

## **Environmental Prediction, changing ocean conditions and considerations for fishery management**

*The Osprey*, Issue No. 43, September 2002. pp 1, 5-9.

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### **Introduction**

Humans have accurately predicted seasonal climate changes for thousands of years. This has been possible because we have learned that there are strong and highly predictable seasonal climate rhythms. In locations with strong seasonal climate changes, each year essentially looks the same: temperatures reach their annual peak in summer and their annual low in winter. Likewise, river runoff, ocean currents, surface winds, upper ocean temperatures, and even phytoplankton production also typically exhibit strong seasonal rhythms. Yet it is also common knowledge that no two years are exactly alike. In some cases year-to-year variations on the seasonal rhythms of climate are quite large, though rarely as large as the typical seasonal changes.

When poor ocean conditions are blamed for causing problems for salmon or steelhead the target of that blame is rarely the strong and predictable seasonal climate change but instead it is focused on the unexpected variations superimposed on the regular seasonal rhythms. Societies have invested large efforts at predicting this type of climate variation, with a special focus on predicting season-to-season and year-to-year climate changes.

Much of the climate prediction effort has been motivated by the promise of societal benefits via an improved forewarning of droughts, floods, or climate-related changes in natural resources like salmonids or other valuable fish stocks. The idea here is simple: better predictions of future climate should lead to better stewardship of limited resources. This notion fits very well with annual activities commonly found in fishery management agencies. Pre-season run-size forecasts, usually based on the number of parent spawners, hatchery smolts released, and/or cohort returns, are issued prior to harvest seasons in order to set harvest rates and determine allocations. Errors in pre-season run-size forecasts have been partially attributed to climate and habitat changes, for instance varying ocean conditions and ocean carrying capacity like that described by Pearcy (this issue). Thus, better climate predictions offer the promise of reducing some of the pre-season run-size forecast errors, at least in cases where the link between climate, environment, and fishery productivity have been quantified.

### **Environmental Prediction**

The state-of-the-art skill in the science of climate prediction rests largely on a demonstrated ability to monitor and predict the status of the tropical El Niño-Southern Oscillation (hereafter simply El Niño). For lead times of one to a few seasons into the future, skill in predicting El Niño has been demonstrated for nearly a decade, with a few

notable successes and a few equally notable failures in that period. Once an El Niño forecast is made, predictions for climate conditions outside the tropics can easily be made. Such climate predictions are now routinely generated from a variety of sources, ranging from past climate data to the outputs generated with sophisticated computer models. In the early stages of the 1997-98 El Niño – as early as June 1997 – both approaches were used to make remarkably accurate forecasts for the 1998 winter and spring climate of North America.

In contrast to the relatively skillful short-term climate predictions described above, western science has demonstrated no skill in climate predictions at lead times longer than one year into the future. In spite of this situation, skillful predictions at lead times from a few years to a few decades into the future may be possible if scientists decipher the now mysterious processes that give rise to multi-year climate variations. If this happens, appropriate monitoring systems can be designed and deployed, and the necessary computer simulation models can be developed.

Climate forecasts are probabilistic in nature, and deterministic climate predictions are simply not believed to be possible by western climate scientists. To the best of our current knowledge, future climate is subject to highly unpredictable changes because random events that we simply cannot foresee may alter future climate. Thus, climate forecasts are always presented as changes in the odds for certain events, making climate forecasting akin to riverboat gambling. Playing roulette, success comes with correctly guessing “red” or “black” more often than not. Like playing the colors on a roulette wheel, the science of climate forecasting uses an approach that assigns odds for relatively crude outcomes like “above average temperature” or “near normal precipitation”. If you ever see a climate forecast for the exact amount of snowfall for your favorite ski resort, you should be certain that it came from someone not schooled in modern scientific approaches.

### **Climate and Salmonids**

Because of the never ending pressures of natural selection, fish and other living creatures have evolved behaviors that allow them to "fit" into their seasonally changing habitats. For northwest salmon and steelhead, aspects of this evolved behavior include the distinct seasonal runs of various stocks of the same and different species. Thus, the strong seasonal rhythms in the life history of salmonids can more likely be explained as a consequence of evolution in an environment with strong seasonal rhythms than as a result of “climate prediction” by fish.

A recent study we took part in (Logerwell et al. (in press)) has helped us infer a few things about the predictability of climate variations thought to be important for “ocean conditions” for Oregon hatchery coho salmon (*Oncorhynchus kisutch*). Oregon hatchery coho have a relatively simple life history, at least in comparison to other species and stocks of Pacific salmon. In the Pacific Northwest most hatchery coho adults spawn during fall or early winter months. After incubation, the eggs hatch into fry that develop as freshwater fish for the next year or so. During their second spring, hatchery juveniles undergo the smolting process. Typically, hatchery coho spend about 18 months at sea before returning to their natal rivers and/or hatcheries to spawn as mature 3 year olds.

There is abundant evidence that Pacific salmon, both of hatchery and natural origins, experience large year-to-year changes in productivity. A 30 year database for Oregon hatchery coho shows that smolt-to-adult survival rates in the period from 1969-1976 ranged from 3-to-12%, while in the period from 1991-1998 those rates were consistently below 1% (see Figure 1). In periods like 1969-1977 and 1984-1991 the year-to-year changes were quite large compared to the averages for those periods. The extremely low return rates in the 1990's indicated in Figure 1 were also observed for many other stocks of wild and hatchery salmonids in the northwest, suggesting a regionally important role for poor ocean conditions during this dismal production period.

Numerous studies have highlighted important associations between variations in climate, the ocean environment, and Oregon hatchery coho smolt-to-adult survival rates (e.g. see Pearcy 1992). In the Logerwell study the results of many earlier studies were synthesized. This synthesis led to the development of a relatively simple model for explaining past changes in smolt-to-adult survival rates with physical environmental data. The model is based on four environmental indices: 1) the coastal ocean temperature in the winter prior to smolt migration; 2) the date of the so-called Spring Transition, the date at which upwelling favorable winds are initiated; 3) the amount of upwelling wind for the smolts' first spring at sea; and 4) the coastal ocean temperature during the maturing coho's first winter at sea. Each of the 4 environmental indices is believed to capture different influences on the quality of the near-surface coastal ocean habitat where juvenile and maturing coho are found. An important finding in this work is that the four different environmental indices are essentially uncorrelated with each other. Yet, considering these four environmental indices in sequence yields an environmental explanation for most of the ups-and-downs in Oregon hatchery coho smolt-to-adult survival rates for the past three decades.

This simple model was developed using data from 1969-1998. We have since made "nowcasts" using observed environmental data to estimate smolt-to-adult coho survival for smolts entering the ocean in 1999, 2000, and 2001 (see the \*'s in Figure 1). Based on our simple model, coastal ocean conditions were much improved for Oregon coho smolts in 1999, 2000, and 2001. Compared to conditions in 1991-1998, this improvement in ocean habitat is related to significantly cooler wintertime coastal ocean temperatures, an earlier onset of springtime upwelling winds, and more upwelling wind in the months of April, May and June.

We interpret the results of this modeling work as evidence that the "ocean conditions" important for Oregon coho are the net result of random combinations of mostly independent climatic processes. That means that knowing the ocean temperature this winter provides no clues about how early, how strong or how often the springtime upwelling winds will blow, nor will it provide much help in predicting ocean temperatures in the subsequent winter. If this is an accurate assessment, and we believe it is, predictability for ocean conditions important for Oregon coho must be limited to the highly predictable seasonal cycle. It also suggests that Oregon coho face a high degree of environmental uncertainty every year, at least in terms of ocean conditions (but surely also in terms of stream and estuary conditions).

### **Life with environmental uncertainty**

Is it remarkable that Oregon coho, and other salmonids, have sustained themselves in the face of past climate and environmental uncertainty? The successful species must have individual members behaving in ways that insulate the population as a whole from undesirable environmental impacts. Many scientists have postulated that a

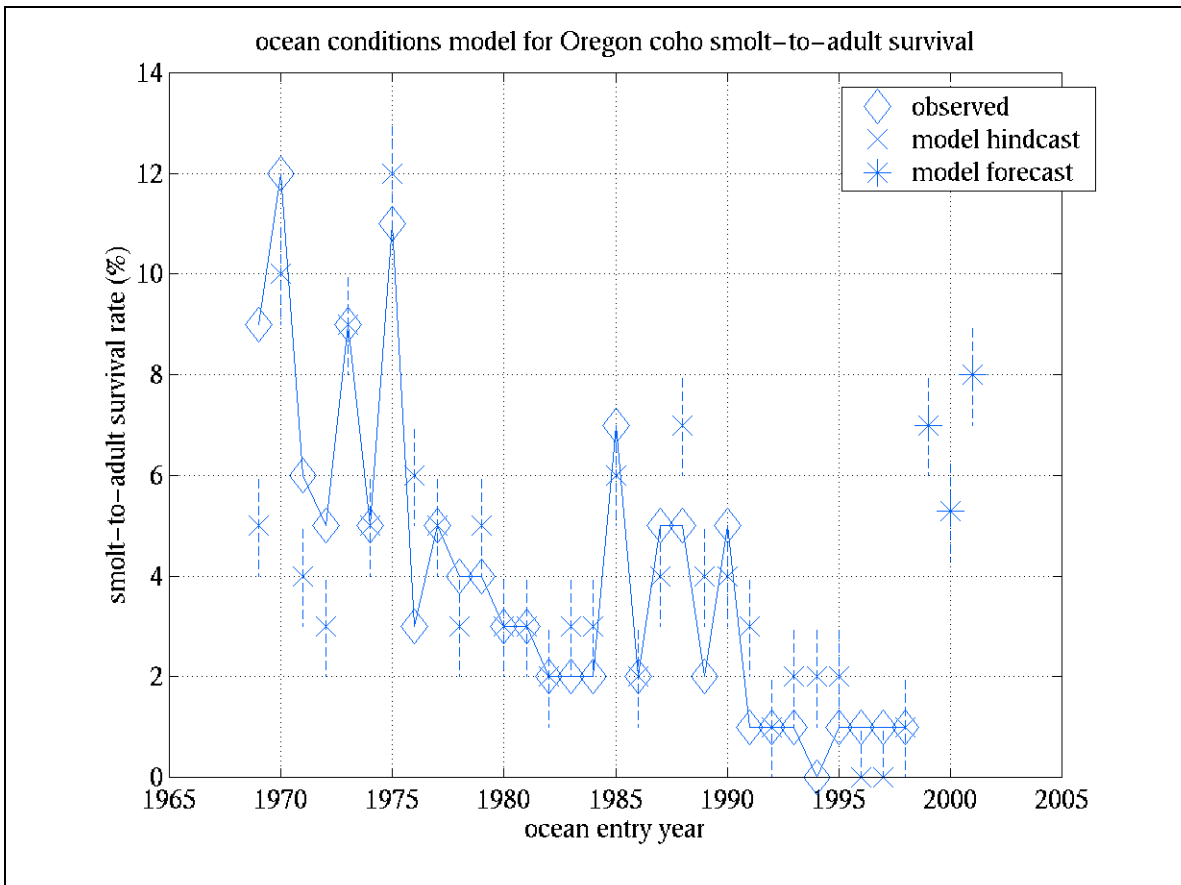


Figure 1: Comparison of modeled and observed Oregon Production Index coho smolt-to-adult survival. This simple environmental model uses observed relationships between smolt-to-adult survival and coastal ocean temperatures, coastal sea level, and winds from 1969-1998 to translate subsequent environmental conditions into smolt-to-adult survival rate estimates. Estimates for ocean entry years 1999, 2000, and 2001 indicate improved ocean conditions over those observed between 1989 and 1998. See Logerwell et al. for more details.

diversity of behaviors and environmental sensitivities serve as evolutionary responses to successful adaptation in uncertain environments (e.g., see ISG 2000). At the metapopulation level, each species of Pacific salmon exhibits many such risk-spreading behaviors via a broad diversity of time-space habitat use by different stocks and substocks of the same species. Lichatowich (1999) put it this way: “life history diversity is the salmon’s response to the old adage of not putting all one’s eggs in the same basket.”

Empirical evidence for diverse life history behaviors and habitat use by salmonids, and their close relationship to the physical environment, are found nearly everywhere researchers have looked. For instance, studies of natural coho smolt

production in western Washington yield evidence for a wide variety of flow sensitivities in nearby watersheds (Jeffrey Haymes, pers. comm., Washington Department of Fish and Wildlife, Olympia Washington). In some systems, coho smolt production is limited by high winter flows that scour nests and damage incubating eggs, in other streams the main limiting factor is low summer flows that reduce rearing habitat, while in still other streams it is high fall flows that allows spawners to access otherwise unreachable tributary spawning beds. The bottom line here is that the complex landscape and variety of watersheds in western Washington provides a diversity of habitats with different environmental sensitivities. Because coho salmon occupy each of the different habitats, the species as a whole carries a diverse portfolio of climate and environmental sensitivity, what we like to think of as an evolved expression of *natural climate insurance*.

**Considerations for fishery management**

How might an explicit consideration of climate and environmental uncertainty aid salmon and steelhead management efforts? Before offering specific remedies, we first review what we believe are key characteristics of approaches for saving threatened fish populations and saving fisheries.

It seems to us that people now know enough about fish ecology to provide a laundry list of needs for policy makers to develop effective action plans to save threatened fish populations (see Table 1). Step one is to recognize that saving fish is a matter of ecology. For saving sought-after species like salmon and steelhead, key pieces of a restoration plan include the following: restricting harvests so adequate numbers of adults can spawn; restoring diversity by reforming and/or closing hatcheries, and reconnecting fish production to habitat; restoring and protecting habitat, and where necessary removing barriers to fish passage; finally, accepting variability, environmental uncertainty, and acknowledging a lack of predictability.

**TABLE 1: Key characteristics of present day efforts to save fish and save fisheries.**

<p style="text-align: center;"><b><u>Saving fish:</u></b> <b>A matter of ecology</b></p>	<p style="text-align: center;"><b><u>Saving Fisheries:</u></b> <b>a matter of politics, economics, law, and ecology</b></p>
<ul style="list-style-type: none"> <li>• Restrict or eliminate harvests</li> <li>• Restore diversity               <ul style="list-style-type: none"> <li>– major hatchery reform, even closures if needed</li> <li>- reconnect production to habitat</li> </ul> </li> <li>• restore and protect habitat               <ul style="list-style-type: none"> <li>– remove barriers to fish passage</li> </ul> </li> <li>• accept variability               <ul style="list-style-type: none"> <li>– acknowledge a lack of predictability</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• shrink seasons and harvests</li> <li>• focus on biomass/numbers</li> <li>• tweak the status quo               <ul style="list-style-type: none"> <li>– fish passage, hatcheries</li> </ul> </li> <li>• eliminate variability               <ul style="list-style-type: none"> <li>– use hatcheries, divorce fish production from habitat</li> <li>– emphasize deterministic prediction</li> </ul> </li> </ul>

In contrast, present day efforts to sustain fisheries are clearly a matter of politics, economics, law, and ecology. As fish numbers have declined, a combination of scientific, political and socio-economic pressures have led to a slow withering of harvest opportunities and seasons that are ratcheted down to smaller and smaller windows of time; policies have generally focused on single-species biomass or numbers of fish, rather than considering the ecosystems that the target fish populations are part of; for salmon restoration, efforts have concentrated on tweaking the status quo, and this has been especially true with efforts to improve fish passage around dams and to reform hatcheries; management agencies have attempted to reduce and/or eliminate variability by using salmon hatcheries to divorce fish production from habitat; deterministic concepts like "maximum sustainable yield" have been used to set harvest goals, and there are few fishery managers that have not been pressured to develop better predictive models so harvests can be maximized while still offering protection for spawning stocks.

From this comparison, the main climate component of the conflict between saving fish and saving fisheries lies in the treatment of environmental variability, and it is in this realm where the potential for policy reform looks greatest. While socio-economic pressures produce political pressures to reduce variability and/or increase predictability so that resource use can be maximized, fish habitat and aquatic ecosystems contain fundamentally unpredictable dynamics. Climate enters this picture through its role in providing strong limitations on ecosystem predictability, a situation that is not likely to change in the future.

So, how might we better manage our fishery resources if changes in climate, ocean conditions, and salmon populations are so difficult to predict? It seems to us that a logical first step would be to deemphasize predictions. If predicting the future presents such a difficult challenge, it would be wise to distance management performance from predictions. Rather than focus on predictions, a more fail-safe approach would focus on monitoring. Simple environmental models like the one used to estimate coho smolt-to-adult survival provide a means for translating the products of environmental monitoring into an estimate for difficult to measure coho survival rates. An even better approach would rest on directly monitoring the target stocks, a daunting task yet one that has received considerable attention in recent research projects along the Pacific coast. If social and political pressures demand preseason predictions, such monitoring-based "forecasts" should explicitly acknowledge the large uncertainties that exist. Thus, when preseason run-size forecasts are made, stakeholders and managers should be presented with a range of possible populations to work with, along with some estimate for the odds of actually witnessing the high, low, and middle parts of the predicted range.

A second critical step is to do enough monitoring that changes in freshwater and marine productivity can be tracked and discriminated. Today, only a small number of streams are monitored for the full life-cycle of anadromous fish. Keeping track of adult spawners and estimating harvests allows for a gross estimate of productivity. A better understanding of changes in marine and freshwater productivity rests on the establishment of long-term, continuous records for the age-structure of spawners, parr and smolt production, in addition to the more commonly collected index counts used to estimate total spawners.

A final and critical step is to place a much higher priority on restoring the natural climate insurance that wild salmon and steelhead populations must have carried to survive and thrive in the face of past environmental changes. This insurance, we believe, is intimately associated with a diversity of life history behaviors, and that a diversity of behaviors is directly linked to the availability of healthy, complex freshwater habitat. A diversity of freshwater habitat leads to a wide range of seasonal runoff patterns, as well as a wide range of short-term runoff responses to short term weather and geologic events. Such environmental variability effectively forces sub-stocks of the same species into different niches and different behaviors via the never-ending process of natural selection. If we are interested in purchasing climate insurance for our salmon and steelhead stocks so they can better cope with changing ocean conditions, we will likely get the best return on investments aimed at restoring the health and integrity of our beleaguered watersheds.

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