An Analysis of Climate Events in the Monterey Bay Based on the Extratropical Northern Oscillation Index (NOIx)

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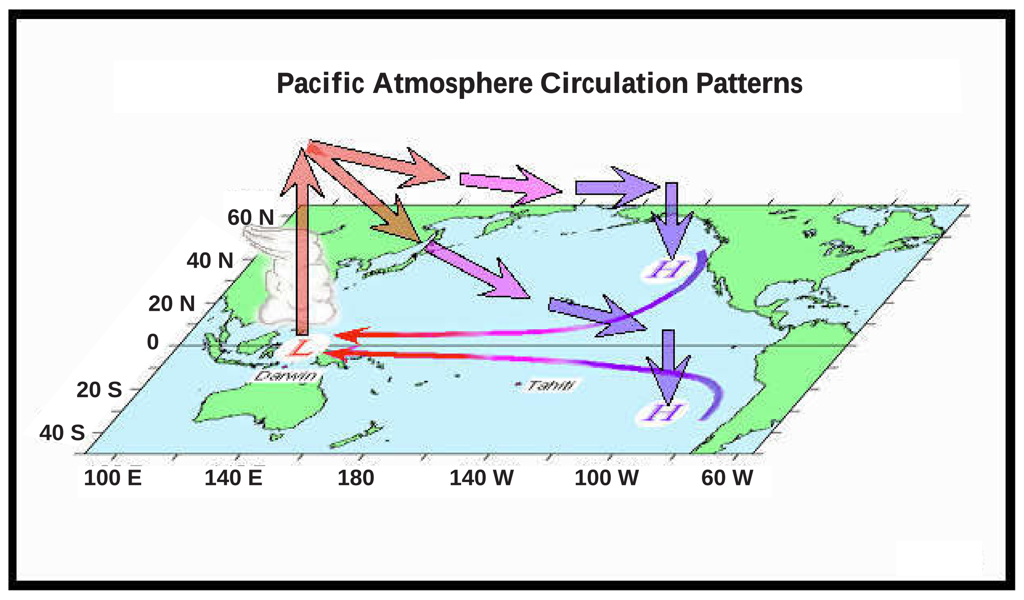

Figure 1. Schematic of large scale atmospheric circulation patterns in the Pacific region. Trade winds from the North and South Pacific Highs warm as they move toward a low in the western tropical Pacific - southeast Asian region. Rising warm, moist air feeds tropospheric winds that return to the extratropics via the meridional Hadley and zonal Walker circulation. This air gradually sinks as it moves to the northeast and southeast, supplying mass to the Highs and the sources of the trades.

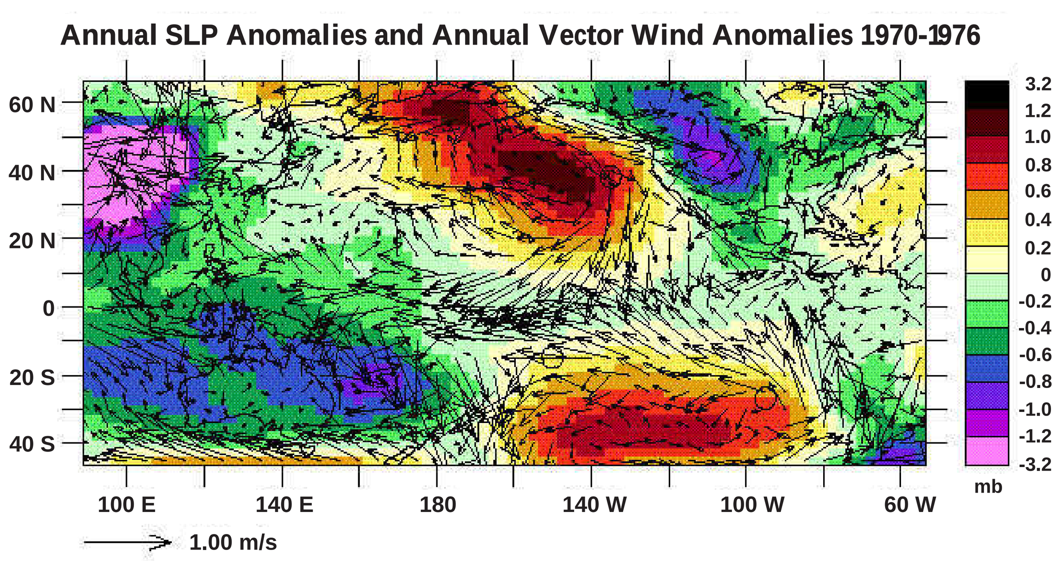

Figure 3. SLP and surface wind anomalies over the Pacific during 1970-76, a period of predominantly positive NOIx values. Yellow-red (green-blue)shades denote positive (negative) SLP anomalies. During this period, the NEP was dominated by high SLP and anomalously strong anticyclonic wind, including more coastal upwelling favorable wind and enhanced trade winds. Anomalies are generally symmetric about the equator.

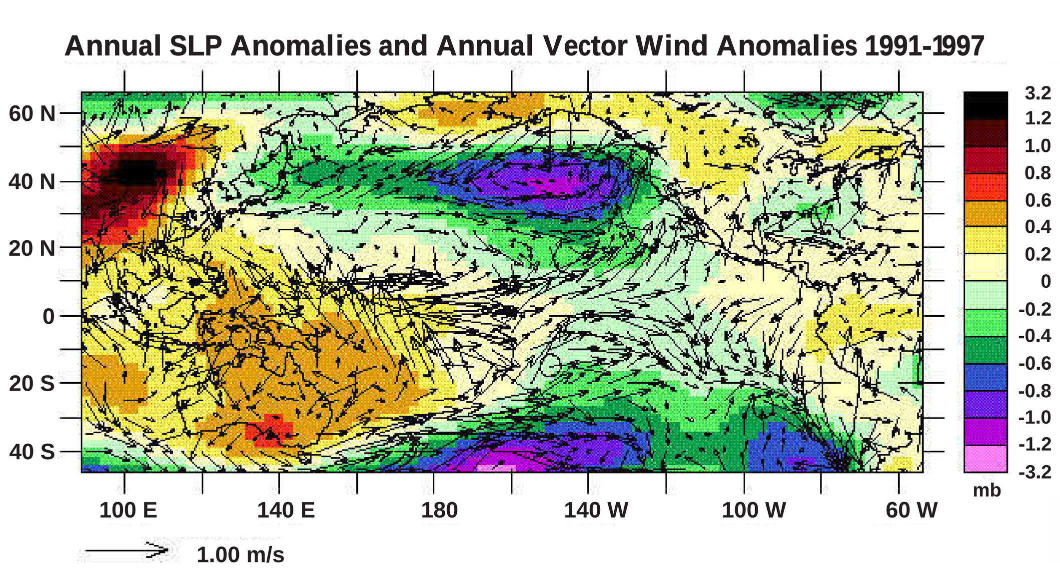

Figure 5. SLP and surface wind anomalies over the Pacific during 1991-97, a period of predominantly negative NOIx values. Yellow-red (green-blue) shades denote positive (negative) SLP anomalies. Anomalies are a near-mirror image to those during the positive phase. During this period, the NEP was dominated by lower than normal SLP and anomalously weak anticyclonic wind, including less coastal upwelling favorable wind and reduced trade winds.

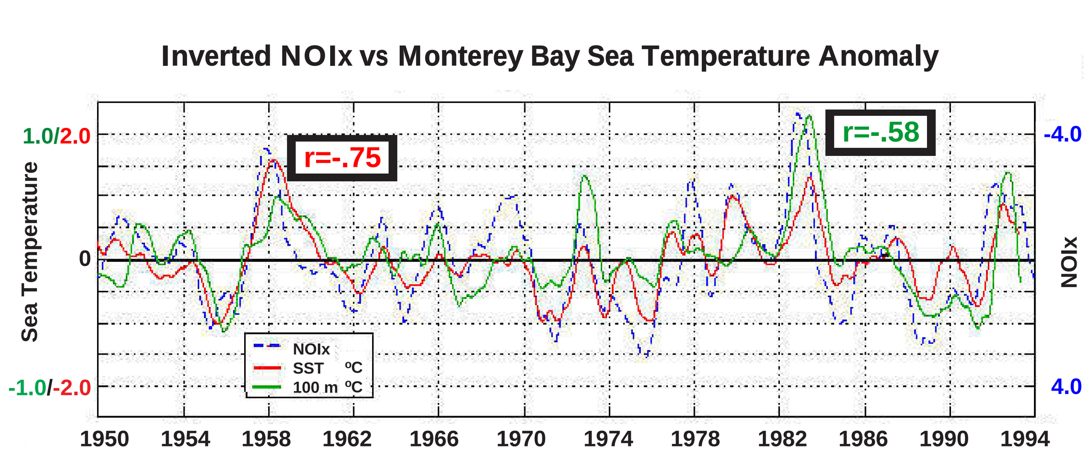

Figure 7. The monthly NOIx (inverted) and sea temperature anomaly at surface and at 100 meters depth, in the MBNMS region (35.5-37.5 N, 123.5-121.5W). Series were detrended and 5 -month running smoothed then 12-month running smoothed. Cooler (warmer) subsurface temperatures correspond to positive (negative) events in the NOIx.

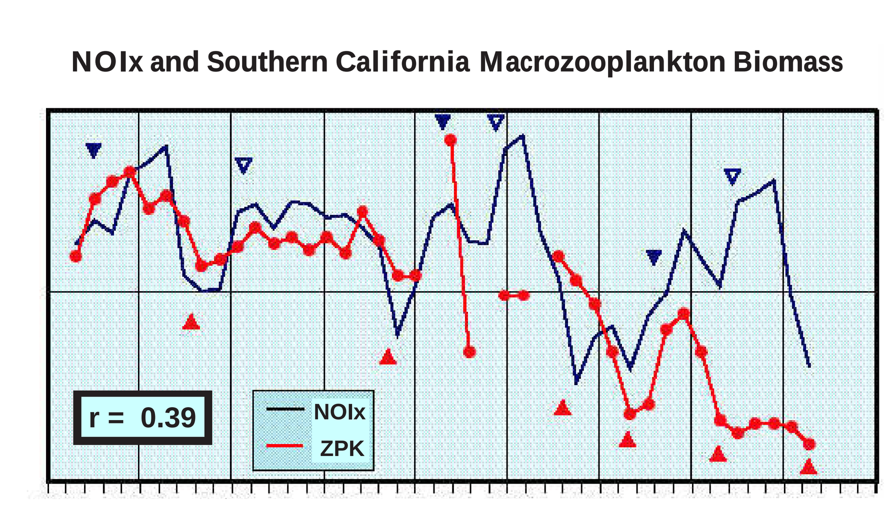

Figure 9. The NOIx and maximum annual macrozooplankton volume along CalCOFI Line 90 off southern California (from Roemmich and McGowan 1995) for 1951-92, Shifts toward positive (negative) NOIx values noted by blue (red) triangles. Reductions in macrozooplankton correspond to sharp declines in the NOIx. Solid (open) blue triangles denote positive NOIx events where biomass does (does not) increase.

Introduction

The Monterey Bay National Marine Sanctuary (MBNMS) in the northeast Pacific (NEP) is linked to distant regions via the atmospheric Hadley-Walker (HW) circulation (Figure 1). Through these connections, the NEP is involved in a wide range of large-scale climate changes (e.g., El Nino and La Nina). These changes show up in the MBNMS as changes in sea level pressure (SLP), surface wind stress, precipitation, ocean temperature, upwelling, and other atmospheric and oceanic factors.

The North Pacific High (NPH) is a major center in the atmospheric circulation. Variations in the NPH are a good indicator of the impacts of large scale climate change and the regional processes responsible for ocean anomalies in the MBNMS, since they are linked closely to the winds that drive the oceans. The Northern Oscillation Index (NOIx), based on the difference in SLP anomalies in the NPH and at Darwin, Australia, is well correlated with remote and local climate change events, including a wide range of upper ocean changes, in the MBNMS.

Results

Comparison of index time series

The NOIx and SOI (Figure 2) are well correlated, reflecting the tendency of the NPH and its counterpart in the southeast Pacific to vary together and out of phase with a low in the west tropical Pacific. Large positive (negative) values of the indices are usually associated with La Nina (El Nino) events. The NOIx identifies 21 positive events and 12 negative events since 1950. Only about half of these are also diagnosed by the SOI. The very strong 1957-58 El Nino event is clearly indicated by the NOIx but is only weakly present in the SOI. This event had major impacts on the NEP (Sette and Isaacs 1960) and helped lead to the realization that El Nino and La Nina events have global impacts. Another notable difference occurred in 1990-91. Both positive (La Nina) and negative (El Nino) events tend to cluster into decadal scale. The NOIx indicates significant climate regime shifts at about 1977, 1984, and 1991.

Pacific Basin Anomaly Fields

Composite maps of anomalies show ocean response patterns during the positive and negative phases of the NOIx. In 1970-76, a period of predominately positive NOIx, high SLP anomalies over the NPH and SPH (Figure 3) and the corresponding SST anomalies during this positive phase of the NOIx (Figure 4) resembled the patterns often seen during La Nina events. SLP, winds, and sea surface temperatures (SST) anomalies during the 1991-97 negative phase of the NOIx (Figures 5&6) were opposite to those during the positive phase (Figures 3&4). In both phases, the SLP, surface wind, and SST anomalies were generally symmetric about the equator. The varying pattern of low and high SLP anomalies reflects atmospheric teleconnections linking the extratropics and tropics.

Correlations With MBNMS and California Current Time Series

Subsurface temperatures also respond to long term atmospheric forcing through processes that affect pycnocline and mixed layer depths. Detrended sea surface and subsurface temperature time series in the MBNMS region (35.5-37.5 N, 123.5-121.5W) correlates negatively with the NOIx (Figure 7). During the positive phase of the NOIx, the thermocline shoals.

Precipitation appears to be linked to variations in the NOIx on decadal scales as well, and fluctuates in response to interannual changes in atmospheric forcing. Santa Cruz (37N, 122W) annual precipitation is greater when the NOIX is negative (Figure 8). Higher (lower) precipitation totals are well correlated with negative (positive) NOIx events.

The NOIx and macrozooplankton biomass (Figure 9) off southern California (Roemmich and McGowan 1995) series are only weakly correlated. However, similarities in the interannual variations of these series suggests that changes in biomass may be explained in part by the NOIx. All sharp declines in the NOIx are reflected in drops in biomass. Shifts toward positive NOIx values are not always accompanied by biomass increases; the NOIx probably represents only some of the factors driving zooplankton population dynamics.

The Oregon Production Index (OPI) is the percentage of the Oregon hatchery-released salmon that returned as adults. The detrended OPI is significantly correlated with the NOIx and reflects the regime shifts indicated by the NOIx (Figure 10). Higher OPI returns are associated with positive NOIx values, and La Nina events, during 1970-76 and 1984-90.

Conclusions

The NPH is a major link between the atmosphere and ocean in the northeast Pacific. It is also strongly tied to climate change occurring over much of Asia, and the Pacific and Indian Ocean regions. Climate processes known to have large physical and biological impacts on the NEP are well represented by the NOIx. The NOIx is potentially very useful for monitoring and predicting climate changes and their biological consequences in the MBNMS ecosystems and may provide insights on the mechanisms linking the physical environment to marine resources.

Acknowledgements

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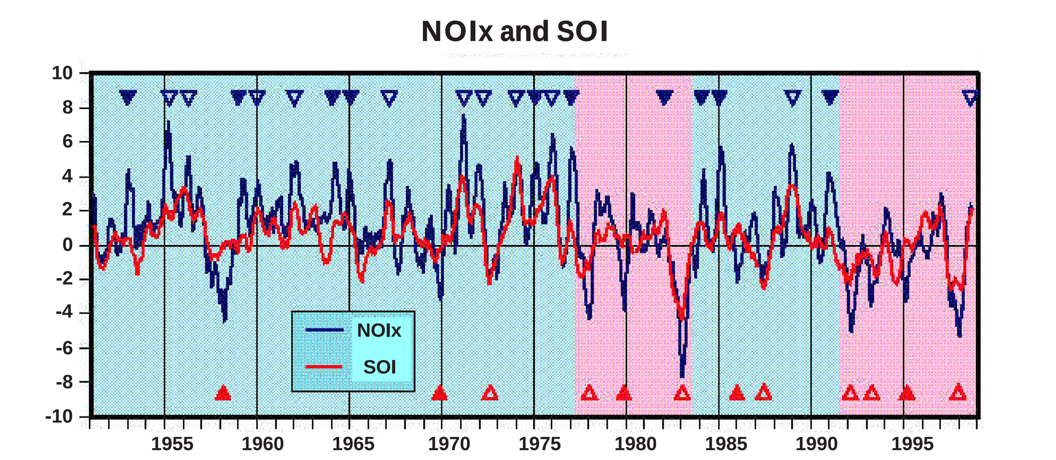

Figure 2. The monthly extratropical Northern Oscillation Index (NOIx) and Southern Oscillation Index (SOI) for 1951-98. Monthly climatologies of SLP were removed prior to computing indices. Series were five-month running smoothed. Moderate/strong positive and negative events in the NOIx are identified by blue and red triangles, respectively. Large positive (negative) values of the indices are usually, but not always, associated with La Nña (El Niño) events. Open triangles are events also classified by the SOI as moderate to strong events. The blue (red) shading indicates periods dominated by positive (negative) values of the NOIx.

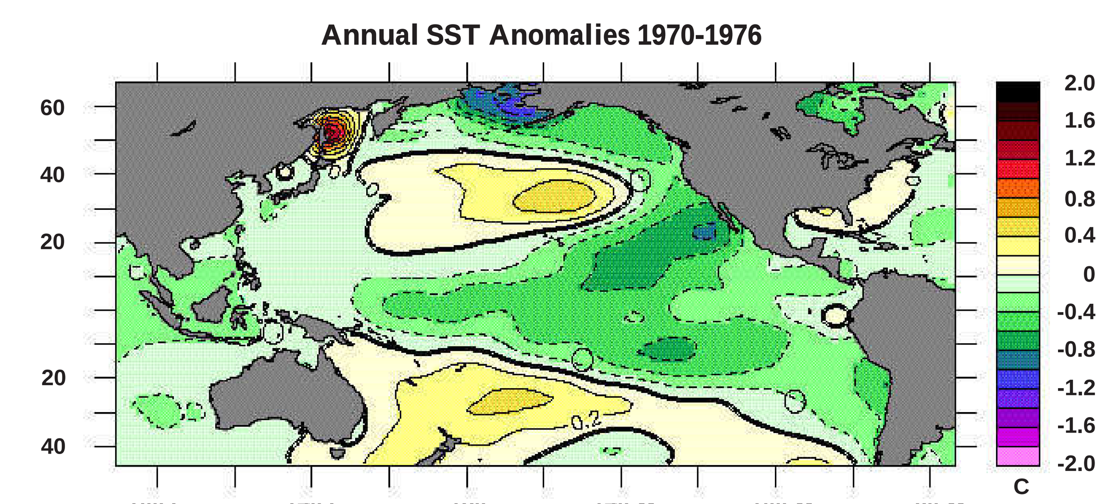

Figure 4. SST anomalies in the Pacific during 1970-76. Yellow-red (green-blue) shades denote positive (negative) anomalies. The SST anomaly field resembles that often seen during La Niña events. Cool SST anomalies were seen in the eastern boundary currents along most of the west coasts of North and South America and the eastern tropical Pacific Ocean. Anomalously warm SSTs occurred in the central north Pacific

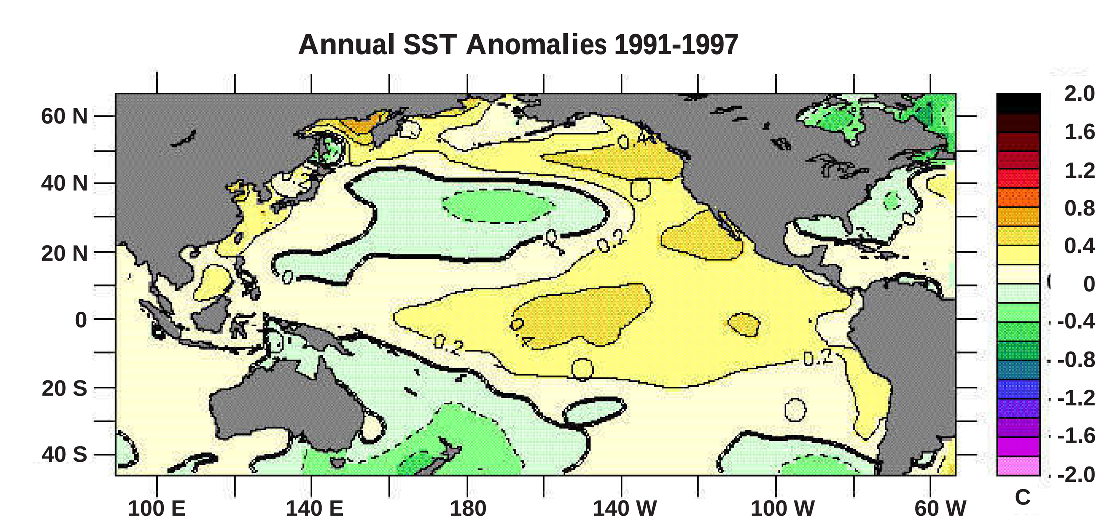

Figure 6. SST anomalies in the Pacific during 1991-97. Yellow-red (green-blue) shades denote positive (negative) anomalies. The SST anomaly field resembles that often seen during El Niño events. Warm SST anomalies were seen in the eastern boundary currents along most of the west coasts of North and South America and the eastern tropical Pacific Ocean. Anomalously cool SSTs occurred in the central north Pacific.

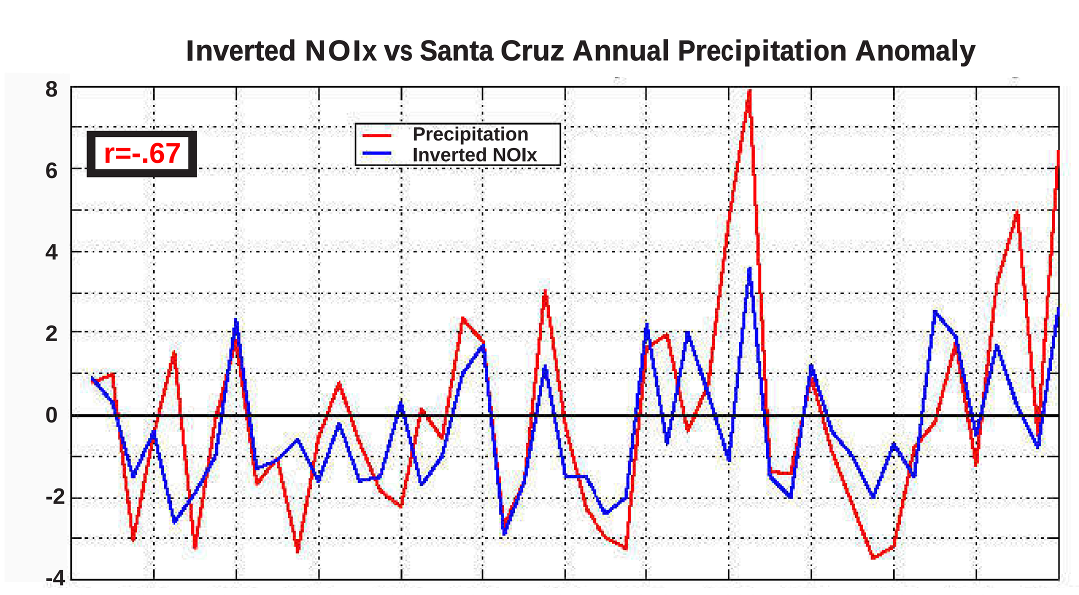

Figure 8: The monthly NOIx (inverted) and Santa Cruz annual precipitation anomaly (37N, 122W) for the period 1950-1998. Higher (lower) precipitation totals are well correlated with negative (positive) NOIx events.

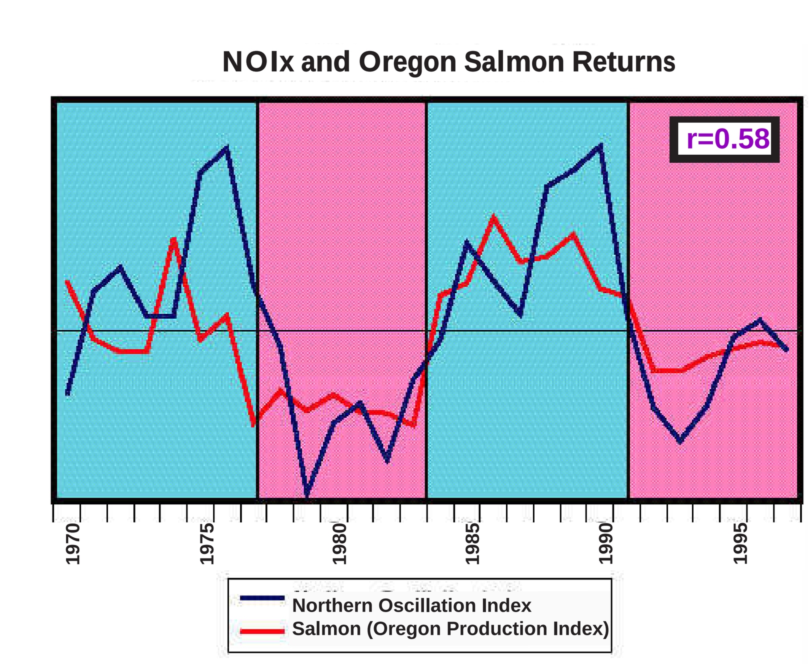

Figure 10. The NOIx and the annual Oregon Production Index (OPI) for 1970-97. The OPI is the percentage of hatchery-released salmon that returned as adults. Series were normalized, detrended, and 3-year running smoothed. Blue and red shading indicates periods dominated by positive and negative values of the NOIx, respectively. Higher, more variable (lower, steady) OPI returns are associated with positive (negative) NOIx values during 1970-76 and 1984-90