copepods, and predators (birds, mammals) nearshore, and especially over Heceta Bank and near Cape Blanco. The pelagic trawl surveys show that juvenile chinook and coho salmon were distributed almost entirely on the shelf both north and south of Cape Blanco (Brodeur et al., in press). More than half the catch of coho and chinook salmon came from the shallowest quarter of the tows made, with coho salmon distribution tending to be displaced slightly offshore relative to chinook. Yearling chinook juveniles tend to be associated with cooler water in newly upwelled regions. Clear differences were observed in the distribution, migration patterns and condition of salmon north and south of Cape Blanco. Nearshore bird biomass is comprised primarily of common murres and sooty shearwaters, with the shearwaters occurring seaward of the murres (Ainley et al., pers. comm.). Humpback whales were associated with regions of Heceta Bank having relatively high biomass of juvenile salmon (Tynan et al., pers. comm.).

A region of warm water, up to 3°C warmer than adjacent upwelled water, was present inshore on the southern part of Heceta Bank (44°15'N, 124°25'W) (Figure 5). This feature has a clockwise circulation around it and is evidently a meander in the coastal upwelling front jet in the lee of Heceta Bank (Barth et al., 2002). This meander was observed often during spring and summer in satellite images of sea-surface temperature. Although this feature contains warm, salty, low-nutrient oceanic water, high concentrations of copepods are found throughout its extent and very high abundances of salmon, humpback whales and birds are found on its inshore edge (Figure 5).

The temperature and chlorophyll fields indicate

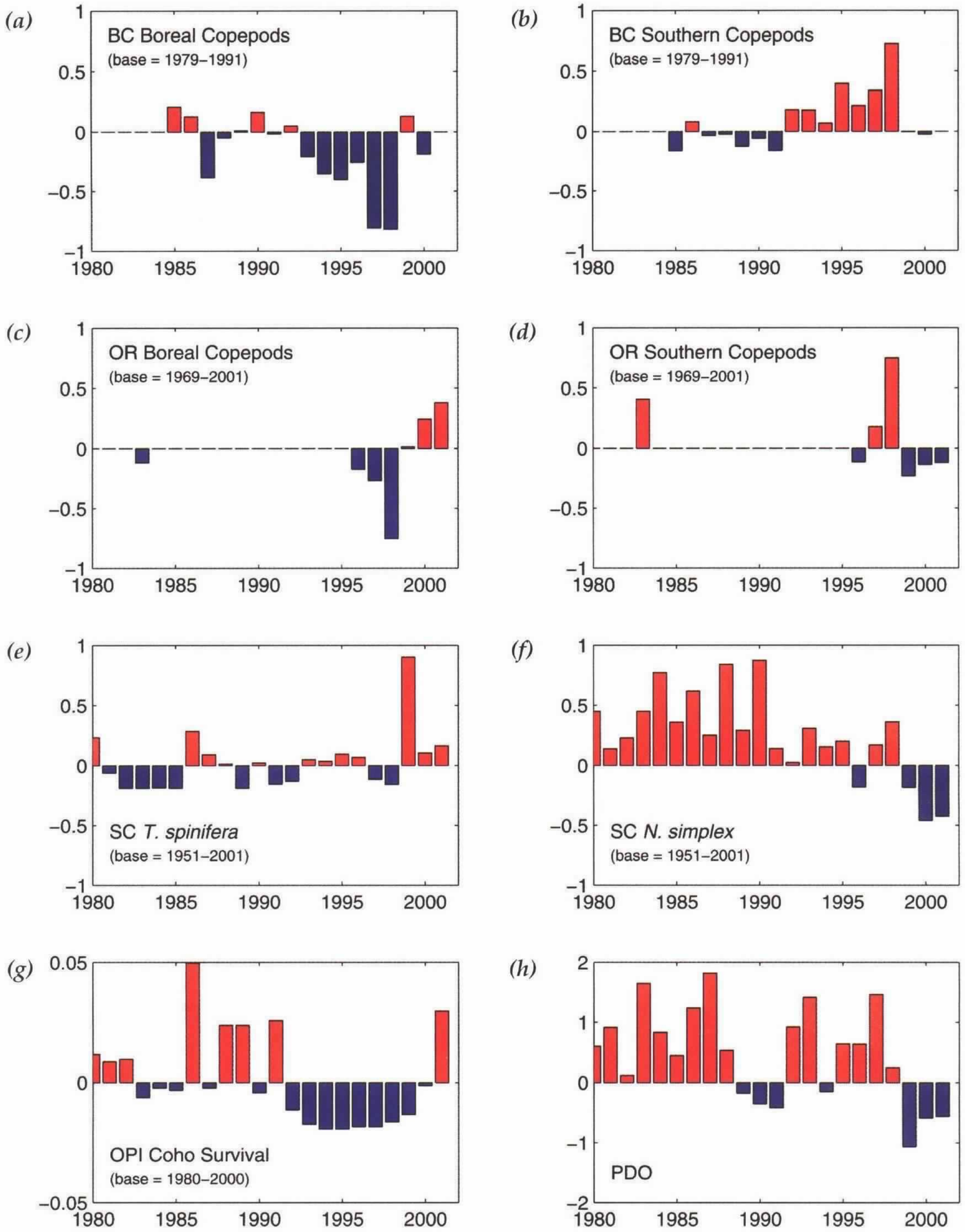

Figure 3. *Anomaly time-series of selected biological observations in the California Current System for the period 1980–2001. The base period for calculating mean biomass, abundance or survival is noted in each panel. Panels* ***a-b)*** *show biomass of boreal copepods and southern copepods off the west coast of Vancouver Island, British Columbia. Panels* ***c-d)*** *show numerical abundance of boreal and southern copepods off Newport, Oregon. Panels* ***e-f)*** *show biomass for the euphausiids,* Thysanoessa spinifera *(a northern species) and* Nyctiphanes simplex *(a southern species) from off Southern California. Panel* ***g)*** *shows the ocean survival rate (ocean entry to spawning return) for coho salmon from the Oregon Production Index (OPI) area from California to Willapa Bay, WA. Panel* ***h)*** *shows the annual mean Pacific Decadal Oscillation (PDO) Anomaly, which is an index of sea surface temperature variability poleward of 10N. Anomalies for panels a-f are in log units (e.g., an anomaly of 1.0 equals a factor of 10 difference from the base mean). Anomaly for panel g) is percent survival (0.05 is a 5% higher survival rate than the base mean). Data are courtesy of David Mackas (a,b), Bill Peterson (c,d), Ed Brinton and Mark Ohman (e,f), and Ric Brodeur (g).*

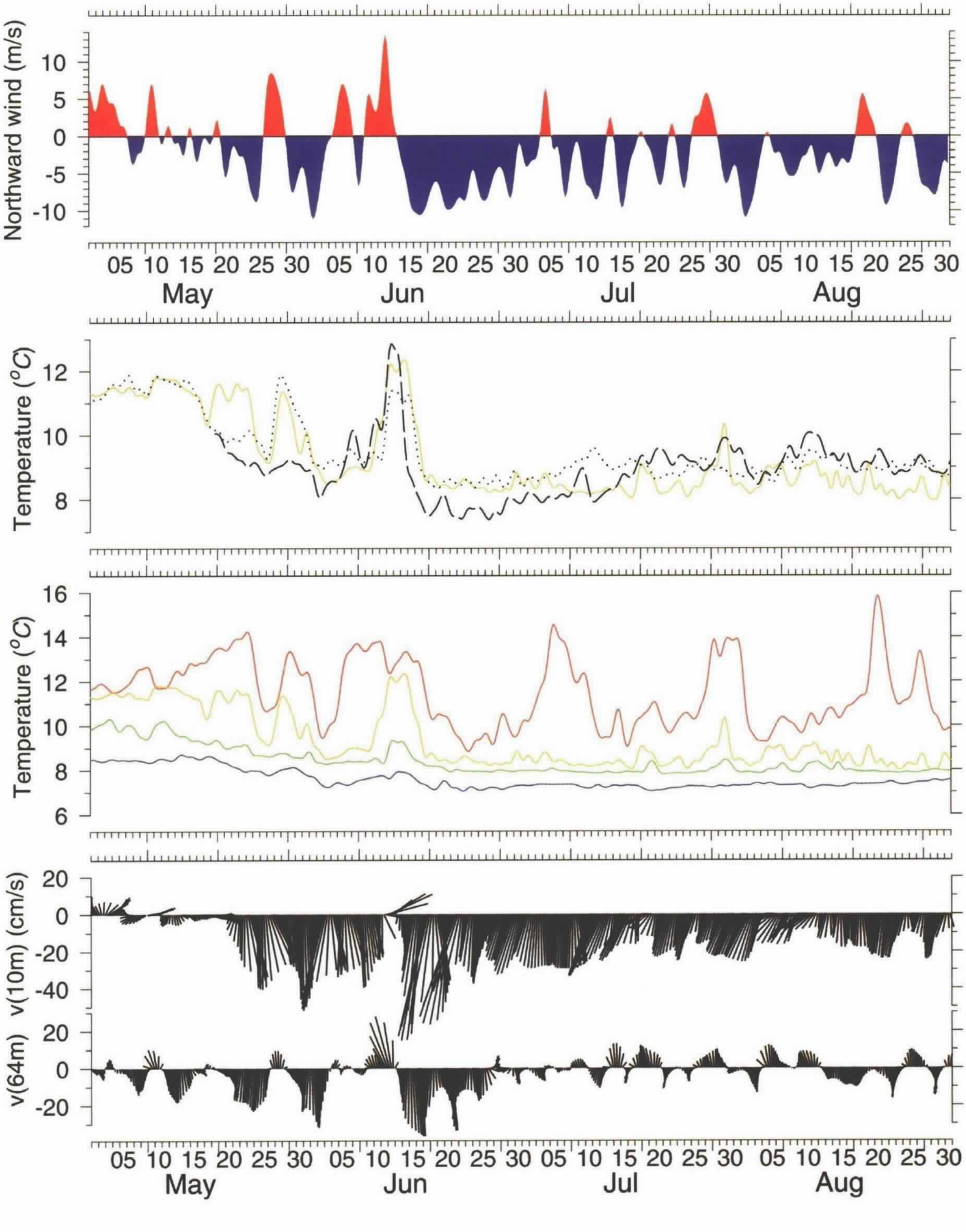

Figure 4. Time-series at LTOP moorings midshelf off Oregon, near Newport (44°64'N, 124.31'W), Coos Bay (43°16'N, 124°57'W) and Rogue River (42°44'N, 124°57'W). ***a)*** *Northward component of wind speed from the NOAA weather buoy offshore of Newport.* ***b)*** *Temperatures from 20m below the surface off Newport (orange), 21m off Coos Bay (dotted), and 22m off Rogue River (dashed).* ***c)*** *Temperature from 2m (red), 20m (solid orange), 35m (green) and 10m above the bottom (71m, blue) at Newport mooring.* ***d)*** *currents at 10m and 64m off Newport; rotated so current toward 21T points upward. All data have been filtered to remove tidal and higher frequency variability. Data from the Newport, Coos Bay, and Rogue River moorings from Mike Kosro, Barbara Hickey, and Steve Ramp, respectively.*

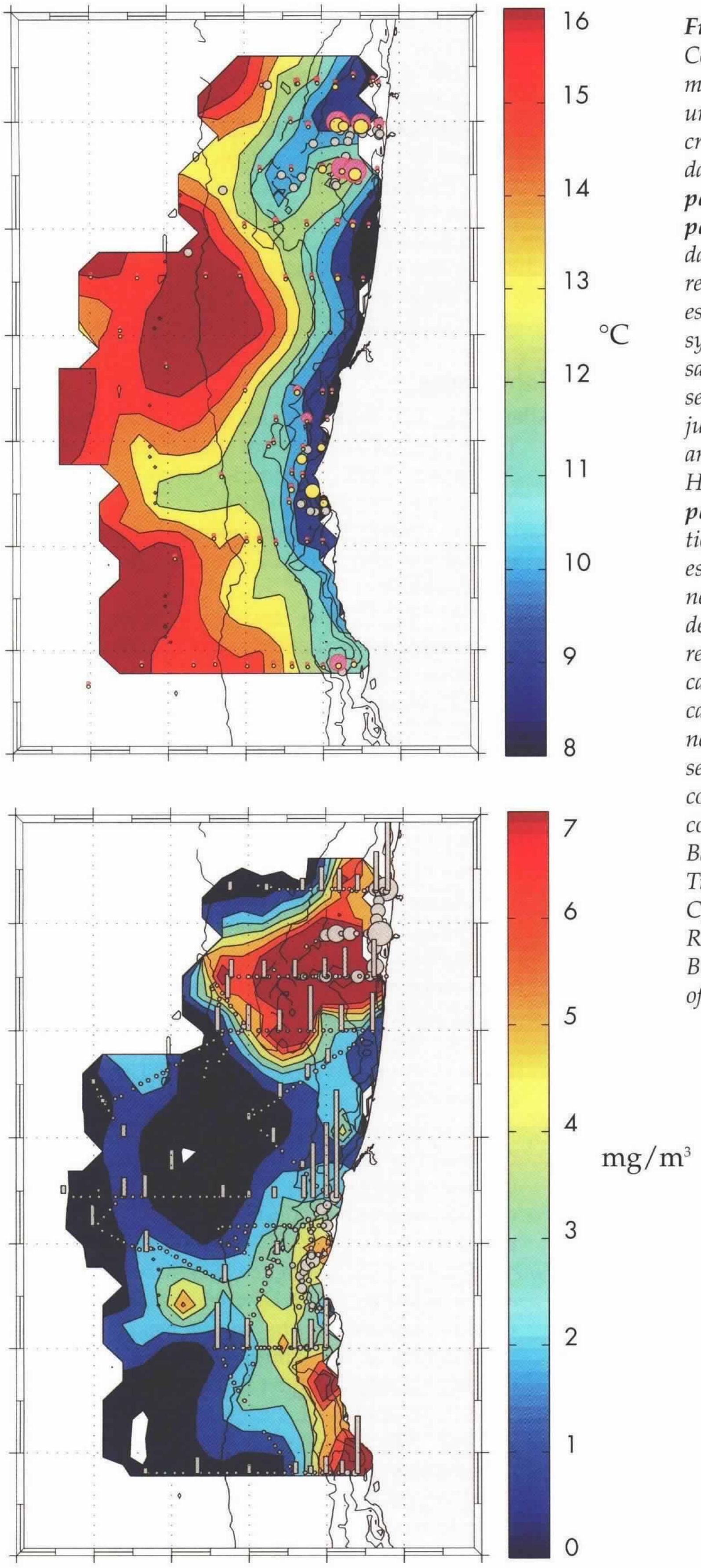

Figure 5. *August 2000 mesoscale survey data. Color contours show temperature (°C) at 5 meters depth from sensors on a towed SeaSoar undulator. Approximately, 12 equally spaced cross-shelf transects were used to provide the data for the contouring of temperature* ***(top panel)*** *and chlorophyll* ***(bottom panel). (Top panel)****, yellow and magenta circles are abundances of juvenile chinook and coho salmon, respectively. The largest circles represent catches of ca. 10 fish per standard trawl. Smallest symbols (offshore) represent trawls in which salmon were not found. The grey circles represent sightings of humpback whales. Note that juvenile salmon were found over the shelf only, and humpback whales were concentrated on Heceta Bank and near Cape Blanco.* ***(Bottom panel)****, color contoured chlorophyll concentration (mg m^{-3}) at 5 meters depth, showing highest concentrations over Heceta Bank and nearshore south of Cape Blanco. Gray circles depict seabird biomass (kg km^{-2}); largest circles represent 170 kg km^{-2}. Histograms (bars) indicate total copepod biomass (mg m^{-3}) from vertical plankton tows spanning the upper 100m or near bottom (if shallower). Tallest bars represent copepod biomass of 65 mg m^{-3}. Note the concentration of bird biomass nearshore and copepod biomass nearshore and on Heceta Bank. SeaSoar data courtesy of Jack Barth and Tim Cowles. Whale sighting data courtesy of Cynthia Tynan. Salmon data courtesy of Richard Brodeur. Zooplankton data courtesy of Bill Peterson. Bird biomass estimates courtesy of David Ainley.*

that a filament of coastal water was swept offshore near Cape Blanco, then northward forming a large meander in the upwelling jet and front. Inshore of this filament, near 43°30'N 125°15'W, warm, low-chlorophyll water was found. Net samples from within the core of the offshore cold filament were dominated by *Pseudocalanus mimus*, a coastal species, indicating the transport of coastal waters offshore more than 100 km (Bill Peterson, pers. comm.). Other copepod species, *Acartia longiremis* and *Calanus marshallae*, characteristic of shelf waters north of Cape Blanco, were abundant in nearshore regions of the filament, but were not common in the farthest offshore part of the filament (near 43°15'N, 125°50'W). These results suggest that different coastal copepod species have varying abilities to survive and grow in offshore regions, with *Pseudocalanus* the most resilient.

Summary and Conclusions

The field observations of the NEP CCS are now about half completed. We have been fortunate to sample during a period when climate signals have been strong, providing an opportunity for the program to witness contrasting responses of the coastal ocean ecosystem. We have learned that some of the shelf zooplankton that are swept offshore in the squirts and jets can survive, while other shelf species either avoid being swept offshore or die quickly once offshore, since they are rarely encountered in the offshore jet waters. Juvenile coho and chinook salmon were never found in the offshore, deep (water >200 m) region during extensive sampling conducted in 2000. The swimming ability of the juvenile salmon may be sufficient to prevent them from being transported offshore as the jet encounters the influence of Heceta Bank and Cape Blanco.

We have been fortunate to sample during a period when climate signals have been strong...

Similar studies to those conducted in 2000 will be conducted in 2002. One difference, arising from the knowledge gained from the 2000 fish surveys, will be a decreased emphasis on sampling fish and plankton in the offshore regions—focusing rather on the shelf regions where the fish are most abundant, and trying to understand the physical and biological characteristics of the habitat important to salmon survival.

LTOP, mooring and HF radar observations in the CCS will continue until 2003. The datasets generated during the program from 1997–2003 will be valuable for developing and testing coupled biophysical models. We anticipate that the field phase of the CCS program will be followed by a synthesis phase which will include the CGOA as well (Weingartner et al., this issue). These regions have very different local forcing—wind-forced upwelling vs. wind-and buoyancy-forced downwelling—but are driven by common large-scale atmospheric pressure systems which makes the comparison of these two ecosystems instructive. Moreover, cross-synthesis between the Northeast Pacific program and other US GLOBEC projects in the Northwest Atlantic (Wiebe et al., this issue), Southern Ocean (Hofmann et al., this issue), and international (PICES, International GLOBEC) programs will be critical to achieving the overall understanding of marine ecosystem variability that is the GLOBEC goal.

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