Forecasting Coho Salmon Survival in the Oregon Production Index Region

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Inter-annual fluctuations in the overall productivity of hatchery-reared coho salmon (*Oncorhynchus kisutch*) in the Oregon Production Index (OPI) region are thought to be mainly determined by marine conditions, given that hatcheries are usually near the mouth of rivers and that smolts spend little time in estuaries before migrating to sea. Previous studies have found good relationships between smolt to adult survival and various ocean indices (Nickelson 1986, Pearcy 1992, Lawson 1997, Koslow et al. in press). Cole (2000) found that coastal sea surface temperature (SST) anomalies along the Oregon and southern Washington coasts could account for over 90% of the variation in OPI coho salmon survival for the 1985 to 1995 ocean entry (OE) year classes. The purposes of this study are to (1) update and modify as necessary the Cole (2000) model for the 1985–1998 OE year classes, (2) to make forecasts for the survival of the 1999 OE year class, and (3) to evaluate the model's robustness by using two different sources of SST data.

Mean weekly SST anomalies within 40 km of the coast were calculated from Pathfinder SST data (http://podaac.jpl.nasa.gov/sst) using a 14.5 year climatology (January 1985–June 1999). Mean weekly SST anomalies were similarly derived from the Reynolds SST data (http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/) also using a 1985–1999 climatology. Estimates of public hatchery coho salmon marine survival came from the Oregon Department of Fisheries and Wildlife (J. Fisher, College of Oceanic & Atmospheric Sciences, Oregon State University, Corvallis, OR 97331 USA, and P. Lawson, Hatfield Marine Science Center NOAA-NMFS/NWFSC, Newport OR 97365 USA, personal communications).

For each OE year class the sum of negative SST anomalies in the year of ocean entry was derived for an Early Marine Phase (EMP), and the sum of positive SST anomalies in the calendar year following the year of ocean entry was derived for a Late Marine Phase (LMP). The sum of positive anomalies for the LMP was linearly weighted by the sum of EMP negative anomalies. The lower the sum, i.e., the more negative the sum, the higher the weighting.

Survival models were constructed for both SST datasets from the output of non-linear multiple regressions (using the ACE algorithm, Breiman and Freidman 1985). Survival was the dependent variable, with the sum of EMP negative anomalies and the sum of LMP positive anomalies as the two independent variables (Cole 2000).

The 1999 OE year class survival was forecast from the 'Pathfinder' and 'Reynolds' models using the appropriate EMP and LMP anomaly sums. N.B., the 'Pathfinder' LMP values for the 1999 OE year class were estimated from the regressed relationship of existing Pathfinder versus Reynolds LMP values.

The two survival models account for over 90% of the variation in coho salmon survival from 1985 to 1998 (Figs. 1 and 2). Good survival is forecasted for the 1999 OE year class, 12.2% from the Pathfinder model and 7.5% from the Reynolds model. Cool conditions during EMP are associated with improved survival (Fig. 1). In contrast, if EMP conditions were cool, warm conditions during the LMP are associated with reduced survival. For example, conditions during the 1991 EMP were cool, and hence conducive to good juvenile survival. This good early survival, however, may have been over-ridden by the 1992 El Niño. Cole (2000) has a more detailed discussion of the relations between SST anomalies and ocean processes and factors affecting coho salmon survival.

Differences between the two models (e.g., shape of the contours and different 1999 forecasts) are due to some differences between SST values in the two datasets. For example, the Oregon SST upwelling signal, which is often found only close to the coast, may sometimes be lost or weakened in the Reynolds anomalies, given that they come from an area that extends further offshore than the Pathfinder anomalies.

In spite of high R^2 values for both models, caution is still needed. For example, a 1984 hindcast using the Reynolds model is very different than actual survival (Fig. 3). N.B., the Pathfinder data does not extend back beyond 1985. Reasons for the inaccurate hindcast are as follows: (1) SST may sometimes be an inadequate proxy of environmental conditions, e.g., 1984 had a very late transition from winter downwelling to summer upwelling conditions (Bilbao 1999; A. Hobday, CSIRO Marine Research, GPO Box 1538, Hobart Tasmania 7001 Australia, personal communication) that was not reflected by coastal SSTs; (2) sometimes the Reynolds anomalies may not adequately reflect conditions very close to the coast (i.e., within ~40 km); and (3) perhaps some unknown biological or ecological factor was acting.

Fig. 1. Survival models and 1999 forecasts from the (a) Pathfinder and (b) Reynolds datasets. The contours (z) represents levels of annual smolt-adult survival. The position of each year-class in the time series is represented by the symbols.

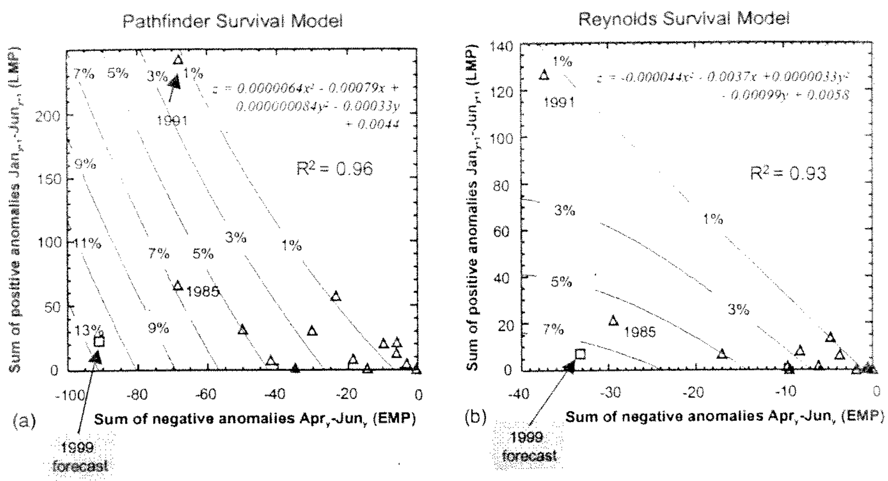


Fig. 2. Actual versus predicted survival from the (a) Pathfinder, and (b) Reynolds models, and 1999 Ocean entry year-class survival estimates.

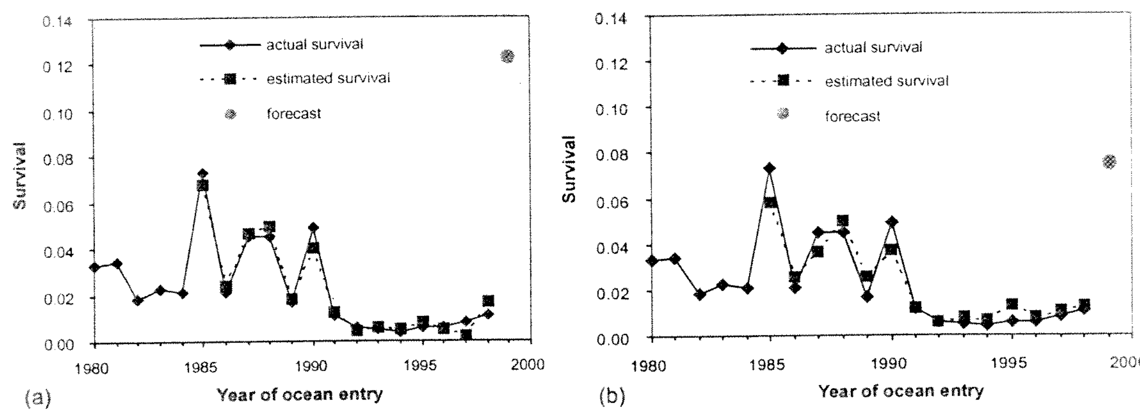
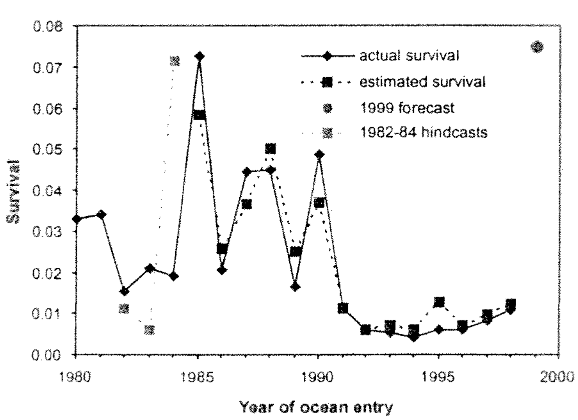


Fig. 3. Reynolds survival model with hindcasts for 1982–1984.



One final note of caution regarding the 1999 forecasts comes from the returns of precocious males ('jacks') (Fig. 4). From jack returns alone we would not expect overall survival to be anywhere near as high as predicted by the SST anomaly models (i.e., ~2.5% vs. 7.5% or 12.2%). Survival of the 1999 year class is likely to deviate strongly either from the jack-based forecast or from the anomaly-based forecasts.

Our conclusions are summarized as follows:

- Cool conditions when coho salmon enter the ocean are associated with good survival. Exceptions appear to be associated with very warm (i.e., El Niño) conditions later in ocean residency.
- Coastal SST anomalies can account for > 90% of variation in survival in 1985–1998.

- Reynolds and Pathfinder survival models are broadly similar.
- The forecasted survival of the 1999 OE year class is very good, 12.2% from the Pathfinder model and 7.5% from the Reynolds model.
- The models have clear management applications, but caution is still needed. Environment-fisheries models often periodically break down, as illustrated by the 1984 hindcast in Fig. 3, and the 1999 forecasts are very different from what would be expected based on the number of jacks that returned.

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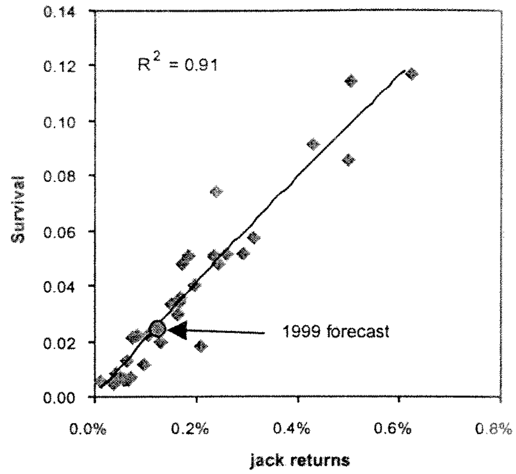
Fig. 4. Jack returns, as a percentage of smolts released, versus smolt: adult survival. A survival estimate for the 1999 ocean entry year class, based on jack returns during 1999, is as indicated.



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