Wavelet Analysis of Trends in Summer Flounder YOY and Spawner-Recruit Relationships

by Eric Powell

Introduction

Two climatic signals are most significant in affecting oceanographic and estuarine processes in the Mid-Atlantic Bight, the North Atlantic Oscillation (NAO) and the Pacific North American (PNA). The NAO is closely related to the Arctic Oscillation (AO) and primarily affects temperature. The PNA has a well-described teleconnection with the El Niño-Southern Oscillation (ENSO) and is dominantly an effector of precipitation and, thus, freshwater inflow, in the northeast region. The NAO has a well-described 8-year cycle and indications of a 4-yr periodicity that are superimposed on longer-term trends. These periodicities are known to profoundly effect estuarine oyster populations, including recruitment and mortality.

Methods

Meteorological Data Sets
  Monthly values for the NAO and PNA indices were obtained from the National Weather Service Climate Prediction Center [1]. Both are obtained from a rotated principal component analysis using the monthly standardized 500-mb height anomalies obtained from the CDAS in the analysis region 20° N-90° N. Details are provided at the NOAA web site.

Analytical Approach
  The time series technique of wavelet analysis was used. Application of this technique to oyster populations is described in Soniat et al. (2006), who reference a wide range of other applications of this technique. Wavelet analysis resolves localized variations in the strength of a signal (i.e., the wave) within a time series. With this approach, the original time series is decomposed into a time-frequency space, which allows the dominant components (i.e., the wavelets) that make up the wave to be identified. Soniat et al (2006) provide references to source the mathematical details of the technique. Earlier analyses by our group have evaluated the use of a number of mother wavelets (e.g., Paul, Morlet). The Morlet wavelets have good frequency resolution, but smear the dominant signals in the time domain. The Paul wavelets provide good time resolution, but smear the signals in the frequency domain. Comparison of the two show that, for applications of the type that follow, the Morlet wavelet provides adequate time resolution and superior frequency resolution over the results obtained from the Paul wavelet. As a consequence, the Morlet wavelet is used here.

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[1]   www.cpc.ncep.noaa.gov/products/precip/CWlink

Fisheries data

The fisheries data used are the spawning stock biomass (SSB) and recruitment estimates (VPA0) for summer flounder obtained as described by Terceiro[2].

Results

Four wavelet analyses are reported as representative of a number of different analyses. Each is a cross-wavelet analysis, equivalent to a cross-correlational analysis, comparing either the NAO or PNA to either the VPA0 or VPA0/SSB (labeled `SR' on the plots that follow) index.
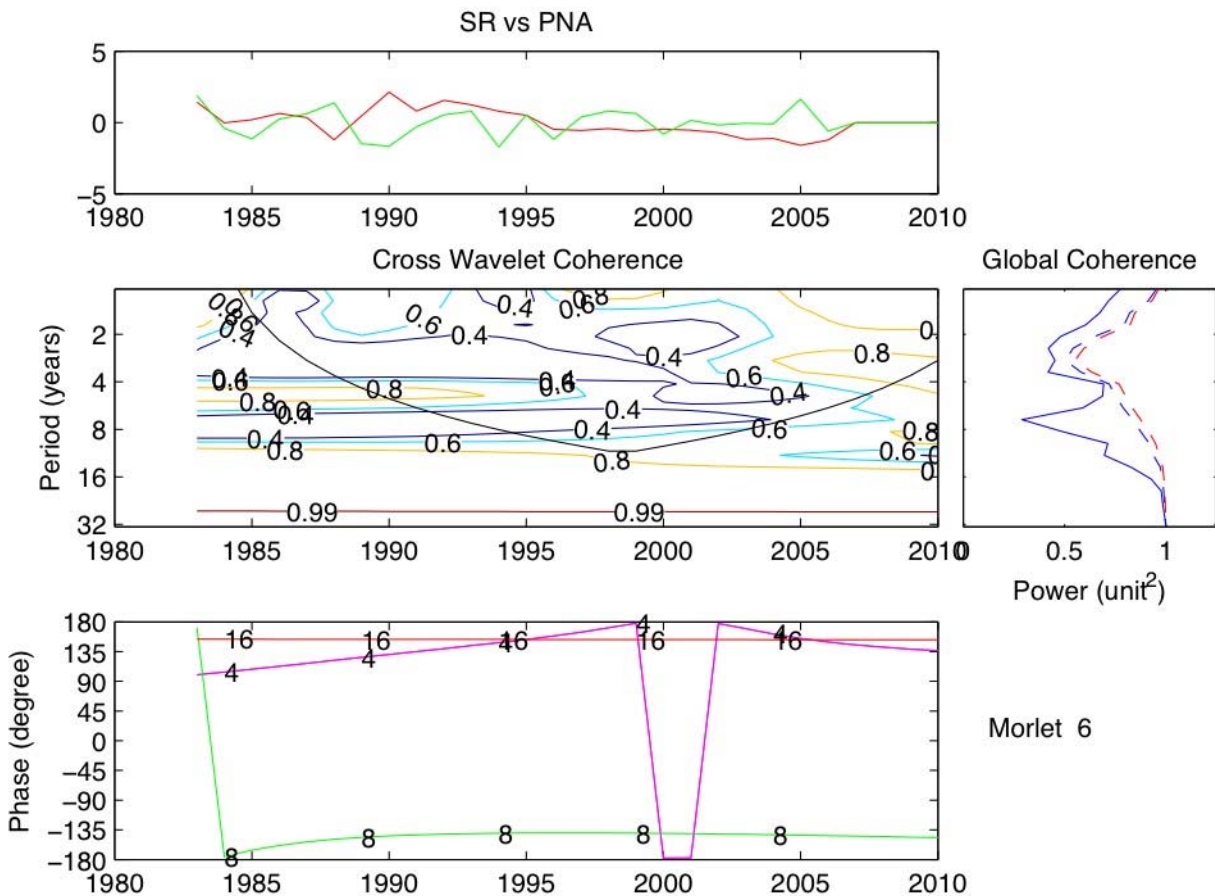

Figure 1. Cross-wavelet analysis between the VPA0/SSB (spawner-recruit) index and the PNA (Pacific North American) index.

Figure 1 shows the cross-wavelet analysis between the spawner-recruit index and the PNA. The top graph reports the data time series standardized to a mean of zero. The middle righthand graph labeled `global coherence' reports the significance of periodicities from <1 to >16 years. The dashed lines on this graph identify the significance at the $\alpha = 0.10$ (left dashed line) and $\alpha = 0.05$ (right dashed line) levels. The time series is 24 years long. A rule-of-thumb is

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[2] Working Paper: Modeling environmental factors and summer flounder recruitment success.

that no periodicity can be safely identified with a period that exceeds half the time series length, so that results exceeding 12 years should be ignored. In the case of the PNA and the spawner-recruit relationship, no significant periodic interaction is found. Other analyses, not figured here, also failed to find any relationship with the PNA and recruitment (VPA0).
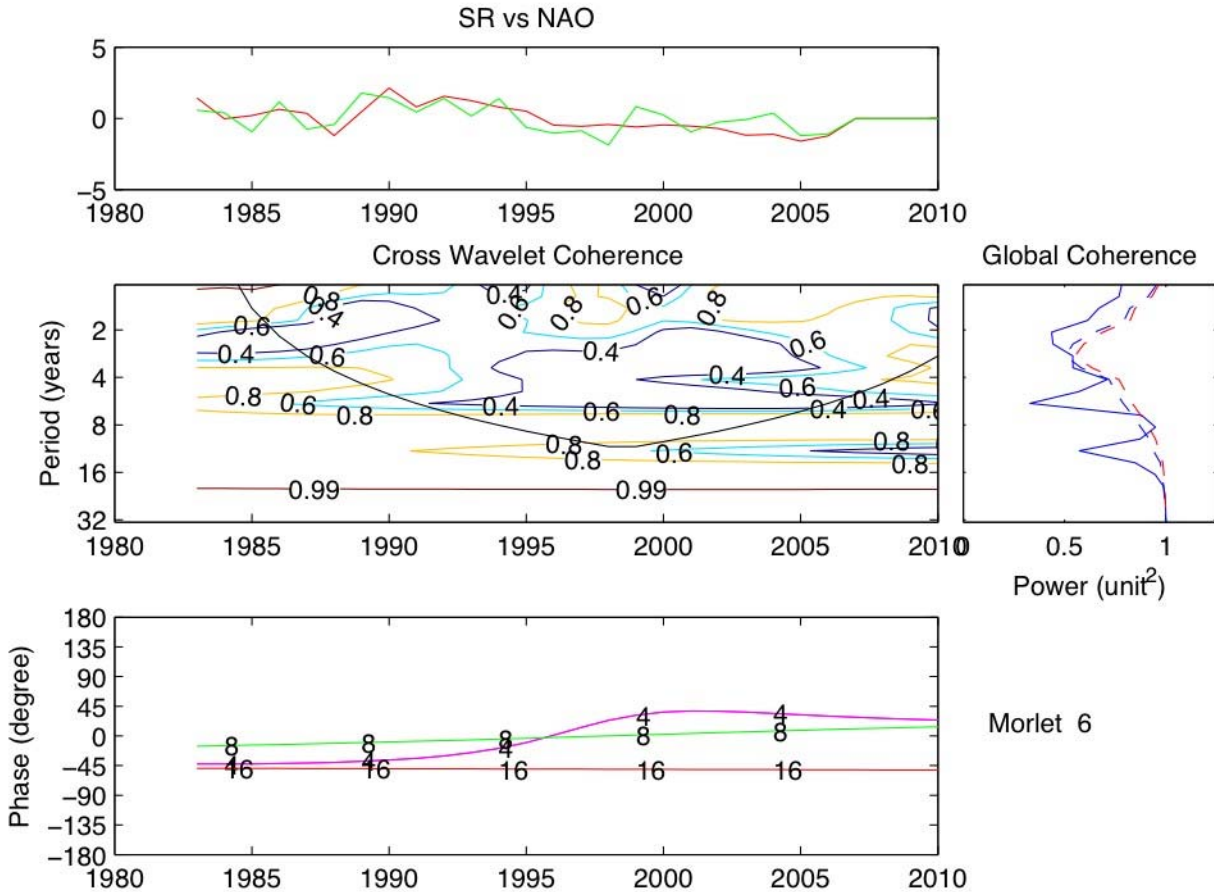

Figure 2. Cross-wavelet analysis between the VPA0/SSB (spawner-recruit) index and the NAO (North American Oscillation) Index.

Figure 2 shows results of the cross-wavelet analysis for the spawner-recruit index and the NAO. The analysis shows two significant coherences, at 4 years and 8 years (middle, right plot labeled `global coherence'). These same two periodicities are significant in other species we have examined such as oysters. The lower plot shows the phase relationships, with the first variable leading the second. Thus, the 8-year periodicity has a phase of near 0. Highs in NAO and the spawner-recruit index more or less coincide. The 4-yr periodicity shows a strong shift in phase between 1995 and 2000. Prior to 1995, the phase was -45°. That is, NAO led the spawner-recruit relationship by
$4 \times (45^{\circ} / 360^{\circ}) = 0.5$ yr. After 2000, the two periods were nearly synchronous.

Figure 3 shows the results of cross-wavelet analysis between the VPA0 index and NAO. The 8-year signal is significant and the 4-yr signal barely so. The phase shift in the 4-year signal is dramatic.
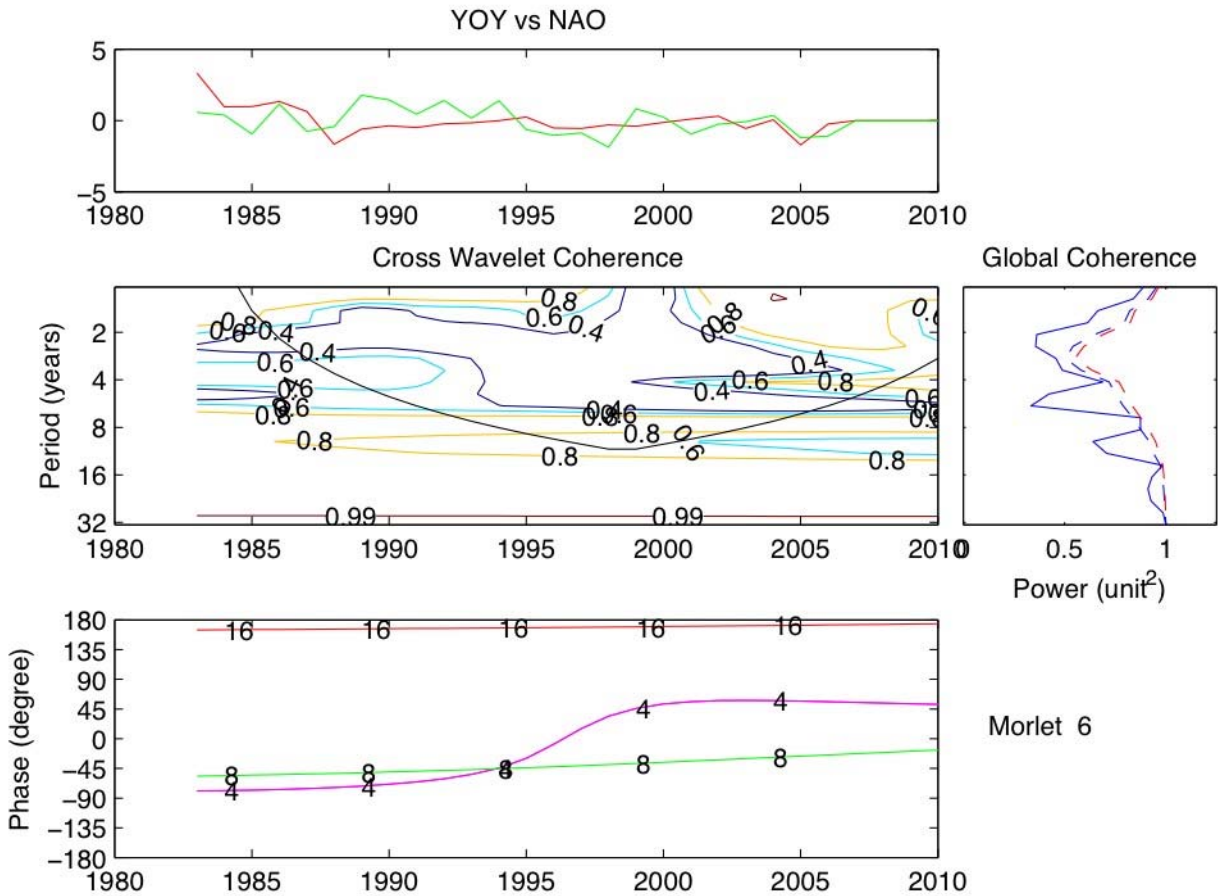
Figure 3. Cross-wavelet analysis between the VPA0 index and the NAO (North American Oscillation) Index.

The spawner-recruit index has a long-term downward trend that might affect the wavelet analysis. A final analysis was conducted with this trend in the spawner-recruit relationship removed prior to analysis. Figure 4 shows that the 8-year periodicity remains strongly significant. The 4-year periodicity is no longer significant, although the phase shift remains apparent.
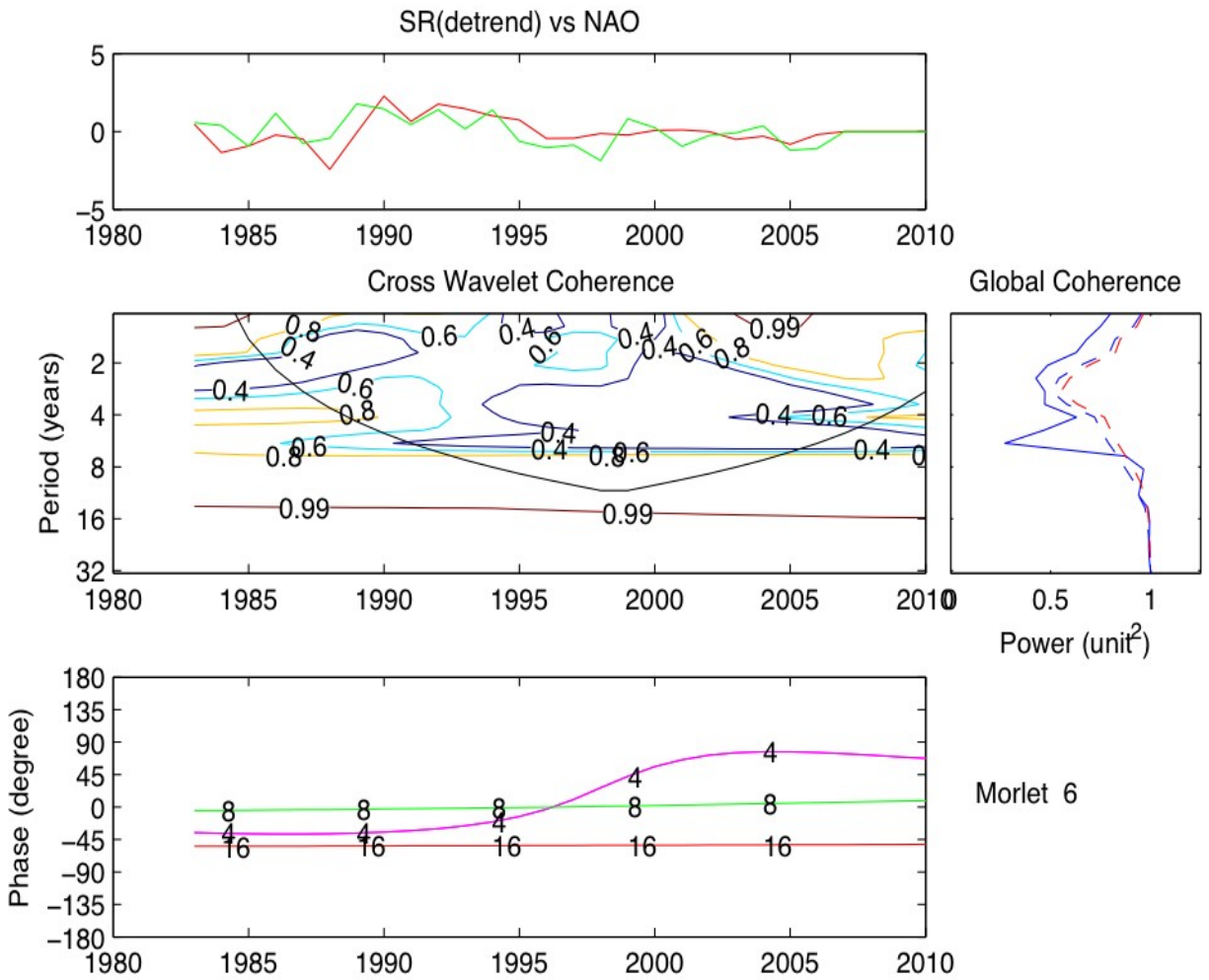
Figure 4. Cross-wavelet analysis between the VPA0/SSB index and the NAO (North American Oscillation) Index, with the spawner-recruit relationship de-trended prior to analysis.

Conclusions

No evidence exists for a relationship between the PNA and summer flounder recruitment. On the other hand, a relationship between the NAO and summer flounder recruitment is strongly supported. The 8-year periodicity, the dominant periodicity in the NAO, is identified as significantly correlated with an 8-year periodicity in the recruitment indices in all analyses. The significance level consistently exceeds $\alpha = 0.05$. No substantive phase shift occurs. The two periodicities are in near-synchrony so that high NAO and high recruitment indices occur more or less simultaneously.

In most analyses, a 4-year periodicity also occurs, although sometimes at a weaker level of significance. This interaction is consistently associated with a phase shift between 1995 and 2000. Such phase shifts are frequently associated with substantive long-term changes in population dynamics. However, this periodicity was no longer significant after the long-term trend in the spawner-recruit data was eliminated. This suggests that the interaction of the two time series was primarily associated with subsets of the time series record. A detailed

examination of the coherence over the time series suggests that the 4-year periodicity was stronger pre-1995 and post-2000 and that the phase shift was coincident with a decline in the significance of this periodicity during the intervening years.

The NAO is consistently associated with temperature shifts in the North Atlantic. The present analysis suggest that some portion of the variability in summer flounder recruitment since 1982 can be explained by this climate forcer and its expression in changes in the temperature regime experienced by the fish.

I have not included a long list of references. Those interested in further information on wavelet analysis are directed towards the references contained in Soniat et al. (2006) [Soniat, T.M., J.M. Klinck, E.N. Powell and E.E. Hofmann. 2006. Understanding the success and failure of oyster populations: Climatic cycles and *Perkinsus marinus. J. Shellfish Res.* 25:83-93]. A recent review of the NAO/AO that provides access to this literature is Cohen and Barlow (2005) [Cohen, J. and M. Barlow. 2005. The NAO, the AO, and global warming: how closely related? *J. Climate* 18:2298-4513].