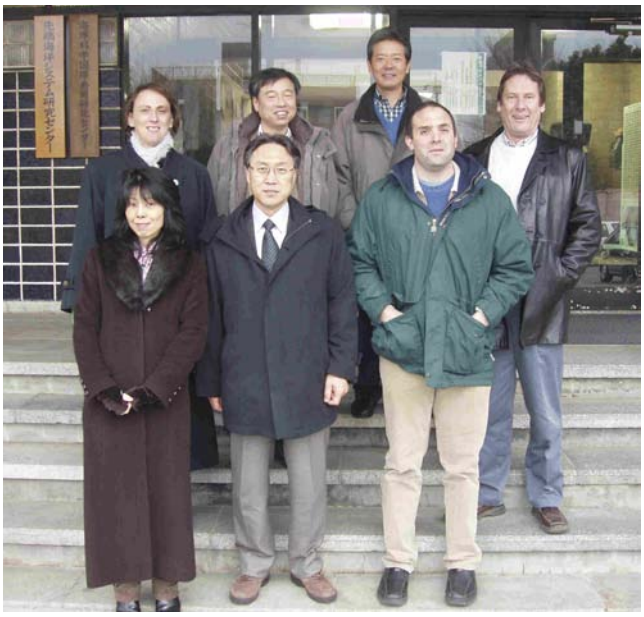
A comparison of regional mechanisms for fish production: Ecosystem perspectives

By Akihiko Yatsu, Kerim Y. Aydin and Jacquelynne R. King

The Terms of Reference and the Action Plan of the Climate Forcing and Marine Ecosystem (CFAME) Task Team, outlines three main components: *Mechanisms*, *Ecosystems* and *Scenarios* (Aydin and Yatsu, 2005; *PICES Press* Volume 13, Number 2). The Task Team initiated their first action on *Mechanisms* with an inter-sessional workshop held January 12–13, 2006, at the Ocean Research Institute of the University of Tokyo, through the courtesy of Prof. Yoshiro Watanabe. The aims of this workshop were two-fold: 1) to develop regional and Pacific-wide conceptual models describing the mechanisms linking climate to fish production by focusing on comparative approaches of selected species; and 2) to revise the concept of carrying capacity based on the knowledge accumulated during the CCCC Program and other studies. Workshop participants (**Photo 1**) were Kerim Y. Aydin (CFAME Co-Chairman, U.S.A.), Akihiko Yatsu (CFAME Co-Chairman, Japan), Jacquelynne R. King (Canada), Gordon (Sandy) A. McFarlane (Canada), Sanae Chiba (Japan), Masahide Kaeriyama (Japan), Yoshiro Watanabe (Japan) and Skip McKinnell (PICES Secretariat).

At this workshop, species-specific production and recruitment trends in relation to climate forcing were reviewed for eight species which represent five life-history strategies (Table 1): Pacific sardine and Pacific herring (opportunistic strategists), pink and chum salmon (salmonic strategists), walleye pollock (intermediate strategist), sablefish and Pacific halibut (periodic strategists) and spiny dogfish (equilibrium strategist). Similarities and differences in the species' response to climatic regime shifts and underlying mechanisms were summarized. Mechanisms linking climate and production for each species in each region of the North Pacific were examined and compared for similarities and possible synchrony.



Participants in front of Ocean Research Institute, University of Tokyo (Back row: Jacquelynne King, Akihiko Yatsu, Yoshiro Watanabe and Sandy McFarlane. Front row: Sanae Chiba, Masahide Kaeriyama and Kerim Aydin. Photo by Skip McKinnell).

The carrying capacity concept was discussed at the species-level. An important point for discussion was how to measure changes in carrying capacity. In addition to traditional measures such as r and K, energy-based changes in the production rate (production/biomass ratio, P/B) or mortality (Z) were discussed with special reference to climatic and ecosystem regime shifts (**Fig. 1**). It was recommended that several different measures of carrying capacity be used for a number of key species and areas in the North Pacific. These multiple measures would integrate changes in component species to long-term variation in ecosystem carrying capacity.

Table 1 Comparison of expected responses to climatic regime shift (RS) by five life-history strategists.

Strategist	Species	Expected response to RS	Rationale	Remarks
Opportunistic	Pacific sardine; Pacific herring	Immediate and drastic	Short life-span and age at maturity	
Intermediate	Walleye pollock	Oscillatory	Juveniles are opportunistic, but good year-classes are followed by strong density-dependence	Cannibalism, especially in the eastern Bering Sea
Salmonic	Pink and chum salmon	Immediate and drastic but with two phases	Freshwater and marine life stages involve two phases for climate forcing	Need to account for artificial propagation
Periodic	Sablefish; Pacific halibut	Immediate year class impacts, but gradual and delayed population response	Low frequency variation in spawner biomass	Older ages of recruitment
Equilibrium	Spiny dogfish	Slight	Very low fecundity and stable early survival	Low population resilience to fishing impacts or habitat deterioration

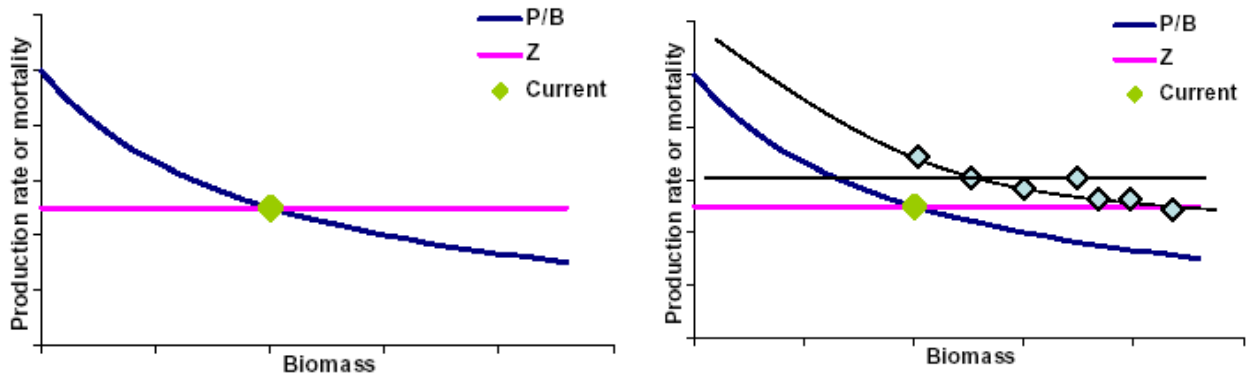


Fig. 1 Equilibrium condition of production rate (Production/Biomass) and mortality (Z) (left panel) and response of biomass, P/B and Z to a regime shift, resulting in gradual shift from "current" to a new equilibrium between thin curve and black horizontal line (right panel). P/B shape is due to local density dependence and age structure. Z "bends" but more slowly, approximated flat.

The results of the workshop were reported at the PICES/GLOBEC Symposium on "*Climate variability and ecosystem impacts on the North Pacific: A basin-scale synthesis*" (April 19–21, 2006, Honolulu, U.S.A.). On behalf of the CFAME Task Team, Dr. Yatsu gave a talk on "Mechanistic linkages of fish population dynamics to climatic forcing: Comparative study on selected stocks representing five life-history strategies in the North Pacific", and Dr. Aydin presented thoughts on the revision of the concept of carrying capacity ("Redefining carrying capacity ten years onward? CCCC research on a moving target").

Initially, it was planned that the January workshop would include preliminary work on ecosystem comparisons. However, because of the truncation of the number of days that the workshop could be held and the absence of key researchers, it was recommended that a separate workshop on "*Climate forcing and marine ecosystems of the North Pacific*" be convened to initiate the second component of the CFAME Terms of Reference, *Ecosystems*.

This workshop was held on October 13, 2006, at PICES XV in Yokohama, Japan. The workshop was attended by 21 participants, from all PICES member countries, and included presentations from the United States, Russia, Korea and China. The workshop focused on three ecosystems of the North Pacific: the California Current System, the Sea of Okhotsk, and the Yellow Sea/East China Sea. Three invited speakers provided an overview of each of these key ecosystems, with the identification of conceptual models of climate forcing. Dr. Vera Agostini (U.S.A.) looked at the upwelling dynamics of the California Current System, summarized this system's zooplankton community composition, and reviewed the biology and population dynamics of two key migratory pelagic fishes: Pacific sardine and Pacific hake. Dr. Victor Lapko (Russia) focused on the importance of sea ice to the physical oceanography of the Sea of Okhotsk, with subsequent impacts on dominant species such as walleye pollock. Dr. Young Shil Kang (Korea) presented information on the Yellow Sea/East China Sea ecosystem, with emphasis on the impact of freshwater discharge from the Yantze River (East China Sea) on salinity changes. These changes, coupled with temperature variability, had impacts on zooplankton biomass and composition. Dr. Xiuren Ning (China) provided a contributed paper on the Bohai Sea ecosystem response to environmental changes, and highlighted the similarity to the Yellow Sea/East China Sea ecosystem with the dominance of freshwater discharge as a driver of ecosystem change. Overall, the three ecosystem selected captured different dominating features of climate forcing mechanisms: boundary current upwelling (California Current); sea ice (Sea of Okhotsk) and freshwater input (Yellow Sea/East China Sea). It was noted that freshwater discharge is also human regulated, which could confound climate forcing impacts. At the CFAME business meeting on October 15, 2006, the Kuroshio/Oyashio Current system was selected to be included in future CFAME work. Much of the species mechanism work conducted by CFAME is applicable to this system, and it represents a second boundary dominated ecosystem which could simplify comparisons between ecosystems by selecting two with similar dominant characteristics (*i.e.*, to be compared to California Current System).

A second contributed paper in the workshop was presented by Dr. Sarah Gaichas on quantitative methods for comparative ecosystem analysis, which will be integral to the upcoming CFAME work on *Ecosystems*. Her presentation proved to be a good introduction to this area, and began a general discussion on ecosystem indicators (classifying ecosystems) and approaches to comparing ecosystems and their responses to perturbations. The underlying objective of CFAME work is predicting species response (whether singularly or aggregated, *i.e.*, ecosystem) to climate perturbations. The mechanisms of climate forcing will be species specific and ecosystem specific. Mechanisms of different species could interact, so integrated ecosystem indicators may be required. It was noted that ecosystem conceptual mechanisms need to

consider the seasonality of climate forcing. For example, there are different important parameters, or frequencies, that impact oceanography and biota for winter than for summer.

The dominant mode of climate-ocean coupling (*e.g*., boundary current upwelling, sea ice, freshwater input) could be one way of characterizing an ecosystem. These characterizations also encompass the overall regional indicators or climate model output products required (*e.g*., sea surface temperature, salinity, ice thickness or ice-free season, mixed layer depth, wind-speed and direction, freshwater discharge). Ecosystems could also be classified by the overall dynamics of the food web (*e.g*., bottom-up, top-down, middle-trophic: wasp-waist or beer-belly). Generally, ecological indicators need to capture species composition, size distribution, trophic dynamics, and need to include low-trophic indicators (for bottom-up impacts) and top-trophic indicators (for top-down impacts). Irrespective of the method of ecosystem comparison, general themes of comparison emerge: size spectra, food web structure, life history strategies, turnover rates or energy flow, and physical habitat structure. Workshop participants acknowledged that the ecological indicators selected, and the method of ecosystem comparison, will be determined by the available data. To that extent, future CFAME work on classifying and comparing ecosystem will be determined by the researchers involved. However, the generalities identified at the workshop for ecological indicators and for ecosystem comparison will need to be encompassed within each project.

The next phase for CFAME research will be linking species' *Mechanisms* and *Ecosystem* responses to climate forcing with climate forecasting *Scenarios*. This work will involve collaboration with PICES Working Group 20 on *Evaluations of Climate Change Projections*, and is anticipated to begin at PICES XVI in Victoria, Canada, in October 2007.



Dr. Akihiko Yatsu (yatsua@fra.affrc.go.jp) is the Director of the Subarctic Fisheries Division, Hokkaido National Fisheries Research Institute (HNFRI). He began his career in Shimizu from 1989–1999, studying the effects of squid driftnet fishing on the high seas ecosystems of the North Pacific, and the biology of neon flying squid. From 1999–2006, he worked in Yokohama, studying the population dynamics and regime shift issues of Japanese sardine and chub mackerel. His current work includes leading the stock assessment of major fisheries resources around Hokkaido, such as walleye pollock and common squid. He also conducts research exploring the linkages between marine ecosystems and environmental changes in the Northwest Pacific. Akihiko co-chaired PICES WG 16 on Climate Change, Shifts in Fish Production, and Fisheries Management *and the PICES Climate Forcing and Marine Ecosystems (CFAME) Task Team from 2004–2006.*

*Dr. Kerim Y. Aydin (Kerim.Aydin@noaa.gov) is the Program Leader for the Resource Ecology and Ecosystem Modeling Program of the Alaska Fisheries Science Center (AFSC), NOAA Fisheries. Kerim received his Ph.D. in Fisheries from the University of Washington, in 2000, with a dissertation on the impacts of climate and prey variation on the ocean growth of Pacific salmon (*Oncorhynchus spp.*). He has been a Postdoctoral Research Associate and Fishery Research Biologist with AFSC since 2000. Kerim's main research focus has been on fish trophic interactions, bioenergetics, and ecosystem-scale predator/prey models. He has been an affiliate faculty member of the University of Washington School of Aquatic and Fishery Sciences since 2003, and is serving as Co-Chairman of the CFAME Task Team.*

Dr. Jacquelynne R. King (KingJac@pac.dfo-mpo.gc.ca) is a Research Scientist in Groundfish Stock Assessment, at the Pacific Biological Station (Fisheries & Oceans Canada) in Nanaimo, Canada. Her research focuses on the impacts of climatic and oceanographic variability on marine fish population dynamics and the implications for fisheries management. She has published research on a suite of disciplines including marine fish life history strategies, statistical methodology, climate impacts on ecosystems, aging methodology, stock assessment, fish population dynamics and behavioural ecology. Jackie was a member of PICES WG 16 on Climate Change, Shifts in Fish Production, and Fisheries Management *and chaired the PICES Study Group on* Fisheries and Ecosystem Responses to Recent Regime Shifts *(FERRRS). She is currently a member of the CFAME Task Team.*