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Editorial

Physical and biological patterns, processes and variability in the northeast Pacific

The US GLOBEC (GLOBal Ocean ECosystems Dynamics) program in the northeast Pacific (NEP) began investigations in 1997 on the effects of large-scale climate change and shorter-term interannual and seasonal variability. While planning a Pacific regional program, it was realized that while the California Current System (CCS; from about Vancouver Island south on the west coast of the US), and the Coastal Gulf of Alaska region (CGOA; north of Vancouver Island and as far west as the eastern Aleutian Islands) differ in their dominant physical processes, they are also inextricably linked. For example, they share source waters from the North Pacific Current, and species such as salmon and important zooplankton taxa. Moreover, the dominant patterns of climate variability in the eastern North Pacific encompass both regions. These connections presented an opportunity to compare how climate variations are expressed on ecosystems dominated by wind-forced upwelling (the CCS) and by wind-forced downwelling and freshwater run-off (the CGOA). The NEP program was implemented as a linked set of studies, with complementary and similar observations being made in both the regions. In both regions, modeling and long-term observation programs were initiated in 1997, and continued through 2003 or 2004. Due to limited research vessel availability it was not possible to intensively sample both regions in the same year, so intensive seasonal field campaigns were conducted in 2000 and 2002 in the CCS, and in 2001 and 2003 in the CGOA. Fig. 1 shows a timeline of studies undertaken in the NEP in both regions. Since the field studies were "discontinued" (at least with funding from US GLOBEC), GLOBEC has continued to support analysis of the ocean data sets and synthesis of these data and model products (and will do so through 2010). Importantly, in each of these regions, the value of sustaining some routine observations along the main GLOBEC study lines (NH line off Oregon; Seward (GAK) Line off Alaska) was recognized and other funding programs (NOAA's NMFS PaCOOS; North Pacific Research Board) have provided funds to maintain a minimal set of core observations along these lines; time-series for these two lines are now more than one decade in length (Fig. 1). Between the CCS and CGOA regions lies the Pacific coast of Canada, which has been sampled by Canadian scientists, and in some locations (shelf off Vancouver Island) for longer than the observations off of the US. Additional details on the goals and studies undertaken by US GLOBEC in the NEP are discussed elsewhere (Batchelder and Powell, 2002; Strub et al., 2002), with more specifics for the CCS and CGOA available in Batchelder et al. (2002) and Weingartner et al. (2002), respectively.

As Fig. 1 indicates, GLOBEC's NEP program is now midway through its regional synthesis and pan-regional synthesis phases. Eleven of the 12 papers in this issue report results from activities undertaken primarily in field phases I and II, and some from the NEP regional synthesis phase. Most of the papers focus more on the CGOA than on the CCS. One additional paper reports results on the nutrient and phytoplankton responses of the waters off Vancouver Island to the strong interannual forcing of the 1997–1998 ENSO event. For introduction here, the twelve papers are grouped into three categories: four papers focus on physics of the CGOA and descriptions of eddies in the Gulf of Alaska; four papers focus on nutrient conditions or models of nutrients, phytoplankton and lower trophic levels; and four papers focus on patterns, dynamics and/or models of marine plankton and salmon.

The first group of papers includes two papers that model the physics of the GOA region using the Regional Ocean Modeling System (ROMS) and two papers that describe physical and biological characteristics of GOA eddies. Dobbins et al. (2009) describe their implementation of a regional scale 3 km horizontal resolution ROMS model of the northern Gulf of Alaska that successfully reproduces both the cross-shelf water mass structure, and the seasonal vertical structure of the water column. The model produces distinct nearshore and offshore regions with a meandering transition zone that is consistent with the observations. Surface-mixed layers are generally shallower than observations indicate, but have appropriate seasonal variation. A set of simulation experiments explored methods for handling the run-off of freshwater, and the sensitivity of the flow on the shelf to tidal mixing and winds. Hermann et al. (2009a) use a series of one-way nested ROMS domains to examine the importance (contribution) of remote and local influences of the 1997–1998 El Niño on the Gulf of Alaska. Remote forcing was that due to changes in velocity and temperature outside of the NEP domain, whereas local refers to direct forcing by winds and run-off inside the NEP domain. Model results indicate that sea surface height anomalies penetrate the NEP domain from the basin-scale domain (remote forcing), with propagation of coastal trapped waves from Baja California to Alaska. Nevertheless, most of the coastal sea level response in Alaska was due to local forcing during this El Niño.

The properties (size, strength, duration, salt, heat, chlorophyll, and propagation speed) of two large diameter (ca. 200 km), long-duration, anticyclonic eddies are described by Janout et al. (2009).

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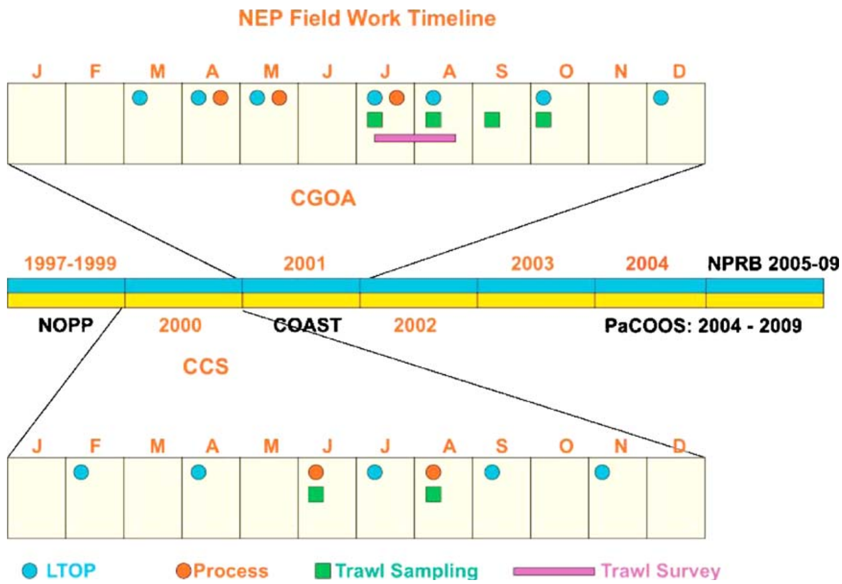

Fig. 1. Timeline of selected field research within the Coastal Gulf of Alaska (CGOA; upper timeline) and California Current System (CCS; lower timeline) since 1997. Seasonal timing of research cruises and types of activities are highlighted by month for 2000 in the CCS and 2001 in the CGOA. Process cruise studies (and trawl sampling in CCS) were done in years 2000 and 2002 only in the CCS, and in 2001 and 2003 only in the CGOA. US GLOBEC research (exclusive of process studies) in the CCS occurred during 1997–2003, and in the CGOA during 1997–2004. Other process-oriented programs in the CCS include a National Ocean Partnership Program (NOPP) study in 1999 and a Coastal Ocean Advances in Shelf Transport (COAST) program in 2001. Since GLOBEC studies were ended, the NOAA Fisheries funded Pacific Coast Ocean Observing System (PaCOOS) program has made 1-2 LTOP cruises per year in the CCS, and the North Pacific Research Board (NPRB) has supported 2 LTOP cruises per year in the CGOA. Not shown in the figure is GLOBEC's NEP regional synthesis phase (2005–2008) and Pan-regional synthesis phase (2008–2010).

In situ observations (e.g., ARGO floats, research cruise observations) and satellite altimetry are combined to describe the evolution of continental slope eddies originating from near Yakutat in the northeastern GOA. Repeat surveys (May, August) of an eddy revealed little apparent exchange of water masses across the lateral boundaries. When Yakutat eddies approach the shelf-break, however, nonlinear processes become important, and the eddy may influence the circulation of the slope flow, the stability of the shelf-break front, and water from the shelf may be transported to the deep basin. Ladd et al. (2009) describe the characteristics of eddies of Haida, Sitka, and Yakutat origin based largely on a single cruise conducted in spring 2005. Observations of hydrography, macro- and micro-nutrients, chlorophyll and zooplankton were made while transiting through each eddy. Temperature and salinity of the individual eddies reflected the region of origin with warmer and saltier water in the Haida eddy. Macro- and micro-nutrients (iron) were highest and chlorophyll was lowest in the Yakutat eddy compared to the other eddies, suggesting that less primary production and nutrient uptake had occurred prior to the survey, or that the Yakutat eddy was too young for much production to have occurred.

The northern Gulf of Alaska is highly productive, even though it is subject to primarily downwelling favorable winds. A variety of mechanisms have been proposed for how nutrients might be injected onto the shelf from offshore regions (Weingartner et al., 2002). One proposed mechanism is through shelf-break eddy interactions, such as those that might occur from eddies described in the prior paragraph. Other propositions include topographically induced upwelling and canyon-associated onshore flows. Hermann et al. (2009b) use a coupled biophysical model of lower trophic levels in the CGOA to quantify horizontal and vertical nutrient fluxes to the euphotic zone on the shelf. Results from the model suggest that there are significant "rivers" of nutrients (horizontal fluxes) and "fountains" of vertical nutrient flux on shallow banks due to tidal mixing of higher nutrient concentration deep waters. Nutrient budgets also reveal significant local wind stress curl-forced upwelling of nutrients over large regions of the shelf.

Off the west coast of Vancouver Island, Harris et al. (2009) document the seasonal, spatial, and interannual variability of nutrients and phytoplankton during the 1997–98 ENSO event. The results from multiple cruises of the Canadian GLOBEC program indicated large phytoplankton blooms in summer 1998 during a non El Niño year, contrasting strongly with the lower total chlorophyll, phytoplankton biomass and diatom abundance and biomass observed in summer 1997. Dynamics of phytoplankton production and phytoplankton composition was strongly influenced by different stratifications, mixed layer depths, and sources of water masses on the shelf during the two contrasting years.

Two papers in this issue describe lower trophic (Nutrient–Phytoplankton–Zooplankton–Detritus) ecosystem models coupled to three-dimensional coastal ocean circulation models. Fiechter et al. (2009) use an ecosystem model with relatively basic biological components but with the inclusion of two additional state variables to represent dissolved iron and bioavailable iron already incorporated into phytoplankton. Iron limitation is implemented as a saturating function of the phytoplankton realized iron:carbon ratio. Monthly fields for 1998–2004 are analyzed and compared with observed spatial and temporal patterns (e.g., spring bloom timing, cross-shelf production). Overall, the model is able to distinguish between high production shelf regions and HNLC regions offshore, and to identify specific nitrate-limited and iron-limited growth conditions. Simulated and observed spatially averaged chlorophyll concentration patterns have similar temporal variability on the shelf, but the model underestimates observed variability offshore. Hinckley et al. (2009) implement an ecosystem model of greater biological complexity (two macronutrients, iron; two sizes of phytoplankton, two sizes of microzooplankton, two types of macrozooplankton, and detritus) in the same CGOA region. Treatment of iron dynamics differs between these two models, with Hinckley et al. using a Michaelis–Menten dissolved iron deficiency function. The idea here is to determine whether a simple (minimal) model is capable of accurately reproducing both nearshore, nitrate-limited, and offshore, iron-limited domains. Results of the simulations indicate that both iron limitation and two size classes of phytoplankton are needed to replicate seasonal observations in both offshore and nearshore regions.

Moving to higher trophic levels, Kline (2009) used stable carbon and nitrogen isotopes in the large calanoid copepod, *Neocalanus cristatus*, to examine seasonal and interannual variations in production sources. Coastal and offshore waters have different carbon isotope ratios, enabling discrimination of production within Prince William Sound (PWS; nearshore) and the Gulf of Alaska (offshore). This cross-shelf gradient was reaffirmed for most years from 1998–2004. On the other hand, the measurements from May of 1999, 2002 and 2004 indicate that offshore carbon isotope ratios were similar to PWS ratios. These three occurrences corresponded with periods of high chlorophyll and low salinity waters near the slope, probably due to offshore flow of coastal water in association with eddies adjacent to the slope. The results document temporal variability in spatial secondary production and provide a basis for interpreting variability in isotope ratios in juvenile pink salmon.

Moss et al. (2009) use a bioenergetics model of juvenile pink salmon to estimate the prey consumption demand and growth potential for several habitats in the Gulf of Alaska during two years that differ greatly in pink salmon survival. An *a priori* expectation that years of high juvenile pink salmon survival (and high returns to hatcheries) would have high growth potential was not confirmed. This suggests that for pink salmon, modeled growth potential may not be an early indicator for strength of a year class. Patterns of abundances in hatchery and wild pink salmon suggest that strong and interannually variable competition for food in nearshore regions may be a survival bottleneck.

LaCroix et al. (2009) examine survival of coho salmon in relation to several environmental factors in southeast Alaska. Juvenile coho salmon indices (growth rate, size, condition and abundance) were unrelated to measured June–August physical conditions in SE Alaska strait habitats or to climate indices such as the North Pacific Index and Pacific Decadal Oscillation. Regression analysis revealed variation in adult coho salmon harvest (year class strength) related to indices of juvenile pink salmon abundance in nearshore habitat during the same period as the juvenile coho. Since juvenile coho salmon growth and condition appeared unrelated to abundance of juvenile pink salmon, they inferred that high abundance of juvenile pink salmon increased the survival of juvenile coho salmon through predator buffering.

Teo et al. (2009) use 1980–2004 data on coho salmon survival from hatcheries spanning California to northern SE Alaska to examine broad- and fine-scale spatial and temporal patterns of covariability. Neighboring regions along the coast exhibit substantial temporal covariation in survival, but at the greatest distances, between the CCS region and SE Alaska, there is no evidence for significant correlations—either positive or negative. Thus, this analysis refutes the hypothesized inverse relation between survival in the northern and southern regions of coho's range in the eastern North Pacific. A caveat to this result is that the analysis considered data from 1980 and later only, thus it was not possible to examine the influence on coho survival of the strong "regime shift" that occurred in 1976–1977, and which is the strongest signal in most longer term assessments of ecosystem change in the northeast Pacific.

These papers represent just a few of the results that continue to emerge from the now decade long investigations of climate, physics and marine ecosystems in the coastal regions of the northeast Pacific. Additional insights on the function and structure of these systems, and on our ability to model complex interdisciplinary coastal systems should emerge as the GLOBEC and other complimentary data sets become more integrated and synthesized in ongoing investigations.

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