Pacific Basin-scale Modeling: Synchrony and asynchrony of sardine and anchovy populations

Large scale, global fluctuations in populations of sardines and anchovies have been observed for the past century (Figure 1). The in-phase synchrony (or out-of-phase asynchrony) of such population fluctuations suggests a bottom-up, climate driven component. The work proposed to be undertaken herein would investigate the natural causes of inter-annual and inter-decadal variability of marine ecosystems in key coastal regions, their impacts to fishing-dependent coastal communities, and in turn the consequences to these marine ecosystems by the responses of these human communities.

Underlying our proposed study is the hypothesis that *synchronous changes in sardine and anchovy growth rates across locations may be accounted for by basin-wide decadal-scale changes in environmental conditions.* Where possible, we will combine long-term datasets on sardine and anchovy growth, with regional and local long-term climate and weather records, and use a common NPZ model coupled to the fish growth and Lagrangian dispersion models to examine consequences of environmental regime changes. Understanding how regime shifts in climatic regimes cascade up the food-web is a good opportunity for using past conditions to infer future effects of climate change.

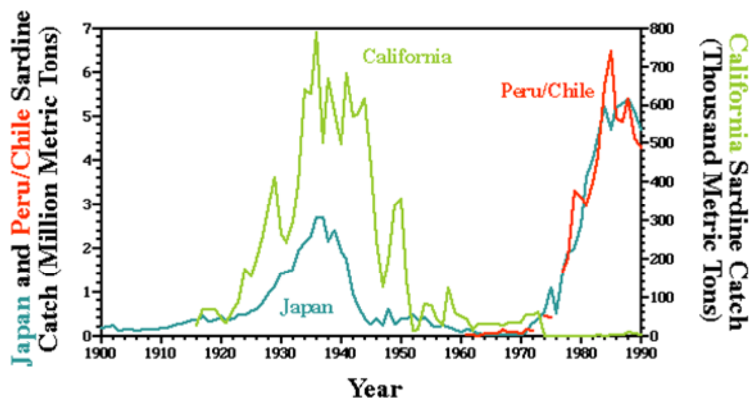

Figure 1. Fluctuations of sardine and anchovy catch in the Pacific over the last century. Based on Kawasaki et al. (1991) and others.

Sardines and anchovies are of interest for several reasons.

- Sardines and anchovies are of importance globally and their fluctuations are significant economically, societally as well as scientifically, e.g., Kawasaki et al. (1992), Lluch-Belda et al. (1989, 1992), Schwartzlose et al. (1999); Chavez, et al. (2004); also see Figure 1.

- Physical three dimensional basin-scale models circulation models and embedded lower trophic models (of key phytoplankton and zooplankton groups) have advanced to the point that realistic, relevant simulations are possible (see Figure 2) and quantitative physical and biological relationships and trends can be extracted on appropriate space and time scales for marine ecological studies of upper trophic levels to take place (e.g., Aita-Noguchi et al. 2004; Rose et al. 2004).

- An APN-funded project led by the PICES Model Task Team (Werner, Megrey, Rose, Kishi, Ito, Yamanaka and Aita-Noguchi) on Pacific herring has yielded promising results on the predicted individual-based model based variations in growth and weight of individuals when examined over the last 50-year period (1948-2002) – see Figure 3. These results have recently been extended (through a second APN project) to consider sardine and anchovy fish bioenergetics.

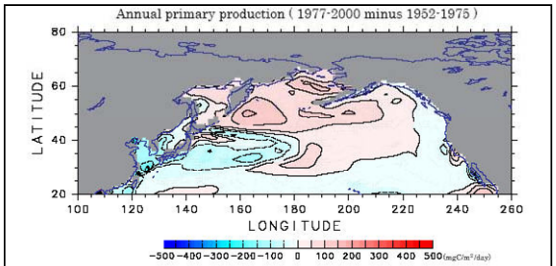

Figure 2. Difference of annual mean primary production (mg C m^{-2} day^{-1}) between the periods of 1977-2000 and 1952-1975, i.e., relative to the Regime shift (Hare and Mantua, 2000). The three-dimensional physical model (e.g., Hasumi, 2000 and Nakano, 2000) was forced by COADS winds and atmospheric conditions from 1948-2002. The results above shows that the primary production increased (red shade) in Bering Sea, North central Pacific where the MLD was deepened, while in the Gulf of Alaska, the primary production also increased because light conditions for photosynthesis improved due to shallower mixed layer but high nutrient concentration (taken from Aita-Noguchi et al. 2004).

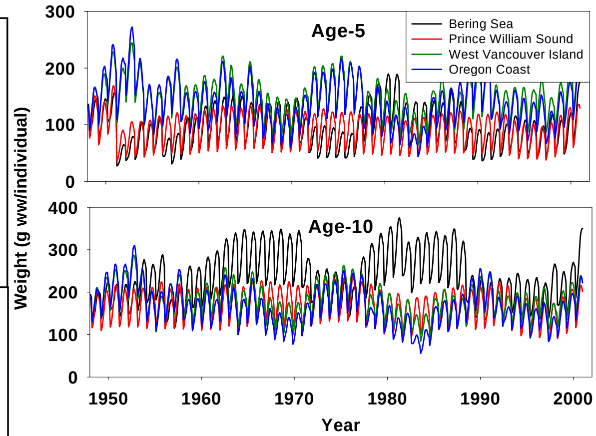

Figure 3. Variations in Pacific herring weight-at-age (gms wet weight) over the last 50 years at four locations in the North Pacific (from Rose et al. 2004). Note the latitudinal dependent change in the mid-1970's (see Figure 2) in agreement with the occurrence of the Regime Shift at that time. Other apparent regimes shifts (e.g., late 1980's) are presently being examined.

Work Plan. Using NCAR's CCSM and extensions to include higher resolution coastal domains, we propose to extend existing modelling approaches developed by the PICES Model Task Team for North Pacific herring, as well as efforts undertaken in other regions of the world's oceans by SPACC described by van der Lingen and Roy (2002), Marchesiello et al. (2004), etc. The results will enable us to quantify how climate (e.g., through changes in temperature, stratification and mixed layer depth, circulation and dispersion) affects marine ecosystem structure and function. Geographic areas of focus will include key upwelling areas where sardine and anchovy populations can be found. We will use changes in fish size (growth in body weight/length) from the coupled model as a metric for fish production and population health. The use of growth is an indirect measure of fish population health but can be predicted and compared with data with a high degree of confidence. Similarly, extensions to population dynamic approaches will also be considered where density-dependent effects will be considered (effects of feeding on abundance of lower trophic levels) as well as competition between the sardine and anchovy populations.

Past and future scenarios: past physical (and chemical) changes in the coastal ocean can be reconstructed from COADS, NCEP reanalysis, and related data sets. Future predicted states may be constructed using IPCC scenarios. These changes will be included in the trophodynamic models of lower and higher trophic levels to estimate the impact on the ecosystem of upwelling areas in key North and South Pacific regions, focusing on sardines and anchovies as the upper trophic level target fish species.

Links to Policy. Fish are a significant source of high-quality protein for humans providing 16% of the animal protein consumed by the world's population, according to the Food and Agriculture Organization (FAO) of the United Nations (1997). They are a particularly important protein source in regions where livestock is relatively scarce. Fisheries supplies <10% of animal protein consumed in North America and Europe, but 17% in Africa, 26% in Asia and 22% in China (FAO, 2000). The FAO estimates that about one billion people world-wide rely on fish as their primary source of animal protein (FAO, 2000; see also Tidwell and Allen, 2001; http://www.ksuaquaculture.org/FishasFood.htm). With this in mind, and following the statements of the Reykjavik Declaration (e.g., pp. 105-108 in ftp://ftp.fao.org/docrep/fao/005/y2198t/y2198t00.pdf "*in an effort to reinforce responsible and* *sustainable fisheries in the marine ecosystem, we will individually and collectively work on incorporating ecosystem considerations into that management aim*" and "*we will undertake to identify and describe the structure, components and functioning of relevant marine ecosystems, diet composition, food webs, species interactions and predator-prey relationships, the role of habitat and the biological, physical and oceanographic factors affecting ecosystem stability and resilience*") our proposed work is highly relevant to policy and management goals. As such, we will need to include expertise in fisheries management and policy formulation issues to evaluate the contribution of the climate-change based model predictions to fisheries management.

Relationship to Global Change Research Programs. The proposed work is of the highest priority to IGBP's GLOBEC Program (Global Ocean Ecosystem Dynamics http://www.globec.org), which is entering its synthesis phase. GLOBEC has identified basin-scale processes as a key component of synthesis as we increase our understanding from regional variability to basin scales (de Young et al., 2004). The proposed work is directly related to GLOBEC's working groups on Modelling and Prediction and Feedback from Ecosystem Changes (B. de Young, co-Chair), as well as PICES' CCCC Model Task Team and the SPACC (Small Pelagics and Climate Change) Regional Program (http://www.pml.ac.uk/globec/structure/regional/spacc/spacc.htm). Finally, IPCC scenarios have not been used (to our knowledge) to study impacts of the higher trophic levels of marine ecosystems (e.g., fisheries). Our work will enable assessment of the value of IPCC predictions for these systems.

Related Research Work. There are a large number of national and international research efforts ongoing worldwide under the general umbrella of GLOBEC, e.g., Small Pelagic and Climate Change (SPACC), PICES (Carrying Capacity and Climate Change), ICES, e.g., the Cod and Climate Change Program, etc., that are attempting to tackle similar issues of climate variability and its impact on fisheries. The collaborators in the present proposed effort are aware and involved in many of these efforts and as such there will be a continuous exchange between the present (proposed) research and the other research teams.

Possible Collaborators:

- USA: Francisco E. Werner, Bernard A. Megrey , Kenneth A. Rose, Vera Agostini, Zack Powell, Dale Haidvogel, Bill Large, Jim Hurrell
- Japan: Michio J. Kishi, Shin-ichi Ito, Yasuhiro Yamanaka, Maky Aita-Noguchi
- China: Wei Hao
- Mexico: Salvador Lluch-Cota, Daniel Lluch Belda
- Peru: Miguel Ñiquen
- Chile: Luis Cubillos, Leonardo Castro

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