Assessment of Environmental Influences on California Commercial Fish and Invertebrate Landings

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Records of the commercial harvest of fish and invertebrates from California waters have been converted from California Department of Fish and Game documents to computer accessible formats (CACom data). Empirical orthogonal function (EOF) analysis of the log-transformed data indicates two robust modes of change in species composition. Together, the first two EOFs explain more than 45% of the variance in CACom data sets that included annual landings of 25, 29, or 43 market groups through the 1930-2001 period. Some market groups include several species, but 29 single-species market groups have been consistently landed and specifically recorded throughout the 71-year period examined. The EOFs and time variable coefficients (*C*), also known as principal components, are similar for each of the three ensembles of market groups (Figure 1). Since time-variation in the EOFs show the persistence (autocorrelation) that is characteristic of specific catch series, indices showing persistence in physical processes were developed from published data sets by accumulating anomalies from overall monthly means (Norton and McLain 1985; Klyashtorin 2001; Hanley and others 2002). Correlation coefficients (r) larger than 0.8 between time variation in the EOFs and environmental series strongly suggest that changes in catch composition are affected by persistent environmental conditions (Figures 2 and 3). The EOF1-species composition changes through the 1930-2000 period (*C*1) are closely related to persisting anomalous conditions in southern California (La Jolla) sea surface temperature (CaSST), the Pacific decadal oscillation index, and related variables (Figure 2). The EOF2-species composition changes (*C*2) are more closely related to local California southward wind stress (SWS) regimes (Figure 3). *C*2 also corresponds to variation in concentration of fish larvae and other zooplankton in California waters over the 1950-2000 period (Roemmich and McGowan 1995, McGowan and others 1998).

The CaSST and *C*1 values are closely related to equatorial atmosphere-ocean processes (Figure 4). The accumulated sea level pressure anomaly at Darwin, in northern Australia, and the accumulated sea surface temperature anomaly of an area in the eastern equatorial Pacific Ocean bounded by 4 °N-4 °S and 90 °W-150 °W (Hanley and others 2002) have overall variability similar to that found in CaSST and *C*1 ($r > 0.80$). The CaSST and *C*1 lag equatorial events during specific intervals (e.g. 1956-1961) suggesting that some California current physical and biological events are the result of changes occurring first in the equatorial ocean (Figure 4).

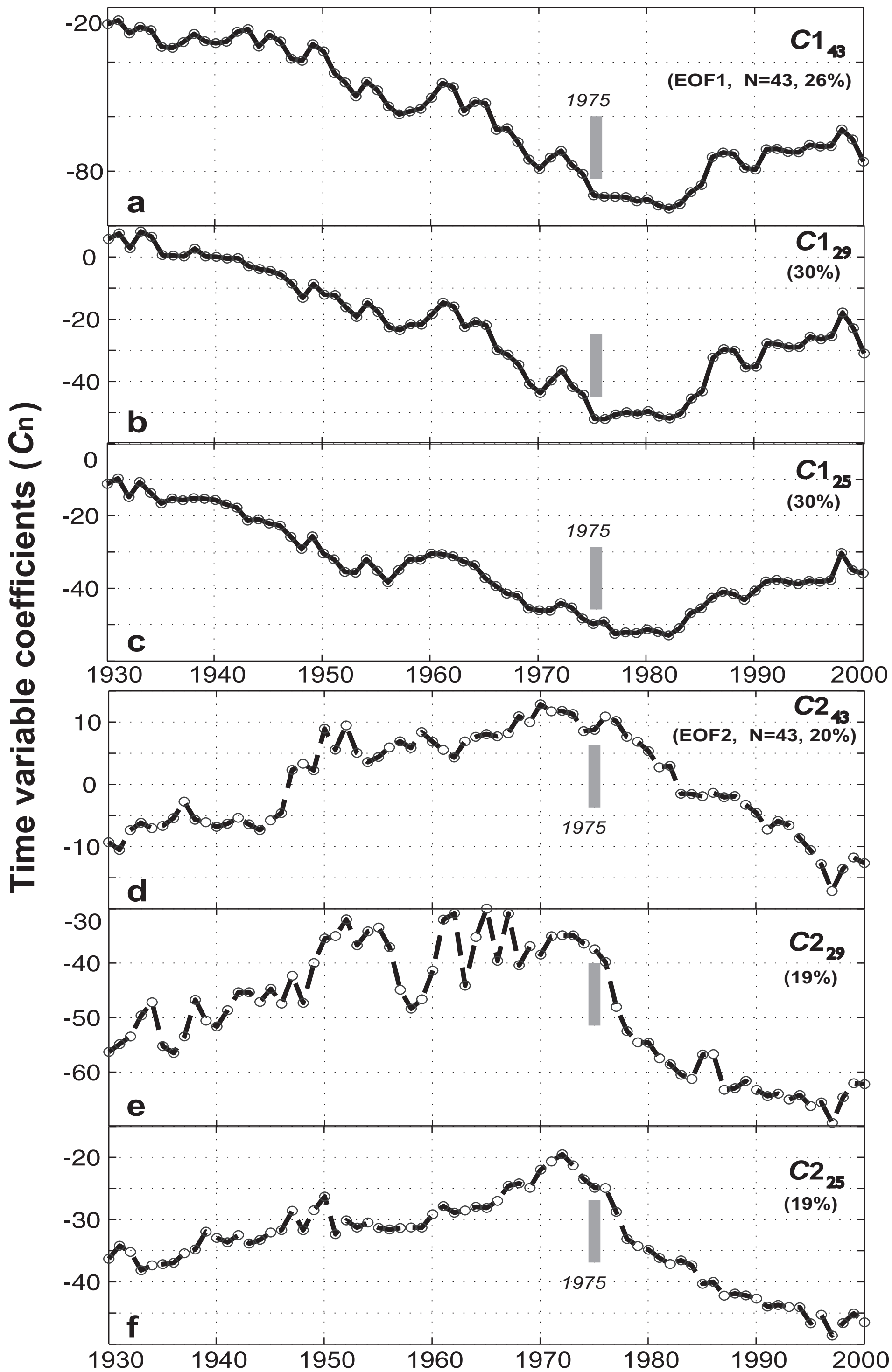

Figure 1 Time-variable coefficients (*C*) for the ensemble of the 43, 29, and 25 market groups having landings throughout 1930-2000. Time variable coefficients for EOF1 (*C*1, solid line) are at the top (a, b, c). Panels d, e, and f give the time-variable coefficients for EOF2 (*C*2, broken line). *C*-values for each year are shown by circles. Only the connecting lines are used in the following graphs.

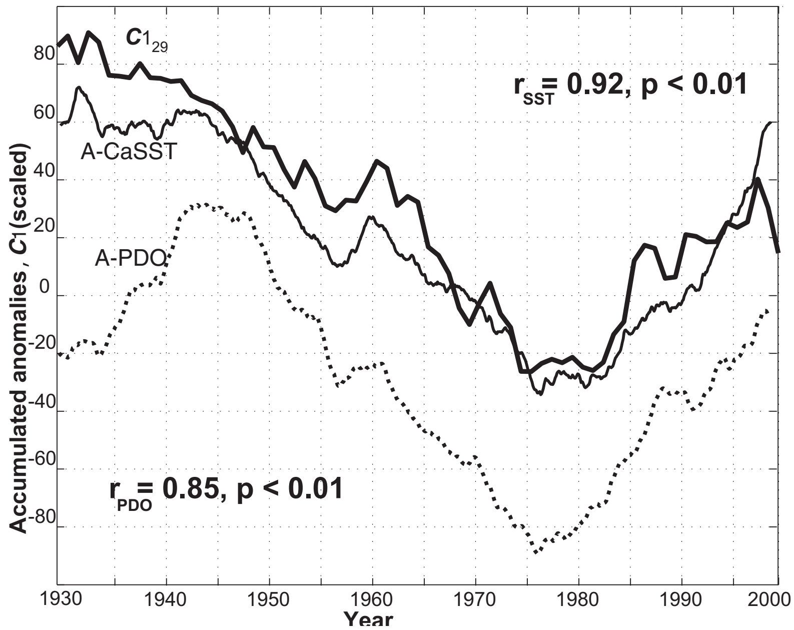

Figure 2 Accumulated monthly anomalies of the environmental indices and annual $C1_{29}$ values for $EOF1_{29}$ (heavy solid line) are scaled to show similarities. The accumulated sea surface temperature anomaly from the La Jolla shore station (A-CaSST) is the thinner solid line. The accumulated Pacific Decadal Oscillation (A-PDO) is the dotted line.

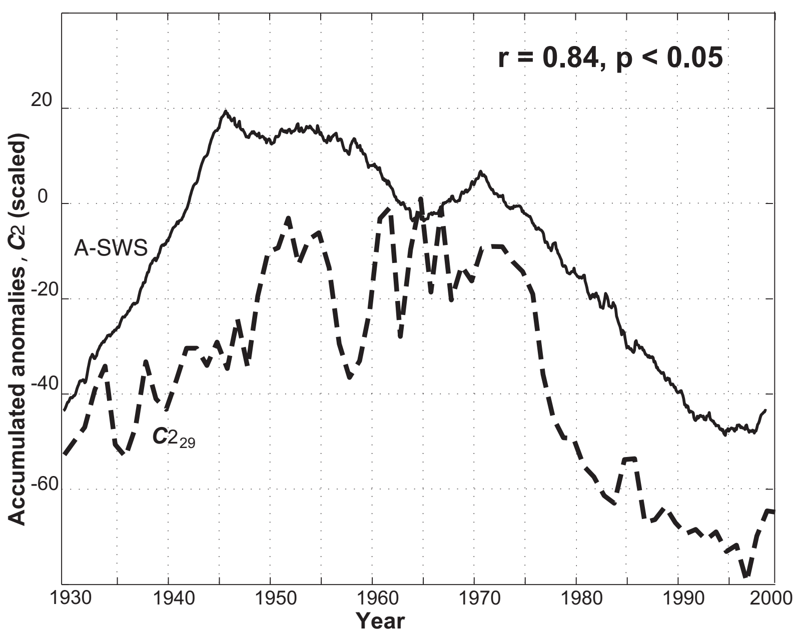

Figure 3 Accumulated monthly anomalies of southward wind stress and annual time variable coefficients ($C2_{29}$) values for $EOF2_{29}$ (heavy, broken line) are scaled to show similarities. The accumulated central California southward wind stress anomaly (A-SWS) is the thinner solid line. Scaling and offsets are as follows: $C2_{29}$ x 2, +60; A-SWS x 10 Pa.

The *C*1 and *C*2 species compositions follow well-known patterns of physical change in the California current environment (Norton and others 1985, Roemmich and McGowan 1995, Parrish and others 2000, Norton and Mason 2003). First, Parrish and others (2000) showed independent variation in central California SST and SWS over the 1881-1995 period. The uncorrelated temporal patterns in *C*1- and *C*2-series and their apparently unique correlation to A-CaSST and A-SWS is consistent with the Parrish and others (2000) result. Second, some of the highest coastal CA SST means of the 20th century occurred during 1957-1962, a period marked by a trend in *C*1 to more positively loaded species. Third, the northeastern Pacific climate change of 1973-1982 is indicated by negative trend in *C*1 during the early 1970s, followed by a relatively stable period (Figure 2). The *C*2 species compositions show the 1973-1982 climate shift by continuous change to more negatively loaded species (Figure 3). Finally, *C*1 and *C*2 have trend changes in response to the cooler ocean climate following the 1997-1998 California El Niño period. The *C*1 and *C*2 species compositions are less closely related to temporal fluctuations in total boats making landings and the total value of the catch adjusted for inflation than to the environmental variables, suggesting that the variation in catch composition is not entirely the result of either overall effort or the fisher's gross income (Norton and Mason 2003). The harvest from California waters appears to depend largely on the fish available, which in turn appears highly dependent on environmental factors.

When each species is examined in terms of EOF1 and EOF2 loading values, a progression of species dominance through the 1930-2000 period is indicated (Figure 5). The 1930s and 1940s (center right in Figure 5) were dominated by the sardine fishery, but scorpionfish, barracuda, and yellowtail were also at their maximum abundance. In the 1950s and 1960s (upper left) landings of jack mackerel and albacore were high. During the 1970s (center left in Figure 5) anchovy and sablefish were near their maximum abundances in the landings. Landings during the 1980s and 1990s (lower left and center) were characterized by several species, including Pacific mackerel, hake, and herring. Finally, in the 1990s and 1930s (lower and center right in Figure 5), the cycle of availability appears to be completing, with sardine, ocean whitefish, and sheephead increasing in the landings. Arrows at the top and the right sides of Figure 5 show correspondence of positive EOF1 loading values to persisting positive sea surface temperature (CaSST, top) and negative EOF2 to anomalously strong southward wind stress (SWS, right). The relationships of EOF loading values to persistence in environmental anomaly may provide alternate means of assessing the ability of species groups to withstand continued harvest pressure.

The *C*1 and *C*2 values indicate that species composition in the landings have changed continuously throughout the 71-year period, with general trends over intervals lasting from 6 to 36 years. These are the time scales of significant fisheries-climate interactions. Some species groups have occurred together under specific environmental conditions during the 1930-2000 period. This result may provide a basis for proactive ecosystem management that establishes harvest regulations, increasing or decreasing the catch of particular species which are dependent on ongoing environmental conditions.

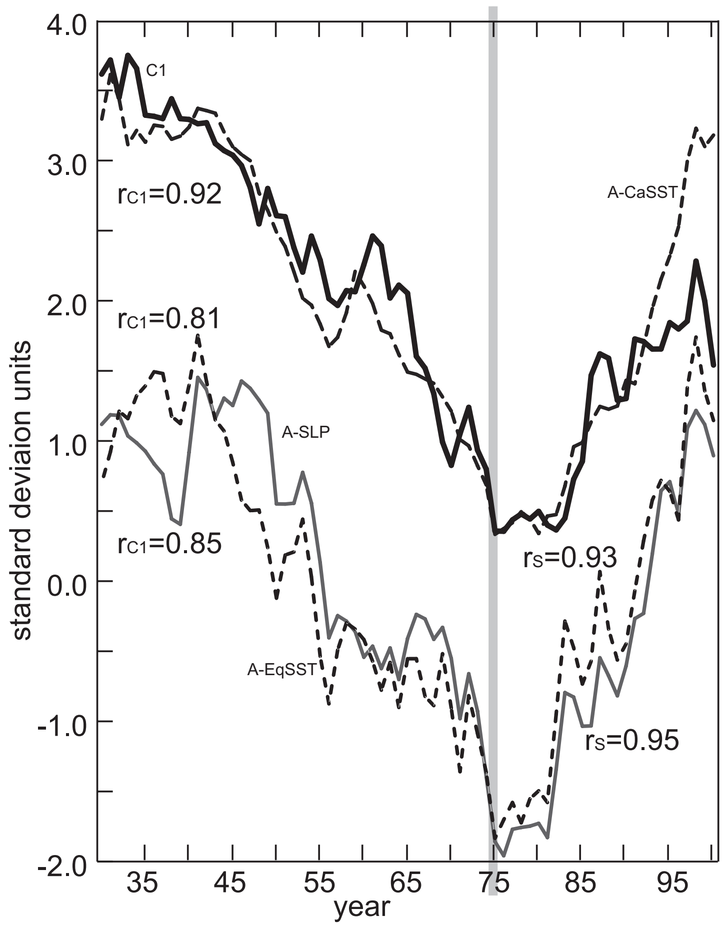

Figure 4 Comparison of $C1_{29}$, (upper solid line) to accumulated southern California SST anomalies (A-CaSST, upper broken line), accumulated equatorial sea surface temperature anomaly (A-EqSST) from 4 °N - 4 °S by 90 °W to 150 °W (lower broken line), and accumulated average sea level pressure anomaly at Darwin, Australia (A-SLP). All values are scaled by standardization; two units have been added to the upper two-time series.

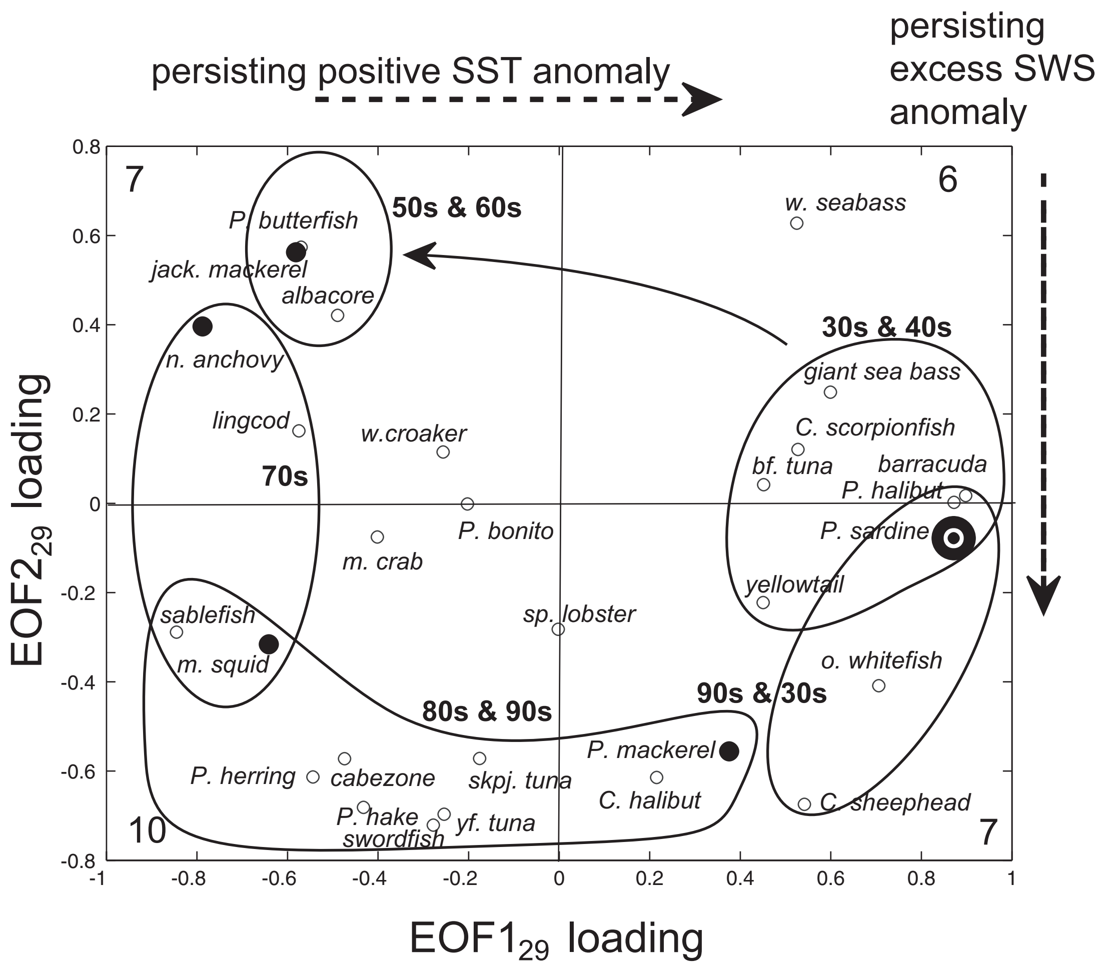

Figure 5 Comparison of EOF1 and EOF2 loading values for each species, with EOF1 on the abscissa and EOF2 on the ordinate. The number of species in each quadrant is given by bold numbers in the corners. Species locations are shown by circles. Filled circles indicate landings of more than a million metric tons during the 1930-2000 period. Sardine landings have exceeded eight million metric tons. Arrows at the top and the right side show correspondence of the "EOF-space" to persisting anomalous sea surface temperature and persisting anomalous southward wind stress, respectively. Species dominant in the landings relative to their own range of variability in the 1930s and 1940s (center right), the 1950s and 1960s (upper left), 1970s (center left), 1980s and 1990s (lower left and center), and the 1990s and 1930s (lower and center right) are indicated.

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