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Adaptive Environmental Assessment and Management of the Pacific Coast Sebastes Fishery

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ADAPTIVE ENVIRONMENTAL ASSESSMENT AND MANAGEMENT OF

THE PACIFIC COAST SEBASTES FISHERY

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Abstract

Through the construction and testing of a model for fleet and resource dynamics of the INPFC Vancouver/Columbia Sebastes fishery, using an Adaptive Environmental Assessment and Management (AEAM) workshop approach, we gained several new perspectives on how the fleet and the stock will respond to fishery regulation in the form of trip quotas and frequency limits. The key to examining this question using a model appears to be how to represent the fleet. We divided the fleet into 3 vessel length classes based on different fishing patterns indicated by catch data. Most critical in investigating fleet dynamics is the process by which the fleet translates per trip quotas and limits on trip frequency into total catch and its species distribution, through modifying their own targeting strategies (e.g., changing gear) or through economic pressures which may change the size and composition of the fleet. A number of approaches were tried to develop both behavioral and empirical modules for fleet response. The empirical approach was to examine the catch data from 1981-83 by vessel class to develop hypotheses on how management regulation might effect trip frequency, trip length and targeting. A number of behavioral approaches were tried including:
1) developing an algorithm on the basis of profit optimization (constrained by quotas and trip frequency limits); and 2) attempting to tailor the output and variables in the model such that they were adequate to represent the system in a way compatible with the "model" used by the processors and fishermen and to search for responses through a gaming situation, with workshop participants taking roles in the regulating fishery and processor sectors. The workshop

and model were very effective at fostering communication between participants including industry representatives, fishery biologists, and regulators.

Future work suggested includes: 1) data analysis to consider the variability between vessels in a vessel class; 2) refinement of the model to include a behavioral hypotheses on fleet effort response to specific regulations, variability within vessel classes, and more fish stock categories; 3) further data gathering to study how tightly linked different species are through catch and targeting and to get solid information on fleet targeting and 4) conduct future workshops involving industry in model evaluation and game playing.

1. Introduction

This report develops the objectives, history, accomplishments and future direction of an exercise in the application of Adaptive Environmental Assessment and Management (AEAM) to examine the effect of management controls on the U.S. Pacific coast Sebastes groundfish fishery. The AEAM approach developed by C. S. Holling and his associates at the University of British Columbia (Holling 1978) emphasizes the use of modeling tools and a workshop framework to bring together resource managers, economists and biologists to address a resource management or impact assessment problem. Important to the success of this kind of a workshop is a modeling team that can develop, modify and display results of a simulation model, serving to organize the ideas of the workshop participants and to focus on the interactions between various parts of the problem. Planning and implementation of this AEAM workshop(s) was carried out by a core group which met several times before the workshop. The approach we adopted used AEAM as a starting point and diverged from the overall procedure as we saw fit.

The problem addressed in the workshop was to assess the effects of trip limits imposed by the Pacific Fishery Management Council (PFMC) on boats targeting on fish of the genus Sebastes (rockfish), upon the fishing fleet, the fishing industry (fish processors) and the Sebastes stock itself. This problem was presented to the core group by the Groundfish Management Team (GMT) which serves in an advisory capacity to the PFMC. The team has been grappling with how to answer questions posed by members of the PFMC about what the impact of regulations would be on the fleet. GMT expertise and data available to the team were focused toward assessing the present stock biomass and recommending annual quotas in the form of Acceptable Biological Catch (ABC) and precluded present consideration of the broader bioeconomic problem. Impetus for this modeling exercise also came from a working group within the Northwest and Alaska Fishery Center (NWAFC), the westcoast Research/Management Cluster, which recognized that an integrated approach to fishery management, involving treatment of the fishery and its economics as well as the fish stock, was needed especially for treatment of multispecies fisheries where the interaction between species, via the various fishing strategies and by-catch, is important.

Another major benefit expected from the workshop approach was to bridge the gap between industry, represented to the PFMC by the Industry Advisory Panel (IAP), and stock protection advocates, represented to the PFMC primarily by the GMT. These two groups have historically related to each other as adversaries. By having both fishermen's representatives and management team members at the workshop we hoped to establish communication between these different interest groups at the planning level rather than in the evaluation of a finished product.

Planning for the workshop began in mid-February 1984 with a number of discussions between Francis and Swartzman. A series of meetings with interested persons resulted in the formation of a core planning group in mid-March. The group then had its first meeting in early April. This was followed by a second core group meeting in early May and by the workshop itself on June 4-6. The core group played an active and busy role in workshop preparation including:

1) Defining and bounding the original problem,
2) Choosing model variables and forming a preliminary "shadow" model,
3) Reviewing relevant data for preliminary parameter estimates including a large amount of computerized data manipulation,
4) Planning the workshop agenda,
5) Suggesting and deciding upon workshop participants,
6) Developing the format and objectives for a simulation game which would replicate the procedure followed by the PFMC in setting quotas and methods for implementing these quotas (e.g., trip limits). This game was designed to gain insight into how processors, fishermen and the resource respond to management decisions by PFMC.

Our goals for the workshop were:

1) To build a model of the Pacific groundfish fishery which provides a simple, realistic representation of the impact of management decisions on the INPFC Vancouver-Columbia area Sebastes Complex stock and fishery.

2) To demonstrate the usefulness of an AEAM workshop as an aid to investigating the effect of management alternatives in a multispecies fishery.

3) To review relevant data with an idea to assessing its adequacy for addressing the question at hand and to suggest where additional data are needed.

4) To generate enthusiasm for a continuation of the dialog between different parties in the Sebastes fishery.

5) To refine the shadow model and develop communication tools for describing modeling ideas and model output to managers and fishermen.

6) To demonstrate the usefulness of microcomputers as an interactive tool for data analysis and workshop style modeling.

2. History of the West Coast Sebastes Fishery and Its Management

Rockfish (genus Sebastes and Sebastolobus) comprise a major biological and economic segment of the Pacific coast trawl fishery. The life history of rockfish is very diverse, with longevity ranging from 11 to over 100 years. Growth and maturity also differ widely as does geographic distribution of the species. Despite this diversity the ex-vessel price is fairly constant among rockfish species, ranging between about 17 cents a pound for widow rockfish to 20 cents a pound for Pacific ocean perch and similar species.

Recent exploitation of rockfish has undergone radical change since the Magnuson Fisheries Conservation and Management Act (MFCMA) was enacted in 1976. Domestic catch has increased radically since that time and recent domestic catches have exceeded the foreign catches of previous years. The fishery pattern for the heavily exploited rockfish has been one of species substitution as a number of species stocks have been depleted due to overfishing. This includes the Pacific ocean perch and, more recently, the widow rockfish (Gunderson 1984). Figure 1 (Demory unpublished manuscript

Figure 3) shows the pattern of increased exploitation and species substitution that has occurred in the fishery.

Under terms of the MFCMA, a Pacific Coast Groundfish Plan was developed. Mechanisms were set up through the PFMC for setting annual suggested quotas (Acceptable Biological Catches - ABCs) and indicating how these quotas are to be met. Since late 1982 coastwide widow rockfish and (since early 1983) the Vancouver/Columbia area *Sebastes* fishery have been regulated through the imposition of limits on catch per trip and, since mid 1983, trip frequency. Table 1 indicates that since the initiation of trip limits on these fisheries there has been a general downward trend in the catch limits per trip. Trip limits are applied in an adaptive fashion and, based on a close monitoring of landings (monthly), are used to maintain the fishery at ABC levels. Although the rationale behind the imposition of trip limits has been to spread catch more evenly over time and among vessels and ports than with other management options, such as time-area closures, closure of the entire rockfish fishery toward the end of 1983 indicated that this objective may be difficult to meet. Also in some cases the fleet response to trip limits has been counter to the intent of the regulations, with increases in exploitation rate actually resulting. These facts indicated that analysis of historical fishing patterns and stock responses was insufficient to solve the basic management problems, and that a different approach to the problem was necessary.

3. Workshop Preparation

Figure 2 gives a time line of major tasks accomplished in preparation for the AEAM workshop. This divides activities into logistics, meetings, data analysis and modeling. The time line for each of these categories shows the striking increase in activity as the time of the workshop approached.

The time period before the first core group meeting was highlighted by preparation and selection of background material for the core group, formation of the core group, a series of meetings to set up the administrative structure of the project and solicitation of GMT support and guidance.

3.1 First core group meeting

Core group members are listed in Appendix Table 1.1. By the time of the first core group meeting we had already decided that the workshop would focus on management of the Vancouver/Columbia *Sebastes* complex. After an introduction to the AEAM approach and a review of current information on and management of the groundfish stock, the first concrete step in the AEAM approach was for the core group to bound the problem. Problem bounding consisted of narrowing the spatial area of consideration to the INPFC Vancouver/Columbia region (a map of the INPFC regions is shown in Figure 3), restricting ourselves to trip limits from among the various management options and narrowing our primary focus to the major rockfish species. We also defined some preliminary variables of interest in the stock, fishing fleet, and processor sectors and identified some indicators which might be useful as model outputs.

Major problems discussed at this initial core group meeting were how to deal with spatial variability of the stock within the Vancouver/Columbia region and how to subdivide the fleet from a bioeconomic perspective. We decided at that time that one of the core group members (Susan Hanna) would examine the Oregon groundfish fishery trip ticket and logbook data bases with an eye to what features best characterize fishing vessels. We were particularly interested in whether the fleet could be subdivided into a small number of vessel classes, and if so what characteristic of the vessels could be best used as an index for this subdivision. A suggested criterion for investigation was vessel length. Three categories were suggested including small ("sole boats") typically ranging in size up to 60', medium sized (rockfish boats) in the 60'-80' range and large boats (>80') with high fishing power and efficient gear ("search and destroy" vessels). We were also concerned about the best spatial subdivisions for the model and tentatively decided on using major ports to define spatial regions: Coos Bay, Newport, Astoria, Ilwaco, Westport, and Puget Sound. This decision was made knowing that fishing boats can make landings at several ports during a season and that this could lead to some inaccuracy on where the boats actually were fishing when port alone is used as an index of fishing area.

A preliminary list of potential workshop participants was assembled at the first core group meeting. We decided to limit the workshop to 20 participants, under the operating principle that having more participants would be unwieldly and would discourage interactions.

The time between the first and second core group meetings was spent on review of relevant models, further data analysis, and a visit to a processing plant to get further information on some of the variables and concerns of the processing sector. Logistics involved the purchase of an IBM XT microcomputer on which to build the model. This computer arrived several days before the second core group meeting.

3.2 Second core group meeting

At their second meeting, the core group finished bounding the problem. Objectives for the workshop were discussed and a final list of prospective participants was prepared. Equations were suggested for a preliminary shadow model and the decision was made to code this model on the IBM XT and have it running in time for the workshop. A list of parameters was made and assignments were made among core group members for preliminary estimation of parameters. A number of papers on bioeconomic analysis of the Atlantic redfish (Sebastes mentella) fishery were reviewed for ideas on how to structure the processor and fleet economic model (Doubleday et al. 1984, Huson et al. 1984), and a preliminary shadow model structure for the processing and fishing fleet sector economics was extracted. There are, however, some striking differences between the single species, sole owner redfish fishery and our multispecies, open market Sebastes fishery which made us believe that the processor and fleet economics would have to be revised.

A great deal of time was taken at the second core group meeting in reviewing the data analysis by Susan Hanna and in deciding how to best characterize the fleet. We decided that the catch and targeting pattern was similar for boats within each of 3 size classes, broken into length groups as suggested at the first core group meeting. We recognized, however, that there is a great deal of variability in catch, and in the species distribution of catch among boats within each of the fleet size categories depending upon such factors as the experience of the skipper, the economic status of the boat, the horsepower of the boat, the type of gear carried, and the needs of the major processor for the vessel. Some of these factors are tangible and others intangible. We agreed, initially, to neglect them and to start with the simplest fleet categorization possible.

It became apparent from the data that the rockfish fishery interacted strongly with the flatfish and sablefish fisheries, and that in many cases the same boats were taking both groups of fish. Furthermore, we expected that restrictions on one fishery would affect catches of species in the other. As such, we added Dover sole (Microstomus pacificus) (the most abundantly caught flatfish species) and sablefish (Anaplopoma fimbria) to the rockfish groups already considered.

We decided to use a quarterly time step for the model, this being a compromise between our desire to represent the dynamic nature of changing target strategies in the fishery on as small a time scale as possible, and the lack of data on a small time scale to estimate model parameters and check model behavior. Since the shadow model was quite similar in structure to the model eventually used at the workshop it will be discussed in the workshop section and not here.

At the second core group meeting we decided to use a gaming situation as a means to develop ideas for model modification at the workshop. The impetus behind the game was the recognition by core group members that we had little understanding of the relationship between the processor and the fishing fleet and how they have responded to the trip limits of the past few years. Also we were interested in what role industry might play in influencing the trip limits set by PFMC. The game, as we initially envisioned it, would simulate the process of setting trip limits and ABC's by the PFMC and would also simulate the response of the fleet through species targeting and effort limitation by quarter through decisions made by the game players. The model would then produce catch statistics based on the effort and targeting decisions of the fleet (after bargaining with the processors) and trip limits would be revised quarterly by the game players depending upon these catches in relation to the ABC. Thus each sector (PFMC, fishery, processor) would have a decision in each round. After an initial learning period on game rules we expected that players, who for the most part would be playing roles they occupied in real life, would shed light on how the groups interact, and might present a means to model this interation. Our inexperience in game facilitation led us to consult with Sharon Lundin and Niel Doherty (NOAA staff having experience in group facilitation) to learn how to facilitate the game and to set workable game rules.

3.3 Final workshop preparation

The time between the second core group meeting and the workshop was dominated by two activities--coding and debugging the shadow model and preparing for the game. The first stage was complicated by the fact that the IBM XT system was new to us. Thus, time had to be spent learning the operating system. The model was coded in FORTRAN77 and input-output was handled by RBASE, a data base management system. In retrospect, the latter decision turned out to be a poor one, resulting in a cumbersome and tedious procedure for changing parameters and displaying output. This was rectified after the workshop when a more standard input-output format was used. The model will be described in the next section.

Preparation for the game involved a series of meetings which resulted in the production of a set of game rules (Appendix 2) and a dry run of the game which was done a few days before the workshop. At this time we discovered that the game took a long time to play because players were not familiar with the rules and there were no set beginning play strategies (as for example in chess). Also we recognized the need during the day for flexible model output because players often wanted data (e.g., last year's catch statistics) displayed in ways that we had not originally anticipated.

Model variables for the shadow model are given in Table 2 and a schematic representation is given in Figure 4. Major variables of interest are represented in double boxes, less important variables are in single boxes and parameters are inside ovals. For purposes of implementation at the workshop we decided to run the shadow model with only a single port, representing landings for the entire Vancouver/Columbia region. This was primarily due to the large number of variables (Table 2) and the time required to estimate parameters by port as well as vessel class. Also, we thought that consideration of vessels by vessel class was more important for seasonal fleet dynamics than consideration of the fleet by port. The large number of parameters and limited time precluded having both vessel classes and port divisions at the time of the workshop. An indication of the number of variables can be obtained from Table 2 and Figure 5, which schematizes the division of the fleet, processors, and stock sectors into subgroups. For example, fishing mortality exists for each species (3 groups), age class (6-10 classes for each group), vessel class (3), and quarter (4). This implies between 216 and 360 variables for this one parameter even without consideration of port. While this is an extreme case, it gives an idea of the proliferation of variables when both fish stock and fishing fleet are represented in some detail.

4. Description of the Model

4.1 Introduction

The model describes the biological state of a multispecies stock, the economic states of the fisheries on that stock, and the economic state of the ports (processors) harboring those fisheries. Equations quantitatively represent how these three states change through time. This is a first attempt at modeling this multispecies fishery.

The multispecies fish complex is represented in terms of three major functional groups: rockfish, Dover sole, and sablefish. Although in nature each group may actually contain several species, in the model each group is treated as if it were a single species (termed functional group). The index j is used to denote these species and the index a to denote the age classes within each species. The fishing fleet is represented for each port by four vessel classes noted by the index i. Three of these classes represent size categories of small (0-59 ft), medium (60-79 ft), and large (80+ ft) trawlers. A fourth vessel class represents the fixed gear fishery on sablefish. Only one port is presently used in the model under the index k (although the model structure allows multiple ports). This port corresponds to landings from the entire INPFC Vancouver/Columbia management area

(Figure 3). For the purposes of this model, a port may be viewed as a generalized fish processor. The costs associated with fish processing, such as labor, packaging, and overhead costs per port, are looked at with this perspective. The model time step is one quarter, making all rates in the model quarterly.

4.2 Stock Calculations

The major factors affecting the dynamics of the fish stocks are mortality (natural and fishing) and recruitment. Fishing mortality is calculated in the model from the total fishing effort on the fish stocks. Effort V, is calculated in units of days fished per vessel class per port, and is a product of trip frequency TRP, average trip length DYS, and number of boats BOAT in vessel class i landing in port k:

$$V(i,k) = TRP(i,k) * DYS(i,k) * BOAT(i,k) \tag{1}$$

In most fishery population dynamics models fishing mortality (FMORT) is represented as the product of fishing effort times catchability. In this multispecies framework, we envision boats as targeting on different fish species groups (e.g., rockfish or flatfish) with catchability changing depending on the boats' target. Since a quarter year time step is used in this model, our computation of fishing mortality must take into account the fact that boats may target on a number of different species on different trips throughout the quarter, or even during a single trip. The average effect of this is achieved by using a parameter FRAC(i,k,t) the fraction of the fishing time per quarter that boats in vessel class i operating out of port k target on species group t.

Effort, when multiplied by catchability Q on age class a of species j while the vessels of class i are targeting on fish stock t, gives the fishing mortality FMORT accrued on age class a of species j by vessels of type i, k, t.

$$FMORT(i,j,k,a,t) = V(i,k) * Q(i,j,k,a,t) \tag{2}$$

The effect of targeting on a particular fish stock or species t is incorporated into the calculation by multiplying the instantaneous fishing mortality rate FMORT(i,j,k,a,t) by the targeting parameter FRAC(i,k,t). In this calculation fish target index t could represent each of the j species in the model, in which case targeting on stock t=1 would be the same as targeting on species j=1 (e.g., Dover sole). On the other hand, vessel classes could be represented as having only one target stock (e.g., fish) and the dynamics of targeting would essentially be removed from the model.

To calculate the total instantaneous fishing morality rate, FSUM, on age class a of species j, we sum the target specific mortality rates FMORT, weighted by the fraction of the time they take effect FRAC, over all vessel classes, ports, and targets:

$$FSUM(j,a) = \sum_{i} \sum_{k} \sum_{t} FMORT(i,j,k,a,t) * FRAC(i,k,t) \tag{3}$$

We now add the mortality due to causes other than fishing (usually termed natural mortality), MORT, to get the total instantaneous mortality MSUM, on age class a of species j:

$$MSUM(j,a) = MORT(j,a) + FSUM(j,a) \tag{4}$$

The instantaneous rate of change in the number of individuals in each age class, dN(j,a), is calculated using the total instantaneous mortality rate MSUM(j,a):

$$dN(j,a)/dt = -MSUM(j,a) * N(j,a) \tag{5}$$

Solving this equation for N(j,a) by direct integration and dividing both sides by the number of individuals at the beginning of the quarter we obtain the survivorship over the quarter:

$$SURV(j,a) = \exp(- MSUM(j,a)) \tag{6}$$

The number of individuals of age class a of species j surviving to the next quarter is calculated in the following way for the first three quarters using the previously calculated survivorship SURV, and the number of individuals present at the beginning of the quarter:

$$N(j,a)_{quarter + 1} = N(j,a)_{quarter} * SURV(j,a) \tag{7}$$

At the end of the fourth quarter we advance each cohort one age class, start the new year with a new first quarter, and include recruitment. We calculate the number of individuals surviving to the oldest age class in a slightly different manner:

$$N(j,1)_1 = RECRT(j)$$

$$N(j,a+1)_1 = N(j,a)_4 * SURV(j,a) \tag{8}$$

$$N(j,amax)_1 = N(j,amax)_4 * SURV(j,amax) + N(j,amax-1)_4 * SURV(j,amax-1)$$

where

RECRT(j) = The number of recruits to age class 1 of species j.

N(j,amax) = The cumulative number of individuals included in the oldest age class amax.

For simplicity, RECRT(j) was set independent of the population size of species j, but population effects could easily be included using an appropriate function incorporating the effect of stock size on recruitment.

4.3 Fishery Yield Calculations

Based on targeting strategy FRAC, natural and fishing mortalities MORT and FMORT, the number and weight of fish per species and age class N and W, and their survivorship over time SURV, we calculate the yield per quarter, YLD, of age class a of species j to the vessel classes of each port while targeting on stock t, using the Beverton-Holt continuous time harvest yield model:

$$\begin{aligned} YLD(i,j,k,a,t) &= \int_0^1 FMORT(i,j,a,t)*FRAC(i,k,t) \\ &\qquad *N(j,a)*W(j,a) \\ &\qquad *\exp(-MSUM(j,a)*T)dT \\ &= \frac{FMORT*FRAC*N*W*(1 - SURV)}{MSUM} \end{aligned} \tag{9}$$

where indexes have been omitted in the second part of equation (9).

Yield by species, by vessel class and by both species and vessel class may be obtained from YLD(i,j,k,a,t) by summing over the proper indices. By dividing these values by trip length TRP(i,k), or number of vessels per vessel class, BOAT(i,k), we obtain the yield per trip or yield per vessel respectively. Since fish weight is given in kilograms, a conversion factor is used to convert kilograms to metric tons. In this documentation these conversions will not be explicitly stated unless they are needed for clarity.

4.4 Fishing Quota Implementation

An algorithm is used to ensure that effort, as determined by the parameters BOAT, TRP, and DYS, results in a yield which does not exceed a predetermined quota, QUOTA(j), set by management for that quarter for species j per boat per trip:

$$YLD(i,j,k) < QUOTA(j)*BOAT(i,k)*TRP(i,k)*SAFE \qquad (10)$$

where

QUOTA(j) = Maximum yield allowable of species j per trip per boat (set by management).

SAFE = A constant margin of safety (0 < SAFE < 1) within which we wish the actual yield to fall relative to the quota so that, in reality, quotas will not be exceeded. Safe is usually set at 0.9.

The value of SAFE determines what fraction of trips actually reach their quotas. SAFE=1 implies all trips fill their quotas.

A variable RATIO(i,j,k) is computed as the ratio of the actual yield to the total safely allowable yield. To achieve the predetermined management constraints:

$$RATIO(i,j,k) = \frac{YLD(i,j,k)}{QUOTA(j)*BOAT(i,k)*TRP(i,k)*SAFE} < 1.0 \qquad (11)$$

If RATIO is greater than 1.0 then the effort is lowered by reducing the number of days of fishing per trip, DYS. The algorithm does this by dividing DYS(i,k) by RATIO(i,j,k) plus some small value BIT:

$$DYS(i,k) = DYS(i,k)/(RATIO)(i,j,k)+BIT) \qquad (12)$$

The size of the parameter BIT determines how quickly the algorithm will arrive at an average trip length with a yield which is below the quota.

If the yield under the new effort conditions still exceeds the quota, the calculations of mortality and yield are repeated using the new trip length DYS as if it were the original value. When all management constraints are met, the economic aspects of the vessel classes and ports are calculated.

This algorithm incorporates management constraints through reducing trip lengths. Management constraints could be incorporated in other uses, such as by reducing the number of vessels per vessel class per port or reducing the number of trips per vessel class per port, by reducing the parameters BOAT or TRP in place of DYS in the above algorithm. Our preliminary hypothesis, however, is that trip quotas will primarily affect trip length. Notice that this algorithm assures that on the average quotas are not exceeded 90% of the time (with SAFE=.9). It does not meet the actual management constraint that no boat can exceed the trip limit, and therefore probably gives an overestimate of yield in response to quotas. This problem of how to implement trip limits in the model has been further examined in on going work (see Appendix 3).

4.5 Vessel Class Economic Calculations

Ex-vessel fish sales are computed using the species-specific ex-vessel price per pound EPRI(j), times the total yield in pounds YLD, per species per vessel class per port:

$$SALE(i,j,k) = EPRI(j) * YLD(i,j,k) \qquad (13)$$

Again, as with yield, the cumulative values of total sales (i.e., sales per vessel class per port over all species) can be calculated by summing over all species. Dividing these values by TRP(i,k) or BOAT(i,k) gives the total sales per trip or sales per boat respectively. Assuming a constant cost of effort for vessel class i per boat-day ACST(i) (Leipzig and Silverthorn - pers. comm.) we calculated the net revenue per vessel class per port RVSUM, and likewise the net revenue per boat per vessel class per port RVVSL, as the difference between sales SALE and costs COSUM. Costs per vessel COVSL is also calculated.

$$
\begin{aligned}
&COSUM(i,k) = ACST(i)*BOAT(i,k)*TRP(i,k)*DYS(i,k)\\
&RVSUM(i,k) = SALE(i,k) - COSUM(i,k)\\
&COVSL(i,k) = COSUM(i,k)/BOAT(i,k)\\
&RVVSL(i,k) = RVSUM(i,k)/BOAT(i,k)
\end{aligned}
\tag{14}
$$

4.6 Port/Processor Economic Calculations

Port economics are described in the model assuming each port to be a generalized fish processor. This construct is after Huson et al. (1984). Costs are itemized in terms of labor, CLABR, packaging, CPAKG, and overhead, COVHD costs:

$$
\begin{aligned}
&CLABR(k) = \sum_j LCST(j) * PCT(j) * YLD(j,k)\\
&CPAKG(k) = \sum_j PCST(k) * PCT(j) * YLD(j,k)\\
&COVHD(k) = \sum_j OCST(k) * PCT(j) * YLD(j,k)
\end{aligned}
\tag{15}
$$

where

LCST(j) = Constant labor cost per pound of fish species j filleted.

PCST(k) = Constant packaging cost per pound fish filleted by port/processor k.

OCST(k) = Constant overhead cost per pound fish filleted by port/processor k.

PCT(j) = Percent of species j biomass landed that is left after filleting.

The cost to the port for buying fish at the exvessel price CSALE, is determined by summing the sales per vessel class per port SALE(i,k) over all vessel classes:

$$CSALE(k) = \sum_{i} SALE(i,k) \tag{16}$$

Gross port profit PRGRS is computed by summing the species specific wholesale prices per fillet pound WPRI(j) along with the price per pound of leftover filleted carcass XPRI(j) over all species processed:

$$PRGRS(k) = \sum_{j} (WPRI(j)*PCT(j) + XPRI(j)(1-PCT(j))) * YLD(j,k) \tag{17}$$

Finally the net profit PRNET per port was calculated by subtracting the total costs per port from the gross profit by port:

$$\begin{aligned} PRNET(k) = PRGRS(k) &- CLABR(k) \\ &- CPAKG(k) \\ &- COVHD(k) \\ &- CSALE(k) \end{aligned} \tag{18}$$

4.7 Model Parameters and Initial Conditions

To run the model, quantitative information is needed to describe the stock dynamics, the fishing effort, the management constraints, and the vessel class and port economics. This information is incorporated into the model through both parameters and initial conditions. Parameters are constants whose values characterize processes described in the model. For example, for the parameter EPRI(j), the exvessel price, we set EPRI(1) = .20; that is the exvessel price per pound round weight of species 1 (rockfish) was twenty cents. The initial conditions on the other hand are the values to which the state variables are set at the beginning of a model run. State variables are varying quantities which describe the state of the system at any time by the values they take on. For example for the state variable N(j,a) we let N(2,3) = 20,000,000 initially. That is, the number of individuals in age class three of species two is equal to 20,000,000 at the beginning of the model run, and then depending on survivorship and recruitment, this number changes over time to reflect the changing state of this fish population in response to fishing pressure and its change due to management regulation.

In addition to the parameters and state variables two other quantities are useful in making computations in the model. These are the intermediate variables (those quantities which take on values during the intermediate computational steps such as FMORT, FSUM, and MSUM) and the output variables (those quantitities other than the state variables which take on values at the end of a computation and are useful in supplying information about the degree to which various processes occurred such as YLD, SALE, and PRNET). Appendix 4 has a general list of these parameters and variables with their definitions.

A more specific list of definitions of the parameters and variables can be found in the "declaration" statements contained in the model code available on request (**see footnote below). Note that although a variable may be listed as a parameter or as an intermediate variable in this model these definitions are not rigidly binding in cases of model modification. For example RECRT(j) is presently a parameter describing constant recruitment; in the future development of the model however it may be appropriate to make RECRT(j) a function of stock size or some environmental variable, in which case RECRT(j) would become an intermediate variable.

4.7.1 Fisheries Biology Parameters and Initial Conditions

What follows is a general description of how fisheries biological parameters and initial conditions were estimated.

As mentioned earlier, total exploitable stock was divided into three components: rockfish, Dover sole and sablefish. Rockfish were assumed to be a conglomerate, with life history parameters for yellowtail rockfish (*Sebastes flavidus*) used to represent their dynamics. Life history parameters for Dover sole and sablefish were taken from the most recent status of stocks reports to the PFMC GMT. Parameter values used in the model are given in Table 3.

Estimates of 1981 catch, biomass and relative availability (partial recruitment) were used to make initial estimates of fishery parameters. Table 4 gives estimates of 1981 catch (PacFIN research and management data

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bases) by species and vessel class, as well as estimates of stock biomasses (rockfish and Dover biomasses were estimated from PFMC status of stocks documents; sablefish biomass was estimated from Canadian status of stocks documents assuming biomass/unit habitat were uniform off the B.C., Washington, and Oregon coasts).

Estimates of fishing mortality were made using values for age-specific availability (partial recruitment) given in Table 3. Rockfish are assumed to recruit between ages 6 and 16 (Tagart, pers. commun. for yellowtail), Dover sole between ages 6 and 10 (ODF&W stock assessment document) and sablefish had knife-edge recruitment at age 3. A linear increase in availability between the initial age of partial recruitment and the age of full recruitment was assumed. Sablefish were portioned into small (<5 lb, ages 3, 4), medium (5-7 lb, age 5) and large (>7 lb, ages 6+) fish and their 1981 catches were estimated accordingly in Table 4, using Washington Department of Fisheries and Oregon Department of Fish and Wildlife market samples.

For each stock group, estimates of 1981 annual fishing mortality and initial numbers at age were obtained as those values which would produce the catches and average annual biomasses of Table 4, with average age-specific availability of Table 3, while maintaining the populations in annual equilibria. Total 1981 fishing mortality was then partitioned into fishing mortality by gear type proportional to the relative 1981 catches given in Table 4. Recruitment (assumed constant) was taken as the initial number in the youngest age class for each stock.

Estimates of 1981 rockfish effort parameters and their data sources and assumptions are given in Table 5. Annual catchability was obtained by dividing annual fishing mortality by annual effort. These values are given in

Table 6. Since fixed-gear effort and catch for sablefish are assumed to be driving variables in the model, fixed gear catchability is set equal to fishing mortality.

In order to account for targeting in the model, two sets of catchabilities are used, one when a vessel is targeting on rockfish and the other when a vessel is targeting on Dover or sablefish. These were estimated by making the assumption that when vessels are targeting on rockfish, their rockfish catchabilities will be elevated over the average and their Dover/sablefish catchabilities will be reduced under the average. The opposite will be true when a vessel targets on Dover/sablefish. Therefore in the model when a vessel targets on rockfish, its 1981 rockfish catabilities (Table 6) are multiplied by 1.25 and its 1981 Dover and sablefish catchabilities are multiplied by 0.75 with the reverse being true when a vessel targets on Dover or sablefish. These estimates were made to provide the model with targeting dynamics and are not based on actual data.

4.2.2. Fleet and Processor Economics Parameters

Fleet and processor economics parameter values, given in Tables 7 and 8, are based on personal estimates by P. Leipzig and J. Babbitt, respectively.

4.8 Model Output

In order to demonstrate the current status of the model, example results from three one-year runs are displayed. The first run (Unrestricted) attempts to replicate the 1981 fishery as closely as possible, employing initial conditions and effort parameter values of Tables 3 and 5 respectively. The option for specifying targeting was not used and catchability from Table 6 was used. The second run (Quota limitation) was the same as the first except trip size limits of 15,000 lb in the first and second quarters, 7,500 lb in the third quarter, and 3,000 lb in the fourth quarter were employed. The third run (Frequency limitation) was the same as the second only an attempt was made to represent a one trip/week trip frequency limit. This was done by reducing the number of trips by 20%, 40% and 0% in trawl vessel classes 1, 2 and 3 respectively. In addition, no vessel was allowed to make more than 10 trips per quarter.

An example of typical model output/quarter 1 from the Unrestricted run is given in Table 9. Annual catches, and vessel and processor economics for all 3 runs are given in Tables 10 and 11 respectively.

5. THE WORKSHOP

The workshop agenda was divided into half day blocks, each block involving a task or exericse. A brief outline of the agenda is given in Appendix Table 1.2. Workshop participants and their affiliations are given in Appendix Table 1.1.

5.1 Model Discussion

After brief introductions and reviews of AEAM, the history of the problem and the objectives of the workshop, the initial morning session dealt mainly with a review of the preliminary model (developed by the core group) and a critique period. The review included model assumptions, relationships (variables and equations) data requirements and where further information was needed.

The major criticism of the shadow model involved specification of the fleet by length class, with all boats in each of the length classes having the same target strategies and fishing power. It was pointed out that a small fraction of the fleet catches most of the fish and that characterizing each class by its average catch may be misleading. The type of gear carried may be more important than length in determining the target strategy of a boat. It was suggested that some sub-classification procedure might be used to reduce some of the expected within vessel-class variability. It was also mentioned that other variables such as individual skipper response, operating costs, market price and the availability of alternative gear types may be important and that this might make sub-classification difficult. Also, sub-classification would involve more classes, which is contrary to our desire for as simple a model as possible. We decided to form a subgroup to address the question of fleet classification. Another suggestion relative to catch variability was to adopt a stochastic approach which directly includes variability in both effort and catchability, between vessels in the same class. It was noted that the data source for fleet economics for the preliminary (or "shadow") model, (Huson et al. 1984) was inadequate for the Washington-Oregon Sebastes fishery and needed to be revised.

Monday afternoon was devoted to the first round of the simulation game. The game served in part to familiarize workshop participants with the input-output capability of the "shadow" model and with its strengths and weaknesses, but was primarily intended to provide insight into how each of the fishery groups influenced and then responded to management decisions by the PFMC.

5.2 Fishery Game

The specific objectives of the game were to determine 1) what the important response of various parts of the west coast groundfish industry and resource are to management decisions (ABCs, trip limits) made on Vancouver/Columbia rockfish, and 2) what the key bioeconomic variables are that determine the response of the industry to regulation.

The workshop participants were divided into 5 groups as follows: Resource, Fleet, Processor, Regulator, and Modeler. At the outset, all participants were provided with quarterly bioeconomic statistics for the 1983 fishing season. The game was supposed to be played in 4 rounds, each round representing a calender quarter of the 1984 fishing year. Each round consisted of 3 phases. At the beginning of each round a 10 minute "confab" period was used by each group to look over and discuss the data provided (either the initial conditions or data from the previous rounds) and any other relevant information. The phases within each round were as follows:

Phase I
- Participants - Resource and Regulators
- Task - Assess status of stocks and fishery, recommend and set 1984 ABCs and trip limits.
- Input - Stock biomasses, virgin stock levels, consultation with industry.
- Default - 1983 recommendations and regulations

Phase II
- Participants - Fleet and Processors
- Task - Arrive at fleet effort levels, target species, and processor's catch targets for quarter.
- Input - Output from Phase I, last year's (quarter's) operating statistics.
- Default - 1983 effort pattern.

Phase III
Participants - Modelers
Task - Run shadow model and generate bioeconomic output from fishery for quarter.
Input - Output from Phases I and II.
Stock biomasses at beginning of quarter.

The important results of this first game session were the modifications suggested for the model as a result of playing the game. The feeling of the workshop participants as a whole was that it was difficult, if not impossible, to play the game with the existing shadow model. Modifications were therefore suggested (those implemented (starred below) are included in the model description (§4)) and fall into the following areas.

*1) Some mechanisms for specifying target species should be included. For example, the fleet group should be able to specify the fraction of trips in a vessel class-quarter that are spent targeting on the various stock groups. In addition, catchabilities should reflect targeting.

*2) Automatic implementation of trip size quotas should be incorporated into the model.

*3) Both fleet and processor economic parameters needed to be refined.

*4) Vessels should be characterized not so much by size but by how they operate. Trawl gear can be partitioned into four categories: sole (bottom) gear without deep water capabilities, sole gear with deep water capabilities, roller rockfish gear, and midwater rockfish gear. Most vessels of the smallest class (0-59 ft) target on nearshore flatfish and use shallow water sole gear. Medium (60-79 ft) and large (80+ ft) class vessels carry both sole and rockfish gear. What appears to distinguish medium from large trawlers is the ability of large vessels to pursue other fisheries (e.g., hake joint venture) during the year.

5) Fleet responses to trip limits are determined by resource availability, management and market controls. Somehow, all of these need to be incorporated into the model in order for it to be a useful tool in evaluating the bioeconomic impact of contemplated management measures.

The game was replayed on the final morning of the workshop. Unfortunately, there were some minor errors in the model code and so the resultant catches were rather meaningless. One major problem which arose, however, was that because participants had a fuller understanding of the structure of the model the second time around, they played the game against the model rather than trying to emulate a real management situation. It was generally agreed, however, that the model's having the ability to specify how much of a vessel class's effort would be devoted to targeting on the various stock groups was a significant improvement.

5.3 Improvements in the Shadow Model

Tuesday morning began with a discussion of the game and of changes required in the simulator. The main difficulty with the preliminary model was that there was no enforcement of the trip quotas. The only connection came in the game, where the game players representing fishermen responded to the quotas by reducing trip frequencies so as to try to meet the quotas. In the real system, however, the quota would be enforced by the fishery managers through changing trip limits and frequencies, which directly impact effort. In this regard the fishermen do not have complete control over their effort. We agreed that there was a need to develop a more realistic effort module to reflect the imposition of the quota. A module to accomplish this was presented by Joe Terry and is discussed in greater detail in Appendix 3. Basically, this module set trip frequencies and lengths a well as fishing fleet target strategy for each vessel in a vessel class on a per trip basis under the assumption that boats in each vessel class will behave as a profit optimizer. One of four task groups was set up to further develop this approach. Another subgroup explored an empirical approach to the problem by investigating how the effort pattern changed after imposition of quotas in 1983 and whether the identified changes could be put directly into the model (much as regression relationship). A third group addressed the earlier identified question of how best to classify the fleet in the model, while a fourth group refined the processor cost and profit parameters and model to make them more compatible with the Washington-Oregon Sebastes fishery.

5.3.1 Fleet Characterization

The fleet characterization group discussed a number of issues. In the interest of simplicity they finally agreed to use 3 size classes: 0-59 feet (small), 60-79 feet (medium) and greater than 80 feet (large). The vessel classes are to be defined in terms of primary gear which determines their targeting strategies. The smaller boats target exclusively on Dover sole. Some of the smaller vessels do have the capability of fishing on non-groundfish species. Sablefish are landed only incidentally. Medium vessels all have the capability of targeting on either Dover sole or rockfish. They may carry either mid-water gear or roller gear for rockfish. Sole gear may be either deep or shallow water gear. Sablefish are only landed incidentally. Some vessels in this size class can fish in the joint venture hake fishery. Larger vessels are similar to the medium vessels but more commonly participate in the summer hake joint venture fishery. The primary means of distinguishing vessels was considered to be the targeting strategy of the vessels. This was expected to change most drastically under trip limit management directed at particular species (e.g., Sebastes). Some mechanism for switching target species needed to be included in the model.

Other points raised by this group were that some measure of the efficiency of the fleet should be included, that during the winter there are fewer fishable days due to the weather and that some means of considering the fisherman's decision between alternative fisheries and not fishing must be developed. The possibility of conducting a fisherman's survey to identify their behavior in response to fishing regulations was also discussed.

Results of the processor group are presented with the model documentation. The processor group decided that incorporating costs in terms of pounds of fish filleted was a clearer and more realistic approach to simulating processor economics than the preliminary model approach adapted from Huson et al. (1984), which had costs on a per pound of fish landed basis. Differing costs and revenues per filleted portion of fish as well as costs and revenues per pound of carcass remaining were assessed on a per fish species (or functional group) basis.

5.3.2. The Terry Algorithm

Presentation of the Terry algorithm to the workshop group generated considerable discussion. Two main aspects were criticized--the profit maximization assumption and the difficulty in estimating per trip catchability as a function of species targeting. It was pointed out that fishermen often repond in their fishing to processor marketing lists even though they may net less than their optimal fishing strategy. The catchabilities for a species when the vessel is targeting on a particular species are difficult to obtain and are not the same as the catchability for a particular vessel class as estimated from catch statistics since these latter sum over all targeting by those vessels (i.e., the targeting sequence or strategy of the vessel is unknown or must be inferred from logbook records). Obtaining the catchabilities needed for the Terry algorithm is a project in itself and might involve selecting a subset of the fleet for further analysis or might involve using scientific survey data. The question was raised as to how flexible the fishing vessels are in switching target strategies mid-trip or from trip to trip. High operating costs of switching gear are a consideration, although apparently many boats carry multiple gear and have shifted effort from rockfish to Dover sole and sablefish in response to trip limits.

5.3.3. Empirical Group

The empirical group, was charged with examining the data on the response of catch patterns to the historical setting of trip quotas and frequency limits in 1983. Results from this group are shown in Table 12. Washington data on trips per vessel class, days per trip and the percentage of the total catch comprised of rockfish are given for each quarter for 1981-83. Vessel classes 1, 2 and 3 correspond to small, medium and large vessels respectively. Trip quotas and frequency limits are also given in Table 12. Larger vessels appeared to respond to trip quotas by taking more trips of shorter duration. All vessel classes, in fact, had shorter trips in 1983 than in previous years. One striking observation is that trip quotas appeared to increase the percentage of rockfish in the catch of smaller vessels. This probably reflects both their increased ability to compete with the quota-limited larger vessels and the demise of the shrimp fishery which brought shrimp boats into the groundfish fishery in 1983. The effect of trip frequency limits (in quarters 3 and 4 in 1983) is less obvious, although it appears that they reduced targeting somewhat on rockfish for small and medium sized vessels. This is seen in the lack of increase in quarter 3 of 1983 in percentage of rockfish in the catch observed in quarter 1 and in 2 for small vessels and the reduction in this percentage in quarter 3 of 1983 for medium sized vessels. In quarter 4 of 1983 the virtual shut down of the rockfish fishery is reflected by the low rockfish percentages in the catch. Despite empirical evidence that trip quotas significantly affected fishing effort (trip frequency and trip length) insufficient data were available upon which to confidently base a prediction (albeit empirical) about the effect of quotas on fishing effort.

The empirical group also wrestled with the problem of re-estimating catchability under various targeting scenarios. Since there were no data upon which to base any inferences, they decided on the approach discussed in the earlier section (4.7.1) on fisheries biology parameters.

5.3.4 Fleet Economics Model Changes

The fleet economics group simplified the existing model by eliminating the division of costs into overhead, labor and crew share costs (from Huson et al. 1984), and replacing them with a vessel class specific daily operating cost. This group also provided estimates for other parameters such as vessel holding capacity, maximum trip length and maximum number of fishing days possible per quarter which might prove useful in implementing an algorithm for the effect of regulations on fleet activity. For example, the larger vessels tend to be able to stay out more days in winter and late autumn due to their greater ability to weather storms and rough seas than the smaller vessels. This difference was represented by differences between vessel classes in the maximum number of fishing days possible per quarter. Although many of these parameters were not needed for the present model version, they will prove useful for more detailed behavioral modules such as the Terry algorithm.

The group assigned to specify the equations for the Terry algorithm were not able to complete their work within the available time. Many of the details needed to include trip frequency limits in this algorithm could not be worked out in a short time. A simpler algorithm was developed that evening which reduces the average number of days per trip for each vessel class arbitrarily until the average yield per trip is less than the trip limit quota (see model description §§4.4). This lacks the finesse of the Terry algorithm in that it deals on a quarterly average rather than a per trip decision base. Since it assures only that the average per trip quota is not exceeded this algorithm might tend to overestimate the actual catch in response to trip quotas, since many operators would be expected to get less than the quota while the highliners (the small fraction in each vessel class that catch most of the fish) would run up against the quota practically every trip.

A survey was made to solicit recommendations on what information would aid in game decisioning. Two types of data were suggested; model output and prior data from the fishery. The following model outputs were suggested: trip length, landings by species per trip (and over all trips in a quarter) by vessel class, and exploitation rate as annual catch per unit biomass per year. Plots of profit versus trip frequency and profit frequency distribution within each vessel class were also desired. Other desired information about the fishery were the average number of vessels, the average trip length in previous years, the past trend in catch and in sales, and the trip frequency distribution by yield category. This latter would give the number of trips garnishing yields between 0-5,000 lb, 5,000-10,000 lb, etc.

On Tuesday night the modeling group implemented all the changes including the new fleet and processor modules, the revised parameter estimates, changes in output format and the quota assurance algorithm. This model was then used on Wednesday morning for a second round of the game. The final hour was used for a recap and critique session.

5.4 Suggestions of Workshop Participants

In general the workshop participants gained considerably from their participation. It was agreed that the problem addressed--to investigate the effects of trip limits and trip frequency limits on the Vancouver-Columbia Sebastes fishery--was important and complex enough to require a major study project. We will present the comments of the participants in the following categories; 1) suggested areas for model refinement, 2) communication between sectors, 3) the simulation game, and 4) suggested directions for continuation.

5.4.1. Model Refinements

Although it was agreed that the workshop model was a good start there is a need for more realism especially in the characterization of the fleet and its relationship to the processors. Fleet behavior in response to regulation needs to be studied in more detail. The Terry algorithm may be a step in the direction of achieving this. The economics in the model were oversimplified and a more detailed treatment of the economics is needed. In this regard it was suggested that perhaps a suite of models, some being more detailed in stock dynamics and others in economics might be better than a single super-model. Variability between vessels in each vessel class needs to be included because it appears to be a real part of the fishery, but also to emphasize that the numbers coming from the model are not solid facts but have uncertainty. The individual stocks will have to be separated in future model versions because the status of the rockfish stocks varies depending upon their spatial distribution, the ease of targeting on them (related to their schooling habits), and (to a lesser extent for rockfish) their desirability as a fish product. This is especially important in light of the apparent phenomenon of the fishery sequentially fishing down one rockfish stock and then moving to the next (e.g., Pacific ocean perch to widow rockfish to yellowtail rockfish to canary rockfish).

5.4.2 Communication between sectors

Many participants indicated that the most valuable contribution of the workshop was in fostering communication between the resource, economic, and industry sectors. The resource people recognized the importance of fleet characterization and the economic "drivers" of the fleet. All participants became aware of the complexity of the problem and the difficulty of simplifying it. The model offers a logical framework for communication between industry and non-industry people. It was recognized that we need more processors and fishermen both at the next workshop and involved in model refinement. It is not clear whether we have the expertise and information to actually predict the effect of regulation on the fleet and the stock, although the modeling process has uncovered many relationships that were not obvious on first approaching the problem, as will be shown in the next section.

5.4.3. The game

The game was an innovative approach to uncover the relationship between the fleet and regulations. Several aspects of the workshop hampered the effectiveness of the game in this regard. First, the model required refinement to provide the output needed for decisioning. Second, the game players were frequently out of role. Third, it was hard to play the game and refine the model since the roles are somewhat contradictory. Fourth, the newness of the game and the player's and facilitators' inexperience slowed game play, raised questions in the middle of the game and resulted in some unprofitable "moves"--although all were part of the learning process.

However, future role play with the game was encouraged, incorporating the lessons we learned in this workshop. It was sugggested that the game be played with "real" actors.

5.4.4. Continuation of work on the problem

Quite a bit of enthusiasm was generated for continuation of the work begun at the workshop. Participants expressed interest in participation in future workshops, in serving as resource persons for data collection or collation and in working on particular model modules. One substantive area for future work is to work with the data bases, especially the PacFIN research data base, to make them amenable to accessing data on the fleet catagorized according to multiple criteria.

6. RECOMMENDATIONS FOR FUTURE WORK

6.1 Workshop follow-up

As a follow-up on the workshop a letter was sent to workshop participants entertaining further comments about the workshop, discussing where they would like to see model development and asking what role they see themselves playing in future work. The responses reiterated many of the comments given at the end of the workshop. Several themes were emphasized. There were:

1) The crux of the success of such a model lies in the fleet characterization and in representing the fleet's response to regulation. As such the model

must be truly a bioeconomic model, somehow melding the two disciplines in a way not done before.

2) Division of the fleet into length classes was a short term expedient that might not stand up against rigorous data analysis. This analysis should be done as part of this program and an attempt made to represent the fleet on a performance basis. Such data analysis will require a melding of existing data sources including the PACFIN management and research data bases and logbook data from both Oregon and Washington.

3) Gaming offers great potential for understanding response mechanisms of fishermen and processors, but gaming must be separated from model building. The game players must be in role, and clear instructions and good supporting material must be provided to aid players in making realistic decisions. There should be greater industry involvement in future workshops.

4) The workshop group was extremely enthusiastic and was appropriate to address the problem. To assure coordination of future work among participants the core group should meet again for planning as well as data and information sharing.

5) The workshop emphasized a distinction between behavioral and empirical models. Empirical models are data hungry and do not assure that model predictions will work outside of the range of available data (e.g., if something should change like the entry of a new type of boat or gear into the fishery). Behavioral models are much more speculative and difficult to

validate. Prediction in this case will depend upon developing an adequate behavioral model for the fleet's response to regulation. Whether this is possible is still unsure.

6) One candidate behavioral model based on a per trip analysis assumes the vessel operator will optimize profit while meeting constraints due to vessel holding capacity, maximum time at sea and management imposed quotas. The success of this approach will depend upon i) the realism of the profit maximization hypothesis, ii) the ability to obtain good estimates for catchability under different targeting strategies, iii) how strongly constrained the vessel is by processor imposed shopping lists or other conflicting and variable factors such as the status of the vessel mortgage, the ability to switch gear and the distance between different fishing grounds, which are impossible to consider in a general analysis.

6.3 Future work

The workshop has suggested a myriad of topics which require further work. In summarizing the major directions that we see as important to further progress on the study objectives we divide work into data analysis, model refinement and modification, further data gathering, and model testing and communication workshops.

6.3.1 Data analysis

To evaluate the present classification of the fleet into length classes and to develop possible alternatives, catch data must be displayed in a variety of ways including by gear type (roller vs midwater, deep water vs. shallow water), by port, by horsepower, and by economic status. Subsampling of logbook data could help in estimating catability for boats targeting on specific groups of fish. Variability of total catch and species mix of catch must also be examined to help estimate how best to include this variability in the model. Methods of exploratory data analysis (Tukey 1978) will prove helpful, especially if the data prove not to be normally distributed. The success of this work will depend heavily on the timeliness and availability of 1) the PACFIN research data base, 2) Washington and Oregon landings information (fish tickets), and 3) Washington and Oregon logbook information. It is of utmost importance to have this data available for the years (1983-84) where significant trip limits were imposed as a regulatory measure.

6.3.2. Model refinement and modification

The preliminary model was oversimplified in a number of areas. Since so many suggestions were made for model modification we include the following list in order of priority (#1 first).

1) Develop a number of alternative bioeconomic behavioral models for the fleet response to regulations and any other important factors (e.g., processor

shopping lists). The Terry algorithm should be one of the modules developed, but others should be encouraged.

2) Include variability in the fleet characterization so that catch and economic output reflect their non-determinism. Variability should also be included in recruitment, when extending results to multiple years.

3) The rockfish and bottom fish need to be divided into more species groups so that the different life history and fishing history on these stocks can be considered. The model does not need modification for this, but parameter estimates must be provided for each of the species considered separately.

4) The economic constraints in the fishery and the fishery-processor connection need to be represented in some fashion through more realistic processor and fishery economics modules.

5) Data on other ports needs to be included so that the spatial variability, already provided in the model, can be implemented.

6) Discards need to be considered, especially if discarding is shown to increase under imposed quotas.

6.3.3. Further data gathering

Questions about by-catch, discards and the per trip response to regulations are difficult to address by asking questions of people. It appears necessary to get this information by employing a number of observers on a variety of vessel classes. Data on discards, by-catch and on changes in target strategy or decisions made while fishing that relate to regulations or to processor "shopping lists" (like when to return to port or change fishing gear) need to be accumulated. Without these data we can have no reality testing of what the experts (industry representatives) tell us will happen. We propose to conduct such a study through a cooperative agreement at Oregon State University. It is also important to know how tightly linked, through the fishery, the different species are, so that regulators can determine whether the groundfish complex should or should not be managed as a single unit.

Another approach is developing a comprehensive survey of the fishing fleet to establish variability within vessel classes, but also to garnish possible insight into the fleet's response to regulation.

6.3.4. Further workshops and communication

Participants were unanimous in their praise of the workshops as a communication medium. We plan more future workshops of two types. The first type has the objective of getting industry involvement and familiarity with the model and for them to play the game such as to provide insight into possible fleet and processor response to regulation through trip quotas and frequency limits, but also to other possible regulation methods such as time-area closures and limited entry. We hope to develop quantitative hypotheses about fleet response to regulation from these workshops, but also to obtain critique on the realism of the other parts of the model. Finally, we will use the workshops to evaluate whether model outputs are sufficiently detailed to represent the system the way it is perceived by the fishing and processing industries.

Since the model may serve as an aid in management decision making we plan to present workshop results and display the model to the Pacific Fishery Management Council.

We do not plan to do further model development in workshop mode. Instead we expect to effect further model developments through members of the core groups who will also make code changes and conduct scenario and sensitivity analysis of the model to assure that the model results are sensible and that they reflect the best available data. To assure coordination of the work we propose quarterly core group meetings, which will also involve interchange of data and presentations on ongoing projects related to this overall study.

Probably the most radical redirection of this project will be to focus our effort on the long term (multi-year) effects of management as opposed to the short term (within year) effects. Of particular importance to the PFMC GMT is the need to quantify fleet dynamics in such a way as to be able to explore the possible bioeconomic consequences of various management alternatives (ABC levels, management complexity in terms of combined areas and species) on the resource and industry. It appears that the only way to handle short term management is adaptively. This requires comprehensive and timely information on landings. However we feel that analysis of the type described here will also provide useful insight to the manager on the likely long term consequences of his contemplated management decisions.

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Table 1.--PFMC groundfish management/regulation actions on INPFC Vancouver/Columbia *Sebastes* and coastwide widow since implementation of FMP in 1982.

Date	Van/Col *Sebastes*	HG	Coastwide widow	OY
Oct 82 - Feb 83			75,000 lb./trip	
Mar 83 - Jun 83	40,000 lb./trip	14,000 t	30,000 lb./trip	10,500 t
Jul 83 - Sep 83	40,000 lb./trip 1 trip/week	18,500 t	30,000 lb./trip	10,500 t
Sep 83 - Dec 83	3,0001b./trip 1 trip/week	18,500 t	1,000 lb./trip 1 trip/week	10,500 t
Jan 84 - Apr 84	30,000 lb./trip 1 trip/week	10,100 t	50,000 lb./trip 1 trip/week	9,300 t
May 84 -	15,000 lb./trip 1 trip/week or 30,000 lb./trip 1 trip/2 weeks	10,100 t	40,000 lb./trip 1 trip week	9,300 t

Table 2.--Classification of model parameters, variables and outputs.

	Port	Species	Age Class	Vessel Class	Quarter	Data Source & Comments
Parameters						
Catchability	x	x	x	x	x	PacFin Research & Production
Fuel Price				x		Redfish Fishery
Fleet Overhead				x		" "
Ex-Vessel Price		x			x	PacFin Production
Crew Share				x		J. Easley
Wholesale Price		x				Redfish Fishery
Packaging Cost		x				" "
% Utilization		x				" "
Processor Labor Cost						" "
Processor Overhead						" "
Variables						
Trip Frequency				x	x	
Trip Length				x	x	
Fishing Effort				x	x	
Fishing Mortality	x	x	x	x	x	
Fleet Cost	x			x		
Processor Labor Cost	x					
Processor Overhead	x					
Packaging Cost	x					
Total Fish Processed	x					
Outputs						
No. Fish		x	x			
Fish Height		x	x			
Stock Biomass		x				
Annual Quota		x				
Gross Revenue	x			x	x	Per vessel
No. Vessels	x			x	x	
Yield	x	x		x	x	
Net Revenue	x			x		Per vessel
Landings	x	x				
Processor Profit	x					

Table 3. Annual life history and fishery parameter.

I Rockfish (MORT=0.125)

Age	$\overline{w}$ (Kg).	Relative Catchability	FMORT (1981) 0-59	60-79	80+	Initial N in 1981 (10^6ind)
6	0.703	0.05	.008	.070	.031	50.700
7	0.857	0.11	.019	.156	.070	40.126
8	1.036	0.19	.032	.267	.120	27.739
9	1.203	0.28	.047	.393	.176	16.098
10	1.316	0.32	.054	.450	.202	7.665
11	1.451	0.38	.064	.534	.239	3.338
12	1.565	0.49	.083	.688	.308	1.274
13	1.636	0.69	.117	.970	.434	0.382
14	1.700	0.76	.128	1.069	.479	0.074
15	1.747	0.87	.147	1.223	.547	0.002
16+	1.900	1.00	.169	1.406	.629	0.002

II Dover (MORT=0.184)

Age	$\overline{W}$ (Kg).	Relative Catchability	FMORT (1981) 0-59	60-79	80+	Initial N in 1981 (10^6 ind)
6	0.268	0.35	.012	.016	.001	40.600
7	0.354	0.62	.021	.028	.002	32.818
8	0.449	0.79	.027	.036	.002	25.937
9	0.544	0.94	.032	.043	.002	20.224
10	0.644	1.00	.034	.045	.002	15.572
11	0.739	1.00	.034	.045	.002	11.936
12	0.839	1.00	.034	.045	.002	9.149
13	0.930	1.00	.034	.045	.002	7.013
14	1.016	1.00	.034	.045	.002	5.376
15	1.107	1.00	.034	.045	.002	4.120
16+	1.343	1.00	.034	.045	.002	13.527

Table 3.--Continued.

III Sablefish

(MORT=0.150)

Age	$\overline{W}$ (Kg).	Relative Catchability	FMORT (1981) 0-59	60-79	80+	Fixed Gear	Initial N in 1981 (10^6 ind)
3	1.362	1.00	.063	0.76	.004	.093	2.950
4	2.123	1.00	.063	.076	.004	.093	2.006
5	2.837	1.00	.018	.021	.001	.196	1.365
6	3.451	1.00	.016	.019	.000	.200	0.928
7	3.952	1.00	.016	.019	.000	.200	0.631
8	4.346	1.00	.016	.019	.000	.200	0.429
9	4.649	1.00	.016	.019	.000	.200	0.292
10	4.877	1.00	.016	.019	.000	.200	0.199
11	5.047	1.00	.016	.019	.000	.200	0.135
12	5.174	1.00	.016	.019	.000	.200	0.092
13+	5.391	1.00	.016	.019	.000	.200	0.195

Table 4. Estimates of 1981 Catch and Biomass. (t)

I. By Species

	Gear	Rockfish	Dover	Sable
CATCH	0-59	3000	2754	826
	60-79	24000	3606	995
	80+	10875	197	56
	Fixed	0	0	2866
	Total	37500	6556	4743
	Avg Biomass	108000	93855	20116

II. Sablefish Catch partitioned by gear.

Market Category	Trawl	Fixed	Total
Small	1521	990	2511
Medium	140	678	818
Large	216	1198	1414
Total	1877	2866	4743

Table 5. Estimates of 1981 trawl fishing effort.

		#Vessels 1/	#landings 2/	#trips/vessel	#days/trip 3/	#days 4/
Q 1	0-59	167		6.28	1.83	1920
	60-79	193		3.15	3.65	2219
	80+	28		2.10	5.48	322
	Total	388	1221	3.15	3.65	4461
Q 2	0-59	167		10.16	1.69	2867
	60-79	193		5.08	3.38	3314
	80+	28		3.39	5.07	481
	Total	388	1972	5.08	3.38	6662
Q 3	0-59	167		16.68	1.85	5153
	60-79	193		9.08	3.40	5956
	80+	28		5.56	5.55	864
	Total	388	3235	8.34	3.70	11973
Q 4	0-59	167		5.10	1.77	1507
	60-79	193		2.55	3.54	1742
	80+	28		1.70	5.31	253
	Total	388	989	2.55	3.54	3502
Total.	0-59	167		38.30	1.79	11448
	60-79	193		19.20	3.57	13230
	80+	28		12.79	5.36	1919
	Total	388.	7417.	19.12	3.57	26598

1/ Assume same # vessels each quarter - from PacFIN Research.

2/ PacFIN production for other Rockfish - from PacFIN Production.

3/ # days/trip in ratio of 0.5/1.0/1.5 from S. Hanna (ODF&W logbook data).

4/ # days fished proportional to # vessels.

Assumptions.

Table 6. Estimates of average annual catchability ($Qx10^6$) in 1981

	Rockfish			Dover		
Age	0-59	60-79	80+	0-59	60-79	80+
6	0.699	5.291	16.154	1.048	1.209	0.521
7	1.660	11.791	36.477	1.834	2.116	1.042
8	2.795	20.181	62.533	2.358	2.721	1.042
9	4.106	29.705	91.714	2.795	3.250	1.042
10	4.717	34.014	105.263	2.970	3.401	1.042
11	5.590	40.363	124.544	2.970	3.401	1.042
12	7.250	52.003	160.500	2.970	3.401	1.042
13	10.720	73.318	226.159	2.970	3.401	1.042
14	11.181	80.801	249.609	2.970	3.401	1.042
15	12.841	92.441	285.044	2.970	3.401	1.042
16+	14.762	106.274	327.775	2.970	3.401	1.042

	Sablefish			
	0-59	60-79	80+	Fixed
3	5.503	5.745	2.084	0.093
4	5.503	5.745	2.084	0.093
5	1.572	1.587	0.521	0.196
6	1.398	1.436	0.000	0.200
7	1.398	1.436	0.000	0.200
8	1.398	1.436	0.000	0.200
9	1.398	1.436	0.000	0.200
10	1.398	1.436	0.000	0.200
11	1.398	1.436	0.000	0.200
12	1.398	1.436	0.000	0.200
13+	1.398	1.436	0.000	0.200

Table 7. Fleet economic parameter values (P. Leipzig).

	Small	Medium	Large
Operating Cost	$500/day	$675/day	$1,125/day
Holding Capacity Thousand lb.	20-40	46-150	151-300
Minimum Turn Around	10 hr	10 hr	25 hr
Maximum Trip Length	4 days	6 days	10 days
Maximum Fishing Days / Quarter			
January - March	21 days	60 days	65 days
April - June	45 days	75 days	80 days
July - September	80 days	80 days	89 days
October - December	35 days	60 days	70 days
Tot Days Fishing	181 days	275 days	304 days

Table 8. Processor economic parameter values (J. Babbitt 1982 estimates).

	Rockfish	Dover sole	Sablefish
Ex-vessel Price (whole)	$0.20/lb.	$0.23/lb	75% large $0.30/lb. 25% small $0.10/lb.
Ex-processor Price (fillet)	$0.80/lb.	$0.96/lb.	75% large $0.50/lb. 25% small $0.40/lb.
Processor Labor (fillet)	$0.25/lb.	$0.40/lb.	75% large $0.15/lb. 25% small $0.25/lb.
Processor PKG. (fillet)	$0.075/lb.	$0.075/lb.	75% large $0.075/lb. 25% small $0.075/lb.
Processor OC (fillet)	$0.10/lb.	$0.10/lb.	75% large $0.10/lb. 25% small $0.10/lb.
Wholesale Price (fillet)	$1.35/lb.		

1) 25% of total fish is used in fillet for all species.
2) Recovery for small fish=25%., for large fish = 60%.
3) OC=operational cost
4) 10% of sale price should be profit.
5) 75% of fish = carcass = $0.005/lb.

Table 9.--Typical quarterly model output - Quarter 1 of unrestricted run.

Summary of total yield and sales by port, Vessel class and species

Rockfish

Port	Class	Yield (MT)	Total Sales (Dollars)	Yld/Trip (MT/Trip)	Sales/Trip (Dollars/Trip)
1	1	613.	$ 270403.20	.58	$ 257.83
1	2	5122.	$ 2258217.00	8.42	$ 3714.48
1	3	2298.	$ 1013281.00	39.08	$ 17232.67
1	4	0.	$ .00	.00	$ .00
Total:		8033.	$ 3541901.00	4.68	$ 2063.43

Dover Sole

Port	Class	Yield (MT)	Total Sales (Dollars)	Yld/Trip (MT/TRIP)	Sales/Trip (Dollars/Trip)
1	1	509.	$ 258026.20	.49	$ 246.03
1	2	676.	$ 342707.80	1.11	$ 563.73
1	3	33.	$ 16674.66	.56	$ 283.58
1	4	0.	$ .00	.00	$ .00
Total:		1218.	$ 617408.80	.71	$ 359.69

Sablefish

Port	Class	Yield (MT)	Total Sales (Dollars)	Yld/Trip (MT/Trip)	Sales/Trip Dollars/Trip
1	1	126.	$ 69411.99	.12	$ 66.18
1	2	151.	$ 83336.14	.25	$ 137.08
1	3	6.	$ 3273.75	.10	$ 55.68
1	4	943.	$ 519733.40	943.00	$519733.40
Total:		1226.	$ 675755.30	.71	$ 393.68

Port	Class	Boats	Trips/BT	Day/Trip	Effort
1	1	167.	6.28	1.83	1919.23
1	2	193.	3.15	3.65	2219.02
1	3	28.	2.10	5.48	322.22
1	4	1.	1.00	.25	.25

Table 9.--Continued.

Summary of trawl vessel costs per boat

Port	Class	Yield	Operation Cost	Sales	Revenue
1	1	7.474	$ 5746.20	$ 3579.89	$ -2166.31
1	2	30.822	$ 7749.32	$ 13908.09	$ 6158.77
1	3	83.462	$ 12946.50	$ 36901.05	$ 23954.55

Summary of total trawl yield and sales by port and vessel class

Port	Class	Yield (Mt)	Sales (Dollars)	Revenue (Dollars)
1	1	1248.	$ 597841.40	$-361774.00
1	2	5949.	$ 2684261.00	$1188643.00
1	3	2337.	$ 1033230.00	$ 670727.50
Total:		9534.	$ 4315332.00	$1497596.00

Summary of Processor/Port Costs and Profit

Port	Labor Costs	Packaging Costs	Overhead Costs	Fish Sales Costs	Gross Sales	Net Profit
1	1614463.00	447048.30	596064.40	4835065.00	8295441.00	802800.40

STATUS OF STOCK

Age	Rockfish NMort.	FMort.	Weight	Number
6	.310E-01	.183E-01	.703E+00	.483E+08
7	.310E-01	.411E-01	.857E+00	.373E+08
8	.310E-01	.703E-01	.104E+01	.251E+08
9	.310E-01	.103E+00	.120E+01	.141E+08
10	.310E-01	.118E+00	.132E+01	.660E+07
11	.310E-01	.141E+00	.145E+01	.281E+07
12	.310E-01	.181E+00	.157E+01	.103E+07
13	.310E-01	.255E+00	.164E+01	.287E+06
14	.310E-01	.281E+00	.170E+01	.542E+05
15	.310E-01	.321E+00	.175E+01	.844E+04
16	.310E-01	.369E+00	.190E+01	.134E+04

Total Number = .136E+09 Total Biomass (MT) = .124E+06

Table 9.--Continued

Dover Sole

Age	NMort.	FMort.	Weight	Number
6	.460E-01	.487E-02	.269E+00	.386E+08
7	.460E-01	.855E-02	.355E+00	.311E+08
8	.460E-01	.109E-01	.450E+00	.245E+08
9	.460E-01	.129E-01	.544E+00	.191E+08
10	.460E-01	.136E-01	.644E+00	.147E+08
11	.460E-01	.136E-01	.739E+00	.112E+08
12	.460E-01	.136E-01	.839E+00	.862E+07
13	.460E-01	.136E-01	.930E+00	.661E+07
14	.460E-01	.136E-01	.102E+01	.507E+07
15	.460E-01	.136E-01	.111E+01	.388E+07
16	.460E-01	.136E-01	.134E+01	.127E+08

Total Number = .176E+09 Total Biomas (MT) = .100E+06

Sablefish

Age	NMort.	FMort.	Weight	Number
3	.380E-01	.472E-01	.136E+01	.271E+07
4	.380E-01	.472E-01	.212E+01	.184E+07
5	.380E-01	.557E-01	.284E+01	.124E+07
6	.380E-01	.559E-01	.345E+01	.845E+06
7	.380E-01	.559E-01	.395E+01	.574E+06
8	.380E-01	.559E-01	.435E+01	.391E+06
9	.380E-01	.559E-01	.465E+01	.266E+06
10	.380E-01	.559E-01	.488E+01	.181E+06
11	.380E-01	.559E-01	.505E+01	.123E+06
12	.380E-01	.559E-01	.517E+01	.838E+05
13	.380E-01	.559E-01	.539E+01	.178E+06

Total Number = .844E+07 Total Biomass (MT) = .221E+05

Table 10. Annual Catches (mt) for example model runs.

I. Unrestricted.

Vessel Class	Rockfish	Dover	Sablefish
1	2858	2747	648
2	23878	3647	777
3	10706	177	30
4	0	0	3276
Total	37442	6571	4731

II. Quota.

Vessel Class	Rockfish	Dover	Sablefish
1	2997	2749	649
2	22964	3312	710
3	2866	44	8
4	0	0	3279
Total.	28827	6105	4676

III. Frequency.

Vessel Class	Rockfish	Dover	Sablefish
1	2189	1970	467
2	21021	2995	644
3	2866	43	8
4	0	0	3294
Total.	26076	5008	4413

Table 11. Economics from example model run.

A. Vessel Economics.

I. Unrestricted.

Vessel Class	#Vessels	Sales	Revenues	R/V
1	167	$3,009,712	$-2,714,027	$-16,252
2	193	$12,805,439	$3,886,119	$20,135
3	28	$4,827,210	$2,666,928	$95,247
4	-	$1,805,861		

II. Quota.

Vessel Class	#Vessels	Sales	Revenues	R/V
1	167	$3,101,396	$-2,651,345	$-15,876
2	193	$12,196,375	$4,186,413	$21,691
3	28	$1,289,708	$ 763,873	$27,281
4	-	$1,807,011		

III. Frequency.

Vessel Class	#Vessels	Sales	Revenues	R/V
1	167	$2,221,378	$-1,840,721	-$11,022
2	193	$11,141,279	$ 3,940,254	$20,461
3	28	$ 1,289,708	$ 772,246	$27,580
4	-	$ 1,815,041		

B. Processor Economics.

		Gross Sales	Net Profit
I	Unrestricted	$39,660,706	$4,498,743
II	Quota	$32,452,516	$3,638,393
III	Frequency	$28,657,774	$2,973,275

Table 12. Washington effort data (from Tagart).

		1981				1982				1983			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	1	3.4	7.0	5.5	3.0	3.0	7.9	6.0	2.5	2.3	7.9	6.1	1.9
TRIPS	2	5.1	6.8	6.5	3.8	4.9	6.9	7.9	4.4	3.4	6.9	6.1	3.4
PER VC	3	5.7	4.3	3.5	2.9	3.9	3.8	4.8	3.0	6.0	9.3	5.4	2.5
	1	7.0	3.3	3.9	3.9	3.1	3.8	4.0	3.0	2.8	3.3	3.2	3.0
# DAYS	2	3.5	3.5	3.9	3.6	3.1	4.0	3.8	3.4	2.5	3.2	3.3	3.1
/TRIP	3	3.1	4.2	3.7	2.8	3.1	3.7	3.1	3.2	2.8	3.1	2.1	-
SPECIES	1	22	32	49	43	33	31	41	43	66	54	45	12
COMP.	2	72	62	83	69	69	43	53	67	77	59	42	14
% ROCK	3	76	76	96	94	80	71	83	79	70	76	79	17
CATCH LIMIT			NONE				NONE			40k	40k	40k	3k
TRIP LIMIT												1/wk	1/wk

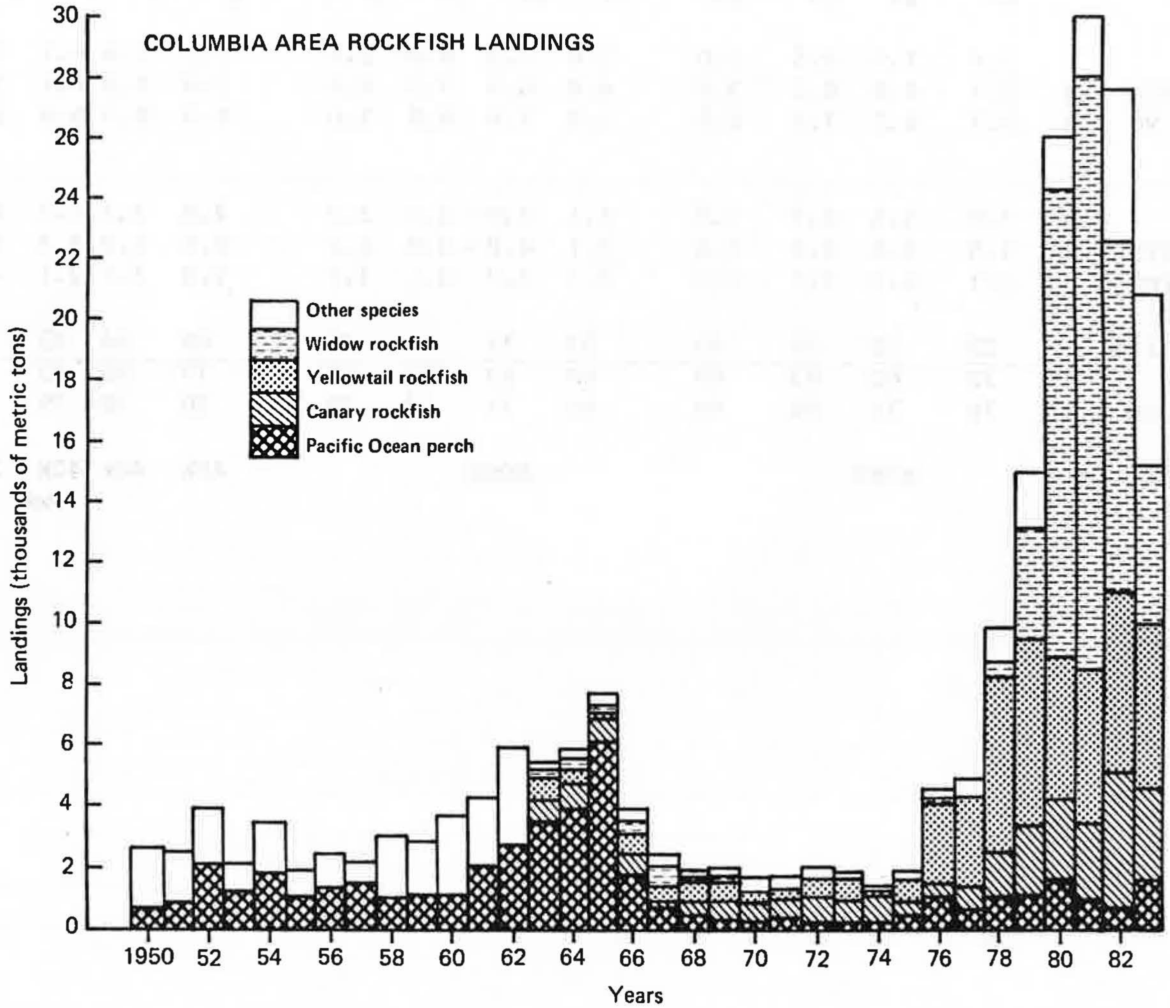

Figure 1. 1950 - 1982 INPFC Columbia Area rockfish landings.

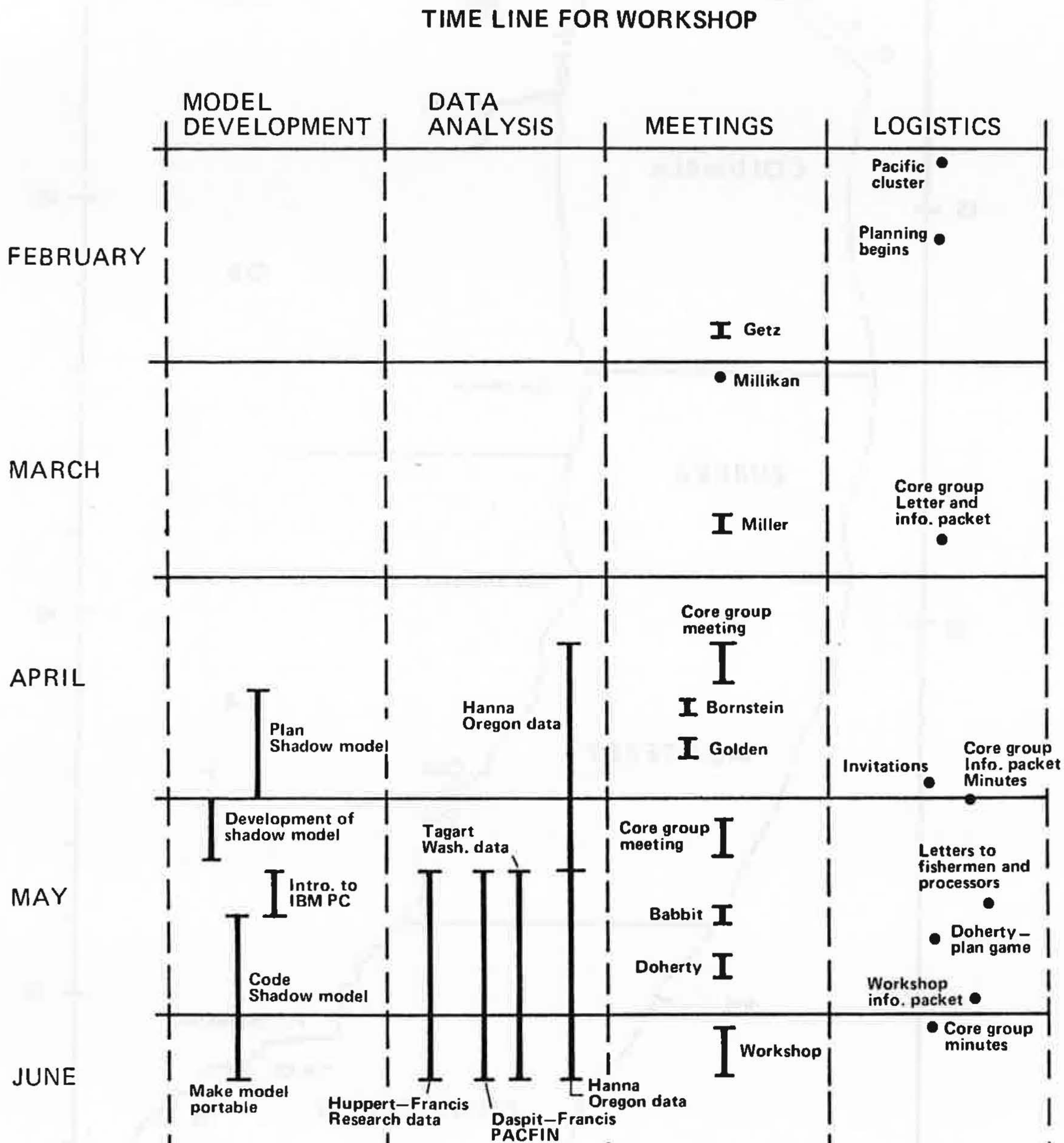

Figure 2. Time line of major project tasks.

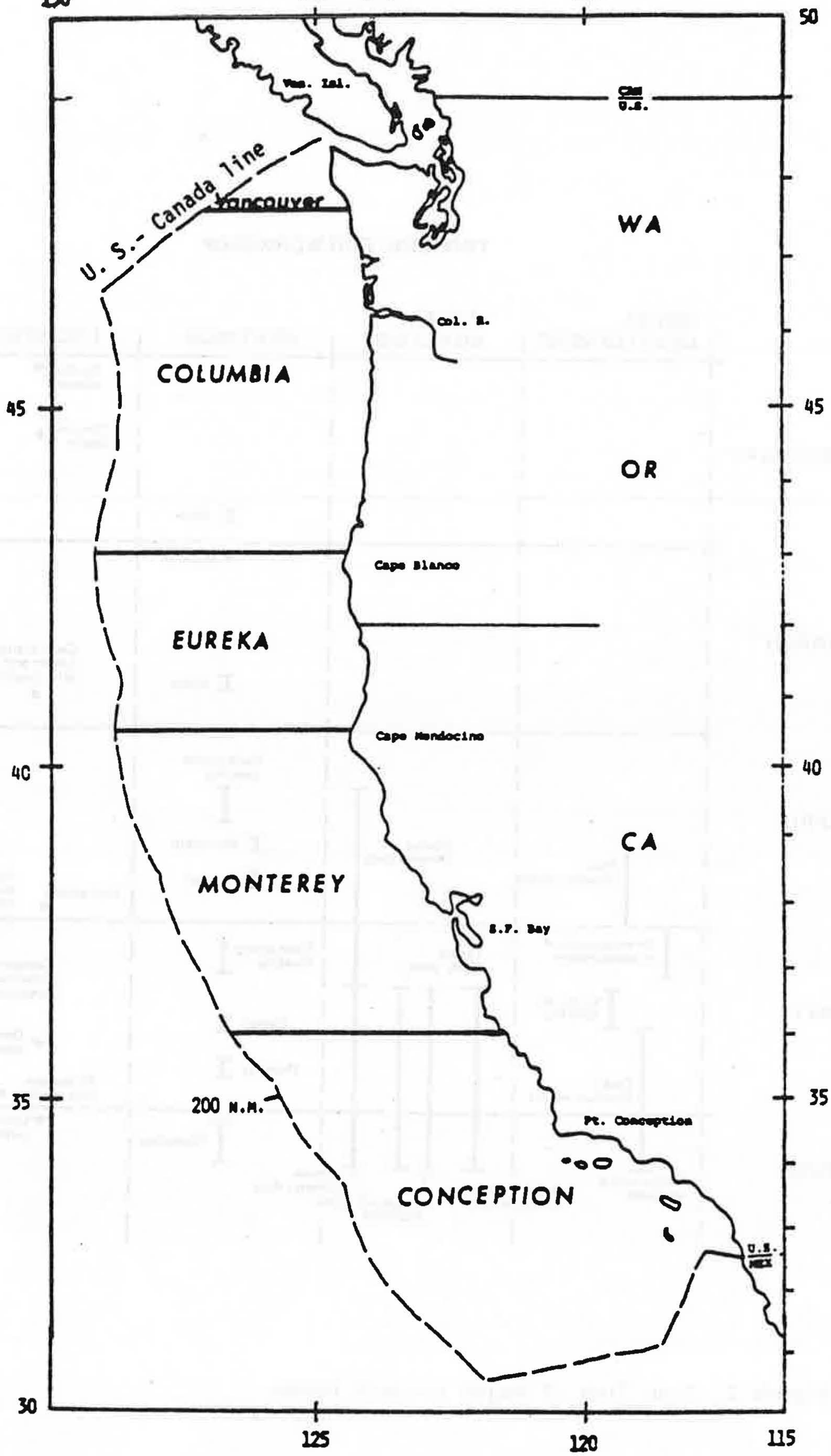

Figure 3. INPFC statistical areas seaward of Washington, Oregon, and California.

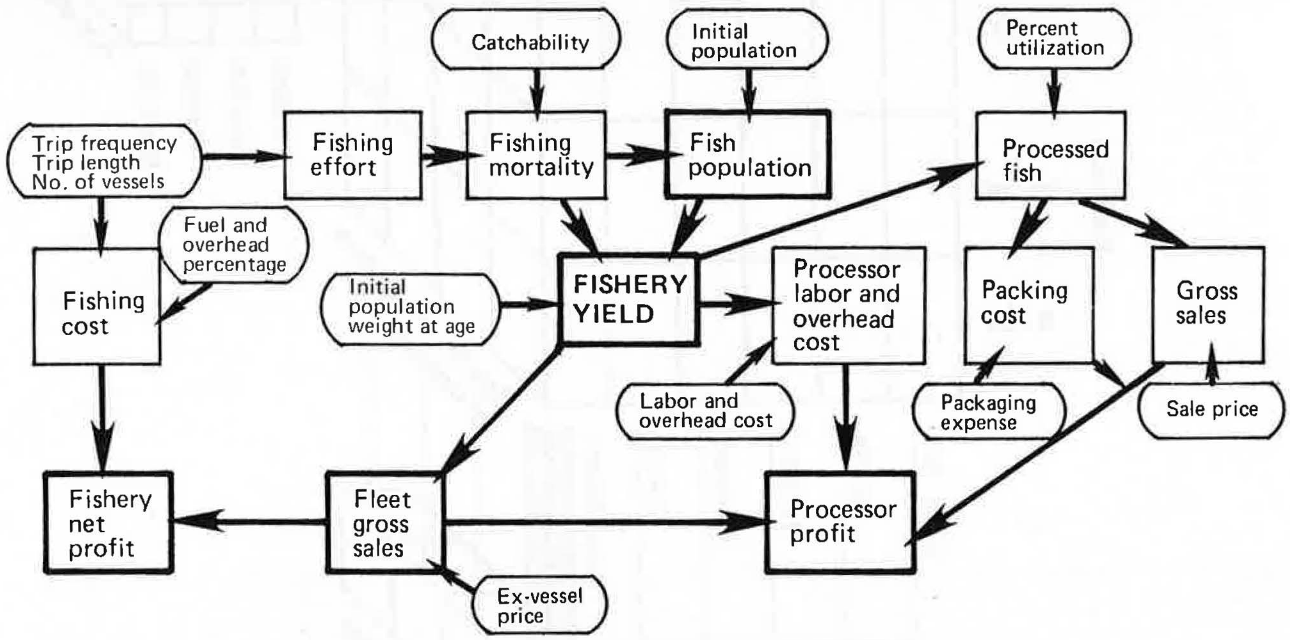

Figure 4. Flow diagram of fishery model.

DIAGRAM OF MODEL STRUCTURE

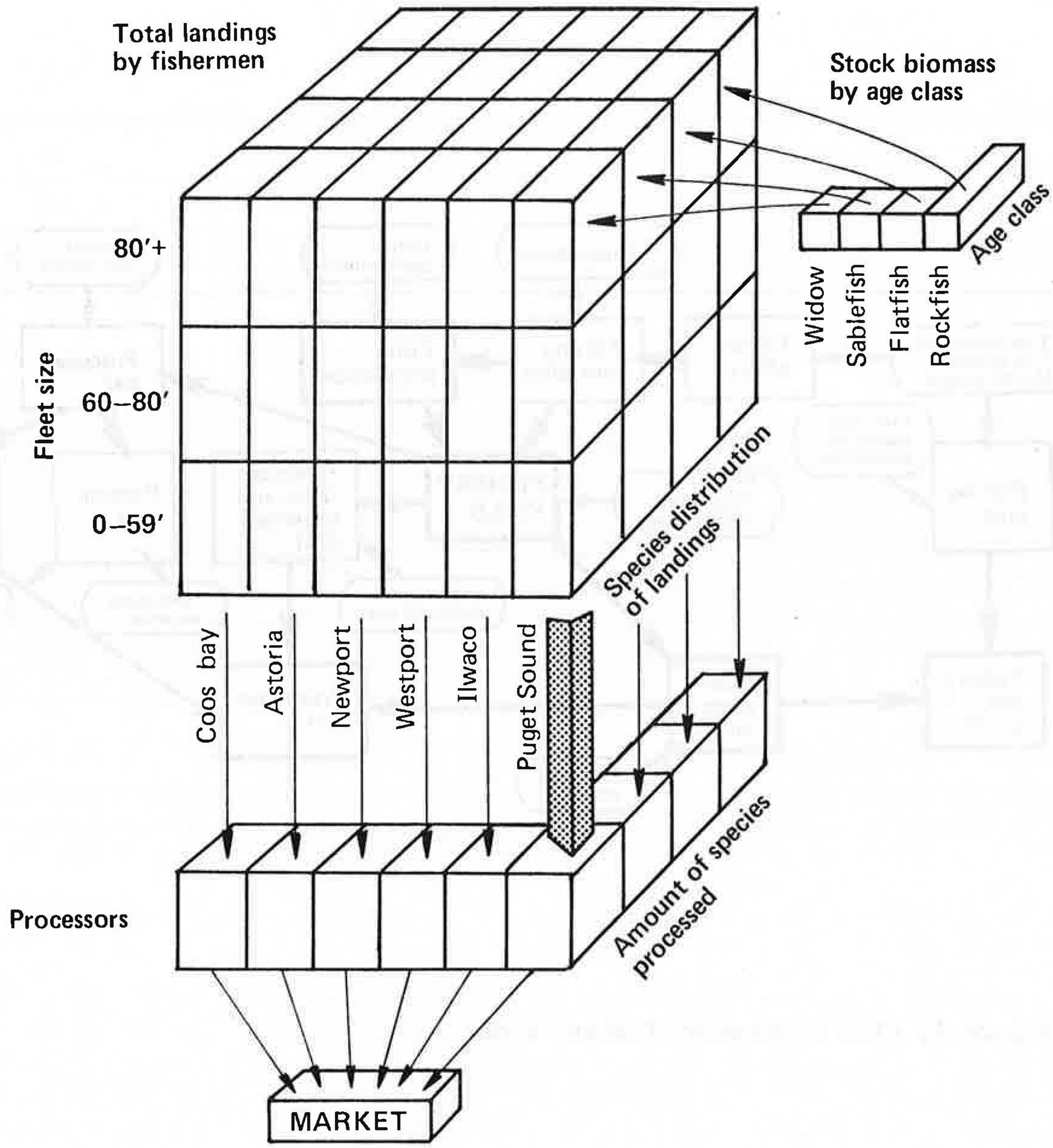

Figure 5. Diagram of model structure.

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WORKSHOP AGENDA

Appendix Table 1.2

Monday -- Morning Session

Introduction -- Dr. William Aron

Review of the Problem

AEAM
Objectives of the workshop

Presentation of shadow model

Critique of shadow model

Monday -- Afternoon Session

Game Introduction

Game Play

Tuesday -- Morning Session

Game Recap

Terry model presentation

Formation of four groups

1. fleet classification
2. theoretical quota implementation -- Terry
3. empirical quota effects -- Francis
4. processor costs

Tuesday -- Afternoon Session

Group reports and discussion

Formation of four groups

1. fleet economic parameters
2. catchabilities by quarter/target species/vessel class
3. revise outputs
4. rewrite quota algorithm to use Terry algorithm

Tuesday -- Evening Session

Implement new parameters

Revise outputs

Implement Getz algorithm

Debug changes

Wednesday -- Morning Session

Game rerun with new model

Closing impressions

Appendix 2.--Game Description

PURPOSE OF THE GAME: The objectives of the game are to determine 1.) what important responses of various parts of the west coast groundfish industry and resource are to management decisions (ABC's, trip limits) made on Vancouver/Columbia groundfish, and 2.) what the key bioeconomic variables are that determine the response of the industry to regulation.

PARTICIPANTS ROLE: Each participant has been assigned to a team. As a member of that team it is your responsibility to act or respond as you feel a member of that group might act. You will be asked to make decisions regarding your area in the harvesting of groundfish, you will also be asked to provide input and/or question other teams, possibly through your team's spokesperson, as they provide input into the simulation exercise. A realistic expression of how you perceive the "real life" players would respond will provide the best results and ensure the success of the exercise.

THE SIMULATION EXERCISE: The exercise itself will be divided into quarters of the year. Each quarter will be divided into four phases. During each phase one or more teams will usually be the center of activity for that phase; and the remaining teams will observe the interaction of the primary teams. At times it will be appropriate for the observers to interact with the primary teams as they are discussing the business at hand. We anticipate that there will be no instances when a team will not be interested in what is happening during another teams discussion.

At the outset, all participants will be provided with quarterly bioeconomic statistics for the 1983 fishing season. During the game, decisions will be made relating to the fishing effort to be applied during each quarter. After each quarter, new data will be generated using the shadow model we have developed. This new data will again be given at the outset of the next quarter, and the effects of last quarters decision can be examined. If questions arise concerning the data supplied, there will be someone identified to answer your questions.

PHASE/QUARTER:

Phase I: All groups confer separately regarding the data provided, and begin to map out a strategy for how you will be affected during this quarter. You may ask questions of one of the facilitators, but not of the other groups.

Phase II: (i) Resource Team: The task of the Resource group will be to assess the status of stocks and fishery, and to recommend to the Regulators what the 1984 ABC's and trip limits should be.
(ii) Regulators: The Regulators will receive this input and then conduct a meeting among themselves to determine what the actual regulations will be, based on the input provided by the Resource group. The Fleet and Processor groups will listen as the Resource group provides their data. They can ask questions (as though it were an open forum) during the Regulators discussion time.

Phase III: Fleet and Processors will meet and discuss the effects of the new regulations for the coming quarter. Specifically, they will arrive at fleet effort levels for the various class vessels, target species, and the processor's catch targets for the quarter.

Phase IV: Modeler Group will run the shadow model and generate bioeconomic output from fishery for the quarter, based on decisions made during that quarter. This data will be used to begin the next quarter.

APPENDIX 3

The Terry algorithm

This approach sets the effort by vessel class (in terms of days/trip, trips/quarter, and number of vessels) and the fraction of trips per quarter targeting on each species or functional group. These change in response to management regulations which control the maximum trip limit (i.e., maximum catch of a particular fish species or group per trip) or trip frequency (maximum number of trips per week or month targeting on a particular group - targeting being defined in terms of the fraction of the total catch comprised of that group). The primary assumption in this algorithm is that a vessel, where possible, will target on the species that gives the maximum revenue per unit effort (RPUE). Targeting on this species will continue until either (1) the holding capacity of the vessel is exceeded, (2) the maximum trip length is exceeded (e.g., the maximun holding time of fresh fish might be a determining factor here), (3) the trip limit for that species is reached. Neglecting trip frequency limits, the optimal solution is to target on the species giving maximum RPUE until one of the above constraints is met, providing that the revenue from the trip is above the opportunity cost Op (that cost below which it pays to do something else besides fishing).

Stated analytically the objective function is to:

$$\text{maximize RPUE} = \frac{\sum_j [(\sum_i F_j C_{ij} B_i P_i (L_i - S)) - E_j L_i]}{L_1}$$

subject to the constraints

$$\sum_i \sum_j F_j\, C_{ij}\, B_i(L_1 - S) <= H$$

$$l_1 <= L_{max}$$

$$\sum_j F_j\, C_{ij} B_i\, (L_1 - S) <= Q_i$$

$$\sum_j [\sum_i (F_j C_{ij} B_i P_i (L_1 - S)) - E_j L_1] >= O_p$$

Optimization consists of choosing the L_1 and the F_j's to maximize the objective function. In this equation L_1 is the length of the optimal trip, i and j denote species caught and species targeted on respectively, F_j is the fraction of the trip spent targeting on species j, S is the steaming time per trip (assumed constant independent of target species), P_i is the price per kg of species i (esvessel price), B_i is the biomass at the start of the quarter of species i (it is assumed that this does not change significantly over the quarter), C_{ij} are the catchabilities for species i when targeting on species j (these may be the same), E_j is the fishing cost per unit time, H is the vessel holding capacity, Q_i are the trip limits for species i per trip and L_{max} is the maximum possible time at sea per trip.

The situation is complicated considerably by including trip frequency limits. Without them the solution is quite easy since only one type of trip, the maximum RPUE targeting trip, is optimal. Once a quota or other constraint is reached it is optimal to head for port and return to sea fishing this same optimal strategy. The only caveats are 1) if the biomass changes considerably during a quarter such that the optimal trip type would change or 2) if at the very end of a quarter after, let us say m trips of the optimal type, only enough time is left for a trip targeting on another species (one that might fill the hold more rapidly). The second of these cases is so insignificant as to be unimportant. The first case, however, could be important and would require a model time step smaller than a quarter (one over which the assumption of constant B_i is more realistic). In that case the approach would still apply. When trip frequency limits are considered it might be possible that two or more types of trip would be optimal (by type of trip we mean a trip targeting on a particular species). If a frequency limit is imposed on the most profitable type of trip, it may still be profitable to switch to a second target for the next trip. We do not present the mathematical formulation of this case here due to its complexity and to the fact that it is not implemented in the present model version. It is part of ongoing research on this project. This algorithm proved too complex to implement in the limited time of the workshop.

Appendix 4.--Glossary of Model Notation

Parameters Definitions

i	Index specifying vessel class
j	Index specifying species class
k	Index specifying port/processor class
a	Index specifying age class
t	Index specifying targeting class
TRP (i,k)	Number of trips per boat in vessel class i of port k.
DYS (i,k)	Number of days per trip for a vessel in vessel class i of port k.
BOAT (i,k)	Number of boats per vessel class i of port k.
FRAC (i,k,t)	Fraction of time spent targeting on species t by vessel class i of port k.
EPRI (j)	Exvessel price per pound of whole fish of species j.
WPRI (j)	Wholesale price per pound fillet of species j.
XPRI (j)	Wholesale price per pound of carcass leftover from filleted species j.
PCT (j)	Percent of species j biomass landed which are left after filleting.
ACST (i)	Cost per day of operating a vessel in vessel class i.
LCST (j)	Labor cost per pound of fillet of species j.
PCST (k)	Packaging cost per pound of fillet for port k.
OCST (k)	Overhead cost per pound of fillet for port k.
QUOTA (j)	Maximum yield allowable of species j per boat per trip.
SAFE	Margin of safety within which management wishes the yield to remain.
BIT	A small value added to RATIO and used in the management algorithm to reduce DYS by an amount sufficient enough to let yield be below the quota.
W (j,a)	Weight of an individual of species j in age class a.
MORT (j,a)	Instantaneous natural mortality on species j of age class a (i.e. non-fishing mortality).
Q (i,j,k,a,t)	Catchability (instantaneous fishing mortality) per fishing day on species j of age a by vessel class i of port k while targeting on species t during the season.

INTERMEDIATE VARIABLE DEFINITION

FMORT (i,j,k,a,t)	Instantaneous fishing mortality per vessel class i of port k on species j age class a while targeting on t during the season.
FSUM (j,a)	Total instantaneous fishing mortality on species j age class a over all vessel classes and ports.
SURV (j,a)	Percent survival to next season of species j of age class a.
V (i,k)	Effort in number of days fished per vessel class i of port k.
RATIO (i,j,k,t)	Ratio of the actual yield to the allowable yield set by management or processor.

STATE VARIABLE DEFINITION

N (j,a)	Number of individuals of species j in age class a.

OUTPUT VARIABLE DEFINITION

YLD (i,j,k)	Yield in metric tons of species j to vessel class i of port k.
SALE (i,j,k)	Total sales at exvessel prices from yields of species i to vessel class i of port k.
COVL (i,k)	Cost of vessel expenses per boat to vessel class i of port k.
COSUM (i,k)	Total cost of vessel expenses to vessel class i of port k.
RVVSL (i,k)	Net profit per boat to vessel class i of port k.
RVSUM (i,k)	Total net profit to vessel class i of port k.
CLABR (k)	Cost of labor expenditures per pound of fillet to port k.
CPAKG (k)	Cost of packaging per pound of fillet to port k.
COVHD (k)	Cost of overhead per pound of fillet to port k.
CSALE (k)	Cost of purchasing yield at exvessel prices to port k.
PRGRS (k)	Gross profit to port k.
PRNET (k)	Net profit to port k.