EDITORIAL

An introduction to the PICES symposium on the nature and impacts of North Pacific climate regime shifts

Retrospective studies of marine ecosystem variability in the North Pacific Ocean, conducted largely under the auspices of the North Pacific Marine Science Organization (PICES) and its Climate Change and Carrying Capacity Program have identified rapid coincident, and persistent changes in both climate and marine ecosystems. Previous studies in this field have focused on the dramatic changes that Occurred coincidentally in both fisheries and climate during the winter of 1976/77. But now there is a growing body of evidence that suggests that similar kinds of shifts also occurred in the 1920s and 1940s and more recently in the 1980s. The current scientific debate is about whether these shifts are the consequences of low frequency- high amplitude climate cycles, or natural interventions (step functions) in the mean state of nature, or stochastic processes, or some combination these processes.

To address these questions, a one-day symposium on *The Nature and Impacts of North Pacific Climate Regime Shifts* was sponsored by the PICES Science Board on October 15, 1999 at the Eighth Annual Meeting of PICES in Vladivostok, Russia. The symposium was devoted to:

1. a detailed analysis of events just preceding and the impacts resulting from the 1976/77 event;
2. the physical mechanisms behind regime shifts; and
3. observational evidence for the occurrence of other regime shifts during this century.

The symposium attracted the submission of 27 abstracts considering topics ranging from ocean physics and climate to plankton and fisheries, eleven of which included authors from the host country of the Annual Meeting. Twelve papers were accepted for the symposium and are included in this special issue. The significance of the contribution made by each of these papers to our understanding of the variability of North Pacific ecosystem's is briefly described below. The papers focusing on evidence of regime shifts are presented first, followed by those that discuss the possible mechanisms.

The occurrence of a regime shift in 1976-77 became widely accepted among biologists studying the North Pacific long before the general community of climatologists agreed upon its lasting significance. Hare and Mantua explore this apparent paradox by examining 100 different environmental time series, 31 climatic and 69 biological, for the period 1965-1997. Evidence for the 1976/77 shift are found in both physical and biological data sets. They also detect signs that a subsequent shift occurred in 1989. This later shift is expressed more clearly in the biological records than in the physical data and this leads the authors to conclude that monitoring North Pacific and Bering Sea ecosystems enable future regime shifts to be identified earlier than seems possible from considering climate data alone. This is largely because the biological processes and characteristics are more sensitive to the regime shifts so the expression of the shifts is far more striking in the biology of the North Pacific. McFarlane and colleagues make use of this enhanced biological response to pose the question whether there have been any further climate shifts since 1976-1977. Basis on changes observed in salmon, hake and groundfish in British Columbia, they agree with the suggestion that another regime shift occurred in 1989.

While much of the interest in the 1976n7 regime shift has been focused on responses in the eastern North Pacific, the effects were basin-wide. Zhang and his colleagues report on what happened in Korean waters. Both physical and biological changes were apparent following the 1976 and the probable 1989 shift. Biomass and production of saury decreased after 1976, whereas those of sardine and filefish increased. Post-1988, recruitment, biomass, and production of sardine collapsed while those of mackerel substantially increased. Their paper discusses the hypotheses to explain how the responses in the oceanographic and biological processes may be linked.

Park and Oh confirm that there was a significant warming of the East Asian Marginal Seas in the 1960s. They suggest that this warming was related to SST changes in the western equatorial Pacific rather than to the SST changes in the central Equatorial Pacific (Nino 3.4 region). Their results suggest that that the possibility of teleconnection between the topics and mid-latitudes should be considered in more detail, especially in the western regions of the Pacific basin.

Kang and colleagues examine physical and biological time series for evidence of climatic impacts on the ecosystems of the Korean peninsula. Many of the biological time series (including chlorophyll a, zooplankton biomass, tree ring width and fish catches) show a clear response to the regime shift of 1976/7. Tree ring growth was also highly correlated with precipitation, extreme growth occurred during the El Nino years between 1969 and 1987. The mixed layer depth off the east coast of Korea extended deeper and became more variable following the 1976-77 regime shift and this they link with the marked changes reported in the composition of fish catches.

Suga and colleagues conducted a detailed analysis of the salinity changes of North Pacific Tropical Water (NPTW) associated with the 1970s regime shift, and improved the documentation of the mean climatological state of NPTW. This water mass is characterized by the subsurface salinity maximum, which is formed in the region approximately bounded by 20^{o} to 30^{o}N and 140^{o}E to 140^{o}W. It then advects westwards and occupies the latitudinal zone between 10^{o} and 23^{o}N, at depths of 100-200 m in the southwestern North Pacific. Repeated observations along 137^{o}E showed that there were salinity increases of NPTW. These, the authors suggested, were the result of increased rates of formation, rather than shifts in the balance between precipitation and evaporation in the formation region, indicating that ocean dynamics played an important role in salinity changes.

Yasuda and Noto discuss the SST charades that occurred in the Kuroshio Extension region during, the 1980s and analyzed their causes. They observed that there was significant shoaling of the mixed layer during the mid-1980s and that this preceded the 1988/89 basin scale regime shift by a few years. They show that this change in mid-1980s was the result of horizontal transport divergence in the Kuroshio Extension. Thus the dynamics of the Kuroshio Current system appear to have played a major role in changing mixed layer depths and SST that occurred during the mid- to late- 1980s in the Kuroshio Extension region and the subsequent basin-scale climate regime shift in the late 1980s; again indicating the importance of the role of ocean dynamics in these shifts.

Savelieva and colleagues examine variability in both the Siberian High and the Aleutian Low and its subsequent impact on rainfall and river discharge ill Siberia. They found evidence for a shift in 1970 in the activity of the Siberian High that preceded the 1977 shift in the Aleutian Low. Following this shift in 1970, winter precipitation and, hence, river discharge, increased in West Siberia but decreased in East Siberia.

Rogachev documents dramatic changes of water characteristics in the region of the Kuril Islands in the northwestern North Pacific from 1990-1996. He shows marked changes occurred in temperature, salinity, Oyashio transport and eddy strength near Boussole Strait, which may have been a consequence of large scale atmosphere-ocean change. In particular, Rogachev showed that rainfall over the Okhotsk Sea increased abruptly in 1994, and that this anomalous precipitation was associated with a meridional migration of the precipitation pattern.

Overland and colleagues introduce a new perspective to the debate on the mechanisms possibly underlying decadal climate variability, by suggesting that 'chaos' may be playing a substantive role. Their conceptual model uses the notion of preferred semi-stable states that never quite repeat, a notion conceptually similar to Lorenz's butterfly strange attractor. They argue that the North Pacific climate, as indexed by the PDO, PNA and NPI, shows properties that are more characteristic of chaotic behaviour than of either an oscillator or steady state. While chaos implies non-predictability, the authors note that the preferred modes of the North Pacific tend to be stable over decadal scale residence times, but are punctuated by rapid transitions between modes.

Observational evidence for decadal scale climate variability in the North Pacific is widespread but complicated to interpret. There is now a general consensus that there are at least two components to the observed decadal variability. Miller and Schneider review the leading theories on forcing mechanisms. These include stochastic atmospheric forcing, atmospheric teleconnections, mid-latitude ocean-atmosphere interactions, tropical-extratropical interactions, oceanic teleconnections and intrinsic ocean variability. It is clear that the Aleutian Low plays a large role in upper ocean dynamics, in generating temperature anomalies, in turbulent mixing, Ekman pumping and advection. They conclude with a review of the biological impacts of decadal variability and possible mechanisms whereby the physics and the biology are linked.

In a study of low frequency variability in the North Pacific, Minobe found evidence for both bidecadal and pentadecadal variations. Major regime shifts in the 1920s, 1940s, and 1970s involved simultaneous phase reversals of these two scales of variation that arise from different physical processes but interact with each other. In Minobe's view, the change in 1988/89 was a minor regime shift, but it is still too early to ascertain whether the changes observed in 1998/99 were the start of a major event. If one believes that the next major regime shift will involve simultaneous phase reversals between the bidecadal and pentadecadal variations, prediction with an ambiguity of about ten years should be feasible.

In summary, many authors have supported the conclusions of the earlier work by finding additional evidence for the 1976/77 regime shift, or finding new ways to look at it. There was an increasing convergence of views about a further change occurring in 1989, particularly on the North American side, but, again, the mechanism remains obscure. Others found evidence for similar persistent changes having occurred at other locations at other times. Of particular interest at the Vladivostok meeting was some tantalizing new evidence that another major event occurred in 1999, but whether this represented a regime shift will only be established if its impact proves to have persistence. This and related topics were explored further at another major conference on variation in climate and marine ecosystems co-sponsored by PICES that was held in March 2000 in La Jolla, California. Selected papers from the conference are to be published in Progress in Oceanography in 2001.

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31 July 2000

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Volume 47, Issue 2-4, October - December 2000

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Edited by S. Hare, S. Minobe, W.S. Wooster and S. McKinnell