7-2007

Modeling Fishery Regulation and Compliance: A Case Study of the Yellowtail Rockfish

Wayne Wakeland
Portland State University, wakeland@pdx.edu

Modeling Fishery Regulation & Compliance: A Case Study of the Yellowtail Rockfish

Wayne Wakeland
Portland State University, Systems Science Ph.D. Program
P.O. Box 751, Portland, OR 97207
Tel: 503-725-4975/Fax: 503-725-8489
Email: wakeland@pdx.edu

***Abstract*—*Motivated by declining fish populations and the apparent inability of regulatory agencies to manage important fisheries, this research measures the accuracy of a fishery model that explicitly models the regulatory process and the resulting degree of compliance by fishers. The method involved careful review and enhancement of a prior model with more limited regulatory sub model, and then measuring, for both models, the mean absolute error of model calculated values for historical spawning biomass, acceptable biological catch, and harvest. The most recent five years of data were held back so that model prediction error could also be computed. Results indicated that although the fitness error for the enhanced model was significantly less than the prior model (23% vs. 38%), predictions were improved only for one of the three measures. The implications for researchers seeking to endogenously model fishery management processes are sobering. Policy makers on the other hand will likely see the results as support for their instinctual skepticism regarding policy models.*

Keywords: fishery regulation, fisher compliance, model fitness, model prediction

1. INTRODUCTION

1.1. Research question

To what degree is it possible to model decisions by regulators to limit fishing, and to estimate the fisher's degree of compliance with these regulations?

1.2. Research context

The specific context for this research is the yellowtail rockfish fishery along the Pacific Coast of the United States.

1.3. Specific Aims

1. To create models that mimic fishery regulation and fisher compliance, striving to limit model complexity; motivated in part by recent research indicating that increased complexity does not improve the policy sensitivity of fishery models (Moxnes 2005).

2. To study the predictive power of a specific fishery model that focus on regulation and compliance.

Section 2 provides background information and shows why the study is relevant. Section 3 discusses the methods employed in the research, and Section 4 provides the results. Discussion and conclusions are provided in Section 5. An Appendix that provides the model equations follows the references.

2. BACKGROUND AND SIGNIFICANCE

Populations of rockfish have dropped dramatically in recent decades. Since 1983, rockfish landings have decreased 78% and catch limits for various species of rockfish have been reduced by 78%-89%. To prevent economic collapse, the federal and state governments created several regulations implementing the conservation and community viability provisions of the Magnuson-Stevens Fishery Conservation Act (1996) and its amendments. Despite these efforts, in January 2000 the West Coast groundfish fisheries were declared a federal disaster (Ecoworld 2000). The decline in fish stocks is considered by many to be the consequence of ineffective natural resource management and short-term policies that resulted in a larger fishing fleet than could be supported long term.

Fisheries are classic examples of "commons" dilemmas, as described by Hardin (1968) and updated more recently in an article published in Science by Dietz et al (2003) who compare the ground fish and lobster fisheries in Maine between 1980 and 2002. The ground fish fishery has been "governed by top-down rules based on *models* that were not credible among users," (emphasis added) with the all too familiar result that fish populations have declined sharply due, in part, to relatively low compliance. The lobster fishery on the other hand "has been governed by formal and informal user institutions," which has resulted in high compliance and rebounding lobster population. The present research examines this issue of the credibility of fishery models.

Mathematics, statistics, computer simulation, and System Dynamics (SD) have all been used to model fishery management systems. Schaefer (1954) provided the classic dynamic (differential equation) model for fish biomass as a function of pristine (unfished) biomass, intrinsic rate of increase, fishing effectiveness, and fishing effort.

Applications of SD to fisheries management include Ruth and Lindholm (1996) who applied SD to multispecies fishery management; Holland and Brazee (1996) and Dudley and Soderquist (1999) who presented an SD-based general fishery model as a tool for studying fishery management policy; Ford (1999) who offered the "Tucannon harvesting model" as an illustration of the application of SD to fisheries; van den Belt (1999) who developed The Patagonia Coastal Zone Management Model, an elaborate SD-based simulator that takes into account the interplay between ecosystems and economic systems; Sampson (2001) who provided a detailed cohort-based SD simulator for exploring fish harvesting policies; and Dudley (2003) whose high level model adds additional feedback loops to the Schaefer biomass dynamic model.

Another relevant body of literature relates to policy setting in fisheries and other similar contexts. Jentoft (2003) describes the adverse relationship between the complexity of the system (rules begetting more rules), its perceived [poor] legitimacy, and the resulting lack of compliance with the rules. Moxnes (1998, 2000, and 2004) shows that the problem more than a commons dilemma—that misperceptions of feedback dynamics complicate matters considerably. Laboratory experiments with policy decision makers in a renewable resource context (setting reindeer quotas to avoid over grazing) revealed that simplistic mental models prevented subjects from making the appropriate decisions, even though they were provided sufficient information to correct their flawed mental models.

Brekke and Moxnes (2003) describe further experiments where subjects were given simple simulation and optimization results to help with their task. The subjects learned from these tools, and their management decisions improved, but subjects did not fully compensate for the limitations of the tools. Later research (Moxnes 2005) explored the role of simple vs. complex fishery models in the context of policy sensitivity analysis, and found that policies were relatively insensitive to the complexity of the underlying biological model. However, policies were highly sensitive to assumptions about non-linear economic relationships that are in fact highly uncertain.

Prior work by the author introduced a System Dynamics model of the Pacific yellowtail rockfish that included fish populations, fishing activity, and regulation (Wakeland, et al 2003). That paper focused on model testing, with emphasis on sensitivity analysis. Primary results, based on several policy analyses, were: 1) that the generally accepted value of .4 for maximum sustainable yield does indeed represent a useful and beneficial rule of thumb, 2) that more frequent updates to acceptable biological catch based on more frequent stock assessment studies would help to stabilize the fishery, and 3) that shortening management response time for adjusting fleet capacity would also be highly beneficial. The limitations of the prior work will be described later in this paper.

Research regarding fishery regulation and fisher compliance is significant because it will help to identify policies and other actions that may lead to more sustainable fisheries and fish populations. Depending on the reproductive cycle of the particular species of fish, it can take decades for a fishery to recover from being over fished, which can have a devastating impact on fishers and fishing communities.

3. METHODS

The primary modeling methodology for the present study was the System Dynamics method, which emphasizes feedback loops and describes relationships via 1^{st} order ordinary differential equations that are numerically integrated to simulate behavior over time. Figure 1 shows the starting point model referred to herein as Model I. Wakeland (2003) provides additional model details.

Many parameter values were taken from the literature and from reports published by the Pacific Fisheries Management Council (Pcouncil 2007). Some parameters were estimated by calibrating the model to best fit a portion of the reference data. Although formal algorithms could be used to calibrate the model parameters, in order to achieve a best fit to the training dataset, ad hoc calibration methods were employed for the present study because of the modest amount of reference data, and a desire on the part of the researcher to learn from the calibration process.

The predicted values for three key indicators, spawner *biomass*, *ABC* (acceptable biological catch, which is used to set trip limits), and *harvest* were compared to actual values, both for the training period and the holdback sample. Fisher compliance was

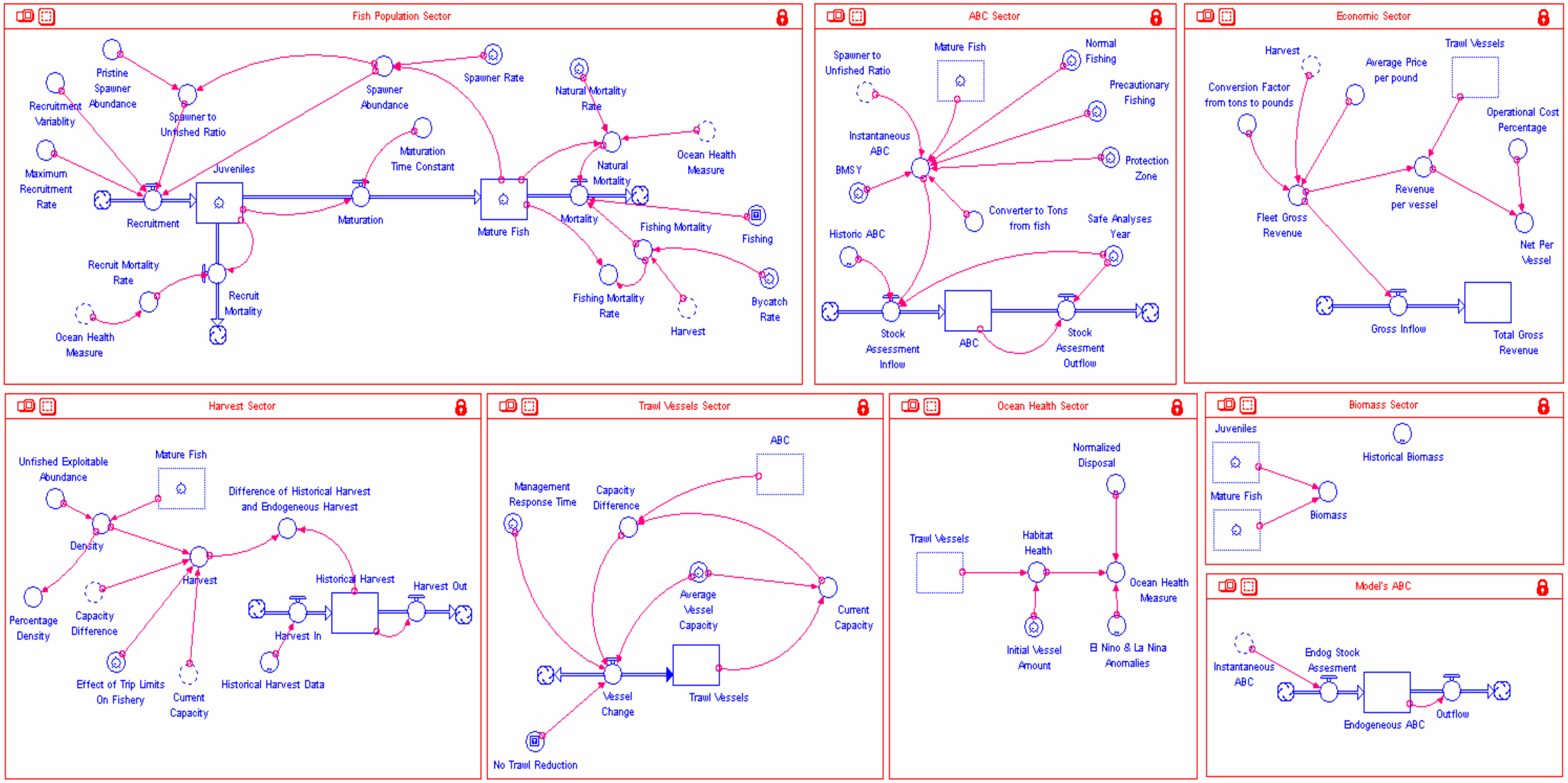

Figure 1. Flow diagram for initial model (Model I). Note that stocks and converter variables with dotted lines (called ghost variables in STELLA) were used to reduce the visual complexity due to connections between the sectors.

estimated dynamically and reported, but could not be compared to reference data because none exists.

The specific steps of the research method are summarized below:

1. Review and summarize the specific predictions from Model I.
2. Review and summarize model improvements suggested at the conclusion of the prior research (Wakeland, et al 2003).
3. Carefully examine the logic of Model I, and note additional potential issues/concerns, with particular emphasis on logic related to regulation and compliance.
4. Revise model logic to address the issues described in Steps 2 and 3, especially the model's ability to endogenously calculate the regulatory aspects of the fishery (*ABC* in particular). The resulting model will be referred to as Model II.
5. Develop and document a revised set of predictions based on Model II.
6. Obtain new fishery data (for *biomass, ABC, and harvest*) that has been collected or established since the previous work was done. This data will be treated as the holdback sample.
7. Compare predictions from each model with what has actually occurred, and with current projections by regulatory agencies.

Additional details of method are provided below.

<u>Step 1</u>

The earlier Pacific Coast rockfish fishery paper (Wakeland, et al 2003) did not frame the results as predictions. Instead, actual data for *harvest* and *ABC* were employed directly within the logic of the model. *Biomass* was not provided in that paper because there was a significant unexplained discrepancy between the historical data and the model. During Step 1 of the present research, the *biomass* discrepancy was identified and corrected. The error was an incorrect conversion factor between *fish population* and *fish biomass* in Metric Tons. Model and actual data for *biomass*, *ABC*, and *harvest* were then plotted; and the absolute mean error was calculated for each variable. Absolute error was used rather than squared error because it is simpler and there did not appear to be any compelling reasons to use a more complex measure of fitness.

<u>Step 2</u>

The 2003 paper identified the following opportunity areas: 1) implementing economic and social factors, 2) incorporating dynamic trip limits, 3) connecting the economic side of the system back to other aspects of the model, 4) improving how the model incorporates changes in ocean health, 5) considering population dynamic models that include the age, size, and weight of fish, and 6) incorporating catch per unit efficiency (CPUE) index.

Subsequent work was in fact done by the research team regarding opportunities 5 and 6 above, but these efforts did not lead to substantial improvements in the model.

Opportunities 2, 3 and 4 were addressed in Step 4 of the present study, as described below.

<u>Step 3</u>

A careful re-examination of Model I revealed several previously undetected model weaknesses (numbered 1 through 5 below). All of these weaknesses are discussed further and remedied in Step 4.

1. The largest weakness was that although formulae were implemented to calculate an endogenous value for ABC, the value was not used in the other endogenous calculations; instead, the historical data was substituted in order to more accurately calculate other modeled variables. This was a serious flaw in the previous work, especially since this fact was not disclosed in the paper!
2. The second major issue was the complex and arbitrary logic to model the results of the spawning process, including the use of multiple "mysterious" and unsupported parameters.
3. Third, the logic to compute *harvest* was complex, not well supported, and relied on arbitrary and/or undisclosed factors. It considered the density of fish relative to pristine unfished conditions, and also utilized a complex function of current vessel capacity and the ABC value from the regulatory sub model.
4. The Ocean Health sub model was actually more problematic than was implied by Opportunity 4 described above. The damage to the ocean floor by trawling activity (one component of ocean health), was modeled as an instantaneous function of the current number of trawlers divided by the initial number of trawlers. This could only be appropriate if the regenerative process for the ocean floor was very rapid. But since the regeneration process is slow, the logic should be accumulative. The other two factors, El Nino effect and Ocean Waste Disposal effect, were incorporated into the model as graphical indices supported by external data. But each factor was then scaled, and the three measures were aggregated using logic that arbitrarily gave equal weight to each factor.
5. Natural carrying capacity was not considered in the equations for natural fish death rates (deaths not due to fishing). Rather, these were modeled as fixed fractions of the Juvenile population and Mature Fish population; on the assumption that heavy fishing would assure that fish populations would never approach the natural carrying capacity. This assumption is invalid for this particular fishery.

Step 4

To address the weaknesses and opportunities for improvement discussed in Steps 2 and 3, the following model improvements were implemented:

To address Opportunity 2 and Weakness 3, two new parameters were added to the fishery sub model: *trip limit effectiveness divisor* and *Pre '85 enforcement fraction* (base value = .7). The variable *Trip limit effectiveness,* L, depends on the *ratio fish over vessels,* and *Degree of* Enforcement, as shown in Equations 1 and 2. Equation 3 shows how L influences the *Harvest in Tons*.

$$O = \frac{M}{V} \qquad [1] \qquad\qquad L = (1 - .5 * e^{-1*\frac{O}{d}}) * X \qquad [2] \qquad\qquad H = \frac{A}{L} \qquad [3]$$

Where: O = ratio fish over vessels (Fish/Vessel)
M = Mature Fish (Fish)
V = Vessels in Fishery (Vessels)
L = Trip limit effectiveness (dimensionless)

d = trip limit effectiveness divisor (Fish/Vessel) (base value = 250,000)
X = Degree of Enforcement (dimensionless) [Pre ’85 enforcement fraction from 1980 to 1984; 1 thereafter]
H = Harvest (Metric Tons)
A = ABC, Acceptable Biological Catch (Metric Tons)

Table 1 provides examples to clarify the logic in Equations 1, 2, and 3. As shown in Table 1, Equation 2 is designed to keep *Trip limit effectiveness* bounded between .5 and 1, such that *Harvest in Tons* could be no more than twice the limit (ABC). This equation is consistent with the data [only] in a qualitative sense.

Table 1: Example illustrations of *Trip limit effectiveness* and *Harvest in Tons*, with the base value for d (250,000); and with V=100, ABC=4000, X=1

M (#)	O (#)	O/d	L	H (tons)	Comments
50,000,000	500,000	2	.95	4200	Fish plentiful; little pressure not to comply with limits (.95)
30,000,000	300,000	1.2	.85	4600	Less fish; some pressure not to comply
24,000,000	240,000	.96	.8	4800	Moderate trip limits; limits are moderately effective (.8)
12,000,000	120,000	.48	.7	6000	Fishing limited; but limits are less effective
5,000,000	50,000	.2	.6	6667	Fishing severely limited; Limits not very effective (.6)

To address Opportunity 3, and model in a simple fashion how fishery economics might influence regulation, several modifications were made. The fishery sub model was modified to include two new parameters: *Breakeven Revenue Amount* (in dollars annually per vessel) and *Profit Fraction Necessary to maintain participation.*

Equations 4, 5, and 6 determine *Revenue per vessel*, and two new variables, *Simple Profit Fraction for participating in fishery*, and *pressure to increase fishing*.

$$R = \frac{F}{V} \quad [4] \qquad \mathrm{S} = \frac{(\mathrm{R - b})}{B} \quad [5] \qquad P = MAX(1,(1.5 - S)) \quad [6]$$

Where:
R = Revenue per vessel ($)
F = Fleet Gross Revenue ($)
S = Simple Profit Fraction for participating in fishery (dimensionless)
b = Breakeven Revenue Amount ($) (baseline value = $30,000)
P = pressure to increase fishing (dimensionless)

Table 2 explains the idea behind Equations 5 and 6, and the variables S and P.

Table 2: Interpretation of Simple Profit Fraction, S, and Pressure to Increase Fishing, P

S	Interpretation of S	P	Interpretation of P
-1	Every dollar spent to participate is a total loss	2.5	Strong pressure
-.5	The fisher is losing half of every dollar spent to participate in the fishery	2	Significant pressure
0	The fisher is receiving just enough revenue to offset the cost to participate.	1.5	Modest pressure
.5	Each dollar spent to participate is returning a gross profit of .5 dollar	1	No pressure
1	Each dollar spent to participate is returning a gross profit of 1 dollar	1	No pressure

Equations 7 and 8 determine how the number of vessels participating in the fishery changes over time, and how pressure to increase fishing influences the *ABC* set triennially in the fishery regulation sub model.

$$C = V * \left(\frac{n - S}{t} \right) \quad [7] \qquad\qquad A = U * \sqrt{P} \quad [8]$$

Where: C = Changing Participation in Fishery (Vessels/Year)
t = Fishers Participation Change Response Time (Year) (base value = 3 years)
n = Profit Fraction Necessary to maintain participation (dimensionless) (base value = .5)
U = Unadjusted ABC value (Metric Tons)

Table 3 illustrates the logic behind Equation 7, which calculates how rapidly fishers would leave or enter the fishery.

Table 3: Explanation for Equation 7, Changing Participation in Fishery, with basal values for parameters T=3 and N=.5; and when V = 100

S	(n-S)/t	C (vessels per year)	Rate vessels leave per year	Rate vessels enter per year	Comment
-1	1.5/3 = .5	50	50		No fish → fishers leave rapidly
-.5	1/3 = .33	33	33		
0	.5/3 = .167	17	17		Breakeven
.5	0	0			
1	-.5/3 = -.167	-17		17	Lucrative

Equation 8 states that the ABC value computed without regarding for pressure from the fishers is multiplied by square root of P, *pressure to increase fishing*. Since P varies from 1 to 2.5; ABC could be increased by over 50% when the pressure from fishers is very strong. This is probably not very realistic today, but may have been true in the past. There is no theoretical support for using a square root. It was chosen so that the response to pressure would be moderated in a nonlinear fashion.

To address Opportunity 4 and Weakness 4, regarding ocean health, a new stock was added, *Habitat Health*, along with an in-flow, *Regenerating Habitat*, and an out-flow, *destroying habitat* (see Equations 9 and 10 below). Two parameters were added to the model, *Max Habitat Health Recovery per year*, and *Fraction Habitat destroyed per vessel per year*. There is no data to support these parameters; their values were set so that plausible behavior resulted.

$$G = MIN((1 - HH), e) \quad [9] \qquad\qquad Y = V * i \quad [10]$$

Where: G = Regenerating Habitat (Habitat Units/Year)
HH = Habitat Health (Habitat Units)
e = Max Habitat Health Recovery per year (Habitat Units/Year)
Y = destroying habitat (Habitat Units/Year)
i = Fraction Habitat destroyed per vessel per year (Habitat Units/Vessel-Year)

The measure for ocean waste disposal was removed from the model, as its effects were inconsequential. The El Nino effect was not changed, nor was the logic for combining the two ocean health effects, which remained a simple product of the two measures, both of which were scaled so that their values varied from 0.8 to 1.0, where 1.0 meant no [adverse] impact.

To address Weakness 1 regarding the fact that the previous model did not use the endogenously calculated ABC, the formula that substituted historical ABC was removed. The previous logic for computing the unadjusted ABC value was not changed as it reflected the correct logic according to the regulatory rules (Pcouncil 2007). As mentioned above, the effect of *Pressure to Increase Fishing* was allowed to moderate ABC. This moderation was done annually rather than triennially, despite limited support in the data for this approach. (a few cases were found where ABC was updated more frequently than every three years).

To address Weakness 2 regarding the spawning process, the complex logic was replaced by simpler logic that unfortunately still remains rather arbitrary. A parameter was added to the model called *Surviving into juveniles per swawner w healthy ocean.* Equation 11 modeled the net rate for *Surviving* (births of juveniles).

$$K = w * J * Q \qquad [11]$$

Where: K = Surviving (Fish/Year)
w = Surviving into juveniles per spawner w healthy ocean (dimensionless) (baseline value=3)
J = Spawner Abundance (Fish)
Q = Ocean Health Measure (dimensionless)

While the value for w cannot be supported directly with data, the logic is much simpler than Model I, and requires just one parameter to be estimated, which is a significant improvement.

To address Weakness 5 (the fact that natural carrying capacity was ignored with respect to the natural death population death rates in the model), a variable called *Natural Mortality multiplier as pristine levels are approached* was added to the model (see Equation 12).

$$NM = e^{SU^2} \qquad [12]$$

Where, NM = Natural Mortality multiplier as pristine levels are approached (dimensionless)
SU = Spawner to Unfished Ratio (dimensionless)

SU varies from zero to one as the fish population approaches the natural carrying capacity. The square of SU remains near zero until SU approaches 1. Thus, NM remains near 1 until the fish population approaches the carrying capacity. Neither the exponent of 2 for the SU term, nor the implied parameter of 1 in front of SU, can be supported theoretically. The rationale for Equation 12 is only that it provides a simple way to invoke a non-linear multiplier for death fraction as the carrying capacity is approached.

The mortality fractions for both juveniles and mature fish were modified to be the product of the constants utilized previously and the mortality multiplier. Since the multiplier is slightly greater than 1 at basal conditions, the constants were reduced slightly in order to preserve the baseline values.

Figure 2 shows the overall structure (flow diagram) for Model II. The corresponding equations and parameters are provided in Appendix A.

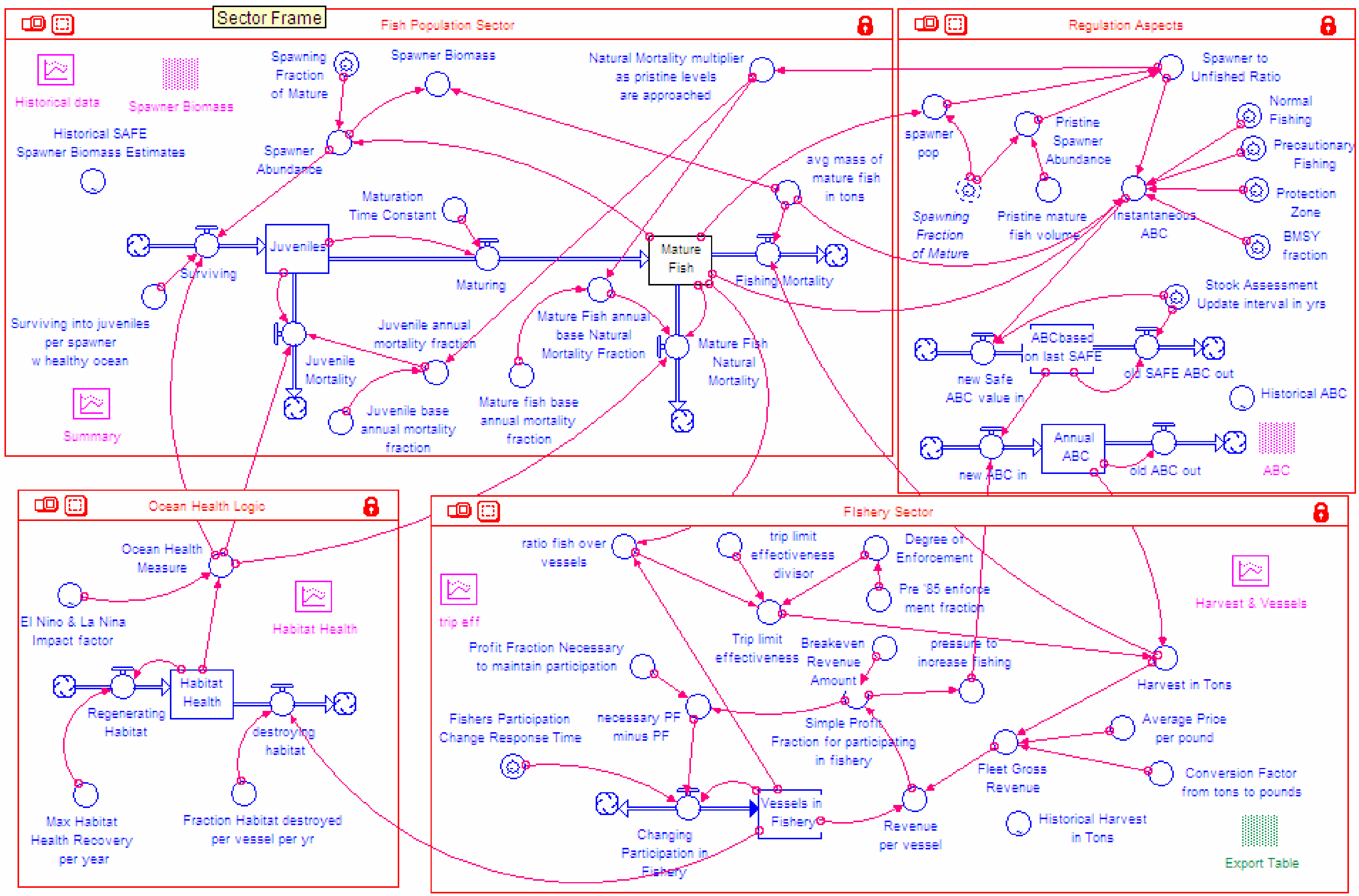

Figure 2: Model II flow diagram.

Step 5

Six model parameters in Model II were adjusted experimentally by the researcher to achieve the best possible fit with historical data. This was done manually, and resulted in a heightened appreciation for the feedback dynamics of the model. Model versus actual data was plotted for the three key variables, and the mean absolute error was calculated for each variable.

Step 6

More recent data was obtained from two sources, both obtained from the Pacific Fisheries Management Council website (Pcouncil 2007), the Final Environmental Impact Statement (FEIS 2007), and the Status of the Yellowtail Rockfish in 2004 (Yellowtail 2005).

Step 7

Model prediction error for Model I and Model II was calculated for the three key variables, based on the data obtained in the previous step. Model fitness error was also re-calculated since the newly obtained data also contained revisions to some of the historical data. Model parameters did not need to be revised because the data that was corrected had previously been ignored because it *looked* erroneous.

4. RESULTS

This section contains four subsections: Model I results, Model II results, updated actual data, and model prediction errors based on the updated actual data.

4.1. Model I Results

Figure 3 shows the Model I results vs. the actual data for the key indicator variables. Note that the last actual historical data point was slightly different for each measure. The degree of error does not inspire confidence. The mean absolute errors were 39% for *biomass*, 44% for *ABC*, and 34% for *harvest*; and the error for individual indicators in some years exceeded 200%! This extraordinary error appeared to possibly be due to a bad data point for 1995 in the actual data. Predicted values for each measure from Model I were saved for subsequent analysis (see Section 4.4).

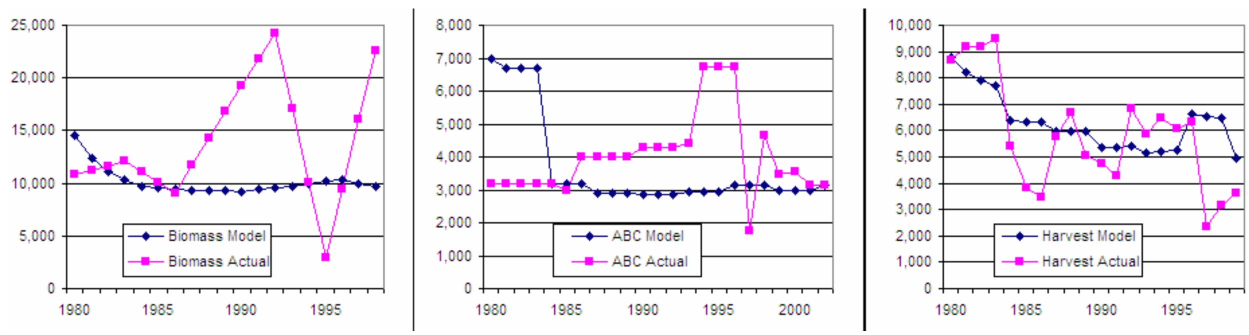

Figure 3. Model I results vs. actual data for *biomass*, *ABC*, and *harvest* (Metric Tons)

4.2. Model II Results

Table 4 shows the parameters that were adjusted, their plausible range, baseline values, and final values. As Table 4 indicates, the final values were slightly modified for three parameters, but for the other three parameters, the baseline value could not be improved upon. The process for this experimentation was time-consuming, and led to useful insights about the model, and potentially about the yellowtail rockfish fishery, which will be discussed later.

Table 4: Parameters Adjusted to Achieve Best Fit with Historical Data

Symbol	Parameter	Plausible Range	Baseline Value	Final Value
W	Surviving into juveniles per spawner w healthy ocean (#)	1 - 5	3	3.5
--	Recruit base annual mortality fraction (#)	.1 - .3	.2	.23
--	Initial value for Mature Fish (#)	20 – 30M	23.5M	27M
--	Pre '85 enforcement fraction (#)	.5 - .8	.7	.7
t	Fishers Participation Change Response Time (Yrs.)	2 – 5	3	3
d	trip limit effectiveness divisor (fish/vessel)	200 – 300K	250K	250K

Figure 4 provides the model vs. actual results for *harvest*, *biomass*, and *ABC* for Model II. The mean absolute fit errors for Model II were 35% for *biomass*, 25% for *ABC*, and 27% for *harvest*, which is a modest improvement over Model I. The predicted values for each measure from Model II were also saved for subsequent analysis (Section 4.4). Model II predicted values for *harvest* were nearly twice as large as those predicted by Model I. This huge discrepancy was very disconcerting to the researchers, but Model II's prediction for a relatively plentiful fishery in the future was quite robust with respect to parameter changes.

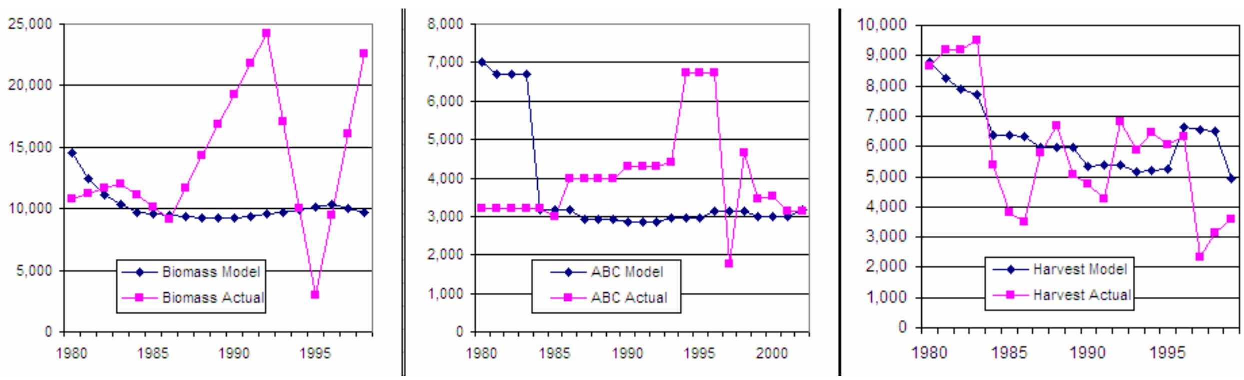

Figure 4: Model versus Actual for Key Indicators for Model II (Metric Tons)

4.3. New and Revised Actual Data

Table 5 provides the revised actual data for key variables that were gleaned from recently released documents. These data were held back (not looked at) until this point so as not to influence the predictions made with Model II.

Also of interest in the recently released documents was the statement that since 2003, commercial fishing for yellowtail rockfish has been substantially curtailed because this fishery co-occurs with other fisheries that are classified as depleted: the canary rockfish and widow rockfish (FEIS 2007, pg. 259).

Table 5: New Data from 2005 and 2006 Reports (Metric Tons)

					Decision Table	
	Harvest	Spawning Biomass	ABC	MSY (OY)	Moderate Catch (F50%)	Likely Sp. Biomass
1992		18,000				
1995		15,822				
1998		15,735				
1999		16,955				
2000	3735	17,909	3539			
2001	2142	18,467	3146			
2002	1260	18,783	3146			
2003	551	16,324	3146			
2004	618	17686	4320			
2005	892	16915	4320		4940	17,232
2006				4680 (4548)	4743	16,169
2007					4634	15,717

Table 5 also provides revised estimates for actual spawning biomass for the years 1992, 1995, and 1998. The original data points for these years were suspect due to their very high degree of variability. The revised data are much more plausible. Table 5 also shows MSY and OY (maximum sustainable yield and optimum yield) for 2006, and reasonable allowable catch estimates for 2005 to 2007. These are provided for comparison to model predictions, since actual harvest has essentially been suspended.

4.4. Model Prediction Error

Figure 5 shows the actual *biomass*, *ABC*, and *harvest* up to the present (2007), along with the fitted and predicted values from Model I and from Model II. The Model II *biomass* prediction was considerably closer to the actual values than Model I. However, as noted earlier, Model II predicted much larger values for *ABC* and *harvest*, and thus, despite a better fit to the historical data, Model II's predictions were much less accurate than Model I.

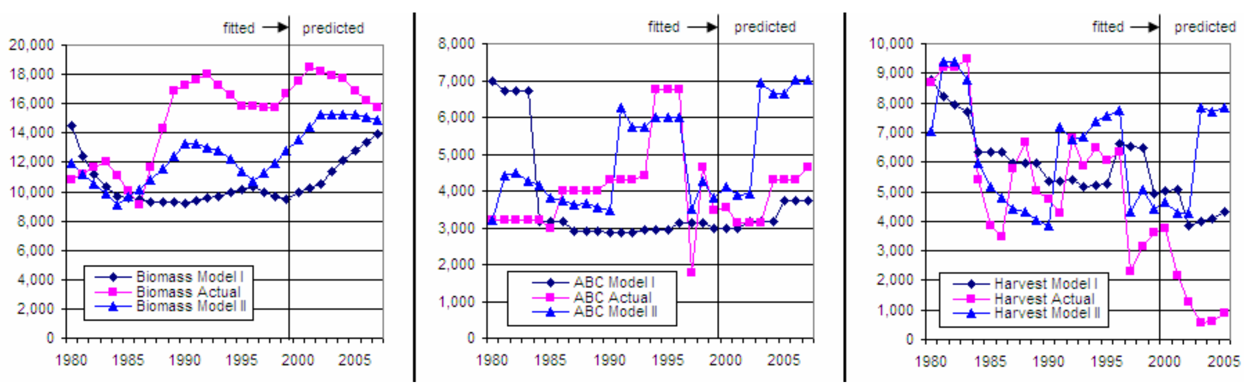

Figure 5. Predicted and actual *biomass*, *ABC*, and *harvest* for Model I and Model II

Table 6 shows the average model fit error and model prediction error for each variable for both models. The revised figures shown in Section 4.4 for actual spawning biomass were use for the mean absolute error calculations. Consequently, the model fit errors shown in Table 6 for spawning biomass for Model I and Model II do not exactly match those reported earlier. As Table 6 shows, the Model II fit to historical data was significantly better than Model I, with percentage error averaging 23% versus 38%. This advantage held with respect to predicting *spawning biomass*, where the prediction error for Model I was comparable to its fit error for this variable. Model II prediction error for *spawning biomass* was actually less than its model fit error.

Table 6: Model Fit and Model Prediction Mean Absolute Errors, expressed as a percentage

		Spawning Biomass	ABC	Harvest	Average MAE
Model Fit Error (n=20)	Model I	30%	49%	34%	38%
	Model II	19%	24%	27%	23%
Model Prediction Error (n=6 for Harvest, 8 for SB and ABC)	Model I	31%	12%	323%	122%
	Model II	14%	51%	601%	222%

Given the fact that the fishery was closed to fishing for reasons totally external to the model, neither model could have predicted the *harvest* accurately. The Model I predictions for *ABC*, which represents the regulation of the fishery, were much more accurate than Model II, a sobering result, since endogenously modeling regulation was a key focus of Model II.

5. DISCUSSION

One possible explanation for poor predictive performance for Model II with regard to *ABC*, despite have predicted *spawning biomass* reasonably accurately, is that the model may not have properly captured the exact figures and logic used by regulatory agencies. Small changes can have a significant effect on the numbers. For example, with the current levels of *spawning biomass*, our understanding of regulatory practice is that "normal fishing" would be allowed, meaning that *ABC* would be 18% of *mature fish*. However, if the regulators chose to leave the fishery in the "precautionary" category, ABC would be 12% of the *mature fish.* This is difference is sufficient to explain virtually all of the Model II model prediction error for *ABC*.

Curiously, Model I predicted *ABC* much more accurately, but this is because the Model I prediction for *spawning biomass* was considerably low, which placed the fishery in the "precautionary" category, which happened to mirror regulatory reality.

As is nearly always the case when using the System Dynamics method, the process of creating and working with the models was at least as useful and informative as the actual numerical results. It became clear to the researcher while working with the model that the yellowtail rockfish fishery is recovering nicely from the over fishing that took place during the early 1980's. The researcher also gained a heightened appreciation for the delicate balance that exists between the fish, the fishers, and the regulatory process. Several parameters are critical to maintaining this balance, including those shown in Table 4, especially the *Fishers Participation Change Response Time*.

Returning to research questions posed at the outset, this research raises doubts regarding the prospects for endogenously modeling fishery regulation. One concern is the presence of exogenous events that impinge on the regulatory process, such as closing a given fishery not because it is in danger, but rather because other fisheries that are co-mingled with it are in danger. Another concern is the fact that regulators use judgment when applying regulatory rules, and do not (and should not) set rules based only on the numbers. This is a significant challenge for those who seek to endogenously model the regulatory process, a finding that seems to be disconcertingly supportive of the recent claim by Pilkey and Pilkey-Jarvis (2007) that environmental scientists "cannot predict the future" even with (or perhaps more accurately, because of) their reliance on quantitative models.

The second research question asked whether the degree to which fishers comply with imposed limits could be modeled. Model II incorporated several features to address this question: *trip limit effectiveness*, *degree of enforcement*, and *pressure to increase fishing.* In aggregate, the presence of these variables in the model did appear to help improve the Model II fit with historical data. But the specific formulae and parameters were speculative and no theoretical support was provided. Furthermore, the poor accuracy of predicted *harvest* by Model II raises considerable doubt. More research will be needed to adequately address this question.

The implications for researchers seeking to endogenously model fishery management processes are sobering. This task is likely to prove to be exceedingly difficult to accomplish. On the other hand, policy-makers are not likely to be very surprised by these results; rather, they will probably see them as further support for their instinctual skepticism regarding formal models of policy processes.

REFERENCES

Brekke AJ and E Moxnes (2003). Do numerical simulation and optimization results improve management? Experimental evidence, *J. of Econ. Beh. & Org. Vol 50*: 117-131.

Dietz, T, Ostrom, E., and PC Stern (2003). The Struggle to Govern the Commons. *Science, Vol. 302*, 1907-1912.

Dudley, RG and CS Soderquist (1999). A Simple Example of How System Dynamics Modeling Can Clarify and Improve Discussion and Modification of Model Structure. Written version of presentation to the 129th Annual Meeting of the American Fisheries Society, Charlotte, North Carolina.

Dudley, RG (2003). A Basis for Understanding Fishery Management Complexities, Proc. 21st Int'l Sys Dyn Conf.

ECOWORLD (2000) Ecoworld Global Environmental Community, *West Coast Groundfish Fisheries declared 'Federal Disaster*. (http://www.ecoworld.org/Home/articles2.cfm?TID=84)

FEIS (2007). http://www.pcouncil.org/groundfish/gfspex/07-08/F0708GF_Spex_FEIS.pdf

Ford A (1999). *Modeling the Environment: An Introduction to System Dynamics Modeling of Environmental Systems*. Ch. 14. Island Press.

Hardin G (1968). The tragedy of the commons, *Science Vol. 162*, 1243.

Holland, D and RJ Brazee (1996). Marine Reserves for Fisheries Management, *Marine Resource Economics*. [need vol, pgs]

Jentoft, S and JK Mikalsen (2003). A vicious circle? The dynamics of rule-making in Norwegian fisheries, Marine Policy [need vol, pgs.]

Magnuson-Stevens Fishery Conservation Act (1996). Public Law 94-265, as amended through Oct. 11, 1996.

Moxnes, E (1998). Overexploitation of Renewable Resources: The role of misperceptions. *Journal of Economic Behavior and Organization* 37(1):107-127.

Moxnes, E (2001). Not only the tragedy of the commons: misperceptions of feedback and policies for sustainable development, *System Dynamics Review, Vol.16*(4): 325-348.

Moxnes, E (2004). Misperceptions of basic dynamics: the case of renewable resource management, *System Dynamics Review, Vol.20*(2): 139-162.

Moxnes, E (2005). Policy sensitivity analysis: simple versus complex fishery models, *System Dynamics Review, Vol.21*(2): 123-145.

Pcouncil (2007). http://www.pcouncil.org

Pilkey, OH and L Pilkey-Jarvis (2007). *Useless Arithmetic. Why Environmental Scientists Can't Predict the Future*, Columbia Univ. Press.

Ruth, M., and J. Lindholm (1996). Dynamic modeling of multispecies fisheries for consensus building and management. *Environmental Conservation* 23:332-342.

Sampson, D. (2001). FindFMSY: A Fishery Simulator for Exploring Constant Harvest Rate Policies. (http://hmsc.oregonstate.edu/projects/findfmsy/)

Schaefer, M.B. (1954). Some Aspects of the Dynamics of Populations important to the Management of Commercial Marine Fisheries. *Bulletin of the Inter-American tropical tuna commission 1, 25-56.*

Van den Belt, M, L Deutsch, and A Jansson (1988). A Consensus-Based Simulation Model for Management in the Patagonia Coastal Zone. *Ecological Modeling* 110, 79-103.

Wakeland, W, O. Cangur, G Rueda, and A Scholz (2003). A System Dynamics Model of the Pacific Coast Rockfish Fishery, Proc. 21st Int'l Sys Dyn Conf.

Yellowtail (2005). http://www.pcouncil.org/groundfish/gfsafe0406/Yellowtail_Rockfish_Final_0506.pdf

Appendix A: Model II Equations

Fish Population Sector

Juveniles(t) = Juveniles(t - dt) + (Surviving - Maturing - Juvenile__Mortality) * dtINIT Juveniles = 37000000
INFLOWS:
Surviving = Spawner__Abundance*Surviving_into_juveniles__per_spawner_w_healthy_ocean*Ocean_Health_Measure
OUTFLOWS:
Maturing = Juveniles/Maturation_Time_Constant
Juvenile__Mortality = Juveniles*Juvenile_annual_mortality_fraction/Ocean_Health_Measure
Mature__Fish(t) = Mature__Fish(t - dt) + (Maturing - Mature_Fish__Natural_Mortality - Fishing_Mortality) * dtINIT Mature__Fish = 27000000
INFLOWS:
Maturing = Juveniles/Maturation_Time_Constant
OUTFLOWS:
Mature_Fish__Natural_Mortality = (Mature_Fish_annual_base_Natural___Mortality_Fraction*Mature__Fish)/Ocean_Health_Measure
Fishing_Mortality = Harvest_in_Tons/avg_mass_of__mature_fish__in_tons
avg_mass_of__mature_fish__in_tons = 2.26/2000
Juvenile_annual_mortality_fraction = Juvenile_base_annual_mortality_fraction*Natural_Mortality_multiplier_as_pristine_levels_are_approached
Juvenile_base_annual_mortality_fraction = .23
Maturation_Time_Constant = 4
Mature_Fish_annual_base_Natural___Mortality_Fraction =
Mature_fish_base_annual_mortality_fraction*Natural_Mortality_multiplier_as_pristine_levels_are_approached
Mature_fish_base_annual_mortality_fraction = .09
Natural_Mortality_multiplier_as_pristine_levels_are_approached = EXP(Spawner_to__Unfished_Ratio^2)
Spawner_Biomass = Spawner__Abundance*avg_mass_of__mature_fish__in_tons
Spawner__Abundance = Mature__Fish*Spawning_Fraction_of_Mature
Spawning_Fraction_of_Mature = 0.3857
Surviving_into_juveniles__per_spawner_w_healthy_ocean = 3.5
Historical_SAFE__Spawner_Biomass_Estimates = GRAPH(time)
(1980, 10785), (1983, 12057), (1986, 9093), (1989, 16861), (1992, 18000), (1995, 15822), (1998, 15735), (2001, 18467), (2004, 17686)

Fishery Sector

Vessels_in__Fishery(t) = Vessels_in__Fishery(t - dt) + (- Changing_Participation_in_Fishery) * dtINIT Vessels_in__Fishery = 300
OUTFLOWS:
Changing_Participation_in_Fishery = Vessels_in__Fishery*necessary_PF__minus_PF/Fishers_Participation_Change_Response_Time
Average_Price_per_pound = 0.34
Breakeven__Revenue_Amount = 30000
Conversion_Factor_from_tons_to_pounds = 1000*2.2
Degree_of__Enforcement = Pre_'85_enforce_ment_fraction+STEP((1-Pre_'85_enforce_ment_fraction),1984)
Fishers_Participation_Change_Response_Time = 3
Fleet_Gross__Revenue = Harvest_in_Tons*Conversion_Factor_from_tons_to_pounds*Average_Price_per_pound

Harvest_in_Tons = Annual__ABC/Trip_limit_effectiveness
necessary_PF__minus_PF = Profit_Fraction_Necessary_to_maintain_participation-Simple_Profit_Fraction_for_participating_in_fishery
pressure_to__increase_fishing = MAX(1,(1.5-Simple_Profit_Fraction_for_participating_in_fishery))
Pre_'85_enforce_ment_fraction = .7
Profit_Fraction_Necessary_to_maintain_participation = .5
ratio_fish_over_vessels = Mature__Fish/Vessels_in__Fishery
Revenue__per_vessel = Fleet_Gross__Revenue/Vessels_in__Fishery
Simple_Profit_Fraction_for_participating_in_fishery = (Revenue__per_vessel-Breakeven__Revenue_Amount)/Breakeven__Revenue_Amount
Trip_limit_effectiveness = (1-.5*EXP(-1*ratio_fish_over_vessels/trip_limit__effectiveness__divisor))*Degree_of__Enforcement
trip_limit__effectiveness__divisor = 250000
Historical_Harvest_in_Tons = GRAPH(Time)
(1980, 8664), (1981, 9184), (1982, 9185), (1983, 9500), (1984, 5393), (1985, 3830), (1986, 3478), (1987, 5785), (1988, 6670), (1989, 5046), (1990, 4754), (1991, 4273), (1992, 6822), (1993, 5861), (1994, 6456), (1995, 6069), (1996, 6344), (1997, 2323), (1998, 3144), (1999, 3598), (2000, 3735), (2001, 2142), (2002, 1260), (2003, 551), (2004, 618), (2005, 892)
<u>Ocean Health Logic</u>
Habitat__Health(t) = Habitat__Health(t - dt) + (Regenerating_Habitat - destroying__habitat) * dtINIT Habitat__Health = .85
INFLOWS:
Regenerating_Habitat = MIN((1-Habitat__Health),Max_Habitat_Health_Recovery__per_year)
OUTFLOWS:
destroying__habitat = Vessels_in__Fishery*Fraction_Habitat_destroyed_per_vessel_per_yr
Fraction_Habitat_destroyed_per_vessel_per_yr = .07/300
Max_Habitat_Health_Recovery__per_year = .025
Ocean_Health_Measure = Habitat__Health*El_Nino_&_La_Nina_Impact_factor
El_Nino_&_La_Nina_Impact_factor = GRAPH(time)
(1980, 0.95), (1982, 0.855), (1984, 0.96), (1986, 0.975), (1988, 0.96), (1990, 0.9), (1992, 0.88), (1994, 0.8), (1996, 0.95), (1998, 0.95), (2000, 0.905)
<u>Regulation Aspects</u>
ABCbased__on_last_SAFE(t) = ABCbased__on_last_SAFE(t - dt) + (new_Safe__ABC_value_in - old_SAFE_ABC_out) * dtINIT
ABCbased__on_last_SAFE = 3200
INFLOWS:
new_Safe__ABC_value_in = PULSE(Instantaneous_ABC,1980,Stock_Assessment_Update_interval_in_yrs)
OUTFLOWS:
old_SAFE_ABC_out = PULSE(ABCbased__on_last_SAFE,1980,Stock_Assessment_Update_interval_in_yrs)
Annual__ABC(t) = Annual__ABC(t - dt) + (new_ABC_in - old_ABC_out) * dtINIT Annual__ABC = 3200
INFLOWS:
new_ABC_in = PULSE(ABCbased__on_last_SAFE*pressure_to__increase_fishing^.5
, 1980,1)
OUTFLOWS:

old_ABC_out = PULSE(Annual__ABC,1980,1)
BMSY__fraction = 0.4
Instantaneous_ABC = avg_mass_of__mature_fish__in_tons*(if Spawner_to__Unfished_Ratio>BMSY__fraction then
Normal_Fishing*Mature__Fish else
if Spawner_to__Unfished_Ratio>0.25 then Precautionary_Fishing*Mature__Fish
else
if Spawner_to__Unfished_Ratio>0.1 then Protection_Zone*Mature__Fish
else
0)
Normal_Fishing = 0.18
Precautionary_Fishing = 0.12
Pristine_mature__fish_volume = 70000000
Pristine_Spawner_Abundance = Spawning_Fraction_of_Mature*Pristine_mature__fish_volume
Protection_Zone = 0.6
spawner_pop = Mature__Fish*Spawning_Fraction_of_Mature
Spawner_to__Unfished_Ratio = spawner_pop/Pristine_Spawner_Abundance
Stock_Assessment_Update_interval_in_yrs = 3
Historical_ABC = GRAPH(time)
(1980, 3200), (1981, 3200), (1982, 3200), (1983, 3200), (1984, 3200), (1985, 3000), (1986, 4000), (1987, 4000), (1988, 4000), (1989, 4000),
(1990, 4300), (1991, 4300), (1992, 4300), (1993, 4400), (1994, 6740), (1995, 6740), (1996, 6740), (1997, 1773), (1998, 4653), (1999, 3465),
(2000, 3539), (2001, 3146), (2002, 3146), (2003, 3146), (2004, 4320), (2005, 4320)