(1) Title of project: Utilizing Ecosystem Information to Improve the Decision Support System for Central California Salmon

(2) Type of Report: Final Report

(3) Francisco Chavez, Principal Investigator.

Biology Team: Brian Wells, Steve Lindley, Eric Danner, John Field (NOAA), William Sydeman, Jarrod Santora (Farallon)

Modeling Team: Fei Chai (UMaine), Yi Chao (UCLA), Monique Messié (MBARI)

(4) Period covered by the report: 9/1/2009-8/31/2013

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(6) Grant number: NNX09AU39G

The final report covers a three-year award with a one-year no cost extension. The project acronym is SAFARI – Salmon Applied Forecasting Assessment and Research Initiative (http://www.mbari.org/bog/safari). The team included a Biology component: Brian Wells, Steve Lindley, Eric Danner, John Field (NOAA), William Sydeman, and Jarrod Santora (Farallon); a Modeling component: Fei Chai (UMaine) and Yi Chao (UCLA); and an Oceanography component: Francisco Chavez and Monique Messié (MBARI).

The stock of Chinook salmon from central California has been increasingly variable over the past decade. For example, in 2007 the number of fish that could be removed by fishing was overestimated and, therefore, the number of spawners remaining was below the prescribed minimum number. As a result, the fishery was closed during 2008 and 2009 and only modestly operated in 2010. The sport and commercial fishing seasons opened in 2011 with mixed success and 2012 and 2013 have been near normal years. Because of its life cycle the Chinook salmon is a good target species for ecological forecasting. Fish spawn in the Sacramento River system and make their way to the open ocean through San Francisco Bay. Work by the SAFARI team suggests that the first few days in the ocean are critical; if the fish are not able to find suitable forage in the form of krill they will not survive to return to the river in the following years. Harvestable and reproductive fish return to the river after three years. Some fraction of two-year-old fish (jacks) return with the three-year-olds and the number of jacks is statistically related to the number of three-year-olds returning the following year. These statistics are variable from year-to-year. The premise of the SAFARI team has been that a more robust and mechanistic approach to forecasting involves a prediction system that determines the magnitude and location of the forage species (krill), a function of environmental forcing. Since krill also have two cohorts, their abundance may be predicted from environmental conditions the previous year leading to a potential forecast of salmon abundance (bad/good) up to 4 years in advance. Estimates of salmon abundance have been carried out from observations of krill and sea level (an index of environmental conditions). The group has also demonstrated that these properties can be estimated from state-of-the-art coupled physical-ecosystem models for the Pacific basin. These concepts have been developed and improved as part of this project and the results are regularly presented to the salmon subcommittee of the Pacific Fishery Management Council (PFMC) and directly to the PFMC via the Director of the NOAA Southwest Fisheries Center. These approaches have been adopted by the NOAA Integrated Ecosystem Assessment (IEA) program, ensuring continued use into the future. The success of this program can be attributed to the strategic mix of the participants (oceanographers, biologists, modelers, end users) and the well-defined problem. The publications resulting from this program are given below.

Santora, J.A, W.J. Sydeman, M. Messie, F. Chai, Y. Chao, S.A. Thompson, B.K. Wells, and F. P. Chavez (2013). Triple check: Observations verify structural realism of an ocean ecosystem model. *Geophysical Research Letters*, 40:1-6

Messié, M. and F. P. Chavez (2013) Physical-biological synchrony in the global ocean associated with recent variability in the central and western equatorial Pacific. Journal of Geophysical Research. http://dx.doi.org/10.1002/jgrc.20278.

Woodson, L., B.K. Wells, P. Weber, R.B. MacFarlane, G Whitman, and R. C. Johnson. 2013. Growth, size, and origin-dependent mortality of juvenile Chinook salmon *Oncorhynchus tshawytscha* during early ocean residence. *Marine Ecology Progress Series*. 487:163-175.

Xu Y., F. Chai, K. A. Rose, M. Ñiquen C. and F. P. Chavez (2013) Environmental influences on the interannual variation and spatial distribution of Peruvian anchovy (*Engraulis ringens*) population dynamics from 1991 to 2007: a three-dimensional modeling study. *Ecological Modelling*, http://dx.doi.org/10.1016/j.ecolmodel.2013.01.009.

Sydeman, W.J., Santora, J.A., Thompson, S. A., Marinovic, B. and Di Lorenzo, E. (2013) Increasing variance in North Pacific climate relates to unprecedented ecosystem variability off California. *Global Change Biology*, doi: 10.1111/gcb.12165

Chavez, F. P. (2012) Climate Change and Marine Ecosystems. *Proceedings of the National Academy of Sciences*, 47, 19045-19046, doi: 10.1073/pnas.1217112109.

Thompson, S. A., W. J. Sydeman, J. A. Santora, B. A. Black, R. M. Suryan, J. Calmabodkidis, W. T. Peterson and S. J. Bograd (2012), Linking predators to seasonality of upwelling: using food web indicators and path analysis to infer trophic connections, *Progress in Oceanography*, 101, 106-120.

Santora J., J.C. Field, I. D. Schroeder, K.M. Sakuma., B.K. Wells, and W.J. Sydeman. (2012) Spatial ecology of krill, micronekton and top predators in the central California Current: Implications for defining ecologically important areas. *Progress in Oceanography*. 106:154-174

Messié, M. and F.P. Chavez (2012) A global analysis of ENSO synchrony: the oceans biological response to physical forcing. *Journal of Geophysical Research*, 117, DOI: 10.1029/2012JC007938.

Wells, B.K., J.A. Santora, J.C. Field, R.B. MacFarlane, B.B. Marinovic, and W.J. Sydeman. (2012) Population dynamics of Chinook salmon (Oncorhynchus tshawytscha) relative to prey availability in the central California coastal region. *Marine Ecology Progress Series*. 457:125-137.

Santora, J.A., W.J. Sydeman, I.D. Schroeder, C.S. Reiss, B.K. Wells, J.C. Field, A.M. Cossio, and V.J. Loeb (2012) Krill Space: A comparative assessment of mesoscale structuring in polar and temperate marine ecosystems. *ICES Journal of Marine Science*, 69:1317-1327.

Suryan R., J.A. Santora, and W.J. Sydeman (2012) New approach for using remotely-sensed Chlorophyll a to identify seabird hotspots. *Marine Ecology Progress Series*, 451: 213-225

Santora, J.A., W.J. Sydeman, I.D. Schroeder, B.K. Wells, J.C. Field. 2011. Mesoscale structure and oceanographic determinants of krill hotspots in the California Current: Implications for trophic transfer and conservation. *Progress in Oceanography*, 91:397-409.

Chavez, F. P. M. Messié, and J.T. Pennington (2011) Marine primary production in relation to climate variability and change. *Annual Review of Marine Science*, 3:227–60, doi:10.1146/annurev.marine.010908.163917.

Messié, M. and F.P. Chavez (2011) Global modes of sea surface temperature variability in relation to regional climate indices. *Journal of Climate*, 24: 4314-4331. doi: 10.1175/2011JCLI3941.1.