Incorporating Climate Driven Growth Variability into Stock Assessment Models: a Simulation-based Decision Table Approach

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Summary

Biological characteristics of managed fishes are likely to vary with time due to environmental variability. Growth of splitnose and yelloweye rockfishes has been previously found to be highly correlated with several productivity indicators in the California Current Ecosystem, and time-series of climate-growth indices have been developed for these two species, using otolith band reading techniques. These indices, however, have not been used to inform stock assessments, due to a lack of guidance for when and how to incorporate indices of time-varying individual growth into an assessment model. We propose to use a generic decision table approach to evaluate the effects of incorporating climate-driven time-varying growth into stock assessment models. Values in the decision table will represent management outcomes (i.e. lost yield and the probability of overfishing) and will be generated using simulation modeling, while existing data for splitnose and yelloweye rockfishes will be used to estimate the prior probability of time-varying growth. This simulation-based decision table approach will provide guidance on whether and how to include the environmental indices in future splitnose and yelloweye rockfish assessments. It could also be used generically to help evaluate the utility of including environmental data in stock assessment models. Funding for this project will support a Master's student, advised by Dr. André Punt and supervised by Drs. James Thorson and Vladlena Gertseva.

Background

Incorporating environmental variability into stock assessments is an important component of the ecosystem-based approach to fisheries management as it extends commonly-used single-species stock assessment modelling methods (Plagányi 2007). Environmental variability translates into variability in life history parameters of fish stocks, including those related to growth and reproduction. Growth and reproduction determine the productivity of a stock, and therefore affect estimates of stock status and management quantities related to spawning stock biomass. Currently, most stock assessment models estimate (or use a fixed value for) each life history parameter and do not incorporate inter-annual variability in life history traits. This is primarily because most species lack an established relationship between life history parameters and environmental variables, and/or time series data for hypothesized environmental variables are missing. Also, there is little advice currently available for when and how to incorporate environmental variables into the stock assessment models used for fishery management and policy advice.

Many species off the U.S. West Coast are hypothesized to be sensitive to environmental forcing including upwelling, the Pacific Decadal Oscillation (PDO), and the El Nino Southern

Oscillation (ENSO). Individual growth of splitnose (*Sebastes diploproa*) and yelloweye rockfish (*Sebastes ruberrimus*) was shown to be associated with large-scale changes in productivity of the California Current Ecosystem. Long-term time-series of individual growth for these species have been recently generated via dendrochronology techniques, which use the width of annual bands deposited in fish otoliths as a proxy for individual growth. Dendrochronology indices for these species have correlated strongly with the PDO and ENSO, as well as with geoduck growth and seabird fledgling success (Black 2009, Black et al. 2010).

Virtually all stock assessments off the U.S. west coast are conducted using Stock Synthesis (Methot 2009). Stock Synthesis is a flexible modeling platform that enables evaluation of the current status of a fishery stock, description of its past dynamics, and derivation of management quantities. It integrates a variety of data sources and offers a number of modeling choices for a stock assessor to explore, including approaches to describe biological characterises of a stock. Stock Synthesis provides a number of options to incorporate environmental data and link them to biological parameters. Previous work has illustrated and evaluated methods to relate changes in average recruitment to environmental variables using Stock Synthesis (Schirripa et al. 2009, Haltuch and Punt 2011), but there remains a dearth of guidance or testing of methods for time-varying growth.

A year-specific index for individual growth such as the dendrochronology index (I_t) as estimated by Black (2009) and Black et al. (2010) can be included in Stock Synthesis assessments in a variety of ways. Basic choices involve linking the index to either the Brody individual growth coefficient (k) or asymptotic maximum length (L_∞), and using either an 'identity' or 'log' link to relate environmental data and the associated parameter. Both identity and log-link models estimate a parameter β_{env} representing the magnitude of change in the life history parameter caused by changes in the environmental variable, and assume that changes in the dendrochronology index are either linearly or loglinearly related to changes in individual growth within the range of values observed. This parameter β_{env} can be fixed at an assumed value, given a penalty based on prior expectations, or given reasonable bounds (i.e. preventing negative/positive loadings when these are implausible). Finally, analysts can estimate an annual deviation in either or both parameters beyond changes represented by the environmental variable. Given the number of possible choices, it is necessary that stock assessors have advice for how to apply time-varying growth in any given assessment.

There have been no efforts to incorporate time-varying growth into the stock assessment for yelloweye rockfish. Earlier attempts to simply link climate data to splitnose rockfish growth estimated inexplicable patterns in time-varying parameters, and the lack of reliable historical age data for this species limited the utility of these attempts and prevented conclusions to be drawn about the effect of time-varying growth on the dynamics of the stock (Gertseva pers. com.). This highlighted the need to use a more complex analysis that involves simulation modelling to investigate this problem.

Simulation-based decision tables are a tool to evaluate the costs and benefits of a scientific or management decision (Punt and Hilborn 1997), and have been used to evaluate which of various possible models is most suitable given available data and biological assumptions (Thorson and Prager 2011). Decision tables involve five steps:

(1) Identifying various states of nature;
(2) Assigning prior probabilities to each state of nature;
(3) Identifying alternative management or scientific decisions;
(4) Identifying the expected risk of different decisions given states of nature; and

(5) Calculating the marginal risk of each management decision while integrating across the possible states of nature.

In our case, states of nature (1) include either the presence or absence of a 'true' relationship between an environmental index and individual growth, while the alternative management or scientific decisions (3) include different possible methods to include time-varying growth. The consequences of including or excluding environmentally-driven time-varying growth when it is present or absent (4) will be estimated using simulation, while the prior probability of time-varying growth (2) will be estimated using data for splitnose and yelloweye rockfish. The marginal risk (5) will summarize the costs (in terms of setting a total allowable catch higher than its 'true' target level) and benefits (in terms of average yield) of including an environmental index within stock assessments. It is this marginal risk that ultimately will be used to guide the decision of whether to include environmentally-varying growth in a given application.

The goal of this proposal is to conduct a detailed exploration of the different techniques to incorporate climate indices for individual growth data into the stock assessments using the splitnose (Gertseva et al. 2009) and yelloweye (Taylor and Wetzel 2011) rockfish assessment models as examples. We will use a simulation-based decision table to evaluate the consequences (in terms of probability of overfishing and lost yield) when fitting models to data simulated with and without 'true' variability in growth. We will also develop guidelines for stock assessors on how to most appropriately include environmental time series data for growth parameters in a Stock Synthesis model.

Objectives

This project has several specific objectives:

1. Use the Stock Synthesis 'bootstrap' simulator to generate data that are similar to those for splitnose and yelloweye rockfish, and evaluate both (a) the ability to correctly identify the presence or absence of an environmental effect on individual growth, and (b) the effect of ignoring an environmental index when present, and estimating an environmental index when absent, upon management quantities of interest, i.e. the probability of overfishing and lost yield.
2. Apply various methods to include an environmental index in Stock Synthesis to data for splitnose and yelloweye rockfish.
3. Synthesize objectives 1-2 to construct a decision table, to demonstrate the costs and benefits of estimating an environmental index in the splitnose and yelloweye rockfish assessment models.

Approach

Objective 1: Simulation testing

We propose to use a simple configuration of the environmental variable (i.e. an 'identity' link of I_t on k), and to evaluate *via* simulation the accuracy and precision of β_{env} estimates when Stock Synthesis is fitted to data that either does ($\beta_{env} \neq 0$) or does not ($\beta_{env} = 0$) include an environmental effect. We will use the Stock Synthesis 'bootstrap' simulator to generate data that perfectly match the assumptions of the estimation model, to be confident that the simulation results reflect model configuration and not a mismatch between estimation and operating model. We will use the data and parameter estimates from the most recent splitnose and yelloweye stock assessments, which will allow us to characterize fisheries management outcomes and how they change when an environmental effect is included in the model. Model outputs for each scenario (e.g., estimating an environmental effect when none is present) can then be summarized using

statistics representing average risk of overfishing (i.e. setting total allowable catch larger than its 'true' target level) and lost yield (i.e., average yield as a percentage of average maximum sustainable yield) given that scenario, and these quantities will be used in the decision table.

Objective 2: Application to splitnose and yelloweye rockfish

We will compile estimates of the environmental link parameter β_{env} estimated using different ways to include an environmental index for individual growth I_t within the most recent splitnose and yelloweye assessment models. We will then apply common model selection tools such as a Wald test ($\beta_{env}/\mathrm{SE}[\beta_{env}] \sim \chi^2_{df=1}$) or the Akaike Information Criterion (Akaike 1974) to identify the weight of evidence that an environmental effect on individual growth is either present or absent. This estimate will be used as the prior probability distribution on the 'State of nature' for the decision table that includes probability of overfishing and lost yield when either estimating or ignoring an environmental effect if it is present or absent.

Objective 3: Decision table

Estimates of the prior probability of environmentally-driven time-varying growth can be combined with previous simulation testing of probability of overfishing and lost yield to develop a decision table (example given in Table 1). This decision table will be used to characterize the costs and benefits of including an environmental index in future stock assessments for splitnose and yelloweye rockfish.

Table 1. An example of the decision table, where probabilities for the state of nature (X and 1-X) are derived from model selection tools comparing assessment models that include or do not include an environmental effect (Objective 2), the management outcomes (i.e., probability of overfishing or lost yield) for each combination of state of nature and treatment (Y_1-Y_4) is estimated from the simulations (Objective 1), and the marginal risks for either including or ignoring an environmental effect represent the risk for either possible treatment of environmentally varying growth (Z_1-Z_2) is used to evaluate whether to include or not include time- varying growth in splitnose and yelloweye assessments.

	Treatment of environmental effect	State of nature: Environmental effect is present	State of nature: Environmental effect is absent	Marginal risk
Prior probability		X	1 - X	
Probable error	Estimate	Y_1	Y_2	$Z_1 = X \cdot Y_1 + (1-X) \cdot Y_2$
	Don't estimate	Y_3	Y_4	$Z_2 = X \cdot Y_3 + (1-X) \cdot Y_4$

Benefits

The decision table framework we propose is a generic way to characterize outcomes of interest to management (i.e. lost yield or probability of overfishing) when either including or not including an environmental index, given an estimate of the environmental link parameter β_{env}. This framework is conceptually similar to the 'inverse prediction' method that Conn et al. (2010) applied to estimates of recruitment compensation, although we also incorporate measures of risk that are important to management rather than simply estimation accuracy. We are certain that this framework could be used generically to identify whether an environmental index should be included in a stock assessment model. This approach could be applied to a variety of environmental variables and biological parameters. Furthermore, even when an environmental index is not available, the method could be used to explore whether data collection to generate such an index is justified on the basis of likely changes in the risk of overfishing or lost yield.

We will generate this decision table using data and parameter estimates from the most recent splitnose and yelloweye rockfish assessments. Therefore, our results could be used to justify the decision to include (or not to include) the dendrochronology index of Black (2009) and Black et al. (2010) in future stock assessments for these species. If time allows, sensitivity testing will be conducted to explore the impact of more age data on the decision table outputs for these species. This exercise would be useful since historical otoliths exist for splitnose rockfish (Gertseva et al. 2009), and reading these historical otoliths could be prioritized for the next splitnose assessment. More age data would affect both the precision of estimates of the 'state of nature,' and the likely outcomes (in terms of lost yield or probability of overfishing) from model configurations when growth does (or does not) vary with time. Therefore, testing the sensitivity of the decision table to more data represents a suitable way to evaluate the benefits of processing historical otoliths for splitnose rockfish.

Deliverables

This project will result in a Master's thesis for a student supervised by Dr. André Punt at University of Washington, with Drs. James Thorson and Vladlena Gertseva serving as committee members. It will also result in a peer-reviewed publication that will present the simulation-based decision table framework for evaluating benefits of integrating an environmental index for individual growth into stock assessments. This publication will also present results specific to splitnose and yelloweye rockfish, which will help make decisions whether to include (or not) an environmental index such as the dendrochronology index of Black (2009) and Black et al. (2010) in future stock assessments for these species.

Work plan and assignment of personnel

A key component of this project is collaboration. Our team consists of strong quantitative scientists, stock assessors and fishery biologists who have a substantial experience in conducting research in the Northeast Pacific Ocean, and have been long involved in fishery management process on the West Coast of the United States.

During months 1-6 of the two-year (24 month) project period we will develop modified input files for the splitnose and yelloweye stock assessment models to incorporate the dendrochronology index (Objective 2). During months 7-12 we will estimate parameters for the decision table using simulation (Objective 1). During months 13-18 we will generate decision table results (Objective 3) and explore sensitivity of the results to model assumptions. During months 19-24 we will prepare and submit a manuscript for a peer-reviewed journal.

All principal investigators (PIs) will be responsible for successful completion of the project. Dr Punt will supervise the Master's student, while Drs Thorson and Gertseva will serve on the student’s committee. Dr Thorson will serve as primary NMFS PI and oversee the development of the decision table results. Dr Gertseva, who conducted the latest stock assessment for splitnose rockfish, will provide guidance on application of the results to future stock assessments.

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