FATE: Ecosystem indicators for a transitional region of the Northern California Current: Filling a critical gap in the CCIEA with observations along the Trinidad Head Line.

Principal Investigators: Eric Bjorkstedt, Southwest Fisheries Science Center, Trinidad CA and Bill Peterson, Northwest Fisheries Science Center, Newport OR

Background

The California Current Integrated Ecosystem Assessment (CCIEA) presently includes oceanographic data focused on three latitudes 33°, 39° and 45°N. At the northern end, the CCIEA is supported by the long-standing Newport Hydrographic Line (NHL) off Newport, Oregon (44.6°N). However, the region between 39° and 45°N is characterized by strong oceanographic gradients and a transition from relatively simply structured coastal upwelling system off the Pacific Northwest to a region marked by complex mesoscale structure associated with major headlands such as Cape Blanco, Cape Mendocino and Point Arena. This region has historically been poorly studied, and presently looms as a data gap in the CCIEA. Moreover, research based on indicators derived from observations collected along NHL commonly raise the question of how far north or south along the coast such indicators are useful (e.g., Francis et al. 2012), particularly with respect to salmon stocks that spawn in the rivers of northern California. We propose to develop ecosystem indicators for this region based on the now-mature Trinidad Head Line (THL; 41°N) in order to assess the latitudinal coherence of ecosystem indicators based on the NHL, while filling a critical information gap in the CCIEA and establishing ecosystem indicatorsfor Klamath River Chinook salmon stocks that hold a central place in management of ocean salmon fisheries along much of the U.S. West Coast.

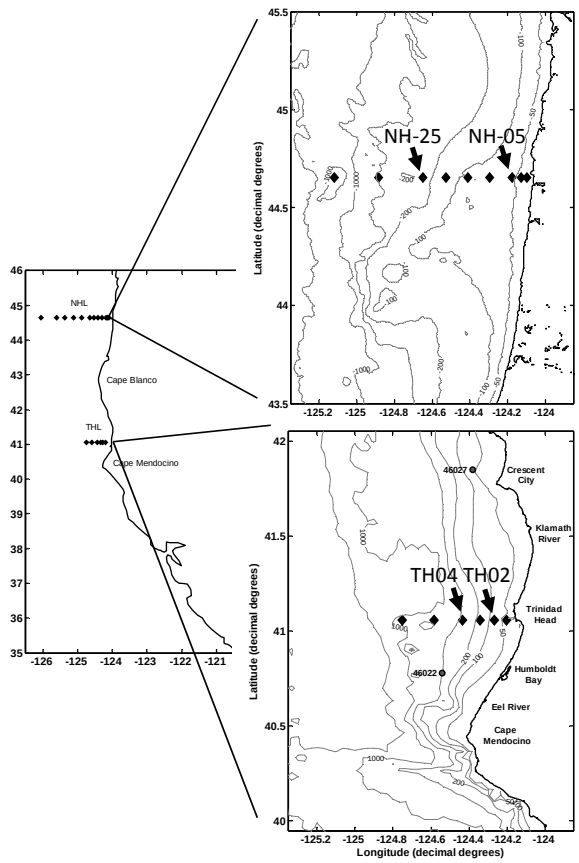

Figure 1: Location and structure of the Newport Hydrographic Line (NHL) and Trinidad Head Line (THL)

The **Newport Hydrographic Line** has developed the longest (18 years and growing) high-frequency time series of hydrographic, chemical, and biological conditions in the northern California Current (NCC). These data reflect biweekly sampling of hydrography, nutrients, chlorophyll, copepods, krill and

ichthyoplankton at seven stations spanning the continental shelf from the nearshore zone to the upper continental slope (Figure 1). The **Trinidad Head Line** was established in late 2006 (and solidified in 2008) as a series of six stations—three spanning the narrow continental shelf and three over the upper and middle continental slope—extending due west of Trinidad Head (approximately 41°N; Figure 1). Survey cruises along the THL collect hydrographic data, water samples for assays of nutrient and chlorophyll concentrations, and zooplankton net samples at approximately monthly intervals; collaborations with other projects have supported several extended periods of bi-weekly sampling since 2011.

The NHL and THL are two of several long-term hydrographic and zooplankton monitoring programs that span much of the California Current Large Marine Ecosystem (CCLME); others include surveys off Vancouver Island Canada (Mackas et al. 2001), CalCOFI Line 67 off Monterey Bay, CA (e.g., Collins et al. 2003), the CalCOFI surveys off southern and central California (Bograd et al. 2003), and IMECOCAL off Baja Mexico (Baumgartner et al. 2000). Despite these extensive efforts, zooplankton information remains sparsely incorporated in to ecosystem assessments. For example, none of the CalCOFI samples are processed to quantify copepod abundance or community structure, and the only detailed zooplankton community information consistently contributed to ecosystem syntheses (e.g., PaCOOS quarterly and annual updates, the annual State of the California Current report, and the CCIEA) is based on samples collected along the NHL and, more recently, the THL. Preliminary comparisons of data from the NHL and THL in the context of these reports suggests a fair degree of coherence, but also highlights variability—especially with respect to the boreal copepod species—that may have important implications for understanding how regional conditions affect local ecosystem dynamics off northern California (Figure 2; Bjorkstedt et al. 2011, 2012).

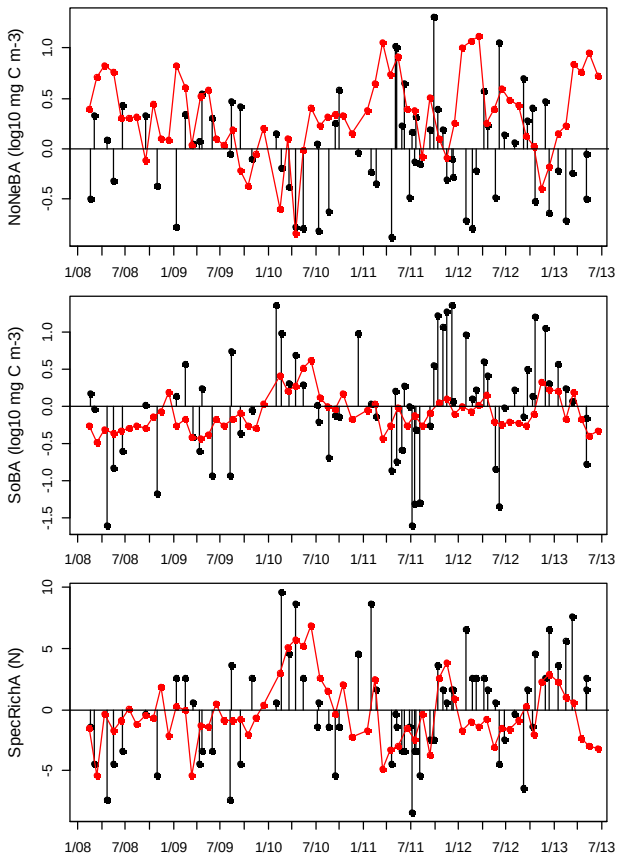

Figure 2. Preliminary comparison of anomalies of Northern Copepod Biomass (top panel), Southern Copepod Biomass (middle panel), and Species Richness (bottom panel) from samples collected at TH02 (black) and monthly averages for NH-5 (red). Anomalies calculated from 2008-2013 means for TH02 and from full time series (1996-2013) for NH-5.

Data from the NHL have supported analysis of ecosystem dynamics across a wide range of temporal scales. Coupled with 'natural experiments'structured by environmental and climate variability over the past two decades, this time series has yielded insight into event-scale responses to fluctuations in wind forcing, seasonal patterns of production and the importance of winter conditions for annual production, and how basin-scale climate forcing propagates to local scales and manifests in the Northern California Current at inter-annual to decadal scales (Peterson and Schwing 2003; Hooff and Peterson, 2006; Keister et al. 2011, Bi et al. 2011, Schroeder et al. 2013).

This work has also shown that, at least off the Oregon coast, the most effective indicators of ecosystem state are rooted in consistent affinities of different copepod species for cold water versus warm water and for nearshore versus oceanic distributions (Peterson and Keister 2003, Hooff and Peterson 2006). Cold-water taxa usually dominate the coastal zooplankton community during the summer upwelling season (typically May through September), while warm-water taxa usually dominate during winter or when El Niño events or persistently warm conditions (as indicated by positive Pacific Decadal Oscillation values) disrupt community transitions related to seasonal upwelling and equatorward flow. Indicators based on these data include: 1) Northern and Southern Copepod biomass anomalies, 2) Copepod Species Richness and 3) the Copepod Community Index (Peterson et al. 2012).

Cold- and warm-water taxa effectively serve as sentinels of change in marine ecosystems by providing early indications of a biological response to climate variability; indeed, several copepod species are often used as an indicator to detect climate change or regime shifts (Hooff and Peterson 2006, Mackas et al. 2006, Peterson 2009). The importance of these shifts for ecosystem dynamics is further magnified by qualitative differences in the energy content of cold- and warm-water copepods. Specifically, two of the cold-water species, *Calanus marshallae* and *Pseudocalanus mimus*, are rich in lipids relative to warm-water taxa. Estimates of northern copepod biomass may therefore serve as effective proxies for the amount of wax esters and fatty acids available to higher trophic levels, and especially to several pelagic fish species for which these energy sources are critical to overwinter growth and survival.

As environmental sentinels and as key players in marine food chains, zooplankton are also useful as leading indicators of ecosystem state and ecosystem response to climate variability. Indeed, NHL-based indicators have been invaluable to the CCIEA: two of threeindicators based on zooplankton data rank among the highest of the 40 indicators that were evaluated for the northern California Current IEA. Moreover, significant and informative correlations have been identified between copepod-community indicators off Oregon and coho salmon returns to coastal rivers of the Pacific Northwest (Peterson and Schwing 2003), Chinook salmon returns to the Columbia River (Burke et al. 2013, Peterson et al. 2012), sablefish recruitment (Schiripa and Colbert 2006), and sardine recruitment (Peterson, unpublished results). Thus, zooplankton-based indicators have strong potential for supporting forecasts of dynamics in commercial fish stocks several years into the future (Mackas et al. 2007).

Despite the latitudinal extent of several correlations between zooplankton-based indicators off Oregon and fish stocks throughout the CCS, outstanding questions remain regarding how conditions influencing zooplankton off Oregon manifest elsewhere in the CCS ecosystem, what is the signature of climate variability in zooplankton communities elsewhere in the CCS, and how far south or north of Newport observations along the NHL provide an unbiased characterization of food chain dynamics and thus can serve as direct or indirect measures of ecosystem state (Sydeman et al. 2011, Thompson et al 2012a, 2012b, Francis et al. 2012). Addressing these questions takes on increasing importance in light of recent, persistent asynchrony in the oceanographic and ecosystem dynamics observed in different regions of the CCS (McClatchie et al. 2009, Bjorkstedt et al. 2010, 2011, 2012). Looking forward, understanding these latitudinal patterns in copepod community structure is of critical importance to the development of coupled circulation-ecosystem models of the CCS (e.g., Goebel et al. 2010) capable of adequately resolving climate-driven community-level variability in zooplankton distributions and production and thus, ultimately, the efficiency of energy transfer to higher trophic levels.

We are now in a position to achieve substantial progress on these several goals and questions, though comparative analysis of observational time series along the NHL and THL. The THL record has matured (6 years to date of monthly to biweekly sampling, with ongoing sampling) to the point where we can expect that comparisons with NHL time series will have sufficient power to detect coherence and discrepancies between the two regions (Figure 2). This expectation is further reinforced (1) by the substantial, if not entirely dramatic, climate variablity that has affected the northern California Current in recent years (e.g.,McClatchie et al. 2009, Bjorkstedt et al. 2010, 2011, 2012), and (2) because the THL samples a region marked by stronger upwelling intensity and mesoscale activity than occurs off central Oregon, setting up potentially stark contrasts over a relatively compact latitudinal slice of the CCS. Moreover, as a consequence of close collaboration and alignment of sampling protocols—the two lines sample copepods using identical gear and sampling protocols, and abundance, biomass, community structure of copepods and other zooplankters have already been enumerated by the Peterson lab for one station on the THL (TH02 at mid-shelf)—bias in this data set is expected to be negligible, allowing rigorous comparison of hydrographic and ecosystem state across the NCC.

Approach

Our analysis will proceed along two parallel tracks that, when brought together, will contribute directly to the CCIEA, while laying a strong foundation for ongoing efforts to inform fisheries management—especially for salmon stocks in the Klamath River and other major watersheds throughout southern Oregon and northern California.

On one track, we will further develop the zooplankton time series available for the THL by continuing to process incoming samples to extend the existing time series for TH02 and to develop complementary time series for stations further offshore (e.g., TH04; in Year One) and inshore (TH01; in Year Two). From these data, we will calculate indicators per the definitions

those indicators currently part of the IEA, including copepod biomass, Northern and Southern Copepod biomass anomalies, and Copepod Species Richness. We will complement this analysis by developing a non-metric multidimensional scaling (NMDS) analysis comparable to that which has been applied with great success to the NHL time series (Keister et al. 2011) to compare zooplankton communities off central Oregon and northern California and to identify and evaluate alternate zooplankton indicators that best represent local conditions off northern California. Statistical evaluation of coherence and divergence between the two lines will account for potential lags, with particular focus on lags that scale with the strength of alongshore advection and event scale production (e.g. Garcia-Reyes, et al. 2013). We will also evaluate how synchrony and asynchrony in the two regions relate to spatial patterns and trends in oceanographic dynamics (see below), using appropriate time series analytical techniques.

In parallel to laboratory analysis of the zooplankton samples, we will compile data to characterize ocean conditions in the region sampled by the THL per variables already included in the CCIEA under "Oceanographic and Climate Drivers and Pressures". Specifically, we will compile information on local SST, winds, sea level anomaly at Crescent City (42°N), pycnocline depth at station TH04, concentrations of dissolved oxygen and nitrate at 150 m depth at TH04, and the upwelling index and its derivatives (e.g., spring transition index [STI], length of upwelling season index [LUSI], and total upwelling index [TUI]) for 42°N. Products from this work will be formatted for publication to the CCIEA website , and in conjunction with other oceanographic and climate indices, will directly support analysis of copepod community data.

Benefits

Data, products, and insights from this work will (1) help to fill a substantial data gap in the CCIEA for a region marked by strong gradients in oceanographic conditions and structure; (2) provide information on the quality of critical marine habitats for juvenile and maturing salmon from populations that spawn in the rivers of northern California and California's Central Valley; (3) augment NHL contributions to the "Ecosystems Considerations" chapter of the Small Pelagics Stock Assessment; (4) enrich several ongoing California Current Ecosystem reports (e.g., the annual CalCOFI report, PFMC reports and PaCOOS reports); and (5) support work to extend the taxonomic resolution of circulation-ecosystem models of the CCS.

Deliverables

In the course of this work, we will produce the following deliverables: (1) summaries of oceanographic and zooplankton indicators for the region off northern California (41-42°N) formatted to CCIEA standards and published to the CCIEA website; (2) publication of zooplankton data and indicators to a new section of the SWFSC web site; (3) presentations at FATE meetings, and PICES or other scientific conferences; and (4) 1-2 manuscripts based on results and insights from comparative analysis of zooplankton communities and zooplankton-based ecosystem indicators for the NHL and THL in the context of oceanographic dynamics and climate forcing.

References

Baumgartner, T., R. Durazo, B. Lavaniegos, G. Gaxiola, M. Hernandez, Y. Green, V. Arenas, S. Lluch, and J. Gómez (2000) The IMECOCAL programme,GLOBEC International Newsletter 6, no. 2: 13-15

Bi, H., W. Peterson, and P. Strub (2011). Transport and coastal zooplankton communities in the northern California Current system. Geophys. Res. Lett., doi:10.1029/2011GL04792

Bjorkstedt, E.P., R. Goericke, S. McClatchie,E. Weber, W. Watson, N. Lo, W.T. Peterson, R.D. Brodeur, S.J. Bograd, T. Auth, J.Fisher, C. Morgan, J. Peterson, R. Durazo, G. Gaxiola-Castro, B. Lavaniegos, F. P. Chavez, C. A. Collins, R. Hannah, J. Field, K. Sakuma, W. Satterthwaite, M. O'Farrell, S. Hayes, J. Harding, W.J. Sydeman, S. A. Thompson, P. Warzybok, R. Bradley, J. Jahncke, R.T. Golightly, S. R. Schneider, R. M. Suryan, A. J. Gladics, C. A. Horton, J. Largier, S. Y. Kim, S. R. Melin, R. L. DeLong, J. Abell (2012) State of the California Current 2011-2012: Ecosystems respond to local forcing as La Niña wavers and wanes. CalCOFI Reports 53: 41-76.

Bjorkstedt E.P., R. Goericke, S. McClatchie, E. Weber, W. Watson, N. Lo, B. Peterson, B. Emmett, R. Brodeur, J. Peterson, M. Litz, J. Gomez-Valdez, G. Gaxiola-Castro, B. Lavaniegos, F. Chavez, C. A. Collins, J. Field, K. Sakuma, P. Warzybok, R. Bradley, J. Jahncke, S. Bograd, F. Schwing, G. S. Campbell, J. Hildebrand, W.Sydeman, S. A. Thompson, J. Largier, C. Halle, S. Y. Kim, J Abell. (2011) State of the California Current 2010–2011: Regionally Variable Responses to a Strong (But Fleeting?) La Niña. CalCOFI Reports 52: 36-68.

Bjorkstedt, E.P., R. Goericke, S. McClatchie, E. Weber, W. Watson, N. Lo, B. Peterson, B. Emmett, J Peterson, R. Durazo, G. Gaxiola-Castro, F. Chavez, J.T. Pennington, C.A. Collins, J. Field, S. Ralston, K. Sakuma, S. Bograd, F. Schwing, Y. Xue, W. Sydeman, S. A. Thompson, J. A. Santora, J. Largier, C. Halle, S. Morgan, S. Y. Kim, K. Merkens, J. Hildebrand, L. Munger. (2010) State of the California Current 2009–2010: Regional variation persists through transition from La Niña to El Niño (and back?). CalCOFI Reports 51: 39-69

Bograd, S. J., CheckleyJr, D. A., & Wooster, W. S. (2003) CalCOFI: A half century of physical, chemical, and biological research in the California Current System. Deep Sea Research Part II: Topical Studies in Oceanography, 50(14), 2349-2353.

Burke, B.J., Peterson, W.T., Beckman, B.R., Morgan C., Daly, E.A. and Litz, M. 2013. Multivariate Models of Adult Pacific Salmon Returns. PlosOne 8(1): e54134.doi:10.1371/journal.pone.0054134

Collins, C. A., J. T. Pennington, C. G. Castro, T. A. Rago, and F. P. Chavez. (2003) The California Current system off Monterey, California: physical and biological coupling, Deep Sea Research Part II: Topical Studies in Oceanography 50, no. 14: 2389-2404

Francis, T. B., Scheuerell, M. D., Brodeur, R. D., Levin, P. S., Ruzicka, J. J., Tolimieri, N., & Peterson, W. T. (2012) Climate shifts the interaction web of a marine plankton community. Global Change Biology, 18(8), 2498-2508.

García-Reyes, M., Largier, J. L., & Sydeman, W. J. (2013). Synoptic-scale upwelling indices and predictions of phyto-and zooplankton populations. Progress in Oceanography. (in press)

Goebel, N. L., Edwards, C. A., Zehr, J. P., & Follows, M. J. (2010). An emergent community ecosystem model applied to the California Current System. Journal of Marine Systems, 83(3), 221-241.

Hooff, R.C. and W.T. Peterson (2006) Recent increases in copepod biodiversity as an indicator of changes in ocean and climate conditions in the northern California current ecosystem. Limnol. Oceanogr. 51:2042-2051

Keister, J. E., Di Lorenzo, E., Morgan, C. A., Combes, V., & Peterson, W. T. (2011) Zooplankton species composition is linked to ocean transport in the Northern California Current. Global Change Biology, 17(7), 2498-2511.

McClatchie,S. R. Goericke, F. B. Schwing, S. J . Bograd,W. T . Peterson, R. Emmett, R. Charter, W. Watson, N. Lo, K. Hill, C. Collins, M. Kahru, B. G. Mitchell, J . A. Koslow, J. Gomez-Valdes , B. E. Lavaniegos, G. Gaxiola-Castro, J. Gottschalk, M. L'Heureux, Y. Xue, M. Manzano-Sarabia, E. Bjorkstedt, S. Ralston, J. Field, L. Rogers-Bennett, L. Munger , G. Campbell, K. Merkens, D. Camacho, A. Havron, A. Douglas and J. Hildebrand (2009) The state of the California Current, 2008-2009: Cold conditions drive regional differences. CalCOFI Rep. 50: 43-68.

Mackas, D. L., R. E. Thomson, and M. Galbraith (2001) Changes in thezooplankton community of the British Columbia continental margin, andcovariation with oceanographic conditions, 1985 – 1999, Can. J. Fish.Aquat. Sci., 58, 685–702

Mackas, D. L., W. T. Peterson, M. D. Ohman, and B. E. Lavaniegos (2006) Zooplankton anomalies in the California Current system before and during the warm ocean conditions of 2005, Geophys. Res. Lett.,33, L22S07, doi:10.1029/2006GL027930.

Mackas, D. L., Batten, S., &Trudel, M. (2007) Effects on zooplankton of a warmer ocean: recent evidence from the Northeast Pacific. Progress in Oceanography, 75(2), 223-252.

Peterson, W.T. and F.B. Schwing (2003) A new climate regime in Northeast Pacific ecosystems. Geophysical Research Letters. 30(17), 1896. doi:10.1029/2003GL017528.

Peterson, W.T. and J.E.Keister (2003) Interannual variability in copepod community composition at a coastal station in the northern California Current: a multivariate approach. Deep-Sea Res. 50:2499-2517.

Peterson, WT, CA Morgan, JO Peterson, JL Fisher, BJ Burke, K Fresh (2012) Ocean Ecosystem Indicators of Salmon Marine Survival in the Northern California Current. http://www.nwfsc.noaa.gov/oceanconditions

Peterson, W. (2009) Copepod species richness as an indicator of long term changes in the coastal ecosystem of the northern California Current.CalCOFI Reports 50: 73-81

Schirripa, M. J., & Colbert, J. J. (2006) Interannual changes in sablefish (Anoplopoma fimbria) recruitment in relation to oceanographic conditions within the California Current System. Fisheries Oceanography, 15(1), 25-36.

Schroeder, I. D., Black, B. A., Sydeman, W. J., Bograd, S. J., Hazen, E. L., Santora, J. A., & Wells, B. K. (2013) The North Pacific High and wintertime pre-conditioning of California current productivity. Geophysical Research Letters.

Sydeman, W. J., S. A. Thompson, J. C. Field, W. T. Peterson, R. W. Tanasichuk, H. J. Freeland, S. J. Bograd, and R. R. Rykaczewski. 2011. Does positioning of the North Pacific Current affect downstream ecosystem productivity?, Geophys. Res. Lett., 38, L12606, doi:10.1029/2011GL047212.

Thompson, S.A., W.J. Sydeman, J.A. Santora, B.A. Black, R.M. Suryan, J. Calambokidis, W.T. Peterson, S.J. Bograd. 2012a. Effects of winter and summer upwelling on top predators: A path analytical approach on "bottom-up" trophic mechanisms. Progress in Oceanography. 101:106-120.

Thompson, S.A., W.J.Sydeman, J.A.Santora, B.A.Black, R.M.Suryan, J. Calambokidis, W.T.Peterson and S.J.Bograd. 2012b. Linking predators to seasonality of upwelling: using food web indicators and path analysis to infer trophic connections. Prog. Oceanogr. 101:106-120