Review of the Multispecies and Ecosystem Modelling Program of the Alaska Fisheries Science Center (AFSC)

for

University of Miami Independent System for Peer Review

June 2005

Dr. Ewen Bell
CEFAS Contract
C2518

COMMERCIAL IN CONFIDENCE

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1. Executive Summary

A review of multispecies and ecosystem modelling as undertaken by the Resource Ecology and Ecosystem Modelling (REEM) group of the Alaska Fisheries Science Center (AFSC) was initiated. Prior to the meeting, background documentation was circulated to the reviewers and further documentation has been provided upon request. A two-day meeting was held in Seattle from May 31st to June 1st 2005. The review panel consisted of two members with independent terms of reference, one to focus on multispecies modelling, and the other to focus on ecosystem modelling. This reviewer has concentrated on the multispecies modelling work of REEM.

The scope of multispecies and ecosystem modelling within REEM and the AFSC is impressive and the commitment to such work is to be commended.

The existing stomach sampling programme, while laudable, has spatial, temporal and species gaps. In order to find ways of augmenting the existing stomach sampling programme, it is **recommended** that the potential for lipid analyses and stable isotope analyses are explored, and that future multispecies modelling is constructed in such a way to use the data. It is also **recommended** that efforts are made to increase the sampling rate outside the survey period.

Some areas of the sampling protocol between the three areas (BS, AI and GOA) are not as harmonised as they may be and a single protocol is recommended.

Individual ration is one of the most fundamental building blocks of multispecies/ecosystem models. Sensitivity testing of models to the assumptions on ration size and conversion efficiency is recommended to highlight where further research is required.

Experiments with some longer survey tows are recommended to ensure that larger individuals are not out-swimming the gear. Likewise, methods to enhance the sampling of small (<30cm) fish are highly desirable.

The types of data collected during the routine stomach sampling are well suited to the parameterisation of multispecies models such as MSVPA/MSM.

The web-based interface to the diet composition database developed by REEM is particularly impressive and should be promoted as a valuable tool for other scientists within AFSC.

The production of the MSM (Multispecies Statistical Model) is welcomed and is a useful development in multispecies modelling.

It is recommended that in the programming stage of future multispecies modelling (including the transcription of MSM to ADMB), flexibility with relation to the number of seasons is incorporated.

Predation and fishing events are based much more on size than age, plus size data are far more readily available than age data. A move away from age-based modelling towards length-based multispecies modelling is therefore **recommended**. The GADGET framework would be an ideal place to start.

The ultimate goal of multispecies and ecosystem models is to predict responses to management regimes. The incorporation of fleet dynamic modelling will greatly enhance the ability to achieve this objective.

2. Background

Within the assessment reports submitted to the North Pacific Fishery Management Council, there is now a requirement for a section on ecosystem considerations. The move from single species to multispecies and ecosystem modelling requires an understanding of the frequency and intensity of inter-species interactions and requires a quantum leap in the degree of modelling complexity required to effectively describe the dynamics of the systems. Due to the complexity of data requirements and modelling approaches required for ecosystem modelling, there can be a reluctance to accept model results, especially from those who already understand the complexities and limitations of simpler single species modelling.

The Resource Ecology & Ecosystem Modelling (REEM) group within the Alaska Fishery Science Center (AFSC) requested the Center for Independent Experts (CIE) to set up an independent review of their research program with particular reference to multispecies and ecosystem modelling. The purpose of this review is therefore to examine the current state of modelling within REEM, their data sources, and potential paths of future research which will assist in the integration of stock and ecosystem models into scientific advice.

This reviewer had a specific term of reference to look at the multispecies modelling (MSVPA/MSFOR/MSM) side of REEM's work, and this report therefore concentrates on that at the expense of the Ecopath area which will be covered by the other reviewer.

3. Description of review activities.

Prior to the meeting, a suite of documentation (listed in appendix 2) was provided to the two reviewers. A two-day meeting was then held with members of the REEM group at the AFSC, in Seattle, Washington, from 31st May to 1st June 2005. Each reviewer had a specific focus: one on multispecies modelling and the other on ecosystem modelling.

During the meeting, a number of presentations were made covering the basic data collection and the subsequent modelling. Due to the degree of overlap between the two modelling approaches, both reviewers sat in on all presentations and discussions.

Subsequent to the meeting, requests for further information and documentation were made to REEM, and these were answered promptly and in full.

4. Estimation of consumption rates and diet parameters

4.1. Data sources

4.1.1. Dietary data

The majority of dietary data for the multispecies modelling comes from the stomach sampling program undertaken by AFSC since 1981. Stomach sampling is currently the most accurate way of generating quantitative data regarding predator choice for prey species and sizes and is currently the method used for parameterising MSVPA models in other sea areas (i.e. North Sea, Baltic Sea). The AFSC stomach content data set covers over 225,000 stomachs from 52 species of fish from the Aleutian Islands (AI), Bearing Sea (BS) and Gulf of Alaska (GOA) although there is considerable skew in the sampling coverage in terms of species, time and space.

Stomach sampling is the only realistic way of determining size preferences of predators in the field; however, there are drawbacks to the reliance upon this methodology for establishing dietary composition. Stomach sampling gives a snapshot of what the predator has eaten over the past 24-48 hours and individual stomachs are therefore more likely to represent local feeding conditions than food preferences per se. When using stomach sampling to parameterise multispecies models at shelf scales (i.e. MSVPA for the Bearing Sea) such local effects become less pronounced as the sample coverage becomes more comprehensive in both space and time.

There are alternative methods of obtaining data to augment the stomach sampling program. Some lipid compounds remain unchanged upon assimilation by a predator. Analyses of predator's lipid compositions have the potential to generate qualitative and, to a lesser extent, quantitative data regarding feeding patterns. Given that lipid structures have a turn-over of a few months, the analyses should also reveal diet composition over a longer time period that stomach analyses. This methodology is still under development but has potential. Stable isotope analyses, in particular of nitrogen, have been successfully used to describe the trophic levels on which predators are feeding. The turn-over period for isotopes is on the scale of 12-18 months (Hesslein et al 1993), so like lipid analyses can give indications of much longer term feeding patterns than stomach sampling. At present, there are no formal ways to incorporate data from these sources into multispecies models such as MSVPA/MSM, and therefore further model development will be required to utilise the data. It is **recommended** that AFSC investigate the utility of these alternative approaches to augment (not replace!) the existing stomach sampling programme.

4.1.2. Input data to consumption rates.

Consumption rates and energy requirements are one of the key elements of multispecies and ecosystem models. Without reliable estimates of these parameters, multispecies models are at best uncertain and at worst potentially misleading. As marine management moves away from reactive short term fishery management towards proactive long-term ecosystem management, the reliability of these parameter estimates will become paramount.

The MSVPA/MSM models as implemented by REEM use growth increments and growth conversion efficiency (GCE) to estimate consumption (rations) of fish predators.

- Annual growth increments are estimated from von Bertalanffy fits to length at age data averaged over a number of years. Presumably these data were generated from observed catches rather than landings and therefore included discards. Where discards of smaller fish occur ("high-grading"), the omission of discarded fish from data used to generate growth curves will over-estimate growth rates.

- GCE is assumed to be age (size) dependent and is determined on the assumption that GCE scales linearly from 0.3 at the youngest age to 0.1 at the age corresponding to 50% maturity. These values are derived from historical literature and are not specific to the species or areas of interest to AFSC. It is assumed that all species follow the same GCE model.
- Values for quarterly ration are constructed from the annual ration using one of two allocation keys. The key used for walleye pollock, Greenland turbot and arrowtooth flounder is based upon bioenergetic modelling of walleye pollock. The key used for yellowfin sole, rock sole and Pacific herring reverses the 2nd and 3rd quarter keys to reflect slower warming of inshore waters in spring.

The two key assumptions here are that all species follow the same pattern of GCEs and seasonal ration fraction. The reversal of the quarter 2 and 3 allocation fractions for inshore seems particularly arbitrary. A useful sensitivity test of the models to these assumptions would be to perturb values of GCE and the quarterly ration allocation keys on a species by species basis. This would clarify whether the assumptions are sound or whether the detailed estimation of food requirements should be a priority research objective and such sensitivity testing therefore **recommended** as a priority.

It is well known from laboratory based gastric evacuation studies that temperature is a key factor influencing digestion rate and it is evident from SAFE reports that data exist for water temperature over several years and spatially disaggregated. Given the global emphasis of climate change/variability with respect to ecosystem advice, enhancement of the consumption/ration estimates to incorporate ambient temperature influences would reinforce the utility of multispecies modelling.

4.2. Methods of collection of dietary data.

The ideal data set of stomach contents would be a spatially and seasonally comprehensive time series of samples, but the realities of marine research dictate that compromises must be made. AFSC have concentrated much of their stomach sampling effort on the standard surveys operating in June and July. In addition to this samples have been taken on a wider seasonal basis, chiefly on observer trips on a more ad-hoc basis. As a result, the stomach content database for AFSC chiefly comprises a time series of summer feeding patterns for the most abundant commercial species. Bioenergetic modelling of walleye pollock indicates that the main feeding period is during the summer, however substantial feeding does take place outside the sampling period.

In order for multispecies and ecosystem models to be representative of whole season feeding activity it is **recommended** that efforts are made to increase the level of sampling outside the survey period.

The undertaking of quarterly surveys each year in all three areas is prohibitively expensive and the benefits may not justify the effort as diet composition appears to change relatively slowly. One solution may be to retain the annual summer sampling program but to run surveys in all quarters once every few years, akin to the “year of the stomach” exercises undertaken by ICES. In this situation, stomachs were sampled on quarterly surveys in 1981 and 1991, and efforts are now being made to repeat the exercise. The compromise combination of a continuous (BS) or tri-annual (GOA & AI) summer stomach programme and periodic (~10 year) full-quarterly programme would result in an enviable series of dietary data (The reviewer acknowledges that there is more or less complete quarterly coverage for 1985 in the BS).

An alternative solution would be to increase the number of stomachs collected during the observer program. Obviously there are logistical implications for this course of action, as additional observers for the purpose of at-sea analysis may not physically fit onto commercial operations, and even the routine storage of stomachs on board may prove difficult. The increase in workload to individual observers could be managed by the targeting of a few stomachs from each haul rather than allocating specific hauls to be thoroughly examined. Given the common feature of intra-haul correlation in stomach content, this approach would anyway be preferable to reduce bias in sampling.

The types of data collected during the routine stomach sampling are well suited to the parameterisation of multispecies models such as MSVPA/MSM.

It became evident during discussion with the REEM group that there were some disparities in the stomach sampling protocol used in areas of the Aleutian Islands (AI), Bering Sea (BS) and Gulf of Alaska (GOA), in particular with reference to the recording of empty stomachs. Given that in data sparse situations information may be pooled across the three regions, it is **recommended** that a rigorous, cross-area protocol should be adopted.

As is common in the many groundfish surveys, catchability is quite low at small sizes, which translates into relatively low sample sizes of stomachs from the smaller size ranges. Addressing this issue is likely to require modifications to gear/survey location and is therefore not desirable as part of the standard survey design. The length of tow performed during the surveys is relatively short, (30 minutes on the BS shelf and only 15 minutes in the GOA and AI regions). Larger individuals are often capable of out-swimming gear for hours and therefore there is the potential to under-sample larger fish. Some longer trails are therefore **recommended,** although it is recognised that tow length is restricted by geography in some areas.

The web-based interface to the diet composition database developed by REEM is particularly impressive and is an invaluable tool for informing others (in particular, stock assessment scientists) of the linkages within the system. The availability of this service should be widely advertised within AFSC as it should help to broaden the horizons of the most committed “single species” scientists. It may be worth considering the recording of “hit rates” on the various pages to aid further construction, as well as to indicate which areas are of most interest to other scientists.

5. Review of multispecies models currently used by AFSC.

5.1. Strengths and weaknesses.

MSVPA/MSFOR builds on well understood single species stock assessment methodology and is used to provide multispecies fisheries advice in other sea areas (the Baltic Sea in particular). MSVPA assessments are usually close to their single species counterparts in terms of fishing mortality and spawning stock sizes, partly because of the dominance of catch data to the model but also because predation chiefly operates on younger, recruiting age groups. The real advantage of moving from single to multispecies modelling comes when forecasting, the incorporation of variable predation rates changing the shape of recruitment trajectories and hence producing more realistic stock. MSFOR/MSM models are at their most useful in medium term projections in the order of three to seven years. At shorter time scales, modelled recruitments have generally not worked their way into the fished portion of the stock.

The types of management action which can be investigated with MSFOR/MSM are changes to fishing mortality and changes in selection pattern. One use to which these models may well be put is the testing of biological reference points (usually defined in single species mode) as management tools in a multispecies system.

In the current implementation of MSVPA/MSM mixed fishery effects are not dealt with, therefore the fishing mortalities of species caught in the same fishery are assumed to be independent. Within MSFOR growth is fixed, hence food availability has no bearing on future stock development and the system is entirely "top-down" whereby predators affect the trajectories of prey but not vice versa. Another common complaint with MSVPA type models is the assumption of fixed "suitability", that is the preference for a prey type by a particular predator. The validity of the fixed suitability assumption has been addressed by AFSC in Jurado-Molina et al. (in press).

Assessment data for Eastern Bearing Sea Pollock (NPFMC Bearing Sea and Aleutian Islands SAFE report on the Eastern Bearing Sea Walleye Pollock Stock Assessment, 2004) shows not only strong trends in weight at age but also evidence for cohort effects (see Figure 1.12 of above document) whereby a slower growing cohort at age 1 remains smaller at age as it moves through the age classes. Again, this sort of information is not modelled within MSVPA/MSM but can have significant impacts upon estimates of fishing and natural mortality.

Predation events are modelled within MSVPA/MSM as functions of age, whereas in reality predation is more likely a function of length. Under the assumption of fixed growth patterns the use of age as a proxy for length is valid, but if moves are made towards modelling variable growth, then coupling that to length based modelling is the logical way forwards and this is discussed in a later section.

The dietary data have been used to parameterise quarterly predation rates within MSVPA/MSM for the Bearing Sea. With the majority of these stomach samples being taken in the summer cruise covering June and July, the dietary data for the second and third quarters are mainly a result of splitting the results of a single cruise into two parts. In addition to this, the seasonal key used to disaggregate the annual ration appears to indicate a distinct summer (Q2&Q3)/winter(Q4&Q1) split. It would therefore seem logical to construct a 2-season multispecies model, which would have the added advantage of boosting the stomach sample size outside the survey period. There are several trade-offs for moving to a 2-season model, one being that recruitment traditionally enters the system at the start of quarter 3 but would now move to 6 months earlier. I **recommend** that any future model development is undertaken with seasonal flexibility in mind such that the user can select any number of seasons depending upon the input data available.

5.2. MSM

The MSM (Multispecies Statistical Model) is a development of the separable catch at age concept into a multispecies framework, using the same feeding functions of MSVPA. The advantage of separable models compared to traditional VPA is that separable models are fitted in a fully statistical way and hence estimates of parameter uncertainty are obtained. In addition to this, the model is forward fitting (as opposed to backwards fitting in MSVPA) and therefore lends itself to historical fitting and forward projection in the same model rather than the two stage process with MSVPA. The uncertainty in estimates of stock size and mortality is maximal in the terminal year (last year of fishery data) for MSVPA. The forward-fitting algorithm of MSM spreads uncertainty across the whole time series, hence the forecasts can be considered to be more accurate. The development of the MSM approach is commended.

A key assumption with separable models the assumption is that fishing mortality can be divided into a fixed selection pattern and variable year effects. The validity of the assumption of fixed selectivity should be verified with model diagnostics and knowledge of changes in fishing practices (gear, mesh size, spatial pattern etc).

A copy of the spreadsheet used for the initial exploration of MSM was provided upon request for evaluation. Whilst Excel is a useful mathematical tool, it has inherent drawbacks as a programming environment for something as complex as multispecies modelling. I acknowledge that the spreadsheet version of MSM was never intended to be more than a feasibility study limited to just two species, but a “simple” extension of the model to three species is no trivial matter and would require extensive adaptation of several sheets. When using Excel for complex modelling, following program flow is difficult, in particular across multi-sheet models. By far the biggest problem with multi-sheet modelling in Excel is, however, the ability to propagate errors through the workbook, either through the intentional changing of formulae in some cells and omitting to propagate the changes to relevant cells, or by accidental changing of formulae in individual cells. These types of errors are notoriously difficult to track down and often lie undetected. While examining the spreadsheet to follow the model through, I discovered some cell and sheet referencing anomalies. Although these errors (fortunately minor) have subsequently been corrected by the author, they serve to highlight the problems of modelling within spreadsheets. The MSM model is in the process of being transcribed into ADMB (Auto-Differential Model Builder), a C-based language, which should be somewhat easier to follow and debug. I would, however, advocate future simulation studies be undertaken in a more formalised programming framework rather than Excel.

5.3. Future direction for multispecies modelling.

MSVPA was originally developed within the ICES community and has undergone little change in recent years. The MSM is a useful alternative to MSVPA, but it still largely suffers from the same limitations, including the assumption of constant suitability, fixed ration and fixed individual growth. MSVPA and its derivatives is also very data hungry, requiring parameter estimation for each age of predator on each age of prey. MSM is no less data hungry and has many of the same basic assumptions (fixed suitability, constant growth). With the exception of a statistical catch at age model (similar to MSM but yet to be published), there has been no real development of MSVPA type modelling within the ICES community for several years. It is generally considered that although MSVPA/MSFOR still has a role in the provision of management advice, the concept has run its course and new avenues of research are likely to be more fruitful. The transcription of MSM into ADMB remains a useful exercise in that the methodology is generally understood and the results are communicable to managers, and it will be a useful tool for the provision of advice in the short term. I would not, however, envisage that a significant amount of time be invested in its further development and suggest efforts be diverted to new methodologies.

As previously mentioned, predation events are predominantly size rather than age based. Gear selectivity is also a size based process, and the majority of measurements from the fishery are also of length, while only a subset of these follow on with age determinations. A move towards size (length) based modelling therefore seems the most appropriate way to develop multispecies modelling.

The stomach data database contains information regarding the lengths of both predator and prey. It would be useful to explore the parameterisation of more simple feeding relationships based upon the ratio of predator length to prey length as opposed to the estimation of parameters for each combination of predator age and prey age as required by MSVPA. There is also the possibility of combining species with similar habitat selection and body size to gape (mouth size) ratios, thereby effectively increasing sample size in data poor situations.

One ready-made multispecies modelling approach which incorporates length based feeding relationships is the **G**lobally applicable **A**rea **D**isaggregated **G**eneral **E**cosystem **T**oolbox (GADGET). GADGET's origins lie in previous multispecies modelling attempts - MSVPA, BORMICON and FLEXIBEST - and it is a statistical model which can cope with multiple areas (and therefore migration patterns) and deals with predation using either age or length based methods. The model structure is modular allowing users to select model complexity for various stocks based upon the input data available. More detailed information, including program download and manuals is available from the web-site http://www.hafro.is/gadget. The model is fully operational but is undergoing continual development, and the programme managers welcome assistance in the creation of new modules. Coding is done in C++ and incorporates AUTODIFF classes from the ADMB framework. Gadget runs on a UNIX/Linux platform. Understanding of the model working and getting input data into the correct format involves a fair period of time and delving into the code considerably more so. GADGET does, however, represent the "cutting edge" of multispecies modelling, and I recommend that AFSC explore the possibility of implementing the model.

The combination of biological and technical (mixed-fishery) interactions into a common modelling framework is highly desirable. While GADGET allows for multiple target species within a fleet, there is currently no method of modelling adaptive behaviour in response to management decisions. The incorporation of fleet dynamic modelling would greatly assist the objective of predicting ecosystem responses to management regimes.

6. Conclusions, recommendations and suggestions for future work

The scope of multispecies and ecosystem modelling within REEM and the 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 their own geographic region but to the wider scientific community.

Suggestions and recommendations have been made throughout this report, this section therefore summarises them.

- It is **recommended** that the potential for lipid analyses and stable isotope analyses are explored as methods to augment the existing stomach sampling programme and that future multispecies modelling is constructed in such a way to use the data.
- The stomach sampling program is skewed in terms of area and season. It is **recommended** that efforts are made to increase the sampling rate outside the survey period.
- Sampling protocols between the three areas (BS, AI and GOA) should be harmonised.
- Individual ration is one of the most fundamental building blocks of multispecies/ecosystem models. Sensitivity testing of models to the assumptions on ration size/conversion efficiency is **recommended** to highlight where further research is required.
- Experiments with some longer survey tows are recommended to ensure that larger individuals are not out-swimming the gear. Likewise, methods to enhance the sampling of small (<30cm) fish are highly desirable.
- Incorporation of environmental (temperature) data to feeding rates could be investigated.
- It is **recommended** that in the programming stage of future multispecies modelling (including the transcription of MSM to ADMB), flexibility with relation to the number of seasons is incorporated.
- A move away from age-based modelling towards length-based multispecies modelling is recommended. The GADGET framework would be an ideal place to start.
- Fleet dynamic modelling will greatly assist the objective of predicting ecosystem responses to management regimes.

Appendix 1. Meeting Agenda

Tuesday 31st May

1. Overview of Resource Ecology and Ecosystem Modelling (REEM) Program, including food habits studies, modelling, 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 modelling 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 1st 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.

Appendix 2. Documents Provided prior to Assessment

1. Livingston, P., Aydin, K., Boldt, J., Gaichas, S., Ianelli, J., Jurado-Molina, J., Ortiz, I. (2003). Ecosystem Assessment of the Bering Sea/Aleutian Islands and Gulf of Alaska Management Regions. *Ecosystem Considerations* Chapter. NPFMC Bering Sea/Aleutian Islands and Gulf of Alaska SAFE. pp 284-335.

2. Essington, T.E., Kitchell, J.F., Walters, C.J. (2001). The von Bertalanffy growth function, bioenergetics, and the consumption rates of fish. Can. J. Fish. Aquat. Sci. **58:** 2129–2138.

3. Aydin, K.Y. (2004) Age structure or functional response? Reconciling the energetics of surplus production between single-species models and Ecosim. *Afr. J. mar. Sci.* **26:** 289–301.

4. Aydin, K.Y., McFarlane, G.A., King, J.R., Megrey, B.A., Myers, K.W. (2005) Linking oceanic food webs to coastal production and growth rates of Pacific salmon (*Oncorhynchus* spp.), using models on three scales. *Deep-Sea Research II,* **52**:757–780.

5. Aydin, K.Y., McFarlane, G.A., King, J.R. and Megrey, B.A. (2003). The BASS/Model report on trophic models of the subarctic Pacific basin ecosystems. PISCES-GLOBEC International Program on climate change and carrying capacity. PICES Scientific Report No. 25 (extract). 19pp.

6. Livingston, P.A. and Jurado-Molina, J. (2000). A multispecies virtual population analysis of the eastern Bering Sea. *ICES Journal of Marine Science,* **57:** 294–299.

7. Jurado-Molina, J. and Livingston, P.A. (2002). Climate-forcing effects on trophically linked groundfish populations: implications for fisheries management. Can. J. Fish. Aquat. Sci. **59:** 1941–1951.

8. Jurado-Molina, J. and Livingston, P.A. (2002). Multispecies Perspectives on the Bering Sea Groundfish Fisheries Management Regime. *North American Journal of Fisheries Management* **22:** 1164–1175.

9. Jurado-Molina, J., Livingston, P.A., Vincent F. Gallucci, V.F. (in press). Testing the stability of the suitability coefficients from an eastern Bering Sea multispecies virtual population analysis. *ICES Journal of Marine Science* .(Authors proofs).

10. Jurado-Molina, J., Livingston, P.A., Ianelli, J. (unpublished manuscript). Incorporating predation interactions in a statistical catch-at-age model for a predator-prey system in the eastern Bering Sea. 29pp.

11. Jurado-Molina, J. and Livingston, P.A., (unpublished manuscript). Sensitivity analysis of the multispecies virtual population analysis model parameterized for a system of trophically-linked species from the Eastern Bering Sea. 22pp.

Appendix 3. Other cited documentation

1. Hesslein, R.H., Hallard, K.A., and Ramlal, P. 1993. Replacement of sulfur, carbon, and nitrogen in tissue of growing broad whitefish (Coregonus nasus) in response to a change in diet traced by d34S, d13C, and d15N. Can. J. Fish. Aquat. Sci. 50: 2071-2076.

Appendix 4. Statement of work

Consulting Agreement between the University of Miami and Dr. Ewen Bell – CEFAS

April 4th, 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 to 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 31st – June 1st, 2005.
3) Develop a report based on the terms of reference for the review.
4) No later than June 15th, 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, and to Mr. Manoj Shivlani, via e-mail to mshivlani@rsmas.miami.edu.

The Centre for Environment, Fisheries & Aquaculture Science
Lowestoft Laboratory, Pakefield Road,
Lowestoft, Suffolk NR33 0HT UK
Tel: +44 (0) 1502 562244
Fax: +44 (0) 1502 513865
www.cefas.co.uk