

# 2005 Review of Multispecies & Ecosystem Models

for

University of Miami Independent System for Peer Review

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## Executive Summary

A review of multispecies and ecosystem modelling was undertaken at the Alaska Fisheries Science Center (AFSC), Seattle. Prior to the workshop, review panel members were issued with 11 documents to consider: five focusing on aspects relevant to Ecopath modeling, five on MSVPA and multispecies assessment modeling, and one generic document from the *Ecosystem Considerations* section of the annual SAFE stock assessment report. A two day meeting was held on May 31st – June 1<sup>st</sup> 2005. The review panel consisted of two invited experts with independent terms of reference, with one to focus on multispecies modelling, and the other to focus on ecosystem modelling. This reviewer has concentrated on the ecosystem modelling work of AFSC.

The scope of multispecies and ecosystem modelling conducted within AFSC is impressive, and the commitment to such work is to be commended. The group has made a number of clear contributions to the field and is at the forefront of model development. Furthermore, the group has shown real commitment and determination in trying to disseminate its model outputs among the wider stock-assessment community, and it has also developed the best web-interface for Ecopath outputs I have seen anywhere. This review includes 25 recommendations for improving the current models, plus suggestions for new analytical techniques or future research.

In this review, methods and data sources have been examined, and there are a number of clear gaps in knowledge some of which may be un-resolvable. This review calls for better documentation of the data sources utilised and the methods employed. Some of the assumptions made during the construction of the three Ecopath models or when estimating consumption rates are called into question and should be clarified.

By re-creating Ecosim outside of its normal software environment, Dr. Aydin and his team have complete control. They have demonstrated their detailed knowledge of the approach and its foibles, and, in many cases, they have developed their own unique solutions to perceived model limitations. A number of minor suggestions are offered for model improvements.

The intention of this review has been to identify the strengths and weaknesses of the various Ecopath models for forecasting the effects of alternative management strategies. The review has attempted to evaluate where further refinements of current modelling approaches might be made, and it has also suggested new approaches or scenarios which might be pursued/explored in the future, perhaps the most interesting of these might be the exploration of length-based methods.

## Description of review activities

The review was undertaken by Dr. John K. Pinnegar from CEFAS (Lowestoft, UK) and included a two day workshop (30<sup>th</sup> May – 1<sup>st</sup> June 2005) held at the Alaska Fisheries Science Center (AFSC) in Seattle, Washington. The review panel consisted of two invited experts, each focussing on a different aspect of multispecies and ecosystem modelling. The panel membership and workshop attendees are listed in Appendix 2, which also includes a detailed agenda specifying the broad topics discussed.

Over the two day period, the AFSC team provided five presentations focussing on:

- Multispecies management & fisheries management needs (Kerim Aydin)
- Data for multispecies models (Kerim Aydin)
- Multispecies models (MSVPA, MSFOR, MSM) for fisheries management in the Bering Sea (Jesús Jurado-Molina & Patricia A. Livingston)
- Ecosystem modeling – E. Bering Sea, Gulf of Alaska and Aleutian Islands (Kerim Aydin, Ivonne Ortiz, Sarah Gaichas).
- Retrospective analysis – time-series “fitting” (Sarah Gaichas).

Each day was concluded with a discussion of the AFSC team’s aspirations and long-term goals with respect to multispecies/ecosystem modeling. The group also considered limitations associated with input data, numerical techniques which might be applied and ways of communicating results.

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During the review workshop, members of the AFSC project team were interrogated with respect to details of their models. Afterwards (once the external reviewers had returned to the UK), additional materials from the project group were downloaded and examined (see bibliography).

The terms of reference given to Dr. Pinnegar prior to this review (by Center for Independent Experts) are detailed below. These required that the reviewer concentrate mainly on Ecopath/Ecosim modeling, however, because of the reviewer’s familiarity with the MSVPA approach Dr. Pinnegar chose to engage in debate regarding these models and documents provided. Outputs and discussion points concerning MSVPA/MSFOR/MSM are not included as part of this report.

### **Terms of reference for this review (also see Appendix 1):**

1. Review methods and data sources for estimating consumption rate and diet parameters for input to the suite of multispecies (MSVPA/MSFOR) and ecosystem models (ECOPATH/ECOSIM and Aydin’s ELSEAS biomass dynamics model) currently being used to model the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands ecosystems, including sampling

techniques, spatial and temporal distribution of sampling, and the use of bioenergetic models to estimate seasonal or annual rations.

2. Review the suite of multispecies and ecosystem models currently being used to model the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands ecosystems. Identify the strengths and weaknesses of the models for forecasting the effects of alternative management strategies. Evaluate whether there is benefit in further refinement of these modeling approaches, or whether resources should be devoted to new model development. If new modeling is recommended, provide recommendations and examples of suggested new approaches.
3. The long-term goal of ecosystem modeling research is to implement ecosystem models in a management advice framework. Identify the most important information gaps and research priorities over a five-year planning horizon that allows the most progress to be made towards achieving this goal.

## The ecosystem assessment process

Prior to the Seattle workshop, the reviewers were issued with a copy of the 2003 *Ecosystem Considerations* chapter prepared by the North Pacific Fishery Management Council (NPFMC) as part of the annual SAFE report. The intent of the *Ecosystems Considerations* chapter is to provide the Council with information about the effects of fishing from an ecosystem perspective, and the effects of environmental change on fish stocks.

In 1999, a proposal came forward to enhance the *Ecosystem Considerations* section by including more information on ecosystem indicators. In 2002, stock assessment scientists began using indicators and in 2003 much of the focus changed to the application of multispecies models. However, by 2003, not all of the modeling tools currently applied were ready for use in fishery projections. Much of the 2003 chapter focused on long-term trends and the status of particular stocks or ecosystem components, as well as indicators. A description of long-term trends was provided in the text but with few illustrations to help the reader obtain an integrated overview of changes at the ecosystem level.

During the Seattle review Dr. Pinnegar recommended that the authors employ some sort of visualization technique, as a way of reducing the large amount of information contained in the *Ecosystem Consideration* chapter to a form which is useful to managers. One such tool is the ‘traffic light’ system used, for instance, in the Eastern Scotian Shelf ecosystem assessment (DFO, 2003) but hitherto not used in Alaskan assessments. This assessment incorporated sixty-four metrics including the stock status of various commercial fish species and marine mammals. The approach allows the easy ‘eye-balling’ of multiple data-sets, and hence makes it easier to detect changes in the ecosystem as a whole (phase or regime shifts). Such a figure can be easily updated each year as new data points become available and has recently been adopted by ICES, the European fisheries management body (see REGNS 2004).

A further example of an ecosystem evaluation tool is the ‘dashboard’ approach developed to illustrate policy performance and indicators in Italy. Figure 1 shows an example from the website [http://esl.jrc.it/envind/db\\_meths.htm](http://esl.jrc.it/envind/db_meths.htm). The outer ring of this dashboard is composed of a series of indicators whose condition has been evaluated on a ‘good’ to ‘bad’ scale. These indicators are then grouped into categories, in the case of figure 2 the categories are environment, social care and economy. These categories are evaluated by weighting each of the indicators to arrive at an overall assessment of the category. Finally, an overall assessment is reached by combining the assessments of each category.

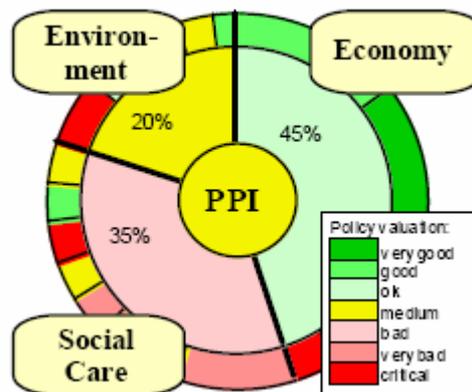


Figure 1: A dashboard illustration of the state of indicators building to an overall performance index (PPI) (from [http://esl.jrc.it/envind/db\\_meths.htm](http://esl.jrc.it/envind/db_meths.htm))

In both examples (the ‘traffic light’ and the ‘dashboard’ approach), re-scaling of the indicators to a common scale of response is critical. However, the scaling procedures are objective and can be modified in such a way as to maintain the greatest degree of faithfulness to the original responses.

Following the review workshop in Seattle, a more recent (November 2004) edition of the *Ecosystems Considerations* chapter was located and downloaded from the AFSC website. This much more substantial document (compared to the 2003 example distributed to the reviewers) did contain an integrated “traffic light” figure, similar to that described above. Furthermore, the new document provides an exhaustive account of available time-series and data sources which might be of great utility when attempting to fit or ‘tune’ Ecosim models. Many of the available time-series described in this latest *Ecosystem Considerations* chapter have not yet been evaluated within the context of Ecosim ‘fitting’ (see section below), thus the regular updating and improvement (each year) of this integrated document should prove invaluable for model construction and refinement. In the 2004/5 document contributors were requested to supply the time series data electronically. Consequently much is now available on the web, or through the editor. **Recommendation 1** suggests that the AFSC team go through the latest (much revised) *Ecosystems Considerations* chapter and consider the utility of data sources listed (both new and old).



The final modeling approach is the use of ECOPATH/ECOSIM, which approximates a whole ecosystem approach to evaluating fishing effects. Models for the Eastern Bering Sea, Gulf of Alaska, and Aleutian islands have been developed and are being utilized to provide indicators of change that relate more to ecosystem-level properties of energy flow and organization as well as changes in predator-prey dynamics.

In the 2003 integrated assessment document (Livingston et al. 2003), little use was made of MSFOR or Ecopath models. Most conclusions were based solely on the multispecies-bycatch model and/or single-species assessments. MSFOR and Ecosim could have contributed much with regard to speculations about the potential causes and impacts of a rapid expansion in arrowtooth flounder and the potential causes of Steller Sea Lion decline or prospects for recovery given current levels of fishing and available food resources. Appropriate models were not ready in 2003 and even in the updated 2004/2005 *Ecosystems Considerations* chapter (Boldt et al. 2003), surprisingly little usage has been made of MSFOR or Ecosim beyond the provision of ecosystem/network indicators (e.g. trophic level, FIB index) or relative levels of mortality inflicted by fishing or predators on particular stocks. Neither approach has been used extensively for policy scenario evaluation. In the 2004/2005 *Ecosystems Considerations* document further details of model configuration, parameterization, and validation were provided (pages 26-38), but the models have not yet been fully included as an integral part of the assessment process. **Recommendation 2** suggests that the AFSC team conduct a series of scenario evaluations in order to test some of the more speculative comments about changes in ecosystem structure (e.g. the expansion of arrowtooth flounder or decline of fulmars, fur-seals and sea lions) included in the *Ecosystems Considerations* document.

The 2004/2005 report considers the importance of ‘forage’ animals but does not estimate their importance for specific predators in terms of diet composition, total consumption, and partial mortalities, even though such data are already available from the existing Ecopath models and are now being made available on the internet (see section below) for the benefit of stock-assessment scientists.

On the first day of the review meeting in Seattle (31<sup>st</sup> May), Dr. Aydin provided a useful account of multispecies modeling generally and how this links with fisheries management needs within the Alaskan context. He discussed briefly the legal framework/landscape, including US legislation which calls for an ‘ecosystems approach’ to management of marine resources (e.g. National Environmental Policy Act of 1969; Clean Water Act of 1972; Marine Mammal Protection Act of 1972; Endangered Species Act 1973; and the Magnuson-Stevens Fishery Conservation and Management Act of 1976). Dr. Aydin identified high-priority research needs, which should be addressed if an integrated ecosystem assessment is ever to be fully comprehensive and successful. These priorities (identified by Dr. Aydin) included:

- An improved system for non-target species management.
- Incorporation of ecosystem considerations into individual stock assessments.
- Research to define ecosystem-level reference points
- Predator-prey data and multispecies/ecosystem models with improved links to bottom-up processes.
- Evaluate OY (optimum yield) ranges and evaluation of harvest policies.
- Research to evaluate fishery/marine mammal interactions.

The question was then raised as to “*what will CURRENTLY OPERATIONAL MODELS provide towards fulfilling these needs?*”

Current ecosystem-based policies include a restriction on fisheries so that catches do not exceed a fixed cap or ‘optimum yield’, based on historic average/maximum yields. The total of all TACs combined may not exceed this cap, set at 2,000,000 mt in the Bering Sea and 700,000 mt in the Gulf of Alaska, although the threshold at which this cap was originally set was not based on a known ‘carrying capacity’ for the ecosystem. As stated in the research priorities identified by Dr. Aydin (see above), and given that suitable models are now available, it might be an opportune time to review the level of these caps from an ecological/multispecies point of view. **Recommendation 3** suggests that the AFSC team consider whether or not these overall fishing caps have any ecological relevance or whether they should be revised (up or down) to reflect real, ecological processes and limits. Discussions are currently underway with regard to splitting the Aleutian Island/Eastern Bering Sea management areas. Presumably, managers will have to seek a new level for restricting total catches in each area. The work proposed here could provide useful input into this process.

System ‘carrying capacity’ will vary with temperature (e.g. productivity) and habitat type, but is often thought of as the total biomass of all components within the ‘virgin’ ecosystem (see Jennings & Blanchard 2004). Knowledge about the ‘virgin’ state of an ecosystem is often poor. However, such information is required in order to establish baselines against which current or future levels of impact can be compared (Steel & Schumacher 2000), without suffering the problem of ‘shifting baseline syndrome’, i.e. when a baseline is set with a short-term perspective and represents an increasingly exploited state over time (see Pauly 1995).

Hence, the AFSC team might try using their Ecopath/Ecosim models, ‘tuned’ using historic time-series where such data are available, and project into the future but without any fishing pressure applied to the system. If unfished for a sufficiently long period, populations would presumably settle to a new equilibrium (if no ‘biomass accumulation’ is applied). From this ‘unfished’ equilibrium the ‘virgin’ biomass of the system might be derived.

An alternative approach has been developed by Jennings & Blanchard (2004) based on macroecological theory, to predict the abundance and size-structure of an exploited fish community from a theoretical abundance-body mass relationship (size spectra). Given that the AFSC team has access to an extensive database of stomach content records (see discussion below) and therefore evidence about predator-prey size ratios (Jennings & Blanchard) derived these from stable isotope data), it should be able to draw conclusions about the biomass of unexploited fish communities in the Bering Sea and Gulf of Alaska.

Jennings & Blanchard (2004) point out that the unexploited biomass of a community (the ‘carrying capacity’) is not necessarily the same as the historically observed state, because climate has also changed over time. Indeed, it is unlikely that ecosystems today would always revert to historic levels even if fishing were stopped, either because phase-shifts have occurred or because the environment is fundamentally different from that existing prior to human exploitation. The above approach takes

this into account and widely available climate scenarios (REF) could be used to estimate the underlying capacity in the future (also as forcing functions in the unfished Ecosim scenarios). Consequently the total fishing ‘cap’ derived for the Bering Sea, Aleutian Islands, or Gulf of Alaska, could be based on a set proportion of the ecological carrying capacity and revised in the future taking into account the prevailing environmental conditions.

In 2003, the ICES multispecies study group (SGMSNS) was tasked with exploring the extent to which fisheries reference points, derived within a single species framework, are valid when multispecies interactions are taken into account. The group used three different fishing scenarios and found that estimated spawning-stock-biomass (SSB) and hence fishery reference points ( $F_{Lim}$ ) established on the basis of these, differed markedly between single-species and multi-species formulations. In the Alaskan context, single-species fishery reference points ( $F_{MSY}$ ,  $F_{40\%}$ ,  $F_{35\%}$ ) are based on  $B_{MSY}$ . No stocks are currently considered ‘overfished’, although stocks such as sablefish are near to the  $B_{MSY}$  reference points. The AFSC team has already used its models (single-species, MSFOR, Ecopath) to examine the % change in biomass of particular stocks following a simulated halt in fishing ( $F_0$ ). The three modeling approaches yielded very different estimates of changes in biomass; for example, the single-species model suggested a massive 60% increase in pollock, whilst Ecopath and MSFOR yielded a much smaller, 10% increase.

**Recommendation 4** suggests that the team carry out analyses to see if biological and hence fishery reference points would be similar or different in a multispecies context.

In 2003, ICES-SGMSNS also explored (using MSFOR) the possible multispecies implications of a ‘recovery plan’ for cod in the North Sea (ICES 2003). No ‘recovery plans’ are proposed for the Bering Sea or Gulf of Alaska regions as most stocks are considered to be well within ‘safe biological limits’. However, the AFSC team could explore the multispecies implications of a ‘recovery plan’ for Steller Sea Lions, which have become increasingly scarce in recent years (**Recommendation 5**), i.e. what would you have to do to fisheries to allow the sea lion stocks to recover, and what would be the impact on stocks and fisheries if stocks were to recover?

During the morning session of 31<sup>st</sup> May, Dr. Aydin discussed his ideas for integrating modeling work within the annual assessment process. He suggested that on a yearly cycle, traditional stock-assessments would be augmented with revised and updated information on ecological indicators (see above), whereas more detailed information from ecosystem/multispecies models would be fed into the process only as part of a five year cycle, contributing to strategic planning.

Although the reviewer finds the idea of only periodic updates of the model ‘key run’ eminently sensible (an approach taken by ICES-SGMSNS), one question would be whether five years is too long a period between updates? Given that funding for most research projects has a shorter duration and with several of the key staff members working towards completing their PhD dissertations, does this five year assessment cycle seem sensible?

A five-year cycle would, by definition, require assured funding resources over a long time period; it is unclear whether this is feasible or likely. Furthermore, if only

reminded every five years, stock assessment scientists may well forget the true utility of multispecies data and assessments, and scientific requests for targeted analyses could only be dealt with on a very occasional basis, in effect many years after the original problem arose.

During discussions on 1<sup>st</sup> June, it was suggested that one of the great advantages of Ecosystem models might be to show the potential impacts of new/expanding fisheries which appear suddenly, under the assessment 'radar' before measures are in place to regulate them. Such a function could not work if operating on a five year cycle.

On the morning of June 1<sup>st</sup>, Dr. Aydin described recent efforts to provide a web interface for use by stock assessment scientists and the general public (see description in section below). This work is a very commendable and exciting, as it communicates biomass and density estimates for all components of the ecosystem, total consumption (who eats who) estimates, diet composition charts, and estimates of causes of mortality (fishing vs. predation etc.) for specific stocks and geographic areas. Working in collaboration with fisheries scientists, **Recommendation 6** suggests that the AFSC team continue to work on methods to ensure better integration of model results/outputs into stock assessment reports, and specifically that the team develop a set of standard graphs and tables which the stock assessors come to expect and appreciate.

## Data: strengths, weaknesses and gaps

In order to construct an Ecopath model, five types of input data are required: biomass/abundance data (usually expressed in  $t/km^2/y$ ), an estimate of consumption rate (usually expressed as a consumption to biomass ratio  $Q/B$ ), production data (usually expressed as a production to biomass ratio  $P/B$  and assumed to equal total mortality  $Z$ ), diet composition data, and fisheries data (catch composition, discards etc.). In the following four sections, this review examines the sources of data available to the modellers and potential gaps and weaknesses that have been identified and explored.

It is important to note that the AFSC team states that it is currently working on a detailed technical description of all data sources utilised in the construction of its models; this was not made available to the reviewer either prior to or after the review workshop. Completion of this document should be seen as an immediate priority (**Recommendation 7**).

### Biomass Estimates

Biomass estimates for fish species have been obtained from a number of sources; some have been derived from stock-assessment estimates and some from scientific survey data using a wide variety of different gears (including trawls, hydroacoustic equipment, long-line, pots, and submersibles). Most, including those taken from stock assessments, have been derived from bottom trawl survey data and there are a number of assumptions and problems implicit in this data-set. Sampling design and gear details are fully described in Zenger (2004), Hoff & Britt (2003) Weinberg et al. (2002) and in technical memoranda produced by AFSC. Some of the more salient points to consider are:

- A. A different survey design is used in each of three geographic areas. For example, for the EBS shelf, a survey is carried out on an annual basis and using a fixed grid (using chartered vessels in the summer, since 1982). By contrast, surveys on a biennial (used to be triennial, 1983-2000) basis for GOA and AI (alternating each year) and using a random stratified design.
- B. Trawl surveys make use of charter vessels and have tended to shift slightly earlier in recent years. Surveys endeavor to use the same vessels (5 year contract) and same gear each year, but they operate outside the peak fishing period. The behavior of fish may be very different at different times of year; i.e. in summer some species disperse to feed and during the winter fishing season, they aggregate to breed.
- C. Surveys in the on the EBS (shelf), Gulf of Alaska, and Aleutian Islands tend to use very short duration trawl tows (30 minutes in EBS, 15 minutes in GOA and AI). A substantial body of research exists which suggests that short tows may not capture strong swimming or large individuals (e.g. Godø et al. 1990). This may be a particular problem for species such as cod.
- D. Surveys provide only variable/intermittent coverage of sites >500m depth (in GOA and AI) and on the shelf-slope (Eastern Bering Sea). This is a particular problem, in the Aleutian Islands where the survey only goes down to 500m, whereas the fishery continues to 3000m depth! Thus, the survey may not reflect the real status of the ecosystem.
- E. Trawl survey estimates hardly ever take variability in the ‘headline height’ (i.e. the vertical opening of the net) into account when estimating ‘swept area’ and thereby absolute abundance per square kilometer. It is well known that the vertical opening of the net can change in response to water depth and many other factors (e.g. the speed and size of vessel doing the towing, as well the weather, among other factors). This can have a marked impact on the perception of stock abundance, particularly for stocks such as mackerel which swim throughout the water column (Godø, and Engås, 1989).

Biomass estimates for marine mammals have a number of potential limitations. Good data exist for counts of pinnipeds (seals) at breeding colonies (see pages 187-195 in Boldt et al. 2004; Angliss & Lodge 2004), and in many cases extensive time-series are available. However, information on spatial utilization and behavior at sea is somewhat lacking (estimates are usually theoretical minimums, based on those observed at colonies), and thus it is difficult to obtain an overall estimate of population abundance. Some animals clearly forage or migrate across model boundaries (see discussion in section below), and residence time in each of the three modeled systems may be poorly parameterized.

Dedicated surveys to determine the abundance of all observed cetaceans in Alaskan waters, have only recently been made (Moore et al 2002, Zerbini et al 2004), and it is unlikely that these recent estimates have been fully incorporated into the Ecopath/Ecosim models developed. **Recommendation 8** suggests that the AFSC team examine the utility of this recently derived data, together with recent marine mammal diet data (e.g. Zeppelin et al. 2004; Sinclair & Zeplin 2002) for possible inclusion in their Ecopath models.

Biomass estimates for seabirds are also potentially problematic. Again, good data exist for counts of seabirds at specific breeding colonies (see pages 199-203 in Boldt et al. 2004); however, information on spatial utilization and numbers at sea are completely lacking. In Europe, various organizations monitor 'Seabirds at Sea' and have developed a standard suite of methodologies in order to improve total population estimates (e.g. Tasker et al. 1984). Trained observers sail on oil industry survey and supply vessels, and occasionally vessels are specifically chartered to work in areas where data are limited.

Available data on benthos have been identified as the biggest cause for concern in models. Currently the models utilize grab data from the 1970s, and it is therefore difficult to know if the system has changed and hence, whether these values are still relevant. Some historic habitat data (maps) may be declassified by the US Navy in due course, and this could help scale biomass estimates better. However, models would still be reliant on out-of-date data. The 2004/2005 *Ecosystems Considerations* report (Boldt et al. 2004) suggests that additional data might be obtained from the RACE bottom trawl surveys. However, these surveys were not specifically designed to assess benthic organisms (mostly sea-pens, corals, sponges and anemones) and only provide information on epifauna (and not infauna). **Recommendation 9** suggests that the AFSC team pursue new sources of funding in the hope of conducting a systematic benthos survey throughout the region. This data would compliment the spatially resolved fish stomach data collected, and could be used in a comparison of presence in stomachs and availability in the environment.

## **Diet Data**

Arguably the most important parameter set for food web models are diet composition matrices, obtainable through stomach sampling. Systematic (year on year) sampling of stomach contents began in 1981, although some data are available from before this period, and these records have now been included in the same electronic database. Over three quarters, or 76%, of all data (totaling 172,778 records) are from the Eastern Bering Sea; much less data is available for the Gulf of Alaska (14.4%, or 32,706 records) and Aleutian Islands (9.4%, or 21,378 records). A detailed account of the stomach sampling program is described in Lang et al. (2002) and Yang & Nelson (2000), although the basic methodology is as follows:

Samples were taken primarily during May through September using bottom and pelagic trawl gear on research and commercial fishing vessels. Sampling occurred throughout the 24-hour day, although usually between 0600 and 2000 Alaska Daylight Time. For all species, stomachs were removed at sea and placed in cloth bags labeled with information regarding the location of capture, fork length, sex, and sexual maturity of the fish. Fish showing evidence of regurgitation (i.e., food in the mouth or throat or a flaccid stomach) were not included in the sample. Stomachs were preserved in 10% formalin and later transferred to 70% ethyl alcohol. Contents were identified to the lowest taxonomic level possible and enumerated. Wet weights were recorded after the contents were blotted with paper towels. Standard length (SL) measurements of prey fish and carapace width (CW) or lengths (CL) of crab prey were taken when whole prey were available.

Whilst good data exist for most common species (Walleye pollock, cod, arrowtooth, YF sole, FH sole) very few replicates exist for some rarer species (as few as one individual for Canary rockfish and dogfish). This could have a serious impact on the diet matrix of an Ecopath model. All three models for Alaskan waters (EBS, GOA, AI) are relatively species-specific (at least with regard to fish), even though the available diet may not be adequate to support this level of resolution. Deb (1997) suggests that stomach contents may provide only a limited picture of feeding dynamics, whilst Cohen and Newman (1988) suggest that many small links in food webs are usually missed. Recent modeling work has demonstrated that the accidental omission (or deletion) of weak links in a model may impact the model's stability and dynamics (e.g. Pinnegar et al. 2005).

Sampling is primarily carried out by trawl gear and using a non-random stratified sampling design (in terms of area and depth). During analyses diets are weighted by stratum (using survey estimates of biomass) in order to account for spatial variability in diets (and to correct for the non random-stratified sampling), however there are some geographic areas and depth zones which have particularly poor coverage. For example, very few samples are available from the deeper waters (>500m) around the Aleutian Islands, even though it is known that the diet of a particular species may change markedly with depth in shelf-edge communities (e.g. Polunin et al. 2001).

Stomach sampling has thus far been relatively opportunistic in relying on charter vessels during summer period (May to September), and with very poor sampling in the winter fishing season. About 20% of stomachs have been obtained from the fishery observer program, whereby observers are asked to target a particular species in a given year. Some target species are still very poorly represented, thus **Recommendation 10** suggests that the AFSC team make a concerted effort to sample (or request) some of the rarer target species in the next few years.

Empty stomachs are recorded in some geographic areas but not in all. There are seemingly some problems of inconsistency in the methodologies used in each area or at least in the methodologies understood by each of the modelers. A technical report/memorandum outlining 'Standard Operating Procedures' for stomach sampling, describing the database and updating readers on sample sizes and diet composition estimates, would be very useful (**Recommendation 11**). This report might also look for long-term changes in diets and communicate the results of GAM analyses (see recommendation 12), etc.

From 2004, AFSC began mainly ship-born analyses of stomachs and recording, as opposed to bringing samples back to the lab for examination. This is a very labor-intensive task (particularly when not part of a dedicated cruise), and it may affect the total number of samples that can be processed. However, analysis at sea may help to resolve the problem of a back-log of stomachs to analyze in the lab, and it also necessitates less consumables and is therefore less wasteful.

So far the team has not really looked at predator-prey size ratios (beyond calculating their suitability for MSVPA). Length-based prey selection may be a subject to consider in the future, particularly if the AFSC team intends to explore length-based methods (see below). Quantile regression techniques are available to help describe the

maximum, median and minimum prey size taken by a particular predator (e.g. Scharf et al. 1998; Pinnegar et al. 2003).

In order to evaluate patterns of predation in time and space (i.e. to look for prey switching), the AFSC team could conduct GAM or similar type of analyses with years, seasons, longitude, depth, predator size, etc. as potential explanatory variables (e.g. see Trenkel et al, in press) (**Recommendation 12**). Such analyses can also help to identify data gaps and target resources.

Stomach-contents data suffer a number of potential problems, notably:

- Such data only reflect diet in the past few hours (diet can vary markedly with season and in space);
- Prey with hard parts (e.g. otoliths) show up better than gelatinous plankton and detritus, etc.;
- Many species regurgitate food upon capture or eat only intermittently;
- Different prey items are processed at different rates;
- Requires skill to identify digested remains and very time consuming.

Several alternative (biochemical) methods have emerged, and these may offer some advantages in describing feeding patterns over longer time periods. Ingested triglycerides and lipids are broken down into free fatty acids and monoglyceride. Fatty acids are stored without substantial modification in adipose tissue. Specific fatty acids are associated with different classes of phytoplankton, and differences in fatty acid composition are detectable in animals that have fed on different diets (e.g. sand-lance vs. herring). Patterns may change significantly in only three weeks in adult cod (*Gadus morhua*) (Kirsch *et al.*, 1998). Analysis of fatty acid profiles have been widely used to elucidate the diets of fish, marine mammals, and seabirds.

Carbon and nitrogen each exist in two stable isotopic forms ( $^{12}\text{C}$  and  $^{13}\text{C}$ ,  $^{14}\text{N}$  and  $^{15}\text{N}$ ) which differ in atomic mass. Animals tend to be ~3‰ enriched in  $^{15}\text{N}$  and ~1‰ enriched in  $^{13}\text{C}$  with respect to their food.  $\delta^{15}\text{N}$  is often used to indicate trophic level (and omnivory).  $\delta^{13}\text{C}$  is often used to indicate primary food sources (e.g. benthic algae or phytoplankton food-chains, C4 plants vs. C3 plants). A major advantage of these data over conventional dietary analyses is that the tissues which are sampled turn over relatively slowly, and stable isotope compositions therefore reflect the diet of the animal over substantial periods of time. In the case of most late juvenile and adult fishes, the time scale concerned will be of a year or more (e.g., Hesslein *et al.*, 1993), but will tend to be shorter for very young fishes (e.g., Doucett *et al.*, 1996).

The methods do not typically yield data which could be utilised in a food web model (although see Lubetkin & Simenstad 2004). **Recommendation 13** suggests that the authors explore the potential utility of lipid/fatty acid analysis and stable isotopes for elucidating differences and changes in diet over time and in space.

In the AFSC database, the prey category ‘offal’ has been used, where the ingested item had obviously been discarded from a processor. This ‘prey’ apparently showed up in many stomach samples (e.g. 50% diet of sablefish), and was particularly apparent in observer collected samples from commercial boats (i.e. offal coming from

same boats!). Data on bird diets is very limited, and Ecopath models do not adequately capture the amount of offal and discards consumed by birds (see recommendation 14).

During the review workshop, it was suggested that mammal and bird diet data collection stopped in the 1970's, and hence may not be representative of feeding patterns in recent years (therefore, conclusions based on this data may be incomplete). The available data also tend to be associated with specific colonies (birds and seals) and may not be representative of diets at sea. Almost all of the marine-mammal diet data have been derived from culls or commercial/scientific whaling, even though useful data may be derived from analyses of scats, spraints, and pellets at colonies (birds and seals), it seems that recent, high-quality data (such as Zeppelin *et al.* 2004) have not been included.

Analyses of scats/spraints and pellets do present some potential problems, however, (e.g. Jobling 1987), notably:

- Reliance on the abundance of hard, indigestible parts of prey, e.g. otoliths and cephalopod beaks;
- Evidence of under-representation of prey species with fragile otoliths, e.g. herring (Gadoid otoliths resist erosion);
- Measurements of otoliths from pellets give misleading estimates for the size of fish eaten.

For cetacean diets, in the absence of samples derived from whaling, autopsies of stranded animals have yielded very useful information. Good examples include Santos *et al.* 2004, Börjesson *et al.* 2003). **Recommendation 14** suggests that the AFSC team re-examine the availability of mammal and bird data, and that the team consult with the AFSC marine mammal team concerning the possibility of using stomachs from autopsies.

Given the historic nature (1970s) of the stomach data for most marine mammal species, there were also problems concerning the resolution of fish prey. It was necessary to 'create' resolved marine mammal diets based on the relative biomass of particular prey species in the environment; i.e. this approach assumes that mammals feed on the species that are available. Elsewhere in the world, there are indications (e.g. in porpoises) which have suggested long-term changes in diet which coincide with changes in the abundance of particular prey, e.g. herring and sand eels in the environment (Smeenk 1987; Evens *et al.* 1997). The assumption that diet reflects availability is probably better than simply spreading consumption equally across a number of prey groups.

### **Consumption rates**

There are many ways of estimating consumption rates (Q/B) for fish. Four methods were considered in the construction of the EBS/GOA/AI models: bioenergetics models (based on laboratory and field experiments), allometric fitting to weight-at-age data (e.g. Essington *et al.* 2001), evacuation rate calculation from field stomach contents data (e.g. MAXIMS, Richter 1999), and empirical methods based on morphological characteristics (e.g. Palomares & Pauly 1998). One goal in selecting

methods was to choose options which could be used consistently in all three ecosystem models and thus provide a reasonable basis for comparison.

It was determined that insufficient data existed for the application of bioenergetics models or evacuation rate calculations (MAXIMS); while models existed for limited number of species (these were used to generate consumption estimates in MSVPA), input data such as foraging rates and water temperature specific to the Alaska region were not consistently available, and lack of these data could result in extremely broad ranges or bias in estimates. Pauly et al.'s empirical methods (which have seen wide usage elsewhere), have an order-of-magnitude error range and thus were considered as a worst case solution only.

Unlike bioenergetics data, weight-at-age data existed for many species throughout the region: the method of fitting the generalized Von Bertalanffy growth equations to these data (Essington et al. 2001) was thus selected.

The generalized Von Bertalanffy growth equation assumes that both consumption and respiration scale allometrically with body weight, and change in body weight over time is calculated as follows (Paloheimo & Dickie 1965):

$$\frac{dW_t}{dt} = H \cdot W_t^d - k \cdot W_t^n$$

Here,  $W_t$  is body mass,  $t$  is the age of the fish (in years), and  $H$ ,  $d$ ,  $k$  and  $n$  are allometric parameters. The term  $H \cdot W_t^d$  is an allometric term for 'usable' consumption over a year or, in other words, the consumption (in wet weight) by the predator after indigestible portions of the prey have been removed and assuming constant caloric density between predator and prey. Total consumption ( $Q$ ) is calculated as  $(1/A) \cdot H \cdot W_t^d$  where  $A$  is a scaling fraction between predator and prey wet weights, that accounts for indigestible portions of the prey and differences in caloric density. The term  $k \cdot W_t^n$  is an allometric term for the amount of biomass lost yearly via respiration.

The differential equation above can be integrated to give the following solution for weight-at-age:

$$W_t = W_\infty \cdot \left(1 - e^{-k(1-d)(t-t_0)}\right) \frac{1}{1-d}$$

From measurements of body weight and age, the above equation can be used to fit four parameters ( $W_\infty$ ,  $d$ ,  $k$ ,  $t_0$ ). Initial fitting of the 4-parameter model showed in many cases, poor convergence to unique minima. To counter this, the following multiple models were tested for goodness of fit:

1. All four parameters estimated by minimization
2.  $d$  fixed at 2/3 (specialized von Bertalanffy assumption)
3.  $d$  fixed at 0.8 (median based on meta-analysis by Essington et al 2001)
4.  $t_0$  fixed at 0
5.  $d$  fixed at 2/3 with  $t_0$  fixed at 0

In general, the different methods resulted in a two-fold range of consumption rate estimates. Consistently model '3' gave the most consistently 'good' results. The poorest fits were almost always obtained assuming that  $d$  was fixed at  $2/3$ .

Essington et al (2001) demonstrated that  $d$  can be very variable among fish species, ranging from 0.39-1.44 (with a mean value of 0.77) and he suggested that the methodology might not be particularly useful for estimating consumption in fast-growing species, such as yellowfin tuna. Consequently, **Recommendation 15** suggests that the AFSC team carry out further exploratory analyses, and that the team report the cases where an assumption of  $d = 0.8$  might over- or under-estimate consumption.

As specific bioenergetics models were not available for most species, it was decided that a total non-respirative loss of 40% would be applied throughout, with a corresponding  $A$  value of 0.6. This value seems somewhat high based on existing meta-analyses of absorption efficiency estimates in fish (e.g. Pandian & Marian 1985); **Recommendation 16** suggests that the AFSC team explore the sensitivity of consumption estimates to different values of  $A$  ( $A = (1 - \text{absorption efficiency})$ ).

## **Fisheries Data**

Most of the fishery data used in the construction of the three Ecopath models were obtained from the North Pacific Groundfish Observer Program. Observers spent 36,624 days at sea in 2004 on 317 vessels and in 21 processing plants. Observers were present for 100% of all fishing days on vessels greater 125 feet in length, and for 30% of all fishing days for vessels ranging between 60 to 125 feet in length. The observers record the total catch weight, they sort through a 300 kilogram sample from each haul to establish the species composition, they collect data on prohibited or endangered species, they carry out biological sampling (record lengths, sex ratios, otoliths), and they record marine mammal sightings.

The Observer database currently has very good coverage of large vessels (>60 feet) but contains much poorer data on small inshore vessels. Also, most of the data concerns the Bering Sea Pollack fleet, with much less data exist on all other areas and fleets. By taking a single 300 kilogram sample from each haul, there is currently no means to assess within-haul variability.

## **ECOPATH Models for EBS/GOA/AI**

On the second day (1<sup>st</sup> June) of the two-day workshop in Seattle, the AFSC team gave two presentations focussing on the construction, balancing, validation and dissemination of the Ecopath models. This was followed by a description of new routines (ECOSENSE), created by the AFSC team to examine uncertainty in Ecosim predictions and also attempts to 'fit' the Gulf of Alaska model to various time series of fish and environmental data. In the following three sections, this review explores the assumptions inherent in the EBS/GOA/AI models, pointing out potential problems and suggesting some solutions.

## **Spatial issues: a closed system**

When initially constructing any Ecopath model, it is important to define the boundaries of the system and whether or not animals can cross these boundaries (see Ciannelli et al. 2003). In constructing the three Alaskan models, a number of spatial issues/conflicts arose, some of which are discussed here.

It was decided that there would be no export or import of material from models, i.e. each system is essentially self-contained, and there are no linkages between the Eastern Bering Sea, Aleutian Islands, and Gulf of Alaska populations. No predator had 'import' as a prey type in its diet matrix and there was no assumption of inward advection of plankton from the open ocean (plankton populations are self-sustaining within each model area).

This resulted in a number of somewhat arbitrary boundaries, particularly that between the Aleutian Islands and Gulf of Alaska. No migration of stocks was assumed across model boundaries except for marine mammals and birds whereby the biomass was scaled on the basis of estimated residence times in each geographic area. In reality, halibut may migrate across model boundaries, and salmon enter the system boundaries via rivers and streams; however, this behaviour was not explicitly modelled.

Models did not include the fringing rocky communities (e.g. kelp, rockfish, sea urchins, and otters) which may be particularly important around the Aleutian Islands where the shelf is very narrow. Similarly, the northern and western boundary of Bering Sea (the border with Russian sector) is not really closed, but in order to be consistent with stock-assessments, it was assumed that there was no transfer of individuals from west to east or vice versa.

In 2003, Aydin et al. compared their Eastern Bering Sea model with one constructed for the western region in collaboration with Russian scientists. The results show that the broad Eastern Bering Sea shelf supports a benthic community of considerable diversity, while the narrower Western Bering Sea shelf contains an ecosystem with a higher per-unit-area production in the pelagic layers and a more productive pelagic phytoplankton and zooplankton community. Keystone species in both systems are walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*). In the Eastern Bering Sea, small flatfish and crab species have a large impact on the energy flow from the benthic web to upper trophic levels. On the other hand, in the Western Bering Sea, a large proportion of detritus entering the benthic food web is consumed by epifaunal species such as urchins and brittle stars. This may be due to the larger percentage of Western Bering Sea shelf area close to shore (in many respects, similar to the Aleutian Islands).

## **Model set-up and balancing**

The AFSC team has chosen to run/recreate Ecopath/Ecosim outside of its normal user interface (software package). This difficult task has involved reverting to the original computer code in Visual Basic. Implementation of this code has been first as a macro within MS Excel; more recently the aim is to convert the code to C++ dll's for implementation in AD Model-Builder.

The reasoning behind the decision to not to use the ‘standard’ package stems from difficulties in getting the package to accept more than 100 functional groups. By operating in an external environment however, the team has much greater flexibility (and control) and can implement new ideas, routines, or functions, a luxury which is not available to other Ecopath users.

The Herculean scale of the task undertaken by Dr. Aydin and his team should not be underestimated (particularly in coping with un-documented smoothers etc.). Other teams have attempted to recreate Ecopath/Ecosim outside of its normal user interface (e.g. CEFAS, UK), but have been much less successful. By delving into the code and inner workings of the package, the AFSC team have gained unique insights and are fully aware of the pitfalls and limitations of the approach generally.

1991 is base year used for all three models, however data from 1990-1994 (4 year period encompassing 2 biennial survey cycles for GOA and AI) have actually been used throughout. Where insufficient stomach data existed for 1990-1994, earlier data were used, but these were down-weighted to have a very limited impact on the average for most species. In order to calculate absolute estimates of fish biomass, survey catchabilities ( $q$ ) were assumed to equal 1. This was probably justified in most cases as  $q$  was calculated to be close to 1 in stock assessments. By contrast, catchability for cod is known to be  $<1$  and consequently cod biomasses were obtained from the survey directly and not from the cod stock assessment. Biomass estimates from the assessment resulted in a model that was very difficult (if not impossible) to balance.

Ecopath provides an instantaneous ‘snap-shot’ of biomasses, trophic flows, and mortality rates, for some reference year (in this case 1991). Biomasses need not however, be at equilibrium for the reference year, provided the Ecopath user can provide an estimate of the rate of biomass ‘accumulation’ (or depletion). In a number of cases, e.g. in a model of the North Sea in 1981 (Christensen, 1995b) it was necessary to recognize that biomasses were in fact changing over the period for which Ecopath reference data ( $B$ ,  $P/B$ ,  $Q/B$ , diet composition) were provided. In these cases, assuming equilibrium for the reference year led to overly optimistic estimates of sustainable fishing mortality rates. Biomass accumulation was assumed in only a few cases in the Alaskan models. Negative biomass accumulation was necessary for walleye pollock in order to balance the Gulf of Alaska model. – This model could not be balanced otherwise

The system of Ecopath linear equations can be solved using standard matrix algebra, and provided that  $DC_{ji}$  (diet composition) and  $E_i$  (net migration) are known or specified, entry is optional for any one of the other four main parameters ( $B_i$ ,  $P/B_i$ ,  $Q/B_i$ ,  $EE_i$ ) (see Christensen and Walters, 2004).

Getting hold of and entering input parameters for an Ecopath model is only the start of the modeling process, and ensuring mass-balance is the next major step (Christensen & Walters 2004). Generally, this is done by manually adjusting biomasses, mortality rates, diets, etc., searching for data inconsistencies, and gradually obtaining a balanced model. An iterative method for obtaining mass-balance has, however, been added to the EwE software, offering a well-defined,

reproducible approach, while also allowing for the exploration of alternative solutions based on parameter confidence intervals. Background, implementation, and computational aspects of the auto-mass balance routine are described by Kavanagh al. (2004).

No automated balancing routine was used in the construction of the Alaskan models, although the AFSC team did use a strict set of criteria such that decisions would be more defensible. A data quality matrix was constructed, with scores ranging from 1 to 8. Scores were used as a basis for ‘priors’ in sensitivity analyses (see ECOSENSE section below).

<b>Rank</b>		
<b>1</b>	Data is established and substantial, includes more than one independent method (from which the best method is selected) with resolution on multiple spatial scales.	
<b>2</b>	Data is direct estimate but with limited coverage/corroborated, or established regional estimate is available while sub-regional resolution is poor.	
<b>3</b>	Data is a proxy; proxy may have known but consistent bias.	
<b>4</b>	Direct estimate or proxy with high variation/limited confidence or coverage	
	<b>Biomass &amp; Catch</b>	<b>PB, QB and Diet</b>
<b>5</b>	Estimate requires inclusion of highly uncertain scaling factors or extrapolation	Estimation based on same species but in ‘historical’ time period, or general model specific to the area.
<b>6</b>	Historical and/or single study only, not overlapping in area or time	Same species in neighbouring region, or similar species in same region
<b>7</b>	Requires selection between multiple incomplete sources with wide range	Proxy from general literature review or model of clade, or outside of region
<b>8</b>	No estimate available (estimated by Ecopath)	Estimated by Ecopath or set at standard level to estimate biomass.

This grading system is broadly similar to the ‘pedigree’ analysis used in the ‘Ecoranger’ routine of the conventional Ecopath software. The main difference seems to be that more prescriptive definitions have been used here. In addition, Ecoranger scales each of B, P/B, Q/B and DC in different ways, whereas ECOSENSE scales input data more consistently and coherently (see further discussion below concerning ECOSENSE).

Estimation of biomass with Ecopath usually requires making explicit assumptions about the ecotrophic efficiency (EE), i.e. about the proportion of the total mortality rate of a group that we account for by the predation, migration, biomass accumulation and fishing rates. There is rarely a sound empirical basis for using any particular value of EE. EE was unknown for all groups in the Alaskan models, but where required to enter a value (to estimate biomass of a group), a default value of 0.8 was used (based on requirement to balance detritus).

Given that each of the three models contains in excess of 100 functional groups (mostly single species) and that data for many of these groups are extremely limited, **Recommendation 17** suggests that the AFSC team consider possible model aggregation schemes. Model aggregation has been shown to impact the perceived system stability and dynamics as well as network indicators (see Pinnegar et al. 2005).

## ECOSENSE

This package has been developed in-house by the AFSC team, and it is documented in two manuscripts provided to the reviewers ahead of the workshop in Seattle (Aydin et al 2003, 2005).

This procedure is a simplified form of the Bayesian Synthesis approach (Givens *et al.* 1993), where the simplification arises since there is no prior information on model outputs, only inputs, and the only added information comes from model structure rather than from fitting to new (time series) data. Several iterations and variations of this procedure were performed, and the selected method was chosen to minimize problems such as “Borel’s Paradox” associated with mapping and updating probability distributions with deterministic models (Givens 1994), although aspects of the problem may still exist.

A total of 10,000 simulated ecosystems were created using a Monte Carlo process. Each ecosystem consisted of a set of parameters for the ECOSIM dynamic equations and a vector of initial biomass values and was not necessarily in initial equilibrium. Ranges of parameters were based on confidence scores of ECOPATH inputs converted to CVs (see above).

- PB(start) was selected from a Uniform distribution in the P/B error range;
- GE was selected from a Uniform distribution in the Q/B error range;
- Each element of the predator’s diet composition was selected from a Uniform distribution in the DC error range and re-normalized (giving each diet component a normal distribution);
- M0 was chosen from a uniform distribution around its original ECOPATH value using the P/B error range. Since ECOPATH sets M0 from EE to “balance” the dynamic equations, at the mean value for all input parameters, the system is in the original ECOPATH equilibrium; however by selecting M0 independently the system begins away from equilibrium;
- The initial biomass of each functional group was chosen from a Uniform distribution with the B error range. Initial fishing rate F was not changed for any species.

Each model was run for 50 years (without a perturbation), and the distribution of year-50 biomass (i.e. the ‘end state’) was examined relative to starting ECOPATH values. The models began out of equilibrium and 50 years was generally sufficient for models to approach within 10% of each model’s unique equilibrium state. Investigation of these distributions indicated that most functional groups had a bi-modal distribution of year-50 biomass, with one mode centered around the original (ECOPATH) equilibrium biomass levels and a second, larger mode at zero. In other

words, in most generated ecosystems a subset of functional groups “died out” of the ecosystem over 50 years

All generated models were rejected if, after running the base case for 50 years, one or more functional groups had decreased to 1/1000<sup>th</sup> of ECOPATH biomass, or had increased to 1000 times its ECOPATH biomass. These criteria rejected over 90% of generated ecosystems from consideration and eliminated the lower (zero) peak from all output distributions. Of 10,000 GOA ecosystems, only 1022 were accepted (no species gone).

A perturbation was applied and each non-discarded ecosystem was run for 50 years. The results reported are the difference, for each generated ecosystem, i.e. a pairwise comparison, between the non-perturbed ecosystem year-50 biomass and the perturbed ecosystem year-50 biomass. The median and confidence levels for these differences are reported.

Note that Aydin et al. (2003) found this statistic (the median) to be relatively insensitive to the ‘vulnerability’ settings used in each scenario (see discussion about ‘vulnerability’ below). This routine might be used to quantify possible ecosystem-wide impacts and uncertainties associated with removal (10% mortality increase) of a particular predator such as cod.

The method developed by Dr. Aydin and his team is clearly very useful; however it is still reliant on rather subjective decisions about the ‘score’ or ‘pedigree’ of a particular input value. The method could theoretically be used to weigh-up the effect of assuming greater or less certainty in inputs (i.e. allocate diet composition a score of 2 rather than 8). Such an exploration might be useful for targeting resources, i.e. what would be the benefit overall if I had better data on....? (**Recommendation 18**).

### **User-friendly web interface**

The AFSC team should be commended on their efforts to create a user-friendly web interface with the intent of communicating their outputs to single-species stock assessment scientists (and the general public).

Although this interface is not yet ‘live’, it already includes many interesting and well thought out features. Members of the multispecies/ecosystems modelling team attempted to sit down with stock assessment scientists and determine what they would like or find interesting, and have tried to make relevant graphics available.

Graphs and tables are generated ‘on the fly’ from relational databases, derived from standard output tables from Ecopath. The available figures include a comparison across all three ecosystems (EBS, AI and GOA), e.g. the biomass or density of a particular species in each system. Also, total and partial mortality figures, e.g. how much goes to various predators or the fishery in each of the 3 systems.

Diet composition pie-charts are also available, these are fully interactive, and ‘surfers’ can click on pie sectors and navigate to mortality inflicted on other species (helps to provide context within an integrated system). Some figures still need explanatory captions (e.g. suggesting which age groups are included) (**Recommendation 19**).

However, this novel website should be given a high profile when it eventually goes ‘live’; it is one of the best attempts I have seen anywhere to communicate Ecopath outputs to the wider fish assessment community.

Some of the outputs from this web interface might be used in a future version of the *Ecosystem Considerations* section of the North Pacific Fishery Management Council (NPFMC) annual SAFE report. The Website might also be useful to answer public questions/allegations/claims, e.g. that seals are taking all the fish, or conversely that fishermen are causing starvation in seals.

### **Functional Response (ELSEAS)**

The way a predator responds to changes in prey availability (functional response) is an issue of critical importance in multispecies/ecosystems. On the second day of the Seattle workshop (1<sup>st</sup> June), Dr. Aydin explained some of his recent modifications to the Ecosim package, and the reasoning behind these.

The developers of Ecosim endeavored to allow users to explore a variety of alternative hypotheses regarding the behavioral ecology of predators and prey (see Mackinson et al 2003), although in reality very few users ever go beyond the default settings. Using a “foraging arena” concept, prey biomass is formulated as flowing between invulnerable and vulnerable states. Parameter settings for the vulnerability flow rate ( $v$ ) influence how much of the prey biomass is available to predators at any point in time. Flexibility in the consumption equation (equation 1 below) allows users to represent alternative forms of functional responses.

The overall consumption equation for predator  $j$  feeding on prey  $i$  in Ecosim is described by the equation:

$$Q_{ij} = \frac{a_{ij}T_j v_{ij}T_i B_i B_j / D_j}{(v'_{ij} + v_{ij}T_i + a_{ij}B_j T_j) / D_j}$$

where  $Q$  is the consumption rate,  $a$  is the effective search rate,  $v$  is the flow rate from invulnerable to vulnerable state,  $v'$  is the opposite flow (where  $v = v'$ ),  $T$  is feeding time,  $B$  is biomass, and  $D$  represents predator handling time effects ( $D_j = 1 + h_j \sum a_{ij} V_{ij}$ ), with  $V$  being the vulnerable prey biomass and  $h$ , handling time (see Mackinson et al 2003).

The AFSC team has taken a slightly different (and highly imaginative) approach based on the work of Essington et al (2001). Aydin (2004) argues that ECOSIM begins with an assumption that all species are tightly connected and energetic surplus does not arise through fishing, whereas single-species fishing theory implies that fishing leads to surplus by removing larger, older, less-productive fish from populations.

Although ECOPATH production ratios and single-species estimated production levels are both derived from the dynamics of von Bertalanffy consumption and growth equations, the dynamics of ECOSIM differ from the implied bioenergetics of fishing as applied to age-structured populations. Specifically, while the ECOSIM “Arena” functional response and the von Bertalanffy equations both lead to the appearance of density-dependence in predator consumption per unit biomass, the difference in starting assumptions between the models leads ECOSIM to “fix production energetics”, while age-structured models capture changes in within-population energetics between populations of younger versus older fish. This may cause ECOSIM to greatly overestimate the amount of biomass supportable in “pristine” systems (see **recommendation 3** above) of large, mature fish, especially when projections are based on models of currently exploited ecosystems. Conversely, ECOSIM would underestimate the amount of prey released by top predator removal compared with VB assumptions (see **recommendation 4** above).

However, if the ECOSIM Arena is seen as a proxy for age structure rather than as a function of predator/prey behaviour (see Aydin et al 2004), the original derivation of von Bertalanffy growth equations, applied as a modification of ECOSIM, may allow the predictions made by biomass dynamics ecosystem models to incorporate critical life-history characteristics of modelled populations. The AFSC team has created a new set of routines which it have named ‘ELSEAS’ to run this modified version of Ecosim.

The main benefit of the new formulation is that it is now possible to separate the true ‘vulnerability effect’ from the ‘foraging effect’ (the two factors are confounded in the conventional version of Ecosim). In ELSEAS, if the user sets  $v$  as being different for different prey types, this can result in true diet switching (but see constraints described in Aydin 2004).

Viewing “vulnerability” as a function of age-structure rather than predator risk has one other major advantage: it allows explicit avoidance of modelling species as essentially identical biomass pools (the “cod is not a tuna” problem, Longhurst 1998). As Aydin (2004) points out, the inclusion of bioenergetic aspects of life history strategies, as implemented by the inclusion of growth and recruitment parameters, may greatly strengthen the modelling of varying life histories within ECOSIM.

This body of work represents a clear advance in the application and development of Ecopath/Ecosim and the AFSC team should be highly commended.

### **Time Series Fitting**

During the afternoon session on 1<sup>st</sup> June, Sarah Guichas explained some of her recent attempts to force or ‘tune’ the Gulf of Alaska model with time-series data. During this presentation she also outlined problems encountered and perceived data gaps.

One problem which quickly became apparent was the paucity of long-term, continuous data sets which could be used for ‘fitting’ the GOA model. For some species (e.g. walleye pollock), stock assessment estimates were available from 1960 onwards, but such assessments were typically derived from a number of different sources (including hydroacoustic surveys), whereas usable trawl survey data existed

only from the mid 1980s onwards. In many cases, biomass estimates based on trawl surveys (using a swept area method) differed markedly from the biomass predicted by the single-species stock assessment. Furthermore, a 'regime shift' is thought to have occurred around 1977 and thus many stock assessments do not extend earlier than this period; consequently, such short time-series are very difficult to 'fit' within Ecosim.

Several authors have attempted to 'drive' Ecosim models, simply using forcing functions, and not fitting to data (e.g. Field 2004). Field's model of the California current successfully replicated biomass trends observed in the real system, when 'forced' using fishing mortality estimates from stock assessments together with NPZ plankton time-series.

However, a similar exercise was attempted in the Gulf of Alaska using recorded catches and phytoplankton time series, but biomass estimates for most species did not match the trajectories observed in the real system, notably in walleye pollock, arrowtooth flounder, halibut, or cod.

All three of the models constructed for Alaskan waters were based on 1991 (although data from 1990-1994 have been included), thus it should only be feasible to compare model predictions with data collected during the period 1991 - 2005. However, because this is such a short period of time, the AFSC team decided to "spin up" the model before hand, running with no fishing applied for 30 years to obtain an "unfished" equilibrium state, before proceeding (1960 is generally year 0) to fish the ecosystem and to fit to 'real' data.

The 'fitting' program is again implemented outside of the conventional Ecopath package/software and is based on a quasi-Newton DFP (Davidson-Fletcher-Powell) minimizer re-written to work in Visual Basic (although the plan is to eventually work in AD Model Builder). All biomass time-series are considered to be relative indices, but scaled with  $q$  (catchability) constant over time (assumed to be the same as in the initial Ecopath base-year). Ecosim estimates a statistical measure of goodness-of-fit to the biomass and catch data. This goodness-of-fit measure is a weighted sum of squared deviations (SS) of log biomasses from log predicted biomasses, and the fitted values are "log vul(pred), log vul(pre)", i.e. 'vulnerability' is iteratively adjusted/manipulated in order to obtain the best fit to the data.

Initial trials with the Gulf of Alaska model, (including a 30 year 'spin-up' period and fishing data from 1960-2002) resulted in some clear problems of mismatch with observed biomass trends. In particular, the ecosystem could not accommodate the enormous Pacific Ocean Perch (POP) fishery which operated in the 1960s and was the largest fishery ever experienced in the Gulf of Alaska. The 'spin-up' did not achieve sufficient POP biomass to support the fishery and thus POP quickly went extinct when exposed to fishing. Similarly, bycatch mortality was high on arrowtooth flounder, but followed by a long-term recovery which initially seemed plausible (a possible explanation for the recent observed increase); however, by the end of the run, fits for pollock, sablefish, and many other species had deteriorated. This suggested that the model could not reconcile the time series by varying only top-down forcing (fishing), and that there may be a need for bottom-up forcing as well.

In a second series of trials, information from the Pacific Tidal Oscillation (PDO) (bottom-up forcing) was included and resulted in a better fit for some groups (e.g. POP and arrowtooth flounder) but not for others (e.g. pollock, herring, sharks, etc.). Adding a recruitment index from the walleye pollock stock assessment, helped not only improve the fit (not surprisingly) of pollock, but also of halibut and juvenile Steller sea lion. Using all available recruitment series improved the fit for many other fish species, but this is essentially the same as ‘tuning’ a stock assessment and tells us very little about the underlying processes.

Similar problems were experienced by Dr. Aydin when attempting to fit his Eastern Bering Sea model to time-series data, even though substantially more and longer time-series of trawl survey data are available for this system. Using recruitment indices helped reconcile biomass estimates for some species, but information on climate variability was also needed.

Discussions between the AFSC team and the external reviewers (on the afternoon of 1<sup>st</sup> June) resulted in a number of suggestions and recommendations for future work and data sources to pursue in the future:

- It is clear that additional data-series are urgently required in order to test hypotheses about bottom-up forcing of the ecosystem. Ideally, some biomass estimate for a low-trophic planktonic organism would be available, but there is no Continuous Plankton Recorder (CPR) survey program for the North West Pacific (although see [http://192.171.163.165/pacific\\_project.htm](http://192.171.163.165/pacific_project.htm)). One avenue that the AFSC team might pursue (**Recommendation 20**) would be to obtain data from the Coastal Zone Colour Scanner (CZCS) which began operating in October 1978 and ceased operating in December 1986. This instrument was designed to map chlorophyll concentrations in ocean waters, and it has more recently been replaced by the SEAWIFS global monitoring satellite (see <http://oceancolor.gsfc.nasa.gov/SeaWiFS/>).
- The Pacific Ocean Perch fishery was active in the Gulf of Alaska between 1956 and 1982, with the largest catches landed by Soviet and Japanese fleets between 1965 and 1970. **Recommendation 21** suggests that the AFSC team examine whether any information exists from Soviet or Japanese sources with regard to the importance of arrowtooth flounder as a bycatch species during this period. Although likely to be anecdotal in nature, such information might indicate whether the patterns predicted by Ecosim have any basis in reality or whether they are simply an artefact of model dynamics.
- Longer time-series might be ‘reconstructed’ by combining information from a number of different sites or sources. Recent developments in numerical techniques such as ‘dynamic-factor-analysis’ (Zuur *et al.* 2003) could make it feasible to construct time series from thus-far scattered sources. This method looks for common trends in a wide range locally-derived time-series. Component time-series are standardized (and therefore unitless), and it is possible to examine whether the underlying trends correlate with explanatory variables such as sea surface temperature or food availability, etc. The unitless time-series resulting from ‘dynamic-factor-analysis’ could be scaled in

accordance with the one-off or occasional surveys, and this method has been proposed for the reconstruction of cetacean time series in Europe.

## Limitations & Capabilities of Ecopath Models

The past two decades have seen an explosive growth in the number and type of multispecies models directed at fisheries questions (reviewed in Hollowed et al., 2000; Whipple et al., 2000). ‘Ecopath with Ecosim’ (EwE) has emerged as one of the most popular approaches, and one of the few that can address large-scale ecosystem issues. However, Ecopath suffers a number of inherent limitations, many of which have been discussed by Plagányi and Butterworth, (2004). In this short section, I consider a few of these limitations and pitfalls, some of which have been addressed or considered by the AFSC team.

Some strengths identified by Plagányi and Butterworth, (2004) include: the structured parameterisation framework, the inclusion of a well-balanced level of conceptual realism, and the inclusion of a Bayes-like approach (ECORANGER) to take account of the uncertainty associated with model inputs.

The AFSC team has taken the ‘Bayes-like’ approach further with the development of ECOSENSE, a new routine (see discussion above) which allows more rigorous analysis of uncertainty in model inputs, as well as an evaluation of the uncertainty associated with model outputs/predictions. Hence the team has made a real contribution to the development of the approach, and it has helped provide credence and scientific rigor.

Weaknesses of the Ecopath/Ecosim approach identified by Plagányi and Butterworth, (2004) include: the constraining nature of the mass balance assumption (of ECOPATH), the questionable handling of some life history responses, and the paucity of systematic and step-wise investigations into model behavior and properties.

All of these limitations have been addressed (to some extent) by the AFSC team. In ECOSENSE, there is no assumption that a model is in equilibrium at the start of a run, but it is important to note that, while this procedure escapes the equilibrium assumptions of the conventional EwE approach, the method still assumes that the ECOPATH equilibrium state is the centre of each distribution. The only way to move away from equilibrium as a null-hypothesis is to obtain historical (time trend) data for species biomass levels. It is also important to note that the Ecosense routine only takes into account error associated with parameterization of food web effects. Recruitment process error, perhaps the most studied and yet the most serious in terms of magnitude and wider implications, is not addressed and may outweigh the multi-species considerations covered here (Aydin et al 2003).

In creating the ELSEAS package, the AFSC team has attempted to address some of the problems associated with different life histories. The inclusion of bioenergetic aspects of life-history strategies may greatly enhance the perceived utility and acceptability of Ecosim modeling, as well as improving model fits to observed biomass trends.

Plagányi and Butterworth, (2004) suggest that a further important limitation relates to the predominant use of EwE as a “blackbox” modelling tool, in that “users fail to consider a range of alternative interaction representations”.

This is clearly not the case here. By running/re-creating Ecosim outside of its normal software environment, Dr. Aydin and his team have complete control and the potential for complete understanding. They have demonstrated their detailed knowledge of the approach and its foibles, and in many cases they have developed their own unique solutions to the perceived model limitations.

## Future Plans (Ecopath)

In the afternoon of 1<sup>st</sup> June, the AFSC team was asked to outline/re-iterate what it sees as interesting areas for future research. Many of these ideas or concepts have been discussed elsewhere in this document, and are a logical extension of work already underway. Other ideas (some contributed by the external reviewers) represent a complete departure from existing work, and these should be viewed as longer-term aspirations and goals.

- Better integration of results/outputs into stock assessment reports. A set of standard updateable outputs (graphs and tables) that stock–assessment scientists come to expect and rely upon (see **Recommendations 6 and 19**).
- Revisit the ‘global cap’ on landings and biological reference points (e.g.  $B_{MSY}$ ) from a multispecies/ecosystem point of view (see **Recommendations 3 and 4**).
- Instigate a plan aimed at enhancing coverage of stomach database in winter months (e.g. through targeted-requests to discard officers).
- Explore the potential utility of lipid/fatty acid analysis and stable isotopes for elucidating long-term changes in diet (**Recommendation 13**).
- Test the hypothesis that transient orcas (killer whales) have been responsible for a ‘trophic cascade’ in the Gulf of Alaska/Aleutian Islands. Are they fishing their own way down the food-web? When whales were extirpated, was there a switch to fur seals and now sea otters? (e.g. Estes et al. 1998) This would require better parameterization of marine mammals and costal (kelp, sea urchin, and sea otter) communities. (**Recommendation 22**)
- Further explore IWC (International Whaling Commission) issues. Do whales eat large quantities of fish, and will a cull benefit fish stocks (and hence fisheries) or, conversely, will fishing affect whale stocks? (**Recommendation 23**).

The AFSC team stated that it would ultimately like to develop a suite of models to run routinely as part of the annual (or a 5-year) assessment cycle. This approach is used elsewhere, in some single-species stock assessments and by the IWC. The group already have Ecopath, MSVPA/MSFOR, MSM, and single-species VPA models; however, a number of other approaches were considered, namely:

- A possible evaluation of updatable Kalman Filter Models (time series fitting and prediction, although it should be noted that non-linear Kalman filter models are still controversial).
- Explore the utility of length-based assessment models (e.g. Gadget); perhaps a 3 or 4 species model (walleye pollock, cod, and crab) similar to the Icelandic ‘Gadget’ model for cod-capelin-shrimp and incorporating migration matrices (multi-species, multi-area, multi-fleet model) (**Recommendation 24**).
- Explore the potential for coupling the EwE and OMP approaches; i.e. to provide “operating models” of the underlying resource dynamics, which can be used to evaluate prospective management approaches within an Operational Management Procedure (OMP; Butterworth and Punt 1999), or analogously a Management Strategy Evaluation (MSE; Smith *et al.* 1999) framework (Cochrane 1998). (**Recommendation 25**).

## Other Modelling Approaches

### Inverse Models

Inverse models are essentially very similar to Ecopath models except in the way that mass-balance is achieved (being closed by residuals (inputs – outputs) rather than ecotrophic efficiencies, as in ECOPATH). Mass-balance models have been constructed using inverse methodology, primarily for the northern Gulf of St. Lawrence, and the Newfoundland-Labrador Shelf (e.g. Savenkoff *et al.* 2004).

Arriving at a balanced network with the Ecopath approach is left largely to trial and error, either through user intervention or Monte-Carlo simulations. In contrast, inverse methods directly compute a balanced network, if it exists, subject to constraints posed by the available data and prior knowledge of the system. A solution is sought that minimizes the squared imbalance between inputs and outputs and between observed/estimated and modeled flows (least-squares criterion) (Vézina and Platt 1988; Savenkoff *et al.* 2001). Inverse methods provide a powerful tool to estimate ecosystem flows using limited data. A particular advantage of the approach is its ability to refine estimates of diet composition in a manner that weights the evidence from different sources in a statistically defensible manner (Savenkoff *et al.* 2001)

**Recommendation 25**, suggests that the AFSC team investigate the potential utility of ‘Inverse methods’ and whether they offer any advantage over Ecosense.

### GADGET

GADGET is a flexible, length-based, modelling framework (see Begley 2005) which can be used for multi-species, multi-area, and multi-fleet simulations. In essence, it evolved from an earlier approach developed by Stefánsson and Pálsson (1998) known as Bormicon. This approach differs markedly from MSVPA in that it is less an exercise in ‘book-keeping’ (accounting for what happens to individual age cohorts),

and instead builds on the ‘statistical catch at age analysis’ (CAGEAN) of Deriso et al. (1985) and Fournier & Archibald (1982).

The single-species version of GADGET (under the name of Bormicon or Fleksibest) has been widely applied and has proven particularly useful for species where it is difficult to obtain reliable age estimates, (e.g. *Sebastes marinus* in Björnsson and Sigurdsson 2003) or where there are large inter-annual variations in growth and thus size at age, (e.g. North-East Arctic cod, Frøysa et al. 2002). The mutispecies version has seen much less usage, although a cod-capelin-shrimp model has been constructed for Icelandic waters and a cod, blue-whiting, and whiting model has been constructed for the Celtic Sea.

(see [www.ices.dk/products/CMdocs/2004/FF/FF2904.pdf](http://www.ices.dk/products/CMdocs/2004/FF/FF2904.pdf))

(see [www.ices.dk/products/CMdocs/2004/FF/FF0504.pdf](http://www.ices.dk/products/CMdocs/2004/FF/FF0504.pdf)).

**Recommendation 24** suggests the AFSC team investigate the potential utility of GADGET and other length-based models within the context of Alaskan waters.

## Conclusions and recommendations

The scope of multispecies and ecosystem modelling conducted within AFSC is impressive and the commitment to such work is to be commended. The group clearly has the capacity to drive forward multispecies/ecosystem modelling not only within its own geographic region but to the wider scientific community; the group has made a number of clear contributions to the field and is at the forefront of model development. Furthermore, the group has shown real commitment and determination in trying to disseminate its model outputs among the wider stock-assessment community, and it has developed the best web-interface for Ecopath outputs I have seen anywhere.

Suggestions and recommendations (25 in all) have been made throughout this report, and this section summarises them and refers back to the specific ‘terms of reference’ for this review.

### **The ecosystem assessment process**

The AFSC team has made excellent progress towards the ultimate goal of implementing ecosystem models within a management framework; however, a number of future objectives are listed below:

**Recommendation 1** suggests that the AFSC team go through the latest (much revised) *Ecosystems Considerations* chapter and consider the utility of data sources listed (both new and old).

**Recommendation 2** suggests that the AFSC team conduct a series of scenario evaluations in order to test some of the more speculative comments about changes in ecosystem structure (e.g. the expansion of arrowtooth or decline of fulmars, fur seals and sea lions).

**Recommendation 3** suggests that the AFSC team consider whether or not these overall fishing caps have any ecological relevance or whether they should be revised (up or down) to reflect real, ecological processes and limits.

**Recommendation 4** suggests that the team carry out similar analyses to those conducted by ICES-SGMSNS, to determine if biological and hence fishery reference points would be similar or different in a multispecies context.

The AFSC team could explore the multispecies implications of a ‘recovery plan’ for Steller Sea Lions, which have become increasingly scarce in recent years (**Recommendation 5**), i.e. what would you have to do to fisheries to allow the sea lion stocks to recover, and what would be the impact on stocks and fisheries if stocks were to recover?

**Recommendation 6** suggests that the AFSC team continue to work on methods to ensure better integration of model results/outputs into stock assessment reports, and specifically that they develop a set of standard graphs and tables which the stock-assessors come to expect and appreciate.

#### **Data: strengths, weaknesses and gaps**

In this review, methods and data sources have been examined and there are a number of clear gaps in knowledge of which some may be irresolvable. This review calls for better documentation of the data sources utilised and the methods employed. Some of the assumptions made during the construction of the three Ecopath models or when estimating consumption rates are called into question and should be clarified.

The AFSC team states that it is currently working on a detailed technical description of all data sources utilised in the construction of its models; completion of this document should be seen as an urgent and immediate priority (**Recommendation 7**).

**Recommendation 8** suggests that the AFSC team examine the utility of recently derived marine mammal abundance data, together with recent marine mammal diet data (e.g. Zeppelin et al. 2004; Sinclair & Zeplin 2002) for inclusion in their Ecopath models.

**Recommendation 9** suggests that the AFSC team pursue new sources of funding in the hope of a systematic benthos survey throughout the region.

**Recommendation 10** suggests that the AFSC team make a concerted effort to obtain stomach samples for some of the rarer target species in the next few years. Also, it is suggested the team endeavor to obtain more samples from the winter peak-fishing period.

**Recommendation 11** suggests that a technical report/memorandum outlining ‘Standard Operating Procedures’ for stomach sampling, describing the database, and updating readers on sample sizes and diet composition estimates would be very useful.

In order to evaluate patterns of predation in time and space (i.e. to look for prey switching), the AFSC team could conduct GAM or similar type analyses with years, seasons, longitude, depth, predator size etc. as potential explanatory variables (**Recommendation 12**).

**Recommendation 13** suggests that the AFSC team explore the potential utility of lipid/fatty acid analysis and stable isotopes for elucidating long-term variability and changes in diet.

**Recommendation 14** suggests that the AFSC team re-examines the availability of mammal and bird diet data. Also, that the team consult with the AFSC marine mammal team concerning the possibility of using stomachs from autopsies.

**Recommendation 15** suggests that the AFSC team carry out further sensitivity testing of consumption estimates, and that it report the cases where an assumption of  $d = 0.8$  might over- or under-estimate consumption.

**Recommendation 16** suggests that the AFSC team explore the sensitivity of consumption estimates to different values of  $A$  ( $A = (1 - \text{absorption efficiency})$ ).

### **ECOPATH Models for EBS/GOA/AI**

The AFSC team consists of among the most accomplished Ecopath users anywhere in the world. By re-creating Ecosim outside of its normal software environment, Dr. Aydin and his team have demonstrated complete control. They have demonstrated their detailed knowledge of the approach and its foibles, and in many cases, they have developed their own unique solutions to the perceived model limitations. However a number of the following, minor points should/could be addressed:

**Recommendation 17** suggests that the AFSC team consider possible model aggregation schemes. Model aggregation has been shown to impact the perceived system stability and dynamics as well as network indicators.

**Recommendation 18** suggests that the AFSC team consider the potential utility of Ecosense to weigh-up the effect of assuming greater or less certainty in inputs (i.e. allocate diet composition a score of 2 rather than 8). Such an exploration might be useful for targeting resources, i.e. what would be the benefit overall if I had better data on....?.

**Recommendation 19** recognises that some figures which form part of the web-based interface still need explanatory captions (e.g. suggesting which age groups are included).

**Recommendation 20** suggests that the AFSC team might obtain data from the Coastal Zone Colour Scanner (CZCS) and the SEAWIFS satellite in order to test hypotheses about bottom-up forcing of the ecosystem.

**Recommendation 21** suggests that the AFSC team examine whether any information exists from Soviet or Japanese sources with regard to the importance of arrowtooth flounder as a bycatch species in the Pacific Ocean Perch fishery.

## **Future Plans**

The intent of this review has been to identify the strengths and weaknesses of the various Ecopath models for forecasting the effects of alternative management strategies. The review has attempted to evaluate where further refinements of current modelling approaches might be made, and it has also suggested new approaches or scenarios which might be pursued/explored in the future, perhaps the most interesting of these might be the exploration of length-based methods (see recommendation 24):

**Recommendation 22** suggests that the AFSC team test the hypothesis that transient orcas (killer whales) have been responsible for a ‘trophic cascade’ in the Gulf of Alaska/Aleutian Islands; i.e. are the whales fishing their own way down the food-web?

**Recommendation 23** suggests that the AFSC team further explore International Whaling Commission issues. Do whales eat large quantities of fish, will a cull benefit fish stocks (and hence fisheries), or conversely will fishing affect whale stocks?

**Recommendation 24** suggests the AFSC team investigate the potential utility of GADGET and other length-based models within the context of Alaskan waters.

**Recommendation 25**, suggests that the AFSC team investigate the potential utility of ‘Inverse methods’ and whether they offer any advantage over Ecosense.

The reviewer was asked to identify the most important information gaps and research priorities over a five-year planning horizon, which, if they were addressed, would allow the most progress to be made towards the ultimate goal of implementing ecosystem models within a management framework. From the above list of 25 recommendations, those that should be viewed as most urgent are recommendations 3, 6, 7\*, 10, 14, 19, and 24.

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## Appendix 1: Statement of Work

### **Consulting Agreement between the University of Miami and Dr.. John Pinnegar – CEFAS**

**April 4<sup>th</sup>, 2005**

#### **General**

The Alaska Fisheries Science Center (AFSC) requests review of the EBS/GOA/AI multispecies and ecosystem predator/prey models that have been parameterized for these regions. These models are proposed for use in an ecosystem assessment framework and might be useful in management strategy evaluations. Although these models are widely used in the scientific realm, their use has been limited in providing actual management advice. We seek rigorous review of the methods used to parameterize and validate these models and advice regarding their application to management questions and evaluations.

The assessment review will require two consultants, 1) multispecies age structured predator/prey model expert (MSVPA/MSFOR), and 2) an expert on mass-balance and biomass dynamic predator/prey models and bioenergetics. Consultant 1 should be thoroughly familiar with various subject areas involved in age-structured multispecies predator/prey models, including population dynamics, separable age-structured models, harvest strategies, Visual Basic, and have experience using these multispecies models in a fisheries management context. Consultant 2 should be thoroughly familiar with: ECOPATH/ECOSIM models, biomass dynamics models in general, use of these models for derivation of ecosystem-level indicators, and use of food habits data for parameterizing these models. This expert should be independent of any group presently involved in the ongoing development and revision of the ECOPATH/ECOSIM models. Familiarity with Visual Basic and/or C programming languages would be desirable along with experience using these models in a fisheries management context. The consultants will travel to Seattle, Washington, to discuss the models with the lead modelers and other scientists at the Alaska Fishery Science Center involved in providing data for these models.

The report generated by the consultant(s) should include:

- a. The strengths and weaknesses of the models and their parameterization;
- b. Recommendations for improvements to the models;
- c. Strengths and weaknesses of the models for forecasting and management strategy evaluations;
- d. Recommendations for model improvements or development of new models to better assess the importance of predator/prey relationships in influencing stock trajectories and ecosystem level production estimates;
- e. Suggested research priorities to improve the models.

Terms of reference for the review include the following:

1. Review methods and data sources for estimating consumption rate and diet parameters for input to the suite of multispecies (MSVPA/MSFOR) and ecosystem models (ECOPATH/ECOSIM and Aydin's ELSEAS biomass

dynamics model) currently being used to model the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands ecosystems, including sampling techniques, spatial and temporal distribution of sampling, and the use of bioenergetic models to estimate seasonal or annual rations.

2. Review the suite of multispecies and ecosystem models currently being used to model the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands ecosystems. Identify the strengths and weaknesses of the models for forecasting the effects of alternative management strategies. Evaluate whether there is benefit in further refinement of these modeling approaches, or whether resources should be devoted to new model development. If new modeling is recommended, provide recommendations and examples of suggested new approaches.
3. The long-term goal of ecosystem modeling research is to implement ecosystem models in a management advice framework. Identify the most important information gaps and research priorities over a five-year planning horizon that allows the most progress to be made towards achieving this goal.

AFSC will provide copies of multispecies and ecosystem model documents, Visual Basic and C code, and other pertinent literature.

Consultant's duties should not exceed a maximum total of 14 days: several days prior to the meeting for document review; the two-day meeting; and several days following the meeting to complete the written report. The report is to be based on the consultant's findings, and no consensus report shall be accepted.

### **Specific**

The consultant's tasks consist of the following:

- 1) Become familiar with the multispecies and ecosystem models, modeling background documents, and other pertinent literature.
- 2) Discuss the models with the lead scientist in Seattle, Washington from May 31<sup>st</sup> – June 1<sup>st</sup>, 2005.
- 3) Develop a report based on the terms of reference for the review.
- 4) No later than June 15<sup>th</sup>, 2005, submit a written report consisting of the findings, analysis, and conclusions (see Annex I for further details), addressed to the "University of Miami Independent System for Peer Review," and sent to Dr. David Die, via e-mail to [ddie@rsmas.miami.edu](mailto:ddie@rsmas.miami.edu), and to Mr. Manoj Shivilani, via e-mail to [mshivilani@rsmas.miami.edu](mailto:mshivilani@rsmas.miami.edu).

## Appendix 2: Detailed Agenda & list of Attendees

**Commissioned Attendees:** Dr. John K. Pinnegar, Dr. Ewen Bell

**AFSC Attendees:** Dr. Kerim Aydin, Jesús Jurado-Molina, Dr. Patricia Livingston, Sarah Guichas, Ivonne Ortiz, Dr. Nancy Friday.

### Tuesday 31<sup>st</sup> May

1. Overview of Resource Ecology and Ecosystem Modeling (REEM) Program, including food habits studies, modeling, and ecosystem assessment components.
2. Overview of North Pacific Fisheries Management Council (NPFMC) management procedures with specific reference to ecosystem-based management needs.
3. Data programs specific to multispecies modeling needs:
  - a. Assessment methods common with single-species techniques (biomass, mortality).
  - b. Fish food habits sampling program.
  - c. Consumption and consumption rate estimation.
  - d. Fisheries catch and bycatch estimation.

#### MSVPA and MSM

1. MSVPA
  - a. Main characteristics, hypotheses and data
  - b. eight – species assemblage for the Bering Sea
  - c. Results
    - i. Testing the sensitivity of MSVPA
    - ii. Testing the stability of the suitabilities
2. MSFOR
  - a. Main characteristics and hypothesis
  - b. Using MSFOR in projections for the future dynamics of the eight – species assemblage for the Bering Sea
3. MSM
  - a. Main characteristics and hypothesis
  - b. Preliminary results
  - c. Advantages of MSM
4. Future tasks for multispecies models

### Wednesday 1<sup>st</sup> June

#### ECOPATH/ECOSIM

1. General methods.
2. Model construction overview (model "balancing").
3. Data quality assessment.
4. New methods/results
  - b. Predator/prey overview information for council and public.
  - c. Model perturbation sensitivity and data quality synthesis.
  - d. Hypothesis testing for historical trends.
    - i. Best Ecosim fitting.
    - ii. Comparison to other functional responses/model types.
  - e. Future projections
    - i. From basis set of possible ecosystems.
    - ii. Based on sampling from historical trends.
    - iii. From statistical properties of food web variation.

#### DISCUSSION

1. Additional data and methods presentation as required/requested.
2. Discussion of:
  - a. New approaches versus refinement of current approaches.
  - b. Integration of results into Ecosystem Assessment and management advice framework.
  - c. Five-year research priorities.



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