Multispecies Models Relevant to Management of Living Resources

Preface

Scientific quality is undoubtedly the most important aspect of a contribution to a symposium, but the value of a contribution is also greatly heightened by a vivid and stirring presentation, and the discussion it stimulates. In order to underline the importance of the latter in communicating scientific results, it was decided to give awards for the "best presentations". On the basis of a plenary vote, the awards were presented to H. Gislason (paper) and to M. Tasker, R. Furness, M. Harris, and R. S. Bailey (poster) for their excellent use of audiovisual aids.

**The ICES Multispecies Assessment Working Group: evolution, insights, and future problems**

J. G. Pope


An overview of the work of the ICES Multispecies Assessment Working Group is presented. This Working Group has been a powerful engine for developing practical multispecies assessment methods in the ICES area. Methods for multispecies virtual population analysis (MSVPA) have been developed and implemented in such a way as to utilize the available data sets. The results of these analyses have caused a profound rethinking of our picture of the North Sea, with predation mortality emerging as a major factor. Prospective models have also been developed which attempt to predict the future behaviour of the system under changing exploitation patterns. These predictions produce results which contradict single-species assessment and indicate that long-term advice has to be based upon multispecies models. Sensitivity analysis of such models indicates that recruitment is a major determinant of these predictions. This suggests that multispecies effects need to be investigated from early life history stages onwards. MSVPA techniques do not seem appropriate for these investigations and fresh modelling initiatives need to be considered. A further area needing urgent modelling investigations is concerned with the interactions between fisheries. These determine the feasible directions of change in exploitation patterns and thus indicate how and in which directions the exploitation of the system can be modified.

**Introduction**

The possibility of multispecies effects on the life history parameters of fish were considered by Beverton and Holt (1957). However, in practice for the next twenty years their models were applied assuming that such effects were constant from year to year. This assumption was questioned by the studies of cod stomachs conducted by Daan (1973) and by the pioneering modelling work of Andersen and Ursin (1977). In particular, they suggested that natural mortality would be influenced by predator stock sizes. Two papers presented to the ICES statutory meeting in 1979 (Helgason and Gislason, 1979; Pope, 1979) and also a paper by Sparre (1980) suggested that the estimation of natural mortality could be achieved by using algorithms for the simultaneous solution of virtual population analysis (VPA) for more than one stock. This led to the setting up of the ICES Ad hoc Working Group on Multispecies Assessment Model Testing in 1980 (Anon., 1980). This WG appointed coordinators for an extensive international stomach sampling programme in 1981 for the predators cod, whiting, saithe, mackerel, and haddock (Daan ed., 1989). The coordinators reported to the 1983 and 1984 ICES statutory meetings (Daan, 1983; Anon., 1984a). This in turn led to the setting up of the Ad hoc Multispecies Assessment Working Group, which first met in 1984 (Anon., 1984b). This paper reviews the progress and the main achievements and insights of this WG and attempts to suggest important areas of work for its future programme.

**Progress in multispecies assessment**

The WG first met in 1984 with subsequent meetings in 1985, 1986, 1988, and 1989 (Anon., 1984b, 1986a, 1987, 1988a, 1989a). These meetings focussed on applying the multispecies VPA model (MSVPA) to the data collected by the species coordinators of the 1981 stomach sampling programme and on applying the results to provide management advice for the North Sea fish stocks. In addition, the group has tried to keep abreast of multispecies developments in other areas of the North Atlantic, particularly the Barents Sea, Iceland, and Newfoundland where the problems are somewhat different from...

The 1984 meeting

During its first meeting, the WG concentrated on the task of producing the first runs of MSVPA based upon the 1981 feeding data. Suitable computer programs, including a method for tuning suitability estimates to stomach content data, were developed by P. Sparre of the Danish Charlottenlund Laboratory (Sparre, 1984). To run the programs necessarily required the creation of a number of new databases, in particular the stomach content database, estimates of feeding levels, estimates of other natural mortality, and a database of quarterly catch-at-age data. A fundamental problem identified during the meeting was that different ages and species of predators were eating different sizes of particular prey ages. This problem results from the lack of a size within age dimension in the model. For example, the ingestion weights of one-year-old sandeel found in the stomachs of one-year-old cod were 94% of the average weight in the sea, while the ingestion weights of the same prey age group in stomachs of five-year-old cod were 116% of the weight in the sea. For whiting the equivalent change was from 33% to 180%. Clearly, the model had to be modified to take this feature of prey selection into account. This was eventually achieved by using a predator-species and age-specific prey weight in the stomach in the formulation, rather than a general average weight-at-age of prey in the sea. There was heated discussion about the validity of this approach and it took some rather hard thinking and arguing to resolve the approach to everyone’s reasonable satisfaction.

In setting up the databases there was still considerable uncertainty about the appropriate food selection model to use, and about the correct levels of some of the inputs, particularly the age-specific feeding levels of predators and the level of other natural mortality (M1) to be used. A first attempt at a sensitivity analysis of the MSVPA results indicated that these were sensitive to these inputs in the ways which might perhaps have been predicted. For example, lower feeding levels reduced predation mortality estimates but not by the full proportional amount. Lower M1 values reduced fishing mortality estimates while having little impact on predation mortality estimates. Table 1 shows the effect of input changes to the estimates of average predation mortality of haddock.

<table>
<thead>
<tr>
<th>Age</th>
<th>Key-run</th>
<th>Feeding level halved</th>
<th>M1 level halved</th>
</tr>
</thead>
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<tr>
<td>0</td>
<td>1.45</td>
<td>1.08</td>
<td>1.50</td>
</tr>
<tr>
<td>1</td>
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<td>0.02</td>
<td>0.05</td>
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<td>0.02</td>
<td>0.05</td>
</tr>
<tr>
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</tr>
<tr>
<td>6+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Short-term effects of adopting a multispecies assessment approach were investigated by regressing MSVPA recruitment results against the equivalent results from single species assessments. Although the multispecies recruitment indices were larger, they correlated well with the single species results and thus would probably not affect the calculation of short-term management advice such as Total Allowable Catches (TACs). Figure 1 illustrates the similarity of single and multispecies recruitment estimates using cod data as an example. A regression of this log/log plot gives a highly significant association ($r = 0.98$; d.f. = 13) with a slope which is near to unity. The single species and multispecies results would thus appear to vary in proportion to one another.

Due to pressure of time, it was not possible to quantify the effects of multispecies interactions on long-term yield. However, the quite difficult problem of how to present such results was considered. The approach recommended was to approximate the gradient of the yield surface for each species for each of a number of fishing fleets. This was to be achieved by considering the effects of an increase of 10% in each of the fishing fleets in turn on the yield of each species by each fleet. This might be thought of as akin to the Jacobian matrix ($J(f,s,g)$).

$$J(f,s,g) = \frac{\partial Y(f,s)}{\partial E(g)}$$

where $Y(f,s)$ is the yield of species $s$ obtained by fleet $f$ and $E(g)$ is the effort of fleet $g$. The resulting matrix of the changes in yield caused by 10% changes in effort of

![Figure 1](image-url)
particular fleets is often referred to as the Jacobian matrix, though in fact it is strictly J(f,s,g)/10.

A further problem initially addressed at this meeting was that of the uniqueness of MSVPA. This had been previously subject to investigations by Dekker (1982) and by Magnus and Magnusson (1983). The latter authors provide mathematically “sufficient” conditions for the results of MSVPA to be unique. So far no one has provided the mathematical “necessary” conditions for uniqueness.

The 1985 meeting

The 1985 meeting of the WG saw a number of technical improvements in the MSVPA computer program (Sparre and Gislason, 1985) and a narrowing down of the assumptions made about feeding. Particularly interesting, however, was an investigation started in this WG but continued in the WG on Methods of Fish Stock Assessment (Anon., 1986b). This concerned the question of whether short-term TAC advice was invariant under changes in the average level of natural mortality used in single species VPAs. This was important because there was a fear that the changing estimates of natural mortality obtained from MSVPA, as its use matured, might cause large and systematic variations in TAC estimates. Some theoretical considerations (Pope, 1983) suggested that this would not be the case, but some actual calculations based upon the work of the North Sea Roundfish WG (Anon., 1985) suggested that there could be problems for some stocks. The WG on Methods of Fish Stock Assessment managed to resolve these difficulties by pointing out that the discrepancies occurred because of the way in which estimates of the recruiting age groups were introduced into single species forecasts. This result, coupled with the finding that MSVPA estimates of recruitment were closely correlated with the single-species estimates, led to the more general conclusion that there was no particular need to take multispecies effects into account (except by adjusting average natural mortality rates) when short-term advice was provided. Such advice could therefore continue to be provided by the single-species working groups.

The other main development in 1985 was the first calculation of the Jacobian matrix of long-term yield, indicating that long-term yield estimates calculated by a simple method (Shepherd, 1984) were generally at variance with yield estimated under single-species assumptions. This difference is discussed further in a later section of this paper.

An integral part of the long-term analysis was calculation of smoothed values of predation mortality (M2) per unit biomass and of the suitability coefficient. These smoothed values provided a means of summarizing some of the more detailed internal results of MSVPA and also a quality check on particular input data. The approach of fitting an Ursin (1973) lognormal feeding curve was to become of considerable importance to future meetings. The paper by Rice et al. (1991) provides an up-to-date review of this work. The WG summarized the biological results into tables of “who eats who” and also considered the variance of stomach content data.

The 1986 meeting

In 1986, the WG continued to build on the work of previous years. Of particular importance were some fresh insights on the subject of M1 calculations. Previously, values of M1 had been based upon conventional levels suggested by the single species working groups, but a working paper (Sparholt, 1986) suggested how estimates might be improved by considering the predation caused by other predatory fish in the North Sea and by birds and mammals. These latter calculations were assisted by inputs on birds from Bailey (1986) and on seals from Prime and Hammond (1986).

The results on short-term yield effects from the previous meeting were confirmed.

Results on long-term yield were derived from two different model methods, proposed by Shepherd (1984) and Sparre (1986), respectively. The results exhibited similar proportional changes in yield but rather different long-term status quo steady state yields. This difference could not be resolved at the time and was held over for the next meeting.

A major initiative was the consideration of the sensitivity of long-term yield to assumptions about recruitment and ration size. Results are shown in Figure 2a and b. Typically, recruitment of a species emerged as the input to which the long-term yield of that species was most sensitive. This was usually followed by the recruitment of other prey species. Relative sensitivities of species to their own recruitment were less than unity for cod, whiting, and haddock suggesting that cannibalism had a buffering effect. In contrast, sensitivities were greater than unity for the small prey species (sprat, Norway pout, and sandeel), suggesting these species might be able to saturate the predators. The other factors had little effect on any species except herring, but the herring results appear to be anomalous and probably the data have been corrupted. Results for herring should therefore not be taken seriously.

The 1988 meeting

At the 1988 meeting, the additional stomach data collected in the first and third quarters of 1985, 1986, and 1987 for some of the predator species became available. These were incorporated into the database and the program was modified to utilize extra data sets (Gislason and Sparre, 1987). This enabled a study of the extent to which suitability remains constant from year to year. The tentative conclusion reached was that suitability
Recruitment increased by 1%

Input parameters increased by 1%

Figure 2. Relative sensitivity of the long-term yield of North Sea species to recruitment and feeding assumptions. (a) Recruitment. (b) Ration size as well as some other parameters (highlighted cells indicate within-species effects).

varied a little from year to year but not by very much. To some extent the changes in suitability could be accounted for by changes in the relative biomass of prey species. The changes identified were consistent with a reaction to the increased abundance of herring in 1985–1987 compared to 1981 when herring was at very low levels. However, a definitive study was hampered by the new stomach data only being available for certain quarters for certain species. With the wisdom of hindsight, a repeat of the complete 1981 study in say 1986 might have been a better choice, since this would have allowed completely independent estimates of suitability for all species and quarters.

On the subject of long-term yield, the difference between the predictions given by the Shepherd model and the Sparre MSFOR model could be resolved by modifying the Shepherd model to take unsmoothed estimates of M2s. This modification gave substantially the same results with both models and indicated that the differences noted in 1986 were due rather to the use of smoothed or unsmoothed M2s than to differences in the feeding models adopted. The problem seems to be that, while the unsmoothed data will undoubtedly contain extra variance due to the sampling error inherent in stomach content investigations, the current methods for smoothing of M2s introduced quite serious biases. In particular, they appeared to spread M2 over more prey ages than had been observed in the predator stomachs.
Both the Sparre MSFOR model and the modified Shepherd model were used to calculate the effect of changing to a 120 mm mesh size in the roundfish fleet and the saithe fleet. The calculations suggested that increasing mesh size would tend to decrease both the yield and the value of the majority of species, a result contrary to the advice given by single-species assessments.

As always, the WG broke some new ground. In order to investigate the fleet structure of the North Sea fisheries, a Principal Component Analysis was run using the partial F structure of the various nations’ fisheries. Finally, to encourage the work being conducted on Boreal systems, it was proposed to hold a special meeting of the WG on this topic in 1990.

The 1989 meeting
The 1989 meeting was called with the intention of extending the work on mesh assessments. In particular, the effect of increasing mesh size on only that part of the roundfish fishery dedicated to cod was investigated. The results were less extreme than those obtained in 1988 but showed a similar divergence from the results of single species mesh assessments.

In addition, the work on the comparison of suitabilities began in 1988 was extended. The conclusion that suitability varied little between years was sustained.

Several new initiatives were taken. One was to try to work the multispecies assessment back before 1974. Estimates of cod, whiting, saithe, haddock, and mackerel year classes were projected back to 1963 (see Pope and Macer, 1991, for detailed results). Attempts to find approximate formulae to fit the yield surfaces were also initiated. The size distribution of the North Sea system was investigated, following Pope et al. (1988), who compared the size compositions of the fish in the North Sea and on Georges Bank and showed that these can be considered as conservative properties of the two systems. Figure 3 compares empirical survey data (Pope et al., 1988) with size compositions estimated from MSVPA, indicating that the slopes in both data sets are very similar.

Major insights
The most important insight gained from the work of the Multispecies Assessment WG is that, after accounting for inter- and intraspecific predation mortality, natural mortality rates are much higher than previously estimated and are variable from year to year. Figure 4 shows the average level of predation mortality rate for each of the seven prey species in the model, while Figure 5 illustrates the variability in predation mortality rate for haddock. The higher levels of natural mortality mean that the numbers of juvenile fish in the North Sea had
Figure 4. Average levels of predation mortality for each of the seven prey species in the MSVPA model.

Figure 5. Variability of predation mortality by age and year for haddock as estimated by MSVPA.
previously been underestimated. The variability implied that single-species and multispecies estimates of recruitment might not correlate very well. However, in practice this does not seem to be the case, at least in the period since 1974 (cf. Fig. 1). It is possible that divergence might be greater before that date if natural mortality rates were systematically higher in the earlier period (Pope and Macer, 1991).

The higher and variable levels of natural mortality have serious implications for the yield of the multispecies system. Single species models predict increases in long-term yield if effort is decreased in the roundfish (cod, haddock, and whiting) and saithe fisheries or if mesh sizes are increased in these fisheries. Multispecies models predict the opposite. Figures 6a and b taken from (Anon., 1988) illustrate these findings for mesh
changes in the roundfish and saithe fleet according to single-species and multispecies predictions, respectively.

It should be carefully noted that these differences come about not because the multispecies natural mortality rates are high but because they vary with predator density and hence increase if management measures generate higher stocks of predators such as cod, whiting, and saithe. In fact, the comparable single-species models were generated using average levels of natural mortality derived from MSVPA. This difference between single and multispecies models is mainly important in the case of long-term yield. In the short term, the yield will be much the same whether calculated on a single or multispecies basis. The reason for this is that in short-term yield calculation values are used to convert catch estimates into current population sizes using VPA. They are also used for converting the population estimates into future catches using prediction programs. The values of natural mortality rate tend to cancel out in these calculations provided they are approximately constant through time. It is possible, however, that systematic shifts in the level of predation mortality might cause differences, particularly in the estimates of recruitment used.

The North Sea haddock illustrates this problem. Figure 7 shows the ratios of multispecies estimates of recruitment and the equivalent single-species recruitment. Natural mortality rates on one-year-old fish have increased in some recent years and this has caused a change in the relationship between single and multispecies estimates of recruitment, particularly for the 1984, 1985, and possibly the 1987 year classes.

Finally, the multispecies model has given fresh insights into the total fish biomass of the North Sea and how much is taken each year by fishing and how much by predation by fish. The various WG reports describe "who eats who" by predator. Figure 8 shows a composite of these to express how much of the biomass is eaten and how much is caught each year. Clearly, the North Sea is a system with a very high turnover rate and predatory fish are very important as competitors to man.

The future of multispecies models
Within North Sea multispecies modelling studies, there is a continuous tension between the need to increase realism by adding details and the need to increase comprehensibility by using simplifying assumptions. To some extent extended models may need developing even if the result is only to show that their effects are relatively unimportant. Incorporation of additional predators and of an area-based stock option for species such as the sandeel and mackerel would seem desirable and obvious extensions to the existing model. Other complications, such as area and size-based models, may need development in order to answer specific management questions, such as the effect of closed areas. For the North Sea, such models may well be derived from collaboration between the Multispecies Assessment WG and the WG on Technical Measures of the Scientific and Technical Committee for Fisheries (STCF) of the EC (Anon., 1988c). The latter WG is collecting detailed information on the spatial distribution of catch and effort of different national fleets which, combined with results from the multispecies assessments, could lead to
Figure 8. Total biomass of the nine species of fish in the North Sea model together with estimates of consumption and catch given on an annual basis.

an area-based description including predation effects, migration, and fishing. At present this would seem rather a large job but stomach samples were originally collected in an area-specific fashion and the STCF WG is trying to provide similar information for catch-at-age data. If the long-term effects of area closures or any other technical measure are to be correctly estimated, then undoubtedly species interaction effects must be taken into account, because the results obtained so far indicate that omitting these is likely to produce misleading results.

One possible way an area-based multispecies model might be developed would be to revive a proposal of Gislason and Sparre (1967) for including geographical effects in the estimation of suitability (see also section 6.7.2 of Anon., 1986a). This proposal suggested that it should be possible to estimate the consumption by subarea of the North Sea using geographically disaggregated stomach content data and survey based descriptions of the proportion of the stocks of predators and prey species in each subarea. This option is becoming more possible in recent years with the wider availability and standardization of trawl surveys (e.g. Anon., 1989b). There would, however, still be problems with the spatial distribution of some prey species such as sandeels, which are not adequately represented in trawl samples. Ms S. Singh (pers. comm.) suggests a possible way around this by making an analysis of variance of the log stomach content data of all predator species at once. The analysis includes predator × prey interactions and prey × station interactions. These interaction terms correspond to the suitability of prey for individual predators and the local availability of prey, respectively. Such a multiplicative analysis of course contains an unknown aliasing effect between availability of prey and their suitability, which is to say that the same data could support the hypothesis that prey are abundant but unsuitable or vice versa. This aliasing can, however, be corrected for, providing estimates are available of the total North Sea population of the species. This approach could therefore provide a way of obtaining spatial distribution data for prey which are not covered by trawl surveys. The only problem would be that such distributional data would only become available for years in which stomach sampling was carried out and therefore the distribution patterns would have to be assumed constant for other years.

Given the technical possibilities for an area-based description of predation, appropriate models would obviously be valuable in studies of the effects of closed
areas in the North Sea. This approach would also be
valuable for exporting the North Sea results to other
areas, because the estimates of within subarea suitability
might be expected to be much less determined by the
taxographical overlap and far more by just size ratios and
ecological characteristics of predators and prey. These
latter components of suitability (Andersen and Ursin,
1977) are presumably less North Sea specific and might
be exported to other areas where they could be recombined
with overlap factors specific to those areas to provide overall suitability indices.

Simplications

One simplification considered in Anon. (1989a) was
fitting simple representations of the yield surface. Pope
(1989) suggested that quadratic yield or value surfaces
could be fitted using the Jacobian matrix results.
Alternatively, surfaces in the form of a multispecies Fox
model could be fitted. Fits of such surfaces provide a
simple basis for estimating multispecies equivalents to
the biological reference points MSY and F_{0,1}. In a
multispecies context, F_{0,1} can have two meanings. One is
the point on the surface where the gradient of the yield
of each fleet is 1/10 of that fleet's gradient at the origin.
The other concept is where the gradient of the overall
yield with respect to each fleet is 1/10 of its value at the
origin. Where a quadratic surface is fitted to the yield
surface, the calculation of these points can in principle
be achieved using simple linear algebra. In practice,
however, these often refer either to negative levels of
effort for some fleets or alternatively very high levels of
effort and associated negative populations of some
species. It is thus sometimes necessary to constrain
solutions within certain limits to obtain sensible
answers. Table 2 shows results from Anon. (1989a)
giving the effort changes in each fleet which would lead
to the biological reference points, provided the quadratic
surface was representative. Perhaps the most infor-
mative reference points are the fleet F_{0,1} values,
which for both yield and value are close to the status
quo. Assuming a linear relationship between cost and
effort and zero profit at the present level of effort, the
maximum economic yield (MEY) may also be estimated.
It suggests a reduction in the effort in the
roundfish and industrial fisheries while more or less
maintaining effort in the herring, saithe, and mackerel
fishing. Of course, these results are only valid if the
quadratic surfaces fit well to the model surface, in this
case MSFOR, and if MSFOR is a reasonable represen-
tation of the system. Assuming that the predictions of
MSFOR are the best currently available, this leaves the
fit of the quadratic surface in question. In practice the fit
is likely to break down at high values of effort, because
eventually the quadratic model must predict negative
yields and values. Clearly, this is not compatible with

Table 2. Relative effort changes required for reaching biological reference points and estimated yield, value, and profit according
to the quadratic multispecies yield (A) and value (B) surface.

<table>
<thead>
<tr>
<th>Fleet</th>
<th>MSY</th>
<th>Overall F_{0,1}</th>
<th>Fleet F_{0,1}</th>
<th>MEY</th>
<th>Status quo</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Roundfish</td>
<td>1.89</td>
<td>1.76</td>
<td>1.04</td>
<td>1.00</td>
<td></td>
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<tr>
<td>Ind. demersal</td>
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<td>1.40</td>
<td>1.11</td>
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</tr>
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<td>0.97</td>
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<td>1.00</td>
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<tr>
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<td>1.30</td>
<td>1.10</td>
<td>1.00</td>
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<td>1.75*</td>
<td>0.87</td>
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<tr>
<td>Mackerel</td>
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<td>2.00*</td>
<td>0.96</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Total yield*a</td>
<td>3949</td>
<td>3931</td>
<td>2821</td>
<td>2985</td>
<td></td>
</tr>
<tr>
<td>Total value*b</td>
<td>339</td>
<td>377</td>
<td>355</td>
<td>378</td>
<td></td>
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<tr>
<td>Total profit*b</td>
<td>-314</td>
<td>-240</td>
<td>-37</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roundfish</td>
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<td>0.59</td>
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<td>0.92</td>
<td>1.10</td>
<td>0.21</td>
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<td>3284</td>
<td>2744</td>
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<tr>
<td>Total value*b</td>
<td>469</td>
<td>468</td>
<td>349</td>
<td>319</td>
<td>378</td>
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<tr>
<td>Total profit*b</td>
<td>-28</td>
<td>-10</td>
<td>-13</td>
<td>94</td>
<td>0</td>
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</table>

*aTonnes \times 10^{-3}; bECU \times 10^{-6}; *Constrained.
MSFOR. The multispecies Fox model (cf. Fox, 1970) also seems to suffer from problems at high effort levels. Therefore, a differently formulated surface needs to be developed which is asymptotically more sensible than either the multispecies quadratic or the Fox surfaces. Such a development would be valuable for presenting the results of multispecies yield calculations, particularly when available in the format of a spreadsheet program which could be interrogated by advisory bodies or by management agencies.

Size compositions of total fish biomass form another possible approach to simplifying the description of multispecies systems (Fig. 3; Pope et al., 1988). Other simplifications worth consideration might include an adequate mathematical description of the suitability coefficients between predators and prey which would enable a less heavily parameterized model to be developed. However, the full advantages would only be gained if the mathematical formulation was unbiased.

Behind any desire to simplify or elaborate the model is the need to both describe and understand the system. Sensitivity analyses of the long-term yield identify recruitment as the most important input for calculating the long-term yield of the North Sea system. We therefore need to know the factors that influence recruitment, particularly those which are related to the abundance of the species in question as well as of other species in the system. For example, if the decline in herring really caused the gadoid outburst, then we must know how, if we are to make predictions for the future. Fortunately, while forward predictions are sensitive to assumptions about recruitment, MSVPA does not require any implicit assumptions and therefore MSVPA, or variants of it, can be used to study actual recruitment levels that occurred in the past. It has proved possible to back track the method further than the previous 1974 time horizon and with some more simplifications and robust assumptions based upon our new knowledge it may be possible to push our multispecies understanding of the North Sea back to the immediate postwar period. To do this, ways have to be found of incorporating rather coarser data than the catch-at-age data currently used. Possible sources might include survey data, total catch data, and catch per unit effort data. Inevitably, the answers will be less accurate but fortunately great precision in recruitment studies is not needed and estimating year-class strength to within a factor of 2 will probably suffice. Coupled with such an approach should be a modelling effort designed to discover what different states of the North Sea could exist given (a) our present knowledge of species interactions and (b) plausible assumptions about how recruitment is affected by spawning-stock size and by as yet unsolved species interactions in the early life phases (e.g. herring predation, Daan et al., 1985).

An alternative approach is to study multispecies interaction effects on the younger ages of fish. The forthcoming 1991 stomach sampling programme includes sampling of pelagic 0-group fish for stomach analysis in its aims and it seems quite probable that this will yield insights into further species interactions. To take advantage of this data source will require new approaches to modelling, since it is unlikely that MSVPA can be profitably extended down to this life stage.

Conclusions

The work in ICES on multispecies assessment conducted first by the ICES Ad hoc Working Group on Multispecies Assessment Model Testing (Anon., 1980) continued by the coordinators of the 1981 stomach sampling programme (Anon., 1984a) and extended by the ICES Multispecies Assessment Working Group (Anon., 1984b, 1986a, 1987, 1988a, 1989a) has changed our perception of how the North Sea should be assessed, how it works, and raises some profound questions about how it should be managed. This paper picks out some of these achievements, but it can only serve as a brief taste of this body of work. It is also very difficult to plot all the directions that such a wide study of the North Sea’s fisheries might lead to in the future although some obvious directions have been indicated.

It is imperative to stress the need for multispecies recruitment studies. The great achievement of the WG to date has been to show that interactions that were previously neglected in fish stock assessment were in fact rather more important than some interactions which were considered. We must be very careful to make sure that in the future we consider any other factors that are likely to affect the state of the North Sea system. Of these, multispecies effects on recruitment seem the most probable source of significant interactions which are as yet unquantified.

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