

## EPOC 2010: Thursday 23 September Morning Session ABSTRACTS

### Harmful algal blooms

8:20 *Is Climate Driving Decadal Trends in Toxic Blooms in the California Current System?*

Emily Sekula-Wood (USC), Claudia-Benitez Nelson (NOAA), Steven Bograd (NOAA) and Clarissa Anderson (USC)

Notes: The widespread domoic acid (DA) poisoning event in 1998 along the US west coast marked a pivotal moment for *Pseudo-nitzschia* bloom ecology. Rather than an isolated event, it appeared to signify an upward trend in the seasonal occurrence of large *Pseudo-nitzschia* blooms over the following decade, particularly in regional hotspots like the Santa Barbara Channel, CA. In the absence of HAB monitoring programs in the 1990s, the increase in blooms was partly attributed to increased monitoring post-1998. Recent analysis of archived sediment trap samples collected at 540 m depth from 1993-2007 in the Santa Barbara Basin, however, reveals an abrupt shift towards an increased frequency and magnitude of DA events over the last decade compared to that previously. DA flux to sediment traps has increased by an average of  $18 \pm 5 \text{ g/m}^2/\text{d}$ , with one large event ( $> 5 \text{ g/m}^2/\text{d}$ ) from 1993-1999 versus 16 large DA events from 2000-2007. We relate this shift to a change in the composition and magnitude of upwelled waters associated with shifting biogeochemical profiles in the California Undercurrent throughout the Southern California Bight since 1998, the transport of which into the Santa Barbara Basin may be further enhanced by a coincident switching of the North Pacific Gyre Oscillation mode.

8:40 *Scales of phytoplankton bloom variability along the U.S. West Coast: implications for monitoring of harmful algal blooms*

Sergey Frolov (MBARI), John Ryan (MBARI), Raphe Kudela (UCSC), and James Bellingham (MBARI)

Notes: Scales of spatial and temporal variability in phytoplankton blooms along the U.S. West Coast are re-examined using a combination of satellite Fluorescent Line Height data, and in-situ measurements of Chl-a fluorescence and phytoplankton species abundance. In the along shore direction, we find that the magnitude of phytoplankton blooms increases two fold, and the speed of blooms increases four fold from south (San Diego) to north (Trinidad). In the cross-shore direction, we find that nearshore blooms are decoupled from the blooms away from the coastline ( $> 4\text{km}$ ).

We interpret our findings with respect to the need to develop a synoptic observing system for potentially harmful algal blooms along the U.S. West Coast. We find that (a) deleterious effects are often associated with blooms of greater than average magnitude and (b) the utility of daily satellite coverage is limited north of San Francisco Bay by increasing cloud cover and speed of blooms. We conclude the presentation by comparing the performance of existing observational

networks and discussing the trade-offs of sampling blooms from fixed, moving, and synoptic platforms.

9:00 *PNWTOX, physical controls on HAB variability in the northern California Current System*

Ryan M. McCabe (UW), Barbara M. Hickey (UW), Neil S. Banas (UW), Michael G. G. Foreman (IOS), Raphael M. Kudela (UCSC), Evelyn J. Lessard (UW), Parker MacCready (UW), Diane Masson (IOS), and Richard E. Thomson (IOS)

Notes: Pacific Northwest Toxins (PNWTOX) is a newly funded project aimed at better understanding the controls on, and forecasting of, Harmful Algal Blooms (HABs) impacting Washington and Oregon beaches. PNWTOX follows two previous projects based in the northern California Current System: Ecology and Oceanography of Harmful Algal Blooms – Pacific Northwest (ECOHAB PNW) and River Influences on Shelf Ecosystems (RISE). Those projects focused, respectively, on two major physical oceanographic features in the PNW, the Juan de Fuca Eddy (a known HAB hotspot) and the Columbia River plume. The overriding conclusion from these prior studies is that lack of understanding of the effect of the Columbia River plume on cross-shelf and alongshelf transport and mixing is the greatest impediment to understanding how phytoplankton, in particular, HABs, arrive at coastal beaches. PNWTOX will address whether the Columbia River plume functions as a conduit or barrier to the transport of coastal HAB populations that may originate from both northern (Juan de Fuca Eddy) and southern (Heceta Bank) sources. The backbone of PNWTOX is the rich data set collected in our prior studies. To aid in interpretation and forecasting we have constructed a large, comprehensive numerical simulation system of the coastal ocean spanning the region from southern Oregon to British Columbia – including Puget Sound and the Strait of Georgia. Our model is based on ROMS and incorporates a broad suite of physically realistic parameters and forcing with a full four-component ecosystem module and particle tracking capabilities. We will discuss some of our early efforts with a focus on mechanisms believed to give rise to observed variability of coastal HABs in our highly stratified region.

9:20 *PerfectStorm: The Largest Documented Seabird Die-off Due to a HAB Event*  
Julia K Parrish (UW), Raphael Kudela (UCSC), Barbara Hickey (UW), Nancy Kachel (UW), Vera L. Trainer (NOAA), Brian D. Bill (NOAA), Mary Sue Brancato (NOAA/CO ASST), André Punt (UW), Peter Strutton (UTAS), Jane Dolliver (CO ASST), David Foley (NOAA), Richard Stumpf (NOAA) and Anthony Odell (UW)

Notes: Ephemeral dense concentrations of deleterious phytoplankton, or harmful algal blooms (HABs), are increasing in frequency and extent in coastal regions worldwide. Here we describe the single largest marine bird mortality event ever definitively ascribed to a HAB, the known loss of >2,000 and estimated minimum mortality of 8,000 scoters, murrelets, loons, and grebes in the Fall of 2009 along the outer coast of Washington State, U.S. Unlike most

previous reports, the mortality mechanism was not toxins, but rather the production of a foam-producing protein with powerful surfactant properties that coated bird plumage, collapsing feathers and resulting in a loss of waterproofing and thermal insulation. Condition data indicated that the majority of the birds were in molt, and thus unable to fly/escape the foam.

Because the responsible species - a dinoflagellate, *Akashiwo sanguinea* - is circumglobal and known to bloom in several coastal areas, we examined the relationship between local oceanographic conditions during the bloom and specifically during the peaks of bird mortality, relative to long-term averages, in order to determine whether changes in climate patterns, and specifically conditions associated with global climate change, may be driving these events.

The location, numbers, and species identification of live-stranded and dead marine birds were estimated from data provided by the Coastal Observation and Seabird Survey Team (COASST), and used to fit a double logistic model of carcass encounter rate informed by a capture-mark-recapture (CMR) model of carcass persistence derived from event-independent COASST data. We used maximum chlorophyll index (MCI) and the spectral shape at 681 nm (which is also used to determine fluorescence line height) determined from the MERIS satellite sensor to capture the spatial extent of the bloom, validated by water samples collected at numerous locations along the Washington outer coast (OCNMS & ORHAB). Although three major peaks in surface bloom concentrations ( $> 1E6$  cells/liter) occurred, only two were coincident with bird mortality. Concomitant temperature, salinity, and wave height data collected from shelf moorings suggest that local maxima in wave height, associated with storms and onshore transport during the two mortality events were responsible for foam production. The third (non-HAB) peak in cell abundance was associated with reduced wave height and upwelling-favorable conditions.

In sum, the "perfect storm" of warm surface waters, early Fall storms, onshore transport, and later than normal molt of migratory species such as surf and white-winged scoters, appear to create extended lethal conditions that will have significant impacts on migratory bird populations should *A. sanguinea* bloom frequency increase. The event in 2009 followed a similar, but much smaller, event two years earlier in California, with no prior confirmed events. While we cannot rule out coincidence, we note that these "perfect storm" events are entirely consistent with expected trends for the California Current, suggesting that this new type of HAB event is unusual but perhaps increasingly common.

9:40 *Avoidance, movement, and mortality: The role of predator-prey interactions in harmful algal bloom dynamics*

Susanne Menden-Deuer (URI) and Elizabeth L. Harvey (URI)

Notes: We hypothesized that the success of harmful algal bloom (HAB) species to form dense, often mono-specific blooms is partially attributable to reduced predation pressure from protistan predators. To gain a mechanistic understanding of predator prey interactions involving HAB species, we observed interactions of the toxic raphidophyte alga, *Heterosigma akashiwo* (Hada) with two potential

predators: the ciliate, *Favella ehrenbergii* (Jørgensen) and the dinoflagellate, *Oxyrrhis marina* (Dujardin). Using video and image analysis, we simultaneously quantified the population distributions and 3D movement behaviors of each species in 1L/30 cm high tanks. The salinity structure in the tanks included linear gradients from 0-30 psu as well as haloclines. *H. akashiwo* and the predator *O. marina* distributed throughout the tank without a preference for a specific salinity. In contrast, *F. ehrenbergii* avoided low salinities; no cells were found above 15 psu. Due to these different salinity tolerances, 50% of the *H. akashiwo* population was inaccessible to *F. ehrenbergii*. Moreover, the ciliate experienced a five-fold higher mortality rate in the presence of *H. akashiwo*, further reducing predator abundance and thus potential grazing pressure. Despite this toxic effect, *F. ehrenbergii* did not avoid dense layers of *H. akashiwo*. Surprisingly, we found that *H. akashiwo* exhibited avoidance behaviors in response to *F. ehrenbergii*. The alga showed more dispersive swimming behaviors (e.g. higher upward velocity) in the presence of *F. ehrenbergii* and more aggregative movements (e.g. faster turn rates) in low salinity waters inaccessible to the ciliate. These predator-induced defenses resulted in significantly higher HAB abundances in regions avoided by the predator. These results indicate that *H. akashiwo* has multiple predator defense mechanisms, both lethal and non-lethal, that could decrease heterotrophic protist grazing pressure. The defense mechanisms identified here may aid in understanding the puzzling success of *H. akashiwo* specifically, and HAB species in general, in the formation and persistence of blooms.

10:20 *Nitrogen imbalance: effects on primary productivity and species composition*  
Richard Dugdale (SFSU), F. Wilkerson (SFSU) and P. Gilbert

Notes: Population growth and the industrialized manufacture of inorganic nitrogen have resulted in a shift from nitrate to ammonium based ecosystems in many estuaries with potential effects in adjacent coastal marine ecosystems including the initiation of HABS outbreaks. The example of San Francisco Bay provides a basis for the evaluation of possible impacts of high ammonium inputs on marine ecosystems in general. The Clean Water Act resulted in the conversion of waste water treatment plants to secondary treatment, resulting in discharge of nitrogen primarily as ammonium. In the presence of significant concentrations of ammonium, phytoplankton use first ammonium, deferring nitrate uptake until ammonium concentrations fall to low levels. As a result, most of the time phytoplankton in SFB are in an ammonium based, low productivity mode, as they cannot access nitrate. However, when ammonium concentrations fall sufficiently low and irradiance/stability conditions are favorable, nitrate uptake is enabled and high productivity blooms may occur. Such blooms occur often in Central and San Pablo Bays in spring, but are rare in Suisun Bay as the concentration of ammonium increases towards the Delta. The chronic food limited condition in the estuary has been linked to the increase in ammonium inputs from sewage treatment plants through both reduced primary productivity and the elimination of diatoms as the major phytoplankton functional group. A direct link between ammonium inputs and the pelagic organism decline (POD) in the estuary has been

established. The extensive coastal bloom of *Ceratium* in all 2009 may be related in some way to the balance of inorganic nitrogen with increased access to the nutricline and increased discharge of ammonium to the coast. The high productivity nitrate based blooms can be simulated in enclosure experiments which can also be used to assess the likelihood of blooms occurring in various parts of the estuary and rivers.

10:40 *MOCHA: Monitoring Oregon Coastal Harmful Algae*

Angel White (OSU), M. Wood (U Oregon), P. Strutton (OSU), B. Eberhart (NOAA), Z. Forster (ODFW), M. Hunter (ODFW), S.M. McKibben (OSU), W.T. Peterson (NOAA), V. Trainer (NOAA), D. Smith (ODA) and J.F. Tweddle (Boston U).

Notes: With initial funding from NOAA's Oceans and Human Health Initiative, and now from MERHAB, a collaborative team has been established to monitor and understand the genesis of HABs for coastal Oregon. The major genera of interest, as for much of the US west coast, are *Pseudo-nitzschia* and *Alexandrium*. This contribution will present an overview of our work to date, along with a suggested plan for an alert system based on a preliminary heuristic model of HAB formation. Our preliminary research has identified regions, such as Heceta Bank, Gold Beach, and the Columbia River outflow that frequently experience HAB impacts. We have developed new satellite 'bloom detection' products and are quantifying the link between toxins in coastal shellfish, cell counts of potentially toxic phytoplankton, toxin concentration in seawater, and the seasonal cycles of upwelling and bloom initiation. Case studies of individual bloom events have provided indication of the relationship between offshore bloom initiation and delivery of toxin to the intertidal. Broader climatological analyses using remotely sensed ocean color data and field data on the abundance of HAB species and/or toxic shellfish indicate a latitudinal gradient of variation in upwelling strength and the phenology of blooms, suggesting the existence of subtle differences between elements of the California Current system that explain local patterns of variation in HAB frequency and type.

## General Session

11:00 *Hypoxic and acidic deep-water in nearshore marine environments in Monterey Bay, California*

\*\*J. Ashley T. Booth (MLML), Erika E. McPhee-Shaw (MLML), Paul Chua (MBARI), William F. Gilly (Hopkins Marine Station), Steven J. Bograd (NOAA), Lou D. Zeidberg (UCLA), Mark Denny (Hopkins Marine Station) and Roger Phillips (MBARI)

Notes: A unique high-frequency, decade-long time series reveals extreme oxygen, pH and temperature fluctuations in a shallow-water (17m) environment in Monterey Bay, CA. Oxygen levels often reached biologically threatening levels and pH dropped to ranges that may dissolve calcium carbonate. The lowest

oxygen and pH occurred during the spring/summer upwelling season, and was associated with intense fluctuations in <1 day. Semidiurnal and diurnal oxygen, pH, and temperature variability were energetic and are apparently caused by tidal-frequency internal waves pushing deep, upwelled water into nearshore habitats. The high variability on such a short scale and the extreme low levels were unexpected and changes our view of the nearshore environment. Although Pacific coast nearshore ecosystems may have evolved in the presence of these hypoxic and acidic events, increasing ocean hypoxia and acidification may increase the frequency, intensity, duration and spatial extent of future intrusions.

11:20 *Spatial and Temporal Variability in Near-Bottom Hypoxia over the Pacific Northwest Continental Shelf*

John A. Barth (OSU), S. D. Pierce (OSU), F. Chan (OSU) and Collaborators<sup>†</sup>

Notes: We use a variety of data sources\* to map the spatial extent of near-bottom hypoxic waters over the continental shelf off Oregon and Washington. In recent years, the appearance of hypoxic (dissolved oxygen less than 1.4 ml/l) waters near the bottom on the mid to inner shelf off central Oregon and Washington, and even the novel appearance of anoxia (zero oxygen) off central Oregon in 2006, has brought attention to this ecosystem stressor. Waters in this seasonal oxygen minimum zone (OMZ) have their origin in nearly-hypoxic waters at the top of the permanent OMZ farther offshore. Wind-driven upwelling brings these waters onto the mid and inner shelf, where oxygen levels are further decreased through respiration of organic matter raining down from the productive surface waters above. We use ship- and autonomous underwater glider-based measurements of near-bottom oxygen to make maps of the extent of hypoxia over the Oregon and Washington shelves (~43-48N) from September 2006 until November 2007. Minimum near-bottom oxygen values are often found over the mid to inner shelf (50-100 m water depth), with oxygen levels increasing closer to shore and farther offshore toward the permanent OMZ. This reflects the shelf respiration contribution to lowering dissolved oxygen. The size of the near-bottom hypoxia zone increases with time during the upwelling season, reaching its maximum extent in mid to late summer. In July 2007, the area of hypoxic water inshore of the 200-m isobath covered nearly 18,000 square kilometers, slightly less than the size of New Jersey and on par with the size of the Mississippi River plume hypoxia region. The percent of shelf waters inshore of the 200-m isobath occupied by hypoxic waters varies from 30% early in the season (May) to nearly 80% in the late summer-early fall (Sep), and tracks the cumulative amount of seasonal upwelling-favorable wind stress. In September 2006, “severe” hypoxia (dissolved oxygen less than 0.5 ml/l) occupied about 15% of bottom waters, including a region of anoxia reported off central Oregon. The severe hypoxia and anoxia in 2006 is attributed to twice as much upwelling-favorable wind stress as normal and a decline in the dissolved oxygen content of the deep, offshore upwelling source waters.

\*Data Sources: Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO); National Oceanic and Atmospheric Administration’s (NOAA)

Northwest Fisheries Science Center; National Science Foundation (NSF) glider observations off Newport, Oregon; Bonneville Power Administration; NSF Science and Technology Center for Coastal Margin Observation and Prediction; NOAA Global Carbon Cycle Program; National Aeronautical and Space Administration Ocean Biology and Biogeochemistry Program; NOAA South Slough National Estuarine Research Reserve; NOAA Olympic Coast National Marine Sanctuary.

<sup>†</sup>Collaborators: B. A. Menge (OSU), W. T. Peterson (NOAA-NWFSC), J. Peterson NOAA-NWFSC), C. Morgan (OSU-CIMRS), R. K. Shearman (OSU), A. E. Erofeev (OSU), M. D. Levine (OSU), B. Crump (Univ. Maryland), L. Herfort (OHSU), R. Feely (NOAA-PMEL), B. Hales (OSU), S. Rumrill (NOAA-SSNERR), and M. S. Brancato (NOAA-OCNMS)

11:40 *Lee Wave Formation Over Fraser Ridge*

\*\*Jeannette Bedard (UVic), Eric Kunze (UVic), Richard Dewey (Venus/UVic) and Jody Klymak (UVic)

Notes: Stratified tidal flows over real topography produces complex, time-dependent and varied dynamics. Here, peak flood tide over Fraser Ridge will be discussed. Fraser Ridge sits in 200 m of water on the prodelta of the Fraser River in Georgia Strait. Orientated northwest-southeast, this ridge is a rocky outcrop 2000-m long by 500-m wide rising 50 m from the bottom and surrounded by river sediment. Fraser Ridge is one of a handful of locations, all off the coast of BC, where reefs made up of glass sponges exist. Since a sponge reef is fixed to the substrate, local fluid dynamics is an important factor in the communities' survival. At peak flood, the bottom ~50 m of water flows north faster than the predicted tides and perpendicular to the long axis of Fraser Ridge. Along the flow direction, the upstream slope is gentle, while the downstream slope is more than four times steeper with the steepest flank at the north end of the ridge. On each flood tide, an internal lee wave the length of the ridge forms which is steeper where the lee slope is steeper at the north end. Near the ridge ends, the accelerated flow below the ridge crest flows around the ridge. At the northwest end of the ridge parallel to the flow are the steepest slopes. Here, there is a region above the slope between ~100 and ~150-m depth where the flow is stagnant. Below ~150-m depth, accelerated flow resumes. The largest sponge reef occupies a pocket extending from the northwest end of the ridge a short distance along the steepest portion of the lee slope directly beneath the complex dynamics of both the steepest lee wave and stagnant region.

## EPOC 2010: Thursday 23 September Afternoon Session ABSTRACTS

### Phenology and Matching Among Trophic Levels

16:00 *Separating variability in phenology from longer-term trends and episodic anomalies in northern California Current chlorophyll time series*  
Andrew Thomas (U Maine), Ryan Weatherbee (U Maine) and Roy Mendelssohn (NOAA)

Notes: Eleven years (1997 – 2007) of SeaWiFS satellite data of the northern California Current are analyzed to isolate and quantify dominant time/space patterns of variability in chlorophyll phenology from underlying longer-term trends and episodic anomalies. We use state-space models to separate the time-varying chlorophyll signal at each location into a series of 3 components: a non-stationary seasonal component which we use to define the phenology, a time-dependent trend, and a stationary uncorrelated residual or “error” term that includes episodic anomaly events. The non-stationary seasonal components are examined over the study area using k-means clustering to quantify time/space patterns of variability in chlorophyll phenology. The resulting geography of phenology has an expected strong cross-shelf zonation, but also identifies latitudinal boundaries. Small but identifiable shifts in timing are evident in the upwelling zones. These are contrasted with the time/space patterns of longer-term trends and the dominant signals remaining in the residual term. All are then compared to previously described interannual signals important to forcing in the California Current. We finish by pointing out the need to clarify both quantitatively (statistically) and in the language we use, differences between shifts in phenology and more stochastic anomaly events.

16:20 *Near-coast Chlorophyll a events and wave-driven transport*  
Erika McPhee-Shaw (MLML), K. J. Nielsen (Sonoma State) and J. Largier (UC Davis)

Notes: Continuous, rapidly sampled temperature and fluorescence (calibrated to chlorophyll a [chl a]) records from two shallow intertidal stations on rocky shores of the northern California coast demonstrate the event-dominated nature of near-coast phytoplankton variability over two summers. Comparison to a nearby shallow mooring offshore of Bodega Marine Laboratories shows that even such shallow records can provide meaningful time series of oceanographic conditions. Chl a time series from spring and summer 2007 and 2008 were characterized by episodic peaks, typically persisting about 1.5 to five days. These bloom events often coincided between the two sites even though they were separated by ~ 150 km. The timing of chl a events was compared to a variety of possible oceanographic forcings, and we found that blooms appeared unrelated to specific cold upwelling episodes. Several events were associated with reversals of upwelling-favorable winds. However, there was a stronger match between many of the dominant chl a peaks and peaks in surface swell height. Scaling arguments

suggest that the time scale and rate of observed increase in chl a cannot be explained by in-situ growth in response to nutrient supply. We suggest instead a predominantly physical mechanism: Near-coast phytoplankton accumulation may be caused by convergence of onshore, surface-swell-driven Stokes flux against the impermeable coastal boundary. The relationship between waves and chl a was strong in spring and early summer, but gone by late summer, suggesting a seasonal pattern of phytoplankton species which might respond to wave transport. This novel interpretation may have significant implications for understanding coastal productivity and near-coast aggregations of toxic blooms and some pollutants.

16:40 *The seasonal cycle of production in the northern California Current: the importance of production during winter months*  
Bill Peterson (NOAA), Leah Feinberg (OSU) and Jay Peterson (OSU)

Notes: When the seasonal cycle of primary and secondary production is examined in detail, it is clear that there are as many as five significant periods of productivity that result in an ecosystem response – (1) the sudden appearance in early winter (January) of *Neocalanus plumchrus*, *N. cristatus*, and *Calanus marshallae* which have awakened from diapause; in most winters *C. pacificus* is present at the same time in significant numbers as well. Both *C. marshallae* and *C. pacificus* reproduce at that time; (2) in years when winter winds become quiescent, a late winter phytoplankton bloom occurs (at anytime between late-January and early March – first noted by Parsons et al. 1967) resulting in bursts in egg production by *C. marshallae* and *C. pacificus* and by the coastal euphausiid, *Thysanessa spinifera*; (3) another burst in primary and secondary production often occurs in April/May commensurate with the start of the upwelling season, (4) yet another burst in primary production is initiated in July/August (often in excess of 25  $\mu\text{g}$  Chl-a L<sup>-1</sup>) at the height of the upwelling season that results in massive egg production by the euphausiid *Euphausia pacifica*, and maximum egg production rates of *C. marshallae*; finally, (5) a fall bloom often occurs in October, after the cessation of the upwelling season, in association with clear skies following the first major southwesterly storm of the season which destratifies the water column and mixed nutrients into the photic zone. Therefore when thinking about interannual variations in plankton biomass and productivity in the northern California, five temporally variable (and possibly independent) events must be kept in mind. Clearly, ecological studies which focus on the upwelling season alone, although necessary, are not sufficient to understand problems related to phenology. Given that interannual variability in production cycles is common, the timing of arrival of migrant species such as shearwaters, albatross, and whales as well as the timing of reproduction by resident fish and birds can either be matched or mismatched with the production cycles. Using data from our 15-year time series of hydrographic and zooplankton measurements along the Newport Hydrographic Line, examples will be shown of the importance of the first two “winter” events discussed above to food chain dynamics: the awakening of large copepods in January (which serve as food for

winter spawned fish larvae such as sablefish), the importance of SST in controlling copepod developmental rates, and the role of the February bloom in triggering egg production by the euphausiid /*Thysanoessa spinifera*/ and the copepod /*Calanus marshallae*/.

17:00 *Impact of advection loss due to wind and estuarine circulation on the timing of the spring phytoplankton bloom in a British Columbia fjord*  
\*\*Megan Wolfe (U B.C.) and Susan Allen

Notes: Rivers Inlet is a glacial fjord located on the central coast of British Columbia. Historically, Rivers Inlet was the location of the 3rd largest sockeye salmon run in Canada. The Rivers Inlet sockeye salmon stock fluctuated in the late 1970's and crashed in the early 1990's with returns reaching only 1% of the historical averages. It is believed that a contributing cause for this rapid decrease is changes in the timing of the spring phytoplankton bloom. The spring phytoplankton bloom drives the zooplankton bloom biomass and composition. Zooplankton are the primary food source of juvenile sockeye salmon, and thus changes in the timing and composition of these lower trophic levels may be a contributor to fluctuations in sockeye salmon biomass. We use a coupled biophysical model to determine the driving forces involved in the timing of the spring phytoplankton bloom in Rivers Inlet. The primary control on the timing of the spring bloom in Rivers Inlet is wind speed and direction. Outflow wind events result in flushing events that will cause horizontal advection of phytoplankton from the basin. Single outflow wind events can result in a 7 day delay in the bloom timing. The shift in bloom timing resulting from multiple outflow wind events is greater than the sum of the individual wind events. Outflow wind events are driven by synoptic scale low pressure weather systems that interact with the BC coast. The timing of the transition between winter low pressure systems and summer high pressure systems is termed the spring transition. Climatic changes in the low pressure systems that encounter the BC coast could cause changes in the spring transition date, thus leading to more frequent and later occurring outflow events and ultimately delaying the timing of the spring phytoplankton bloom in fjords along the British Columbia coastline.

17:20 *Match-mismatch of larval fish first feeding vs winddriven turbulence in the CCS: application of a mechanistic-based model for sardine and anchovy*  
Andrew Leising (NOAA)

Notes: Most pelagic fish larvae undergo a critical phase when they deplete the remaining energy in their yolk-sac and begin to feed on prey in the water column. During this phase, they must consume an adequate amount of prey within a fairly short period (< 1 day) or they will die. Thus models of fish recruitment are very sensitive to survival through this stage. The larvae of small pelagics, such as sardine and anchovy, are of a size during this phase that they are particularly susceptible to changes in their prey-capturing dynamics due to water column turbulence. Low to moderate levels of turbulence may act to increase ingestion

rates, via an increase in the encounter rate of predator with prey. However, higher levels of turbulence can decrease ingestion via a decrease in the ability of the predator to successfully capture its prey once a prey is sighted, due to the turbulent motion. Here, I apply a fully mechanistic-based model of the swimming and feeding of fish larvae as they search for, encounter, and capture prey, as influenced by turbulence for sardine and anchovy within the CCS. Turbulence was estimated from quickscat winds. Prey fields and mixed layer depths were estimated from CALCOFI data. Examining the period from 2000-2007 within the CALCOFI region, there are typically several areas in any given cruise where both anchovy and sardine feeding would be enhanced due to turbulence. However, there were occasional periods, such as the springs of 2004 and 2007, when there were very strong winds throughout much of the region, and thus larval fish feeding was disrupted. Further implications and applications of the model for both analysis of long-term changes in fish recruitment, and in light of possible climate change impacts, will be discussed.

## **EPOC 2010: Thursday 23 September Evening Poster Session ABSTRACTS**

### **General Session**

*Observations of high-resolution coastal surface circulation on the U.S. West Coast*  
Sung Yong Kim (SIO), Eric J. Terrill (SIO), Bruce D. Cornuelle (SIO), Burt Jones (USC), Libe Washburn (UCSB), Mark A. Moline (CPSU), Jeffrey D. Paduan (Naval Postgrad School), Newell Garfield (SFSU), John Largier (UC Davis), Greg Crawford (VIU), and P. Michael Kosro (OSU)

Notes: The newly-completed U. S. West Coast high-frequency radar network provides an unprecedented capability to monitor and understand ocean dynamics and phenomenology through hourly surface current measurements at up to 1 km resolution. These novel observations reveal coastal surface ocean variability having multiple temporal and spatial scales, poleward propagating alongshore currents, a clear seasonal transition forced by upwelling-favorable winds and their relaxation, and continuity across scales from sub-mesoscale to mesoscale.

*Seasonal Variation of Fresh Water Content off the Oregon Coast Estimated from Glider Observations*

\*\*Piero Mazzini (OSU), Barth, J.A.(OSU), Shearman, R.K.(OSU), Erofeev, A.Y. (OSU), Brodersen, J. (OSU), Rubiano, L. (OSU), Adams, K. (OSU)

Notes: Due to rough ocean conditions produced by the passage of synoptic cold fronts and strong winds associated with them during the winter season, oceanographic observations over the Oregon continental shelf have been concentrated mostly during summer, leaving large gaps during the winter. Since 2006, the Glider Research Group at Oregon State University (<http://gliderfs2.coas.oregonstate.edu/gliderweb/>) has used autonomous underwater gliders to survey the Oregon continental shelf and slope nearly

continuously throughout the year. The gliders sample a cross-shelf section off Newport, Oregon (44.65°N, “the NH-line”), from the surface up to 200 meters depth from the 25 meters isobath out over the continental slope. These high-resolution data allow the investigation of winter-time conditions as well as seasonal variations. Freshwater input from rivers can significantly change water mass characteristics especially over the inner-shelf. The outflow from the rivers Umpqua, Rogue, Coquille and Siuslaw in southern and central OR, and Klamath in northern CA added up, may reach up to several thousands of  $\text{m}^3\text{s}^{-1}$  during winter time (rainy season). The cross-shelf density gradients caused by the fresh water runoff plus the northward downwelling-favorable along-shelf wind stress can drive strong northward currents. Due to the great importance to the shelf dynamics, fresh water content was calculated using the glider data from the NH-line, and two main distinct seasonal regimes were found: during winter time fresh water was trapped on the inner-shelf, coinciding with high discharges from the rivers cited above; during other seasons, especially summer, fresh water was found mainly on the mid and outer shelf advected southward from the Columbia River and held offshore by upwelling-favorable winds.

*The Influence of Physical Drivers on Primary Productivity and Biomass Distribution in the Santa Barbara Channel*

\*\*Mark Brzezinski (UCSB), Libe Washburn (UCSB), Chris Gotschalk (UCSB), and Nick Dellaripa (UCSB)

Notes: Bio-physical data collected during 16 Santa Barbara Coastal Long-Term Ecological Research (SBC-LTER) cruises illustrates spatial and temporal changes in both productivity and biomass distribution within the Channel. An empirical orthogonal function (EOF) analysis was performed on the primary productivity data at the surface of the Channel. We found that the variability in the productivity data can be attributed to three main physical factors: seasonal controls on productivity, changes due to the presence of an eddy, and along-shore variations. A known feature of the local circulation is a channel-wide eddy that is present at various times throughout the year. That eddy is manifested in our data as 1) the sloping of isopycnals, with changes in depth of up to 60 meters, 2) a vertical shear of the horizontal current velocities as seen from Acoustic Doppler Current Profiler (ADCP) profiles, and 3) closed circulation of surface currents from high-frequency radar output. The time-series amplitude of the second EOF mode, which accounted for 17% of the variance in the surface productivity, is significantly correlated with periods in which an eddy was present, resulting in this being labeled out “eddy mode”. The eddy that persists within the channel heavily influences the biomass distribution by concentrating it at the surface of the eddy core as well as subducting it to depth along the sloping isopycnals. Analyzing the dynamics of the ocean circulation within the Santa Barbara Channel is important for understanding the patterns of primary productivity and the distribution of phytoplankton.

*Crossshore Hydrographic Structure off the Washington Coast: Observations of the California Undercurrent and Other Prominent Features from the Cascadia Seaglider Time Series*

\*\*Noel Pelland (UW), Charles Eriksen (UW), Craig Lee (UW)

Notes: The California Undercurrent (CUC), an important element of the Northeast Pacific Eastern Boundary Current (EBC) system, is well known for its significance in poleward transport and corresponding distribution of low oxygen, high nutrient equatorial Pacific (EPAC) water along the western continental slope region of North America. As our understanding of the broad scale continuity and dynamical constraints on the strength and structure of this current continue to grow, opportunities evolve to investigate on a regional scale the CUC's connection to other components of the EBC as well as its role in generating instability, transient features, and lateral propagation of EPAC water. Motivated by these questions, we present preliminary results from a novel dataset designed to bridge the gap between longer timescale moored measurements and short term, high resolution shipboard surveys: a detailed set of basic hydrographic properties as observed from Seaglider deployments off the Washington coast, constituting the "Cascadia" time series from late 2003 to early 2009. Achieving roughly 120 crossings of the CUC region in two separate locations, glider physical variable measurements and inferred geostrophic velocities are mapped onto quasisyntoptic cross shore sections, allowing a detailed picture of prominent mean state features, seasonal and multiyear variability of cross shore current structure, and multivariable Empirical Orthogonal Function (EOF) analysis along one or both sections. Early returns display alongshore current and water property structures consistent with canonical understanding of the CUC, as well as an intriguing annual period offshore propagation signal of temperature anomaly. Future work will involve a more detailed look at forcing mechanisms significant to the Washington coastal region and incorporation of altimetry for a further understanding of glider observed current features in the broader EBC context.

*Satellite-observed changes in the upper ocean heat budget of the northeast pacific during 1993-2004*

Scott R. Springer (ESR/Seattle), G. S. E. Lagerloef (ESR/Seattle)

Notes: We find that interannual variability of upper ocean temperatures in the northeast Pacific Ocean during 1993-2004 is dominated by Ekman transport and its divergence. The leading empirical orthogonal functions (EOF) of both sea surface temperature (SST) and sea surface height (SSH) in this region are highly correlated with each other and with the basin-wide Pacific Decadal Oscillation (PDO) index, which transitioned from the warm to the cold phase in 1999. Sea surface velocities (SSV) constructed from satellite-observed SSH, SST, and vector winds using Ocean Surface Current Analysis - Real time (OSCAR) show that Ekman and geostrophic components of velocity changed by similar magnitudes but with different spatial structures. Combining SSV with the SST field, in situ sub-surface temperature data, and surface heat fluxes from an

atmospheric model makes it possible to construct an approximate SST budget based on an integral model damped to climatological means. Anomalous Ekman advection of the mean temperature gradient dominated smaller contributions from the other terms in the budget, a result which agrees generally with analysis of a simulation using an ocean general circulation model. Previous studies have demonstrated the dominance of Ekman pumping to pycnocline depth and SSH variability. The dominant role of Ekman transport and its divergence accounts for the covariability of SSH and SST.

*Coastal upwelling supplies oxygen-depleted water to the Columbia River estuary*  
G. Curtis Roegner (NOAA), Joseph A. Needoba (CMOP) and António M. Baptista (CMOP)

Notes: Low dissolved oxygen (DO) is a common feature of many estuarine and shallow water environments, and is often attributed to anthropogenic nutrient enrichment from terrestrial-fluvial pathways. However, recent events in the US Pacific Northwest have highlighted that wind-forced upwelling can cause naturally occurring low DO water to move onto the continental shelf, leading to mortalities of benthic fish and invertebrates. The hydrography of coastal estuaries in the Pacific Northwest is strongly linked to ocean forcings, and here we report observations on the spatial and temporal patterns of oxygen concentration in the Columbia River estuary. Hydrographic measurements were made from transect (spatial survey) or anchor station (temporal survey) deployments over a variety of wind stresses and tidal states during the upwelling season in 2006 through 2008. During this period, biologically stressful levels of dissolved oxygen were observed to enter the Columbia River estuary from oceanic sources, with minimum values close to the hypoxic threshold of  $2.0 \text{ mg L}^{-1}$ . Riverine water was consistently normoxic. Upwelling wind events controlled the timing and magnitude of low DO events, while tidally-modulated estuarine circulation patterns influenced the spatial extent and duration of exposure to low DO water. Strong upwelling during neap tides produced the largest impact on the estuary. The observed oxygen concentrations likely had deleterious behavioral and physiological consequences for migrating juvenile salmon and benthic crabs. Based on a wind-forced supply mechanism, low DO events are probably common to the Columbia River and other estuaries and, if conditions on the shelf deteriorate further as observations and models predict, Pacific Northwest estuarine habitats may soon experience a major decrease in environmental quality.

## **Harmful Algal Blooms**

*Environmental Factors Linked to Interannual Variability in Shellfish Toxicity in the Gulf of Maine*

Madeline Peek (U Maine), Andrew Thomas (U Maine) and Ryan Weatherbee (U Maine)

Notes: Dinoflagellates of the genus *Alexandrium* produce a saxitoxin that causes paralytic shellfish poisoning, the primary HAB concern in the Gulf of Maine. Factors causing Interannual differences in *Alexandrium* bloom timing, location and magnitude remain uncertain. A 23 year time series of shellfish toxicity (1985-

2007), monitored ~ weekly (or more) by the Maine Department of Marine Resources at ~ 100 stations provides a coastal record of *Alexandrium*-induced toxicity variability. Five metrics quantify annual toxicity at each station in each year: date of first toxicity (1), temporal extent of toxicity (2), magnitude of annual toxicity (3), integrated annual toxicity (4) and date of maximum toxicity (5). We examine the relationship between the interannual signal in these toxicity metrics and concurrent time series of 3 environmental factors: Penobscot River monthly total discharge, total monthly rainfall at a coastal station, and monthly alongshore wind stress from an offshore NOAA meteorological station. Spearman rank correlations compare each toxicity metric at each station to each environmental factor, with results displayed on maps showing stations with significant correlations. The strongest linkages evident (maximum number of stations with > 95% significance) are negative correlations between July alongshore wind stress from the southeast and metrics 2, 3 and 4. These are indicative of reduced toxicity associated with stronger upwelling and offshore Ekman transport. Furthermore, these results were geographically isolated to stations between Penobscot Bay and Portland. Very few stations east of this show the same correlation and very few stations anywhere show correlation between any metric of toxicity and river discharge or rainfall.

*On the origin of the waters associated with the Pseudo-nitzschia toxic bloom occurred in Todos Santos Bay (northwestern Baja California) during April 2007*

David Rivas (CICATA-IPN), Rocia Mancilla-Rojas (CICATA-IPN), Ernesto Garcia-Mendoza (CICESE), Antonio Almazan-Becerril (CICY)

Notes: Here we study numerically the circulation associated with the intense toxic algal bloom occurred in Todos Santos Bay area (northwestern Baja California, ~ 31:88°N) during April 2007. This bloom is the southernmost report of the presence of domoic acid (DA) in the California Current System and it is also the first formal report of the distribution of both toxic *Pseudo-nitzschia* species and DA on the Baja California west coast. Such an analysis shows that the accumulation of toxic cells was most probably caused by environmental conditions associated with the wind-driven upwelling in the region. We carried out high-resolution, numerical model simulations to be used in a tridimensional Lagrangian analysis, which provides information about the origin and distribution of the waters present in Todos Santos Bay (TSB) by the end of April 2007. The results show that such waters come mainly from locations west of the Bay (even beyond the model's domain), approaching to the continental shelf, embedded in a flow that bifurcates in a equatorward current and a poleward current at 32-33°N, the so-called Ensenada Front. A significant portion of the waters are found in the Southern California Bight (SCB) a few weeks before their arrival in TSB, consistent with observations in that area during early April. After their pass through TSB, most of the water parcels flow southward confined within the surface layer, but another portion remain at subsurface levels and flow poleward crossing SCB, most probably advected by the poleward undercurrent over the slope. Estimations of residence times of the waters within TSB result in about one

and a half months for the surface waters and one month for the subsurface waters. The present analysis offers a good framework to understand the ecology processes behind the *Pseudo-nitzschia* blooms in TSB and Baja California.

*Regression models for Pseudo-nitzschia blooms and domoic acid off the Oregon Coast*  
\*\*Morgaine McKibben (OSU), Angel White (OSU), Pete Strutton (UTAS), Michelle Wood (U Oregon), Gwenn Miller (U Oregon), Bich-Thuy Eberhart (NOAA), Vera Trainer (NOAA)

Notes: Regression models are currently being developed to link two types of response variables, bloom threshold levels of *Pseudo-nitzschia* cells and toxic levels of domoic acid (DA), with explanatory variables in the form of environmental parameters gathered both in situ and via satellite. Our goal is to determine which parameters are the best predictors and which model type is most robust. The foundation of the models is a growing database, currently containing over 1200 discrete particulate and dissolved DA samples from the Oregon and southern Washington coastline. Each sample includes whole water cell counts of *Pseudo-nitzschia*; co-located ancillary biological and physical data; and physical proxies of bloom proliferation, including upwelling intensity and USGS river outflow rates. All models will be developed and tested using the same suite of environmental parameters to allow inter-comparison of performance. Additionally, to test predictive capabilities using remotely sensed data, each model will be tested with MODIS satellite products (chlorophyll concentration, sea surface temperature and fluorescence line height) in lieu of in situ data. An estimated 300-600 more samples and their ancillary data will be collected each year through at least 2012 and used to both augment the existing database and refine the models.

### **Dispersal and Connectivity in Marine Organisms: Implications for Productivity, Spatial Distribution, Population Structure and Ocean Zoning (e.g. Marine Reserves)**

*Physical factors affecting the distribution of Greenland halibut (Reinhardtius hippoglossoides) and Pacific halibut (Hippoglossus stenolepis) early life history stages in the Eastern Bering Sea.*  
\*\*Cathleen Vestfals (OSU), Lorenzo Ciannelli (OSU), Janet Duffy-Anderson (NOAA), Carol Ladd (NOAA) and Dongwha Sohn (OSU).

Notes: Apart from direct harvest, recruitment variability is considered the main source of adult population variability in marine organisms. Reconstructing dispersal pathways that connect individuals from the source (e.g., fish spawning areas) to sink locations (e.g., juvenile settling location) is therefore critical to understanding recruitment variability and population dynamics. We examined the effects of ocean currents on the transport of two key commercial fish species, Greenland halibut (GH, *Reinhardtius hippoglossoides*) and Pacific halibut (PH, *Hippoglossus stenolepis*), in the Bering Sea during their early life history stages.

The Regional Ocean Modeling System (ROMS) ocean circulation model was run for 10 years (1995-2004) and transport along three transects above Bering, Pribilof, and Zhemchug Canyons was quantified. Annual and monthly along-shelf transports were then compared to field data collected from bottom trawl and ichthyoplankton surveys conducted by the Alaska Fisheries Science Center (AFSC) to understand the connectivity between spawning and settlement locations of the two flatfish species. Differences in transport were found between canyons, along with strong interannual variation in flow, which is hypothesized to originate from variability in the thermal regime of the Bering Sea shelf. In addition to providing valuable life history information to fisheries scientists and managers, this research will help to understand the influence of projected future climate change on larval drift and settlement.

*Feeding rates of adult Euphausia pacifica on natural particle assemblages in the coastal upwelling zone off Oregon, USA*

\*\*Xiuning DU (Ocean U China), William T. Peterson (NOAA) and Tracy Shaw (NOAA)

Notes: Feeding experiments on adult *Euphausia pacifica* were initiated in February 2010 with the plan to determine how feeding rate and selectivity changes during the upwelling season. Incubation experiments were conducted using krill caught at the shelf break 25 miles offshore of Newport, Oregon. We measured the clearance rates and daily rations by feeding the krill on natural plankton assemblages. Feeding rates were calculated from microscopic counts of the phytoplankton and ciliates species. Preliminary rates based on experiments conducted showed that *E. pacifica* had higher grazing rates on diatoms (the dominants were *Thalassiasira* and *Chaetoceros*) during the spring bloom in February compared to post-bloom conditions in April when plankton biomass was low and *E. pacifica* had negative clearance rates on total enumerated biomass and extremely low or negative feeding rates based on Chl a data; very low biomass of larger phytoplankton taxa (diatoms and dinoflagellates) in April made it difficult to determine *E. pacifica* grazing preference. In addition, we found that *E. pacifica* had a high preference for ciliates and that they did not like eating the smaller flagellates. Our results support the hypothesis that *E. pacifica* feeds omnivorously on the natural assemblages with ciliates as an important food source and with larger food taxa preferred over the smaller taxa.

*Dispersion and connectivity estimates along U.S. west coast from a realistic numerical model*

Christopher A. Edwards (UCSC), Patrick Drake (UCSC), and John A. Barth (OSU)

Notes: Near-surface particle dispersion, larval dispersal and connectivity along the U.S west coast are explored using a realistic numerical model of the California Current System. Seasonal model velocities were qualitatively and quantitatively evaluated using Global Drifter Program data. Millions of passive, Lagrangian particles were released into modeled currents for seven years within 10 km of the coast, yielding climatological maps of particle dispersion. Particle densities varied with release region, release season and time-since-release. At short time-since-

release (30 days), peak densities were found at the coast during all seasons, but the maximum density shifted steadily offshore with time in winter and spring. Dispersal distances and coastal connectivity varied with season of release, release location and pelagic larval duration (PLD). Connectivity was clearly influenced by major geographic features such as the Gulf of the Farallones and Cape Mendocino.

*A Lagrangian Perspective on the Recirculatory Flow around Vashon Island, Puget Sound, Washington*

Mitsuhiro Kawase (UW), Lorenz Hauser (UW), Larry Leclair (WDFW), Ray Buckley (WDFW), Maureen Hess (UW/WDFW)

Notes: During Summer and Fall of 2007 and 2008, several drogued, satellite-tracked Lagrangian drifters were released from the eastern shore of Vashon Island in the south Main Basin of Puget Sound as part of a study to estimate larval dispersal rates of brown rockfish (*Sebastes auriculatus*) from an artificial reef at Point Heyer. Trajectories ranged from 6 to 30 days in deployment. The drifter tracks delineate the well-known clockwise recirculation around the island with a return time of 12 to 19 days, corresponding to track-average flow speeds of 4 to 6 cm/s. Several stagnation points, where the drifter would spend an extended period of time or finally settle, are identified, including the southeastern corner of the Main Basin around Redondo Beach; the northeastern shore of the Point Defiance Peninsula; and near Steilacoom south of Tacoma Narrows. Exchange between the recirculation and the surrounding waterways is limited, and there are indications of seasonal and possible interannual variability. During spring tide, drifters would enter Tacoma Narrows from Dalco Passage and may enter the South Sound or be ejected back into Dalco Passage. Only once was a drifter injected directly from Tacoma Narrows to Colvos Passage; this is somewhat at odds with a previously held notion that the strong ebb current from the Narrows is the source of momentum for the northward flow through Colvos Passage. Drifters would enter Colvos Passage directly from Dalco Passage during periods of weaker tide. Later in the season drifters would escape to the north into the Main Basin of Puget Sound, possibly driven by the onset of the southerly wind associated with the Fall transition or by the accelerated exchange circulation due to deep water intrusion into Puget Sound. The trajectories are compared with simulated trajectories using output from a three-dimensional circulation model of Puget Sound.

### **Phenology and Matching Among Trophic Levels**

*Progress towards environmental recruitment indices for California rockfish*

Eric Bjorkstedt (NOAA), Kathryn Crane (HSU), Anna Morgante (HSU), Steve Ralston (NOAA), and Rob Van Kirk (HSU)

Notes: Recruitment variability to populations of winter-spawning rockfish reflects highly variable survival through the larval stage, presumably as a consequence of environmental and ecological conditions affecting early life

history stages. Existing studies relate recruitment success to mean environmental conditions over (biologically) arbitrarily defined periods spanning one or more months, yet environmental processes thought to be critical to productivity (hence larval survival) vary substantially at shorter time scales, and spawning does not occur with uniform intensity over protracted periods. We report here on recent progress on three complementary facets of a project aimed at developing environment-driven indices of recruitment success for rockfish that resolve environmental effects at a higher temporal resolution. One aspect of this work is directed at developing otolith growth trajectories for pelagic juvenile rockfishes and using these data to model environment-growth relationships during the critical early life history stages. A second element of the work focuses on the use of simple oceanographic models to resolve the effects of variable forcing on coastal ecosystems during the winter and early spring when many important rockfish species place their larvae in the plankton. The third element of this work is to integrate environmental conditions into indices of larval survival, work that includes efforts to develop and refine individual-based models for rockfish early life history stages.

## **Climate Change and Spatial Ecology**

### *Impacts of climate change on the habitat of Bering Sea arrowtooth flounder*

Nick Bond (NOAA), P. Spencer and A. Hollowed

Notes: The population of arrowtooth flounder (*Atheresthes sp.*) in the Bering Sea has grown markedly over the past 20 years. Since this species is a major predator on the commercially-valuable stock of walleye pollock (*Theragra chalcogramma*), it is important to determine how its population is liable to evolve in association with climate change. Arrowtooth flounder tend to avoid the summer “cold pool”, defined as water cooler than 2 degrees C in the middle shelf domain. The cold pool cannot be properly simulated by most IPCC-class global climate models due to their poor representation of the bathymetry of the shelf and perhaps vertical mixing. Analysis of past observations, however, reveals that the area and southward extent of the cold pool corresponds closely with the maximum sea ice extent the winter before. The latter parameter can, in principle, be projected by global climate models. These projections and an empirical relationship based on historical observations can form the basis for making estimates of future cold pool extents, and ultimately, potential arrowtooth flounder populations. This application represents an example for which a crucial environmental parameter cannot be forecast directly, but can be inferred using a proxy.

### *Modes of biophysical variability on the Bering Sea shelf*

Albert J. Hermann (UW), Kerim Aydin (NOAA), Nicholas A. Bond (UW), Wei Cheng (UW), Enrique N. Curchitser (Rutgers), Georgina A. Gibson (U Alaksa Fairbanks), Kate

Hedstrom (ARSC), Ivonne Ortiz (NOAA), Muyin Wang (UW), and Phyllis J. Stabeno (NOAA)

Notes: The term climate change denotes spatially correlated changes in both atmospheric and oceanic properties; these are expected to drive spatially correlated changes in ecosystem structure. Coupled physical/biological models can be used to downscale broad-scale climate patterns to the regional level. These coupled models, while imperfect, can be used to explore both bottom-up and top-down effects on the spatial restructuring of ecosystems driven by climate change. Of special interest are the emergent properties of these coupled simulations, and how they compare with the observed system. In this presentation we describe the use of multivariate Empirical Orthogonal Functions to examine the covariance structure of predicted physical-biological modes from coupled models of the North Pacific. In particular, we examine the predicted effects of climate change on pelagic vs. benthic food webs on the Bering Sea shelf, and their dependence on ice cover. This type of analysis should help to quantify the greater predictability of spatially and trophically averaged quantities, as compared to univariate time series from a single fixed location.

*Effects of climate variability on the distribution, abundance and habitat usage of juvenile salmonids in the coastal waters of the northern California Current*

Cheryl A. Morgan (OSU), William T. Peterson (NOAA), Joseph P. Fisher (OSU) and Jesse F. Lamb (OSU)

Notes: Each June and September from 1998 until present, hydrographic, plankton, and juvenile salmon surveys are conducted off Oregon and Washington, USA along 8 transect lines between 44.6° and 48° N latitude, with stations ranging from 2 to 60 km offshore. During the study period, large shifts in the physical and biological conditions in the northern California current occurred, including the 1997/98 El Niño, the 1999 La Niña, positive and negative values of the PDO, and years of strongly contrasting upwelling intensity. These varying conditions provide insights into how abundances, distribution, survival and habitat usage of Chinook and coho salmon may change in response to climate changes. Abundances of Chinook and coho salmon were significantly correlated with water depth (negatively), chlorophyll (positively) and copepod biomass (positively). Abundances of yearling and subyearling Chinook salmon, but not yearling coho salmon, were correlated with temperature (negatively). Abundances are higher during years when the PDO was negative. The strength of coastal upwelling in June influences the offshore extent of salmonid distributions – when upwelling is strong the fish are found at greater the distance offshore; no correlation was found between upwelling strength and fish distribution in September when upwelling is weak-to-nonexistent. The optimal physical habitat parameters seem to be strong upwelling, high chlorophyll concentrations, and a boreal copepod community each of which is influenced by the PDO. Climate change scenarios that include a weakening of the PDO or of upwelling strength, suggest a negative impact on salmon.

## EPOC 2010: Friday 24 September Morning Session ABSTRACTS

### General Session – cont'd

8:20 *The Columbia River estuary as an ocean sentinel: temperature, hypoxia and other tales*

Antonio M. Baptista (CMOP), Charles Seaton (CMOP), Joseph Needoba (CMOP), Michael Wilkin (CMOP), Katie Rathmell (CMOP), Paul Turner (CMOP), Sarah Riseman (CMOP) and Curtis Roegner (NOAA)

Notes: Observations from multiple Columbia River endurance stations and from a WA shelf glider are being used to characterize the response of the Columbia River estuary to ocean variability, and to explore the use of estuary properties as a sentinel for ocean change. The planned focus of the talk is on temperature and oxygen data, although other variables are being examined and some might also be opportunistically highlighted.

Anchoring the talk will be the introduction of an “upwelling index” that is based exclusively on estuarine temperatures and salinities, and the discussion of lessons learned from an “oxygen watch” that links oxygen levels in the estuary

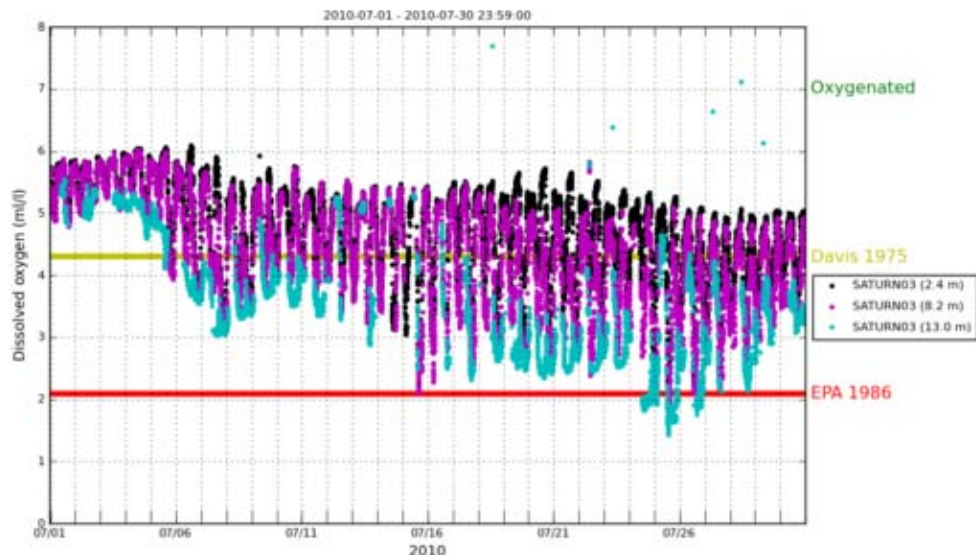


Figure: Oxygen at three depths in the south channel of the Columbia River estuary, displayed against oxygen-tolerance thresholds for salmon. Oxygen in the estuary responds to shelf winds and oxygen levels in the WA shelf (see more at [http://www.stccmop.org/datamart/observation\\_network/hypoxia](http://www.stccmop.org/datamart/observation_network/hypoxia)).

(e.g., see Figure) with upwelling and with hypoxia in the WA shelf. All analyses will be based on data from the observation network of the SATURN collaborative (<http://www.stccmop.org/saturn>), a signature technology of the multi-institutional NSF Science and Technology Center for Coastal Margin Observation & Prediction (CMOP). SATURN is a sub-system of the Northwest Association of

Networked Ocean Observing Systems (NANOOS), the Pacific Northwest arm of the Integrated Ocean Observing System (IOOS).

8:40 *VENUS: A Bottom-Up Coastal Ocean Observatory*

Richard Dewey (VENUS/UVic)

Notes: The Victoria Experimental Network Under the Sea (VENUS) has been built as a bottom-up ocean observatory. The first phase, operational since 2006, consists of a network of oceanographic systems connected via fibre optic cables to shore stations in both Saanich Inlet and the Strait of Georgia. With three bottom-centric Nodes, the network has already provided many terabytes of high-resolution data and supports a wide range of on-going, interactive research investigations. A second phase is now under development and includes components reaching up into the water column, to the ocean surface. Funded for deployments through 2013 are multiple Ferry thermosalinographs, Gliders, AUVs, a Vertical Profiler, CODAR arrays, and specialized platforms for both climate and process oriented research. Updates on the system status, key signals revealed over the last few years, lessons learned, and preparations for Phase II will be presented.

9:00 *Initial Development of the Eastern Pacific Ocean Prediction Forum (ePOPf)*  
Chris Mooers (CEE/PSU), Yi Chao (JPL & UCLA), Ted Strub (COAS/OSU), and Rich Patchen (CSDL/NOS)

Notes: Early thoughts on ePOPf were presented at EPOC 09. Since then, the draft ePOPf Prospectus has developed further with the help of an ad hoc Organizing Committee whose members are from WA, OR, CA, BC-North, and BC-South. The planning efforts have culminated in the ePOPf West Coast Modeling Workshop to be held in Portland, OR on 20 to 22 SEP 10 for the convenience of EPOC attendees. The focus is on establishing a super-regional operational model and a testbed to support regional coastal ocean research and operational models. The “fresh caught” workshop Findings & Recommendations will be presented at EPOC 10.

### **Dispersal and Connectivity in Marine Organisms: Implications for Productivity, Spatial Distribution, Population Structure and Ocean Zoning (e.g. Marine Reserves)**

9:20 *Genetic connectivity in plankton populations: from Lagrangian surface drifters to microsatellite markers*

Tatiana Rynearson (URI), Chris Piecuch (URI) and Jeremy Lins (URI)

Notes: On spatial scales of 10's of km, a single diatom species can be comprised of multiple genetically distinct populations, each of which harbors high levels of genotypic diversity. Large blooms can arise from different populations suggesting that intra-specific diversity in diatoms has broad ecological

implications. However, it is unknown how these patterns of diversity and population structure extend to larger spatial scales. Because habitat connectivity can determine geographic patterns of biological diversity, we studied how marine planktonic habitats in the North Pacific are physically connected by ocean currents over large spatial scales using Lagrangian drifter trajectories. Our data set comprised trajectory measurements taken by >1000 WOCE SVP Lagrangian surface drifters from 1989-2008. Interregional connectivity was determined using transit time spectra, which measure the probability of transit from one region to another as a function of time. Transit time spectra were used to explore the transport of hypothetical plankton cells (diatoms, larvae, etc) between regions on timescales  $\leq 1$  year providing probabilistic insight into the nature of surface-ocean material exchange in the North Pacific. From a population dynamic perspective, these calculations of transport time and probability can provide baseline estimates for interregional migration rates. This approach complemented a field study in the eastern Pacific to examine genetic connectivity of planktonic diatoms using microsatellite markers. Nearly 1000 single cell isolates of the cosmopolitan diatom *Ditylum brightwellii* were collected in the spring of 2007 along a 1300 km transect from the estuarine waters of Puget Sound, WA up to the coastal waters of Southeastern AK. The transect was sampled twice over one month to examine temporal patterns of population structure and multiple genetically distinct populations were identified. We are currently combining microsatellite-derived population structure with drifter-derived estimates of transport time and probability to examine the relative influences of mixing and selection in the plankton. Importantly, the new drifter-based probabilistic framework we developed can be applied to many mero- and holo-planktonic organisms over a broad range of spatial and temporal scales.

9:40 *Finding Nemo in Puget Sound: larval dispersal estimates from genetic parental identification in brown rockfish (*Sebastes auriculatus*)*  
Lorenz Hauser (UW), Maureen Hess (UW), Mitsuhiro Kawase (UW), Raymond Buckley (UW) and Larry Leclair (WDFW)

Notes: Although the effects of MPAs on biomass, age distribution and species richness are well established, the extent of larval exchange between MPAs and surrounding areas is essentially unknown. Therefore, the benefit of areas surrounding MPAs from increased reproductive output of protected stocks and the ability of isolated MPAs to maintain sufficient recruitment without larval influx cannot be evaluated. Population genetic estimates of dispersal rates are often not informative because levels of gene flow are too high to allow estimation of connectivity. Genetic parentage identification, on the other hand, has the potential of providing direct estimates of dispersal from spatial information of parent and offspring, though the method has so far been only employed in tropical species with relatively short larval duration. Here, we report larval dispersal estimates of brown rockfish (*Sebastes auriculatus*) in Puget Sound from genetic parentage assignment, that will be integrated with oceanographic models (see associated talk by Kawase *et al*) and transgenerational tagging by induced strontium marks in

larval otoliths. Several parent offspring pairs could be identified, suggesting some self recruitment in the study population but also some immigration that corresponds well to oceanographic patterns. The results demonstrate the applicability of genetic parentage identification to temperate species with long larval phases and show complex patterns of dispersal in Puget Sound.

10:20 *Observations of High-Frequency Internal Waves Approaching Newport, Oregon*  
\*\*Ata Suanda (OSU), John A. Barth (OSU), Merrick Haller (OSU) and Patrick Mcenaney (OSU)

Notes: One of the difficulties in modeling population connectivity for intertidal species is the multiple time and space scales with which organisms experience the ocean. While much work has been conducted on the advective effects of large-scale, subtidal motions over the shelf, less is known about how cross-shelf larval transport occurs over the last kilometer of the coastal ocean. Currently many regional circulation models do not accurately treat the inner shelf. Internal waves are an unresolved process in these models and may provide the final link between offshore larval pools and onshore populations. As internal waves become nonlinear, they have the potential to advect water parcels and the materials they contain such as nutrients and larvae across shelf.

To provide insight into the role of internal waves in redistributing mass and momentum across the inner shelf, we conducted a combined in-situ and remote sensing observational effort off Newport, OR. During a two-week period in August 2010, high-frequency current measurements from a bottom-mounted Acoustic Wave and Current Profiler (Nortek AWAC) and temperature measurements from a thermistor chain (RBR TR-1060) will be combined with land-based X-band radar observations which are currently used to detect the surface gravity waves approaching the shore. While shipboard radar observations of internal waves are becoming more commonplace, one our goals is to see if internal waves can be detected by the land-based instrument despite the background of shoaling surface gravity waves. Our other questions include: What are the generation mechanisms of the observed internal waves? Can we see a phase relation with the shelf-break generated internal tide? To what degree are the waves nonlinear and potentially effective in communicating features of the shelf circulation with the coastline? Our work will elucidate the impact of internal waves on inner-shelf circulation, provide a useful dataset for model-data comparison, and hopefully help inform model parameterizations of horizontal mixing near the coastal boundary.

10:40 *Nearshore velocity gradients lower the speed limit for coastal dispersers*  
\*\*Kerry Nickols (UC Davis), B. Gaylord and J. L. Largier

Notes: For many nearshore marine organisms, the larval phase is the primary dispersive phase that establishes connections between and among populations. Relatively little is known about transport over the inner shelf and in nearshore waters through which larvae must move to access stronger alongshore flows at

greater distances from shore. Previously, we have shown a robust pattern at 5 sites along the California coast where velocity decreases logarithmically toward shore, similar to the hydrodynamic “law of the wall”. Further investigation indicates that this region of attenuated flow is most likely the product of bottom friction and horizontal shear. The character of the coastal velocity profile also implies that eddy diffusivity increases linearly. We use a 2-D particle tracking model to explore the effects of nearshore velocity and diffusivity gradients on dispersal kernels of short dispersing species. These background alongshore flow conditions have the potential to reduce alongshore larval moment, which may be further reduced by other nearshore ‘speed bumps’ such as recirculation associated with topography and biologically-mediated flow environments, such as kelp forests.

11:00 *Connectivity of Larval Dispersal along the Oregon Coast by Numerical Simulations*  
Sangil Kim (OSU) and Jack Barth (OSU)

Notes: Connectivity of larval dispersal is explored over the Oregon coast during the summer upwelling season of 2001 by numerical simulations. The study region, with strong wind-driven currents and variable topography, is modeled using the Regional Ocean Modeling System forced by the Coupled Ocean Atmosphere Mesoscale Prediction System. A large number of passive particles as models of planktonic larvae are released daily for 120 days from 1 May to 28 August at different depths of 1, 7, 15, 20, 50, and 75 m at every grid point shoreward of the 200-m isobath (on average 32 km offshore). The particles are restricted to a fixed depth, so only horizontal circulation influences their trajectories. Competency time window for larval settlement is assumed to be in between days 15 and 35 after larvae are released. Larval settlement occurs at the shallowest location during the competency time window. The present simulation suggests that larvae are retained near the shore when the winds, averaged over the previous 6 to 8 days, are relaxed or downwelling-favorable. Connectivity matrices reveal that some of the places of highest retention are similar to the proposed Oregon marine reserve sites, especially Cape Perpetua. The Heceta Bank region has high probabilities as both a source and a destination for settled larvae. Larvae released in the Heceta Bank region often settle at higher latitudes than their release location. There is a strong correlation between the number of settled larvae, that is, larvae shallower than the 50-m isobath, and a 6 to 8-day running mean of the alongshore wind stress. This suggests that the best timing for larvae settlement, and hence release 15-35 days earlier, can be predicted by the mean of the alongshore wind stress for the past 6-8 days.

11:20 *Persistent frontal features and climate change: Structuring of connectivity in the Eastern Pacific*  
C. Brock Woodson (Stanford), M.A. McManus (U Hawaii), J.A. Tyburczy (OSU), J.A. Barth (OSU), L. Washburn (UCSB), M.H. Carr (UCSB), D. Malone (UCSB), P.T. Raimondi (UCSC), B.A. Menge (OSU) and S.R. Palumbi (Stanford)

Notes: Understanding connectivity in marine ecosystems is critical for marine protected areas (MPAs). Using a 10+ year data set, we present evidence that persistent frontal zones provide a distinct structure to recruitment for multiple species suggesting a spatially structured connectivity pattern. Persistent nearshore fronts are shown to be regions of elevated primary production and recruitment of rockfishes, barnacles, and mussels from Oregon to Southern California. The consistent effect across species and genera provides a potential mechanism for the expansion of marine reserve design theory beyond single-species to the community and ecosystem level. The scales of frontal features are also critically dependent on upwelling. During non-upwelling seasons, scales are on the order of 100's of kms, however during upwelling, these scales are reduced to less than 50 km. Potential impacts of climate change, including delayed onset of upwelling, may lead to non-structured environments for pelagic larvae and limit the effectiveness of MPA networks.

11:40 *Larval advection and control regulating larval recruitment in upwelling regions: Implications for population connectivity*  
Steven Morgan (UC Davis) and Jennifer Fisher (UC Davis/NOAA)

Notes: Larvae are thought to be highly vulnerable to offshore transport in upwelling regions along the eastern margins of continents, thereby limiting recruitment to infrequent wind-relaxation events and years of weak upwelling. In contrast, several recent studies conducted in the strong, persistent upwelling off Northern California have shown that a diverse array of crustacean larvae are neither advected offshore nor limited to recruiting during relaxation events. Interspecific differences in larval behavior regulate the distances larvae disperse cross-shelf and likely alongshore, affecting population connectivity. New evidence suggests that the spatial and temporal variation in surfzone hydrodynamics may play a substantial role in regulating recruitment to communities in upwelling regions.

## **EPOC 2010: Friday 24 September Afternoon Session ABSTRACTS**

### **General Session – cont'd**

16:00 *Temporal and spatial patterns in wind stress curl over the central Southern California Bight*  
Marlene Noble (USGS) and Kurt Rosenberger

Notes: In 2001, the U. S. Geological Survey, together with several other federal and municipal agencies, began a series of field programs to determine along and cross-shelf transport patterns over the continental shelves in the central Southern California Bight. As a part of these programs, moorings that monitor winds were deployed along the shelf break off the Palos Verdes peninsula and within San Pedro Bay for six 3 to 4 month summer and winter periods between 2001 and

2008. In addition, nearly continuous wind records for the 7-year period were obtained from a coastal and a basin site. Coastal winds were from Los Angeles airport, located just inshore of the beach in Santa Monica Bay. Winds over the adjacent offshore basin were from NDBC buoy 46025, located about 55 km northwest of Catalina Island.

The alongshelf component of the low pass-filtered wind dominates the wind field and is well correlated between the basin and coastal sites; correlation amplitudes are 0.7. The annual mean winds, which are downcoast at both sites, are rotated more onshore at LAX than over the basin. On average, fluctuations in the portion of the wind stress that is correlated between the two sites are 4 times larger over the basin than at the coast. Hence, the data from these two widely separated sites suggests that wind stress curl is strong, positive and exists over the entire basin/shelf region in all seasons. However, when wind stress measurements over the shelf are included in the analysis of the coastal and basin wind stress field, the results suggest that the spatial patterns for wind stress curl vary with season. In winter, when wind stress amplitudes are largest, the cross-shelf gradient in wind stress decreases uniformly across the basin, the shelf, and the coast. Hence a positive curl in wind stress exists across the entire region. In summer, when wind stress amplitudes are small, the cross-shelf gradient in wind stress is nearly zero across the basin and shelf. The only large gradient is observed on the inner shelf, where wind amplitudes decrease markedly toward the coast. Hence, wind stress curl in the summer months can be weak or absent over most of the central Southern California Bight. This suggests that transport patterns over the basin and shelf that are driven by wind stress curl may change markedly between the winter and summer seasons.

16:20 *Seasonal upwelling over the Washington shelf: effects of submarine canyons and the California Undercurrent*

\*\*Thomas P. Connolly (UW) and Barbara M. Hickey (UW)

Notes: The Washington shelf maintains high levels of chlorophyll *a* despite relatively weak upwelling favorable winds compared with coastal locations further south. Submarine canyons in this region help maintain high subsurface nutrient levels over the continental shelf by steering deep slope water across the shelf break towards the coast. Until recently, because of the small scales of submarine canyons, estimates of the regional significance of submarine canyons have typically been extrapolated from isolated observational and idealized modeling studies. In addition, the dynamics of wind-driven canyon upwelling are not well understood in the presence of a poleward undercurrent. We use a system of nested models to investigate the interaction between local topographic effects, which occur over scales of tens of kilometers, and the larger scale alongshore pressure gradient, which is set up over hundreds of kilometers. During the modeled summer 2005 season, intensive hydrographic surveys and time series from moored sensors are used to evaluate the model's representation of currents and water properties. The model captures the seasonal development of important regional features: the equatorward coastal jet, the poleward California

Undercurrent, the Vancouver Island Countercurrent and the Juan de Fuca eddy. Over the Washington shelf, enhanced upwelling is observed near two dynamically distinct submarine canyons, the wide Quinault canyon and the narrow Juan de Fuca canyon which intersects the coast and is coupled to an estuarine circulation. Results suggest that, contrary to previously used assumptions, the seasonal development of a poleward undercurrent during late summer does not completely shut down the enhanced upwelling that occurs near submarine canyons. It is therefore possible that submarine canyons have even greater regional significance than previously thought.

16:40 *Wind- forced currents and advection of dissolved oxygen off the central Oregon coast during the 2009 upwelling season*  
\*\*Kate Adams (OSU), Jack Barth (OSU), Justin Brodersen (OSU)

Notes: With motivation to understand the influence of subtidal physical processes such as horizontal advection and wind-driven upwelling on ecosystem dynamics off the central Oregon coast, along-shore and cross-shore current variability along the 15- and 70-m isobaths are investigated for the 2009 upwelling season (April – September). Physical and dissolved oxygen data are analyzed from four moorings: Lincoln Beach (44.88N, 15-m, LB15), Newport (44.65N, 80-m, NH10), Strawberry Hill (44.28N, 70-m, SH70) and Strawberry Hill (44.28N, 15-m, SH15). Along-shore current data from SH70 and SH15, located south of the submarine bank complex (Stonewall and Heceta banks), exhibit weaker correlations to local wind velocities (NOAA NDBC 46050) than moorings north of the banks (NH10 and LB15) where bottom topography is greatly simplified and oriented parallel to the coastline. Previous work has shown weak mean southward velocities inshore of the bank complex along the 15-m isobath compared with data to the north (Kirincich 2008). The lowest concentration of dissolved oxygen has been reported over the bank complex with increases to both the north and south. Depth-averaged advection time series are applied to dissolved oxygen gradients in along-shore (LB15 to SH15) and cross-shore (SH70 to SH15) directions. Estimates of the percent of dissolved oxygen variability due to advection in this region are computed for early and late upwelling season periods. The remaining dissolved oxygen variability not explained by advection is compared with rates of respiration in this area.

## **Climate Change and Spatial Ecology**

17:00 *Marine Distribution and aggregation of discreet populations of Chinook salmon (*Oncorhynchus tshawytscha*) taken in the Oregon troll fishery*  
\*\*Robert Ireland (OSU), Lorenzo Ciannelli (OSU), Renee Bellinger (OSU), Pete Lawson (NWFSS/NRS) and Michael Banks (OSU)

Notes: A thorough understanding of ocean distribution is critical to sustaining and recovering individual stocks of Chinook salmon. Project CROOS, Collaborative Research on Oregon Ocean Salmon, is a unique partnership of scientists and

commercial fishermen that combines catch location data with stock assignments obtained from genetic micro-satellite analysis to investigate the distribution of Oregon Chinook across multiple spatial scales. Using catch data collected by collaborating Oregon troll fishermen, we investigated the distribution of individual populations of Chinook salmon along the nearshore regions of the Oregon Coast. The study focused on two distinct spatial scales: 1) the coast-wide, latitudinal distribution of the 13 most abundant stocks that contributed to the Oregon catch in 2007, and 2) stock-based patterns of Chinook aggregation on spatial scales as low as tens to hundreds of meters.

The Oregon Chinook fishery is primarily supported by salmon stocks that originate from the hatcheries and rivers of California and Oregon. Based on 2007 catch data, we report three separate patterns in the coastal distribution of Oregon-caught Chinook. Stocks from the Sacramento River, Mid-Oregon Coast and Upper Columbia basin were distributed coast-wide in the Oregon catch. Chinook salmon that originated from northern California and southern Oregon were found to be more abundant south of 44° North – the approximate latitude of the coastal town of Florence, Oregon. Stocks from the north Oregon coast and the lower Columbia basin were primarily taken north of 44° North. Chinook from the Columbia River basin made up approximately 6.5% of the catch in both years, were more abundant prior to early September, and tended to be mostly 4-year-olds. This pattern suggested that Columbia River Chinook were primarily non-permanent residents of the Oregon shelf most common during the summer before their freshwater spawning run. Using the distance-based metrics compared with random permutations, we found some evidence that Chinook salmon appear to be associated with river cohorts. However, these discreet stocks were generally intermingled with other stocks in mixed-stock aggregations.

17:20 *Seasonal to Decadal Dynamics of Giant Kelp Biomass in the Santa Barbara Channel*

\*\*Kyle Cavanaugh (UCSB), David Siegel (UCSB) and Daniel Reed (UCSB)

Notes: Synthesizing long-term observations at multiple scales is vital to understanding and predicting ecosystem responses to a changing climate. Recent increases in the availability of time-series satellite data allow regional variability in producer biomass and productivity to be evaluated on seasonal to decadal scales. Here, we combined LANDSAT satellite imagery with diver sampling to assess local and regional changes in the biomass of giant kelp (*Macrocystis pyrifera*) at unprecedented temporal resolution. Our objectives were to: 1) develop new methods for estimating giant kelp biomass from an extended time series (>25 years) of satellite imagery and 2) characterize the controls on kelp forest biomass across multiple temporal and spatial scales. We successfully developed an automated classification technique where each pixel in an image was modeled as a combination of kelp and water spectra, thus producing continuous maps of fractional kelp coverage. Monthly diver observations of canopy biomass in fixed plots at two kelp forest sites were well correlated with satellite determinations of fractional kelp coverage ( $r^2 = 0.63$ ) allowing us to

examine the dynamics of giant kelp biomass across multiple spatial scales. Correlative analyses involving a range of oceanographic and climatic variables (e.g., swell height, sea surface temperature, nutrients, ENSO, PDO, and NPGO indices) provided insight into the possible responses of the giant kelp system to variability in these drivers. The spatial coverage of LANDSAT allowed us to investigate how the roles of these drivers varied in space due to wave exposure, local temperature and nutrient conditions. We found that region-wide seasonal dynamics were negatively correlated with maximum wave height and sea surface temperature. Sub-regions with similar temporal dynamics were separated by wave exposure gradients. Linking remotely acquired data with long-term ecological field measurements can facilitate a better understanding of the patterns and drivers of biomass and primary production for many terrestrial and aquatic ecosystems.

## **EPOC 2010: Saturday 25 September Morning Session ABSTRACTS**

### **Climate Change and Spatial Ecology cont'd**

8:20 *How well are Mesoscale Phenomena along the Coast of Washington Linked to Eastern Pacific Climate Forcing*  
Jessica M. Kleiss (UW), Nicholas A. Bond (UW), Albert J. Hermann (UW) and Enrique Curchitser (Rutgers)

Notes: The marine ecosystem of the Pacific Northwest experiences a variety of episodic events of significance to environmental health. Notable examples include the particularly large harmful algal bloom (HAB) observed off the Washington state coast in early fall 2004, the delayed upwelling of the summer of 2005, and record-setting low concentrations of dissolved oxygen (hypoxia) in 2006. As part of a project supported by Washington Sea Grant, we are investigating how these mesoscale phenomena are linked to the large-scale eastern Pacific atmosphere-ocean system. The occurrence of mesoscale phenomena is specified from existing high-resolution hindcast simulations from the Regional Ocean Modeling System (ROMS). The large-scale eastern Pacific climate forcing is characterized with data from the NCEP Reanalysis for the atmosphere and Simple Ocean Data Assimilation (SODA) for the ocean. The large-scale data serves as predictors for statistical relationships, as guided by previous research. The statistical relationships that are determined in this phase of our project will eventually be used with IPCC-class global climate model forecasts to project the frequency and magnitude of crucial coastal phenomena over the course of the 21st century.

8:40 *Changes in the nutrient supply to the eastern North Pacific with global warming and increased stratification in a coarse-resolution earth system model*  
Ryan R. Rykaczewski (UCAR/GFDL) and John P. Dunne (NOAA/GFDL)

Notes: We explore the response of primary production in the eastern North Pacific to global climate change and illustrate that the nature of anthropogenic change may be unlike variability observed in the past. Nutrient and carbon cycling in the ocean are represented using an earth system model, allowing comprehensive assessment of relevant hydrographic, atmospheric, and biogeochemical processes at a global scale and coarse resolution. We project that nitrate supply and productivity will increase in the eastern North Pacific during the 21st century despite an increase in stratification and limited change in wind-driven upwelling. The increase in nitrate supply is attributed to enrichment of the deep source waters resulting from decreased ventilation. However, we also note that the high degree of spatial variability in the eastern North Pacific poses a challenge to the current generation of earth system models, and we discuss the ecological implications of resolving important hydrographic processes at higher resolution.

9:00 *Climate-related changes in ocean transport control North Pacific zooplankton biogeography*  
Julie E. Keister (UW), Emanuele Di Lorenzo (GIT), Vincent Combes (OSU), Cheryl A. Morgan (OSU) and William T. Peterson (NOAA)

Notes: North Pacific boundary ecosystems are strongly impacted by climate-related physical variability, but direct tests of the mechanistic links between climate and the biological structure are rare. The Pacific Boundary Ecosystems and Climate Study (POBEX) is exploring the role that large-scale ocean transport plays in bottom-up control of Pacific boundary ecosystems. Using zooplankton observational data and passive tracer experiments in a Regional Ocean Modeling System (ROMS), we are testing the physical controls on zooplankton variability in the Northern California Current (NCC) and Kuroshio/Oyashio (KO) region. In the NCC, coastal zooplankton communities show shifts between cold-water species dominance and warm-water species dominance on seasonal and multi-year timescales. These zooplankton shifts correspond to the PDO, and to changes in salmon survival, indicating strong bottom-up ecosystem control. Our model results indicate that horizontal Ekman-layer advection is likely the dominant physical control of regional NCC zooplankton community structure. We show that the low-frequency component of the transport strongly correlates ( $R > 0.9$ ) with the regional variance in species composition. Hindcasts of the zooplankton community composition reveal 6-7 year cycles of species dominance over the 1950–2008 model domain, and a shift toward warm-water communities following the 1976 ‘regime shift’ to positive PDO conditions.

9:20 *Modeling Pacific top predator habitat in a changing climate*  
Elliott L. Hazen (NOAA), Salvador Jorgensen (Stanford), Ryan Rykaczewski (UCAR/GFDL), Dave Foley (NOAA), Steven Bograd (NOAA), John Dunne (GFDL), Ian Jonsen (Dalhousie), Arliss Winship (Dalhousie), Greg A. Breed (UCSC), Autumn-Lynn Harrison (UCSC), James Ganong, Mike Castleton

(Stanford), Alan Swithenbank (Stanford), Daniel Costa (UCSC) and Barbara Block (Stanford)

Notes: Abstract: As many top predators in marine systems are in decline, it is important to assess which species are at greatest risk and which marine habitats are most important for conservation. The tagging of Pacific predators (TOPP) project provides a rich dataset as researchers have tagged 4300 animals resulting in 268,000 data-days. We used spatially explicit habitat models (e.g. generalized additive mixed models) to examine present-day distributions and foraging habitat of top predator species in the Pacific from 2001-2009 as a function of fixed bathymetric variables, sea surface temperature, and chlorophyll-a. From these results, we are able to develop predictive models for a subset of species whose distributions were well explained by these physical features. Consequently we can use high-resolution climate models from the Geophysical Fluid Dynamics Laboratory to predict potential habitat under future scenarios. While many top predators exhibit plasticity in behavior particularly with respect to temperature, the pelagic prey (e.g. deep scattering layers, schooling fish, krill) they feed upon are likely more sensitive to ocean changes and more closely linked to primary production. Increased frequency of El Niño / La Niña events and changes in timing and intensity of upwelling could further affect biodiversity and potential habitat in the north Pacific, particularly the critical habitat within the California current.

9:40 *Effect of fishing on the spectral sensitivity of fish populations to climate variability*

Louis W. Botsford (UC Davis), Matthew D. Holland (UC Davis) and Alan Hastings (UC Davis)

Notes: There is increasing concern for the effects of the combination of fishing and climate change on fish populations. There have been several reviews of possible mechanisms, but there has not been an analysis of cohort resonance. Cohort resonance is the term for a selective sensitivity of age-structured populations to environmental variability on time scales near  $T$ , the dominant age of spawning. Recent results in population dynamics show that as fishing mortality increases, this response can increase in magnitude and the sharpness of the peak at frequency  $1/T$ . The upper limit on the increase in magnitude and sharpness is set by the value of fishing mortality rate that causes the population to collapse; as fishing mortality increases the lifetime reproduction of the population diminishes to a point at which individuals are no longer replacing themselves, and the population collapses. Here we quantify these effects on several dominant fished species in the eastern Pacific.

## General Session – cont'd

10:20 *Understanding ocean acidification in the Pacific Northwest: contributions from NANOOS*

Jan Newton (UW), R. Feely (NOAA), C. Sabine (NOAA), S. Alin (NOAA) and A. Devol (UW)

Notes: The Northwest Association of Networked Ocean Observing Systems, NANOOS, which is the regional IOOS association for the Pacific Northwest US, has built its regional ocean observing system (RCOOS) to serve key issues of concern for PNW stakeholders. The topic of ocean acidification is relevant to three of the high priority NANOOS issues: climate change, ecosystem impacts, and fisheries.

A combination of factors renders the Pacific coast of North America especially vulnerable to corrosive water events (Feely et al. 2008). Waters along the Pacific coast are, to a degree, naturally corrosive due to natural respiration processes and the oxidation of organic matter. Anthropogenic additions of CO<sub>2</sub> further reduce the pH and carbonate saturation state of Pacific coast waters to levels that can challenge calcification in shelled organisms (Feely et al. 2008). Seasonal upwelling transports these corrosive water onto the continental shelf, where in some places, they reach all the way to the surface and can be transported into estuaries. Inputs of nutrients and organic matter to coastal estuaries can reduce pH and carbonate saturation state even further (Feely et al. 2010). Consequently, natural processes, anthropogenic additions of CO<sub>2</sub>, additions of strong acids from combustion and agriculture, and additions of nutrients and organic matter to estuaries all combine to intensify ocean acidification in northwest coastal estuaries.

The same northwest coastal estuaries that are threatened by ocean acidification have, for more than a century, been the source of highly valued shellfish and shellfisheries. In Washington State alone, shellfish growers in 2005 produced approximately 90 million pounds of shellfish with an estimated value of \$97 million (Pacific Coast Shellfish Growers Association 2010). A field study to collect data on Puget Sound water chemistry of Puget Sound found evidence of low pH waters in Hood Canal and the Puget Sound main basin (Feely et al., 2010). Low pH values indicate that the water chemistry is changing and becoming more acidified as the ocean absorbs more carbon dioxide (CO<sub>2</sub>) from the atmosphere, a condition that is corrosive to shells of organisms such as oysters.

To better understand the effects of ocean acidification on shellfish within Puget Sound, the Puget Sound Partnership and EPA funded UW, NOAA, Pacific Shellfish Institute, Washington Department of Ecology, Taylor Shellfish, and Baywater, Inc. to conduct collaborative studies investigating if corrosive seawater is affecting shellfish populations. The work monitors both water conditions and shellfish larvae, providing high-resolution oceanographic data in concert with measurements on ocean acidification and larval settlement from two locations where shellfish are growing, Dabob Bay and Totten Inlet. Data from 2009-10 seasons will be discussed.

In collaboration with NOAA, NANOOS-supported moorings are now monitoring pCO<sub>2</sub> at several sites, including Dabob Bay and Hood Canal in Puget Sound, off Newport, OR, and most recently off La Push, WA on a new buoy funded by the Murdock Charitable Trust. The data will be valuable to understanding coastal conditions and boundary conditions for the fertile estuaries.

10:40 *Modeled Phytoplankton Biodiversity in the California Current System*  
Nicole .L. Goebel (UCSC), Chris .A. Edwards (UCSC), Jon P. Zehr (UCSC) and Mick Follows (MIT)

Notes: A large-dimensional, self-assembling, emergent ecosystem model previously implemented in the California Current System (CCS) is used to investigate the biodiversity of the simulated phytoplankton community. In this model, niche differentiation and the resultant biogeography and temporal variability of each phytoplankton type resulted in an average of 8 individual phytoplankton (our measure of biodiversity) that dominated the upper 99% of total biomass in the surface waters of the domain over a 5 year model run. This measure of biodiversity ranged from a minimum (~2) in high nutrient coastal waters to a maximum (~8) in offshore oligotrophic waters. A longitudinal gradient also existed offshore with an increase in diversity from North to South. Temporal variability in this average diversity ranged 2-3-fold depending on the region. This overall level of biodiversity is relatively high for an ecosystem model, however it may not compare to that observed in nature. In an altered version of the model, we allow individual phytoplankton to be introduced (speciation) upon mortality (extinction) of individuals with unsustainable biomass as defined by a low level threshold. We test whether this alternative version of the model optimizes representation of modeled biodiversity, as well as the new individual phytoplankton types that emerge.

11:00 *Toward an uncertainty budget for a coastal ocean model*  
Roger M. Samelson (OSU), S. Kim (OSU) and C. Snyder (NCAR)

Notes: Estimates of three components of an uncertainty budget for a coastal ocean model in a wind-forced regime are made, based on numerical simulations. The budget components behave differently in the shelf regime, inshore of the 200-m isobath, and the slope-interior regime, between the 200-m isobath and a fixed longitude (126°W) that is roughly 150 km offshore. The first of the three budget components is an estimate of the uncertainty in the ocean state given only a known history of wind stress forcing, with errors in the wind forcing estimated from differences between operational analyses. It is found that, over the continental shelf, the response to wind forcing is sufficiently strong and deterministic that significant skill in estimating shelf circulation can be achieved with knowledge only of the wind forcing, and no ocean data, for wind fields with these estimated errors. The second involves initial condition error and its influence on uncertainty, including both error growth with time from well-known initial conditions and error decay with time from poorly known initial conditions

but with well-known wind forcing. The third component is that of boundary condition error and its influence on the interior solutions, including the dependence of that influence on the specific location along the boundary of the boundary condition error. Boundary condition errors with amplitude comparable to the root-mean-square variability at the boundary lead eventually to errors equal to the root-mean-square variability in the slope-interior regime, and somewhat smaller errors in the shelf regime. Covariance estimates based on differences of the wind-forced solutions from the ensemble mean are not dramatically different from those based on the full fields, and do not show strong state dependence.

11:20 *Coastal-Trapped Waves: Wind in Baja California Drives Temperature and Circulation in the Santa Barbara Channel*  
Melanie Fewings (UCSB) and Libe Washburn (UCSB)

Notes: The Santa Barbara Channel (SBC) and Northern Channel Islands have many species-rich kelp forest ecosystems, some contained in Marine Protected Areas. It is important to understand what controls the ocean circulation and temperature patterns that affect nutrient supply, larval transport, and adult habitat in the kelp forests. Onshore of the 30-m isobath, where kelp forests exist, previous studies of the circulation have focused on the mainland and little is known about the Islands. In the western SBC, local winds are upwelling-favorable in summertime and are important for driving the circulation. In contrast, the eastern SBC is in the lee of Point Conception so the wind forcing there is weak, and local wind explains little of the velocity variance. Using mooring data and satellite winds from QuikSCAT, we show that coastal-trapped waves are important for driving circulation and temperature in the eastern SBC. The near-bottom temperature and pressure on the 15-m isobath in the eastern SBC are better correlated with winds 600 km to the south, in Baja California, than with local winds. The best correlation is for temperature and pressure lagging the wind by 2.5 days, consistent with the propagation speed of a low-mode coastal-trapped wave (CTW). Data from temperature sensors at 33 sites and acoustic Doppler current profilers and bottom pressure sensors at 21 sites on the 8-18 m isobaths show that fluctuations in temperature, stratification, velocity, and pressure at periods of 4-25 days consistent with CTWs are coherent across the SBC region, including on the north and south sides of the Channel Islands. The amplitude of the pressure fluctuations drops off from the mainland to the Islands with a cross-shelf scale of  $O(100 \text{ km})$ . We discuss the relative importance of CTWs vs. local wind in driving the circulation at periods of 4-25 days at each site, the effect of Point Conception on the propagation of the waves, and the possibility that CTWs modulate internal tidal motions that bring cold, nutrient-rich water to kelp forests.

11:40 *A model study of the Salish Sea estuarine circulation*  
David A. Sutherland (UW), Parker MacCready (UW), Neil S. Banas (UW-APL) and Lucy F. Smedstad (NRL)

Notes: A realistic hindcast simulation of the Salish Sea, which encompasses the estuarine systems of Puget Sound, the Strait of Juan de Fuca, and the Strait of Georgia, is described for the year 2006. The model shows moderate skill when compared against hydrographic, velocity, and sea surface height observations over tidal and subtidal timescales. Analysis of the velocity and salinity fields allows the structure and variability of the exchange flow to be estimated for the first time from the shelf into the farthest reaches of Puget Sound. This study utilizes the total exchange flow formalism that calculates volume transports and salt fluxes in an isohaline framework, which is then compared to previous estimates of exchange flow in the region. From this analysis, residence time distributions are estimated for Puget Sound and its major basins, and are found to be markedly shorter than previous estimates. The difference arises from the ability of the model, and the isohaline method for flux calculations, to more accurately estimate the exchange flow. In addition, evidence is found to support the previously observed spring-neap modulation of stratification at the Admiralty Inlet sill. However, the exchange flow calculated increases at spring tides, exactly opposite to the conclusion reached from an Eulerian average of observations.

\*\* Denotes Student Presenters