FATE FY2007 Pre-Proposal

Title: Incorporating environmental forecasts into stock assessments and stock assessment decision tables

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Background:

In the initial phase of this work we demonstrated that there are physical oceanographic variables that significantly interact with sablefish recruitment. Significant relations were found juvenile recruitment and northward Ekman transport, eastward Ekman transport, and sea level during key times and at key locations within the habitat of this species. The overall model explained nearly 70 percent of the variability in sablefish recruitment between the years 1974 and 2000 (Schirripa and Colbert 2006). The relationship to northward Ekman transport (NET) is strongest in February at 48° N. This location is the area where the North Pacific Current diverges to from the Alaskan and California Current Systems and during the early egg/larval period. Here, this is the time when NET is shifting from northerly to southerly transport. Eastward Ekman transport is most strongly associated with recruitment in June at 45° N. This is the central-northern Oregon coast region just south of the Columbia River plume when the larvae and small fish may be very susceptible to predation. Transport is off-shore but varies from strong (-800) to near zero. Stronger upwelling generally provides better conditions (more nutrients and a shift from southern to northern copepods) for juvenile sablefish. Sea surface height (SSH) further south (42 N°) in July explains nearly 35 percent of the total variation. These three variables are also nearly orthogonal, suggesting that there is little interdependence among them. Stability was tested by successively deleting one year of data for the last five years (1996-2000), refitting the model, and predicting deleted years as well as 2001 and 2002. There was little change in the dynamic or predictability of the model when using less and predicting more recruitment years. Bootstrapping techniques were applied to the parameter estimates and the resulting distributions were found to support the modeling assumptions. A variation of the above model was used in the 2005 sablefish assessment to draw preliminary conclusions concerning the 2005 year-class strength as well as historic (1925 and beyond) year-class strengths. This historical analysis (hind casting) provided additional information for assessment of virgin stock levels. Fitting the recruitment relationship internal to the stock assessment model allowed for fitting, hind casting, and forecasting to be done simultaneously.

In the second phase of this work we are more directly addressing the mission statement of FATE, which states that the program is to produce ecological and oceanographic products for the purpose of improving fishery stock assessments (FATE Science Plan 2005). While significant progress within FATE has been made towards developing biological and leading indicators, very little work has been directed at determining exactly how best to use the FATE products in the current stock assessment framework. We are currently working to directly address this question by using selected FATE products and coupling them with a fisheries data simulator to produce data sets of populations with known properties and that are explicitly driven by environmental forcing, then evaluating these data sets with the currently used stock assessment modeling framework in an effort to reconstruct the true underlying properties of the biological/environmental relationships. More specifically, we are working to examine the ability of the Stock Synthesis II Assessment Program (SS2; Methot 2005a and 2005b) to ascertain the effect of environmental leading indicators on fish population recruitment and the interactions with the population spawning stock. By producing data sets with known parameter values that originate from designed simulations using the fishery simulation model (FSIM Goodyear 2004, 2005), we are testing the ability of SS2 to ascertain the effects of the leading indicators on the underlying population model as well as the ability to differentiate between effects of such factors as environmental drivers and random variations about that underlying model. By simulating population and fisheries dynamics from predetermined parameters, we are able to examine the ability of SS2 to accurately estimate these parameter values in a typical assessment process. Results from this work have been useful to the stock assessment community by making improvements to the SS2 model and the manner in which it models environmental relationships within fish populations. This work is progressing on schedule as is already being used in a workshop setting to address questions with regard to virgin population size, a critical parameter in determining the current status of the stock with regard to overfishing.

This proposal addresses the next phase of this work, namely, using forecasts of the state of the ocean environment and productivity to determine the possible future condition of fish populations. Forecasting the future productivity regimes of the ocean environment is becoming increasingly important to managers and industry. NOAA Fisheries has taken a greater interest in such forecasts of ocean productivity. The first objective of the NOAA Fisheries Strategic Plan (http://www.nmfs.noaa.gov/om2/obj-1.html) is to "maintain healthy stocks important to commercial, recreational, and subsistence fisheries". Two of the strategies that are to be used to achieve this objective are

- *We will periodically assess stocks to ascertain whether changes in their status due to natural or human-related causes have occurred. These stock assessments require adequate fishery monitoring and resource surveys.*

- *Using these assessments, we will predict future trends in stock status. Our forecasts will take into account projected biological productivity, as well as economic, market, and social forces that will affect levels of fishing effort.*

The North Pacific Marine Science Organization (PICES; http://www.pices.int/) is also moving in the direction of forecasting, as demonstrated by the mission statement of the new PICES Science Program, "Forecasting and Understanding Trends, Uncertainty and Responses of the North Pacific Ecosystem" (FUTURE). The theme of this program reads as follows:

- *To understand and forecast responses of North Pacific marine ecosystems to climate change and human activities at basin-wide and regional scales, and to broadly communicate this scientific information to governments, resource managers and the general public.*

Along these lines, the PICES Fifteenth Annual Meeting held in 2006 conducted a workshop entitled "Linking climate to trends in productivity of key commercial species in the subarctic Pacific". The objective of workshop was to review the evidence for climate impacts on production of commercial fish species and to discuss the feasibility of developing medium-term to long-term forecasts of climate impacts on fish production and the responses of fisheries to these changes in production. Participants in this workshop addressed three themes: Theme 1 – Evidence of Climate Change Impacts; Theme 2 – Management implications; and Theme 3 –Techniques for comparing production trends of selected species across regions. Workshop participants discussed the implications of research findings on recommendations for PICES forecasts of climate impacts on marine resources. Participants from 5 of the 6 member-nations of PICES participated in the Fishery Science Committee (FIS) sponsored workshop. Participants identified 30 important commercial species or species groups that could be included in a forecast of climate change impacts on fish production. One modeling construct that was suggested during the workshop would involve forecasts of future fish production using stock assessment projection models modified to incorporate climate forcing on core processes such as growth, maturation, production, predation mortality, catchability, availability, and fishing mortality. Functional responses of fish to climate would be developed to forecast changes in maturity schedule, growth, reproductive success, mortality, and selectivity of surveys or fisheries. The participants envisioned that over time, these forecasting tools would be used to develop a decision tables for managers. Managers would use the decision tables to evaluate management strategies given probabilistic statements regarding expected ocean conditions over medium-term time periods. There are several advantages to this construct for forecasting. First, the framework would ensure continuity between changes in stock assessments and the forecasting tool. Second, this type of modeling construct would facilitate rapid incorporation of new information for several managed species into ecosystem models providing improved whole ecosystem projections. Third, stock assessment authors throughout the PICES region are attempting to develop spatially explicit models. Utilizing a modeling construct that is consistent with stock assessment models would ensure rapid incorporation of spatial considerations into the forecast. We feel that the work we are prosing not only addresses these sorts of forecasting activities, but also are a natural succession the previously funded FATE proposals.

Approach:

Our current work has produced a translation program that reads the outputs data from the FSIM simulator and creates the observation data file as input to the SS2 assessment software and is ready to address the issues outlined above. Our evaluations have demonstrated that we are capable of achieving full agreement between the FSIM simulated and the SS2 estimated parameter values and population trajectories. This is a significant achievement, especially given the fact that the two models are running on completely independent platforms. This independence adds to the credibility of and robustness of the modeling experiments we a proposing.

Key to the FSIM simulator is its ability to produce simulated data about a population that is driven from a stock-recruitment function that is modulated by environmental forcing. We used the Beverton-Holt stock recruitment function as the basis of the simulations:

$$R = 1/(\alpha + \beta / P) \tag{1.1}$$

Long-term temporal trends intended to simulate climatic effects are incorporated into the simulations by reading a time series of deviations from mean recruit survival. These are incorporated in the simulation by multiplying the predicted (mean) recruitment from the stock-recruitment relationship by *exp(D)*, where *D* is an empirically derived, or assumed deviation from the expected recruitment in log units (i.e. *D* = log(*O/E*). where *O* ="observed" recruitment, and *E* = expected recruitment). Parallel to this, the SS2 model has the ability to use an annual environmental covariate in the fitting of the stock-recruitment function. In SS2 the expected level of recruitment is given by:

$$\hat{R}_y = \frac{4hR_0S_y}{S_0(1-h)+S_y(5h-1)}e^{\beta E y} \tag{1.2}$$

Where the estimated parameters are:

- *h* is the parameter for steepness of the function
- *R0* is the virgin or, initial recruitment
- *S0* is the virgin or, initial spawning biomass
- *Sy* is the Spawning stock biomass in year t
- β is the additional parameter that relates the environmental series to the recruitment residuals
- *Ey* is the standardized environmental anomaly centered on zero

For year in which recruitment residuals are not estimated, the level of total recruitment R_y is set equal to $\hat{R}_y$.
For years in which recruitment residuals are estimated, the level of total recruitment is given by:

$$R_y = \hat{R}_y e^{-0.5\sigma_R^2} e^{\tilde{R}y} \tag{1.3}$$

Where:

- σ_R is the standard deviation for recruitment in log space
- $\tilde{Ry}$ is the lognormal recruit deviation in year *y*

Te level of σ_R scales the log-bias adjustment so that the expected arithmetic mean of the set $\{R_y\}$ is equal to the mean of the $\hat{R}_y$ for the same years. In this way, both models modulates recruitment due to environment in the same manner.

The FSIM simulator can be run for any number of years, however, the translation program (which makes the SS2 input files) can be set to output all or only part of this simulated data. By setting the translation program to output only the environmental data for an additional, for example, ten years we in effect produce data sets that duplicate a typical assessment data set with regard to observational data but with an additional ten years of only environmental data that we can use to simulate a 10-year forecast of ocean productivity. We are proposing a modification of the SS2 assessment model that will take advantage of this ability of the simulator by extending the use of the environmental time series into the model projections of the future state of the population via the stock-recruitment function. We retain the true underlying population trajectory for these ten forecast years (within the FSIM environment) while attempting to reproduce these same trends with an SS2 projection.

Past work on this project has utilized SSH stage data collected from four different sites off of Oregon and Washington. We propose for this work to begin to utilize newly available satellite data for measurements of SSH. Preliminary analysis has shown a significant correlation between the stage data and the satellite altimeter data gathered from the TOPEX/Poseidon and Jason-1 satellites for year in which they overlap. However, the satellite data has the distinct advantage of calculating and integrated SSH from a user-defined polygon as opposed to merely taking the mean of point estimates from existing stations scattered along the coast. Furthermore, we will the long-term (1925-present) SSH data along with time series analysis to forecast possible values for sea surface height for the ten year projections. Time series analysis accounts for the fact that data points taken over time may have an internal structure (such as autocorrelation, trend or seasonal variation) that should be accounted for. We will use time series analysis to obtain an understanding of the underlying forces and structure that produced the observed data as well as to fit a model and proceed to forecasting, monitoring or even feedback and feedforward control. Autocorrelation and Autoregressive integrated moving-average (ARIMA) models are useful for a wide variety of time series analysis, including forecasting, quality control, seasonal adjustment, and spectral estimation as well as providing summaries of the data.

In order to estimate the future characteristics of the stock under the various productivity assumptions we will use the SS2 model in its Markov-Chain-Monte-Carlo (MCMC) mode. Usually the MCMC mode is used to produce model outcomes that integrate all parameter estimate uncertainties into on probability distribution. However, by fixing the statistical model parameter estimates during the MCMC procedure we will create a set of stochastic runs where the 10-year forecasts that are produced are based only on the variation in future recruitment and not the model parameter value uncertainties. Future recruitments will have a starting value equal to the deterministic value determined from the stock-recruitment function as modified by the environmental anomaly, but will stochastically vary from this mean value according to the standard deviation of the stock-recruitment function (i.e. sigma-r). The error around the mean value can be chosen to be either normal or log-normally distributed.

One of the requirements of the stock assessment documents is to provide managers with a type of decision table. Generally, a decision table is 3 x 3 matrix that considers three states of nature (some representation of less than average, average, and greater than average stock productivity) and the three levels of catch associated with each state of nature (Table 1). The columns of the table represent the three possible states of nature while the rows represent the three levels of catch associated with the various states of nature. The center block of the decision table depicts the projected state of the population assuming the “base case” model and the associated base case catch. The other blocks depict the projected state of the stock (in terms of SSB and depletion) assuming all possible combinations of states of nature and catch levels. Each state of nature is generally assigned a probability to help direct managers as to which state of nature may be more or less likely. Currently, the variation in the various states of nature is being depicted by assuming various values for critical model parameters, such as stock-recruitment steepness (*h* the in Table 1) and survey catchability (*Q* in Table 1).

We are proposing to develop decision tables in which the various states of nature are represented not by various parameter values, but by various assumptions with regard to the future productivity of the ocean environment. We will assume the “base case” model for each state of nature as the best choice to represent the stock dynamics and utilize forecasts from the time series analysis to develop the various assumptions regarding the possible future productivity of the U.S. west coast as represented by SSH . Where possible, we will investigate using other existing forecasts and/or leading indicators to formulate assumptions of the states of nature. Ultimately we will want to use forecasts of the states of nature that we can assign some sort of quantitative probability to, a value that is often difficult to arrive at when using various parameter values as is currently done. Furthermore, rather than assigning one probability to an entire assumed state of nature, we will make attempts at finding ways of assigning annual probabilities based on the confidence of the forecast values. In the end, we do not intend for this work to replace the existing decision table design, but rather to compliment them by offering a different perspective on how to view the forecasts.

Deliverables

- Tested modifications to the SS2 assessment model to enable the utilization of environmental data in the forecasts of recruitments and subsequent stock characterizations
- Time series analysis of sea surface height off the U.S. west coast

- Evaluation of the SS2 MCMC mode to deliver stochastic forecasts of recruitment that take into account forecasts of assumed or predicted ocean productivity
- Management decision tables and forecasts for 2007 sablefish assessment that utilize forecasts of California Current productivity

Benefits

This work will start to lay the groundwork for how stock assessments can utilize forecasts of ocean conditions and ecological indicators and bring them into the management arena. While we will be using actual values from the sablefish assessment as well as for SSH data, we intend this work to demonstrate a generalized approach that can be applied to any species that the investigator feels is subject to environmental forcing. Benefits should be realized from both the stock assessment as well as the management communities. By presenting decision tables based on the concept of ocean productivity we will give the Pacific Fisheries Management Council the option to consider climate as part of their management strategy. Furthermore, we foresee presenting these results to the PICES community in an effort work with that organization to demonstrate how forecasts of the environment can be used in a management arena.

Organizations

NOAA Fisheries/NWFSC/ FRAM, Office of Science and Technology, OSU/CIMRS

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Table 1. Example decision table of twelve year projections depicting three states of nature each of which assume varying degrees of productivity (*h*, stock-recruitment steepness) and stock size (*Q*, survey catchability).

			Low Stock/Production h = 0.26 Q = 0.37		Base Case h = 0.34 Q = 0.33		High Stock/Production h = 0.43 Q = 0.30	
Management Decision	**Year**	**TOTAL**	**SSB**	**Depletion**	**SSB**	**Depletion**	**SSB**	**Depletion**
	2006	5553	67361	27%	77136	35%	88006	41%
	2007	4585	67601	27%	78310	36%	89895	42%
	2008	4466	67625	27%	79240	36%	91499	42%
Low Catch	2009	4271	66580	26%	78945	36%	91749	43%
	2010	4106	65307	26%	78404	36%	91712	43%
40:10	2011	3925	63683	25%	77422	35%	91183	42%
Low Stock / Production	2012	3791	62647	25%	77182	35%	91461	42%
	2013	3646	61351	24%	76598	35%	91357	42%
	2014	3510	60100	24%	76062	35%	91282	42%
	2015	3383	58899	23%	75581	35%	91259	42%
	2016	3263	57747	23%	75153	34%	91288	42%
	2017	3152	56697	22%	74851	34%	91455	42%
	2006	5553	67361	27%	77136	35%	88006	41%
	2007	5912	67601	27%	78310	36%	89895	42%
	2008	5787	66974	26%	78591	36%	90852	42%
Base Case Catch	2009	5581	65254	26%	77618	35%	90422	42%
	2010	5415	63296	25%	76383	35%	89689	42%
40:10	2011	5234	60998	24%	74717	34%	88471	41%
Base Case / Production	2012	5105	59245	23%	73746	34%	88014	41%
	2013	4962	57244	23%	72444	33%	87190	40%
	2014	4829	55279	22%	71181	33%	86390	40%
	2015	4705	53359	21%	69969	32%	85641	40%
	2016	4589	51480	20%	68803	31%	84942	39%
	2017	4482	49687	20%	67747	31%	84372	39%
	2006	5553	67361	27%	77136	35%	88006	41%
	2007	6669	67601	27%	78310	36%	89895	42%
	2008	6530	66605	26%	78222	36%	90483	42%
High Catch	2009	6345	64506	25%	76868	35%	89672	42%
	2010	6209	62148	25%	75230	34%	88534	41%
40:10	2011	6071	59442	23%	73151	33%	86899	40%
High Stock / Production	2012	5961	57235	23%	71717	33%	85978	40%
	2013	5823	54776	22%	69949	32%	84687	39%
	2014	5694	52344	21%	68211	31%	83412	39%
	2015	5575	49952	20%	66519	30%	82186	38%
	2016	5464	47594	19%	64865	30%	81006	38%
	2017	5363	45311	18%	63311	29%	79947	37%