AGE STRUCTURE METRICS FOR PRECAUTIONARY MANAGEMENT: CAN SIMPLER ASSESSMENT TECHNIQUES SAVE FISH, TIME, AND MONEY?

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ABSTRACT

Stock assessment techniques currently used in the United States are extremely costly to implement, involve significant data requirements, and are inaccessible to all but a few stock assessment scientists. A systematic decrease in fishery yields and the designation of several species as overfished on the west coast of the United States have resulted in stricter protocols regarding sustainable fisheries management and the rebuilding of overfished stocks, including the need to set annual harvest limits for all exploited species. An alternative and simpler approach to stock assessment which could address this need is described and an evaluation framework set up. Although no results have been obtained to date, possible costs and benefits of incorporating this approach into fisheries management are discussed.

Keywords: Bioeconomic modeling, fisheries, stock assessment, simple indicators, retrospective evaluation.

INTRODUCTION

In 2003 the Pew Oceans Commission (POC 2003), and in 2004, the United States Commission on Ocean Policy (USCOP 2004), published paradigm-shifting reports on the current state of, and future recommendations for, the management and policies governing U.S. marine resources. As well as urging a shift towards ecosystem-based Science and Management (EBSM), one of their main findings was that at least 82 marine fish populations were at risk of extinction, and of 500 federally-managed stocks, only 22 percent of them were being managed sustainably. These reports came at a time of crisis for the fishing industry on the west coast of the U.S., a crisis which had been in the making since the peak of the groundfish fishery in the early 1980s. By the late 1980s, it was clear that harvests could not be maintained at their high levels and allowable catches became increasingly strict throughout the next decade. In 1996 the Sustainable Fisheries Act (SFA 1996) amended the Magnuson-Stevens Fishery Conservation Act of 1976 (MSA 1976) which set a clear charter for fishery managers under the rubric of sustainable management. Under this act, overfishing must be eliminated and rebuilding plans developed and implemented for all overfished stocks.

On the west coast of the U.S., eight species of groundfish are currently designated as 'overfished', seven of them long-lived rockfish species (FMP 2009). The economic impacts of such management actions can be severe as measures to eliminate overfishing (such as sharp quota reductions) affect both the overfished species and species that are caught in association with these overfished stocks. For example, the canary rockfish (*Sebastes pinniger)* has historically been a commercially important species. Since the early 1990s, catches started to decline and the first stock assessments were carried out. Allowable catches were drastically reduced and trip limits for this species dwindled until it was declared 'overfished' in 2000. Commercial targeting of this species effectively ceased and most removals since then have been from accidental or auxiliary catch (Stewart 2007). This species has become severely limiting in most trawl fisheries. In the trawl whiting fishery, canary bycatch has become so constraining that the presence of any of this species in the catch may cause vessels to cease fishing and choose new locations.

Accompanying the designation of species as 'overfished' has been a large-scale reduction in catches for most species on the west coast over the past 20 years. In economic terms, when comparing the peak of the groundfish fishery in the early 1980's to the turn of the century, total ex-vessel revenues fell by 47%, rockfish ex-vessel revenues fell by 69%, and flatfish ex-vessel revenues fell by 73% (Hanna 2000).

Fisheries in the United States are managed primarily on a species by species basis, with harvest levels based on an estimate of the stock's abundance and Maximum Sustainable Yield (MSY). The critical assumption underlying this approach is that fish populations can be sustained by a minimum biomass of spawning females, regardless of their age and size, and any biomass above this level can be harvested without detriment to the sustainability of the population. The theory supporting this approach has been refined over much of the last century and its use in U.S. fisheries management is mandated in the MSFCMA.

Recent research on the life history of fishes suggests that this traditional MSY-based approach is missing important mechanisms regarding how stocks respond to exploitation (Berkeley et al 2004, 2006; Heppell et al 1999, 2005). For example, for many long-lived species such as rockfish, older females have reproductive capabilities which may be disproportionate to their biomass due to the higher survivability of larvae produced by older animals. This higher survivability could be due to higher quality larvae produced by these animals and the different timing of larval release which may make year classes more resilient to environmental change (Berkeley et al 2004). A number of recent papers have concluded that maintaining an optimal age-structure is necessary to maintain a stock's resilience to natural and man-made perturbations (Marteinsdottir and Thorarinsson, 1998; Scott et al, 1999; Secor, 2000; Vallin and Nissling, 2000; Berkeley et al, 2004; Hsieh et al, 2006; Longhurst, 2006). Because fishing generally results in substantial truncation of the age-structure of the population, the current biomass-based approach may not be the most effective way to maintain high fishery yields (Berkeley 2006). O'Farrell and Botsford (2006) use length frequency data from both the past and the present to assess persistence of five species of nearshore rockfish on the west coast of the U.S. They estimate that four of the five species have experienced lifetime egg production declines due to age truncation to levels that suggest that persistence of these species is impaired.

As well as the theoretical concerns surrounding the MSY approach, in order for fishery managers to effectively set limits on allowable catch, information is needed on the status of the stocks in question. This is one of the main challenges of managing our current system. Determining stock abundance and calculating MSY are data-intensive and extremely costly processes. For example, data collection for U.S. west coast stock assessments include annual research surveys, juvenile rockfish surveys, acoustic surveys, onboard fishery observers, port samplers, fishing vessel logbooks, and delivery fish tickets. These data sources contribute to a network of vast databases containing fisheries data. Moreover, once these data are collected and analyzed, the formal assessment process is so challenging that it is technically inaccessible to all but a few stock assessment scientists, and may take many months to complete *for a single species*. Given limited financial resources, less than a third of the federally-managed groundfish species on the west coast of the U.S. have been assessed to date, and most species that are assessed 'regularly' go several years between assessments. With the introduction of federal requirements to set Annual Catch Limits (ACLs) for all groundfish species with the reauthorization of the MSFCMA in 2007 (MSA 2007), the constraining nature of the current assessment technique is of concern, especially in the absence of a feasible recognized alternative.

Several researchers have identified alternative management models to overcome the limitations of the MSY approach (Walters et al 2005; Quinn and Collie, 2005). These range from simple modifications to completely new approaches which fundamentally reject MSY in their framework. Froese (2004) proposed a very different approach to fisheries stock assessment and management. His idea was to manage fisheries under a simple protocol of monitoring three indicators of stock health: 1) the proportion of mature fish in the catch (P_{mat}), 2) the proportion of optimally-sized fish in the catch (P_{opt}), and 3) the proportion of large, old females in the catch (P_{mega}). These indicators are based on length compositions that can be easily derived from commercial catches and can be compared against biological parameters which may be relatively easily determined (King and McFarlane 2003). Such a technique has the potential to be used to not only supplement the current assessments, but to use in setting ACLs in a science-based, quantitative way for those species that have not had formal assessments. As this approach may be more time- and cost-effective to implement than the current method, the frequency of assessments and number of stocks being assessed could be increased. Additionally, this method could be used as a tool for reaching the goal of an ecosystem-based approach to management in that it would provide an ecologically-based and easily understood benchmark with which a large component of ecosystem health could be evaluated.

While there may be a theoretical basis for assuming that this method could be effective - and Froese himself carries out some comparisons which he finds to be satisfactory - this method has not been rigorously tested to date. The purpose of our project, therefore, is to carry out a comparison of Froese's method to the existing MSY-based approach. The research questions we will address are: 1) Is an age-structure metrics approach to assessing stock status applicable for use in U.S. fisheries, either when used alone, or in conjunction with the current MSY-based approach?, 2) Does the use of this technique allow harvest limits to be set with less uncertainty surrounding stock status than would otherwise be the case?, and 3) How do the costs and benefits of this approach differ to those of the current system?

In order to address the first two questions, we will use a discrete choice optimization model of the west coast groundfish trawl fleet in conjunction with a virtual population model of canary rockfish to test and compare the two assessment techniques in terms of economic effects on the fleet and ecological effects on the canary population.

In order to compare the costs of implementing the two approaches, interviews and surveys of fishery managers around the world will be carried out to determine the costs of managing our current system, and the potential costs of managing under Froese's protocol. Information from the survey will be incorporated into a final cost-benefit evaluation of the two methods once the modeling component is completed.

One of the fundamental ideas when this project was being developed was to utilize a retrospective approach to determine what would have happened if this alternative management protocol had been available to fishery managers. There was much discussion and debate regarding the value of this approach during a preliminary project workshop[1]. This question had important implications for deciding the best approach to take in investigating the research problem. As a result it was decided that the modeling would be based on the best available historical data, which resulted in the modeling approach discussed in the next section.

MODEL OVERVIEW

The 'model' is actually comprised of two separate parts. The first is the biological operating model. A virtual population of canary rockfish using robustly determined biological parameters is maintained using a function of Stock Synthesis 3 (SS3)[2]. Stock Synthesis is a program which provides a statistical framework for the calibration of a population dynamics model and is the main stock assessment tool in use in the United States. The beginning population biomass and age-structure for this virtual population are set to their best available estimates at the beginning of the modeling period using existing fisheries data. For this project, the beginning of the modeling period is January 1981, when fish ticket data first became available for the west coast groundfish fishery. It is also a time when catches of canary were high, and there were limited concerns regarding the sustainability of the stock. The population is parameterized using biological parameter estimates from the existing stock assessments for canary rockfish. This virtual population is contained in a separate module of SS3. In order to mimic sampling of the population several bootstrap data sets (with differing sampling error variances) are created from the virtual population. These data sets are employed to assess stock status using 1) a protocol based on Froese's protocol, and 2) the SS3-based MSY approach. After the first assessment year two virtual populations are created, one maintained under Froese's protocol and the other maintained under the MSY approach.

The two assessment types are then used to devise harvest controls in the form of trip limits (limits on the amount of a species that may be caught in a given time period). Trip limits have been the main form of effort control used historically, although gear and seasonal

[1] A workshop was held at Oregon State University from July 8-10th 2009 with a mix of ten economists and ecologists attending from academic institutions, government agencies, and the private sector. The main purpose of the workshop was to chart the course of this project.

[2] For more information on SS3 see the NOAA fisheries toolbox at: http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm

restrictions have also been used. They have differed in the length of time they are set for, although they have mostly been in the form of bi-monthly limits. For the purposes of this project, bi-monthly limits will be used. These trip limits form the bridge between the biological model and the economic model. For the traditional MSY-based approach, the currently used harvest control rule based on maintaining the stock at or above 40% of the level that would exist without fishing (B_{40}) (Berkeley 2006) will be used to devise trip limits. There is some discussion regarding what harvest control rule to use when applying the modified Froese approach. Cope and Punt (2009) lay the groundwork for relating Froese's method to traditional target reference points such as B_{40} but further research needs to be undertaken to explore this issue further. For our project we will compare several strategies suggested in their paper, as well as a simple linear adjustment method which adjusts trip limits up or down depending on the values of P_{mat}, P_{opt}, and P_{mega}.

The economic model attempts to describe how the groundfish trawl fleet reacts to conditions in the fishery. These conditions include: 1) management actions such as changes in trip limits, gear restrictions and allowable catch, 2) market conditions such as changes in price of fish species and costs of fishing, and 3) resource availability such as changes in catch per unit effort (CPUE). This type of modeling has been performed in the past. For example, Babcock and Pikitch (2000) use dynamic programming to model targeting decisions made by bottom trawling vessels in the U.S. west coast groundfish fishery under management-imposed trip limits. We aim to build upon this work to encompass the entire west coast fleet of trawlers and all possible targeting decisions.

The output from the economic model is yearly-catch by age of canary rockfish and forms the input for the next year's biological model run. The models will be run iteratively i.e. one year at a time. A schematic showing the model overview is given below:

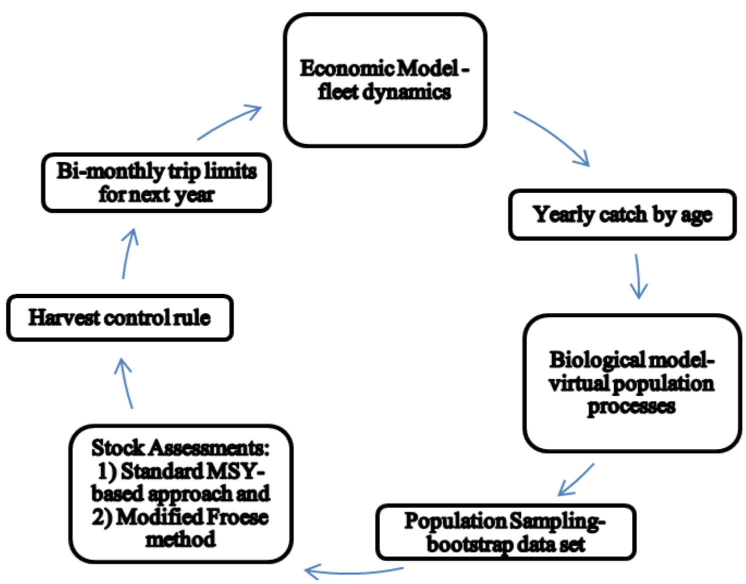

Figure 1: Overview of the model. This cycle will be repeated every year for two virtual populations, one maintained using the traditional MSY-based approach and the other maintained using the modified Froese protocol.

The economic model of fleet behavior

The economic model is a discrete choice model of trawl fleet dynamics which is written in the General Algebraic Modeling System (GAMS). The model maximizes profit over the entire fleet in each year and is based on parameters that have been observed historically.

While canary rockfish have been caught historically by many different gears, the main component of the catch has been from bottom trawling for rockfish, nearshore trawling with flatfish as a target, and to a lesser extent, the dover sole/thornyhead/sablefish deepwater complex. Canary have also been targeted by recreational fishers and has been present in bycatch of fixed gear fisheries although the proportion of canary catch in these fisheries is quite low. Management regulations concerning the take of canary rockfish apply mainly to the trawl fishery, and thus we will model the trawl sector of the fishery, keeping other sources of take constant at historical effort levels.

The west coast groundfish trawl fleet targets several different complexes which can be broadly categorized into 6 strategies:

1. Dover/Thornyhead/Sablefish (DTS)
2. Shelf rockfish
3. Pelagic trawl for pacific whiting
4. Pelagic trawl for the widow rockfish/yellowtail rockfish complex
5. Shrimp trawling
6. Nearshore flatfish mixed species

Each of these strategies can be categorized based on a combination of gear types used and species composition of the catch, data for which is available from fish tickets and logbooks. For example, the DTS strategy occurs in deep water (>183 m depth) using a flatfish trawl without roller gear. The species composition catch from this strategy is mainly composed of dover sole, thornyheads, and sablefish. Similar rules have been devised to sort all trips that vessels have made during the modeling period into these 6 target strategies (in general, each trip has a fish ticket associated with it). A complication is that some vessels target a combination of strategies in a single trip making categorization difficult. On examination of the data, however, it appears that the number of vessels that do this is relatively small.

Not all vessels participate in the same number of strategies. In a given year some may only engage in one or two of them while others engage in all six. To model this, the trawl fleet is split into sub-fleets, each of which share a common combination of strategies that vessels pursue. The size of each sub-fleet is set at the level indicated in the data.

Given these choices of fishing strategies among the different sub-fleets, the amount of effort that fishermen will direct to each choice is not random, but will depend on the profit that the fisherman expects to receive by pursuing that strategy by taking into account prior information gained in the fishery (Salas et al 2004; Holland and Sutinen 1999). The expected profit from each strategy depends on several factors:

- The management actions that are imposed on the fishery, such as trip limits, seasonal restrictions, and gear restrictions
- The expected amount of catch by species and the price that the fishermen expect to receive for each species
- The costs that the fishermen incur by operating in the fishery. The main variable cost of fishing is the cost of fuel, which varies over the strategies.
- Seasonal variations in the availability of each target species. For example, DTS species aggregate in certain months of the year for spawning. One would expect effort devoted to this strategy during these months to increase.

A discrete choice model in the GAMS environment has been built which determines the optimal mix of strategies in which each sub-fleet engages in a given time period. The model maximizes profit (net revenue over all species minus net costs) over the entire fleet:

$$\max_{x} \pi = \sum_{F}((\sum_{J} X_{fj} \cdot \sum_{N} R_{nj}) - (\sum_{J} X_{fj} \cdot B_{lj}))$$

(Equation 1)

where f=sub-fleets, j=strategies, n=species; X is number of trips, R is revenue per trip, B is cost per trip

This function is maximized subject to various constraints. These constraints include:

<u>*Capacity constraints*</u>- we assume that the number of vessels in each sub-fleet is determined exogenously and is set at historical levels.

<u>*Time constraints*</u>- we set the length of each trip by strategy at the average length of trip by strategy as determined by logbook data. These lengths multiplied by the number of trips of each strategy cannot exceed the available time in each time period.

$$\sum_{J} X_{fj} \cdot D_j \leq G_f$$

(Equation 2)

*where **j**=strategies, **f**=sub-fleets; **X** is number of trips, **D** is length of trip, **G** is total number of vessels in a fleet multiplied by number of available fishing days*

<u>*Trip limit constraints*</u>- We set trip limits for each species group (except canary rockfish) at their historical level. The trip limit for canary rockfish is determined endogenously through the interaction between the economic model, the virtual population, and the stock assessment processes:

$$\sum_{F}\sum_{J} \boldsymbol{X_{fj} \cdot C_{nj} \leq E_n}$$

(Equation 3)

*where **f**=sub-fleets, **j**=strategies, **n**=species; **X** is number of trips, **C** is catch per trip, and **E** is a vector of trip limits for all species*

Catch per unit effort- We assume that the CPUE of all other species remains at the same level as observed historically. We allow CPUE of canary rockfish to differ depending on changes in their population size and structure as determined in the biological model. Eide et al (2003) estimate a harvest function for the Norwegian bottom-trawl cod fisheries which is a variation of the commonly-used Schaefer harvest function. They used estimates of the cod biomass, fishing effort, and harvest to econometrically estimate the parameters in this function. We propose to estimate a similar function:

$$\boldsymbol{CC_j = q \cdot M^{\alpha_j} \cdot X^{\beta_j}}$$

(Equation 4)

*where **j**=strategy; **CC** is canary catch per trip, **q** is catchability, **M** is biomass, **X** is number of trips taken*

The output from the model includes the number of trips per strategy chosen by each sub-fleet. The subsequent catch by length of canary rockfish in each time period can be calculated by multiplying the total catch of canary rockfish by the trawl selectivity curve determined exogenously by stock assessment scientists.

DATA ISSUES

A main issue that has yet to be addressed is that of discards. Before the introduction of onboard monitoring by cameras, fishermen discarded species which they could not deliver, i.e. those species for which they had already reached a trip limit. In 2001, Dr James Hastie built a model to estimate bycatch rates for the west coast trawl fishery which has subsequently been used by the Pacific Fishery Management Council for evaluating overfished stocks. In the absence of a feasible alternative (the actual amount of discards is unknown as they are mostly unreported), we hope to incorporate these discard rates into our model.

The data that are required for this project are contained within large government sponsored databases. Although access to these databases is theoretically open to the public, the reality is quite different when confidentiality issues are considered. We have thus been utilizing a consultant on this project who are experts at U.S. fisheries data procurement[3]. While we had expected to be able to present results at this conference, several delays originating from the database maintainers, and from issues with the data itself has meant that we have only recently

[3] The Research Group, Corvallis, Oregon, U.S.

come into possession of the main body of the data. In the next section we will describe the results that we expect to see and save the actual results for a later date.

EXPECTED RESULTS AND DISCUSSION

The main questions that we are examining are:

1. Is the modified Froese technique as effective as the established MSY-based approach in accurately determining stock status?
2. Is the modified Froese technique less costly to implement than the established MSY-based approach?

It may be expected that the current stock assessment technique based on vast quantities of fisheries-dependent data, fisheries-independent research cruises, the efforts of many fishery scientists, and rigorous vetting and review by panels of experts, provides a more precise and thorough view of the status of the assessed stock. However, the sheer number and magnitude of assumptions that must be made to align theory with practical implementation may mean that some measure of accuracy and prediction is missing. It is quite possible that a simpler technique based on fisheries dependent data which makes fewer assumptions about population processes but focuses instead on a wholesale view of the fishery may be more *accurate*, even if some measure of detail is missing. This question will be investigated thoroughly and any preliminary predictions are unfounded.

The question of comparing the costs of implementing each technique, however, appears to lead to an obvious answer, albeit with a caveat. The data requirements for implementing an age-structure metrics approach are restricted to fisheries dependent data which can be collected at point of delivery, and does not require expensive fisheries independent surveys that are currently performed every year. The regulatory and physical (in terms of personnel, data collection and storing) infrastructure for collecting catch data are already in place on the west coast of the U.S., indeed these types of data are already being collected for use in the current system. The caveat, therefore, is how much data are required to implement this new approach, given that it is possible to implement successfully? This is a question that will be explored once testing is complete.

Apart from simple comparisons between the two techniques, the real value of this project probably lies somewhere in between. That is, could a simple age-structure metrics approach be used in conjunction with the status quo method to better evaluate the status of our fisheries? Could we decrease the frequency with which expensive fisheries-independent surveys are carried out by incorporating a simpler technique and without detriment to our ability to manage our fish stock sustainably? Could this simple technique be used to efficiently evaluate non-commercially important species in order to improve our understanding of the ecosystem as a whole? These are all questions that currently don’t have clear answers, but which we will attempt to address in the months ahead.

EXTENSIONS

The modeling approach described so far is an attempt to describe the interactions between the management of a single stock and an entire fleet of groundfish trawlers, both of which exhibit spatial heterogeneity in their distribution and behavior. After this first round of analysis is completed , consideration of other species present on the west coast of the U.S., and consideration of spatial heterogeneity in species distribution and fisher characteristics is warranted. Spatial heterogeneity can be incorporated by further refining the model to include area-specific characteristics of both fish stocks and the fleet.

The main restriction made in our modeling approach to date, namely that only one species is being assessed using the alternative approach and that catch levels of other species remain constant at historical levels is useful when comparing our proposed management protocol to the method currently being used. Once the proposed method has been evaluated, this restriction can be relaxed to incorporate other species into the model, and thereby gain greater insight into the potential effect that the introduction of such a method can have.

CONCLUDING REMARKS

It is clear that a simpler, more accessible method for assessing fisheries health needs to be implemented in the United States. Such an approach may be especially warranted given the introduction of new regulations and management protocols including annual catch limits. An age-structure metrics approach based on Froese's protocol may be capable of addressing this need. Furthermore, resource economics provides the practical tools needed to evaluate any new approach to fisheries management in the context of improving social welfare. We hope to retrospectively evaluate whether the use of a simple, low-cost, and accessible assessment technique could have improved social welfare over the past thirty years, and in doing so provide the impetus that is needed to encourage it's use in the future.

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