Title

Detecting, Characterizing and Determining the Biological Response to Regime Shifts off the California Coast

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Detecting, Characterizing and Determining the Biological Response to Regime Shifts off the California Coast

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Project Hypotheses
First, using one method of change detection analysis called the cumulative sum, it is possible to detect and characterize regime shifts along the California coast using sea surface temperatures (SSTs) and other variables. Second, physically-determined regime shifts and changes in ocean climatology, determined largely through detailed temperature time-series, can be linked to corresponding changes in biological communities, particularly phytoplankton, which exhibit rapid generation times.

Project Goals and Objectives
First, using observations of SST and other variables along the California coast, detect and characterize all of the regime shifts that have been reported in the North Pacific since circa 1920.

Second, analyze a seven-year time series of weekly pigment samples collected in Monterey Bay, CA. Link the biological pigment data series to corresponding temperature data collected at Pacific Grove and MBARI moorings in Monterey Bay. Samples have been collected from June 2003 up to the present time and the sampling continues.

Briefly describe project methodology
First, in the detection of regime shifts using coastal observations, the method of cumulative sums was used to detect, localize (in time), and characterize each of the six events that have been reported since 1920.

Second, samples were analyzed by HPLC to determine taxon-specific pigments indicative of specific algal groups. In Monterey Bay, the dominant algal groups include diatoms and dinoflagellates, marked by the pigments, fucoxanthin and peridinin, respectively.

Describe progress and accomplishments toward meeting goals and objectives
First, on the detection and characterization of regime shifts along the coast of California and the west coast of North America, the results show that all six events could be detected by careful

examination of the cumulative sum plots. The cumulative sum patterns were also very useful characterizing each event and showed that although the events in 1946, 1976-77 and in 1989 were similar, the response to the 1976-77 event was far greater than to any of the other events. The events in 1925 and 1939 were generally similar but the response to the 1999 event was weak and poorly expressed. Perhaps the single result that we find most significant is that over the past century, almost half of the warming that has occurred off southern California can be traced to the 1976-77 regime shift which took place over a period of approximately seven months. In summary, we met or exceeded all of our objectives and goals regarding the coastal observations.

Two papers describing these results have been published in refereed journals. Second, a total of 340 HPLC pigment samples (2003-2010) have been analyzed from Monterey Bay (commercial wharf, Monterey, CA). The data set is nearly continuous and reveals a clear 2.5 year period (2004-2006) in which relative dinoflagellate abundance increased dramatically.

Project modifications
First, although we started by examining coastal observations of SST from Scripps Pier off southern California, and the Hopkins Marine Station at Pacific Grove in Monterey Bay, we expanded our analyses to include SST data from two locations off Vancouver Island. This helped us to obtain more insight into the spatial variations in the response to the six events. Second, the pigment data (expressed as peridinin/chl a (g/g) clearly show a predictable dinoflagellate peak in the fall (October) of every year, coincident with the arrival of the Davidson Current in Monterey Bay, based on SST data from Pacific Grove. Dinoflagellate blooms may be the product of allochtanous, advective seeding rather than local, in situ development.

Interestingly, the classic 'fall' bloom in temperate environments is not considered characteristic of the California Current; however, the high-resolution pigment data-set collected here clearly shows a regular pattern of dinoflagellate proliferation in the fall. We are investigating a direct relationship to the often abrupt change in flow and water mass properties associated with the arrival of the Davidson Current.

Project outcomes
With regard to the coastal observations of SST, we have produced long, quality-controlled records for four locations along the west coast of North America that can be used directly without any gap-filling or other adjustments to the data. In our second study that compares the 1976-77 and 1989 regimes shifts off southern California and Hawaii, we developed a rather simple, but new, technique called the method of expanding means which was used to determine how well sustained regime shifts are for periods of up to several years or more. Second, seven years of weekly HPLC pigment data providing quantitative evaluations of the relative abundances of diatoms and dinoflagellates—a key element of HAB prediction and seasonality. A secondary analysis of off-shore pigment samples from the Gulf of Alaska (sampled daily for 6-week periods in summers of 1984, 1985,

1986, 1987 has also been completed; we are attempting to identify broad scale Pacific biological responses to putative regime shifts.

Impacts of project

The results of our analyses of coastal observations along the west coast of North America, Hawaii, and more recently, the east coast of South Korea have shown that while the 1976-77 regime shift resulted in increases in SST off the west coast of North America and Hawaii, it resulted in a slight decrease in temperature off the coast of South Korea. Such wide-spread observations may help us to determine if these events are wave-like nature. Our results should also lead us in the direction of searching for possible pre-cursor events that could aid in predicting regime shifts. Overall, little is known about the details of how regime shifts take place and the results of this study move us one step closer in this direction.

Our analysis of Monterey Bay phytoplankton pigments has identified surprises that are relevant to a) the general pattern of bloom dynamic and seasonal species succession and b) the collection of hypothesis that have emerged regarding causative processes responsible for the apparent increase in HAB phenomena. First, we now hold a strong, consistent data series that shows predictable increases in relative dinoflagellate abundance in fall (October) of every year between 2003-2009. Recent scientific reports noting high abundances of dinoflagellates in Monterey Bay have suggested we have entered the 'age of dinoflagellates' in Monterey Bay; the implication is that the system has changed. We indeed have seen a 'blip' in dinoflagellate activity in the years 2004, 2005 but we believe the data show strong evidence that we are back into a normal sequence of diatom/dinoflagellate relative abundance. A overview paper, "The rise and fall of dinoflagellates in Monterey Bay California, 2003-2009" is now being prepared for submission to Science (Welschmeyer et al. 2010, in prep). Secondly, the apparent rise and fall of dinoflagellate activity in Monterey Bay helps in sorting through the relative importance various theories that have been introduced to account for apparent increases in HAB observations. For instance, much has been written concerning the notion that eutrophication/pollution from coastal runoff serves as an important vector promoting the increased prevalence of dinoflagellate blooms. Such a hypothesis is inconsistent with watershed runoff and water quality in Monterey Bay—if the 'age of dinoflagellates' was permanent, we would have cause to worry; however, it appears that it is not.

Benefits, commercialization and application of project results

We have yet to see tangible evidence that our results have commercial or economic value, but from the requests for reprints of our first two papers, there is interest in the scientific community. As indicated above, our results can be used as stepping stones to gain more insight into the nature of regime shifts, their predictability, and their biological linkages and impact. If regime shifts were better understood, and, in particular, their biological linkages, then we might expect that there would be commercial/economic value.

Economic benefits generated by discovery
If regime shifts could be predicted, then there should/would be direct implications for the development of coastal, open ocean, and aquatic resources. Aquaculturists will benefit from the general model of fall (October) increases in dinoflagellate abundance that our data reveal.

Issue-based forecast capabilities
As we have already alluded to, the ability to predict regime shifts is an important issue. These events are almost certainly related to regional ecosystems in a cause-and-effect relationship although the details of this relationship have yet to be clarified. Pre-cursors may exist that could allow us to predict these events. If we can predict them, and have more information on the cause-and-effect relationship, then we may be able to forecast the ultimate biological impact. Finally, because regime shifts fall into the category of decadal climate variability, there is a direct connection to climate change.

Tools, technologies and information services developed
The present state-of-knowledge concerning regime shifts is insufficient to address such topics as "tools, technologies, and information services".

Publications
Technical reports
N/A

Conference papers, proceedings, symposia
N/A

Peer-reviewed journal articles or book chapters
A closer look at regime shifts based on coastal observations along the eastern boundary of the North Pacific.
Authors: Laurence C. Breaker
Date: 2007
Journal Name: Continental Shelf Research
Issue/Page Numbers: Volume 27, 2250-2277.

Expressions of the 1976-1977 and 1988-1989 regime shifts in sea surface temperature off southern California and Hawaii
Authors: L.C. Breaker and S. F. Flora
Date: 2009
Journal Name: Pacific Science
Issue/Page Numbers: Volume 63, 39–59.

Theses, dissertations
N/A

Workshops/presentations given
In 2008, Breaker gave a power point presentation on regime shifts based on the work previously discussed to students and faculty at UC Santa Cruz. In 2008, Breaker also gave a power point presentation on regime shifts to the RAP, which represents the research arm of the Monterey Bay National Marine Sanctuary.

Dissemination of results
N/A

Students
Jennifer Broughton
MLML
Department: Biological Oceanography
Degree program enrolled in: Masters
Thesis/dissertation title: Standard C-14 technique yields significant underestimates of ocean primary production: TCO2 gas exchange analysis.
Supported by Sea Grant funds? [X] yes [] no
Start date: 02/01/2008
End date: 02/01/2009

Kelene Keating
MLML
Degree program enrolled in: Masters
Thesis/dissertation title: Chemtax analysis of phytoplankton pigments in Monterey Bay, 2003–2009.
Supported by Sea Grant funds? [x] yes [] no
Start date: 02/01/2009
End date: 02/01/2010

Cooperating organizations
N/A

International implications
Our recent work on detecting regime shifts off the east coast of South Korea has been assisted by the National Fisheries Research and Development Institute of Korea and the Korean Oceanographic Data Center by providing the data that were used in this study.

Keywords
Regime shifts, sea surface temperature, detecting regime shifts, cumulative sums, Monterey Bay, Hopkins Marine Station, Southern California, Scripps Pier, Vancouver Island, 1976-77 regime shift, change points, sustained changes, pattern recognition, method of expanding means.

Notes
Our work on detecting regime shifts at different locations around the North Pacific basin continues, as does our work to link the physical changes to the biological responses. A key question for future work on regime shifts is whether they represent an overall increase (or decrease) in the state of the system or are variables such as temperature conserved ocean wide, with increases occurring at some locations and compensating decreases in others? This has direct implications for how global warming occurs in the ocean.