Resource Management Committee

ICES CM 1999/D:4
Ref.: ACFM, G

REPORT OF THE
STUDY GROUP TO EVALUATE THE EFFECTS OF MULTISPECIES INTERACTIONS

Lowestoft, UK
7–11 September 1999

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 INTRODUCTION

1.1 Terms of Reference

At the 1998 Annual Science Conference in Lisbon (Portugal), a Study Group to Evaluate the Effects of Multispecies Interactions (SGEEMI) was established (C. Res. 1998/2:27) to:

a) review progress, and continue the development of, existing multispecies models to incorporate additional components (such as growth and spatial structure), and develop new models as appropriate, to provide a basis for long-term advice for fisheries;

b) identify the field work required to support the models;

c) evaluate biological reference points in a multispecies context for the long-term management of fishing in relation to potential changes in fishing mortality and selection pattern, in particular for the North Sea.

Some of these TOR were set up to provide ACFM with the information required to respond to requests for advice/information from NEAFC and EG DGXIV.

SGEEMI will report to the Resource Management and Living Resources Committees at the 1999 Annual Science Conference and communicate results to WGECO and to ACFM before its October/November 1999 meeting.

1.2 Participants

SGEEMI met from 7-11 September 1999 in Lowestoft, UK. The meeting was attended by:

Sara Adlerstein	Germany
Marinelle Basson	England
Ewen Bell	England
Höskuldur Björnsson	Iceland
Mark Bravington	England
Peter Bromley	England
Niels Daan (Chair)	Netherlands
Helen Dobby	Scotland
Daniel Duplisea	England
Henrik Gislason	Denmark
John Harwood	Scotland
Joe Horwood	England
Fritz Köster	Germany
Julian Metcalfe	England
Carl O'Brien	England
Tiit Raid	Estonia
Kevin Stokes	England
Sigurd Tjelmeland	Norway
Morten Vinther	Denmark

1.3 Background

The ICES Multispecies Assessment Working Group was put to rest in 1997, because it was felt there was no need for routine multispecies stock assessment and subsequent advice on management issues. Nevertheless, it is widely realised that the development of long-term management strategies depends on a good understanding of species and fleet interactions, and requests for advice reflect the continued interest in this field. With the establishment of a new Study Group, there is apparently a wish to give Multispecies Assessment in the North Sea a fresh start. Therefore, the meeting was used largely for a brainstorm session, during which ongoing studies were reviewed (Section 2) and ideas about potentially promising avenues were discussed (Section 3). Although SGEEMI was asked explicitly to evaluate biological reference points for the North Sea in a multispecies context, such an evaluation is by no means straightforward and must be approached in indirect ways (Section 4). Therefore, no advice could be provided at this stage. The study group concentrated on exploring the possibilities and on an outline of a possible future line of action.

2 ONGOING STUDIES

2.1 Reference points

Gislason (in press) used single species and multispecies VPA models to examine the effect of species interaction on biological reference points for cod, herring and sprat in the Baltic. The results have been described in previous reports (ICES 1998a, 1998b) and only a short summary of the findings is included here. In order to study the effect of changes in the biomass of forage fish for cod a version of MSVPA was constructed, where cod growth was made a function of the available food. Other food was subdivided into two components. The biomass of both types of other food was related to cod predation. Growth at age was assumed to be directly proportional to the total amount of food available to each age group. The growth model provided a significant fit to the observed changes in cod weight-at-age. Single species VPA, MSVPA and MSVPA with food dependent growth were used to estimate historic stock sizes and mortalities for the three species over the period from 1977 to 1996. A Ricker stock recruitment relationship was fitted to the estimated SSB and recruitment from each of the models. The models were subsequently used to predict long-term equilibrium yield and SSB. The usefulness of various single species reference points was explored by changing the fishing mortality generated by the fishery on cod and by the two pelagic species in each of the three models.

The results in this example demonstrate that reference points differ in single and multispecies contexts. Reference points for fishing mortality based on single species yield and SSB calculations are difficult to use when natural mortality depends on the absolute abundance of the predators and their alternative prey. Reference points based on maximising total yield from the system may lead to impractical results when species interact. Multispecies predictions suggested that the maximum total yield could be obtained by reducing the cod stock to a very low level of biomass in order to benefit from the higher productivity of herring and sprat, its major prey. Such a result stresses the need for incorporating socio-economic considerations in the definition of target reference points. Management advice based on biomass reference points will also differ. In the single species situation the combinations of cod and pelagic fishing effort for which the equilibrium spawning stock biomass of the three species is above the biomass reference points forms a rectangular area. When biological interaction is taken into account the limits of this area becomes curved. The multispececies models thus show that reference limits for forage fish cannot be defined without considering changes in the biomass of their natural predators. Likewise, reference limits for their predators cannot be defined without considering changes in the biomass of their prey.

2.2 Model development

2.2.1 Multispecies assessment in the Baltic

Following a recommendation by the Working Group on Multispecies Assessments of Baltic Fish during its last meeting in 1995 (ICES 1996), the MSVPA/MSFOR implemented in the 4M program package and the underlying data bases have been further developed by the Study Group on Multispecies Model Implementation in the Baltic (ICES 1997a, 1999a). The Study Group has made the following steps to implement the multispecies model as a regular assessment tool:

1) Set-up of a revised data-base on catch and weight at age in the catch per quarter and Sub-division for cod, herring and sprat, enabling assessment in any combination of areas; update of the stomach content data-base and enhance the stomach content compilation procedure.

2) Revision of quarterly consumption rates of cod considering intra- and inter-annual as well as spatial variability in stomach contents, predator weights and ambient temperatures.

3) Assess the reliability of estimated cod cannibalism by reviewing the stomach sampling, analysis and data compilation procedures, checking the likelihood and impact of intra-cohort, trawl and discard feeding and testing the applicability of available suitability sub-models.

4) Improvement of the 4M program package with respect to user-friendly features and compilation of a user manual giving detailed specification and documentation.

5) Implementation of a practicable tuning procedure, a module allowing to model growth of cod in dependence of available food and introduction of various stock recruitment relationships in the MSFOR-module (see section 2.2.2).

6) Spatially dis-aggregated MSVPA test runs have been performed and implications for further spatial assessment attempts have been described.

The Baltic Fisheries Assessment Working Group has utilised age and year specific predation mortalities in the single-species assessments, which have been updated regularly according to the results of MSVPA. The improvements formulated above enabled the WG in 1999 to run updated MSVPA in order to test the applicability of the 4M package as an routine assessment tool (ICES 1999b). In general, fishing mortality rates and recruitment dynamics derived from MSVPA were rather close to those obtained in the single-species approach, whereas deviations in biomass levels were more pronounced. The trials demonstrated that, particularly in case of sprat, multispecies tuning makes the assessment less sensitive to tuning options and reduces also the range of estimated values in retrospective analysis. Short-term predictions are presently carried out with an average age-specific predation mortality for most recent years. Long-term projections for the various stocks have been conducted so far independent of changes in predator abundance on the basis of simple stock recruitment relationships, also using average predation mortalities. For short-term predictions, the implemented version of MSFOR can readily be used. However, development of realistic medium- to long-term projections requires further effort. The following actions have been suggested (ICES 1999a):

Technically oriented:

- validate and correct the newly compiled catch and weight-at-age data, set-up a data base of weight-at-age in the stock derived from research surveys, evaluate the possibilities for extending input data backwards in time and develop procedures for routine updates and maintenance strategies;
- install the 4M program package as well as the necessary data bases on the ICES computer system and ensure maintenance and further testing of the program.

Assessment oriented:

- validate the revised cod consumption rates (not yet taking into account the potential impact of oxygen deficiency) by developing a bioenergetic model as an alternative approach;
- explain historical trends in weight-at-age for the three species, and predict weight-at-age and maturity ogives on the basis of prey availability and environmental conditions, because these factors potentially affect future spawning stock biomass, quantity and quality of eggs and recruitment;
- model suitability coefficients considering environmental factors triggering predator/prey overlap and intensity of prey switching;
- explore the feasibility of introducing a statistical spatial multispecies framework, allowing modelling of migration rates and spatial differences in stock parameters due to differences in environmental conditions.

Management oriented:

- implement a suitable medium- to long-term projection methodology for simulation of stock and catch development under different management options and environmental scenarios;
- apply and validate different types of multispecies prediction models of less complexity outside 4M;
- evaluate the stability and suitability of biological reference points considering species interactions, environmental processes and the spatial heterogeneity thereof.

2.2.2 The 4M program package

The Study Group on Multispecies Model Implementation in the Baltic (SGMMIB) used during its meeting in December 1998 the 4M program package (Vinther *et al.* 1998), which is a more user-friendly version of the Fortran MSVPA/MSFOR package previously used for multispecies assessment. Moreover, the 4M package has been extended with a several new features and extensions:

▪ batch and multiple runs

4M is an interactive system where the users communicate with the system through a graphic user interface. For repetitive routine tasks this set-up can be laborious and a batch command facility has been defined. In batch mode, the system supplies a number of templates and users can use these or create their own command files.

Multiple run mode represents another way to automate a set of VPA and prediction runs with varying values of input variables for sensitivity and other analyses. The output from multiple runs contains only the most essential variables and input value(s) for each run.

• ***ad hoc* multispecies tuning**

MSVPA terminal fishing mortalities in the fourth quarter have previously been estimated by trial and error until the sum of the estimated quarterly MSVPA Fs was sufficiently close to the annual F values produced by single-species VPA. This process has been laborious and time consuming. A first try to incorporate tuning in MSVPA was made by ICES (1992). Although the method appeared to give sensible results, discrepancies in the way XSA and MSVPA treat the plus-group prevented final testing of the method.

Multispecies tuning can be considered as a successive exchange of natural mortalities (M) and terminal fishing mortalities (F) between MSVPA and the tuning modules for individual species until equilibrium is obtained. In the present implementation, tuning is not integrated in the MSVPA program, but is made through calls to separate external tuning modules. This is very inefficient with respect to run-time, but the approach allows use of existing tuning software, e.g. the Lowestoft VPA package (Darby and Flatman 1994) or ICA (Patterson 1998). At the moment, only the Lowestoft VPA package (XSA and separable VPA) has been tried, but the interface method would be similar for other tuning packages. The basic principle for *ad hoc* multispecies tuning is:

1. Perform a MSVPA run using dummy terminal F's.
2. For each species write a file in the appropriate tuning format including multispecies natural mortality rates.
3. Perform single-species tuning for each species, using multispecies M values.
4. Read output from tuning and convert terminal annual F's into quarterly F's for each species.
5. Perform a new MSVPA run based on all quarterly terminal F values.
6. If $\Sigma (F_{new} - F_{old})^2 >$ limit go to step 2.

The tuning modules and MSVPA program use separate catch-at-age data sets, which ideally should be identical in terms of annual catch numbers for a given area. However, it is technically possible to use different data sets if stock definitions differ between single- and multispecies assessment. The implicit assumption is then that the two "stocks" have the same fishing- and natural mortality. Vinther & Thomsen (1998) give more details on the implementation of multi species tuning.

• **Stock recruitment relationship**

Recruitment in 4M prediction may be constant, stochastic or defined from a stock recruitment relationship. All recruitment values are given by year, quarter, species and age. Normally, values or parameters for the first prediction year are given only and these values are automatically used in succeeding years. It is however possible to provide values by individual years (a feature mainly used for constant recruitment and for recruitment age greater than 0). The following options are implemented:

- Constant recruitment: User selected input of recruitment by year (range): year, quarter, species, age, recruits;
- Stochastic recruitment: Input represents random selection from a normal (or log normal) distribution: year, quarter, species, age, mean number of recruits, CV;
- Stochastic stock/recruitment: Dynamics are handled by considering a class of stock-recruitment models as defined by Deriso (1980) and Schnute (1985), which includes the classical Ricker (1954), Beverton and Holt (1957), logistic (Pearl 1925) and proportional models as special cases.

In the present implementation, a delay (number of quarters) between spawning and recruitment are given as input and the SSB values used in the relationship are defined accordingly. Stochastic stock-recruitment is implemented by giving a CV for each parameter.

• **Accounting for changes in food intake and growth**

Since food intake and growth are assumed constant in traditional MSVPA, changes in biomass of prey will not affect the growth of their predators. A first step to include bottom-up effects in 4M includes growth of predators as a function of the amount of available food. Gislason (1998) has implemented a spreadsheet version of the MSVPA and MSFOR programs for the Central Baltic stocks. His concepts have been implemented in 4M with a few modifications due to the use of quarterly instead of annual data.

Weight-at-age is defined as the weight at age in the preceding year plus a growth term. Growth depends on average growth observed and on the amount of available food in relative to the average. Food intake is defined by a bioenergetic model, which takes into account standard metabolism, somatic growth and spawning. Estimated weight-at-age, food intake and available food are mutually dependent and are estimated by iteration until convergence of the values of estimated weight-at-age.

The assumption that biomass of 'other food' or total biomass is constant appears to be inconsistent with the assumption that food intake is a function of available food. Therefore, average biomass of 'other food' is assumed to decline exponentially as a function of the amount eaten. The 'other food' component can be divided into several taxonomic groups.

The concept might also be used to model variable (density dependent) mean weight-at-age of prey species like herring and sprat. These species will then act as predators on a number of relevant prey groups. The extensions work in both the VPA and the prediction mode.

2.2.3 Multispecies modelling in Iceland

In Icelandic waters the ecosystem is dominated by relatively few species, of which cod and capelin are the most important. The cod stock was at a minimum in 1993/1994 but has increased since the adoption of a catch rule in 1995, which was based on maximisation of the yields of cod, capelin and shrimp while minimising the risk of collapse of the cod stock. Catch of shrimp increased rapidly when the cod stock was small but has rapidly decreased over the last two years, mostly due to predation by cod. Two multispecies effects are thought to be of crucial importance:

- The effect of capelin stock size on cod growth: this effect is quite pronounced and may be used to predict the weight of cod in the following year. Capelin migrate north during summer, off the continental shelf, and become inaccessible to cod. These migrations vary between years and explain part of the variability in cod growth.
- Predation by cod on shrimp: the predation is highly variable but the amount eaten has often been considerably larger than the amount of shrimp caught.

Currently, work is going on implementing the relationship between the 3 species (cod, capelin and shrimp) using the area disaggregated multispecies model BORMICON (Stefánsson and Pálsson 1997; Stefánsson 1999; Björnsson 1999). Two levels of area disaggregation are tested, 16 and 3 areas (figure 1). In the 16-area scenario, shrimp live in areas 3 to 6 with area 3 being the most important one. The most important cod area is usually area 2. The number of cod in area 3 is highly variable, as is the predation on shrimp. Therefore, migration of cod from area 2 to area 3 is allowed to vary interannually. In the 3-area scenario, suitability of shrimp as prey for cod varies. The goal of examining these two scenarios is to evaluate the losses and benefits of increased complexity introduced by increased spatial disaggregation.

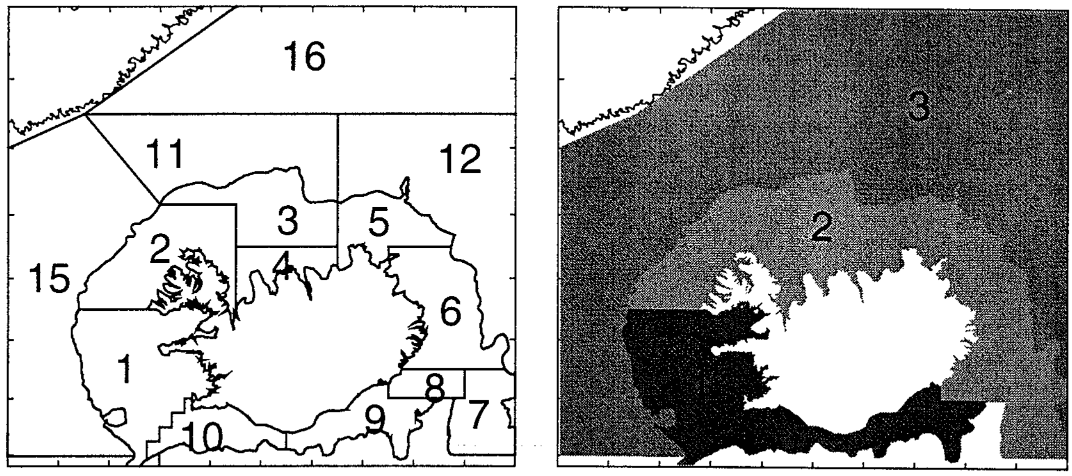

Figure 2.2.3. Division of the BORMICON model according to (a) 16-area and (b) 3-area scenario.

A large number of different data are used to calculate the objective function which represents a weighted sum of the different components and which is minimised during the estimation process:

- Length distribution of cod and shrimp in surveys and commercial catch
- length and area disaggregated survey indices of shrimp
- age and area disaggregated survey indices of cod
- age-length-keys of cod
- stomach content data
- proportion mature of cod in catches and survey
- proportion of sexes in shrimp.
- age and area disaggregated acoustic measurement of capelin
- mean length at age of cod.

Parameter estimation in multispecies scenarios as examined here took a long time (1–2 weeks) due to the large number of parameters (100–200). This means that varying the weight of different data sources in the objective function and re-running the optimisation is virtually impossible. Current developments are attempting to increase the speed of the optimisation by using network distributed processing while the incorporation of automatic differentiation is planned for the near future.

2.2.4 Highlights from the Barents Sea

The Barents Sea has few dominating fish species. Cod and capelin are the most important, and they are strongly interrelated, capelin being the most important source of food for cod (Gjøsæter 1978). Strong year classes of Norwegian spring spawning herring have a strong impact on the ecosystem during the first 3–4 years of life before they migrate out of the Barents Sea, by grazing down juvenile capelin (Hamre 1994). As a consequence, the capelin stock may show a temporary collapse, leading to reduced individual growth of the cod.

The Northeast arctic cod stock is at present assessed using XSA. Because of problems with the assessment during the last few years, the assessment may in future be based on a model of the catches with a length dimension which takes growth into account (FLEXIBEST). Cannibalism is calculated from stomach samples and added as an extra 'catch'. The assessment involves an iterative procedure until convergence (by hand). Capelin is the most important prey item for cod (Bogstad and Mehl 1977) and growth is related to capelin consumption using a bioenergetic model (Ajiad 1996). Future growth is based on a forecast of capelin biomass (ICES 1999c).

Maturation of capelin is estimated by a length, sex and age-structured model (CAPSEX). Based on a PINRO-IMR trawl-acoustic survey in September, the maturing part of the stock is projected until spawning in April. The predation mortality caused by cod is calculated using a model fit to outputs from the MULTSPEC model. In 1999, the stock was managed using a limit reference point based on the smallest spawning stock biomass that gave a high recruitment. An attempt to evaluate a target reference point failed because the spawning stock in 1974/1975 vanished and the resulting recruitment function could therefore not be used. A more comprehensive analysis is needed, which takes into account sources of information on feeding conditions before 1984 (the first year of the joint IMR-PINRO stomach sampling project), that have not been used previously.

Based on new survey information, the harp seal stock has been adjusted from about 900 000 animals to more than 2 million animals (ICES 1999d). This stock may have a significant impact on both cod and capelin, but the seasonal geographical overlap between the species is poorly known. Work has recently been undertaken to include harp seal predation (however uncertain it may be) into CAPSEX.

Multispecies modelling started in the mid-1980s with the development of MULTSPEC (Tjelmeland & Bogstad 1998), centred around the joint IMR-PINRO stomach content data base. From the onset, multispecies modelling comprised growth dependency on consumption and spatial disaggregation. The simpler but compatible models AGGMULT (Tjelmeland & Bogstad 1998) and CAPSEX (Tjelmeland 1997, 1998) are used to investigate harvesting control rules.

Only some aspects of multispecies management have been implemented in the Barents Sea so far: the significance of capelin as source of food for cod and mortality on capelin from predation by cod. In the near future it will also be possible to develop harvesting control rules for one species conditional on harvesting control rules set for other species. However, a true multispecies harvesting control rule is not feasible yet, because this would involve an agreement between the parties involved about the relative value of the different species, and how to value the marginal value of high catches relative to the marginal value of low catches. This, if at all possible, requires a long process of negotiation.

2.2.5 Incorporating length-based predation

The main purpose of the work carried out so far was to implement a multispecies model which required the estimation of a smaller parameter set than the standard MSVPA. Such a model might be used in areas of sparser stomach contents data or might even make the task of a spatial multispecies model feasible.

The reduction in the number of suitability parameters begins by recognising that predation is essentially dependent on size of respective species and not on their age. It is assumed that each age cohort contains a range of fish sizes and all individuals grow according to a Von Bertalanffy growth curve. A length-based model can then be used to determine the predation impact on a particular species. Instead of assuming a suitability value or preference for each predator-age-prey-age interaction, the suitability for each species-age-length (u_{ps} p –predator-age-length, s – prey-age-length) cohort is written as the product of a species-species interaction term (U_{pp}) and a suitability function that depends only on the ratio of the length of prey to predator (λ)

$$u_{ps} = U_{pp}\, f(\lambda;\alpha,\beta,\lambda_{max})$$

where f is a beta function and parameters α, β and λ_{ma} are constants. λ_{max} represents a maximum prey to predator length ratio.

This Length-based Multispecies VPA (LMSVPA) is constructed in a similar manner to the MSVPA in that the model is run backwards in time adding in the catch data and losses due to predation and other natural mortality in order to calculate the species-species interaction coefficients. Quarterly fishing mortality rates are calculated by Newton iteration while the species-species suitability coefficients (U_{ps}) are calculated by iteration within the LMSVPA using all the available stomach contents data. Estimates of the parameters α, β and λ_{ma} are made by hand tuning through minimising the difference between observed and predicted stomach contents data. The suitability parameters are then used in a projection model (LMSFOR) together with assumed future values for recruitment and fishing mortality to make long and short term predictions about the future state of the fish stocks.

Stomach contents data are currently only available by age and therefore the success of the model has to be evaluated by summing predicted stomach contents over prey length classes and averaging over predator length classes. A distribution of the differences between predicted and observed stomach contents data does not appear to be much worse than that observed when considering the standard age-based model. Runs of the LMSVPA and associated predictive model have also been compared to those of the standard MSVPA. Historical stock sizes are comparable, although the LMSVPA gives lower estimates of the predated biomass of those species which are both predator and prey. However, due to the fact that mortality of these species is dominated by the catch, these differences produce only small changes in overall stock biomass. Since the LMSFOR uses the suitability values obtained from the LMSVPA, these effects follow through into the equilibrium predictions with overall stock biomass and yields not significantly different to those produced by the corresponding runs of MSFOR. These results are particularly reassuring when we consider the enormous reduction in the number of parameters this model uses when compared to the MSVPA. (See Dobby *et al.* 1991 for further details)

The species-species suitability parameters were initially tuned using the age-based stomach contents data via the 'MSVPA type' suitabilities. One of the aims of the project was to produce an implementation of the model that could be used in areas for which less stomach contents data are available. By reducing the age-based stomach contents data to species-species data before running the model, we showed that such data can be used to calculate U_{pp} values that are not significantly different to those obtained from the full stomach contents data set. The results of the historical stock estimates and the predictions also prove to be relatively robust to such changes.

We conclude that the incorporation of the length-base approach to predation adopted here provides a biologically more realistic model which requires fewer parameters and yet still performs as well as the standard MSVPA. The separation of suitability into length effects and species interactions may mean that estimation of these parameters might be possible from less extensive stomach contents data. For example, estimation of the species-species interaction terms would not require disaggregation of stomach contents data into length classes, while it may be possible to parameterise the length function from the physiology or morphology of the species. Although it does rely heavily on the age-based data of MSVPA, this model does provide a link where a fully dynamic, length-based approach could be incorporated in the future.

2.2.6 Multispecies interactions in the pelagic phase

All commercially exploited species in current MSVPA models go through a pelagic phase during the first few months of life. Eggs, larvae and early juveniles of different sizes and different species are found together in the sea, and may interact through predation, competition, and indirect effects. These interactions may be quite different from interactions between larger fish, on which attention is usually focussed. For example, there may be interactions between the larvae of species, which don't interact as adults, such as sole and cod. Also, adults of species such as herring and sandeel, which feed on small pelagic organisms, may consume the pelagic larvae of groundfish.

During this time, at least 99.99% of the eggs and larvae will die. Subsequent recruitment depends critically on variations in this number, and projections under MSFOR are sensitive to assumptions about recruitment. Multispecies interactions in the pelagic phase are thus both biologically plausible, and very important from an advisory perspective. Although this point has been understood for many years (Sissenwine & Daan 1991), there has not been much systematic exploration of the implications.

It seems doubtful whether there will ever be enough data to allow direct quantitative assessment of pelagic-phase interaction effects in a species-rich system. Fortunately, though, such data are not necessary for multispecies projection. Single-species stock-recruit models can be extended to include species interactions along the lines proposed by Murphy (1986) and Fogarty *et al.* (1991) by using an extended Ricker model:

$$E[R_i] = a_i\, S_i \exp(\textstyle\sum_j b_{ij}\, T_{ij})$$

where R is recruitment, i and j are species, S is adult spawning potential (usually spawning stock biomass), T is biomass of predators or competitors, and a and b are parameters to be estimated. The set of T_{ij} may or may not include S_i, depending on whether there is substantial single-species density dependence during this phase of life history. The appropriate set may be selected by checking cross-correlation between species for historic consistency.

The sign of the coefficient b_{ij} depends on the nature of the interaction between the species. Although we might generally expect b_{ij} to be negative, there are at least two mechanisms by which b_{ij} might be positive. The first is an indirect effect, with species j removing a potential predator of larval species i. The second might be called a reverse-predation effect: if larval i feeds heavily on larval j, an abundance of j could result in faster growth for i, thus reducing exposure to predation.

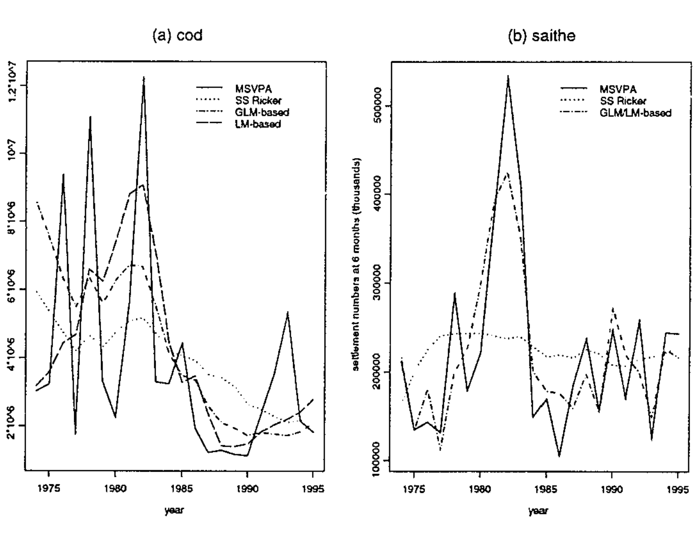

Figure 2.2.6. Fitted recruitment models to MSVPA time series of recruitment of (a) cod and (b) saithe.

For the ten North Sea MSVPA species, the model was fitted to estimates of recruitment at the age of 6 months produced by MSVPA. As proxies for predators/competitors, we used spawning stock biomasses of all the other ten species. By choosing which species to include, fits can be improved substantially over the single-species Ricker model (Figs 2.2.5.a and b). However, there are many ways of obtaining almost equally good fits, by using different species on the right-hand side; in other words, there is considerable model uncertainty. The parameter estimates are quite large, so that estimated interactions are often enough to affect average recruitment by a factor of 3 or more as the abundance of another species varies. Implications for management advice, e.g. on the effects of different mesh sizes, are likely to be very different depending on which species are used. This is a key area of sensitivity for multispecies modelling, and the possibility of pelagic phase interactions cannot be ignored.

There may be biological reasons to rule out some of the interactions that have been selected on purely statistical grounds, either through existing data or through field studies. However, unless the range of models can be narrowed down very considerably, the imprecision in our predictions may be such that it is not worth expending energy in trying to resolve other issues of multispecies interaction.

2.2.7 Exploitation of simulated ecosystems

Strategic decisions about fishing policy should entail multispecies considerations, and reliable management needs to be based on results that are robust to model uncertainty. Therefore, we considered two dynamic size-based models of hypothetical fish communities (Duplisea & Bravington 1999): (1) based on individual species and (2) based on an aggregated community. The first model is a length-based version of MSVPA where numbers of individuals in length-cohorts are tracked and species interactions are mediated by predation mortality. The second model is an energy flow model derived from biomass size spectrum theory, which considers flow of energy through the aggregated community without regard to species. The effect of optimal size-based harvesting strategies on community properties such as stability and persistence of size-spectra, are compared between the two models. By comparing model results, we can identify which properties are robust to model uncertainty, and the processes, of which we know little, that can strongly affect results. These types of conclusions are needed both to direct further research and to define the limits of management advice that can be derived from the models.

Preliminary results indicate that optimal yields are obtained by restricting fishing effort on small fish, and allowing heavier exploitation on large fish. This results from the growth and predation feedbacks in the model: reduce the large predators in the system and allow the fishery to remove the subsequent surplus yield of prey species that have a higher specific growth rate.

2.3 Field Studies

2.3.1 Feeding ecology of North Sea Fish

A study funded by the EU (Anon. 1998) investigated a variety of feeding aspects of the main predators in the North Sea (cod, haddock, whiting, saithe, and mackerel). Data were from existing stomach data bases, mainly the North Sea International Stomach Database containing records collected during the 1981 and 1991 Stomach Sampling Projects. These projects were aimed at collecting data to estimate input parameters for Multispecies Virtual Population Assessment. Additional samples were also obtained. Spatial and temporal variation in feeding was investigated in terms of total stomach contents (percentage empty stomachs and weight) and species composition. Most analyses used data from pooled stomach samples. Variation of stomach content with predator length, area (Roundfish areas, south/central/north region or latitude and longitude), month or quarter, year, depth, time of the day and with country performing the sampling was investigated qualitatively and through generalised linear and additive models (GLM, GAM), contingency tables and bootstrap depending on the predator. Diet variation was investigated through bootstrap, multivariate ordination and multinomial log-linear modelling. Stomach contents were compared between years except for mackerel. Diet overlap and spatial predator-prey overlap were calculated. Intra and inter species competition was investigated using GAMs. Distributions of organisms derived from benthos surveys and haddock stomachs were compared. The relationship of mean prey weight with predator length accounting for prey length was investigated using GAMs. The effect of using age-length keys instead of otoliths readings to estimate consumption of prey at age by saithe was analysed. Further, stomach contents of North Sea and Baltic cod were compared using GAMs. Also the effect of choosing evacuation models to estimate consumption was analysed with a model that simulates food intake and evacuation of single fish. Finally, data were obtained to study feeding aspects of haddock and whiting at small spatial scale.

Analysis of percentage empty stomachs indicated that, among the variables considered, season had the strongest effect with highest levels in winter. Area differences were not detected for saithe nor whiting while for haddock higher levels were found in central North Sea, for mackerel in the south and for cod in the south west. Levels of empty stomachs for haddock increased with predator length in winter and decreased in other months and same trend was found for mackerel in winter when only juvenile had food in the stomachs. For other predators no relationship of percent of empty stomachs with length was found. Analysis of stomach weight showed that levels were generally determined by predator length except for mackerel in winter and fall when contents were uniformly low. Differences in stomach weight with area were detected for all predators. Levels were low in areas found to have high percentages of empty stomachs. Seasonal variation with generally low levels in winter and fall was found for all predators except for whiting. Analysis of daily fluctuations of stomach contents indicated that haddock feed at night and saithe during daytime. Also, weight of stomach contents was affected by intra and inter-specific competition. In terms of prey composition, contents were dominated by fish and crustaceans, with whiting and haddock representing the extremes. Common fish prey were Norway pout dominating the diet in quarters 1 and 4 and sandeels in quarters 2 and 3. This was less pronounced for cod which also fed heavily on herring and whiting and had a wider fish prey spectrum. Shift from invertebrate to fish prey with predator size was common. Spatial variation was less significant than seasonal differences. In haddock stomachs, sandeels were most commonly found near the Scottish coast, Norway pout in the north and invertebrates in central North Sea while whiting diet was dominated by crustaceans and fish in the north and was variable in the south. The most striking difference between years was the replacement of euphausiids in most predators' diet in 1981 by hyperiids in 1991. Stomach contents were generally higher in 1991 than in 1981 for most predators but haddock. The abundance of herring as prey was also higher that year.

Although the diet composition of cod, whiting and haddock was similar at the North Sea level, the overlap was very low at the rectangle level. Highest similarities were between small haddock and whiting and they decreased with length. Spatial-temporal predator and prey overlap was found to be variable. High overlap was for all predators with prey age 1 in winter and spring and with young of the year in summer. Weight-at-length of prey in stomachs of haddock, whiting, saithe, and cod was largely independent of predator length. Comparison of benthos survey and haddock stomach data did not provide information on feeding aspects but suggested that stomach data can provide useful information on distribution of benthic species. The choice of evacuation models on food consumption was found to cause over- or under- estimates of consumption mainly through the meal size assumptions. Further, data from additional sampling showed high variability of the stomach contents of whiting and haddock within small areas suggesting that a single sample from a statistical square may not be representative. Also the presence of feeding hot spots was identified. Results indicated that applying survey-based age length keys to assign ages to Norway pout found in saithe stomachs produces similar estimates as actually ageing the prey. Last, inter-ecosystem comparison indicated that feeding conditions for cod in the North Sea were better than that in the Baltic for individuals older than 3 years, which coincides with patterns found in growth rates.

Finally, the study points out insoluble difficulties in using the Stomach Content Database for particular statistical analysis. The sampling design aimed at obtaining average values within quarters and Roundfish areas by predator length classes. This limits the scope of analysis of statistical properties of stomach contents in general. Also, several countries shared the sampling effort and their operations did not overlap in time nor space, thus "country effects" found significant when incorporated in some analysis are confounded with temporal and spatial variation of stomach contents.

2.3.2 Stomach contents of North Sea saithe

WD-8 describes the diet of saithe as observed during the ICES co-ordinated stomach sampling projects, 1980–1991, with emphasis on potential bias. The analyses are focused on the precision of the diet data relevant for MSVPA or similar multispecies assessment models.

Simple summaries of the proportion of empty or regurgitated stomachs indicate that the classification of stomachs had been different between countries. As an example; the Scottish samples includes more than 2 000 stomachs of which 46% are regurgitated whereas only 2% of the stomachs sampled by Norwegian vessels were regurgitated. The proportion of empty stomachs is however 24% for Norwegian samples and 9% for the Scottish samples. Generalised Additive Models (GAM) were used to identify significant factors, like area or season, which might have caused these differences. A GAM analysing the in proportion empty stomach showed a significant country, area and quarter of the year effect, but the model fit indicated that the proportion empty were much more variable than expected from a binomial variable. Addition of more explanatory variables to the model did not improve the model fit much and gave inconsistent results. A different classification of stomachs among countries (or sampling surveys) during the sampling period is the most likely reason for the observed discrepancies. Such bias will influence the estimate of the average population diet used in MSVPA.

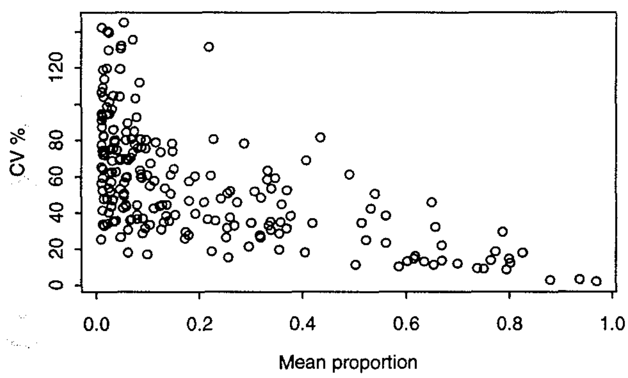

Figure 2.3.2. Bootstrap mean prey weight proportion in the diet and CV calculated for individual prey groups for each stratum defined by year, quarter and saithe size class.

The bootstrap method was used to provide estimates of confidence limits of the average prey proportion for each combination of size class, year and quarter. Preys were initially pooled into 11 groups with emphasis on the MSVPA species. One thousand samples of coherent prey composition and weighting factor, each of the same size as the observed data, was drawn by simple Monte Carlo sampling with replacement. In the calculation of average stomach content for each bootstrap sample, the non-identified prey items were allocated proportionally to the observed preys in a similar way as done in the processing of data for use in MSVPA. The estimated coefficient of variation of the mean proportion of a prey item was in general high (Fig 2.3.2).

A GAM analysis of the data presented in fig 2.3.2 showed that the number of samples and the mean proportion of a prey can be used to predict CV, such that the sampling level for a possible future stomach sampling can be determined.

The bootstrap estimated mean proportion and variance of a prey was used to test the significance of the difference in the diet in 1980–83 and 1991 for the various size classes of saithe. In general, the mean proportions of less abundant found prey species like sandeel, whiting, 'other fish' and 'other invertebrates' were not significant different for the two periods. The more abundant prey items krill, Norway pout, haddock and herring showed a higher frequency of significant differences between the two periods. The increase in the proportion of herring in the diet was large and significant and in agreement with the known change in herring biomass.

2.3.3 ELIFONTS

The ELIFONTS project (Effect of Large-scale Industrial Fisheries On Non Target Species) was a collaboration between institutes in the UK and Denmark, co-funded by the European Commission. The objectives were to determine the availability of lesser sandeel to predators (seabirds, seals and predatory fish) in the Firth of Forth (ICES rectangles 41E7 and 41E8) in 1997 and 1998, to investigate how this affected the foraging behaviour and reproductive output of the predators, and to study the effects of the commercial fishery (which has taken between 10 000 and 100 000 tonnes of sandeel per year from these rectangles since 1991) on sandeel availability.

Changes in sandeel biomass between 1997 and 1998, and the relative size of different age classes were determined using grabs, dredges, acoustic surveys and CPUE data. Preliminary analysis indicates that total biomass at the start of the year probably declined slightly from 1997 to 1998, but there was a large decline in the biomass of one-year old fish. The pattern of sandeel removals through the year showed a strong peak in June and July, primarily because 95% of the commercial catch is taken in these two months. In 1998, landings from the study rectangles were 150% higher than in 1997. There were significant differences in the diet of the predators in the two years, with all predators consuming smaller amounts of sandeel in 1998. Seabirds feed their young primarily on 0-group (which are not usually taken by the fishery) but adults rely on 1+ sandeel to feed themselves during the May/June incubation period. Breeding performance of kittiwakes (which can only catch sandeel when they are near the surface) was significantly correlated with the ratio of CPUE in May to that in June for the Firth of Forth area. This ratio probably reflects the change in availability between the two months. Seal body condition and pup survival were significantly correlated with sandeel CPUE for the entire southern North Sea. Body condition of fish was significantly lower in 1998. Most of these relationships are probably the result of variations in sandeel recruitment or behaviour, but the fishery could affect the availability of sandeel to seabirds during June in years when catches are particularly high and 0-group recruitment is low or late.

2.3.4 Behaviour of cod in relation to prey

One of the purposes of multispecies assessment is to advise on long-term biological reference points for fisheries management in a multispecies context. At CEFAS, a project has started to support the development of biological models that are based on a better understanding of the interactions between predators and prey. Studies of other animals (e.g. birds and mammals) show that the functional response in predator-prey interactions significantly affect the dynamics and growth of populations. We expect such functional responses to exist in fish populations, but at present they are rarely included in marine fisheries models, primarily because of the difficulty of collecting relevant data at appropriate temporal and spatial scales. This project seeks to rectify this omission.

The project will involve an integrated approach. Acoustic and trawl surveys will be used to assess the relative densities of predators (cod) and prey (sandeel) on feeding grounds, Acoustic telemetry (acoustic transponding tags and sonar buoys) will be used to monitor local movements of cod on feeding grounds in relation to sandeel distribution and abundance. Data storage tags will be used to monitor the larger-scale movements of cod between feeding grounds over extended (>1 year) periods. Analysis of cod stomachs (ICES Year of the Stomach data 1981, 1991) may help to identify feeding preferences in relation to prey availability. Sandeel distributions will be also be assessed in association with descriptions of sediment type (e.g. from the British Geological Survey) and from ongoing and proposed benthic mapping surveys. Technical improvements are expected to include the development of methods for measuring the feeding activity of free-ranging predators, and evaluation of coded acoustic tags and sonar buoys for monitoring local movements of fish. Results are expected to provide a sound biological basis for the development of multispecies models at CEFAS

3 NEW CHALLENGES IN THE CONTEXT OF THE NORTH SEA

It is notable that the most recent developments and application of multispecies models has centred on the Baltic and Barents Seas and Icelandic waters. These systems are characterised by the dominance of a limited number of fish species with clear and strong interactions, and by having strong and well-defined environmental drivers. These conditions do not apply to the North Sea, and multispecies work is correspondingly more difficult.

At several points during the meeting, it was not clear what is the definition of a multispecies approach and if certain questions fell under the terms of reference of the study group. The definition of a "multispecies" approach that arose out of this was:

Multispecies approaches deal with species considered important by management (including seabirds and marine mammals) as well as any other species that are necessary to understand the major processes affecting those species' population dynamics, or which themselves are strongly affected. Multispecies approaches do not necessarily consider with all the system components or even a majority of them.

Although individual species would generally serve as the starting point, there may be a need for some level of aggregation in the system, which could hypothetically go from aggregating two species to all species at each trophic level or any arbitrary combination, such as individual fish and 'other food'. However, the search for emergent properties was deemed to be an "ecosystem approach" or "top-down" sensu Silvert (1982), whereas a "multispecies approach" would reflect a "bottom-up" approach. The top-down approach does not require a mechanistic understanding of system components but may still provide generally right answers; the bottom-up approach requires detailed modelling but may still provide precisely wrong answers. A top-down approach may indicate whether bottom-up models are giving absurd results.

Ecosystem approaches are also considered by other ICES working groups and therefore, it is useful to draw a demarcation line. It was generally concluded that the Study Group should not attempt to identify emergent properties of the ecosystem but should always be mindful of possible simplifications and not remove aggregate methods and models from its repertoire. Although the effects of environmental variability may be incorporated in the models, depending on data availability, the focus of multispecies approaches is clearly on species interaction as well as technical interaction between different fleets.

3.1 The usefulness of MSVPA in the context of stock assessment

In the Baltic, the 4M model is used regularly to update estimates of natural mortality. For sprat, in particular, the estimates of natural mortality from the model have improved the correspondence between the estimated stock size and survey indices. As described in section 2.2.2, tuning has recently been incorporated in 4M and it seems likely that the model will be taken over by the Baltic assessment working group and used for annual assessments of cod, herring and sprat.

In the North Sea, the MSVPA has been used for providing estimates of the average natural mortality of commercially exploited fish species and for making long term predictions of yield and biomass under various assumptions about effort and mesh changes. Comparisons of multi and single species predictions suggest that in most cases the differences between the two approaches are negligible in the short term but show that they can be significant in the long term. The effect of species interactions on medium term predictions has not yet been investigated, nor has the effect of historic changes in the level of predation mortality on perceived stock recruitment relationships. Also the influence of species interactions on biological reference points remains to be fully explored. The M4 package appears to provide a suitable starting point in this respect.

From a theoretical point of view, MSVPA is superior above single species VPA, because VPA is in essence based on estimates of removals from the population and predation simply reflects removals by a 'fleet' of predators. However, multispecies assessment depends heavily on the availability of reliable catch data for all species included. Problems with biases in the catch data for one species impinge on the assessment of others. Thus, in practise the application of such models may be problematic. Also, preparation of input data and assessments would have to be carried out simultaneously for all stocks included and this would clearly create logistic problems for the working groups involved. Moreover, the guidelines for changing the weights given to different pieces of information in the tuning process are unclear when species interaction is also part of the model. Changing the weight given to a particular tuning fleet or survey could have knock-on effects on other assessments and it may be cumbersome to ensure that an overall optimum interpretation of the data had been achieved. However, because multispecies tuning has not yet been attempted in the North Sea, these worries may prove wrong. The question of whether the approach would add value to the present procedure has therefore not yet been answered.

The analysis of the stomach content data has suggested several ways to improve the sampling protocol (sections. 2.3.1 and 2.3.2). However, the 1981 and the 1991 stomach samples revealed only small changes in the food composition of the predators, and provided little contrast from which a better understanding of the processes influencing food selection could be derived. A formal statistic test of the significance of the changes that did occur is difficult due to the statistical properties of grouped stomach samples, but should be pursued further. Reducing the number of parameters describing prey suitability in the 4M model and combining it with an estimation routine capable of estimating the suitability parameters would allow a first statistical test of the constant suitability assumption. A more satisfactory statistical treatment would have to await the implementation of a stochastic multispecies model and additional information about the sample variance of the catch-at age, effort and survey information. If quarterly age-length compositions were provided routinely for the catches, the model might be modified to one which is biologically more appropriate, with a considerable reduction in the number of parameters. In future stomach sampling programs individual stomachs should be collected and analysed rather than bulked samples. In these respects, the possibilities of MSVPA are by no means exhausted.

3.2 Model development

Forward-projection species interaction models are essential testbeds for evaluating the possible performance of different management strategies. The range of testbed models ("operating models") needs to encompass the most important sources of uncertainty, so that a realistic idea can be provided of the robustness of results. Operating models should not be based only on "point estimates" of important parameters, since otherwise they will not properly reflect the inherent uncertainty, which is crucial to management decisions. Equally, though, operating models that are clearly inconsistent with historical data should be discarded.

A key consideration is how complex the models should be made, given that we will never have all the data we would like. It may be even counterproductive to develop overly complicated models, because the ability to properly characterise all uncertainty may be lost. The appropriate level of complexity also depends on the kinds of questions we are trying to answer. For almost all types of question, it will probably be necessary to incorporate some kind of growth/feeding response, and some kind of pre-settlement interactions. This immediately implies a shift towards length-based models and the use of length data. Growth responses cannot be modelled satisfactorily just using age data and age-based models. Nor is mean length-at-age data sufficient; differential fishing pressure by size within age classes may have significant effects on apparent growth. Further development of multispecies interaction models in the North Sea and elsewhere will require ICES Assessment WG to make available length-based catch data.

Area-based models would be necessary in order to answer area-based questions. However, in order to parameterise these models, extensive data would be required on the spatial distribution of predators in response to changes in large-scale distribution patterns of prey, for all species modelled. In the North Sea at least, these data have not been explored. Multispecies modelling cannot currently assist in answering questions about spatial aspects of management, such as the effects of closed areas.

Unfortunately, spatial dynamics are known to be important in determining the aggregate behaviour of systems, e.g. with regard to stability and to the shape of functional responses. It is necessary to somehow reflect this range of possible behaviours in constructing operating models. The most feasible approach seems to be to use simplified simulations to determine the effect of a range of possible functional responses, and to use historical data to model the extent of overlap between predator and prey species as a function of predator and prey density.

Complexity also depends on the number of species or stocks included in the model, and on whether any aggregation of species is employed. It is fairly simple to check whether conclusions are robust when particular species are removed from the model. If this proves to be the case, it might inspire some confidence that conclusions would also not change much if we were to include other species not currently in the model.

Aggregation of species is already followed implicitly in the "other food" term, but might be useful elsewhere in multispecies models. Of course, aggregation of commercial species will lead to conclusions that seem less focussed to a management system accustomed to single-species TACs. It may be, though, that imprecise conclusions for individual species might be replaced by quite robust conclusions for species groups. In the context of the precautionary approach, increased imprecision translates fairly directly into decreased effort; so if aggregation of species proves to lead to more robust conclusions, this loss of focus may be a price worth paying.

Fleet definitions are another important issue. The existing fleet structure in North Sea MSVPA bears little resemblance to the complex structure of >50 fleets identified in the STCF data base. When providing advice on the impacts of management, it would be imprudent to ignore the considerable technical interactions inevitable in the mixed-species fisheries. This disaggregated data base was set up In the beginning of the nineties to evaluate possibilities to improve the exploitation patterns of the North Sea fish stocks and includes quarterly catch, effort and economical data by fleet. Catch data were given by age group and ICES square so that the effect of a local area closure might be evaluated. There are more than half a million records for the two years sampled, 1989 and 1991.

On a national basis, EU-logbook data (spatial information of catch and effort), landings statistics (landings quantity and value by EU-size grade) and data from biological sampling (size grade-length and age-length keys) were combined to give data by fleet, species and age group. To day, logbook data and landings statistics are routinely computerised for most countries and data extraction from the national data bases should be a minor job. Furthermore, the quality of discard data has improved since 1990 as a result of extensive sampling programs, and more realistic estimates are now available. An updated STCF base for the most recent years would be valuable for the definition of fleet segments for use in evaluating reference points in a multispecies context.

Length-based multispecies models require age-length compositions of the catches in order to evaluate size preference as well as growth changes in relation to prey availability. Therefore, a new version of the STCF database should include at least quarterly length distributions of catches as well as age-length keys. Such a data set, together with an unambiguous specification of how data are combined, should form the basis for the estimation of catch-at-age by assessment working groups. This set up would also allow a comprehensive evaluation of basic sources of uncertainty in routine single species assessments, because mean weights at age are an important parameter for estimating biomass reference points and stock recruitment relationship. Therefore, the requirements are not only to satisfy needs from a multispecies point of view but are universally inherent to the provision of sound management advice.

The discussion above about appropriate levels of complexity relates primarily to multispecies projection models for use in management evaluation. However, the issue o arises more generally when developing multispecies models (Zachary**??). It is a standard statistical result that the most complex model that might be developed is unlikely to be the one with the best predictive power. It is not straightforward to apply this axioma in the context of multispecies assessment, because the models may not fit neatly into the hierarchy of complexity assumed in the usual statistical framework. However, operating models with varying degrees of complexity should be useful in determining optimum complexity.

A lot of the work needed on these subjects has already been planned under EU project 'Development of structurally detailed statistically testable models of marine populations', which is linked directly to the BORMICON model and in which several members of the group are involved. The development of a new generation of multispecies models for the North Sea (and other areas) should be linked to that project in order to make optimum use of limited manpower, but, given the large number of species, a split into more manageable subsystems involving fewer species may be important. How this could be done is not obvious and possible effects of ignoring links between subsystems needs to be examined in all cases.

4 SPECIFIC STUDIES

4.1 Growth

During its last meeting, the Multispecies Working Group (ICES 1997b) reviewed changes in weight-at-age for several stocks incorporated in the MSVPA covering the period 1974 to 1995. Long-term changes were indicated for different age groups of whiting and saithe throughout the 1980s, while for other stocks inter-annual variability was considerable but without long-term trends. The analysis was based on average weight-at-age in the catch, which may in fact not be the best data set to study variability in growth, due to the varying impact of different fleets using different size selective gears. Other studies revealed clear evidence for changes in growth rate of North Sea cod, plaice and sole. Brander (1995) showed considerable fluctuations in growth of cod in relation to ambient temperature. Growth rates also vary by area, with a trend of decreasing length-at-age from north to south (Heesen & Daan 1994). For plaice, significant growth changes have been related to euthrophication and seabed disturbance by beam trawling activity (e.g. Rijnsdorp and Van Leeuwen 1996). These growth changes are probably related to a decrease in size and age at sexual maturity (Rijnsdorp 1989). However, other processes like evolutionary changes resulting from selection imposed by fishing may also cause declining size at maturity (Rowell 1993; Stokes and Blythe 1993). Fecundity has undergone long-term changes in plaice and sole as well. However, a direct coupling neither to population density (Horwood 1993) nor to growth rates is evident (Millner *et al.* 1991; Rijnsdorp 1990).

Investigations of a possible coupling between growth, sexual maturation and egg production (also in terms of quality) and the availability of suitable prey and food consumption were identified as a high priority research area for future multispecies studies. In a longer perspective, progress may allow to:

- improve historical estimates of SSB (or egg production), the contribution of first time spawners and stock recruitment relationship;
- evaluate variability in consumption rates per predator size/age group;
- enhance predictions of SSB in dependence of food supply, competition by other predators and environmental conditions.

This would require an understanding of the processes interlinking somatic growth, reproductive effort and metabolic requirements. As a first step, a detailed analysis of length and weight-at-age changes in response to food availability, competition (i.e. abundance of predators having similar food preferences) and possibly ambient temperature should be initiated. This study should consider area specific features to obtain sufficient contrast in the data sets. Furthermore, the study should attempt to differentiate between apparent changes in growth rate due to varying intensity in size selective predation and removal by the fishery as well as migration. Linking food consumption (or food availability) to sexual maturation and quality and quantity of egg production are further steps of the proposed investigation, but may require, besides an extended analyses of survey data, substantial backup by experimental studies. Progress for planktivorous species depends critically on the understanding of zooplankton dynamics in the system.

4.2 Recruitment

Interactions in the pre-settlement phase have been described in the North Sea for a variety of species and life stages by various studies, including:

- predation on fish eggs by planktivorouss fish species and life stages (e.g. Daan 1976, 1985; Garrod & Harding 1981; Pommeranz 1981),
- predation on larvae by older conspecifics and other planktivorous fish (e.g. Grave 1981), which is difficult to identify due to supposedly fast digestion (e.g. Hunter & Kimbrel 1980),
- predation on pelagic 0-groups by older conspecifics and other piscivores fish (e.g. ICES 1988; Bromley et al. 1997, Last 1989; Robb & Hislop 1980).

There is also the potential for intra- and interspecific food competition slowing down growth rates, increasing mortality rates and consequently leading to knock-on effects. The present set-up of MSVPA does not allow intra-cohort cannibalism since the iteration procedure does no longer converge. Intra-cohort cannibalism was encountered especially in 0-group whiting and those data have been excluded from the MSVPA input (ICES 1988).

Introducing predator abundance in stock recruitment relationships as an explanatory variable may explain a significant part of the recruitment variability encountered without the necessity to quantify the feeding relationships (see section 2.2.5). If the underlying biological interactions are real, these have major implications for forecasting. The main problem is that there are many different statistical models that might explain the data and the implications may be different depending on the model chosen. Therefore, identification of most important species specific size- or stage-group interactions is needed in order to restrict the number of possible models. Therefore, it is suggested to conduct a specific study on the identification of predators on early and juvenile life stages, which can subsequently also be used to identify areas and time windows of enhanced predation pressure as well as modelling of predator specific functional feeding responses to prey availability.

Such a study may involve the following subtasks:

- Review of the available literature and analysis of existing data bases to identify species, life stages and sizes interacting as predator and prey in the pre-recruit (pelagic and transition) phase and to get an indication of the intensity of other interactions than presently incorporated in MSVPA..
- Describe the temporal and spatial (horizontal and vertical) overlap between potential predators and prey based on available distribution data obtained by larval, 0-group and other surveys.
- Ascertain areas and times of expected enhanced overlap by coupling information on time and location of spawning and settling with hydrographical information.
- Specific process studies addressing the nature and impact of interactions in the pre-recruit phase may have to be initiated, particularly in relation to vertical migration and horizontal distribution in relation to meso-scale hydrographic processes and food availability.

Work on different aspects of recruitment is in progress elsewhere. Although the results of these process studies are expected to be of great benefit within the context of multispecies modelling, this may take considerable time. Given the complexity of the problem, the group felt that is beyond its mandate to make specific proposals for a comprehensive approach.

5 MULTISPECIES REFERENCE POINTS

5.1 Introduction

The last term of reference was to 'evaluate biological reference points in a multispecies context....'. Following the definitions of single species reference points (SSRPs) within ICES, the terms 'multispecies reference points (MRPs) and 'biological reference points in a multispecies context' have increasingly been used, but it is not clear what is exactly meant by these terms. There is the notion that they 'take interactions between species into account', but there is no clear definition of terms or of any associated operational objectives.

The concept of MRPs stems from concerns that SSRPS may not always safeguard stocks since multispecies interactions have been ignored. Particularly, they may not provide sufficient protection to:

a) the predators of the harvested species, since SSRPs may not ensure sufficient food for them (high profile where predators are marine mammals or seabirds),

b) the harvested species itself under all circumstances (e.g. very low levels of prey or high levels of predators), and

c) the ecosystem (notions such as 'maintaining ecological relationships', 'high probabilities of reversibility of changes or recovery of depleted stocks within a given time frame', etc.)

There may even be different interpretations of 'MRPs' versus 'BRPs in a multispecies context'. The latter could be interpreted as a single species reference point adjusted in some way to take account of dependent predators, i.e. reason (a). There is usually an implicit assumption of bottom-up regulation rather than true feedback interaction in these cases. Where the assumption of bottom-up regulation becomes untenable, such simple adjustments may be inappropriate.

A multispecies reference point is, however, a misnomer (ICES 1997b). The very nature of interactions imply that instead, one would have a reference curve or contour. For example, there may be a contour of different combinations of predator F and prey F, all of which would have a low probability of predator SSB and/or prey SSB falling below the respective thresholds. The problem is that most ecosystems contain many predator-prey interactions, so that the result would be a multi-dimensional reference surface. Unlike the situation for single species, there is no longer a unique link between fishing mortality and SSB in a multispecies context. For example, different combinations of F for different species could imply the same SSB. It was noted that the calculation of reference points for a specific stock, based on outputs from, for example, MSVPA cannot be considered multispecies reference points, since they are conditioned on the dynamics of the other stocks in the system.

Although the reasons for wanting to take interactions into account are clearly valid and important, it would be inappropriate to assume that this could be done by 'extending' the single species approach. In addition to the fact that one is no longer considering single points, it is not even clear whether reference points (particularly candidate F reference points such as Fmed, F0.1 etc) could in practice be calculated for each species within a multispecies system. This is because predation mortality in a multi-species model can be highly variable or contain trends depending on the dynamics of the predator species.

5.2 The way forward

The problem of defining, estimating or interpreting MRPs is complex, and it is not yet obvious whether further safeguards, over and above the existing SSRPs, are required. However, there is no reason for abandoning the current approach, which defines reference points for single species, based on single species considerations. The main question that needs to be addressed is whether SSRPs provide the protection they were intended to provide even when we take interactions into account.

This question can be approached by doing simulation studies, which compare stock dynamics in a single species model to those in a multi-species model under different management scenarios and using SSRPs. There are some details of the simulations that still need to be refined and decided upon, but the approach seems feasible. The potential importance of incorporating pre-settlement dynamics and growth in the multispecies simulation model was noted. It should be possible to make some progress within a year or two.

It is important to note that only limit reference points can meaningfully be tested. Objectives defined in the multispecies context will inevitably contain trade-offs between species or species groups. This can only be resolved by associating relative values to species, and this is clearly beyond the scope of this group. The very nature of simulation and forecasting of a fishery does, however, imply some sort of management or harvest control rule.

If simulation studies indicate that SSRPs are never, or not always, sufficient, it would be possible to test how existing reference points could be amended. Alternative definitions of reference 'points' or sets of points could also be tested in the same simulation environment, though there are still many difficulties associated with defining alternative reference points. Part of the problem lies in the actual definition given that predation mortality, growth etc. are no longer constant, and part of the problem lies in the substantial increase in dimensionality of the problem.

With regard to the non-constancy of life history parameters, one option would be to estimate bounds for reference points by considering 'worst case' scenarios, for example, using highest historic predation mortality. However, this may lead to unrealistically restrictive reference points.

The increase in dimensionality could be approached by, for example, grouping together species taken together in a fishery. This may, however, imply that advice from the multispecies model can only be given in terms of the species group rather than the individual species, and this may be inadequate from a management point of view. It is important to note that reference points are only useful if they relate to measurable (estimable) quantities (e.g. SSB, F), and to parameters, which can, at least in theory, be controlled (e.g. F).

There may be cases where multispecies considerations are in the context of safeguarding food for dependent predators, which may or may not be harvested themselves. Providing 'reference point' advice on this issue is essentially different from providing reference point advice with regard to a harvested stock. Such issues are not the primary focus of this SG, and should be considered on a case by case basis.

There are also unexploited fish stocks (predators or prey) in the ecosystem. It would currently not be possible to give advice on suitable reference points for these stocks. F reference points are meaningless for unexploited stocks, and meaningful biomass reference points can only be defined given an objective, and the assumption that SSB can be estimated. Even in future therefore, it may not be possible to give advice on reference points for unexploited stocks in the ecosystem.

Despite attempting to distance the exploration of BRPs from any fishery objectives, one objective is implicit throughout; that all fisheries continue and remain viable. It may transpire that the rebuilding of certain predator stocks beyond the limit reference point renders some prey stocks so small that the fisheries on them would no longer be commercially viable as indeed may have been the pre-exploitation case. This primary objective may therefore prove impossible in some cases and we must accept that the presence of some stocks in modern fisheries may simply be an artefact of human intervention: one must be prepared to lose them!

When evaluating the suitability and reliability of SSRPs in a MS context, particularly in long term scenarios, we may be forced to consider upper limits on biomass for predators in order to safeguard prey species. This consideration is unlikely to affect short term predictions, but has implications for setting a "value" for particular stocks. This requires input from the stakeholders and should preferably not be left to scientists.

6 RECOMMENDATIONS

In order to facilitate future development of multispecies assessment models, length age distributions of quarterly catch data should be routinely stored in the IFAP data base.

[Rationale: Predation is a length- rather than age-based process. Consequently, models of species interaction that make direct use of the length compositions of stomach contents and of the catches are biologically more sensible, while they also require less parameters. The development of a new generation of multispecies models, which allow a full range of statistical analyses, which can deal with length-age distributions and which may adapted to the North Sea in the future, might be used more effectively, if length-age compositions are stored in the ICES data base. Such information could also be used directly in single species assessment to resolve uncertainties related to mean weights at age and to the use of age-length keys.]

A detailed analysis should be made of changes in growth and maturation of all MSVPA species in order to relate these to possible effects of prey availability, density dependence and environmental factors.

[Rationale: The multispecies forecasts are based on a top-down approach, which do not take into account limitations on production that may be caused by prey availability. Including growth constraints, if evidence for these can be derived from empirical survey data (as exemplified for Baltic cod), would enhance biological realism of these models. The research proposed does not include the incorporation in the forecast models as yet. Nevertheless, it will require a major research effort that will depend on the possibility of external funding.]

The Study Group meet for 5 days in early December 2000 (Chair: ??) in Mallorca, Lowestoft, IJmuiden (?) to:

- evaluate the effect of applying single species reference points from a multispecies point of view, with particular reference to limit and precautionary reference points as presently advocated for the North Sea and Baltic fish stocks;
- review progress made intersessionally with regard to support studies for aspects to be incorporated in multispecies models.

[Rationale: In the multispecies context, single species reference points do not exist as such, but are replaced by multidimensional surfaces, where the actual value for a species depends on the human impacts on other components of the system. We propose to evaluate by simulation whether precautionary reference points based on single species

considerations may be expected to lead to increased probabilities of exceeding limit reference points when applied in a multispecies model]

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8 LIST OF WORKING DOCUMENTS

WD-1: S. A. Adlerstein – Feeding ecology of North Sea fish with emphasis on the data base of the stomach sampling project 1991 for use in multispecies assessment – an executive summary.

WD-2: S. A. Adlerstein *et al.* - Current and future multispecies-related research topics in Hamburg

WD-3: H. Dobby – Robustness of multispecies fisheries modelling using a length based approach to predation.

WD-4: D. E. Duplisea & M. V. Bravington – Harvesting a size-structured ecosystem. ICES CM 1999/Z:01.

WD-5: H. Gislason –Single and multispecies reference points for Baltic fish stocks. ICES Journal of Marine Science, in press.

WD-6: F.-W. Köster - ICES Study Group on Multispecies Model implementation in the Baltic – summary of report on meeting 2–8 December 1998.

WD-7: S. Tjelmeland - Biological reference points and harvesting control in the Barents Sea - a discussion role.

WD-8: M. Vinther & H. Gislason – Draft ms: Stomach contents of saithe (*Pollachius virens* L.) in the North Sea during the period 1980–1991.