Title: Improving ecosystem-based fisheries management and integrated ecosystem assessments by linking long-term climatic forcing and the Pelagic Nekton Community in the Northern California Current

Principal Investigators:
Richard Brodeur[1], Lorenzo Ciannelli[2], Jameal Samhouri[3]
[1]NMFS/NWFSC, Newport, OR, [2]COAS, Oregon State University, Corvallis, OR, NMFS/NWFSC, Seattle, WA[3]

Collaborators:
Caren Barceló, OSU COAS, Corvallis, OR

Background

Pelagic nekton communities are among the most ecologically and economically important components of marine ecosystems worldwide. From sardines and anchovies to squid and mackerel, these species are at once the object of dedicated and emerging fisheries and links connecting lower and higher trophic levels in the coastal ocean. These characteristics make an understanding of the dynamics of pelagic nekton communities fundamental to nascent ecosystem-based fisheries management efforts. In the California Current Large Marine Ecosystem, pelagic nekton community composition has been known to vary substantially in response to changes in environmental conditions (Brodeur et al. 2006), and climate change promises to bring with it new and unexpected environmental conditions. Synthetic, empirical, multi-decadal research that links climate to changes in pelagic nekton communities is sorely lacking, especially in the Northern California Current (NCC). **Our proposal aims to develop new indicators that will describe how the pelagic nekton communities in the NCC have responded to climatic forcing during the period 1998-2011, with the twin goals of providing critical ecosystem information for fisheries management and expanding the availability of indicators for Integrated Ecosystem Assessments.**

Climate change is one of the principal threats to biodiversity of marine organisms and to the structure and functioning of ecosystems. Ocean temperatures have warmed dramatically in almost all Large Marine Ecosystems of the world over the last 30 years (Belkin et al. 2009) and are projected to continue to increase in the North Pacific over the next 40-50 years (Overland and Wang 2007), including the California Current (Auad et al. 2006). In addition to temperature changes, climate change may alter the cycle of productivity in the NCC (Bakun 1990, Snyder et al. 2003), with potentially negative consequences to the ecosystem (Bograd et al. 2009, Schwing et al. 2006, Barth et al. 2007). It is therefore realistic to expect that future climate change will substantially affect habitats, communities, species and individual organisms for the rest of the century. For instance, recent changes in nekton community structure will continue as species shift their distributions relative to their temperature preferences (Poloczanska et al. 2007, Cheung et al. 2009), possibly leading to the loss of some economically-important cold-adapted species and the establishment of new, warm-adapted species. Indeed, Cheung et al. (2009) predict that marine systems are projected to see more dramatic shifts in species distribution patterns than terrestrial systems.

Moving to ecosystem-based fisheries management in the NCC ecosystem requires considering the effects of climate on the biota (Field and Francis 2006), including the development and evaluation of ecological indicators that directly and indirectly measure climate impacts on marine communities (Levin et al. 2009, Schwing et al. 2009). Previous research has shown that pelagic nekton communities respond quickly to abrupt changes in this dynamic ecosystem (Emmett and Brodeur 2000, Brodeur et al. 2005, Emmett et al. 2006); however, most of this research has been conducted on monthly or annual abundances of species and has not taken into consideration their distribution patterns and how these species may respond to environmental variability over the longer term. Studies examining the effects of climate on biodiversity and species distributions have been done in the Northeast Atlantic (Beare et al. 2004, Perry et al. 2005, MacKenzie et al. 2007, Hiddink. and Hofstede 2008, Hofstede et al. 2010, Ciannelli et al. 2007), Northwest Atlantic (Frank et al. 1990, Murawski 1993, Nye et al. 2009), the Bering Sea (Ciannelli and Bailey 2005, Hoff 2006, Mueter and Litzow 2008, Bartolino et al. 2011) and other regions of the world (see reviews by Roessig et al. (2004) and Cheung et al. (2009)). **There is presently little knowledge on how climate-related changes will affect nekton diversity and ranges in the NCC**.

Previous studies of climate forcing in the NCC have been conducted primarily on heavily exploited demersal fishes, confounding the relative effects of fishing and climate. In contrast, the pelagic environment of the NCC has received considerably less fishing impact, and considerably less attention in the literature, compared to these moderate- to heavily-exploited demersal ecosystems. As shown by Murawski (1993) in the Western North Atlantic, pelagic species, even those caught in bottom-trawl surveys, showed the greatest latitudinal distribution responses to changing ocean temperatures. Indeed, highly mobile pelagic nekton in the NCC appear to respond quickly to even relatively small environmental changes by following gradients in their habitats (Brodeur et al. 2006). Climate change will also affect other physical variables (e.g., salinity, nutrient availability, oxygen) that can alter the distribution patterns of marine nekton (Frank et al. 1990, MacKenzie et al. 2007). **The pelagic zone of the NCC has seen extreme and perhaps unprecedented interannual variability in oceanographic conditions during the last decade (Bograd et al. 2009), which makes this environment an ideal 'laboratory' for examining nekton community responses to physical forcing**.

Not only will the native marine communities be influenced by climate warming, but changing environmental conditions may increase the probability that non-native taxa will successfully become established and modify ecosystem structure and function. In the NCC, this type of response has already been documented with the recent northward movement of the Humboldt squid to the west coast of the US (Brodeur et al. 2006, Field et al. 2007, Zeidberg and Robison 2007, Litz et al. 2011). Northward shifts of isotherms are likely to increase diversity as the number of species added far exceeds the numbers lost to more northern latitudes, as observed during El Niño or other warm anomaly years (Pearcy and Schoener 1987, Brodeur et al. 2006). Also, in contrast to current thinking that species will move poleward in unchanging communities to stay within their preferred ecological conditions, the more likely scenario is that species will be reshuffled into novel groupings, creating what is referred to as "no-analog communities" (Williams et al. 2007a, b). Similarly, new species interactions that develop within reshuffled communities may have substantial impacts on predator-prey relationships, fisheries and other ecosystem services (Ainsworth et al. 2011). **As such, there is an acute need to better understand the possibility of climatic variability inducing unexpected responses, such as different species co-occurring and the development of no-analog future communities** (**Doney et al. 2011).**

Approach

Annual systematic surveys have been conducted using consistent methodology in June and September since 1998 along nine transect lines at 50-55 stations, off Washington and Oregon (Fig. 1), ranging from 45 to 48^{o} N. Measurements of hydrography, zooplankton and pelagic fishes are made at each station. Vertical profiles of temperature, salinity, fluorescence, oxygen and turbidity are taken at each station. Nekton are sampled with large trawls (336 m^2 mouth opening) in the upper 18-20 m of the water column at every station. Mesh size is relatively small in the codend to retain juvenile specimens. Taxa are identified at sea or frozen and brought back to the lab for identification. Total counts and weights are available for each nekton taxon caught. Length data are recorded for a subset of individuals (n=50 per station) of all species.

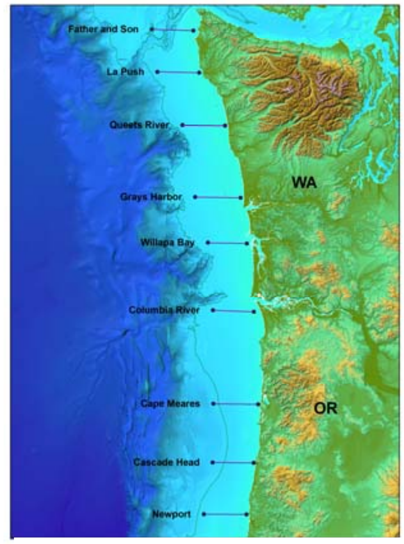

Fig. 1. Location of sampling area off Washington and Oregon

Table 1. List of spatial indicators and related population characteristics adapted from Woillez et al. (2009).

Spatial Indicator	Population characteristics
Weighted mean center of biomass	Mean geographic location of the species
Mean bottom depth of biomass	Mean bottom depth of the species
Minimum latitude of occurrence	Southerly extent of the species
Maximum latitude of occurrence	Northerly extent of the species
Isotropy	Elongation of the spatial distribution of the species
Positive Area	Area of presence occupied by the species
Spreading Area	A measure of the area occupied by the species that takes into account variations in fish density
Global Index of Collocation	Overlap of species/age class spatial populations

During year one of the proposed study, **we will examine how nekton diversity, ranges, and community composition have changed in the NCC in the recent past**. To do so, we will select the dominant nekton species (top 25-30) and analyze their abundance and distribution trends over the 1998-2011 time period. In some cases (e.g. hake, jack mackerel, sardines, anchovies), we will divide our catches into juvenile and adult age classes (Phillips et al. 2007) to see if these age classes are responding similarly. For the survey region, we will examine seasonal (June and September) and interannual (1998-2011) changes in location and dispersion for each of the dominant species/age classes by calculating a variety of spatial summary statistics (Table 1), following Woillez et al. (2007) and Nye et al. (2009). Seasonal and interannual changes in the spatial distributions of age-structured nekton populations will be investigated using multiple factor analysis (Woillez et al., 2007) and will provide a multivariate spatial indicator for monitoring purpose (Petitgas and Poulard, 2009). All species (including rarer taxa) will be examined for each cruise to determine trends in diversity and evenness across annual and monthly scales based on the Shannon-Wiener diversity index, taxonomic diversity index (Δ, Warwick and Clarke 2001, Tolimieri and Anderson 2010), and Pielou's index of evenness (Brodeur et al. 2008). Community-wide analysis will be done using hierarchical cluster analyses performed in conjunction with non-metric multidimensional scaling (MDS) ordinations to identify annual, monthly, and cross-shelf assemblages, updating earlier work (Brodeur et al. 2005), but including more detailed analysis in relation to environmental variables described earlier. These analyses will pay particular attention to the development of novel species assemblages (no analog communities) later in the time series. Once the important environmental determinants of habitat for each species are identified, we plan to use Generalized Additive Models (GAMs) or multivariate fitting models to examine the relative importance of the various environmental variables for each species. We propose different formulations of GAM, including threshold and variable coefficient GAM. In previous applications, these formulations have proved successful in assessing non-additive (Ciannelli et al. 2004) and non-stationary (Bartolino et al. 2011) species-environment relationships.

In the second year, we will test for multivariate relationships between basin-scale environmental indices (i.e. MEI, PDO, including appropriate time-lags) and changes in the NCC pelagic nekton community. The 14 year period from 1998-2011 includes several El Niño events (1998, 2003, and 2010) and also contrasting cooler years (2001, 2008). Therefore, we should be able to recognize and identify basin-scale climate signals in our analyses. We will use Principal Component Analysis to examine the relatedness of the overall species composition between years to see if changes occur in the community that may be related to regime shifts (Brodeur et al. 2006). Joint monitoring of environmental indices, population metrics and spatial indices based on CUSUM (Cumulative Sum) control charts will provide an assessment that could be used on an annual basis for at least two management purposes. First, the assessment will provide information germane to management of fisheries for which nekton serve as a forage base. Second, it will succinctly summarize indicators for wild fisheries and ecosystem health components in future Integrated Ecosystem Assessments in the California Current (Petitgas 2009, Woillez et al. 2010, Levin and Schwing 2011).

Also during the second year, we will compare the metrics found from our recent (1998-2011) sampling to a similar study done from 1981 to 1985 by Oregon State University (Brodeur and Pearcy 1986, 1992, Emmett and Brodeur 2001). These data (> 850 collections, 17 cruises) have been entered into our database and verified, although no formal community and distribution analysis has been undertaken. By analyzing this vast data set, we hope to shed light on interannual and interdecadal differences in nekton community composition and metrics, similar to that done for the Northeast region of the US (Lucey and Nye 2010). With the exception of hake and salmon, most of the pelagic species we will be examining are not heavily exploited over time which makes this data set somewhat unique in terms of looking at climate effects without the confounding effects of fishing. Finally, we will use multivariate techniques (e.g., Methratta and Link 2006) to evaluate a suite of nekton community indicators including abundance and diversity, dominance curves, and ratios of pelagic to demersal fish, predators, and jellyfish, during all years but particularly years of highly-contrasting environmental conditions. This will identify which spatial and temporal scales (i.e. monthly, cross-shelf) and assemblages provide the optimum predictive relationship with the abundance trends.

Benefits

This project will directly contribute to FATE’s goal of **creating indices of ecosystem properties and processes** that reflect the condition of the ecosystem and the potential for changes in the distribution and habitats of the economically and ecologically important fish stocks in the California Current. The Pacific Fisheries Management Council has started to incorporate ecosystem information into fisheries management. This includes a synoptic overview of the status and trends in the abundance of prey for groundfish, with an eye toward implementing more/less conservative fisheries management guidelines when prey are less/more abundant. Our proposal will summarize changes in the status of the forage base for groundfish over the last ~15 years, thus providing critical ecosystem information for developing precautionary fisheries management guidelines. In addition, assessing stocks using spatial indicators in conjunction with traditional biological indicators can provide supplementary information for fisheries management decisions (Link et al. 2011). Specifically, identifying responses of fisheries resources to environmental forcing will provide assessors the raw materials to incorporate a climate index in stock-recruitment relationships.

Enhanced retrospective analyses of ecosystem parameters in relation to climate has been identified as a key component to predicting future changes in US coastal ecosystems (Osgood et al. 2008). An increased understanding of how pelagic species respond historically will allow us to forecast how they may change under different climate scenarios, as is presently underway by Brodeur for a broader geographic range (California to the Bering Sea, in collaborations with W.L Cheung). In addition, the analyses of the pelagic nekton survey data that we propose will fill the research needs of future IEAs in the California Current. The recently published California Current Integrated Ecosystem Assessment (CCIEA) lays out a long-term plan to evaluate the status of a wide variety of ecosystem components (Levin and Schwing 2011). Chief among the ecosystem components are wild fisheries and ecosystem health, and the 2011 CCIEA represented a first attempt to assess their status using rigorously vetted indicators. One of the indicators that rose to the top of the evaluation was the spatial structure of populations, but due to logistical constraints the corresponding analysis was limited to groundfish. Indeed, many candidate indicators otherwise identified as reliable failed to appear in the report because of data limitations. Therefore, the CCIEA could be bolstered by augmenting the availability of leading ecosystem indicators for the pelagic ecosystem. The work we propose will provide new and needed indicators to assess the status of the wild fisheries and ecosystem health components of future IEAs in the California Current.

Finally, this project will provide ecological and fisheries training opportunities for a doctoral student (Barceló), who will be encouraged to participate in national and international scientific meetings and management council meetings.

Deliverables:

- Update (to 2011) the existing time series of nekton densities and diversity and evenness indices along the west coast during June and September from annual pelagic surveys.
- For the 2011 CCIEA, several promising indicators that could be derived in part from the pelagic nekton survey data (forage species biomass, status, and trends; zooplanktivorous fish biomass; ratios of forage fish to jellyfish biomass and pelagic to demersal fish biomass) were not recommended for reporting, primarily because data were not available to the authors in a summarized format. Other community composition indicators, such as species diversity, were reported only for groundfish. Our proposal will provide this information about pelagic nekton community composition in a format that will be of immediate use in future IEAs in the California Current.
- Provide summaries to Ecosystem Status Reports being produced annually for CalCOFI and every four years for the North Pacific Marine Science Organization (PICES).
- Post the most robust indices to a forecasting webpage to make these available to the scientific community and managers.
- Present findings at national (e.g., CalCOFI, AFS) and international (PICES, ICES, Ocean Sciences) scientific meetings as appropriate.
- Prepare at least two manuscripts for publication in peer-reviewed primary scientific journals based on the results of our analyses.

References

Ainsworth C.H., J.F. Samhouri, D.S. Busch, W.W.L. Cheung, J. Dunne and T.A. Okey. 2011. Potential impacts of climate change on Northeast Pacific marine foodwebs and fisheries. ICES J. Mar. Sci. 68: 1217-1229.

Auad, G., A. Miller, and E. Di Lorenzo. 2006. Long-term forecast of oceanic conditions off California and their biological implications, J. Geophys. Res. 111, C09008.

Auth, T.D., R.D. Brodeur, H.L. Soulen, L. Ciannelli, and W.T. Peterson. 2011. The response of fish larvae to decadal changes in environmental forcing factors off the Oregon coast. Fish. Oceanogr. 20:314-328.

Bakun, A. 1990. Global climate change and intensification of coastal ocean upwelling. Science 247:198-201.

Bartolino,V., L. Ciannelli, N.M. Bacheler, and K.S. Chan. 2011. Ontogeny and sex disentangle density-dependent and density-independent spatiotemporal dynamics of a marine fish population. Ecology 92: 189-200.

Barth, J.A., B.A. Menge, J. Lubchenco, F. Chan, J.M. Bane, A.R. Kirincich, M.A. McManus, K.J. Nielsen, S.D. Pierce, and L. Washburn. 2007. Delayed upwelling alters nearshore coastal ocean ecosystems in the northern California Current. Proc. Nat. Acad. Sci. 104:3719-3724.

Beare, D.J., F. Burns, A. Greig, E.G. Jones, K. Peach, M. Kienzle, E. McKenzie, and D.G. Reid. 2004. Long-term increases in prevalence of North Sea fishes having southern biogeographic affinities. Mar. Ecol. Prog. Ser. 284: 269–278.

Belkin, I.M. 2009. Rapid warming of Large Marine Ecosystems. Prog. Oceanogr. 81:207-213.

Bograd, S.J., I. Schroeder, N. Sarkar, X. Qiu, W.J. Sydeman, and F.B. Schwing. 2009. Phenology of coastal upwelling in the California Current. Geophys. Res. Lett. 36, L01602.

Brodeur, R.D. and W.G. Pearcy. 1986. Distribution and relative abundance of pelagic nonsalmonid nekton off Oregon and Washington, 1979 1984. NOAA Tech. Rep. NMFS 46, 85 p.

Brodeur, R.D. and W.G. Pearcy. 1992. Effects of environmental variability on trophic interactions and food web structure in a pelagic upwelling ecosystem. Mar. Ecol. Prog. Ser. 84:101-119.

Brodeur, R.D., J.P. Fisher, C.A. Morgan, R.L. Emmett, and E. Casillas. 2005. Species composition and community structure of pelagic nekton off Oregon and Washington under variable oceanographic conditions. Mar. Ecol. Prog. Ser. 298:41-57.

Brodeur, R.D., S. Ralston, R.L. Emmett, M. Trudel, T.D. Auth, and A.J. Phillips. 2006. Recent trends and anomalies in pelagic nekton abundance, distribution, and apparent recruitment in the Northeast Pacific Ocean. Geophys. Res. Let. 33, L22S08.

Brodeur, R.D., W.T. Peterson, T.D. Auth, H.L. Soulen, M.M. Parnel, and A.A. Emerson. 2008. Abundance and diversity of coastal fish larvae as indicators of recent changes in ocean and climate conditions in the Oregon upwelling zone. Mar. Ecol. Prog. Ser. 366:187-202.

Cheung, W.L., V.W.Y. Lam, J. L. Sarmiento, K. Kearney, R. Watson, and D. Pauly. 2009. Projecting global marine biodiversity impacts under climate change scenarios. Fish Fish. 10:235-251.

Ciannelli, L., K.S. Chan, K.M. Bailey, and N.C. Stenseth. 2004. Nonadditive effects of the environment on the survival of a large marine fish population. Ecology 85: 3418-3427.

Ciannelli, L., and K.M. Bailey. 2005. Landscape dynamics and underlying species interactions: the cod-capelin system in the Bering Sea. Mar. Ecol. Prog. Ser. 291: 227-236.

Ciannelli, L., G. Dingsør, B. Bogstad, G. Ottersen, K.S. Chan, H. Gjøsæter, J.E. Stiansen, and N.C. Stenseth. 2007. Spatial anatomy of species survival rates: effects of predation and climate-driven environmental variability. Ecology 88: 635-646

Doney, S.C., M. Ruckelshaus, J.E. Duffy, J.P. Barry, F. Chan, C.A. English, H.M. Galindo, J.M. Grebmeier, A.B. Hollowed, N. Knowlton, J. Polovina, N.N. Rabalais, W.J. Sydeman, L.D. Talley. 2011. Climate change impacts on marine ecosystems. Ann. Rev. Mar. Sci. 4:1-27.

Emmett, R.L. and R.D. Brodeur. 2001. Recent changes in the pelagic nekton community off Oregon and Washington in relation to physical oceanographic conditions. North Pacific Anad. Fish. Comm. Bull. 2:11-20.

Emmett, R. L., G.K. Krutzikowsky, and P. Bentley. 2006. Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998-2003: Relationship to oceanographic conditions, forage fishes, and juvenile salmonids. Prog. Oceanog. 68:1–26.

Field, J. and R. Francis. 2006. Considering ecosystem-based fisheries management in the California Current. Mar. Pol. 30: 552–569.

Field, J., K. Baltz, J.A. Phillips, and W.A., Walker. 2007. Range expansion and trophic interactions of the jumbo squid, *Dosidicus gigas*, in the California Current. CalCOFI Rep.48: 131-146.

Frank, K.T., R.I. Perry, and K.F. Drinkwater. 1990. Predicted response of Northwest Atlantic invertebrate and fish stocks to CO_2-induced climate change. Trans. Am. Fish. Soc. 119:353-365.

Hiddink, J.G. and R.T. Hofstede. 2008. Climate induced increases in species richness of marine fishes. Glob. Change Biol. 14: 453–460.

Hoff, G.R. 2004. Biodiversity as an index of regime shift in the eastern Bering Sea. Fish. Bull. 104:226-237.

Hofstede, R.T., J. G. Hiddink, and A.D. Rijnsdorp. 2010. Regional warming changes fish species richness in the eastern North Atlantic Ocean. Mar. Ecol. Prog. Ser. 414:1–9.

Levin P.S., M.J. Fogarty, S.A. Murawski and D. Fluharty. 2009. Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean. PLoS Biology 7, e14.

Levin P. and F. Schwing. 2011. Technical background for an Integrated Ecosystem Assessment of the California Current. NOAA Tech. Memo. NMFS-NWFSC-109, 361 pp.

Link, J.S., J.A. Nye and J.A. Hare. 2011. Guidelines for incorporating fish distribution shifts into a fisheries management context. Fish Fish. 12:461-469.

Litz, M.N.C., J.A. Phillips, R.D. Brodeur and R.L. Emmett. 2011 Occurrences of Humboldt squid (*Dosidicus gigas*) in the northern California Current. CalCOFI Rep. 52:97-108.

Lucey, S.M. and J.A. Nye. 2010. Shifting species assemblages in the Northeast US continental shelf Large Marine Ecosystem. Mar. Ecol. Prog. Ser. 415: 23–33.

MacKenzie, B.R., H. Gislason, C. Möllmann, and F.W. Köster. 2007. Impact of 21st century climate change on the Baltic Sea fish community and fisheries. Glob. Change Biol. 13:1348-1367.

Methratta, E.T. and J.S. Link. 2006. Evaluation of quantitative indicators for marine fish communities. Ecol. Ind. 6: 575-586.

Mueter, F.J. and M.A. Litzow. 2008. Sea ice retreat alters the biogeography of the Bering Sea

continental shelf. Ecol. Applic. 18:309–320.
Murawski, S.A. 1993. Climate change and marine fish distributions: forecasting from historical analogy. Trans Am Fish Soc. 122:647-658.
Nye, J.A., J.S. Link, J.A. Hare, and W.J. Overholtz. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Mar. Ecol. Prog. Ser. 393:111-129.
Osgood, K.E. (ed.) 2008. Climate impacts on U.S. Living Marine Resources: National Marine Fisheries Service concerns, activities, and needs.NOAA Tech. Memo. NMFS-F/SPO-89, 1-118
Overland, J.E., and M. Wang. 2007. Future climate of the North Pacific Ocean. Eos Trans. AGU 88, 178, 182
Parnel, M.M, R.L. Emmett, and R.D. Brodeur. 2008. Ichthyoplankton community in the Columbia River Plume off Oregon: effects of fluctuating oceanographic conditions. Fish. Bull.106:161-173.
Pearcy, W.G. and A. Schoener. 1987. Changes in the marine biota coincident with the El Niño in the northeastern Subarctic Pacific. J. Geophys. Res. 92: 14417–14428.
Perry, A.L., P.J. Low, J.R. Ellis, and J.D. Reynolds. 2005. Climate change and distribution shifts in marine fishes. Science 308: 1912–1915.
Peterson, W.T and F.B. Schwing. 2003. A new climate regime in northeast Pacific ecosystems. Geophys. Res. Let. 30(17), 1896, doi:10.1029/2003GL017528.
Petitgas, P., and Poulard, J.-C., 2009. A multivariate indicator to monitor changes in spatial patterns of age-structured fish populations. Aquat. Living Resour. 22: 165–171.
Petitgas, P., 2009. The CUSUM out-of-control table to monitor changes in fish stock status using many indicators. Aquat. Living Resour. 22: 201–206.
Phillips, A.J., S. Ralston, R.D. Brodeur, T.D. Auth, R.L. Emmett, C. Johnson, and V.G. Wespestad. 2007. Recent pre-recruit Pacific hake (*Merluccius productus*) occurrences in the northern California Current suggest a northward expansion of their spawning area. CalCOFI Rep. 48:215-229.
Poloczanska, E.S., R.C. Babcock, A. Butler, A.J. Hobday, O. Hoegh-Guldberg, T.J. Kunz, R. Matear, D. Milton, T.A. Okey, and A.J. Richardson. 2007. Climate change and Australian marine life. Oceanogr. Mar. Biol. Ann. Rev. 45: 407-478.
Roessig, J.M., C.M. Woodley, J.J. Cech, Jr, and L.J. Hansen. 2004. Effects of global climate change on marine and estuarine fishes and fisheries. Rev. Fish Biol. Fish. 14:251-275.
Schwing, F. B., N. A. Bond, S. J. Bograd, and T. Mitchell. 2006. Delayed coastal upwelling along the U.S. West Coast in 2005: A historical perspective. Geophys. Res. Letters doi:10.1029/2006GL026911.
Schwing, F.B, W.T. Peterson, N. Cyr, and K.E. Osgood. 2009. Future research requirements for understanding the effects of climate variability on fisheries for their management. Pp. 621-636 in: R.J. Beamish and B.J. Rothschild (eds.), The Future of Fisheries Science in North America, Fish & Fisheries Series, Springer.
Snyder, M. A., L. C. Sloan, N. S. Diffenbaugh, and J. L. Bell. 2003. Future climate change and upwelling in the California Current. Geophys. Res. Letters 15:doi: 10.1029/2003GL017647.
Tolmieri, N. and M. Anderson. 2010. Taxonomic distinctiveness of demersal fishes of the California Current: moving beyond simple measures of diversity for marine ecosystem-based management. PLoS ONE 5(5): e10653. doi:10.1371/journal.pone.0010653.
Warwick, R.M., and K.R. Clarke. 2001. Practical measures of marine biodiversity based on relatedness of species. Oceanog. Mar. Biol. Ann. Rev. 39:207-231.

Williams, J.W., S.T. Jackson, and J.E. Kutzbach. 2007a. Projected distributions of novel and disappearing climates by 2100 AD. Proc. Nat. Acad. Sci. 104(14): 5738-5742.

Williams, J.W. and S.T. Jackson 2007b. Novel climates, no-analog communities, and ecological surprises. Front Ecol. Environ. 5(9):475-482.

Woillez, M., J.-C. Poulard, J. Rivoirard, P. Petitgas, and N. Bez. 2007. Indices for capturing spatial patterns and their evolution in time, with application to European hake (*Merluccius merluccius*) in the Bay of Biscay. ICES J. Mar. Sci. 64:537-550.

Woillez, M.J. Rivoirard, and P. Petitgas. 2009. Notes on survey-based spatial indicators for monitoring fish populations. Aquat. Living Resour. 22:155-164.

Woillez, M., Petitgas, P., Huret, M., Struski, C., and Leger, F. 2010. Statistical monitoring of spatial patterns of environmental indices for integrated ecosystem assessment: application to the Bay of Biscay pelagic zone. Prog. Oceanogr. 87:6-17.

Zeidberg, L.D. and B.H. Robison. 2007. Invasive range expansion by the Humboldt squid *Dosidicus gigas*, in the eastern North Pacific. Proc. Nat. Acad. Sci. 104: 12948-12950.