NPAFC
Doc. 1427
Rev. _____

RELATING SPATIAL AND TEMPORAL SCALES OF CLIMATE AND OCEAN VARIABILITY TO SURVIVAL OF PACIFIC NORTHWEST CHINOOK: A SUMMARY

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Submitted to the
NORTH PACIFIC ANADROMOUS FISH COMMISSION

September 2012

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
Velez-Espino, L.A., Sharma, R., Wertheimer, A.C., Mantua, N., and Francis, R.C. 2012. Relating spatial and temporal scales of climate and ocean variability to survival of Pacific Northwest Chinook Salmon: a summary. NPAFC Doc. 1427. 7 pp. Fisheries and Oceans Canada. (Available at http://www.npafc.org).

Pacific Northwest Chinook, *Oncorhynchus tshawytscha*, have exhibited a high degree of variability in smolt-to-adult survival over the past three decades. This variability is summarized for twenty two Pacific Northwest stocks and analyzed using Generalized Linear Modeling techniques. Results indicate that survival can be grouped into eight distinct regional clusters: (1) Alaska, Northern BC and North Georgia Strait; (2) Georgia Strait; (3) Lower Fraser River and West Coast Vancouver Island; (4) Puget Sound and Hood Canal; (5) Lower Columbia Tules; (6) Columbia Upriver Brights, Willamette and Cowlitz; (7) Oregon and Washington Coastal; and (8) Klamath River and Columbia River Summers. Further analysis for stocks within each of the eight regions indicates that local ocean conditions (particularly sea surface temperature) following the outmigration of smolts from freshwater to marine areas had a significant effect on survival for the majority of the stock groups analyzed. Our analyses of the data indicate that Pacific Northwest Chinook survival covaries on a spatial scale of 350-450 km.

INTRODUCTION

This document summarizes the information in Sharma et al. (*in press*) regarding environmental covariates of Chinook salmon (*Oncorhynchus tshawytscha*) survival in the Pacific Northwest (PNW). Chinook salmon are a high valued species for recreational and commercial fisheries, and are of high cultural significance for Native American tribes in the north-west Pacific region of North America (Hunn, 1990). Large variability in adult returns has created substantial challenges for managing Chinook salmon fisheries. Because most Chinook salmon fisheries are now supported by large-scale hatcheries that release a known number of juveniles each year and monitoring programs provide estimates for natural smolt abundances in major production basins, a better understanding for how stock specific marine survival responds to ocean conditions could lead to better models of recruitment and therefore better informed management. This paper focuses on conditions occurring during this early marine life cycle phase, with the intent of assessing the degree to which marine environmental variables can explain observed variability in marine survival of PNW populations of Chinook salmon.

From southeast Alaska to northern California, Chinook salmon smolts typically leave the freshwater environment to enter an ocean that is either in or near a state of transition from winter to spring conditions (Quinn 2005). Depending on the timing of this spring transition, out-migrants could encounter spring-like conditions characterized by a coastal ocean that has experienced significant upwelling that supports nutrient enrichment and elevated primary productivity, or winter-like conditions characterized by downwelling that favours low nutrients and low primary productivity, or the transition between the two (Bakun, 1996). Immediately after ocean entry, juvenile Chinook salmon spend a large amount of time on the coastal shelf either migrating along the coast or staying close to their natal rivers (Trudel *et. al.*, 2009). This early marine life history phase has been shown to be extremely important with many studies linking inter-annual variations in different aspects of ocean conditions such as upwelling and water temperature with indicators of *Oncorhynchus spp*. marine survival (Logerwell *et. al.*, 2003; Peterson & Schwing, 2003; Lawson *et. al.*, 2004; Peterson *et. al.*, 2006). This paper focuses on conditions occurring during this early marine life cycle phase, with the intent of assessing the degree to which marine environmental variables can explain observed variability in marine survival of Pacific Northwest (PNW) populations of Chinook salmon from the Klamath River in the south to southeast Alaska in the north.

METHODS

We examined covariation of marine survival at different spatial scales to determine the relative effects of broad-scale, regional, and local conditions on the interannual variation in survival of selected PNW Chinook salmon stocks. This variability was summarized for twenty two Pacific Northwest stocks and analyzed using Generalized Linear Modeling techniques. We then evaluated the hypotheses that: (1) ocean productivity as expressed by sea surface temperature (SST) anomalies (positive or negative) are inversely related with marine survival of Chinook salmon across our study area; and, (2) that large scale ocean atmospheric processes like the El Niño Southern Oscillation (ENSO; Wolter & Timlin, 1998) and the Pacific Decadal Oscillation (PDO; Mantua *et. al.*, 1997) impact the local conditions in near-shore coastal waters and thus also affect the survival of Chinook salmon. These hypotheses were assessed by relating patterns in SST, ENSO, and PDO to survival anomalies for multiple Chinook salmon stocks coastwide. Our analyses focus on tagged stocks that were either natural populations or the best representation of natural populations (i.e., hatchery tagging programs that are managed to mimic wild fish behaviour).

RESULTS

Eight groupings of stocks were identified by a cluster analysis of survival to age-2 ocean recruits: (1) Alaska, Northern BC, and North Georgia Strait; (2) Georgia Strait; (3) Lower Fraser River and West Coast of Vancouver Island (WCVI); (4) Puget Sound and Hood Canal; (5) Lower Columbia Tules (Spring Creek and Columbia Lower River Hatchery [LRH]); (6) Columbia Upriver Brights, Willamette, and Cowlitz; (7) Oregon Coastal (Salmon River) and Washington Coastal (Queets); and, (8) Klamath River and Columbia River Summers (these two populations are currently depressed). ANOVA tests indicated that year effects drive most of the variation in stocks over time, and that year effects were common across all groups. We tested the full model including the year x region and the year x stock interactions to evaluate the effects of region and stock, with the year effect. The year x stock interaction was not significant, but the year x region interaction was significant. This test also indicated significant differences in survival between regions.

Correlations of survival between individual stocks also indicated regional synchrony. Figure 1 displays a summary of pair-wise correlations of survival in relation to distance between stocks. The number positive correlations greater than 0.4 occurred at higher frequencies for stocks with streams of origin entering the ocean at distances less than 450 km apart.

We analyzed the upwelling data and SST data with respect to survival for Chinook salmon stocks across multiple locations. This broad scale spatial analysis showed no consistent relationship between upwelling and survival of stocks across different regions: approximately equal numbers of negative and positive correlations >0.4

were observed. In contrast, SST tended to be negatively correlated with survival; all correlations >|0.4| were negative, indicating that colder water tended to have a positive effect on survival (Sharma et al. *in press*) We tested for localized SST effects on survival by using data for one stock from each group. The stocks examined were Alaska Spring, Big Qualicum River, Columbia Upriver Brights, Salmon River (Oregon Coastal), WCVI, Spring Creek, South Puget Sound and Klamath (Figures 2 and 3). This analysis was carried out for the months of April through September, which correspond to the period of initial marine residency after smolts move from freshwater into the ocean environment.

In addition, we analyzed environmental conditions that occur across different temporal and spatial scales, and presented lagged time-series models to link them to survival of specific Chinook salmon stocks. Assuming that the SST-survival relationships identified here are indicative of a robust mechanism that will persist in a changing climate, the effect of climate change can be inferred for Chinook based on the relationship with SST. A one-degree increase in SST's during the key-transition period (April through July) from freshwater to ocean environments could result in a reduction in survival between 1% and 4% across the species range.

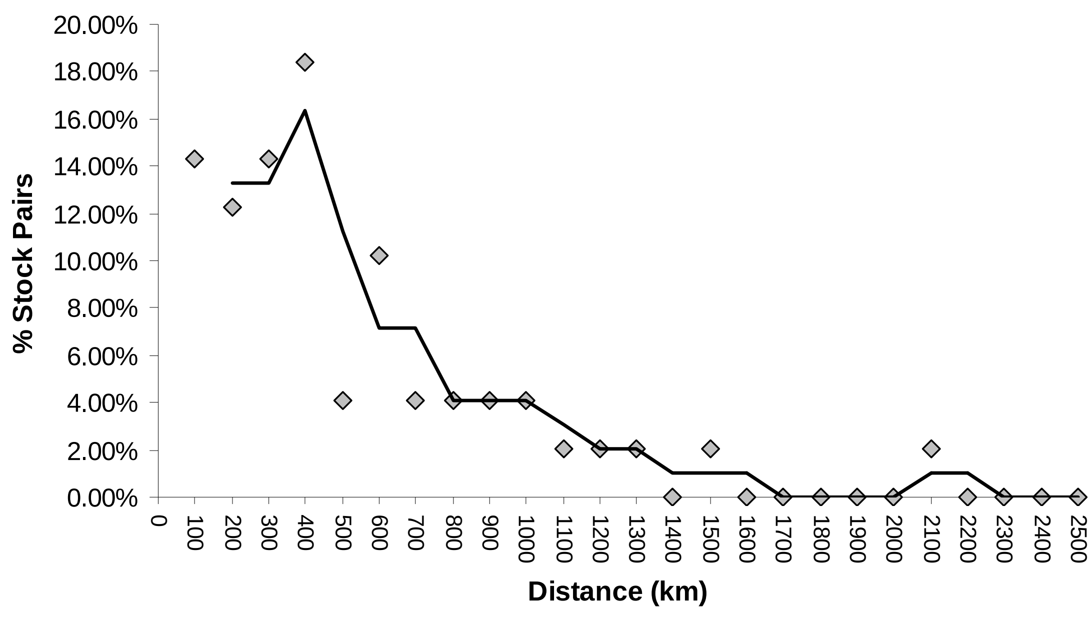

Figure 1. Proportion of stock pairs with survival $r > 0.4$ as a function of distance (km) between river mouths. The solid line represents the second-order moving average.

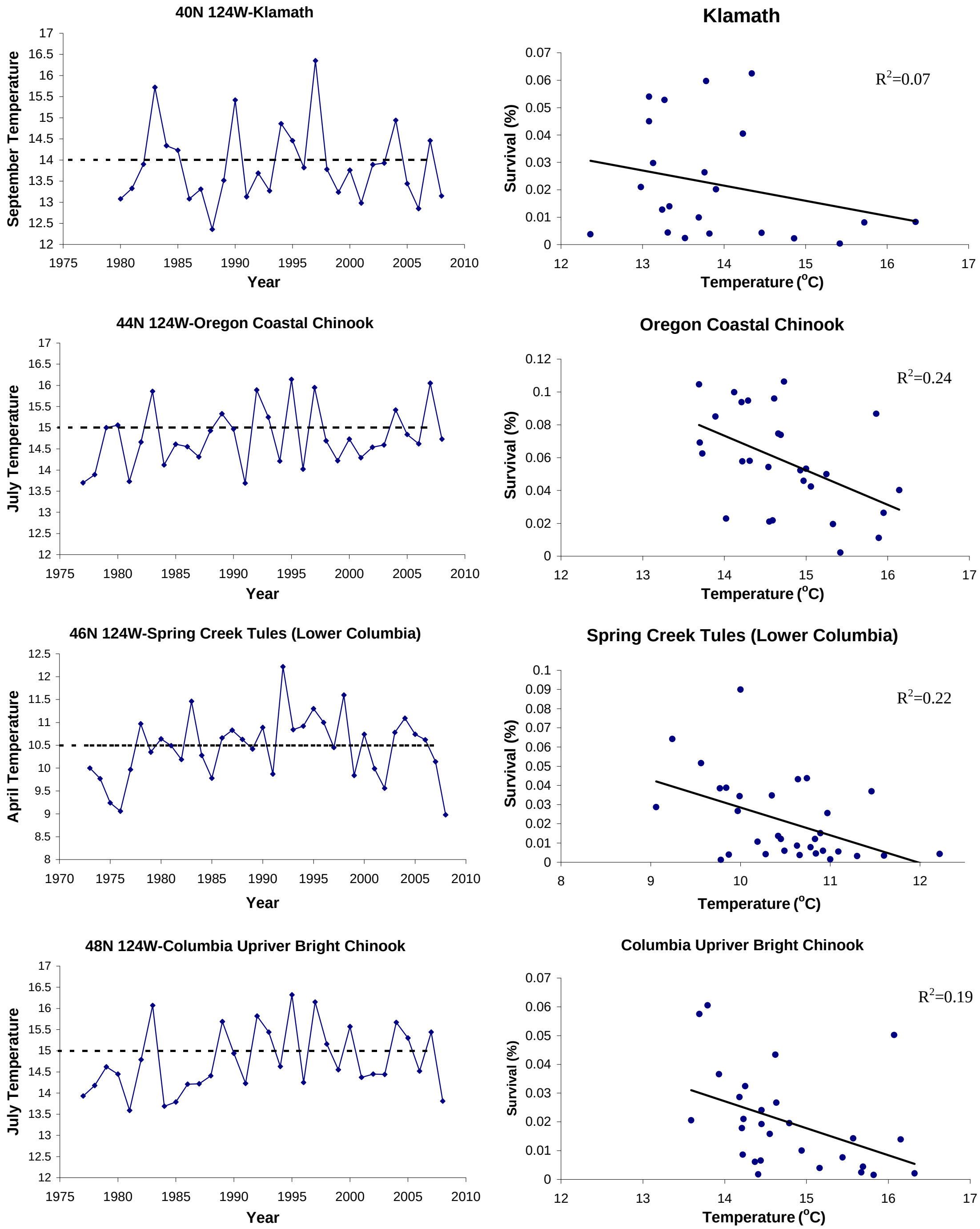

Figure 2. Relationship between survival of Chinook salmon stocks and SST (right) for Klamath, Salmon River (Oregon Coastal Chinook), Spring Creek Tules (Columbia) and the Columbia Upriver Brights stocks. The SST was obtained from COADS database for locations near the coastal shelf (left) and were the most highly correlated with survival during the first few months after smolts emigrate into the ocean. Stations reported are 40oN 124oW, 44oN 124oW, 46oN 124oW and 48oN 124oW.

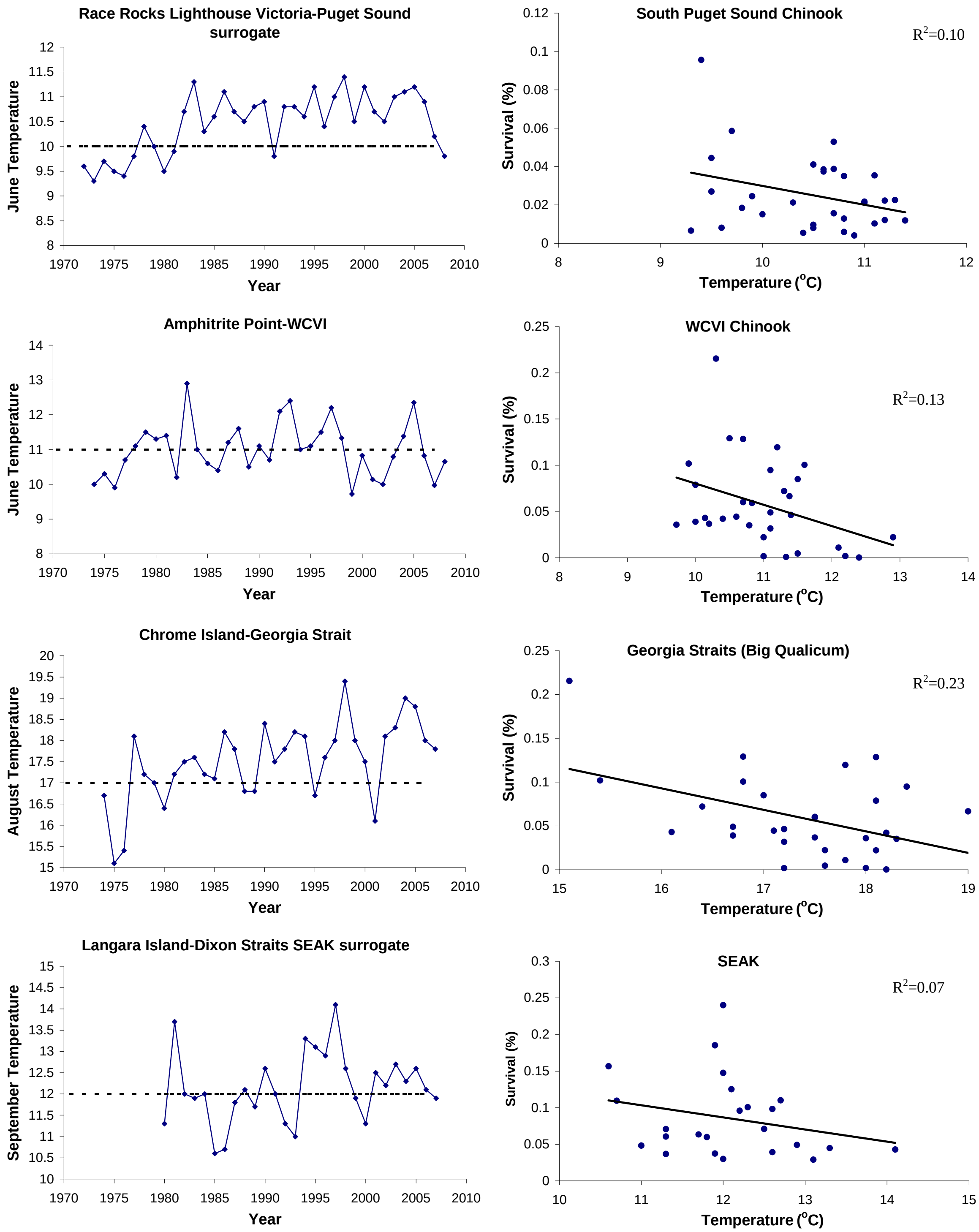

Figure 3. Relationship between survival of Chinook salmon stocks and SST (right) for Puget Sound, West Coast of Vancouver Island (WCVI), Georgia Strait and South East Alaska (SEAK) stocks. The SST was obtained from BC lighthouse database for nearest locations (left) that could be used as surrogates for these systems.

DISCUSSION

While there is significant synchrony in the marine survival of the Chinook salmon stocks evaluated across a broad geographic scale, survival rates covary more closely at a regional level. Our results indicate that there is a positive correlation in survival rates among Chinook salmon stocks that occur at a geographic scale of 350- 450 km, the strength of which decreases as distance between stocks increases. This is consistent with other studies showing regional covariation in survival for pink salmon, chum salmon, and sockeye salmon, with correlations between survival rates being greater at distances less than 500 km (Mueter et al. 2002, Pyper et al. 2005).

Broad-scale and regional concordance in survival rates demonstrate that shared environmental conditions impact Chinook salmon stocks at these scales. However, most of the variation in survival between stocks is not explained at these scales, indicative of a large influence of some combination of local ocean conditions or stock specific responses to similar environmental conditions impacting survival (e.g. Hilborn et al. 2003). This observation is consistent with the paradigm of Pacific salmon biology that conditions during early marine residency are important determinants of marine survival and year-class strength (Groot and Margolis 1991; Quinn 2005). Factors influencing survival during the early marine phase are a complex interaction of physical and biological processes, including temperature, upwelling, lower-trophic level production, competition, and predation (Holtby et al. 1990; Koslow et al. 2002; Briscoe et al. 2005; Malick et al. 2009). We found that marine survival generally decreased with increases in SST across stocks, although the relationship was not statistically significant for all stocks evaluated. Survival of PNW Chinook is strongly linked to global climate patterns, and this study demonstrated these connections empirically by relating a derived species-scale parameter (survival) to processes that occur on a variety of scales.

The SST in the North Pacific Ocean has varied greatly from 2005 to 2008. Poor ocean conditions in 2005 had an adverse effect coastwide on Chinook survival (PSC, 2008). Based on our models, we predicted higher than average survival for 2008 out-migrants with larger than average runs in 2010, 2011 and 2012 (for the 3, 4, and 5 year olds for ocean-type Chinook, and 4, 5, and 6 year olds for stream-type Chinook). These are the types of spatial and temporal patterns that can be used to infer trends in survival over the near-term. These predictions could be taken a step further by using lag-linked models relating ENSO to the PDO (Sharma et al. *in press*), which in turn affects regional conditions on the continental shelf and thus survival of Chinook coastwide.

REFERENCES

Bakun, A. 1996. Patterns in the Ocean. California Sea Grant. 323 pp.

Briscoe, R. J., M. D. Adkison, A. Wertheimer, and S. G. Taylor. 2005. Biophysical factors associated with the marine survival of Auke Creek, Alaska, coho salmon. Trans. Am. Fish. Soc. 134: 814-828.

Groot, C. and Margolis, L. 1991. Pacific salmon life histories. UBC Press, Vancouver BC. 564 p.

Hilborn, R., T.P. Quinn, D.E. Schinder, and D.E. Rogers. 2003. Biocomplexity and fisheries sustainability. Proc. Nat. Acad. Sci., 100:6564-6568.

Holtby, L. B., B. C. Andersen, and R. K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus*

kisutch). Can. J. Fish. Aquat. Sci. 47:2181–2194.
Hunn, E.S. 1990. Nch'i-Wana, "the big river": Mid-Columbia Indians and their land. University of Washington, Seattle, Washington, U.S.A, 378 pp.
Koslow, J. A., A. J. Hobday, and G. W. Boehlert. 2002. Climate variability and marine survival of coho salmon (*Oncorhynchus kisutch*) in the Oregon production area. Fisheries Oceanography 11:65–77.
Lawson, P., Logerwell, L., Mantua, N. Francis, R. and Agostini, V. 2004. Environmental factors influencing freshwater survival and smolt production in Pacific Northwest coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 61:360-373.
Logerwell, L., Mantua, N., Lawson, P., Francis, R. & Agostini, V. 2003. Tracking environmental process in the coastal zone for understanding and predicting Oregon coho (*Oncorhynchus kisutch*) marine survival. Fisheries Oceanography 12:554-568.
Malick, M. J., M. D. Adkison, and A. C. Wertheimer. 2009. Variable effects of biological and environmental processes on coho salmon marine survival in southeast Alaska. Trans. Am. Fish. Soc. 138:846-860.
Mantua, N., S. Hare, Y. Zhang, J. Wallace, and R. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production, Bull. Am. Meteorol. Soc. 78:1069–1079.
Mueter, F., Ware, D., and Peterman, R. 2002. Spatial correlation patterns in coastal environmental variables and survival rates of salmon in the north-east Pacific Ocean. Fisheries Oceanography 11:205–218.
PSC. 2008. 2007 Annual report of catches and escapements, exploitation rate analysis and model calibration. Report TCCHIHOOK (08)-1, Pacific Salmon Commission, Vancouver BC.
Peterson, W, T. and Schwing, F.B. 2003. A New Climate Regime in Northeast Pacific Ecosystems. Geophy. Res. Letters 30:6-1:6-4.
Peterson, W.T., Hooff, R.C., Morgan, C.A., Hunter, K.L., Casillas, E., & Ferguson, J.W. 2006. Ocean conditions and salmon survival in the northern California current. Web document, http://www.nwfsc.noaa.gov/research/divisions/fed/ecosysrep.pdf
Pyper, B. J., F. J. Mueter, and R. M. Peterman. 2005. Across-species comparisons of spatial scales of environmental effects on survival rates of Northeast Pacific salmon. Trans. Am. Fish. Soc. 134:86–104.
Quinn, T. P. 2005. The Behavior and Ecology of Pacific Salmon and Trout. University of Washington Press, Seattle.
Sharma, R., Vélez-Espino, L.A, Wertheimer, A.C., Mantua, N., and Francis, R.C. *In press.* Relating spatial and temporal scales of climate and ocean variability to survival of Pacific northwest Chinook. Fisheries Oceanography.
Trudel, M., Fisher, J., Orsi, J.A., Morris, J.F.T., Thiess, M.E., Sweeting, R.M., Hinton, S. Fergusson, E.A., and Welch, D.E. 2009. Distribution and migration of juvenile Chinook salmon derived from coded wire tag recoveries along the continental shelf of western North America. Trans. Am. Fish. Soc. 138:1369-1391.
Wolter, K., and M. S. Timlin, 1998. Measuring the strength of ENSO events - how does 1997/98 rank? Weather 53:315-324.