Climate Change and Salmon: Some Thoughts from Outside the Box

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This talk is meant to show how mathematical models, although they are gross abstractions of reality, can help us explore territory outside the box of conventional wisdom. I first gave four examples from my own personal experience of trying to relate climate to various aspects of marine biological production. The insights gained were:

- Time series analysis helped us understand that major changes in Alaska salmon production occurred suddenly, infrequently, and during the first several months in the ocean (Francis and Hare 1994).
- Multivariate analysis (EOF) enabled us to quantify spatial patterns in both climate (PDO) and NE Pacific salmon production and project these patterns on the time domain. We were able to demonstrate that, during the 20th century, Alaska and Pacific Northwest salmon production were out of phase (Mantua et al. 1997, Hare et al. 1999).
- Non-linear statistical modeling (GAM) helped reveal that off the Oregon coast, there is a string of relatively independent physical oceanographic processes, which, coupled together, affect coho salmon marine survival (Logerwell et al. 2003).
- Pacific Northwest coastal marine ecosystem modeling revealed that climate has both top down and bottom up effects on marine ecosystem dynamics (Field et al. 2001).

I then presented several general lessons that were learned from these four modeling exercises:

- To be useful, models must be demonstrably consistent with history.
- The essence of modeling is to facilitate the acquisition of just enough detail to produce observed patterns.
- Feeding and being fed on are the same thing.
- Be wary of one-dimensional cuts through complex systems (e.g. PDO).

Next, I gave two cutting edge examples of where modeling has been used to begin to understand biophysical interactions occurring on complex space and time scales to create observable patterns in marine ecosystems. First, Lehodey et al. (1998) and Lehodey (2001) used coupled biogeochemical, general circulation, and simple food chain models to predict downstream development of skipjack tuna forage around equatorial Pacific convergence zones and fronts. They then went one step further, added in a spatially explicit skipjack tuna life history model, and were able to show how ENSO mediates a remarkable out-of-phase dynamic coupling between skipjack habitat (equatorial warm pool), equatorial Pacific productivity (cold tongue), and downstream forage production (warm pool). And second, moving north, Aydin (2000) was able to show that two processes could make a huge difference to salmon growth during their final year on the high seas: the availability of zooplankton in the winter when zooplankton abundance is at its lowest, and the temperature mediated spatial overlap in spring and summer between salmon and the pelagic squid, *Berryteuthis anonychus*.

I concluded with several thoughts:

- Modeling is a great tool for exploring outside the box.
- The new wave combines climate driven ocean circulation models with complex food web models.
- Looking back at history is one thing; looking forward into the future is another.
- It is false to assume that policymakers require reduced uncertainty in order to take action.
- Confronting uncertainty helps you to think outside the box.

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