Salmon Co-Variability in the Northeast Pacific Ocean

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The coastal ecosystems in the Alaska Gyre and the California Current are being studied by a U.S. GLOBEC program off the coasts of the Pacific Northwest (PNW) and Alaska. U.S. GLOBEC observations began in 1997, with the goal of understanding how changes in the winds and currents affect the productivity of the coastal ecosystems and the survival of juvenile salmon after they enter the ocean. In the North Pacific Ocean, the eastward flowing North Pacific Current splits as it nears North America and feeds water into both the counterclockwise Alaska Gyre and the equatorward California Current (Figure 1). Records of salmon catch from these regions suggest that the biological productivity of these ecosystems alternates with characteristic periods of 3-7 years (the El Niño-La Niña cycle) and several decades. The intriguing aspect of these longer fluctuations is that salmon off Alaska are abundant when salmon off the PNW are scarce (Figure 2). Since 1999, this pattern has reversed (salmon returns are down in Alaska and up in the PNW). Does this "out-of-phase" relationship hold a clue to the underlying mechanism for changes in salmon abundance in both systems? Although Figure 2 shows a general inverse phasing of salmon (all stocks combined) abundance in the PNW and Alaska regions of the NEP, recent reanalysis by GLOBEC investigators (Botsford and Lawrence, accepted) indicates that the response to the "regime shifts" is species specific. Abundances of sockeye, pink, and coho salmon in Alaska and coho salmon in the PNW have responded strongly to large-scale changes in the marine climate (as evidenced by the Pacific Decadal Oscillation (PDO) index). However, chinook salmon populations in both the PNW and Alaska have remained nearly constant during 1950-1990, which encompasses the time of the major 1976-77 shift in ocean conditions.

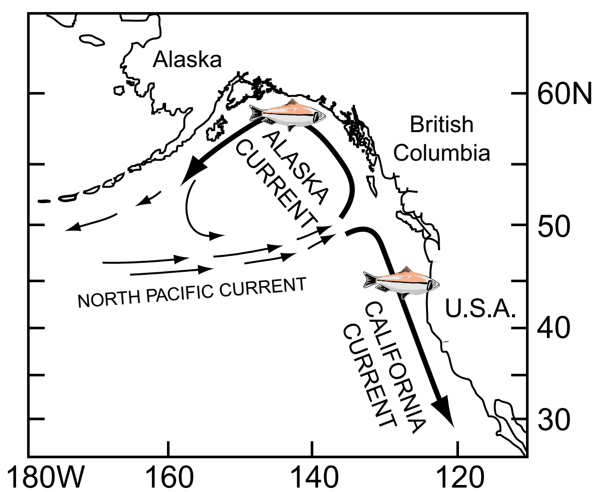

***Figure 1**. Schematic diagram of the surface currents in the NEP ocean. U.S. GLOBEC study sites are indicated by the fish symbols.*

The U.S. GLOBEC research team investigating this mystery in the Northeast Pacific (NEP) consists of over 90 investigators from 26 institutions. Activities include a sustained program to monitor changes in both systems, computer models of ocean circulation and ecosystem-fish dynamics, and retrospective studies

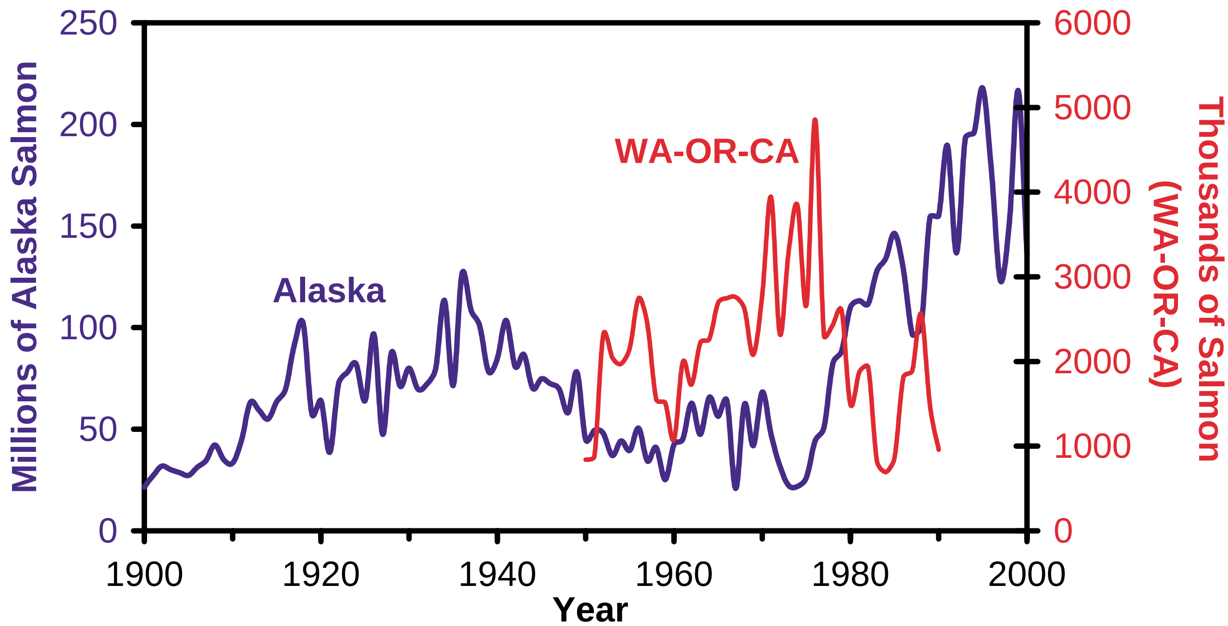

***Figure 2**. Commercial catch of salmon in the two regions of the NEP. Fluctuations with high and low periods of 20-30 years are evident, as are shorter period fluctuations. Note that salmon catches are greater in Alaska when PNW catches are low and vice versa. Commercial salmon fishing has been prohibited off the PNW since 1990.*

of longer time series of the ecosystems (currents, nutrients, plankton, fish, birds and mammals). Multiple and diverse platforms (ships, moorings, satellites, land-based radars) are used to make *in situ* and remote sensing observations of physics, chemistry and biology.

Juvenile salmon survival in the coastal ocean is likely controlled by their success at consuming prey and avoiding predation. Thus, U.S. GLOBEC field work emphasizes both process-oriented investigations and spatial surveys of juvenile salmon, their predators and their prey. Major field years for the PNW studies are 2000 and 2002, while 2001 and 2003 are major field years for the Alaska region studies. Figure 3 shows the results of a survey of ocean conditions off Oregon and Northern California during August 2000, including descriptions of temperature, phytoplankton and copepod abundance, juvenile salmon, and birds and mammals. There are clear patterns in the distributions, with evidence of concentrations of salmon, one of their prey (copepods) and predators (birds, mammals) nearshore, and especially over Heceta Bank and near Cape Blanco. The field work off Alaska in 2001 examined similar processes to those examined in the PNW, but the spatial mapping effort was not as extensive. Instead, in Alaska, there is a much greater emphasis on using moorings to measure currents, water properties and biology. Satellite sensors are being used to measure surface currents, temperature and plankton distributions to provide the larger-scale context for the field measurements.

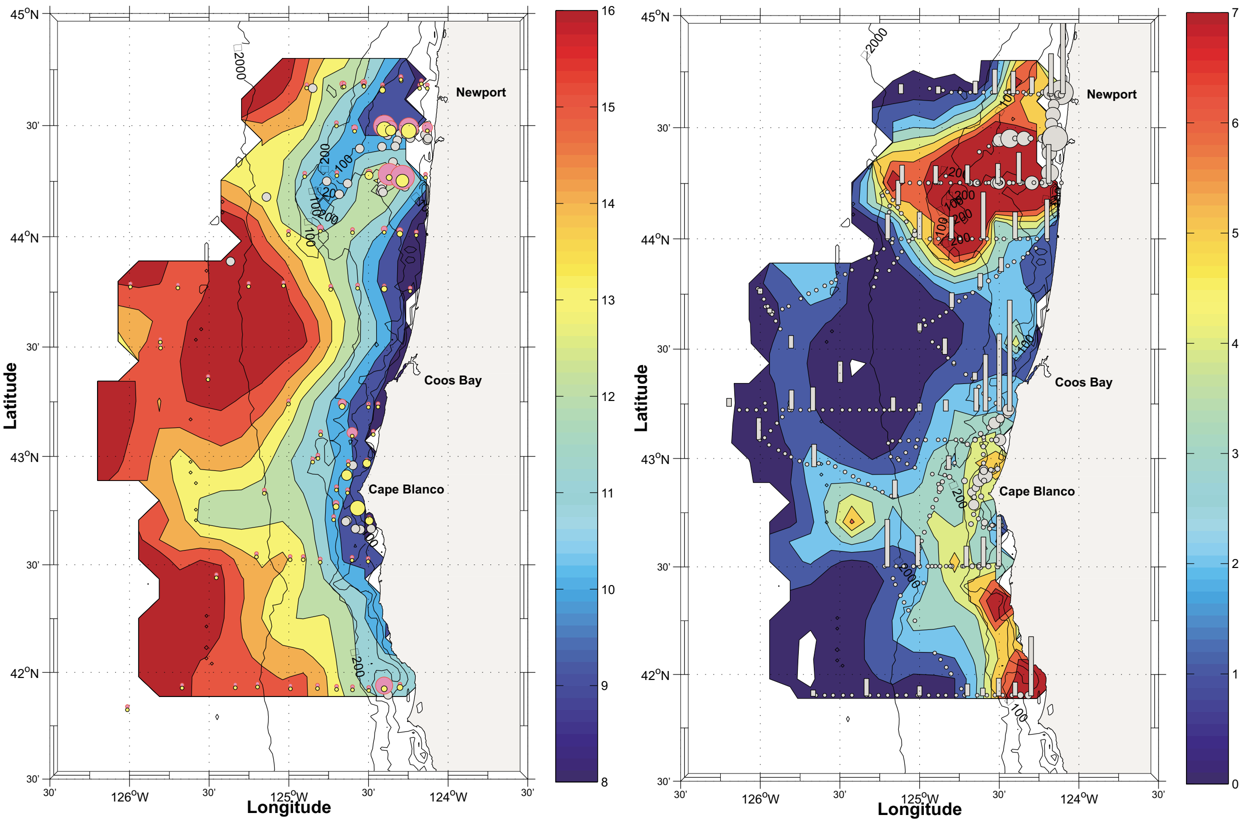

Figure 3. August 2000 mesoscale survey data. Left Panel*.* *Color contours show temperature (ºC) at 5 meters depth from sensors on a towed Seasoar undulator. Approximately, 12 equally spaced cross-shelf transects were used to provide the data for the contouring of temperature and chlorophyll (right panel). Yellow and magenta circles are abundances of juvenile chinook and coho salmon, respectively. The largest circles represent catches of ca. 10 fish per standard trawl. Smallest symbols (offshore) represent trawls in which salmon were not found. The grey circles represent sightings of humpback whales. Note that juvenile salmon were found over the shelf only, and humpback whales were concentrated on Heceta Bank and near Cape Blanco.* ***Right Panel****. Color contoured chlorophyll concentration (mg m^{-3}) at 5 meters depth, showing highest concentrations over Heceta Bank and nearshore south of Cape Blanco. Gray circles depict bird biomass (kg km^{-2}); largest circles represent 170 kg km^{-2}. Histograms (bars) indicate total copepod biomass (mg m^{-3}) from vertical plankton tows spanning the upper 100m or near bottom (if shallower). Tallest bars represent copepod biomass of 65 mg m^{-3}. Note the concentration of bird biomass nearshore and copepod biomass nearshore and on Heceta Bank. Seasoar data courtesy of Jack Barth and Tim Cowles. Whale sighting data courtesy of Cynthia Tynan. Salmon data courtesy of Richard Brodeur. Zooplankton data courtesy of Bill Peterson. Bird biomass estimates courtesy of David Ainley.*