

REPORT OF THE
**Study Group on Multispecies Assessments
in the North Sea**

Bergen, Norway
25–29 August 2003

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1 INTRODUCTION

1.1 Participants

| | |
|--------------------------|----------------------|
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1.2 Terms of reference

The **Study Group on Multispecies Assessment in the North Sea [SGMSNS]** (Co-Chairs: M. Vinther, Denmark and J.K. Pinnegar, UK) met in Bergen, Norway from 25-29 August 2003 to:

- a) evaluate the effect of applying single-species reference points in a multispecies framework, with particular reference to limit and precautionary reference points as presently proposed by ICES in the North Sea;
- b) evaluate the single-species recovery plan for North Sea cod by taking into account biological interactions;
- c) review the data sources collated by SGGROMAT for the construction, by quarter, of historical stock lengths and weights-at-age for North Sea MSVPA species;
- d) review the developments in representing ecological linkages and management objectives within North Sea mass-balance tropho-dynamic models.

SGMSNS will report by 5 September 2003 for the attention of the Resource Management Committee and ACFM and ACE.

1.3 Scientific justification for the study group

The ICES Multispecies Assessment Working Group (MAWG) was disbanded in 1997 (ICES 1997a) because it was thought that there was no need for routine multispecies stock assessment and advice on fisheries management issues. Nevertheless, it has since been widely recognised that the development of viable long-term management strategies depends on a good understanding of species and fleet interactions, and recent ongoing requests for advice reflect the continued interest in this field.

This study group is tasked with producing an updated key-run of the North Sea MSVPA (Multispecies Virtual Population Analysis) and attempting to identify the future direction of multispecies work in the context of the North Sea.

The 2001 and 2002 meetings of the ICES Study Group on the Precautionary Approach to Fishery Management (ICES 2002a, 2003a) highlighted the possibility that multispecies interactions can cause problems for the use of precautionary reference points at both the lower and upper limits. For example, for a target species at low spawning stock biomass (SSB), high predation on early life history stages could add uncertainty to the determination of \mathbf{B}_{lim} , the relation between \mathbf{B}_{lim} and \mathbf{F}_{lim} , and the annual estimation of biomass and recruitment. When SSB of the target species is high, multispecies interactions could affect the selection and determination of target reference points and management targets such as \mathbf{F}_{MSY} and \mathbf{B}_{MSY} . Although it may not be possible to provide multispecies reference points *per se*, SGMSNS may be able to identify which interactions will cause most problems for limit reference points, and which choices and options for optimisation are most likely to be reasonable and robust.

1.4 Overview of the history of MSVPA

MSVPA has its origins in the North Sea model of Andersen and Ursin (1977). When this model was published it was criticised for containing too many inestimable parameters to be useful in fisheries management and it was therefore considered relevant to develop a simpler model more akin to the single-species models used by the ICES Stock Assessment Working Groups. Focussing on the predatory interactions between the commercially exploited fish stocks for which catch-at-age data were available and assuming constant, instead of food-dependent, individual food intake and growth it was possible to construct a multispecies model, MSVPA, with only three equations: the catch and stock number equations of the single-species VPA plus an equation describing how predation mortality, $M2$, depends on the biomass of the prey and the total food intake of the predator:

$$N_{i,t} = N_{i+1,t+1} \cdot e^{(F_{i,t,t+1} + M1_i + M2_{i,t,t+1})}$$

$$C_{i,t,t+1} = N_{i,t} \cdot \frac{F_{i,t,t+1}}{F_{i,t,t+1} + M1_i + M2_{i,t,t+1}} \cdot (1 - e^{-(F_{i,t,t+1} + M1_i + M2_{i,t,t+1})})$$

$$M2_{i,t,t+1} = \frac{\sum_{All\ predators} \frac{Food_j \cdot \bar{N}_{j,t,t+1} \cdot SUI_{i,j}}{SUIT_{o,j} \cdot B_o + \sum_{All\ MSVPA\ prey} SUI_{h,j} \cdot \bar{N}_{h,t} \cdot w_h}}{SUIT_{o,j} \cdot B_o + \sum_{All\ MSVPA\ prey} SUI_{h,j} \cdot \bar{N}_{h,t} \cdot w_h}$$

where

$N_{i,t}$: Number of prey species age group i at time t

$C_{i,t,t+1}$: Catch of prey species age group i between time t and $t + 1$

$M2_{i,t,t+1}$: Predation mortality of prey species age group i between time t and $t + 1$

$M1_i$: Other natural mortality of prey species age group i

$F_{i,t,t+1}$: Fishing mortality of prey species age group i between time t and $t + 1$

$Food_j$: Food intake mortality of prey species age group i between time t and $t + 1$

$SUI_{i,j}$: Suitability of prey species age group i to predation by predator species age group j

B_o : Biomass of other food

$\bar{N}_{j,t,t+1}$: Average population of species age group j in time interval between t and $t + 1$

w_h : Average weight of prey species age group h

Given fixed preference for specific foods (constant 'suitabilities'), food intake and average weights, the three equations can be used to provide estimates of fishing and predation mortality by iteration within a specific time interval. Once population numbers have been estimated for the years for which food composition data are available, revised estimates of suitability can be derived. These estimates can then be inserted into the MSVPA, and used to calculate new population numbers. This procedure is repeated until the suitabilities have converged. A comprehensive account of the mathematical aspects of MSVPA and the underlying assumptions of the model can be found in Magnusson (1995).

The idea of incorporating a model of predation mortality in the single-species VPA was initially put forward in two independent papers presented at the statutory meeting of ICES in 1979 (Helgason & Gislason 1979, Pope 1979). The presentations generated enough interest for ICES to convene an Ad Hoc Working Group on Multispecies Assessment Model Testing (ICES 1980). This Ad Hoc Working Group recommended that a stomach sampling programme should be established in the North Sea to provide the food composition and food intake data necessary to estimate the interaction terms in the MSVPA and, in particular, to test the underlying assumptions of the predation model. In 1981, approximately 60000 stomachs were collected from the five commercially exploited fish species (namely, cod, haddock, whiting, saithe and mackerel) assumed to be the major fish predators in the North Sea (Daan 1989). The stomach contents were analysed to provide estimates of the average food composition and total weight of stomach content by predator age, prey age and quarter and the results were given to the ICES Ad Hoc Working Group on

Multispecies Assessment who met in 1984 to perform the first quarterly North Sea MSVPA (ICES 1984). The ICES Ad Hoc Working Group on Multispecies Assessment used numerous meetings to refine the model, test a predictive version, the MSFOR model, and add additional food composition data. Fish stomachs were thus collected in 1985, 1986 and 1987 for some of the predators (but in quarters 1 and 3 only). In 1991, an additional year of food composition data was collected for all of the MSVPA predators as well as for a suite of other predators expected to prey on commercially important fish species (Hislop 1996). Today, the total food composition database for the North Sea now contains the results from analysing approximately 200,000 fish stomachs.

Over the period from 1984 to 1997, the ICES Multispecies Assessment Working Group (MAWG) performed sensitivity analyses of MSVPA and MSFOR. They examined the constant suitability assumption, the difference between single and multispecies long- and short-term predictions of effort and mesh changes, added additional other predators (grey gurnard, starry ray (*Raja radiata*), horse-mackerel, seabirds, Western stock mackerel, grey seals), developed alternative simpler models and tried to reduce the parameters of the model describing food selection. An overview of the most important results obtained during the 1980's is given in Pope (1991).

The major conclusion of the work is that natural mortality is much larger for the younger ages of species exploited for human consumption than previously assumed. MSVPA was found to be quite robust to changes in input parameters. A 10% change in an input parameter always produced a smaller change in the response variables (Finn *et al.* 1991). MSFOR predictions were found to be most sensitive to the assumed future recruitment. Suitability is reasonably constant over time (Rice *et al.* 1991), albeit with a tendency for predators to be more conservative in their diet choice than predicted by the model (negative switching; Larsen & Gislason 1992), but the MSVPA was able to provide reasonable predictions of the food composition in 1991 when only 1981 food compositions were used to estimate the predation parameters.

Most importantly, it was found that the long-term predictions of the MSFOR model differed significantly from single-species predictions. The conclusion was that the North Sea fisheries generally operate at a level of effort below F_{max} , a result very much at odds with single-species yield-per-recruit calculations in particular for the larger gadoids. Due to the high natural mortality of the younger age groups and to the increase in their predation mortality when the biomass of older fish (their predators) increase, attempts to protect young fish will not generally result in increased landings, under an assumption of constant recruitment. Mesh size increases in the roundfish fishery were found to result in comparatively smaller increases in the biomass of older fish than predicted by single-species models due to reductions in recruitment caused by increased predation of young fish. The relatively modest increases in the biomass of older fish were too small to compensate for the loss of small fish escaping through the meshes, resulting in an overall decrease in yield as mesh size increased. Generally speaking, the major conclusion of the multispecies work undertaken in the MAWG was that growth over-fishing is much less important than previously thought leaving recruitment over-fishing to be the main concern in routine fish stock assessment and management.

Outside the North Sea the MSVPA has been applied in the Baltic (e.g. Sparholt 1994, ICES 20003b), in the Barents Sea, and recently on Georges Bank (Tsou & Collie, 2001) and in the Berings Sea (Livingston & Jurado-Molina, 2000).

The MAWG was mostly concerned with biological interactions. However, from a management point of view technical interactions between fleets and species are also important. In 1989 and 1991 data on landings-at-age by fleet by ICES statistical rectangle were collected by the STCF working group and the availability of these data spurred the development of a new version of the MSVPA/MSFOR programs - the so-called 4M model (Vinther *et al.*, 2002) - in which the impact of technical interactions could be evaluated. Unfortunately, however, detailed data on the catch composition of the various North Sea fleets has not been made available since and the model has therefore not yet been used to its full potential. Apart from including technical interactions, the 4M model has much better features for data handling than the old MSVPA/MSFOR programs. It is possible to tune the terminal fishing mortalities to survey CPUE (catch-per-unit-effort) and effort time-series used by the single-species working groups applying the tuning packages (XSA, SXSA and ICA). Furthermore, the model provides possibilities for studying the effect of area closures.

1.5 Structure of the report

The terms of reference (ToRs) are addressed within four sections of this report. Specifically, ToR a) is addressed within Section 5, ToR b) is addressed within Sections 6, ToR c) is briefly discussed in Section 7, and ToR d) is addressed in Section 8.

In Section 2, two new developments in the 4M software are introduced, 4M-OPTIM and 4M-HCR. In Section 3, details of the revised set-up and input data for a so-called North Sea 4M key-run are presented. Section 4 presents the results of the North Sea 4M key-run in some detail. Other multispecies modelling approaches are discussed and in Section 9

and the response of WGBE and WGMME, to a request from WKMSNS to provide additional input data on seabirds and marine mammals is discussed in Section 10.

Future terms of reference for SGMSNS and recommendations are provided in section 12.

2 UPDATE AND REVISION OF 4M PROGRAM AND INPUT DATA

2.1 The 4M-package

The 4M package (Multispecies, Multi-fleet, Multi-area Model-package) (Vinther *et al.* 2002) was used to run MSVPA and MSFOR at this study group. The aim of 4M has been to create an integrated-software-system handling model input, the models, and analysis and presentation of output. Basically 4M combines the modules (MSVPA and MS-FORECAST) written in ANSI C with a SAS environment for data management, analysis and presentation.

No further development has been made within the 4M package since the Workshop on MSVPA, 2002 (ICES 2002b). However, two new features 4M-OPTIM and 4M-HCR use the 4M forecast as an external routine. The new programs have been developed using the R-language, which is a freeware available from the internet (<http://cran.r-project.org>).

2.1.1 4M –OPTIM, Objective functions and 4M forecasts

A routine, 4M-OPTIM (Working Document 3), estimates factors for scaling of *status quo* F, such that an objective function is minimized. The objective function focuses on biological reference points (e.g. B_{pa} and F_{pa}) and yield and consists of three weighted components for (1) biomass, (2) F reference points, and (3) yield. This gives the possibility to define scenarios in a multispecies (and Multi-fleet) environment with objectives such as “having all stock SSB above B_{pa} and maximize Yield” or “find an exploitation pattern on all species which results in the “best” recovery in cod biomass”.

2.1.2 4M-HCR, Harvest Control Rules and 4M forecasts

4M-HCR (Working Document 2) estimates annual factors for the scaling of *status quo* F which are consistent with the harvest control rules contained in the latest proposal from the European Commission for establishing measures for the recovery of the cod stock (Reg 2003/0090 (SNS)). The rules have been implemented in a generic way such that HCRs can be applied to any number of species. For each species, the target (e.g. for cod, 30% SSB increase per year, but limited to a plus/minus 15% annual TAC change) can be defined individually. More information is given in sections 6.

2.2 Catch data and population numbers

Both the stock areas and age-group ranges differ between the ICES single-species assessments and those used in the 1997 MSVPA key run. The differing set-ups, with respect to species age-groups, are shown in Table 2.1. Compared to the single-species assessment data, with the exception of Norway pout, the 1997 MSVPA key run has more age groups defined for each species. To facilitate the use of multispecies VPA tuning (Vinther 2001) and for direct comparison of the two catch-at-age data sets, the current MSVPA adhered to the single-species assessment data and procedures, wherever possible.

The initial set-up of the North Sea MSVPA included stocks within ICES Subarea IV. This spatial division was in accordance with the stock distribution area for most of the traditional single-species assessments at that time. However, the more recent single-species assessments for roundfish stocks, mackerel and herring refer to the stock in an extended area (see Table 2.1), such that the North Sea contributes only to a part of the stocks' total distribution area. The current MSVPA again applies to ICES area IV; data have been selected accordingly, by the subtraction of catches from areas outside of the North Sea.

The key run at the 1997 MAWG (ICES 1997) included data for the period 1974-1995. The 2002 key run extended the time-series up to 2000 and back to 1963. The time-series was further extended at the present meeting to include 2001 data, using the methods described in detail in last year's report (ICES 2002b).

2.2.1 Terminal fishing mortality

Estimation of terminal fishing mortalities for use in VPA and as *status quo* F for forecasting was carried out using multispecies tuning (Vinther, 2001). This procedure involves the interactive exchange of natural mortalities from the

MSVPA and terminal F from ICES tuning packages (XSA, ICA and SXSA) until convergence. The tuning used the same CPUE time-series and options as used by the single-species assessment WGs. However, TSA (Fryer, 2001) normally used for the whiting assessment has not been implemented in the 4M-tuning, and XSA was used instead.

When the single-species assessment does not include the 0-group (e.g. cod) or when there exists an improved estimate through updated assessment (e.g. herring year class 2001 updated in the 2003 assessment) the terminal F from tuning was corrected manually to fit an estimated stock number. The 2001 year class for each species was mainly based on a guesstimate taking into account the latest WG numbers from single-species assessments on the 0-group, if such exist. Where the 1-group is the recruiting age in an ICES assessment, the 2001 year class was estimated based on 1-group fish in 2002. Table 2.2 presents the methods for calculating the 2001 year class numbers. This method was applied for both the multispecies and single-species VPA, using the relevant time-series.

2.3 Stock recruitment relations used for forecast.

This year a revised key-run forecast was made in order to tackle TOR a) and b). The stock recruitment relations (Figure 2.1) used for forecasts were based on the full MSVPA time-series estimates, with a few data points excluded (Table 2.3), to obtain a maximum recruitment within the time-series. The arithmetic mean was used for haddock, Norway pout and sandeel due to the relatively poor fit of the Ricker curve for these species. Parameters were estimated separately from the relevant single- or multi- species VPA time-series.

2.4 Sensitivity analysis

In Working Document 1 analyses the assumption of constant food suitability is examined based on runs using stomach data sets from different periods (1981 or 1991). Below the main conclusions from this study are given. An extended account of the full working document is presented in section 13.

In this study it was demonstrated, that the assumption of time invariant suitability needs to be seriously reconsidered. Marked suitability changes were observed between 1981 and these changes may reflect differences in predator-prey spatial overlap during the two sampling periods. Whether the observed differences reflect inter-annual variability or a possible decadal trend can not be deduced from just two years of data. Both processes may influence the magnitude of annual consumption and mortality of fished species to an unknown extent. An additional effect from using different stomach data sets is related to differences in the amount of 'other food' eaten. High amounts of other food translate into lower predation mortalities and hence lower estimates of stock numbers for the VPA-species and vice versa. Pronounced fluctuations or trends in the abundance of relevant 'other food' populations may indirectly cause mortality fluctuations of VPA-species, which can not be considered in assessments or predictions. Again, with only two data sets the nature of such fluctuations can not be disentangled. The results from forecasts where future recruitment values were assumed to be known precisely (from independent source)s and therefore set to be identical in both runs (one with 1981 stomachs, one with 1991 stomachs) illustrate the potential magnitude of these effects. The absolute numbers presented however, should not be considered to reflect reality.

Routinely in 4M forecasts, recruitment values are taken from retrospective runs to keep the recruitment levels internally consistent with the F and M patterns applied. However, even with this procedure being applied, the use of a particular stomach data set, led in some cases to deviations in the predicted yield levels.

To resolve the demonstrated effects, investigations into variations of predator prey overlap as well as additional stomach sampling programs should be undertaken.

Table 2.1

Set-up of single- and multispecies assessment for the North Sea.

| | Single-species assessment 2001 | | MSVPA key run 1997, Data 1974-1995 | | MSVPA key run 2002, Data 1963-2000 | MSVPA key run 2003, Data 1963-2001 |
|---------------------|--------------------------------|---------------|------------------------------------|---------------|---|---|
| | ICES area | Age groups | Age groups | Predator/Prey | Remarks | Remarks |
| VPA species | | | | | | |
| Cod | IIIan, IV, VIId | 1-11+ | 0-11+ | Yes/Yes | Human consumption only | |
| Haddock | IIIa, IV | 0-10+ | 0-11+ | Yes/Yes | Human cons., industrial and discards | |
| Whiting | IV, VIId | 1- 8+ | 0-10+ | Yes/Yes | Human cons., industrial and discards | |
| Saithe | IIIa, IV, IV | 1-10+ | 0-15+ | Yes/(Yes) | includes IV and IIIa, not eaten | |
| North Sea Mackerel | no separate assessment | | 0-15+ | Yes/No | Moved to "other predators" new age group 0-6+ | |
| Herring | IV, IIIa, VIId * | 0-9+ | 0-9+ | No/Yes | | |
| Norway pout | IIIa, IV | 0-4+ | 0-3 | No/Yes | | |
| Sandeel | IV | 0-4+ | 0-4+ | No/Yes | | |
| Sprat | IV | biomass model | excluded | No/Yes | Included, age 0-4+ | |
| Plaice | IV | 1-15+ | 0-15+ | No/(Yes) | Not eaten | |
| Sole | IV | 1-15+ | 0-15+ | No/(Yes) | Not eaten | |
| Other predators | | | Size or age groups | | | |
| Grey gurnards | | | 0-3 | Yes | | Excluded |
| West mackerel | VI, VII, VIIIa,b,d,e | 1-15+ | 0-1 | Yes | | Diet, size class 1, 4 quarter set to "other food" |
| <i>Raja radiata</i> | | | 0-3 | Yes | Size 0 and 1 combined into one | |
| Grey seals | | | 1 | Yes | | |
| Horse Mackerel | | 0-15+ | excluded | | Included, size groups 1-3+ | |
| Sea birds | | | 1 | Yes | | |
| Other species | | | 1 | Yes | Excluded | |

Prey (Yes) indicates very low predation mortality

**Herring catch data include all autumn spawners in ICES areas IV, IIIa and VIId

Table 2.2

Fine-tuning of the 2001 year class

| Species | 2001 year class | Other year classes |
|----------------|----------------------------|--|
| Cod | 47% of average 1963- | |
| Haddock | From XSA | |
| Whiting | 94% of average 1980- | |
| Saithe | 76% of average 1967- | 1999 and 2000 year class as 80% of average 1967- |
| Herring | 200% of average 1963- | |
| Sprat | Average of last 5 years | |
| Sandeel | 80% of the 1996 year class | |
| Norway Pout | 80% of average 1974- | |
| Sole | 147% of average 1963- | |
| Plaice | 146% of average 1963- | |

Table 2.3

Recruitment used in forecasts (Ricker relation or Arithmetic Mean)

| Species | Recruitment | Omitted Years |
|----------------|--------------------|----------------------|
| Cod | Ricker | 1969 |
| Haddock | AM | |
| Whiting | Ricker | 1977-1980 |
| Saithe | Ricker | |
| Herring | Ricker | |
| Sprat | Ricker | 1973 and 1975 |
| Sandeel | AM | |
| Norway Pout | AM | |
| Sole | Ricker | |
| Plaice | Ricker | |

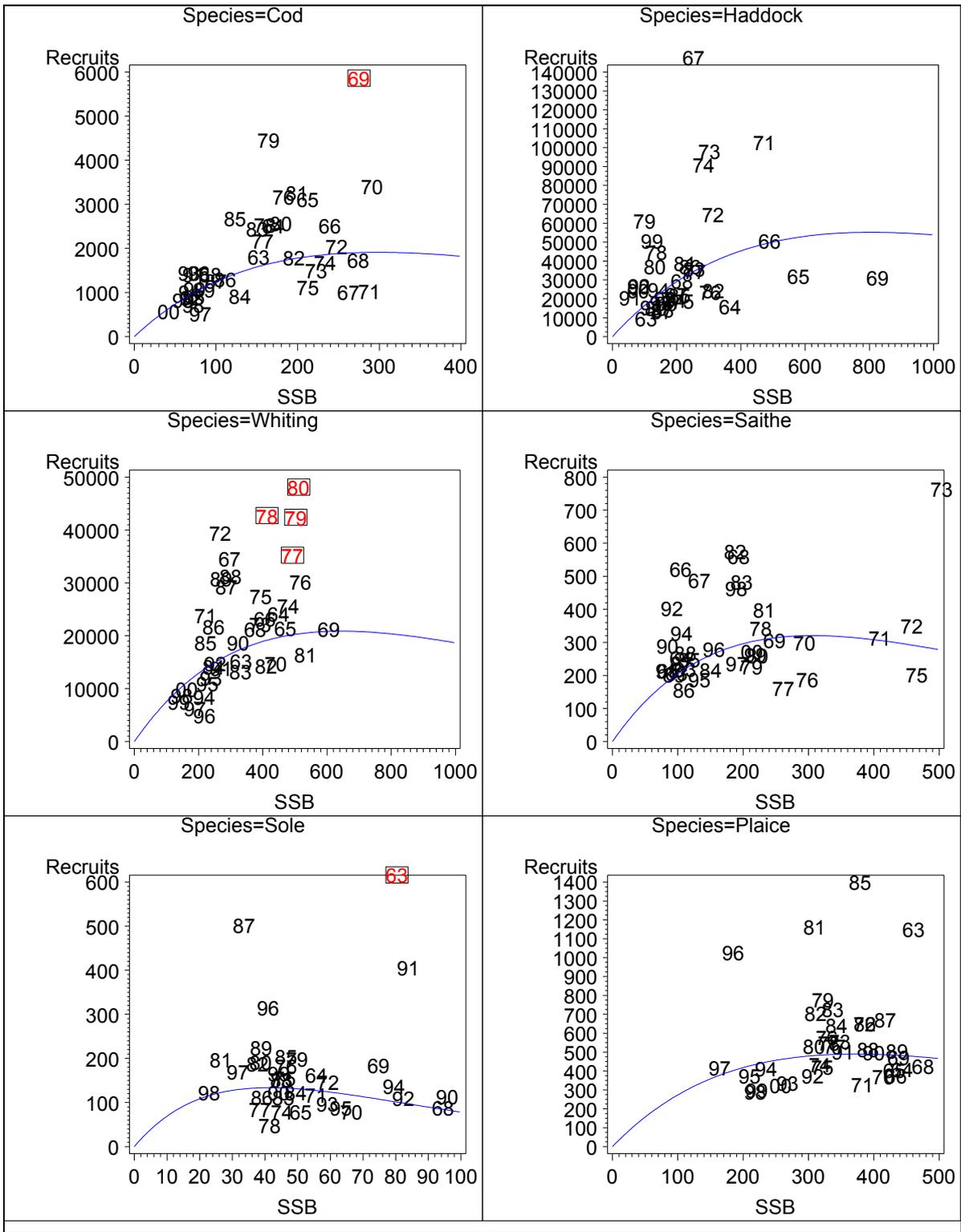


Figure 2.1 SSB-recruit estimates and fitted Ricker relation. (Data points in “boxes” are not used)

3 SET-UP FOR THE NORTH SEA KEY-RUN

MSVPA includes 10 fish species for which catch-at-age data are available (cod, whiting, saithe, haddock, herring, sprat, Norway pout, sandeel, plaice, and sole), and six other predators for which stock size at age or length are available (grey seals, North Sea mackerel, Western Mackerel, Starry Ray (*Raja radiata*), sea birds, and horse Mackerel). This year a revision of the number “other predators” was made and diet data for Western Mackerel was adjusted.

3.1 Exclusion of “other predator” grey gurnard

In MSVPA, stock numbers-at-age are generated as the amount needed to account for subsequent catches and consumption for the year class, taking the additional residual mortality into account. At the youngest ages, predation generally dominates the mortality, while the fishery takes over at the older ages.

According to the stomach contents data, up to 5% of the diet of grey gurnards came from 0-group cod in 1991. The MSVPA model assumptions lead to a type 2 functional response (Magnuson, 1995) which means that for a prey stock at low density a further decrease in the density will result in a relatively big increase in mortality. During the last 15 years, there has been a general decrease of the cod stock, and in combination with the increase in the gurnard stock, this leads to a very high mortality on the 0-group cod. As VPA works backward in time, the higher mortality of the 0-group will result in an apparently higher recruitment. Thus, one may get the impression that the cod recruitment at age 0 is a function of the amount of gurnards. This is illustrated in Figure 3.1. Estimated recruitment at age 0 is significantly and positively correlated with the abundance of gurnards (here represented as biomass). Figure 3.2 shows the biomass of grey gurnards as estimated for last year’s key-run (ICES 2002b) and Figure 3.3 shows the natural mortality of 0-group cod estimated from an MSVPA with and without grey gurnards included. Again, it is clear that the mortality is linked to the size of the grey gurnard stock.

Since in some cases important predator prey interactions originated from very low numbers of stomachs, an inspection of the 1991 stomach database was undertaken to consider the data background for the gurnard 0-group cod interaction. This analysis revealed a total of 20 ICES squares with 0-group cod in grey gurnard stomachs (in quarter 3), and this related to a total of 246 stomachs. Since the stomachs were pooled by length class the exact number of individuals preying on 0-group cod could not be estimated. A group of squares with higher amounts of 0-group cod were located in the area of the shelf breakfront in the Norwegian Trench, where 0-group cod are known to concentrate in the third quarter. The other squares with cod occurring in grey gurnard stomachs were scattered across round fish areas 1 to 3 (Figure 3.4). Due to the high numbers and the distribution patterns, it would seem that the grey gurnard 0-group cod interaction is based on sound data and an exclusion of these data can not be justified based on poor sampling.

If we believe the model, then gurnards appear to be the key to cod recovery. The estimated high recruitment of cod is not, however, confirmed from surveys. 0-group cod are in general poorly represented in third quarter surveys due to their small body size. Nevertheless there is no evidence of increasing cod recruitment from e.g. the English or Dutch ground fish surveys, illustrated in Figure 3.5.

Although gurnards appear to have an impact on the recruitment of cod, their actual quantitative influence is not well represented by the model and so the decision was made for the moment to exclude gurnards from the key-run. The cod recovery plan scenarios would not provide much information if in all scenarios cod disappear due to grey gurnard impact, therefore grey gurnards were likewise not included in any of these runs

3.2 Adjustment of the Western mackerel diet

The predicted consumption of large amounts of Norway pout by Western mackerel in the fourth quarter was considered by members of SGMSNS as being somewhat suspicious and therefore the original stomach database was investigated to determine the amount of data that actually supported this feeding interaction. The analysis revealed that this interaction was almost exclusively based on 18 stomachs from a single haul. 8 other stomachs from 3 ICES squares contained Norway pout in this quarter of 1991. Because of this very weak data, the interaction between Norway pout and Western mackerel (size class 1, quarter 4) was set to zero in the key run, as well as in all other scenario runs.

3.3 MSVPA options

The input data and their sources are as described in Section 2 of this report. Detailed input datasets are available at the ICES web server (www.ices.dk).

The MSVPA options (Table 3.1) are similar to previous years options (with the exception of exclusion of grey gurnards).

3.4 Forecast options

This year, both single and multispecies forecasts were made in order to tackle TOR a and b. The forecast includes the same species configuration as the VPA. Values for stock numbers, mean weight, proportion mature and M1 were taken from the most recent VPA data. The stock size in 2001 of “other predators” was assumed unchanged in the forecast. A three years average, 1999-2001, was used for the exploitation pattern and mean F and the age span for calculating mean F was the same as that used in the single-species WG. Recruitment of VPA species was generated as specified in Table 2.3.

Table 3.1 Options used in MSVPA

| | | |
|----------------------------|----------------|------------------------------|
| VPA mode | | = multi |
| Weight in stomach | | = use weight in the stomachs |
| Plus group | Cod | = Yes, ICES |
| Plus group | Whiting | = Yes, ICES |
| Plus group | Saithe | = Yes, ICES |
| Plus group | Haddock | = Yes, ICES |
| Plus group | Herring | = Yes, ICES |
| Plus group | Sprat | = Yes, ICES |
| Plus group | Norway pout | = no |
| Plus group | Sandeel | = Yes, ICES |
| Plus group | Plaice | = Yes, ICES |
| Plus group | Sole | = Yes, ICES |
| Food model | | = constant other food |
| Consum model | | = use fixed values |
| Include VPA species | Cod | = yes |
| Include VPA species | Whiting | = yes |
| Include VPA species | Saithe | = yes |
| Include VPA species | Haddock | = yes |
| Include VPA species | Herring | = yes |
| Include VPA species | Sprat | = yes |
| Include VPA species | Norway pout | = yes |
| Include VPA species | Sandeel | = yes |
| Include VPA species | Plaice | = yes |
| Include VPA species | Sole | = yes |
| Incl other predator | Grey Gurnards | = no |
| Incl other predator | Grey Seals | = yes |
| Incl other predator | NS. Mackerel | = yes |
| Incl other predator | Other species | = no |
| Incl other predator | Raja radiate | = yes |
| Incl other predator | Sea birds | = yes |
| Incl other predator | Horse Mackerel | = yes |
| Incl other predator | West Mackerel | = yes |
| Include as predator | Cod | = yes |
| Include as predator | Whiting | = yes |
| Include as predator | Saithe | = yes |
| Include as predator | Haddock | = yes |
| Include as predator | Grey Gurnards | = no |
| Include as predator | Grey Seals | = yes |
| Include as predator | Horse Mackerel | = yes |
| Include as predator | NS.Mackerel | = yes |
| Include as predator | Other species | = no |
| Include as predator | Raja radiata | = yes |
| Include as predator | Sea birds | = yes |
| Include as predator | West Mackerel | = yes |
| Include as prey | Cod | = yes |
| Include as prey | Whiting | = yes |
| Include as prey | Saithe | = no |
| Include as prey | Haddock | = yes |
| Include as prey | Herring | = yes |
| Include as prey | Sprat | = yes |
| Include as prey | Norway pout | = yes |
| Include as prey | Sandeel | = yes |
| Include as prey | Plaice | = no |
| Include as prey | Sole | = no |
| First and last VPA year | | = 1963 to 2001 |
| Year range stomach content | | = 1981 to 1996 |

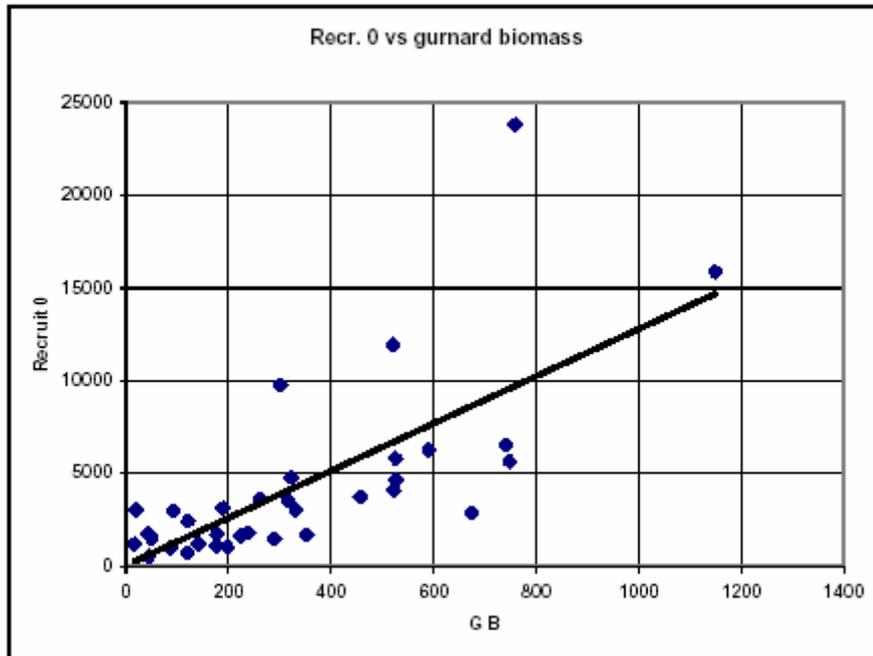


Figure 3.1 Relationship between recruitment of cod at age 0, (as estimated by MSVPA), and the amount of grey gurnards.

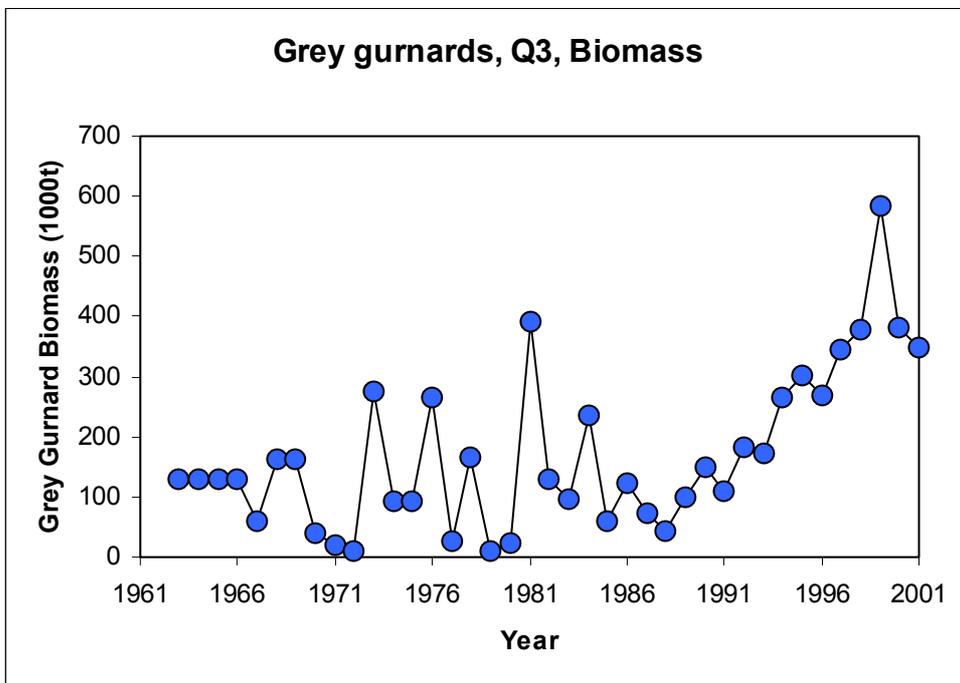
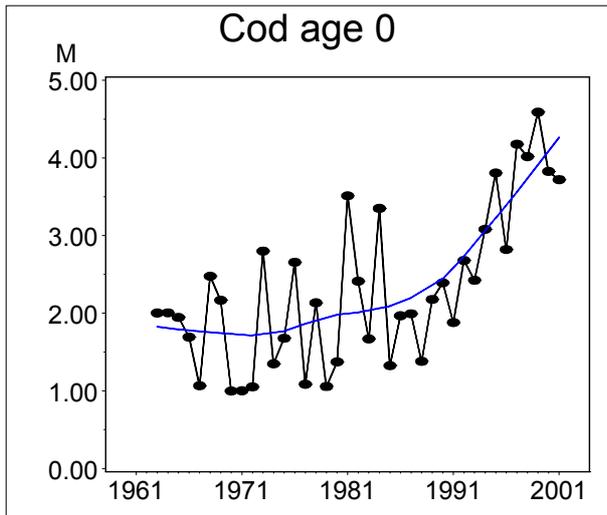


Figure 3.2 Biomass of grey gurnard as used in MSVPA.



Gurnard included as other predator

Gurnard excluded

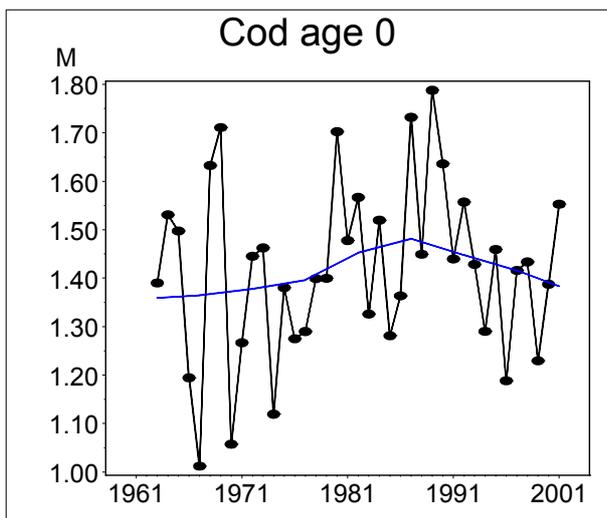


Figure 3.3 Natural mortality ($M1+M2$) of 0-group cod as estimated from MSVPA, with and without gurnards included.

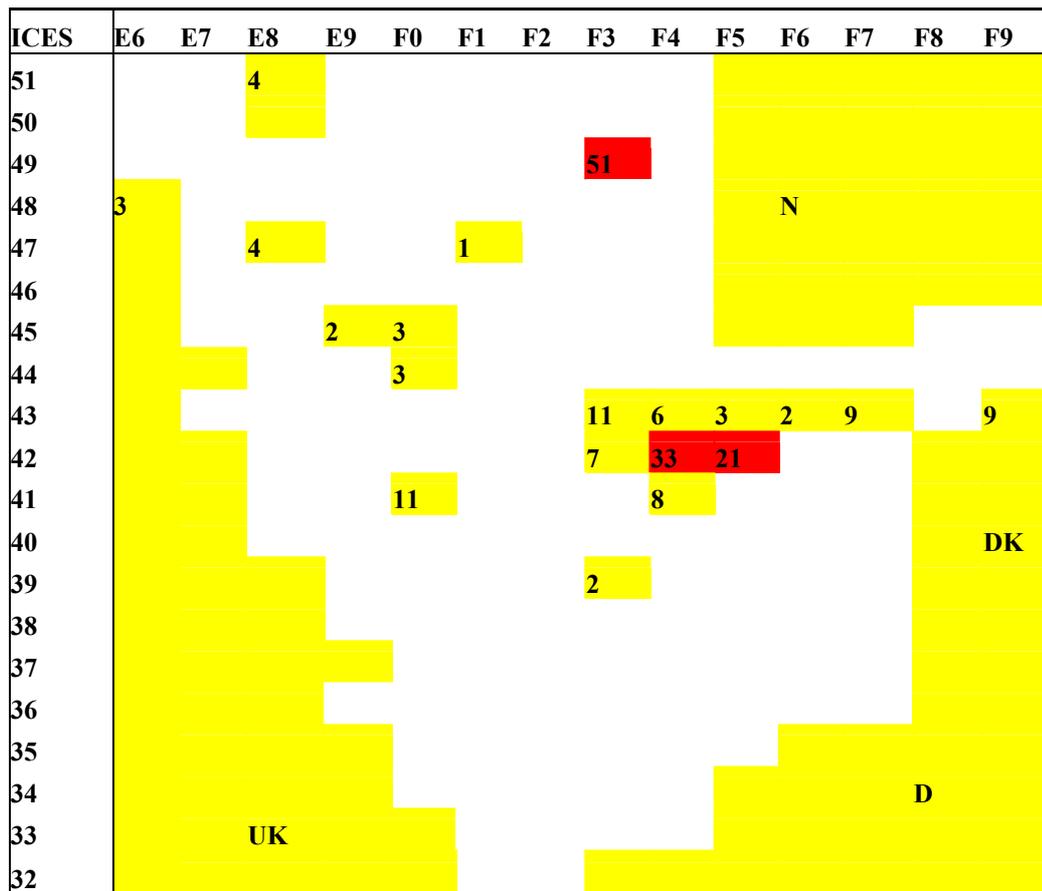


Figure 3.4 Distribution of gurnard stomachs with 0-group cod
 Numbers indicate the total weight (g) of 0-group cod in all grey gurnard stomachs sampled in an ICES square. Orange squares: weight < 15g, red squares: weight > 15 g

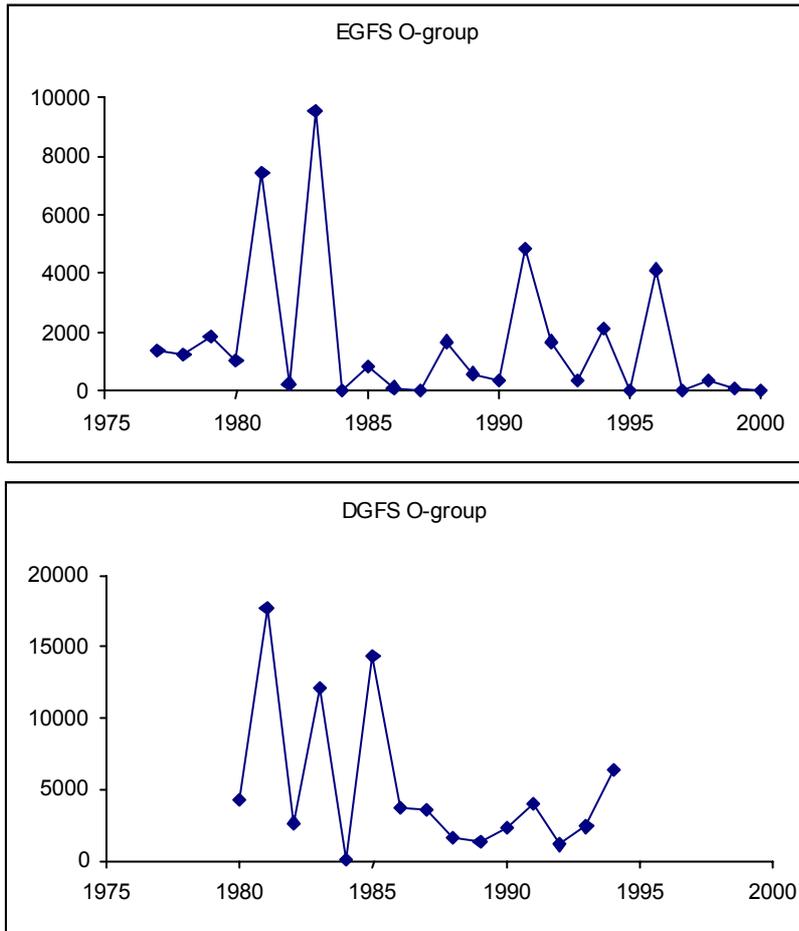


Figure 3.5 North Sea cod: 0-group survey data.

4 RESULTS AND DISCUSSION OF NORTH SEA KEY RUN

4.1 Key run output

Last year's MSVPA report (ICES 2002b) gave a detailed account of the output of the 2002 key-run. This year's presentation is focused on changes caused by the exclusion of grey gurnard and the adjustment of the western mackerel diet.

Detailed output datasets, as well as the input data, are available at the ICES web server (www.ices.dk). In this report an output summary by species is given in Table 4.1 and data are visualized in Figure 4.1. Natural mortalities at age are shown in Figure 4.2.

Compared to last year's key run, the exclusion of grey gurnard has considerably changed the recruitment at age 0 for cod, although the historical stock numbers-at-age 1 have only changed slightly. 0-group cod mortality is now much lower and fluctuates widely without the clear trend (Figure 4.2) that was observed last year. The mortality pattern for older cod is similar to last year's. As observed in the single-species assessment WG, cod mean F has increased and SSB decreased for the most recent years when compared with last year's assessment.

Gurnards predate also on 0-group whiting, and the gurnard exclusion has had a similar effect on whiting as is seen for cod. The 0-group mortality is now slightly lower and shows a downward trend, opposite to the upward trend observed in last year's key run. The same change in trend can be seen for the 1-group mortality, while the mortality of remaining age groups are quite similar for the two key-runs.

The adjustment of the western mackerel diet, in the fourth quarter of 1991, changed the diet from 73% 0-group Norway pout and 27% "other food" to 100% "other food". Due to the huge mackerel stock this has impacted the mortality of 0-group Norway pout significantly. There is now a highly fluctuating mortality without a trend for the period 1980 and onwards, while the previous key-run showed an upward trend, tracking the trend in mackerel biomass. The mortality pattern for the older Norway pout is similar to last year's key-run.

Saithe is the main predator on Norway pout and haddock. The reduced predation on Norway pout by mackerel in this key-run produced more Norway pout available for saithe. A consequence of this is that the predation on haddock by saithe has decreased slightly in the most recent years.

The patterns of natural mortality-at-age of herring, sprat and sandeel are very similar to last year's key-run.

Table 4.1 MSVPA output summary

Species Cod

| Year | Mean F Ages 2 to 8 | Recruits Age 0 1.July (millions) | Recruits Age 1 1.January (millions) | Yield ('000' t) | Stock Biomass 1.January ('000' t) | Spawning Stock Biomass 1.January ('000' t) | Eaten by model predators ('000' t) | Dead by other causes ('000' t) |
|------|--------------------------|---|--|---------------------|---|---|--|--|
| 1963 | 0.461 | 1448 | 168 | 99 | 315 | 152 | 31 | 52 |
| 1964 | 0.470 | 2163 | 379 | 110 | 372 | 170 | 49 | 62 |
| 1965 | 0.533 | 2765 | 501 | 162 | 478 | 212 | 72 | 76 |
| 1966 | 0.501 | 2157 | 664 | 196 | 588 | 239 | 90 | 92 |
| 1967 | 0.597 | 656 | 682 | 232 | 649 | 262 | 94 | 96 |
| 1968 | 0.601 | 1381 | 244 | 279 | 662 | 274 | 66 | 94 |
| 1969 | 0.561 | 5494 | 302 | 204 | 561 | 275 | 88 | 85 |
| 1970 | 0.538 | 3042 | 1156 | 226 | 570 | 291 | 114 | 89 |
| 1971 | 0.656 | 675 | 1114 | 320 | 680 | 288 | 111 | 97 |
| 1972 | 0.821 | 1684 | 203 | 371 | 696 | 247 | 73 | 89 |
| 1973 | 0.684 | 1147 | 421 | 251 | 528 | 222 | 61 | 73 |
| 1974 | 0.671 | 1320 | 288 | 202 | 455 | 233 | 50 | 67 |
| 1975 | 0.700 | 764 | 450 | 186 | 408 | 212 | 43 | 60 |
| 1976 | 0.682 | 2808 | 210 | 196 | 410 | 182 | 50 | 56 |
| 1977 | 0.700 | 1806 | 840 | 192 | 383 | 157 | 68 | 63 |
| 1978 | 0.779 | 2172 | 519 | 265 | 475 | 160 | 70 | 62 |
| 1979 | 0.671 | 4103 | 571 | 239 | 510 | 164 | 88 | 73 |
| 1980 | 0.770 | 2221 | 1074 | 265 | 515 | 179 | 96 | 76 |
| 1981 | 0.748 | 2904 | 436 | 311 | 604 | 199 | 95 | 77 |
| 1982 | 0.862 | 1436 | 708 | 281 | 504 | 195 | 70 | 63 |
| 1983 | 0.878 | 2092 | 330 | 247 | 404 | 150 | 56 | 52 |
| 1984 | 0.823 | 556 | 589 | 208 | 348 | 129 | 44 | 50 |
| 1985 | 0.805 | 2319 | 132 | 203 | 348 | 123 | 44 | 45 |
| 1986 | 0.853 | 944 | 653 | 192 | 282 | 111 | 45 | 43 |
| 1987 | 0.871 | 906 | 252 | 192 | 301 | 100 | 33 | 40 |
| 1988 | 0.873 | 1058 | 170 | 176 | 280 | 93 | 31 | 36 |
| 1989 | 0.928 | 697 | 253 | 122 | 203 | 85 | 24 | 27 |
| 1990 | 0.708 | 711 | 120 | 107 | 189 | 73 | 21 | 26 |
| 1991 | 0.871 | 1053 | 137 | 88 | 173 | 72 | 23 | 23 |
| 1992 | 0.789 | 533 | 251 | 88 | 172 | 69 | 22 | 25 |
| 1993 | 0.836 | 1094 | 117 | 104 | 196 | 67 | 25 | 27 |
| 1994 | 0.808 | 648 | 273 | 94 | 199 | 67 | 30 | 29 |
| 1995 | 0.670 | 549 | 187 | 121 | 221 | 72 | 28 | 32 |
| 1996 | 0.863 | 1090 | 137 | 106 | 225 | 78 | 35 | 33 |
| 1997 | 0.852 | 160 | 340 | 102 | 215 | 80 | 34 | 33 |
| 1998 | 0.941 | 356 | 40 | 122 | 223 | 72 | 25 | 29 |
| 1999 | 1.092 | 475 | 89 | 78 | 158 | 60 | 22 | 19 |
| 2000 | 1.177 | 224 | 143 | 59 | 101 | 42 | 13 | 14 |
| 2001 | 0.873 | 713 | 56 | 41 | 93 | 24 | 16 | 15 |
| Avg. | 0.757 | 1495 | 390 | 180 | 377 | 151 | 53 | 54 |

Table 4.1 MSVPA output summary (Cont'd)

Species Haddock

| Year | Mean F Ages 2 to 6 | Recruits Age 0 1.July (millions) | Recruits Age 1 1.January (millions) | Yield (('000' t) | Stock Biomass 1.January (('000' t) | Spawning Stock Biomass 1.January (('000' t) | Eaten by model predators (('000' t) | Dead by other causes (('000' t) |
|------|--------------------------|---|--|---------------------|---|---|--|--|
| 1963 | 0.725 | 963 | 11672 | 274 | 973 | 104 | 406 | 145 |
| 1964 | 0.899 | 7657 | 175 | 420 | 976 | 366 | 176 | 158 |
| 1965 | 0.832 | 23838 | 969 | 368 | 879 | 579 | 362 | 134 |
| 1966 | 0.890 | 42213 | 2748 | 458 | 775 | 490 | 614 | 111 |
| 1967 | 0.833 | 139406 | 5602 | 291 | 711 | 253 | 1878 | 189 |
| 1968 | 0.614 | 20950 | 30553 | 311 | 2585 | 217 | 1476 | 317 |
| 1969 | 1.130 | 22742 | 2728 | 1115 | 2390 | 825 | 647 | 333 |
| 1970 | 1.105 | 77247 | 1903 | 965 | 1660 | 1057 | 1037 | 220 |
| 1971 | 0.767 | 94539 | 12031 | 526 | 1548 | 473 | 1651 | 189 |
| 1972 | 1.059 | 56351 | 13770 | 409 | 1708 | 313 | 1396 | 158 |
| 1973 | 0.901 | 89869 | 5451 | 346 | 1058 | 302 | 1331 | 150 |
| 1974 | 0.868 | 82562 | 12001 | 371 | 1339 | 284 | 1614 | 172 |
| 1975 | 1.037 | 10622 | 14910 | 520 | 1448 | 220 | 907 | 161 |
| 1976 | 1.063 | 14948 | 1619 | 430 | 777 | 305 | 302 | 103 |
| 1977 | 1.063 | 26192 | 1552 | 250 | 479 | 256 | 395 | 64 |
| 1978 | 1.075 | 36340 | 2999 | 201 | 417 | 136 | 577 | 61 |
| 1979 | 1.065 | 52975 | 4024 | 171 | 481 | 99 | 814 | 79 |
| 1980 | 0.983 | 28572 | 7134 | 228 | 780 | 132 | 690 | 96 |
| 1981 | 0.724 | 30658 | 2305 | 221 | 654 | 226 | 518 | 93 |
| 1982 | 0.694 | 16033 | 3018 | 215 | 676 | 314 | 338 | 88 |
| 1983 | 0.961 | 27396 | 2008 | 230 | 536 | 254 | 414 | 76 |
| 1984 | 1.007 | 10954 | 4765 | 194 | 628 | 196 | 312 | 79 |
| 1985 | 0.946 | 13622 | 1591 | 245 | 534 | 209 | 255 | 81 |
| 1986 | 1.054 | 28779 | 1672 | 232 | 478 | 242 | 405 | 69 |
| 1987 | 1.003 | 4945 | 3613 | 170 | 503 | 154 | 205 | 60 |
| 1988 | 1.013 | 5802 | 389 | 193 | 349 | 157 | 103 | 46 |
| 1989 | 0.856 | 6706 | 641 | 106 | 235 | 136 | 108 | 29 |
| 1990 | 0.953 | 18233 | 769 | 85 | 174 | 81 | 246 | 27 |
| 1991 | 0.808 | 12112 | 2031 | 78 | 229 | 56 | 215 | 34 |
| 1992 | 0.933 | 18542 | 1784 | 123 | 292 | 82 | 276 | 47 |
| 1993 | 0.875 | 7175 | 2725 | 169 | 414 | 120 | 181 | 55 |
| 1994 | 0.895 | 16336 | 897 | 149 | 338 | 144 | 211 | 58 |
| 1995 | 0.736 | 9467 | 3463 | 140 | 463 | 151 | 238 | 64 |
| 1996 | 0.944 | 9280 | 1015 | 153 | 412 | 167 | 161 | 63 |
| 1997 | 0.767 | 13901 | 1633 | 137 | 411 | 200 | 237 | 60 |
| 1998 | 0.791 | 11640 | 1702 | 127 | 380 | 164 | 226 | 48 |
| 1999 | 1.088 | 42395 | 1245 | 110 | 279 | 123 | 491 | 58 |
| 2000 | 1.166 | 16097 | 9179 | 103 | 763 | 80 | 603 | 97 |
| 2001 | 0.831 | 4571 | 2552 | 163 | 716 | 191 | 229 | 110 |
| Avg. | 0.922 | 29555 | 4637 | 282 | 781 | 253 | 570 | 107 |

Table 4.1 MSVPA output summary (cont'd)

Species Herring

| Year | Mean F Ages 2 to 6 | Recruits Age 0 1.July (millions) | Recruits Age 1 1.January (millions) | Yield (('000' t) | Stock Biomass 1.January (('000' t) | Spawning Stock Biomass 1.January (('000' t) | Eaten by model predators (('000' t) | Dead by other causes (('000' t) |
|------|--------------------------|---|--|---------------------|---|---|--|--|
| 1963 | 0.209 | 35099 | 15067 | 596 | 2159 | 1965 | 753 | 256 |
| 1964 | 0.316 | 46539 | 15483 | 883 | 2340 | 2132 | 751 | 258 |
| 1965 | 0.642 | 25302 | 21928 | 1285 | 2264 | 1972 | 696 | 228 |
| 1966 | 0.571 | 16946 | 11820 | 907 | 1852 | 1695 | 532 | 179 |
| 1967 | 0.751 | 27877 | 8518 | 778 | 1426 | 1313 | 437 | 137 |
| 1968 | 1.258 | 26815 | 16301 | 857 | 1147 | 935 | 578 | 113 |
| 1969 | 1.010 | 14278 | 13477 | 515 | 902 | 718 | 450 | 92 |
| 1970 | 1.014 | 22786 | 7081 | 517 | 821 | 728 | 348 | 80 |
| 1971 | 1.300 | 17793 | 13553 | 550 | 698 | 515 | 335 | 76 |
| 1972 | 0.618 | 12980 | 10558 | 450 | 693 | 550 | 340 | 71 |
| 1973 | 1.036 | 6025 | 6525 | 449 | 624 | 535 | 258 | 53 |
| 1974 | 0.984 | 12685 | 2751 | 266 | 338 | 301 | 150 | 34 |
| 1975 | 1.392 | 2573 | 6003 | 254 | 276 | 188 | 114 | 26 |
| 1976 | 1.374 | 2083 | 889 | 159 | 201 | 190 | 62 | 16 |
| 1977 | 0.665 | 3167 | 877 | 39 | 113 | 101 | 39 | 8 |
| 1978 | 0.045 | 3384 | 1528 | 11 | 93 | 72 | 56 | 12 |
| 1979 | 0.056 | 9395 | 1733 | 24 | 141 | 118 | 93 | 20 |
| 1980 | 0.239 | 12492 | 4811 | 59 | 225 | 161 | 195 | 32 |
| 1981 | 0.322 | 22714 | 5322 | 167 | 349 | 275 | 225 | 43 |
| 1982 | 0.235 | 33535 | 7730 | 231 | 443 | 341 | 302 | 61 |
| 1983 | 0.320 | 29578 | 12025 | 313 | 663 | 503 | 341 | 90 |
| 1984 | 0.405 | 20684 | 11089 | 314 | 955 | 728 | 397 | 117 |
| 1985 | 0.592 | 33430 | 10095 | 548 | 1213 | 931 | 414 | 133 |
| 1986 | 0.512 | 44024 | 20338 | 519 | 1316 | 950 | 631 | 164 |
| 1987 | 0.505 | 33342 | 26298 | 729 | 1827 | 1303 | 883 | 208 |
| 1988 | 0.500 | 24955 | 14019 | 750 | 2049 | 1677 | 713 | 205 |
| 1989 | 0.503 | 21738 | 11011 | 752 | 1751 | 1481 | 533 | 182 |
| 1990 | 0.402 | 47559 | 8160 | 600 | 1447 | 1294 | 667 | 157 |
| 1991 | 0.454 | 29370 | 7784 | 573 | 1190 | 1052 | 428 | 130 |
| 1992 | 0.532 | 55479 | 5593 | 577 | 1019 | 803 | 529 | 114 |
| 1993 | 0.668 | 49238 | 8790 | 521 | 892 | 579 | 532 | 106 |
| 1994 | 0.733 | 28901 | 7919 | 467 | 863 | 653 | 399 | 100 |
| 1995 | 0.786 | 34444 | 5908 | 532 | 848 | 639 | 400 | 99 |
| 1996 | 0.406 | 22379 | 6339 | 264 | 774 | 576 | 277 | 91 |
| 1997 | 0.326 | 14095 | 11617 | 208 | 871 | 610 | 333 | 118 |
| 1998 | 0.412 | 12546 | 5829 | 327 | 1218 | 894 | 373 | 136 |
| 1999 | 0.324 | 21445 | 6036 | 330 | 1178 | 965 | 360 | 135 |
| 2000 | 0.335 | 22676 | 10779 | 325 | 1173 | 924 | 355 | 153 |
| 2001 | 0.287 | 47435 | 11865 | 363 | 1493 | 1183 | 615 | 187 |
| Avg. | 0.591 | 24302 | 9576 | 462 | 1022 | 835 | 408 | 113 |

Table 4.1 MSVPA output summary (cont'd)

Species Norway pout

| Year | Mean F Ages 1 to 2 | Recruits Age 0 1.July (millions) | Recruits Age 1 1.January (millions) | Yield (('000' t) | Stock Biomass 1.January (('000' t) | Spawning Stock Biomass 1.January (('000' t) | Eaten by model predators (('000' t) | Dead by other causes (('000' t) |
|------|--------------------------|---|--|---------------------|---|---|--|--|
| 1963 | 0.441 | 118726 | 20918 | 137 | 443 | 276 | 705 | 105 |
| 1964 | 0.176 | 191039 | 28556 | 61 | 447 | 213 | 1123 | 126 |
| 1965 | 0.098 | 243466 | 45205 | 43 | 661 | 272 | 1487 | 156 |
| 1966 | 0.093 | 157842 | 59739 | 52 | 877 | 373 | 1292 | 155 |
| 1967 | 0.345 | 225133 | 45895 | 182 | 825 | 449 | 1353 | 171 |
| 1968 | 1.077 | 485767 | 68802 | 451 | 985 | 421 | 2552 | 262 |
| 1969 | 0.254 | 665615 | 125622 | 113 | 1450 | 345 | 3835 | 332 |
| 1970 | 0.437 | 442830 | 176188 | 237 | 2132 | 566 | 3183 | 315 |
| 1971 | 0.511 | 471766 | 162287 | 305 | 1947 | 598 | 3314 | 331 |
| 1972 | 0.757 | 266579 | 160003 | 444 | 1902 | 590 | 2755 | 262 |
| 1973 | 0.866 | 418458 | 64295 | 345 | 1048 | 497 | 2244 | 211 |
| 1974 | 2.054 | 247373 | 118766 | 721 | 1284 | 263 | 1655 | 215 |
| 1975 | 1.033 | 453916 | 84554 | 494 | 1031 | 328 | 2298 | 252 |
| 1976 | 0.966 | 298337 | 137938 | 429 | 1539 | 389 | 2343 | 243 |
| 1977 | 0.686 | 135091 | 93945 | 363 | 1214 | 412 | 1390 | 167 |
| 1978 | 0.769 | 202965 | 42101 | 231 | 739 | 387 | 1221 | 145 |
| 1979 | 1.055 | 256576 | 66910 | 330 | 830 | 271 | 1448 | 191 |
| 1980 | 1.128 | 138686 | 88239 | 521 | 1116 | 388 | 1331 | 184 |
| 1981 | 0.830 | 341706 | 36189 | 426 | 803 | 474 | 1515 | 181 |
| 1982 | 1.130 | 227577 | 105281 | 355 | 1135 | 246 | 1650 | 200 |
| 1983 | 1.035 | 154990 | 82740 | 445 | 1102 | 415 | 1218 | 182 |
| 1984 | 1.259 | 153806 | 62753 | 340 | 957 | 446 | 1163 | 148 |
| 1985 | 1.328 | 145342 | 50394 | 217 | 757 | 325 | 1055 | 108 |
| 1986 | 1.249 | 195786 | 44607 | 176 | 575 | 195 | 1168 | 110 |
| 1987 | 1.014 | 60638 | 53708 | 146 | 622 | 161 | 787 | 75 |
| 1988 | 1.175 | 111009 | 13240 | 101 | 259 | 145 | 591 | 60 |
| 1989 | 0.990 | 119422 | 29679 | 161 | 331 | 80 | 706 | 79 |
| 1990 | 0.848 | 88864 | 29967 | 127 | 410 | 150 | 593 | 71 |
| 1991 | 1.068 | 149866 | 27463 | 152 | 411 | 178 | 748 | 93 |
| 1992 | 1.083 | 85147 | 53388 | 257 | 628 | 188 | 729 | 105 |
| 1993 | 0.834 | 60912 | 29531 | 173 | 539 | 288 | 576 | 71 |
| 1994 | 1.471 | 207716 | 18688 | 176 | 333 | 171 | 762 | 108 |
| 1995 | 0.512 | 132779 | 89675 | 183 | 866 | 142 | 1312 | 155 |
| 1996 | 0.417 | 187161 | 39753 | 122 | 762 | 430 | 1113 | 137 |
| 1997 | 0.489 | 100602 | 79742 | 129 | 903 | 269 | 1251 | 142 |
| 1998 | 0.283 | 87189 | 32998 | 61 | 638 | 367 | 824 | 88 |
| 1999 | 0.712 | 195345 | 29862 | 85 | 462 | 214 | 908 | 117 |
| 2000 | 0.586 | 82202 | 83445 | 175 | 861 | 204 | 1169 | 144 |
| 2001 | 0.370 | 168104 | 26171 | 57 | 632 | 410 | 1197 | 93 |
| Avg. | 0.806 | 217342 | 66903 | 244 | 883 | 321 | 1450 | 161 |

Table 4.1 MSVPA output summary (cont'd)

Species Plaice

| Year | Mean F Ages 2 to 10 | Recruits Age 0 1.July (millions) | Recruits Age 1 1.January (millions) | Yield (('000' t) | Stock Biomass 1.January (('000' t) | Spawning Stock Biomass 1.January (('000' t) | Eaten by model predators (('000' t) | Dead by other causes (('000' t) |
|------|---------------------------|---|--|---------------------|---|---|--|--|
| 1963 | 0.264 | 1068 | 313 | 109 | 572 | 461 | 0 | 46 |
| 1964 | 0.273 | 323 | 1016 | 117 | 657 | 443 | 0 | 54 |
| 1965 | 0.276 | 319 | 307 | 106 | 602 | 431 | 0 | 50 |
| 1966 | 0.259 | 289 | 303 | 106 | 610 | 433 | 0 | 51 |
| 1967 | 0.243 | 256 | 275 | 112 | 614 | 512 | 0 | 50 |
| 1968 | 0.221 | 342 | 244 | 120 | 571 | 475 | 0 | 46 |
| 1969 | 0.254 | 387 | 325 | 130 | 539 | 438 | 0 | 43 |
| 1970 | 0.333 | 288 | 368 | 146 | 526 | 414 | 0 | 41 |
| 1971 | 0.316 | 245 | 274 | 111 | 498 | 382 | 0 | 39 |
| 1972 | 0.341 | 566 | 233 | 113 | 493 | 385 | 0 | 38 |
| 1973 | 0.381 | 472 | 539 | 117 | 484 | 348 | 0 | 37 |
| 1974 | 0.391 | 351 | 449 | 101 | 461 | 317 | 0 | 36 |
| 1975 | 0.366 | 339 | 333 | 93 | 477 | 321 | 0 | 38 |
| 1976 | 0.315 | 493 | 322 | 103 | 458 | 328 | 0 | 36 |
| 1977 | 0.335 | 450 | 469 | 112 | 481 | 340 | 0 | 38 |
| 1978 | 0.329 | 466 | 428 | 108 | 477 | 331 | 0 | 37 |
| 1979 | 0.458 | 691 | 443 | 138 | 482 | 322 | 0 | 36 |
| 1980 | 0.399 | 446 | 657 | 125 | 499 | 308 | 0 | 38 |
| 1981 | 0.402 | 1077 | 424 | 126 | 481 | 309 | 0 | 37 |
| 1982 | 0.442 | 622 | 1024 | 141 | 570 | 311 | 0 | 44 |
| 1983 | 0.420 | 640 | 591 | 138 | 563 | 337 | 0 | 44 |
| 1984 | 0.390 | 559 | 609 | 156 | 585 | 343 | 0 | 45 |
| 1985 | 0.381 | 1316 | 532 | 163 | 572 | 379 | 0 | 44 |
| 1986 | 0.443 | 565 | 1252 | 165 | 685 | 386 | 0 | 53 |
| 1987 | 0.439 | 589 | 538 | 158 | 668 | 417 | 0 | 52 |
| 1988 | 0.408 | 429 | 560 | 160 | 644 | 391 | 0 | 51 |
| 1989 | 0.381 | 422 | 408 | 177 | 605 | 435 | 0 | 46 |
| 1990 | 0.363 | 414 | 401 | 173 | 557 | 400 | 0 | 43 |
| 1991 | 0.445 | 417 | 394 | 168 | 490 | 352 | 0 | 37 |
| 1992 | 0.470 | 289 | 396 | 143 | 443 | 306 | 0 | 33 |
| 1993 | 0.488 | 251 | 275 | 119 | 385 | 268 | 0 | 29 |
| 1994 | 0.518 | 331 | 239 | 112 | 332 | 235 | 0 | 24 |
| 1995 | 0.482 | 290 | 315 | 98 | 305 | 210 | 0 | 22 |
| 1996 | 0.552 | 944 | 276 | 86 | 279 | 184 | 0 | 21 |
| 1997 | 0.613 | 334 | 898 | 85 | 354 | 164 | 0 | 28 |
| 1998 | 0.516 | 207 | 317 | 74 | 376 | 218 | 0 | 30 |
| 1999 | 0.512 | 214 | 197 | 84 | 370 | 220 | 0 | 30 |
| 2000 | 0.320 | 240 | 204 | 83 | 337 | 257 | 0 | 27 |
| 2001 | 0.421 | 690 | 229 | 82 | 336 | 265 | 0 | 26 |
| Avg. | 0.389 | 478 | 446 | 122 | 498 | 343 | 0 | 39 |

Table 4.1 MSVPA output summary (Cont'd)

Species Saithe

| Year | Mean F Ages 3 to 6 | Recruits Age 0 1.July (millions) | Recruits Age 1 1.January (millions) | Yield (^{'000'} t) | Stock Biomass 1.January (^{'000'} t) | Spawning Stock Biomass 1.January (^{'000'} t) | Eaten by model predators (^{'000'} t) | Dead by other causes (^{'000'} t) |
|------|--------------------------|---|--|--------------------------------|--|--|---|---|
| 1963 | 0.332 | 159 | 194 | 24 | 178 | 98 | 0 | 36 |
| 1964 | 0.458 | 206 | 144 | 43 | 225 | 104 | 0 | 45 |
| 1965 | 0.469 | 165 | 186 | 56 | 275 | 85 | 0 | 55 |
| 1966 | 0.421 | 473 | 149 | 84 | 342 | 104 | 0 | 65 |
| 1967 | 0.323 | 440 | 428 | 81 | 387 | 133 | 0 | 77 |
| 1968 | 0.301 | 513 | 398 | 94 | 552 | 193 | 0 | 113 |
| 1969 | 0.256 | 258 | 464 | 114 | 731 | 248 | 0 | 149 |
| 1970 | 0.434 | 251 | 233 | 230 | 933 | 293 | 0 | 174 |
| 1971 | 0.335 | 265 | 227 | 264 | 1026 | 409 | 0 | 183 |
| 1972 | 0.403 | 302 | 240 | 298 | 891 | 458 | 0 | 151 |
| 1973 | 0.424 | 715 | 273 | 269 | 834 | 504 | 0 | 141 |
| 1974 | 0.585 | 218 | 647 | 283 | 840 | 508 | 0 | 139 |
| 1975 | 0.505 | 155 | 197 | 281 | 832 | 466 | 0 | 139 |
| 1976 | 0.801 | 139 | 140 | 378 | 722 | 298 | 0 | 114 |
| 1977 | 0.651 | 114 | 126 | 224 | 520 | 261 | 0 | 77 |
| 1978 | 0.483 | 295 | 103 | 144 | 428 | 227 | 0 | 68 |
| 1979 | 0.406 | 178 | 267 | 110 | 399 | 213 | 0 | 67 |
| 1980 | 0.461 | 212 | 161 | 115 | 411 | 221 | 0 | 68 |
| 1981 | 0.313 | 350 | 192 | 108 | 492 | 232 | 0 | 86 |
| 1982 | 0.502 | 527 | 317 | 155 | 503 | 188 | 0 | 86 |
| 1983 | 0.617 | 436 | 477 | 168 | 482 | 197 | 0 | 84 |
| 1984 | 0.820 | 169 | 394 | 211 | 499 | 150 | 0 | 91 |
| 1985 | 0.861 | 198 | 153 | 248 | 496 | 117 | 0 | 84 |
| 1986 | 0.956 | 107 | 179 | 227 | 439 | 109 | 0 | 74 |
| 1987 | 0.705 | 187 | 97 | 217 | 354 | 106 | 0 | 54 |
| 1988 | 0.666 | 218 | 169 | 150 | 276 | 111 | 0 | 44 |
| 1989 | 0.702 | 153 | 197 | 119 | 249 | 94 | 0 | 43 |
| 1990 | 0.628 | 240 | 139 | 104 | 266 | 84 | 0 | 48 |
| 1991 | 0.585 | 166 | 217 | 117 | 284 | 83 | 0 | 49 |
| 1992 | 0.643 | 355 | 150 | 108 | 295 | 91 | 0 | 53 |
| 1993 | 0.517 | 171 | 321 | 103 | 348 | 111 | 0 | 60 |
| 1994 | 0.513 | 281 | 155 | 100 | 359 | 106 | 0 | 65 |
| 1995 | 0.428 | 139 | 254 | 114 | 474 | 133 | 0 | 89 |
| 1996 | 0.428 | 232 | 126 | 110 | 473 | 155 | 0 | 87 |
| 1997 | 0.296 | 188 | 210 | 103 | 478 | 190 | 0 | 90 |
| 1998 | 0.353 | 414 | 170 | 100 | 425 | 189 | 0 | 78 |
| 1999 | 0.341 | 216 | 375 | 107 | 461 | 218 | 0 | 82 |
| 2000 | 0.264 | 224 | 195 | 82 | 524 | 213 | 0 | 101 |
| 2001 | 0.244 | 265 | 202 | 88 | 689 | 263 | 0 | 133 |
| Avg. | 0.498 | 264 | 238 | 152 | 497 | 204 | 0 | 88 |

Table 4.1 MSVPA output summary (cont'd)

Species Sandeel

| Year | Mean F Ages 1 to 2 | Recruits Age 0 1.July (millions) | Recruits Age 1 1.January (millions) | Yield (('000' t) | Stock Biomass 1.January (('000' t) | Spawning Stock Biomass 1.January (('000' t) | Eaten by model predators (('000' t) | Dead by other causes (('000' t) |
|------|--------------------------|---|--|---------------------|---|---|--|--|
| 1963 | 0.154 | 448979 | 173748 | 162 | 1587 | 819 | 1442 | 308 |
| 1964 | 0.109 | 444112 | 170310 | 128 | 1556 | 811 | 1444 | 308 |
| 1965 | 0.116 | 327827 | 172745 | 130 | 1624 | 866 | 1369 | 300 |
| 1966 | 0.130 | 243872 | 131208 | 143 | 1412 | 843 | 1017 | 283 |
| 1967 | 0.199 | 530235 | 106324 | 188 | 1327 | 858 | 1084 | 306 |
| 1968 | 0.193 | 346032 | 224513 | 193 | 1817 | 760 | 1430 | 317 |
| 1969 | 0.129 | 206383 | 108108 | 113 | 1358 | 848 | 978 | 242 |
| 1970 | 0.449 | 456786 | 69422 | 191 | 1030 | 718 | 759 | 234 |
| 1971 | 0.330 | 218464 | 224471 | 188 | 1285 | 286 | 871 | 262 |
| 1972 | 0.200 | 666622 | 93641 | 196 | 1365 | 927 | 1233 | 306 |
| 1973 | 0.141 | 615209 | 221026 | 168 | 1796 | 760 | 1700 | 337 |
| 1974 | 0.288 | 689750 | 124612 | 340 | 1561 | 1007 | 1266 | 352 |
| 1975 | 0.309 | 553953 | 226701 | 359 | 1916 | 899 | 1618 | 366 |
| 1976 | 0.435 | 520063 | 114590 | 426 | 1408 | 903 | 985 | 293 |
| 1977 | 0.495 | 631889 | 216807 | 588 | 1704 | 737 | 1188 | 353 |
| 1978 | 0.542 | 494639 | 302295 | 800 | 2129 | 782 | 1319 | 380 |
| 1979 | 0.475 | 692674 | 195837 | 684 | 1993 | 1105 | 1426 | 389 |
| 1980 | 0.618 | 340086 | 250287 | 724 | 2059 | 929 | 1325 | 324 |
| 1981 | 0.528 | 950115 | 102775 | 528 | 1293 | 825 | 1248 | 287 |
| 1982 | 0.561 | 249283 | 382476 | 595 | 2183 | 533 | 1269 | 417 |
| 1983 | 0.363 | 785724 | 77180 | 530 | 1694 | 1354 | 1217 | 375 |
| 1984 | 0.404 | 334543 | 292856 | 750 | 2159 | 888 | 1214 | 391 |
| 1985 | 0.929 | 1314962 | 96018 | 707 | 1380 | 957 | 1523 | 314 |
| 1986 | 0.471 | 721450 | 488288 | 685 | 2570 | 416 | 1929 | 534 |
| 1987 | 0.391 | 439188 | 220879 | 791 | 2759 | 1770 | 1682 | 517 |
| 1988 | 0.861 | 1017294 | 93245 | 1007 | 2054 | 1627 | 1612 | 356 |
| 1989 | 0.680 | 558905 | 291947 | 826 | 1803 | 472 | 1335 | 256 |
| 1990 | 0.818 | 866436 | 127650 | 584 | 1197 | 624 | 1291 | 222 |
| 1991 | 0.810 | 882284 | 233931 | 898 | 1439 | 418 | 1349 | 296 |
| 1992 | 0.470 | 447534 | 259457 | 820 | 1816 | 688 | 1173 | 345 |
| 1993 | 0.393 | 778378 | 106143 | 576 | 1608 | 1140 | 1266 | 357 |
| 1994 | 0.538 | 790977 | 228464 | 770 | 1868 | 876 | 1338 | 394 |
| 1995 | 0.447 | 442680 | 262602 | 915 | 2063 | 936 | 1202 | 412 |
| 1996 | 0.577 | 1463056 | 116180 | 776 | 1831 | 1320 | 1685 | 465 |
| 1997 | 0.418 | 417264 | 566111 | 1114 | 3146 | 725 | 1594 | 636 |
| 1998 | 0.621 | 505091 | 109776 | 1000 | 2707 | 2223 | 1196 | 473 |
| 1999 | 0.608 | 719607 | 115324 | 718 | 1731 | 1218 | 1148 | 335 |
| 2000 | 0.889 | 812416 | 200013 | 692 | 1565 | 688 | 1324 | 291 |
| 2001 | 0.705 | 1167416 | 214978 | 858 | 1681 | 721 | 1689 | 316 |
| Avg. | 0.456 | 617748 | 197767 | 561 | 1781 | 905 | 1327 | 350 |

Table 4.1 MSVPA output summary (Cont'd)

Species Sole

| Year | Mean F Ages 2 to 8 | Recruits Age 0 1.July (millions) | Recruits Age 1 1.January (millions) | Yield (('000' t) | Stock Biomass 1.January (('000' t) | Spawning Stock Biomass 1.January (('000' t) | Eaten by model predators (('000' t) | Dead by other causes (('000' t) |
|------|--------------------------|---|--|---------------------|---|---|--|--|
| 1963 | 0.365 | 579 | 10 | 35 | 82 | 80 | 0 | 6 |
| 1964 | 0.228 | 127 | 551 | 15 | 85 | 55 | 0 | 7 |
| 1965 | 0.246 | 43 | 120 | 21 | 128 | 50 | 0 | 11 |
| 1966 | 0.240 | 78 | 40 | 38 | 128 | 110 | 0 | 10 |
| 1967 | 0.308 | 104 | 74 | 36 | 115 | 106 | 0 | 8 |
| 1968 | 0.373 | 52 | 99 | 35 | 109 | 94 | 0 | 8 |
| 1969 | 0.423 | 147 | 50 | 29 | 90 | 74 | 0 | 6 |
| 1970 | 0.351 | 43 | 140 | 20 | 80 | 66 | 0 | 6 |
| 1971 | 0.444 | 80 | 41 | 22 | 76 | 55 | 0 | 5 |
| 1972 | 0.393 | 111 | 76 | 18 | 68 | 59 | 0 | 5 |
| 1973 | 0.452 | 115 | 105 | 16 | 60 | 44 | 0 | 4 |
| 1974 | 0.462 | 43 | 110 | 16 | 64 | 45 | 0 | 4 |
| 1975 | 0.462 | 119 | 41 | 19 | 62 | 46 | 0 | 4 |
| 1976 | 0.405 | 147 | 113 | 15 | 57 | 46 | 0 | 4 |
| 1977 | 0.382 | 49 | 139 | 16 | 60 | 38 | 0 | 4 |
| 1978 | 0.493 | 12 | 46 | 19 | 62 | 41 | 0 | 4 |
| 1979 | 0.461 | 162 | 11 | 19 | 56 | 49 | 0 | 4 |
| 1980 | 0.443 | 156 | 154 | 13 | 48 | 38 | 0 | 3 |
| 1981 | 0.448 | 160 | 148 | 14 | 54 | 26 | 0 | 4 |
| 1982 | 0.496 | 151 | 152 | 20 | 65 | 37 | 0 | 4 |
| 1983 | 0.466 | 75 | 143 | 24 | 72 | 45 | 0 | 5 |
| 1984 | 0.553 | 86 | 71 | 26 | 72 | 49 | 0 | 5 |
| 1985 | 0.515 | 168 | 81 | 23 | 60 | 46 | 0 | 4 |
| 1986 | 0.500 | 76 | 160 | 17 | 57 | 39 | 0 | 4 |
| 1987 | 0.430 | 466 | 72 | 17 | 58 | 33 | 0 | 4 |
| 1988 | 0.497 | 114 | 444 | 21 | 77 | 45 | 0 | 5 |
| 1989 | 0.392 | 188 | 109 | 22 | 102 | 38 | 0 | 8 |
| 1990 | 0.434 | 77 | 179 | 33 | 118 | 95 | 0 | 9 |
| 1991 | 0.470 | 369 | 73 | 35 | 110 | 83 | 0 | 8 |
| 1992 | 0.451 | 73 | 351 | 32 | 109 | 82 | 0 | 8 |
| 1993 | 0.531 | 60 | 69 | 31 | 107 | 59 | 0 | 8 |
| 1994 | 0.533 | 101 | 57 | 33 | 91 | 79 | 0 | 6 |
| 1995 | 0.568 | 52 | 96 | 30 | 75 | 63 | 0 | 5 |
| 1996 | 0.675 | 278 | 49 | 22 | 55 | 40 | 0 | 3 |
| 1997 | 0.584 | 134 | 264 | 15 | 51 | 31 | 0 | 3 |
| 1998 | 0.621 | 87 | 127 | 21 | 63 | 22 | 0 | 5 |
| 1999 | 0.569 | 129 | 82 | 23 | 64 | 44 | 0 | 4 |
| 2000 | 0.622 | 85 | 123 | 22 | 61 | 44 | 0 | 4 |
| 2001 | 0.527 | 197 | 81 | 20 | 54 | 34 | 0 | 4 |
| Avg. | 0.457 | 136 | 125 | 23 | 77 | 55 | 0 | 5 |

Table 4.1 MSVPA output summary (Cont'd)

Species Sprat

| Year | Mean F | Recruits Age 0 1.July | Recruits Age 1 1.January | Yield | Stock Biomass 1.January | Spawning Stock Biomass 1.January | Eaten by model predators | Dead by other causes |
|----------------|--------|-----------------------------|--------------------------------|-----------|-------------------------------|---|--------------------------------|----------------------------|
| Ages 1 to 2 | | (millions) | (millions) | ('000' t) | ('000' t) | ('000' t) | ('000' t) | ('000' t) |
| 1963 | 0.067 | 444592 | 221999 | 67 | 1443 | 1094 | 1458 | 276 |
| 1964 | 0.068 | 294749 | 220122 | 70 | 1419 | 1084 | 1297 | 267 |
| 1965 | 0.078 | 353403 | 146964 | 76 | 1297 | 1070 | 1122 | 239 |
| 1966 | 0.132 | 402116 | 185185 | 107 | 1275 | 991 | 1078 | 256 |
| 1967 | 0.058 | 325408 | 212636 | 71 | 1369 | 1037 | 1079 | 283 |
| 1968 | 0.059 | 228118 | 175176 | 71 | 1623 | 1331 | 1233 | 256 |
| 1969 | 0.058 | 147927 | 102110 | 69 | 1215 | 1057 | 733 | 189 |
| 1970 | 0.055 | 229273 | 66568 | 62 | 850 | 748 | 429 | 173 |
| 1971 | 0.078 | 278206 | 126018 | 86 | 1024 | 834 | 560 | 230 |
| 1972 | 0.074 | 562749 | 148114 | 108 | 1304 | 1069 | 1022 | 299 |
| 1973 | 0.138 | 655862 | 310099 | 261 | 1984 | 1487 | 1434 | 409 |
| 1974 | 0.134 | 332925 | 360351 | 278 | 2406 | 1860 | 1371 | 501 |
| 1975 | 0.292 | 594961 | 184069 | 568 | 2705 | 2417 | 1514 | 493 |
| 1976 | 0.336 | 318136 | 335304 | 527 | 2504 | 1986 | 1299 | 438 |
| 1977 | 0.220 | 290078 | 161939 | 283 | 1864 | 1609 | 1167 | 317 |
| 1978 | 0.436 | 429048 | 147302 | 400 | 1644 | 1410 | 1034 | 280 |
| 1979 | 0.557 | 240760 | 221329 | 412 | 1315 | 955 | 867 | 194 |
| 1980 | 0.736 | 191290 | 118214 | 305 | 1012 | 816 | 674 | 116 |
| 1981 | 0.809 | 67542 | 79049 | 180 | 585 | 452 | 320 | 62 |
| 1982 | 0.870 | 38469 | 34029 | 139 | 325 | 272 | 141 | 36 |
| 1983 | 0.909 | 114438 | 16496 | 82 | 158 | 133 | 123 | 33 |
| 1984 | 0.640 | 34720 | 57914 | 78 | 228 | 139 | 157 | 47 |
| 1985 | 0.261 | 31695 | 14847 | 49 | 234 | 211 | 143 | 41 |
| 1986 | 0.116 | 101884 | 15740 | 15 | 204 | 180 | 149 | 43 |
| 1987 | 0.871 | 123820 | 42981 | 44 | 217 | 150 | 245 | 45 |
| 1988 | 0.698 | 181609 | 23876 | 82 | 230 | 192 | 260 | 43 |
| 1989 | 0.803 | 117522 | 54678 | 63 | 272 | 183 | 279 | 45 |
| 1990 | 0.171 | 85397 | 28899 | 41 | 239 | 192 | 214 | 40 |
| 1991 | 0.314 | 126012 | 34217 | 69 | 254 | 201 | 205 | 55 |
| 1992 | 0.334 | 175840 | 55070 | 103 | 310 | 228 | 285 | 72 |
| 1993 | 0.462 | 314529 | 62154 | 180 | 429 | 334 | 372 | 105 |
| 1994 | 0.446 | 126156 | 150193 | 323 | 719 | 495 | 392 | 147 |
| 1995 | 0.699 | 54310 | 55979 | 357 | 696 | 614 | 296 | 117 |
| 1996 | 0.514 | 69920 | 20219 | 135 | 479 | 448 | 148 | 64 |
| 1997 | 0.292 | 102985 | 37554 | 100 | 260 | 205 | 157 | 67 |
| 1998 | 0.416 | 157684 | 46980 | 162 | 345 | 276 | 233 | 88 |
| 1999 | 0.309 | 153819 | 74825 | 188 | 505 | 394 | 267 | 111 |
| 2000 | 0.263 | 114582 | 78947 | 195 | 677 | 561 | 331 | 136 |
| 2001 | 0.412 | 108802 | 54737 | 211 | 639 | 557 | 334 | 111 |
| Avg. | 0.364 | 223624 | 114946 | 170 | 930 | 751 | 626 | 172 |

Table 4.1 MSVPA output summary (Cont'd)

Species Whiting

| Year | Mean F Ages 2 to 6 | Recruits Age 0 1.July (millions) | Recruits Age 1 1.January (millions) | Yield (('000' t) | Stock Biomass 1.January (('000' t) | Spawning Stock Biomass 1.January (('000' t) | Eaten by model predators (('000' t) | Dead by other causes (('000' t) |
|------|--------------------------|---|--|---------------------|---|---|--|--|
| 1963 | 0.890 | 12195 | 5633 | 233 | 580 | 333 | 242 | 87 |
| 1964 | 0.580 | 21218 | 1536 | 141 | 536 | 449 | 267 | 90 |
| 1965 | 0.561 | 18430 | 3567 | 176 | 630 | 470 | 301 | 93 |
| 1966 | 1.059 | 20215 | 3334 | 242 | 565 | 407 | 281 | 75 |
| 1967 | 0.769 | 31573 | 5358 | 207 | 540 | 297 | 366 | 84 |
| 1968 | 0.873 | 18347 | 10232 | 237 | 821 | 376 | 447 | 116 |
| 1969 | 0.641 | 18315 | 1552 | 319 | 711 | 606 | 287 | 96 |
| 1970 | 0.786 | 11801 | 2251 | 286 | 539 | 440 | 178 | 66 |
| 1971 | 0.487 | 20888 | 3303 | 174 | 367 | 222 | 221 | 60 |
| 1972 | 0.710 | 36363 | 6328 | 208 | 549 | 267 | 446 | 87 |
| 1973 | 0.913 | 19213 | 7839 | 286 | 740 | 392 | 398 | 102 |
| 1974 | 1.000 | 22669 | 3327 | 323 | 643 | 479 | 283 | 90 |
| 1975 | 1.150 | 24446 | 6464 | 276 | 665 | 393 | 350 | 103 |
| 1976 | 0.987 | 27253 | 4405 | 326 | 725 | 517 | 352 | 96 |
| 1977 | 0.765 | 32184 | 4697 | 289 | 709 | 492 | 406 | 103 |
| 1978 | 0.691 | 39679 | 5378 | 205 | 660 | 412 | 494 | 103 |
| 1979 | 0.669 | 39339 | 6415 | 249 | 804 | 502 | 540 | 112 |
| 1980 | 0.826 | 45055 | 6331 | 235 | 810 | 511 | 613 | 114 |
| 1981 | 0.765 | 13432 | 3375 | 202 | 721 | 533 | 300 | 85 |
| 1982 | 0.616 | 11254 | 2175 | 140 | 515 | 411 | 199 | 70 |
| 1983 | 0.697 | 10229 | 2031 | 167 | 428 | 331 | 162 | 58 |
| 1984 | 0.879 | 11097 | 2498 | 147 | 357 | 246 | 162 | 52 |
| 1985 | 0.746 | 15700 | 2080 | 100 | 320 | 222 | 194 | 53 |
| 1986 | 0.853 | 18817 | 3824 | 168 | 413 | 246 | 253 | 66 |
| 1987 | 1.081 | 26211 | 3335 | 161 | 442 | 287 | 324 | 69 |
| 1988 | 0.832 | 28306 | 2891 | 181 | 441 | 299 | 329 | 70 |
| 1989 | 0.950 | 27787 | 4834 | 153 | 486 | 271 | 378 | 76 |
| 1990 | 0.899 | 15724 | 2616 | 204 | 457 | 323 | 229 | 64 |
| 1991 | 0.675 | 10840 | 1810 | 145 | 354 | 271 | 146 | 52 |
| 1992 | 0.664 | 11710 | 1682 | 121 | 328 | 252 | 148 | 51 |
| 1993 | 0.717 | 9104 | 1998 | 109 | 329 | 239 | 136 | 48 |
| 1994 | 0.680 | 5399 | 1643 | 86 | 291 | 217 | 97 | 45 |
| 1995 | 0.639 | 8046 | 1361 | 97 | 289 | 228 | 103 | 46 |
| 1996 | 0.617 | 1907 | 1019 | 68 | 267 | 219 | 67 | 39 |
| 1997 | 0.462 | 3362 | 569 | 53 | 216 | 190 | 61 | 34 |
| 1998 | 0.413 | 5731 | 957 | 39 | 190 | 148 | 83 | 31 |
| 1999 | 0.495 | 4561 | 1542 | 54 | 205 | 139 | 80 | 33 |
| 2000 | 0.576 | 6948 | 1493 | 57 | 227 | 163 | 95 | 42 |
| 2001 | 0.394 | 13069 | 1657 | 43 | 290 | 216 | 168 | 56 |
| Avg. | 0.744 | 18421 | 3419 | 177 | 491 | 334 | 261 | 72 |

MSVPA summary for the years 1963 - 2001

Species: Cod

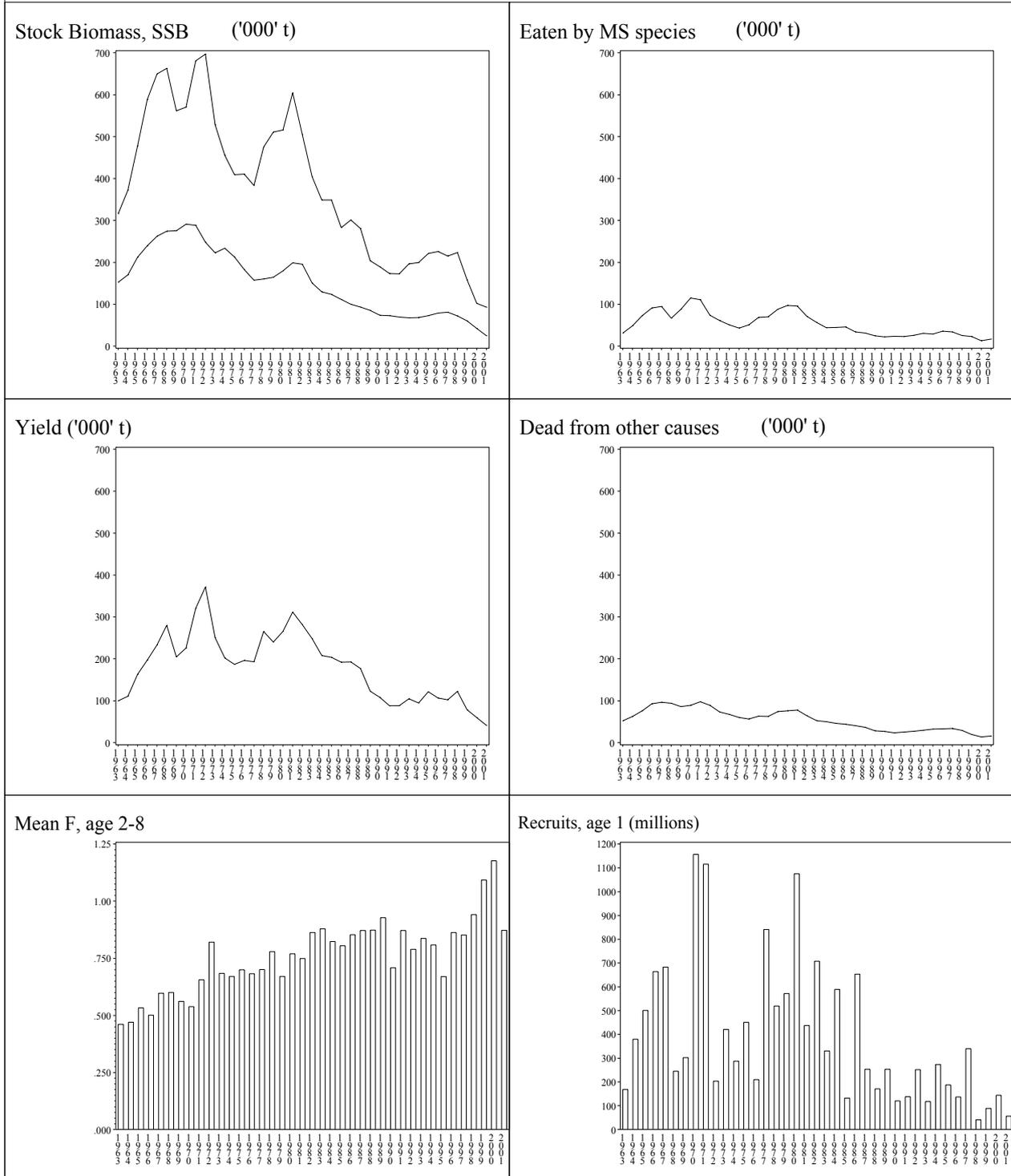


Figure 4.1 MSVPA summary

MSVPA summary for the years 1963 - 2001

Species: Haddock

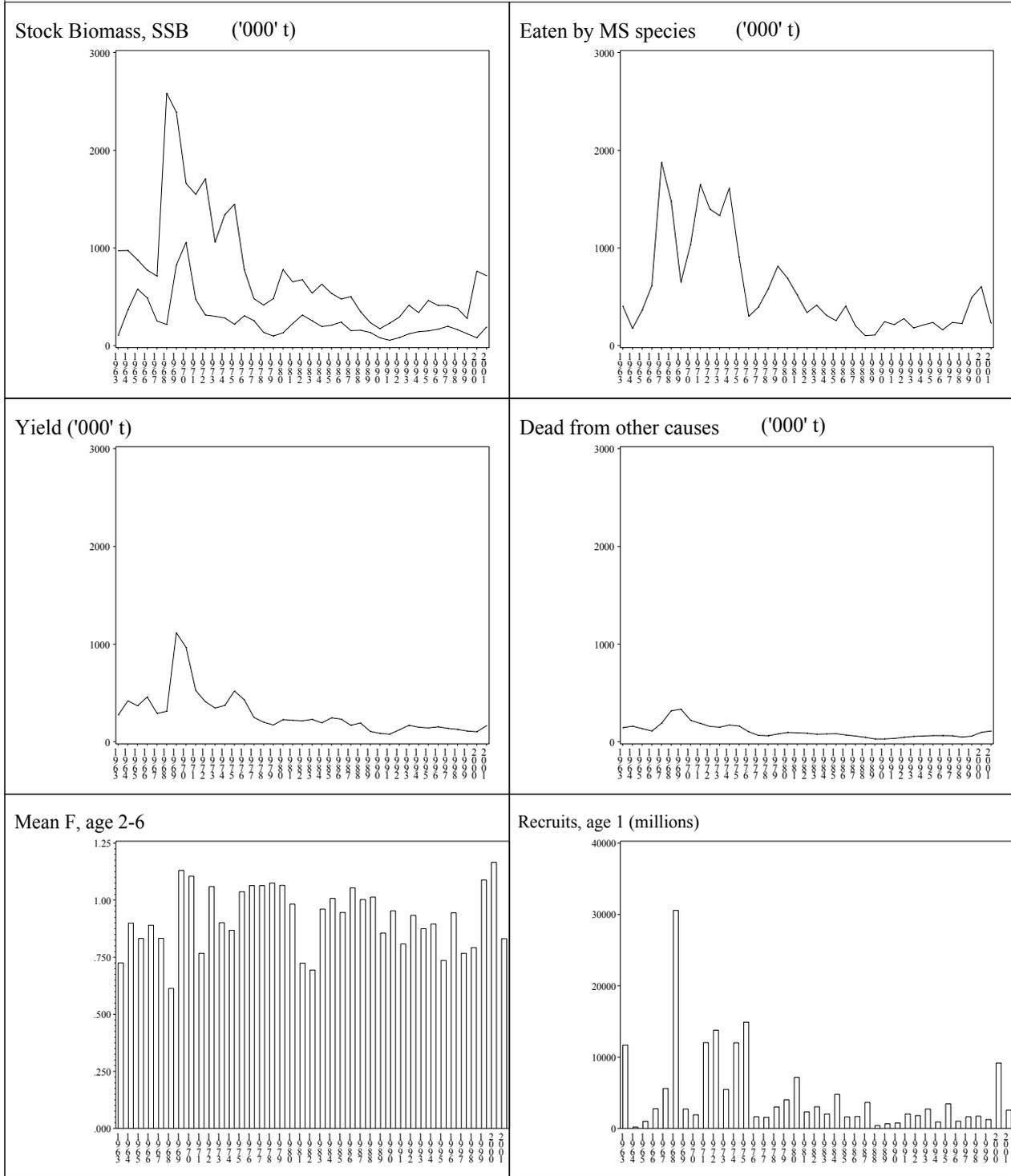


Figure 4.1 (Cont'd)

MSVPA summary for the years 1963 - 2001

Species: Herring

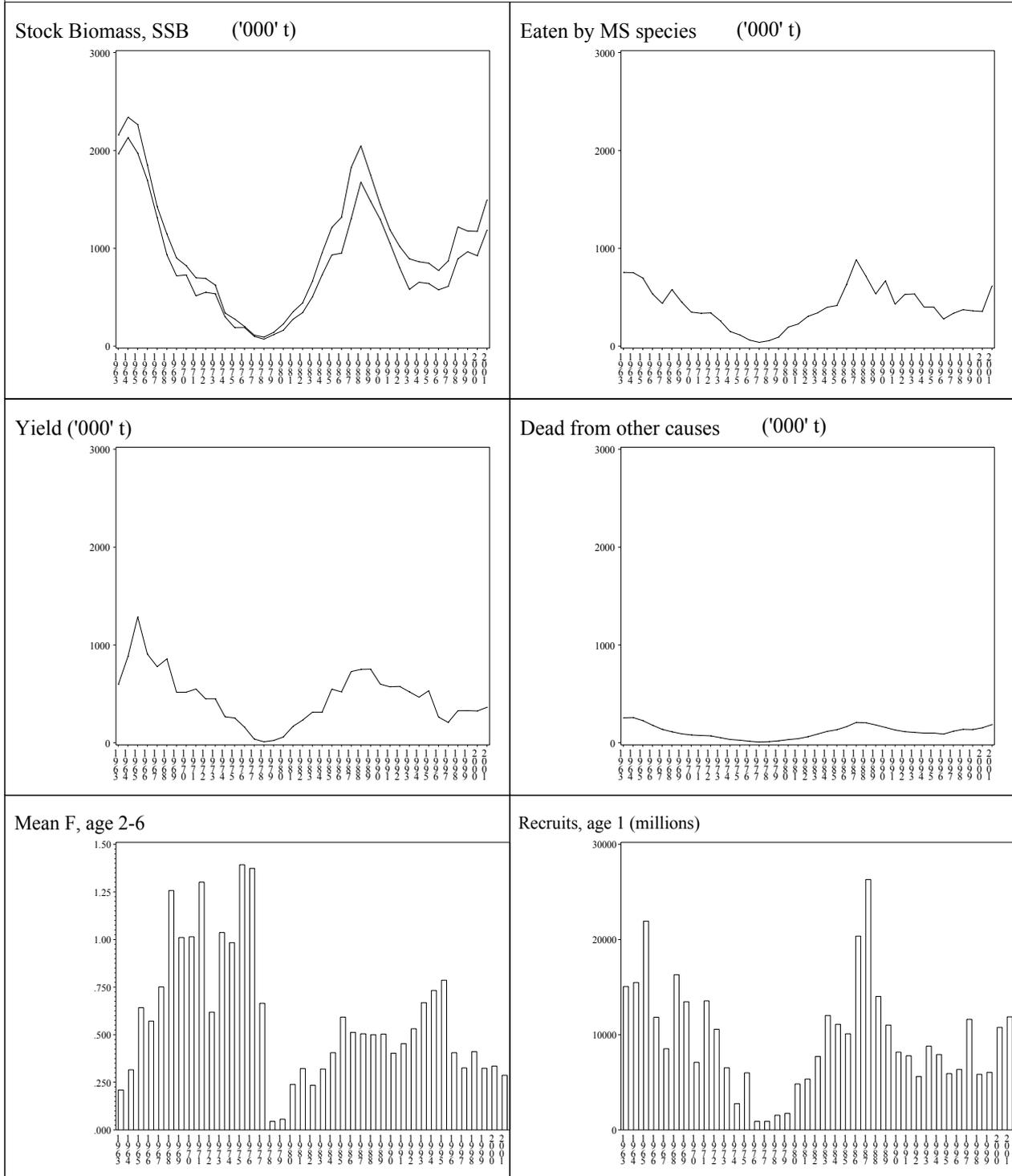


Figure 4.1 (Cont'd)

MSVPA summary for the years 1963 - 2001

Species: Plaice

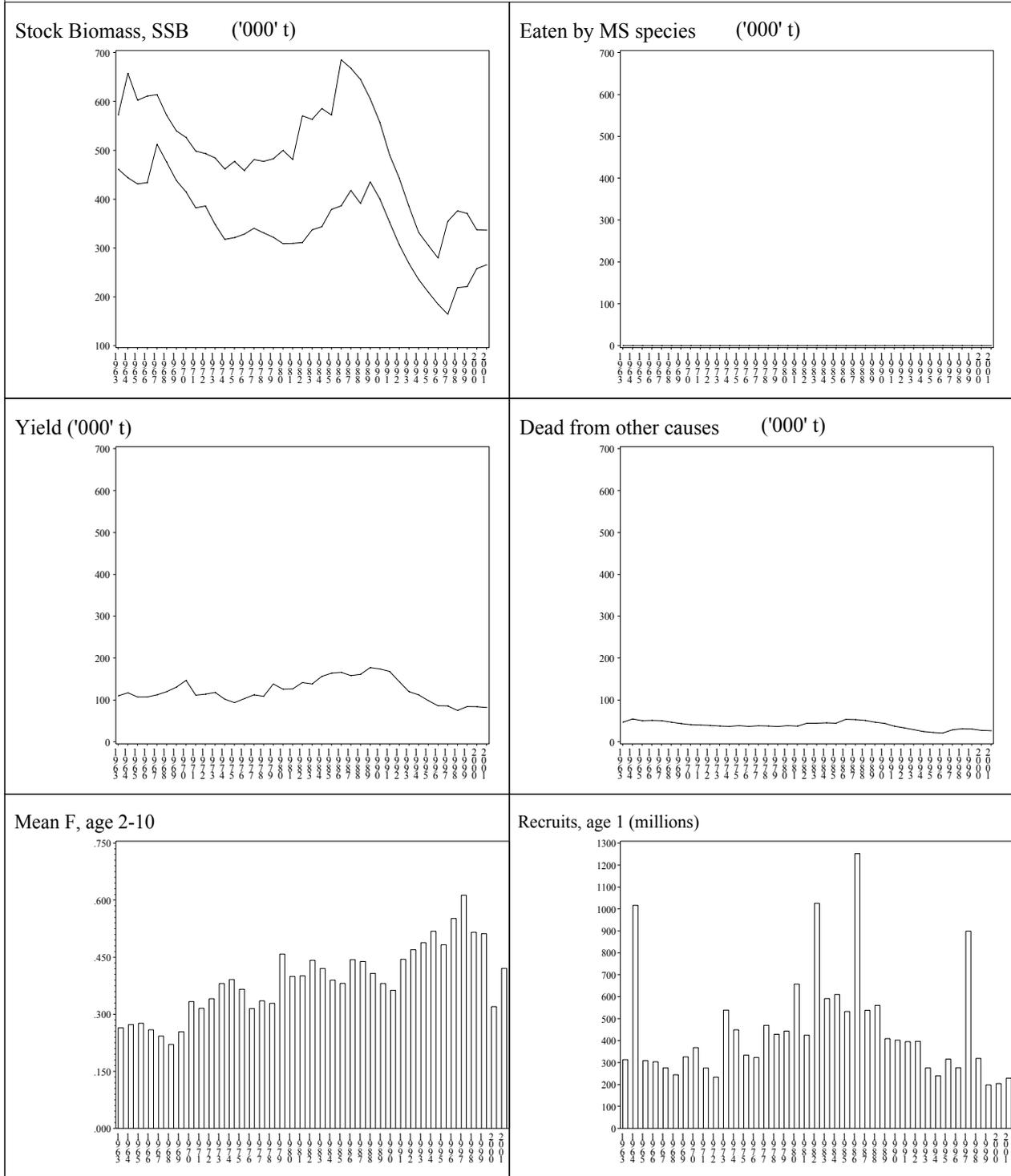


Figure 4.1 (Cont'd)

MSVPA summary for the years 1963 - 2001

Species: Saithe

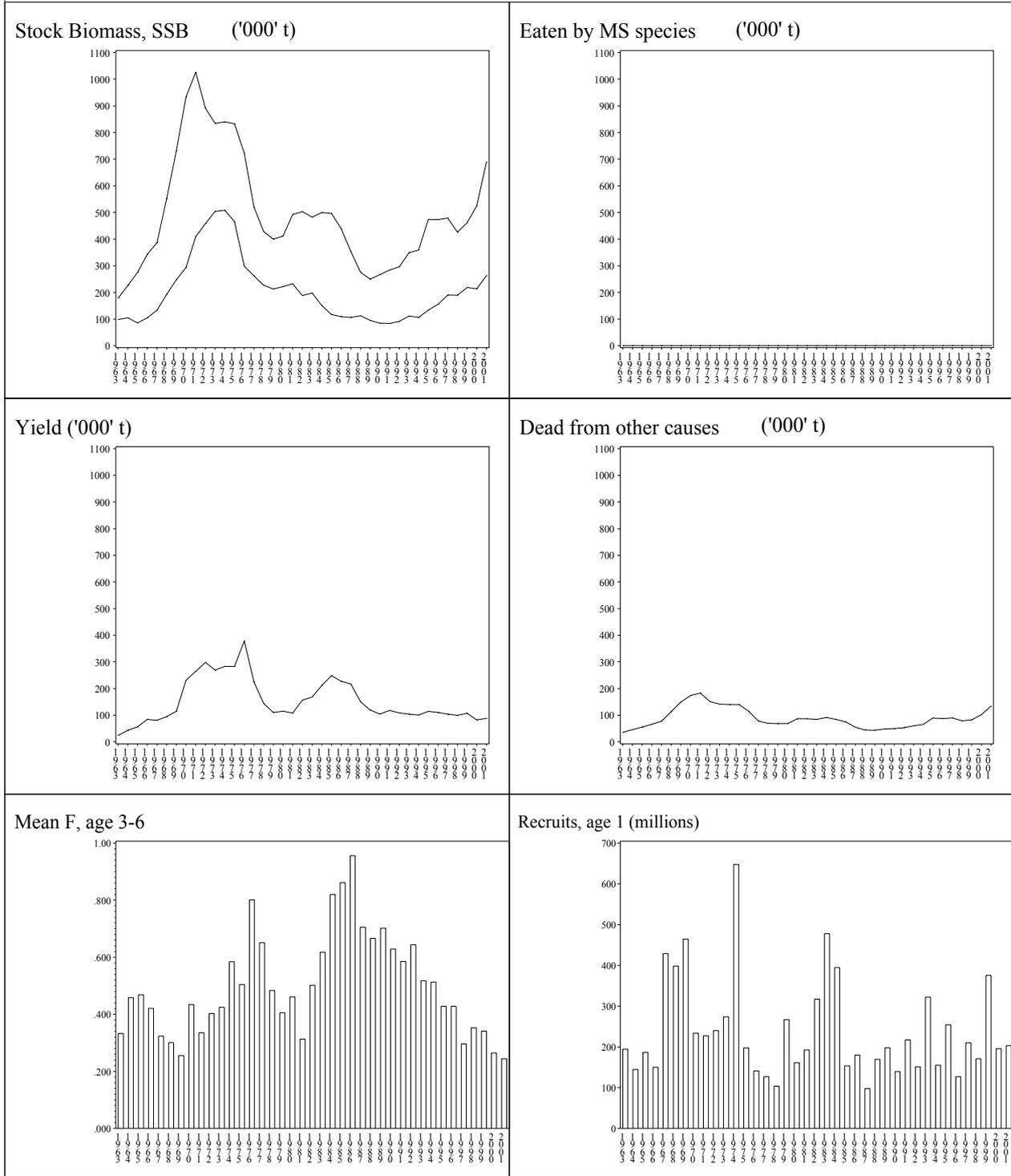


Figure 4.1 (Cont'd)

MSVPA summary for the years 1963 - 2001

Species: Sole

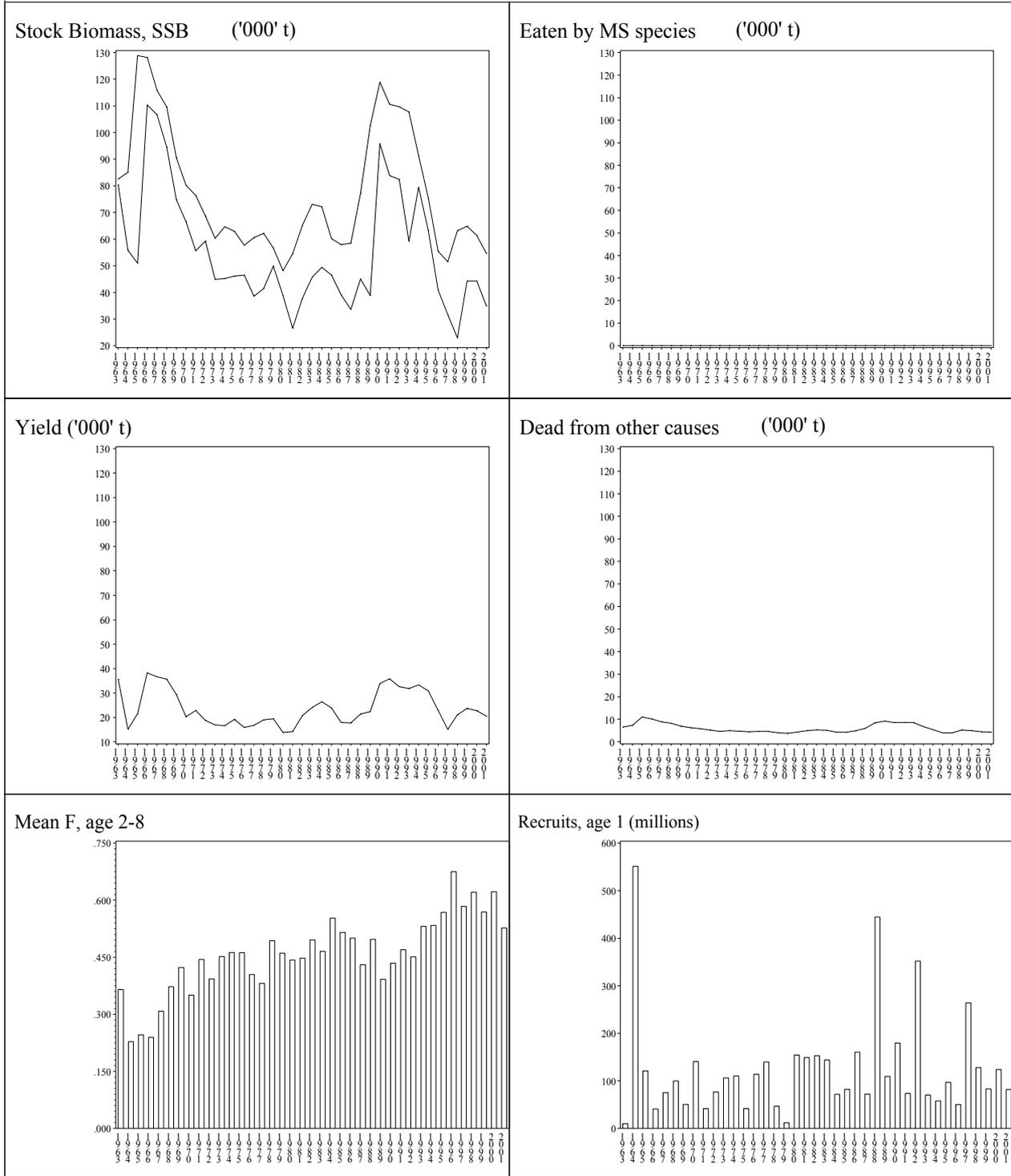


Figure 4.1 (Cont'd)

MSVPA summary for the years 1963 - 2001

Species: Sprat

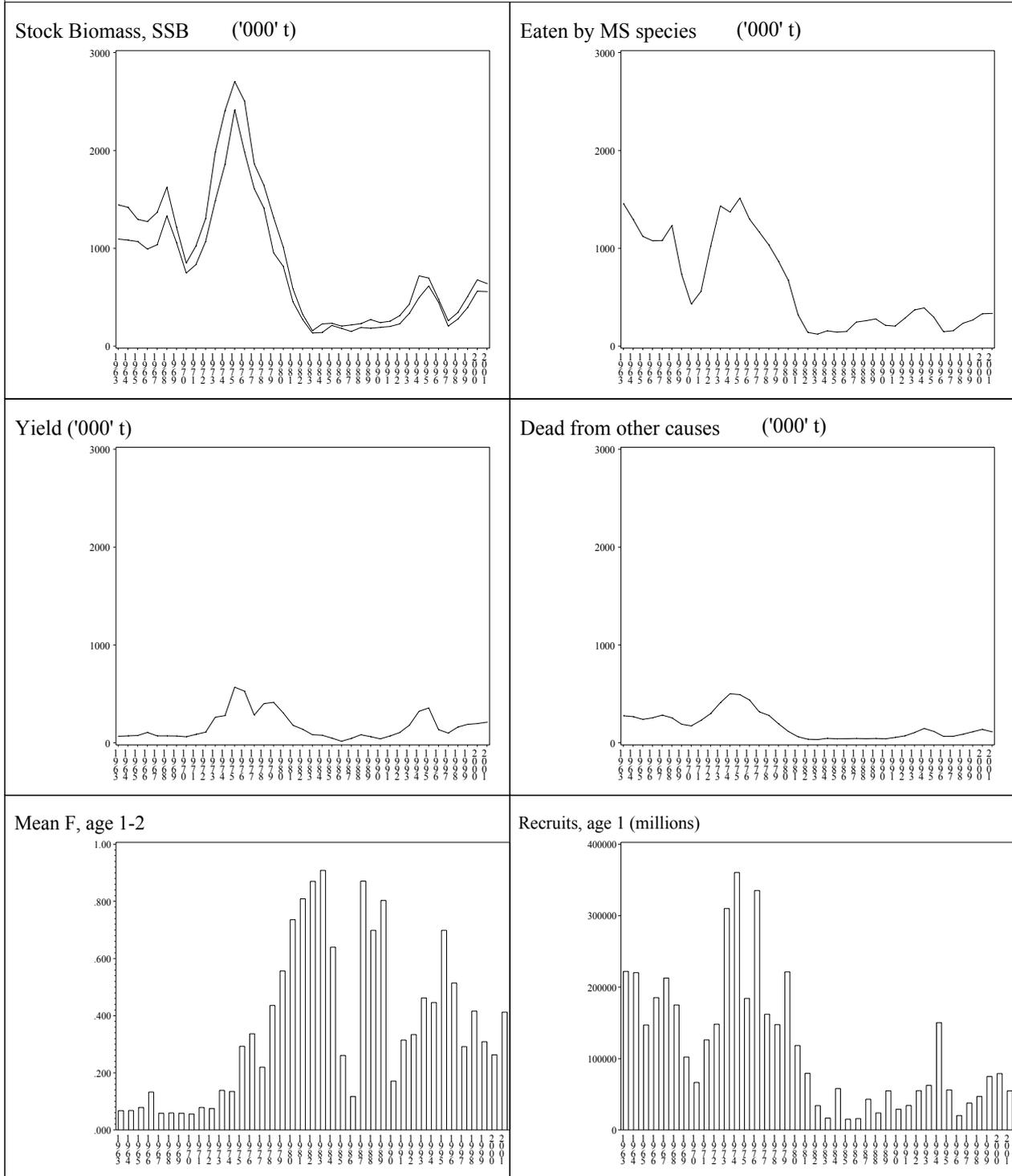


Figure 4.1 (Cont'd)

MSVPA summary for the years 1963 - 2001

Species: Whiting

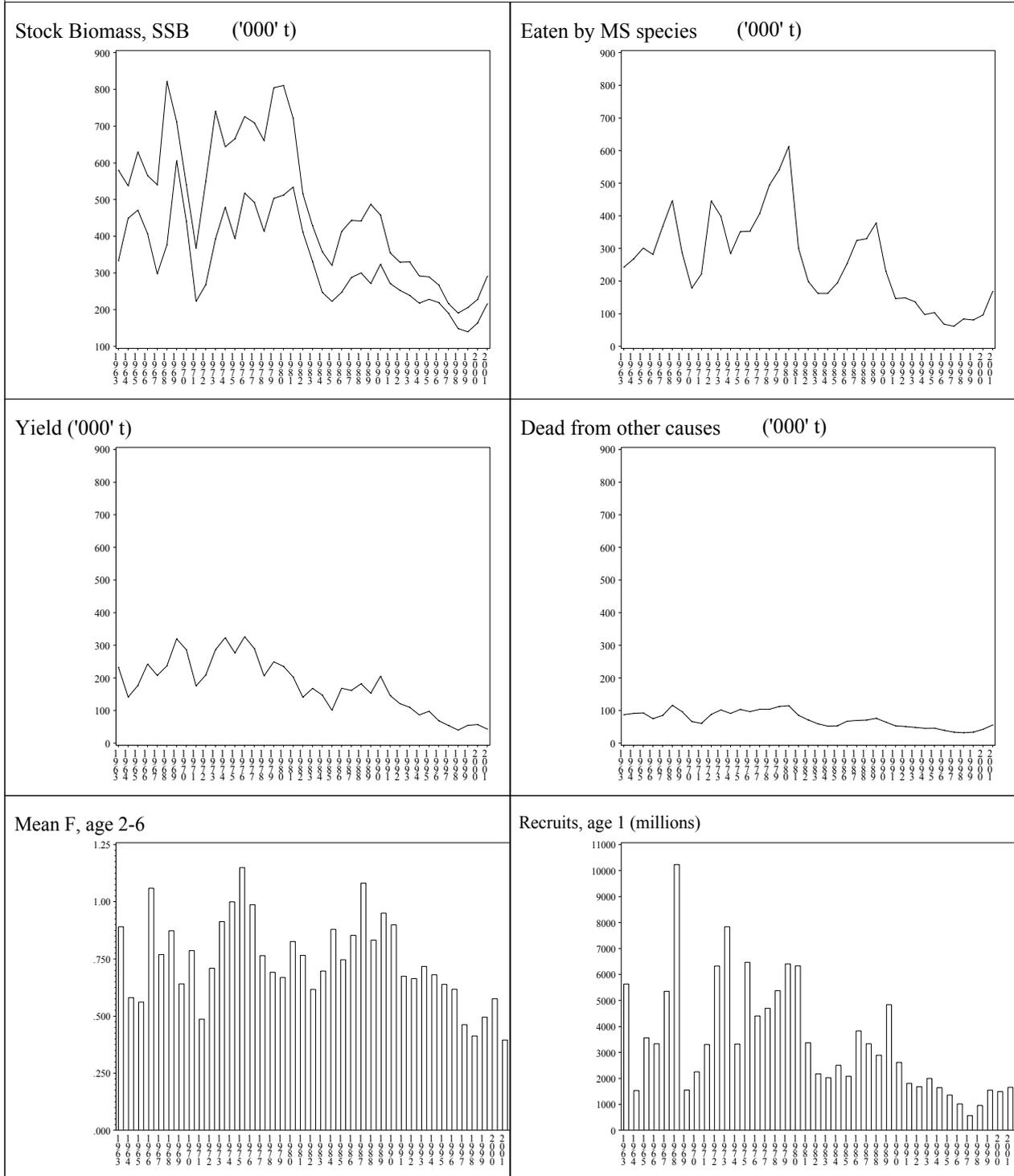


Figure 4.1 (Cont'd)

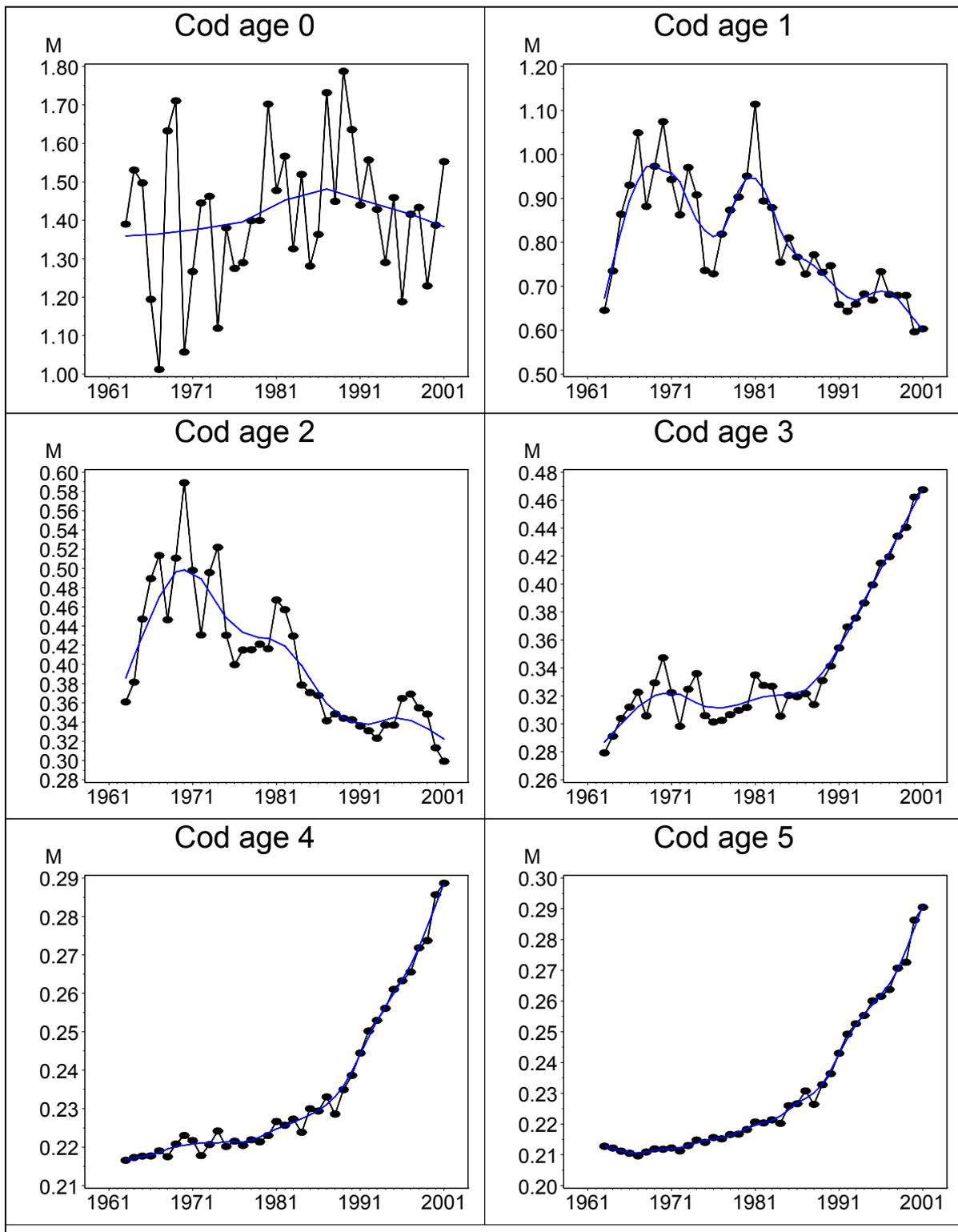


Figure 4.2 Natural Mortalities (M1+M2) from MSVPA key-run, estimates and Loess fitted trend line.

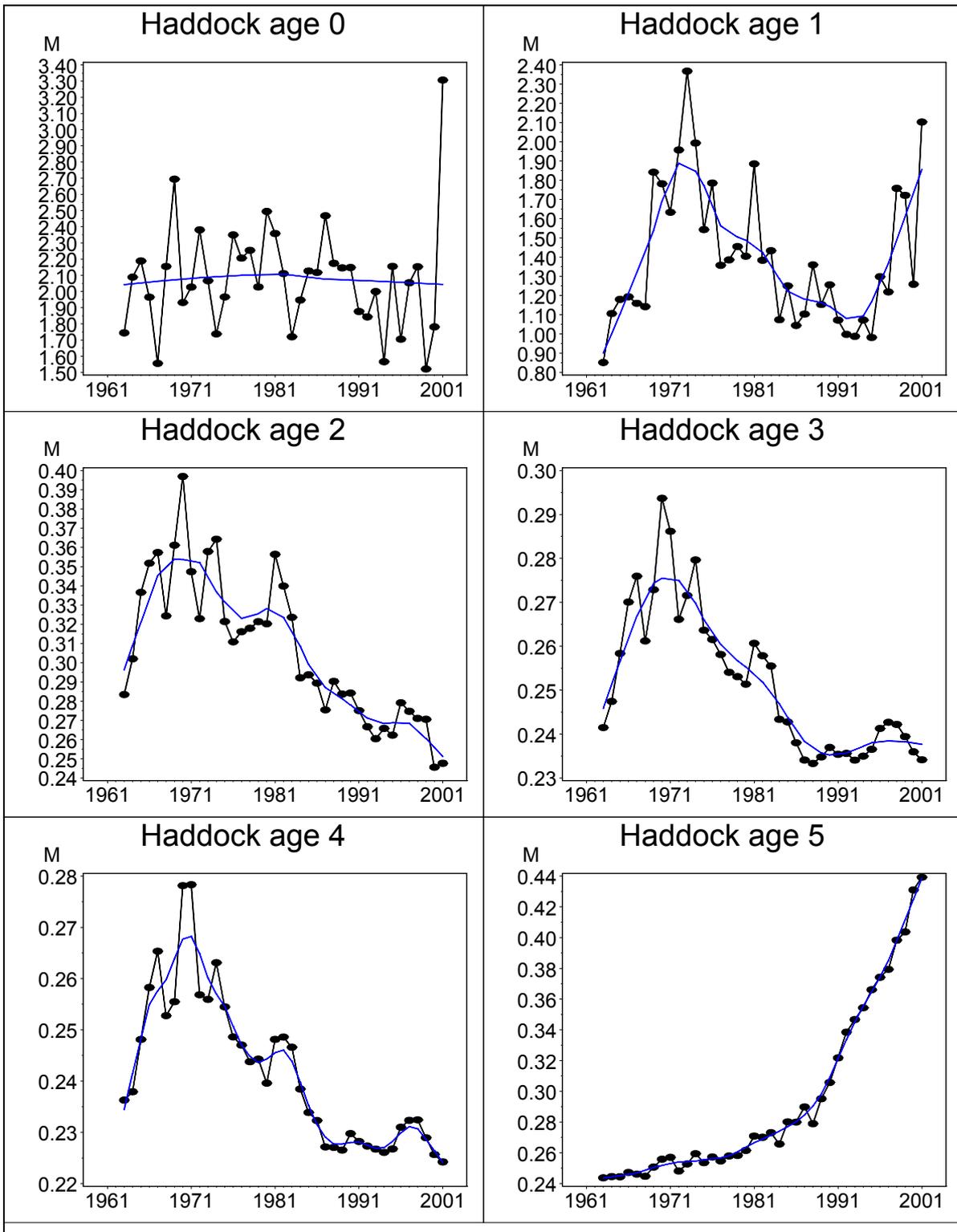


Figure 4.2 Natural Mortalities (M1+M2) from MSVPA key-run, estimates and Loess fitted trend line. (Cont'd)

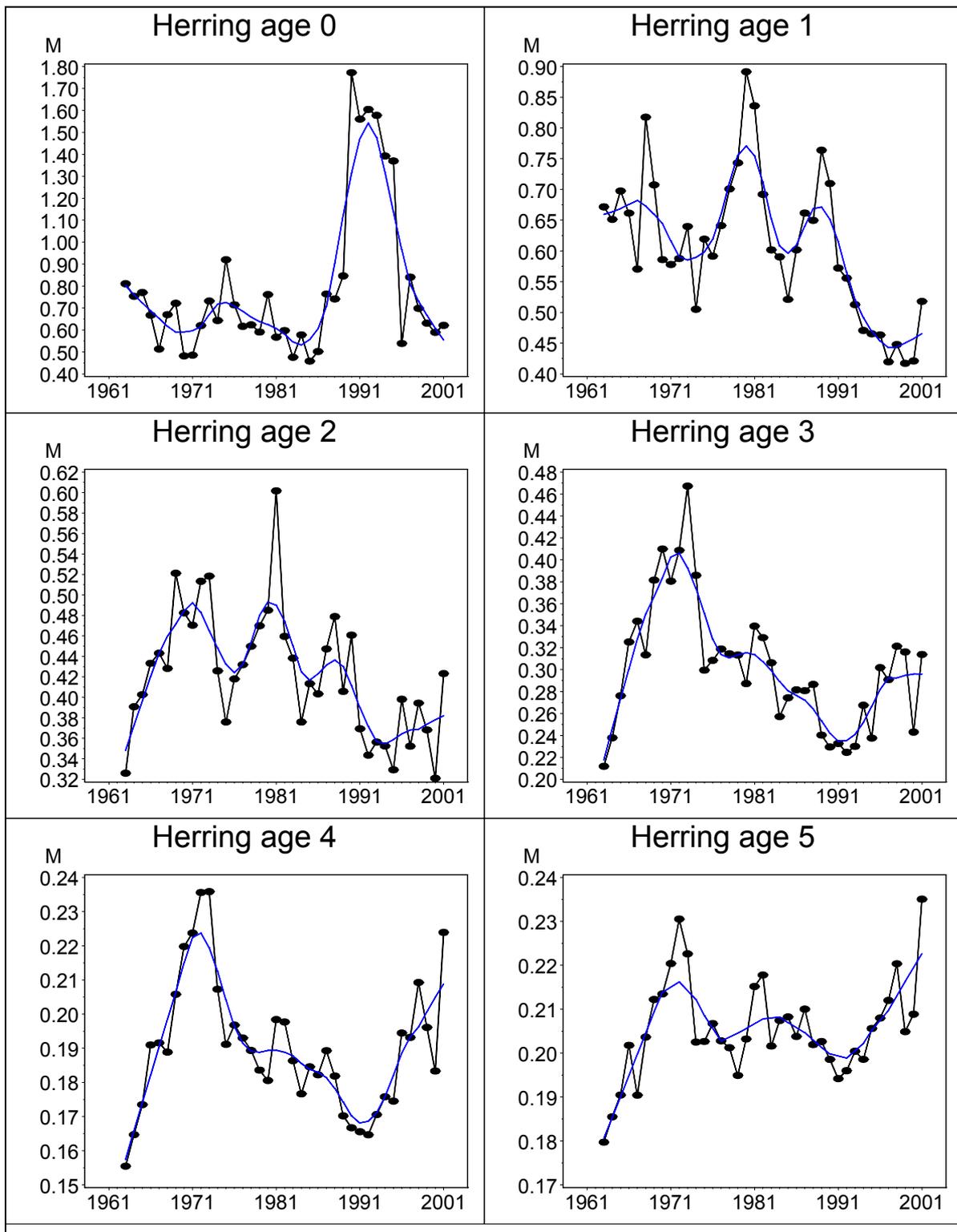


Figure 4.2 Natural Mortalities (M1+M2) from MSVPA key-run, estimates and Loess fitted trend line. (Cont'd)

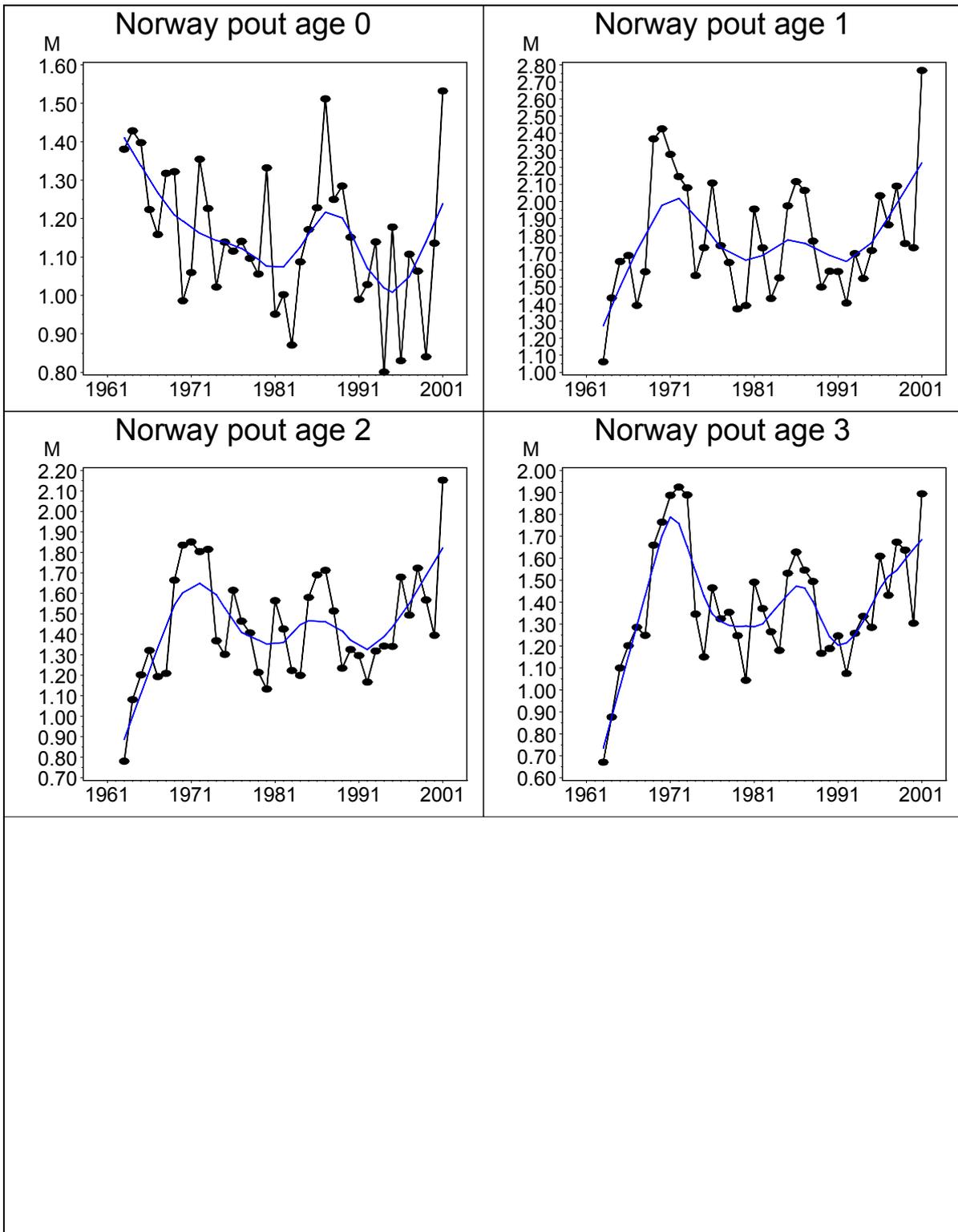


Figure 4.2 Natural Mortalities (M1+M2) from MSVPA key-run, estimates and Loess fitted trend line. (Cont'd)

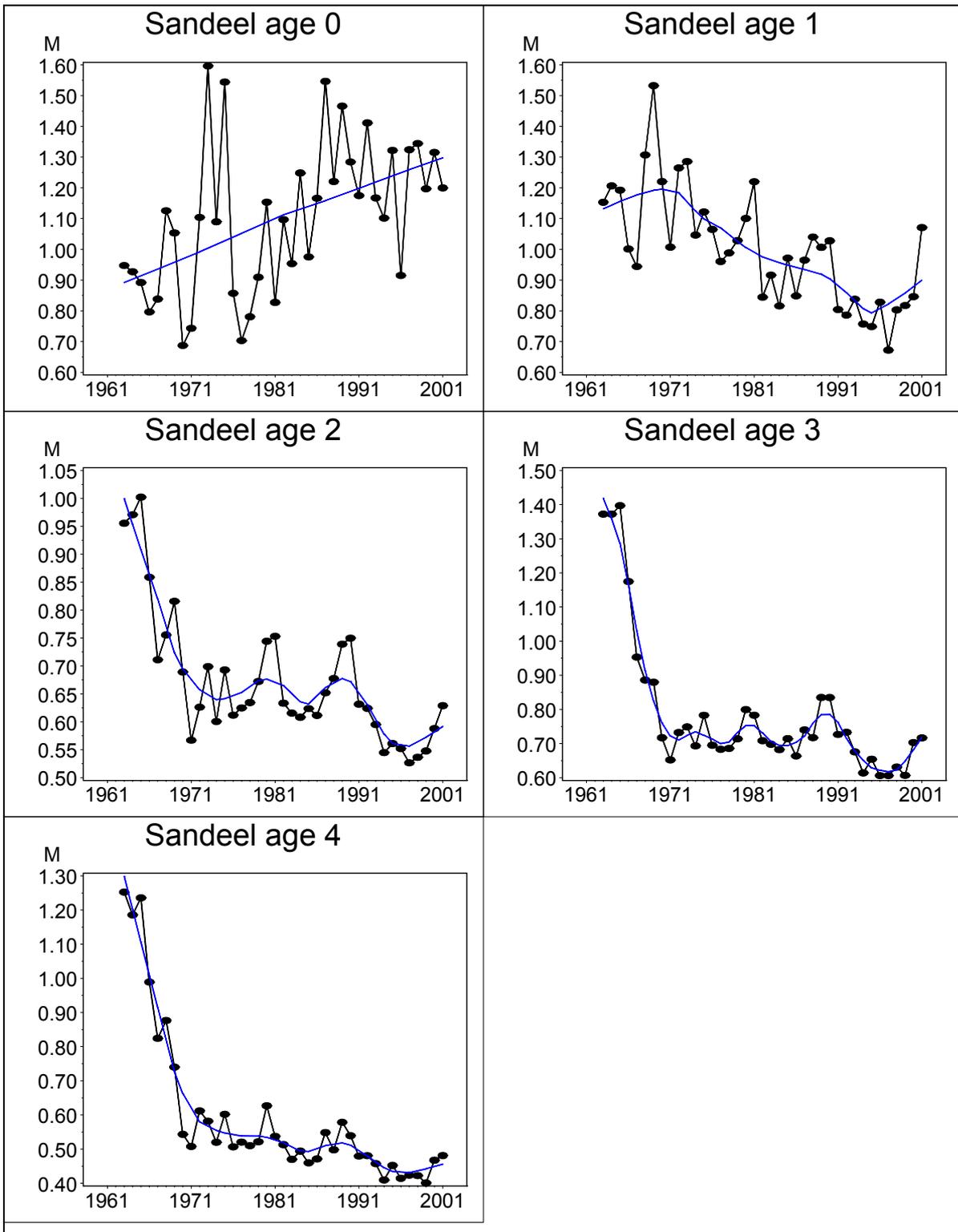


Figure 4.2 Natural Mortalities (M1+M2) from MSVPA key-run, estimates and Loess fitted trend line. (Cont'd)

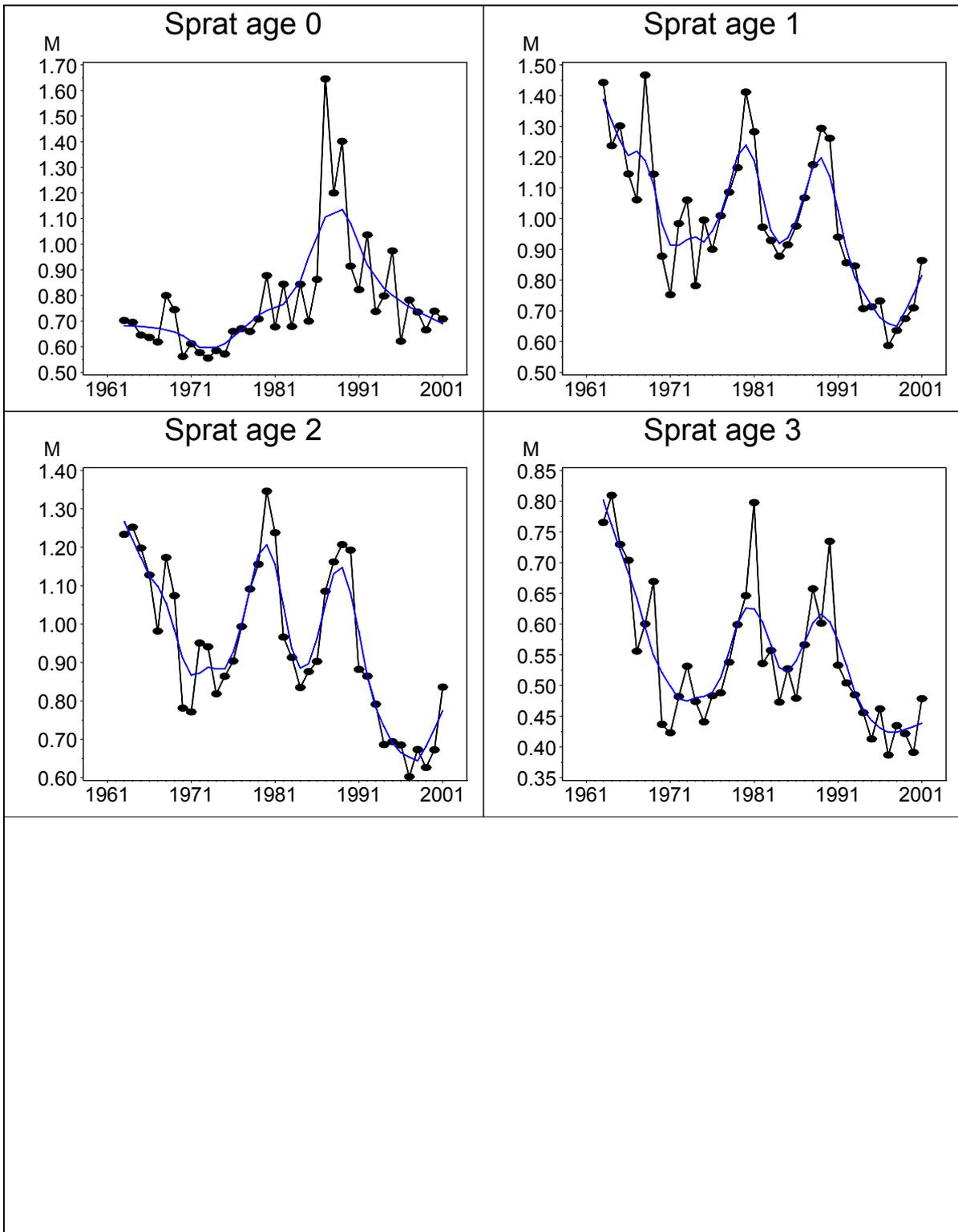


Figure 4.2 Natural Mortalities (M1+M2) from MSVPA key-run, estimates and Loess fitted trend line. (Cont'd)

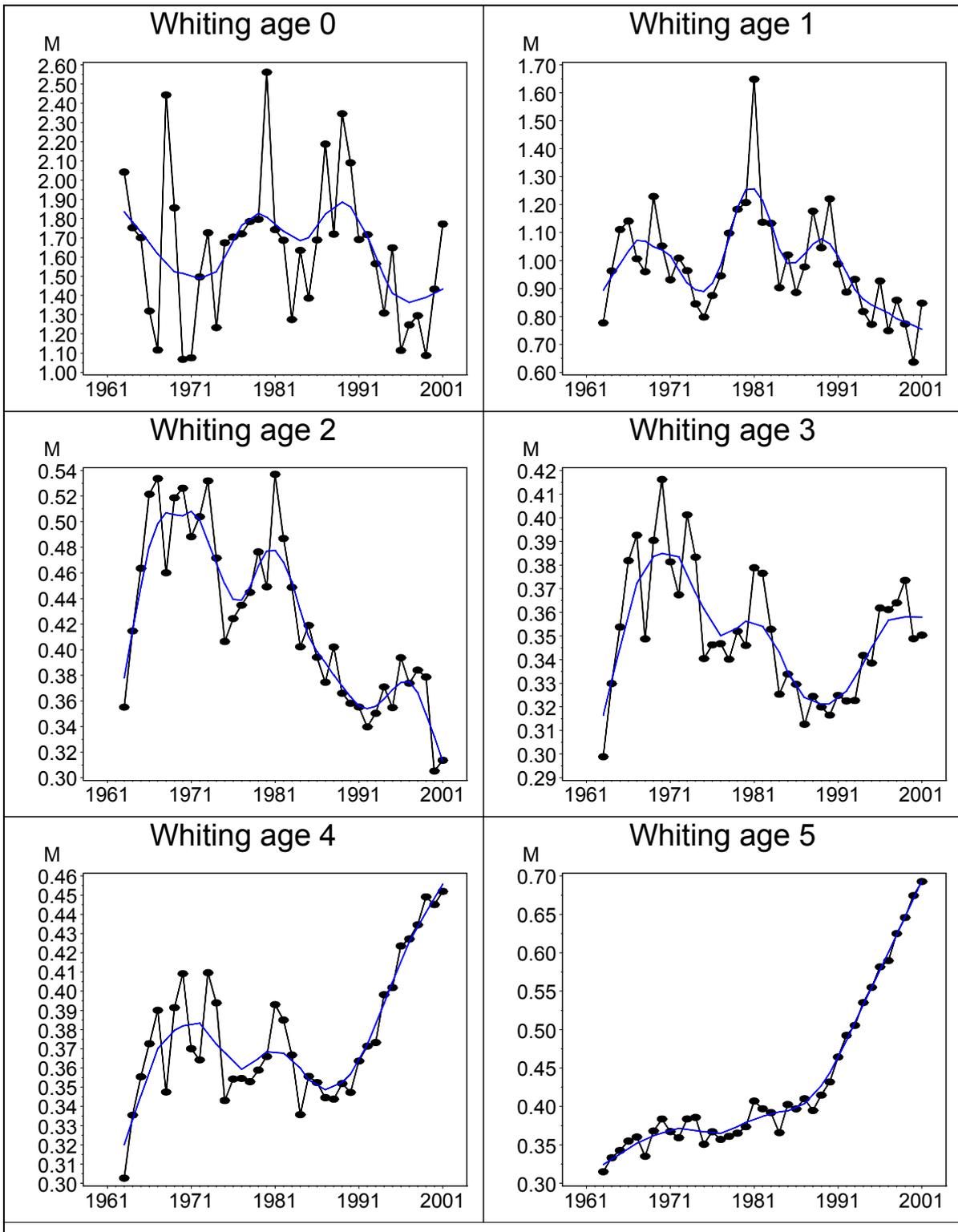


Figure 4.2 Natural Mortalities (M1+M2) from MSVPA key-run, estimates and Loess fitted trend line. (Cont'd)

5 SINGLE-SPECIES REFERENCE POINTS IN A MULTISPECIES FRAMEWORK

TOR a) evaluate the effect of applying single-species reference points in a multispecies framework, with particular reference to limit and precautionary reference points as presently proposed by ICES in the North Sea

5.1 Background

In the proposed framework for revising ICES precautionary reference points (ICES 2003a), the key element is the \mathbf{B}_{lim} , and from which other reference points are derived from that. \mathbf{F}_{lim} is derived as the F which leads to an equilibrium SSB at \mathbf{B}_{lim} . The \mathbf{B}_{pa} and \mathbf{F}_{pa} are derived taking assessment error into account, so that when the stock is assessed to be at \mathbf{B}_{pa} , the probability that it actually is below \mathbf{B}_{lim} should be small, and similar for \mathbf{F}_{pa} . ICES regards avoiding recruitment impairment as the primary objective of its implementation of the precautionary approach. The process of revising reference points in ICES is still in progress, and few reference points have been revised thus far.

The terms of reference for this group (SGMSNS), are to what extent reference points derived within a single-species framework are valid when multispecies interactions are taken into account. To propose a full set of reference points based on multispecies assessments is far beyond what can be achieved, currently. SGMSNS therefore took the approach to address a limited set of specific questions. The considerations are restricted to the limit points, since they are the basis for the other reference points.

5.2 Effects of multispecies interactions

The only multispecies interaction that is accounted for by MSVPA is predation mortality by model species. Therefore, only part of the shortcomings of a single-species framework is considered, and not effects like growth dependence on food availability, competition between species, influence of predation on pre-recruits, etc.

Variable natural mortality will influence estimates of historical recruitment, and to a lesser extent estimates of historical SSBs. This will change the historical stock-recruitment data, which are the basis for deciding on \mathbf{B}_{lim} . No attempt was made during this meeting to reassess \mathbf{B}_{lim} -values. This was partly because there is no universally accepted method for deriving \mathbf{B}_{lim} from stock-recruit data. Additionally, recruitment estimates by MSVPA may be quite sensitive to noise in the stomach data. The influence of the grey gurnard abundance on estimated cod recruitment may be an example (see Sections 3 and 4 of this report). Grey gurnards were excluded from the present key run for that reason, but there may be other, less obvious examples.

The link between \mathbf{B}_{lim} and \mathbf{F}_{lim} needs to be revisited when moving to a multispecies context, for two reasons:

1. The equilibrium F corresponding to a given SSB is no longer unique, because it depends on the state of the other stocks in the system.
2. When F-values have been specified for all species, there is equilibrium with a unique set of SSB values. The opposite may not be true. This point could not be explored in depth during the meeting, but when attempting to find a vector of Fs corresponding to a given vector of Bs, the search did not converge. Thus, if one has decided on a set of SSB values, there may be several possible combinations of F values that lead to that set of SSBs. Hence, additional constraints will have to be specified in order to find unique values for F.

Therefore, there is no unique determination of F corresponding to the derivation of \mathbf{F}_{lim} from \mathbf{B}_{lim} . Rather, \mathbf{F}_{lim} would depend on how other stocks are exploited. To outline the likely range of each \mathbf{F}_{lim} would need screening a wide range of F-levels for all species. In the multispecies setting, the joined limits $SSB > \mathbf{B}_{lim}$ for all species translates into a multidimensional parameter-space for F. The estimation of the boundaries of this space is not straightforward. First, it is not quite sure whether the outcome constitutes a reasonably behaved, continuous space. Widely diverging exploitation patterns might satisfy all constraints on SSB, while intermediate regimes might violate constraints, and a unique solution might therefore not exist. Secondly, consideration of the whole parameter-space would include options like closing fisheries on prey species, in order to increase the yield of predatory species. Evidently, the parameter-space may include quite unrealistic grounds. However, setting limits to potential exploitation scenarios is far beyond the competence of the current study group. Thirdly, in the absence of an objective, common to all species (e.g. maximum total yield, or net income, etc), a complex multidimensional hull covering all F-levels for which $SSB > \mathbf{B}_{lim}$ for all species remains. Assuming this complex space might be described in a unique and consistent way, it would be impossible to communicate this to any human reader.

5.3 Scenarios

The present approach is to study the sensitivity of SSB to the introduction of predation mortality at some selected F-values in a long-term equilibrium. Since no new evaluation of stock-recruitment relationships were made, recruitment was assumed to be stable. Therefore, only the effect of altered natural mortalities on the equilibrium is studied.

Three sets of predictions were made:

1. With all F-values at F_{lim} .
2. With F-values at the average of the last 3 years (*F status quo*)
3. F as it was in the 1960s. This is taken to represent a period with more moderate exploitation. However, herring was heavily exploited and their stock became depleted in the mid 1970s.

The currently adopted limit points are given in Table 5.1. For some species, ICES has not defined B_{lim} , F_{lim} or both. For the present purpose, values were derived as noted in the table footnotes.

Table 5.1Values used as F_{lim} and B_{lim}

| Species | B_{lim} (000 t) | F_{lim} | B_{pa} (000t) | F_{pa} |
|-------------|-------------------|-------------------|-----------------|-------------------------|
| Cod | 70 000 | 0.86 | 150 000 | 0.65 |
| Haddock | 100 000 | 1 | 140 000 | 0.7 |
| Whiting | 225 000 | 0.9 | 315 000 | 0.65 |
| Saithe | 106 000 | 0.6 | 200 000 | 0.4 |
| Herring | 800 000 | 0.35 ^a | 1 300 000 | 0.25(0.12) ^e |
| Sprat | - | 0.9 ^b | - | - |
| Mackerel | - | 0.26 | 2 300 000 | 0.17 |
| Norway Pout | 90 000 | 1.09 ^c | 150 000 | - |
| Sandeel | 430 000 | 0.86 ^d | 600 000 | - |
| Plaice | 210 000 | 0.6 | 300 000 | 0.3 |
| Sole | 25 000 | 0.56 ^a | 35 000 | 0.4 |

- F_{lim} set at 1.4 times F_{pa}
- Average of the 5 highest estimates from single-species mode assessment in 4M
- Average F between 1974 and 1983 (ICES 2002d) single-species assessment
- Mean of the 5 highest F values from (ICES 2002d) single-species assessment
- Separate F applied by age groups 0.25 ages 2-6 and 0.12 ages 0-1 (ACFM 2002)

The F-values taken to represent the 1960s, as well as the F-values representing the *status quo* were derived from MSVPA runs. These values are different when derived in a single-species mode and a multi species mode. In the predictions, single-species predictions were made with F-values derived from the single-species runs of MSVPA, and the multispecies predictions with F-values from multispecies MSVPA runs. The actual values are given in are given in Table 5.2.

Table 5.2

F-values used in simulations.

| Species | F_{lim} (current) | Single | Multi- | Single | Multi- | |
|-------------|------------------------|------------------------|------------------------|---------------------|---------------------|------|
| | | species F_{1960s} | species F_{1960s} | species F_{sq} | species F_{sq} | |
| Cod | b) | 0.86 | 0.55 | 0.53 | 1.11 | 0.94 |
| Haddock | | 1 | 0.86 | 0.85 | 1.05 | 1.25 |
| Whiting | | 0.9 | 0.82 | 0.77 | 0.55 | 0.90 |
| Saithe | | 0.6 | 0.37 | 0.37 | 0.28 | 0.28 |
| Herring | | 0.35 | 0.73 | 0.68 | 0.32 | 0.32 |
| Sprat | | 0.9 | 0.09 | 0.07 | 0.33 | 0.33 |
| Mackerel | a) | a) | a) | a) | a) | a) |
| Norway Pout | | 1.09 | 0.32 | 0.36 | 0.58 | 0.56 |
| Sandeel | | 0.86 | 0.22 | 0.15 | 0.66 | 0.73 |
| Plaice | | 0.6 | 0.26 | 0.26 | 0.42 | 0.42 |
| Sole | | 0.56 | 0.31 | 0.31 | 0.57 | 0.57 |

- Kept constant because mackerel is taken as an external predator (see ICES 2002b)
- Only cod in the North Sea proper is considered in the MSVPA, comprising approx. 85% of the cod stock assessed by ICES

5.4 Scenario results

The main question that was addressed was whether the equilibrium value changes, to an extent that the objective ‘to avoid impaired recruitment’ is jeopardised, when moving from single to multispecies framework. Furthermore, some consideration was given to how valid this result would be for other combinations of fishing mortality. Finally, the long-term consequences of the current exploitation regime were considered.

The parameters considered were SSB, yield, and the total annual removal.

Figure 5.1. shows the comparison between single and multispecies runs. Figure 5.2. shows a comparison across fishing mortalities.

5.4.1 Contrast between single and multi species results

Figure 5.3 shows in detail the equilibrium SSB when F is at the currently adopted F_{lim} (or substitutes for undefined values) for all stocks, as percent of the currently adopted B_{lim} values. Apparently, the F_{lim} leads to SSB well above B_{lim} for several species, and close to B_{lim} for the others. The difference between single-species and multispecies is not great, although the equilibrium SSB is somewhat lower for most species in the multispecies framework. For the other F -regimes simulated here, there are clear differences between single- and multispecies scenarios, but hardly of an order of magnitude that would lead to drastically different conclusions in qualitative terms. However, the ‘total removal’ differs considerably between single and multispecies projections for several species (Figure 5.2), indicating that the natural mortality assumed in single-species assessments may not be adequate, and in some instances considerably underestimated.

5.4.2 Predator- prey interactions

As noted above, an F_{lim} value derived by an equilibrium correspondence with B_{lim} is conditional on the exploitation of other species in the system.

Some influences on long-term behaviour are intuitively clear:

- Primary effects of predation: If the exploitation of predators is reduced, thereby increasing their abundance, the survival of the prey will be poorer, and the equilibrium SSB for the prey will be lower than expected based on the prey exploitation rate alone. Predation of saithe on haddock is the prime example (Figure 5.4), MSVPA estimates for the abundance of haddock is primarily driven by saithe predation. Contrary to the single-species line of reasoning, the haddock stock will greatly benefit from a regime based on F_{lim} for all (predator and prey) species.
- Secondary effects of predation: The survival of prey species will depend on the abundance of other prey species, that is: prey species may replace each other in predator’s diets. This effect will be predator specific, and its severity related to the predator’s abundance. Haddock is predominantly eaten by saithe and cod. The survival of haddock will therefore depend on the abundance of other prey species that are also important for saithe and cod, that is: primarily Norway pout and to a lesser extent herring. Consequently, the exploitation of Norway pout and herring will affect the stock of haddock, though the predation by saithe and cod.
- Tertiary effects of predation: For a cannibalistic predator, survival at a young age will depend on the availability of alternative prey. For cod and whiting, cannibalism appears to be a major process. Altering the abundance of typical prey for cod and whiting (e.g. haddock, Norway pout and whiting for cod; haddock, sandeel, and sprat for whiting) will affect the cannibalistic predation rate, and thereby affect all other prey abundances. In the current predictions, high and low exploitation rates were simulated, more or less consistently over all species. Higher prey abundance therefore coincided with higher predator abundance, which may have masked potential tertiary effects. For cod as well as for whiting, however, the differences between high and low exploitation scenarios (F_{lim} respectively F_{60s}) in single-species mode greatly exceed those in multispecies mode. Apparently, cannibalism constitutes a negative feedback, not moderated by the predicted prey abundance levels in the simulated scenarios.

It is not clear to what extent current MSVPA results adequately cover secondary and tertiary effects induced by prey replacement and cannibalism, because of data limitations and non-linear model behaviour.

Some results are less intuitive. The abundance of haddock seems to be strongly negatively influenced by the abundance of saithe. In the *status quo* F regime, haddock is severely reduced. This may be because at present, the fishing mortality of saithe is low, and the equilibrium saithe biomass high. As noted above, saithe is a main predator on haddock, in addition to cod and whiting. Thus, a naive interpretation would be that the haddock would be severely depleted unless the saithe is heavily exploited. There may be cases where the response by the system is heavily dependent on a limited number of data, and if these data are poor, it may give rise to unrealistic results. This may be one such example. The sensitivity of the haddock to the saithe abundance was noted already in 1990 and in 1997 (ICES 1991, ICES 1997), but was not explored further at the time.

Grey gurnards were included as predator in last years key-run. This had a large impact on the recruitment estimates for cod, which appeared to be quite strongly positively correlated to the abundance of gurnards (ICES 2002b and sec 3.1). Cod is a minor part of the diet of gurnards, but since the total consumption by gurnards is substantial, and cod only appeared as 0-group, their assumed consumption on cod was large compared to the amount of cod at the end of the recruiting year emerging from the VPA. Partly because of this, the gurnards were not included in this year's runs of MSVPA.

Given the heterogeneous quality of the individual data, in particular the stomach data, similar undue effects may exist that are still unrecognised. Thus, as a minimum, counter-intuitive results should be traced back to the data from which they originate before being accepted at face-value.

5.4.3 Catches

As might be expected, the difference between single and multispecies equilibrium values, with respect to catches is largely consistent with the SSBs at F_{lim} . A higher SSB, representing a larger stock, also leads to a higher catch.

5.4.4 Total removals

The amount of total removals (by predators and the fishery) was quite different in the single and multispecies runs, as noted above. It is also noteworthy however, that the total removal was rather similar between the F-regimes. This may suggest that when the recruitment is kept fixed, the production of the system as a whole is fairly stable. However, all the regimes studied here represent rather heavy exploitation of most species, and further explorations are needed in order to draw any firm conclusions.

The run with F *status quo* was made to evaluate the performance of the current exploitation of the North Sea. Again, the results are broadly comparable with those from single-species projections, with the exception of haddock, which is discussed above. The projection indicates that most stocks will be quite close to B_{lim} . In particular, cod and will be just below B_{lim} , sandeel well below, while the others are above B_{lim} to a greater or lesser extent.

5.5 Conclusions

The equilibrium biomass at a given fishing mortality for a prey species will depend on the exploitation and hence the abundance assumed for the other species, both predators and prey, in the system. Therefore, F_{lim} values derived as proposed by SGPA are conditional on the exploitation regime in the system as a whole, and may need to be revised if that changes. The validity of the F_{lim} values derived from B_{lim} in a single-species framework depends on how well the assumed natural mortalities represent the actual state of the system. At an F_{lim} exploitation regime, the difference between values derived in a single-species and a multispecies framework were relatively small.

The present calculations have been made assuming future recruitment at arithmetic mean level of the past. This assumption may be justified by the requirement that B_{lim} should be such that 'recruitment is not impaired', and consequently F_{lim} values leading to reduced recruitment are not relevant. However, this restricts the study to the effect of predator – prey interactions on SSB per recruit and yield-per-recruit.

With the exception of haddock, the overall conclusion of the current comparison of single and multi species predictions of three selected management scenarios, is that currently effective F_{lim} values are adequate to ensure B_{lim} provided recruitment is not impaired at B_{lim} , that is: the M values used in single-species assessment adequately represent predation mortalities for the current situation. For haddock, the model predicts a collapse in SSB, due to predation by saithe.

If F_{lim} values are to be derived in a multispecies framework, the exploitation regime for the whole system has to be specified. Setting limits to potential exploitation scenarios is far beyond the competence of the current study group. For the revision of reference points currently in progress, a simple procedure could be to find the F corresponding to B_{lim} species by species, leaving the other F -values at specified realistic values. These F_{lim} values may be informative about adequate values under the specified exploitation regime, but should still be treated with some caution due to the sensitivity to data that are of variable quality. Such calculations may be undertaken in the future, but requires that a framework for the overall exploitation is specified.

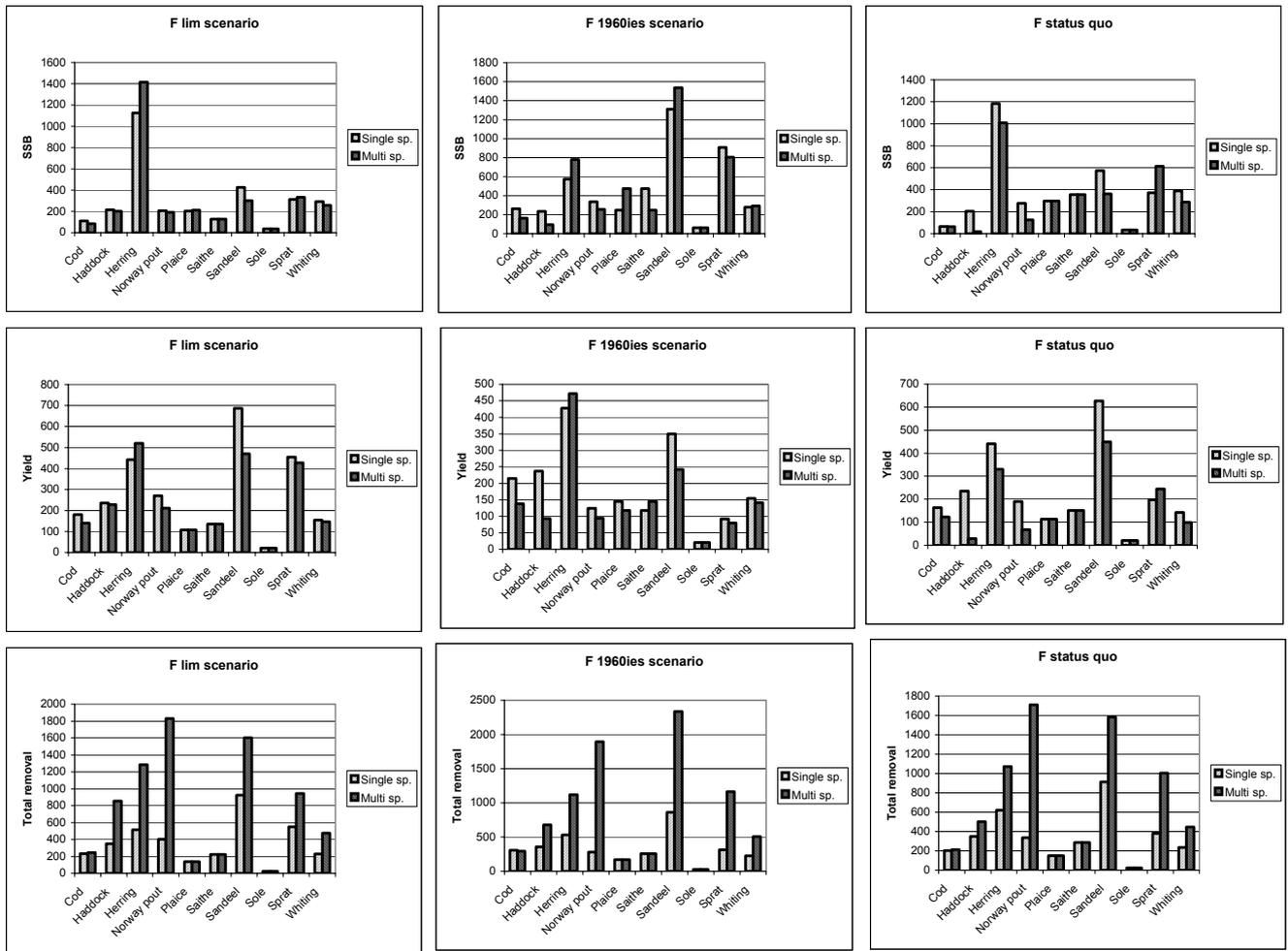


Figure 5.1 Comparison of single-species and multispecies long-term predictions for 3 different F-scenarios. Upper: SSB, Middle: Yield, Bottom: total removals (F + M)

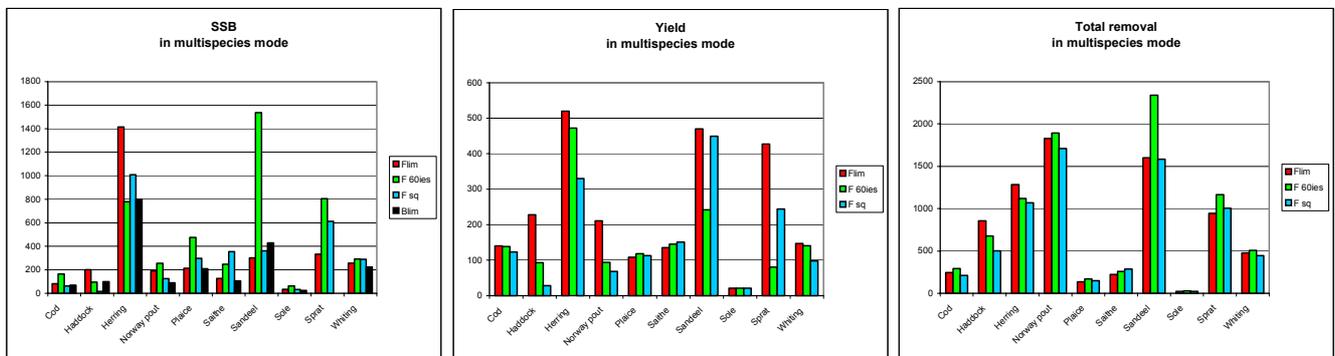


Figure 5.2 Comparison of SSB, Yield and total removal with 3 different F-scenarios in multispecies long-term prediction. B_{lim} values are included in the figure showing SSB.

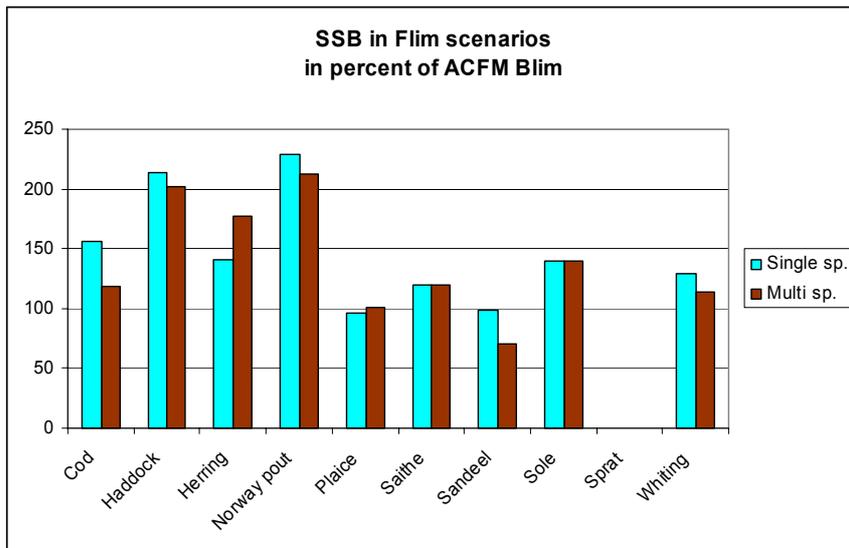
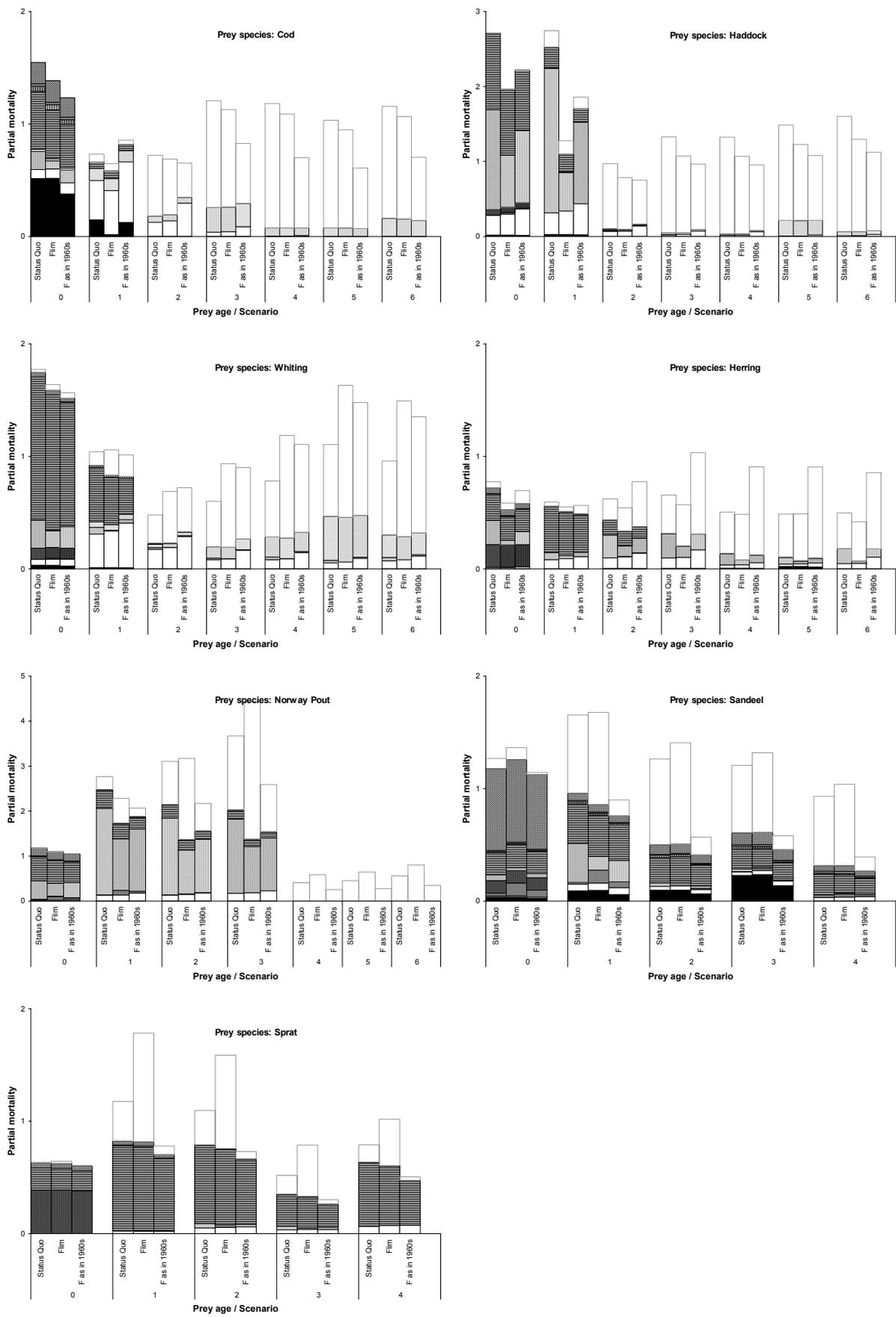


Figure 5.3 Comparing percentage deviation from B_{lim} in long-term equilibrium.



■ Birds □ Cod ■ Haddock ■ Horse mackerel □ Saithe □ Seals ■ Whiting ■ Rays ■ North Sea Mackerel ■ Western Mackerel □ Fisheries

Figure 5.4 Summary of partial mortalities (M2 and F), by predator species and age, at equilibrium under the three simulated regimes: *status quo* fishing mortality, currently advised F_{lim} levels, and conditions conforming to the 1960s regime.

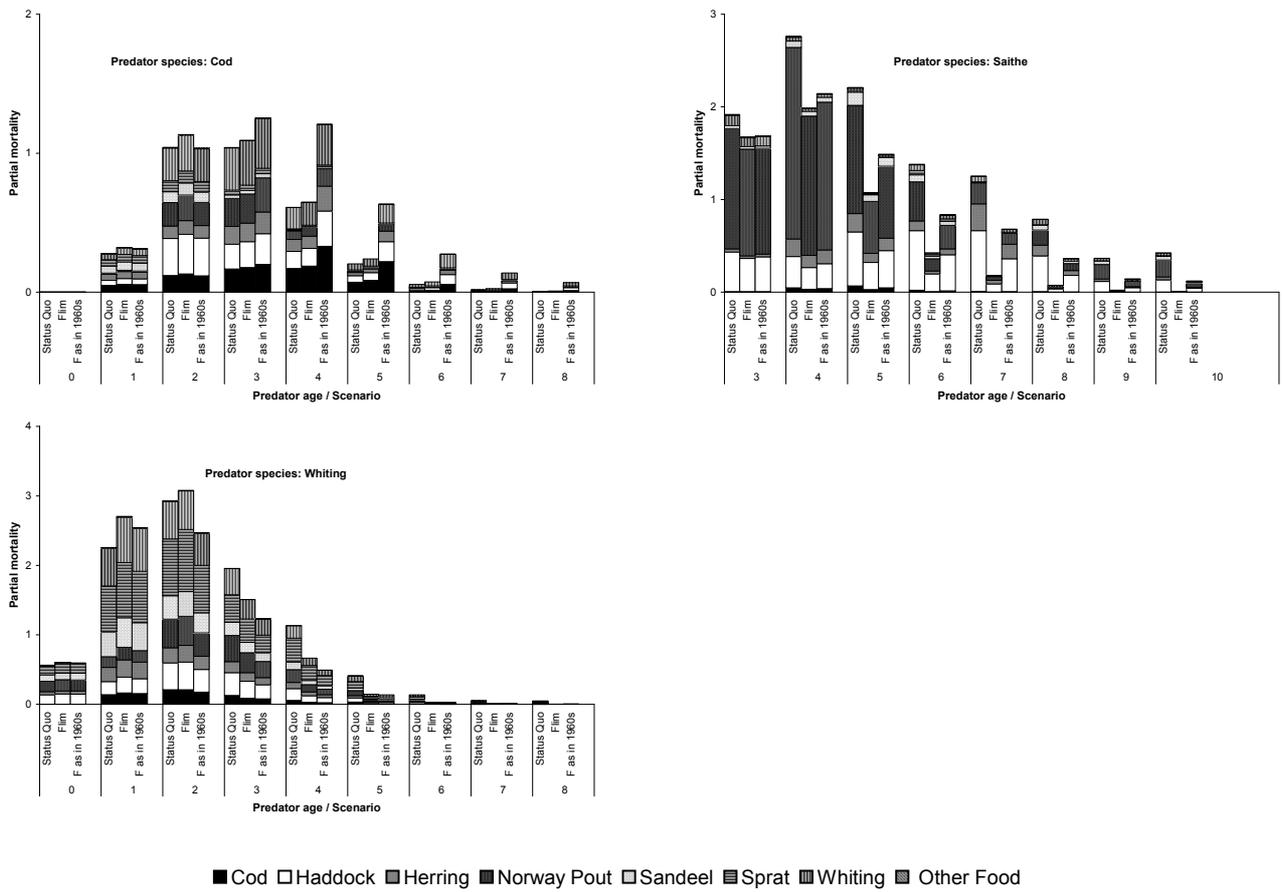


Figure 5.5

Summary of partial mortalities (M2 and F), by prey species and age, at equilibrium under the three simulated regimes: *status quo* fishing mortality, currently advised F_{lim} levels, and conditions conforming to the 1960s regime.

6 EVALUATION OF THE COD RECOVERY PLAN TAKING INTO ACCOUNT BIOLOGICAL INTERACTIONS

TOR b) for the 2003 SGMSNS includes evaluation of the cod recovery plan:

- b) evaluate the single-species recovery plan proposed for North Sea cod by taking into account biological interactions;

Over the past 2-3 years, a number of different management measures (e.g. area closure, effort reduction, drastic TAC cuts) have been applied in the attempt to rebuild the North Sea cod stock. The latest proposal from the European Commission (Reg 2003/0090 (SNS)) includes both effort reduction/control and Harvest Control Rules (HCR) for setting TACs. Effort reduction requires knowledge of national catch and effort data (by fleet), and these are not yet available. Therefore, this analysis focussed on the effect of applying HCR in a single and multispecies context.

6.1 Procedure for setting Total Allowable Catches

Article 6 quoted from the EC Reg 2003/0090 (SNS):

1. Each year, the Council shall decide by qualified majority on the basis of a proposal from the Commission on a TAC for the following year for each of the depleted cod stocks.

2 The TACs shall not exceed a level of catches which a scientific evaluation carried out by the STECF in the light of the most recent report has indicated will result in an increase of 30% in the quantities of mature fish in the sea at the end of the year of their application compared to the quantities estimated to have been in the sea at the start of that year.

3. The Council shall not adopt a TAC whose capture is predicted by the STECF, in the light of the most recent report of the ICES, to generate in its year of application a fishing mortality rate greater than the following values:

(fish stock and fishing mortality rate)

Cod in the Kattegat 0.60

Cod in the North Sea, Skagerrak and Eastern Channel 0.65

Cod to the West of Scotland 0.60

Cod in the Irish Sea 0.72

4. Where it is expected that application of paragraph 2 will result in a quantity of mature fish at the end of the year of application of the TAC in excess of the quantity indicated in Article 3, the TAC shall be set at a level of catches which, following a scientific evaluation carried out by the STECF in the light of the most recent report of ICES, will result in a quantity of mature fish at the end of the year being equal to the target level indicated in Article 3. [Comment, Article 3 refers to B_{pa} values]

5. Except for the first year of application of this Article,

(a) in the event that the rules provided for in paragraphs 2 or 4 would lead to a TAC which exceeds the TAC of the preceding year by more than 15%, the Council shall adopt a TAC which shall not be more than 15% greater than the TAC of that year or;

(b) in the event that the rule provided for in paragraphs 2 or 4 would lead to a TAC which is more than 15% less than the TAC of the preceding year, the Council shall adopt a TAC which is not more than 15% less than the TAC of that year.

6. Paragraphs 4 or 5 shall not apply when their application would entail an exceeding of the values laid down in paragraph 3.

The regulation also includes an Article 7, for setting TAC in exceptional circumstances ($SSB < B_{lim}$), but gives no HCR for such conditions.

6.2 Methodology

Articles 6 & 7 of the Commission's proposal have been translated into a computer program, 4M-HCR, (Working Document 3), which calculates forecast F from HCR. The 4M forecast program is used as an external procedure for estimating stock sizes, catches *etc.* given a set of forecast Fs

The procedures for applying HCR and 4M forecast can be outlined as follows:

1. Based on a VPA (4M), estimate initial stock size, recruitment function, prediction F, etc.
2. Write initial stock size, prediction F *etc* for use in 4M prediction
3. Use 4M to make a prediction for the next year. Write 4M output on ASCII files.
4. Read output from 4M prediction and apply HCR routine for estimation of F next year (4M-HCR)
5. Write initial stock size next year, prediction F etc for use in 4M prediction (4M-HCR)
6. Go to 3 until final prediction year has been reached

4M-HCR will automatically make the predictions for a specified number of years.

The HCRs have been implemented in a generic way such that they can be used for a number of species. Each species has a set of input reference points, and minimum and maximum TAC change.

Mean weight in the sea, mean weight in the catch, residual natural mortality (M1) and proportion mature were assumed fixed throughout whole forecast period. When HCR is used to calculate F for the next year it was assumed that recruitment and predation mortality (M2) were unchanged. The assumption of fixed M2 is undoubtedly wrong as the predator and prey stocks change during the year. The error made is however small.

The 4M single- or multispecies key-run (see section 3) was used as the starting point for all simulations. *Status quo* F or F_{pa} were used for year 2002 and HCR were applied from 2003 onwards. This is at least one year too early, as the EC regulation has not yet become official, but the results from the multispecies and single-species scenarios are made for comparison and not to predict the year for cod recovery.

6.2.1 Compilation and implementation of article 6 and 7

Figure 6.1 shows how Article 6 and 7 are transformed into a decision tree for setting fishing mortalities. On the figure, the index "i" refers to the year for which F is estimated using HCR. Index "i-1" refers to values the year before. TAC_1 is thereby the expected TAC for the coming year and TAC_0 is the TAC obtained in the current year. SSB is traditionally measured the 1. January and SSB_0 becomes the SSB measured 1. January of the end of the prediction year and SSB_1 the SSB the following year.

Article 7 of EC Reg 2003/0090 deals with the situation with $SSB_1 < B_{lim}$, but no HCR is given for this situation. We have made a rule saying that SSB should be a least reach B_{lim} at the end of the year, however limited by TAC can only decrease to 50% of the previous year's TAC.

Reference points adjustment.

The "North Sea" cod stock as defined by ICES North-Sea working group encompasses areas IV, IIIa and VIId. This stock has a defined B_{pa} of 150,000 t. The MSVPA multispecies cod stock encompasses a smaller stock area (IV only). For the period 1982-2001 85% of the cod landed in area IV, IIIa and VIId was taken in area IV. B_{pa} and B_{lim} were adjusted by the same percentage, such that B_{pa} becomes 127,500 t. F_{pa} was left unchanged.

Less than 5% of the IV & IIIa haddock are caught in IIIa and reference points for haddock were left unchanged. Approximately 90% of the area VI & VIId whiting is caught in area IV and biomass reference points were adjusted accordingly.

6.2.2 Scenarios using 4M-HCR

In total 17 different HCR scenarios were tested and cod recovery examined using single or multispecies models. Various recruitment relationships and F levels in year 2002 were included (Table 6.1 and 6.2). There was not sufficient time to run scenarios with a fixed average recruitment derived e.g. from the full time-series or from the most recent years

6.3 Results

6.3.1 Single-species Predictions

Scenario 1 : Without HCR and F at F *status quo* cod SSB is predicted to reach B_{lim} in 2010, and does not reach B_{pa} by 2010 (Figure 6.2).

Scenario 2: Without HCR and F at F Cod is predicted to reach B_{lim} in 2005, and B_{pa} in 2009 (Figure 6.2, 6.4 and 6.5).

Scenario 3: With HCR and F_{2002} at F_{pa} cod SSB is predicted to reach B_{lim} in 2004, and B_{pa} in 2007(Figure 6.6 –6.7).

Scenario 4: With HCR and F_{2002} at *status quo* cod SSB is predicted to reach B_{lim} in 2004, and B_{pa} in 2006.

The surprising result that B_{pa} was reached earlier in scenario 4 (HCR with $F_{2000}=F$ *status quo*) than in scenario 3 (HCR with $F_{2002}=F_{pa}$) is due to the HCR specification itself: In the first year when SSB is lower than B_{lim} , F is reduced such that $SSB = B_{lim}$ and TAC is set accordingly. The lower the initial SSB, the smaller the TAC. Due to the limitation in subsequent TAC increase in the following years (max. 15% p.a.) the effect of the dramatic TAC reduction in year 1 lasts on.

In all 4 SSVPA scenarios the SSB and yield of whiting show a tendency to gradually increase and all 4 SSVPA scenarios experience a drop in haddock SSB and yield drop until 2003.

6.3.2 Multi species predictions

Scenario 8: Without HCR and F at F *status quo*, cod SSB will not reach B_{lim} in 2010 (figure 6.8-6.9)

Cod SSB declines. Haddock SSB and yield decline dramatically in the first years, and SSB falls below B_{lim} in 2004 (figure 6.16-6.17). Whiting SSB stays around B_{pa} and yield stays approx. constant (Figure 6.14-6.15). Herring shows an initial increase in SSB and yield but decreases to initial levels; all values remain above B_{pa} (Figure 6.18-6.19). Norway pout SSB exhibits an initial increase up to B_{pa} , but subsequently declines back to B_{lim} around 2007, yield follows a similar pattern (Figure 6.22-6.23). Sandeel SSB is predicted to initially increase but then falls below B_{lim} in 2005. Again yield follows a similar pattern to that of SSB (Figure 6.20-6.21).

Scenario 9: Without HCR and F at F_{pa} cod SSB is predicted to reach B_{lim} in 2005 but will not reach B_{pa} by 2010 (Figure 6.10-6.11).

Cod SSB and yield increase, SSB B_{lim} is reached in 2005, however, B_{pa} is not reached by 2010. Haddock SSB and yield is dramatically reduced (by more than 50%) in the first 5 years and stays at a low level. Whiting SSB and yield remain approximately constant. Herring SSB increases by a factor of 2 and is predicted to remain at a high level. Herring yield increases rapidly until 2004 and then remains at a high level. Norway pout SSB increase rapidly until 2005 (yield follows), exceeds B_{pa} in 2004, but then drops until 2008 and subsequently remains somewhat below B_{pa} . Sandeel SSB is predicted to fall below B_{pa} in 2004 and gradually decreases towards B_{lim} .

Scenario 10: With HCR on cod and F_{2000} at F_{pa} cod SSB is predicted to reach B_{lim} in 2004 and B_{pa} in 2008 (Figure 6.12-6.13).

Cod reaches B_{lim} in 2004 and B_{pa} in 2008 and continues to rise thereafter. Cod yield also increases steadily, however at a lower level compared to scenario 9. Haddock SSB and yield is predicted to decline dramatically (by more than 50%) in the first 5 years and stay at a low level thereafter. Whiting SSB and yield remain approximately constant. Thus haddock and whiting follow a similar trajectory to that described for scenario 9. For herring, Norway pout and sandeel the predictions are also very close to those described for scenario 9.

Scenarios 11-12 mimic the effect of technical interaction effects. As cod, haddock and whiting in most cases are caught in the same fisheries a cod TAC decrease should be followed by a similar decrease in the haddock and whiting fisheries to reduce discards or illegal landings. By the use of HCR on haddock and whiting this mixed fisheries effect is simulated. In general the differences in SSB and yield predictions for cod, haddock and whiting are comparatively small between scenarios 10 to 12, when the stocks without HCR are fished at F_{pa} .

Sensitivity of HCR predictions to the choice of the stock-recruitment relationship:

Generally, it is believed that recovery rate of stocks is highly dependent on the stock-recruitment relationship. To test the effect of S/R relationships covering different periods of time have been used in the predictions. In scenarios 5 - 7 and 16 - 17, only data from the last 10 years have been used for fitting a Ricker stock recruitment relation. The effect was small and did not reverse any of the predicted trends.

Relative share of cod prey in predator stomachs:

Analyses of predicted predation mortalities revealed that the most important predator of older cod age classes were seals. Younger cod age classes were predominantly preyed upon by seabirds, whiting and cod itself. When using scenario 10 (HCR for cod) as an example, the only trend predicted for the years 2002 to 2010 was an increase in cod cannibalism. (Figure 6.24).

6.4 Conclusions

6.4.1 Cod recovery:

- 1) Both, single and multi species models predict cod SSB to continue to decline when fished at the current F level.
- 2) When the proposed HCR for cod are applied, both single and multi species models predict cod SSB recovery. The predicted recovery of cod SSB is slower when taking multispecies interactions into account, and B_{pa} is reached approximately one year later, (2008 instead of 2006 / 2007 in the single-species predictions).
- 3) Under multispecies considerations, the increase of cod yield is predicted to be slower as seen for SSB.
- 4) It must be borne in mind that all scenario predictions are based on the 2003 key-run, where grey gurnard was excluded as a predator in the model. When grey gurnard was included in the multi species model with a biomass as estimated for 2001, cod was predicted to go extinct when fished at the F_{pa} .

6.4.2 Effects of a cod recovery plan on other species in the North Sea:

- 1) In all multispecies scenario simulations, haddock SSB was predicted to decline to beyond B_{lim} .

This is the case, even though predation by saithe on haddock has already been reduced in the 2003 key-run. This decrease is an indirect consequence from omitting Norway pout prey from mackerel stomach data. This leaves more Norway pout as prey for saithe, which then in turn preys less on haddock. The sensitivity of haddock to saithe abundance was noted earlier by this Working Group (e.g. 1990 & 1997 reports, see as well 5.4.2 in this report). By contrast, single-species simulations predicted that haddock SSB and yield would increase after an initial drawback under HCRs for cod

- 2) Multi species scenario simulations predict that whiting SSB and yield initially remains constant with a tendency to decrease during the second half of the decade. From 2006 onwards whiting SSB is predicted to stay below B_{pa} . By contrast, single-species scenario simulations predicted that whiting SSB and yield would increase under HCRs for cod.
- 3) Multi species simulations predict that Norway pout SSB would fall below B_{pa} after approximately 5 years of the application of the HCRs for cod, when continued to be fished at F_{pa} . Single-species simulations predict that SSB would remain stable above B_{pa} .
- 4) Sandeel is predicted to stay above B_{lim} in the longer term, when using single-species models. However, under multispecies considerations sandeel SSB is predicted to fall below B_{pa} in 2004 and gradually decrease towards B_{lim} .

Table 6.1 Overview of the HCR scenario simulations

| Scenario No | Hcr Applied to Species | Single-Species or Multi Species Mode | F Applied In 2002 For All Species | F Level And Pattern in the Prediction taken from | Cod S/R | Cod S / R Time Period Used |
|-------------|------------------------|--------------------------------------|-----------------------------------|--|---------|----------------------------|
| 1 | NONE | Single | FCURRENT FROM SSVPA | FCUR / 2001 | Ricker | 1963 -2000 |
| 2 | NONE | Single | F_{PA} | FCUR / 2001 | Ricker | 1963 -2000 |
| 3 | COD | Single | F_{PA} | FCUR / 2001 | Ricker | 1963 -2000 |
| 4 | COD | Single | FCURRENT FROM SSVPA | FCUR / 2001 | Ricker | 1963 -2000 |
| 5 | COD | Single | F_{PA} | F_{PA} / 2001 | Ricker | 1991 -2000 |
| 6 | COD | Single | FCURRENT FROM SSVPA | FCUR / 2001 | Ricker | 1991 -2000 |
| 7 | COD | Single | FCURRENT FROM SSVPA | FCUR / 1999 - 2001 | Ricker | 1991 -2000 |
| 8 | NONE | Multi | FCURRENT FROM MSVPA | FCUR / 1999 - 2001 | Ricker | 1963 -2000 |
| 9 | NONE | Multi | F_{PA} | F_{PA} / 1999 - 2001 | Ricker | 1963 -2000 |
| 10 | COD | Multi | F_{PA} | F_{PA} / 1999 - 2001 | Ricker | 1963 -2000 |
| 11 | COD HAD | Multi | F_{PA} | F_{PA} / 1999 - 2001 | Ricker | 1963 -2000 |
| 12 | COD HAD WHG | Multi | F_{PA} | F_{PA} / 1999 - 2001 | Ricker | 1963 -2000 |
| 13 | COD HAD WHG | Multi | FCURRENT FROM MSVPA | FCUR / 1999 - 2001 | Ricker | 1963 -2000 |
| 14 | COD HAD | Multi | FCURRENT FROM MSVPA | FCUR / 1999 - 2001 | Ricker | 1963 -2000 |
| 15 | COD | Multi | FCURRENT FROM MSVPA | FCUR / 1999 - 2001 | Ricker | 1963 -2000 |
| 16 | COD | Multi | FCURRENT FROM MSVPA | FCUR / 1999 - 2001 | Ricker | 1991 -2000 |
| 17 | NONE | Multi | FCURRENT FROM MSVPA | FCUR / 1999 - 2001 | Ricker | 1991 -2000 |

Table 6.2 Summary of F values used in the simulations

| Species | F_{cur} 1999-2001 | F_{pa} |
|---------|---------------------|----------|
| COD | 1.05 | 0.65 |
| HAD | 1.03 | 0.70 |
| SAN | 0.73 | 0.60 |
| POK | 0.28 | 0.40 |
| WHG | 0.49 | 0.65 |
| HER | 0.32 | 0.25 |
| SOL | 0.57 | 0.40 |
| PLE | 0.42 | 0.30 |

Calculations for one year

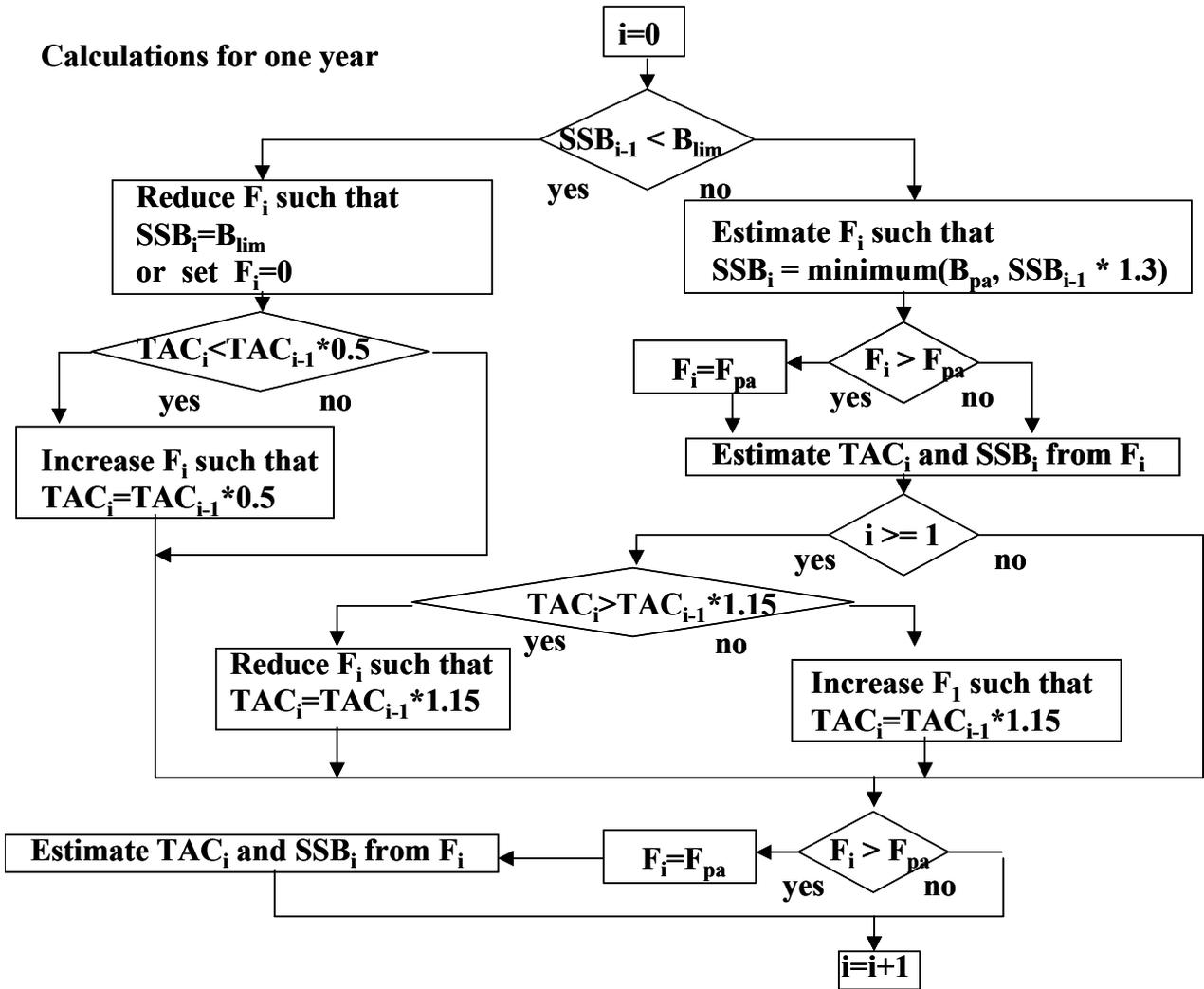


Fig. 6.1: Implementation of the HCRs in the simulation runs.

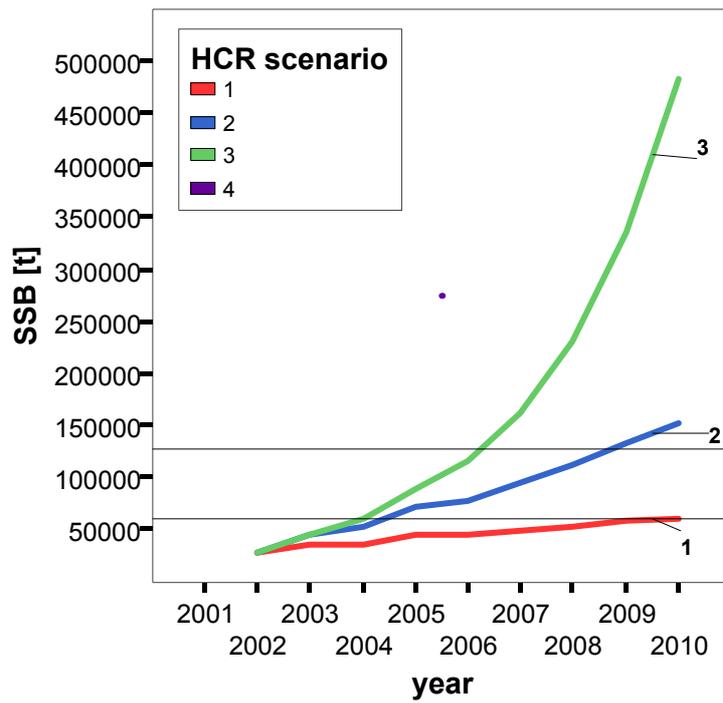


Figure 6.2 HCR Prediction scenarios 1-3: SSB cod; Cod B_{pa} and B_{lim} are represented as horizontal lines.

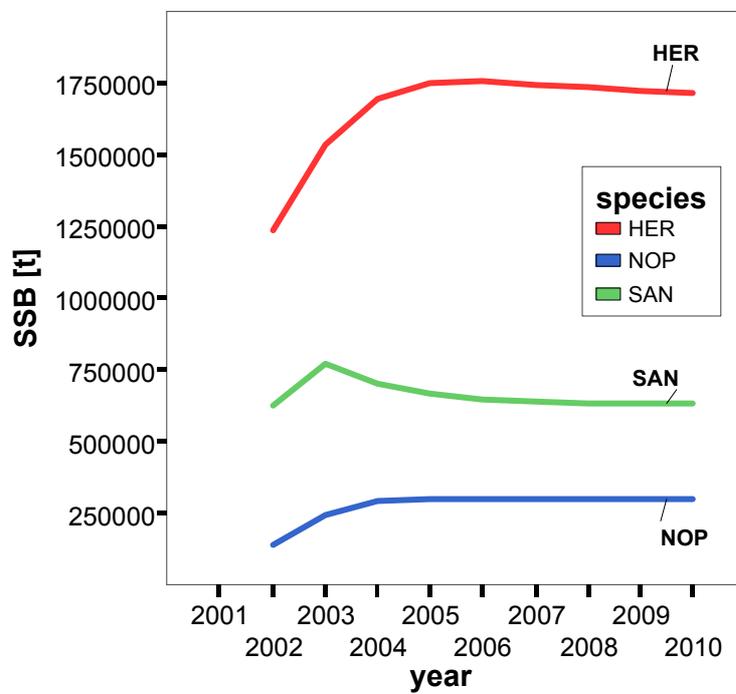


Figure 6.3 HCR Prediction scenario 3: SSB of herring, Norway pout and sandeel.

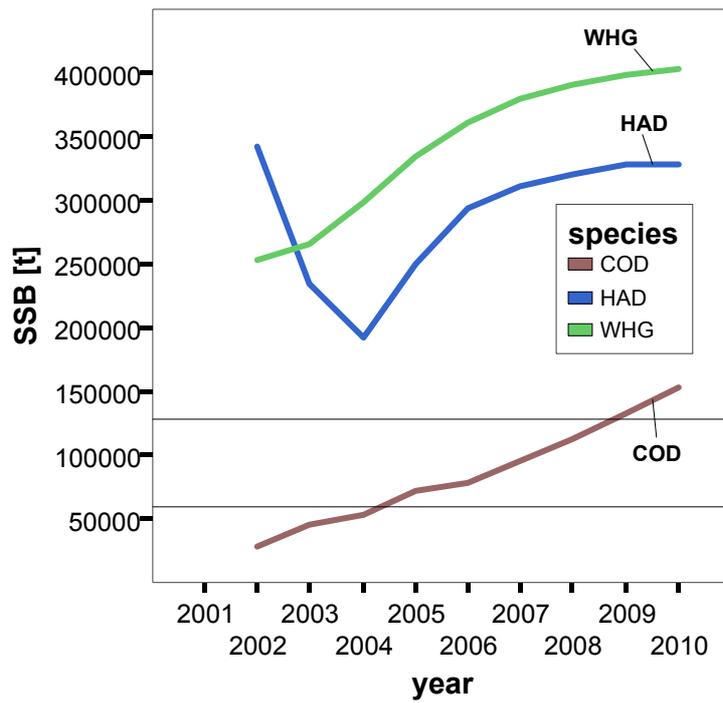


Figure 6.4. HCR Prediction scenario 2: SSB of whiting, haddock and cod; cod B_{pa} and B_{lim} are represented as horizontal lines.

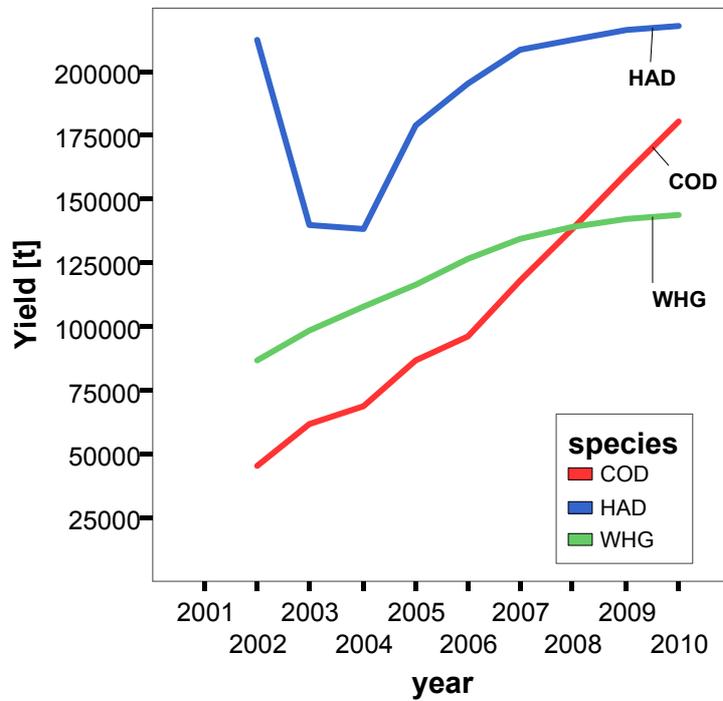


Figure 6.5 HCR Prediction scenario 2: Annual yield of whiting, haddock and cod.

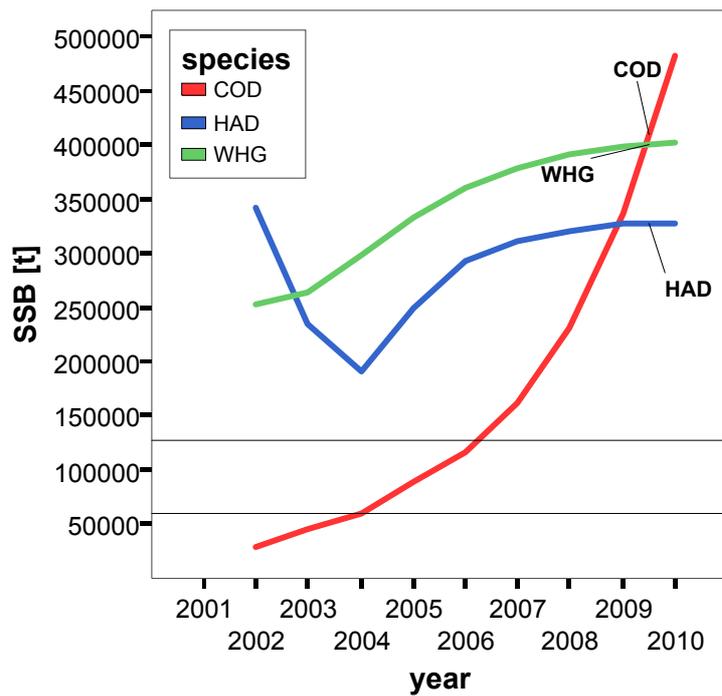


Figure 6.6 HCR Prediction scenario 3: SSB of whiting, haddock and cod; cod B_{pa} and B_{lim} are represented as horizontal lines.

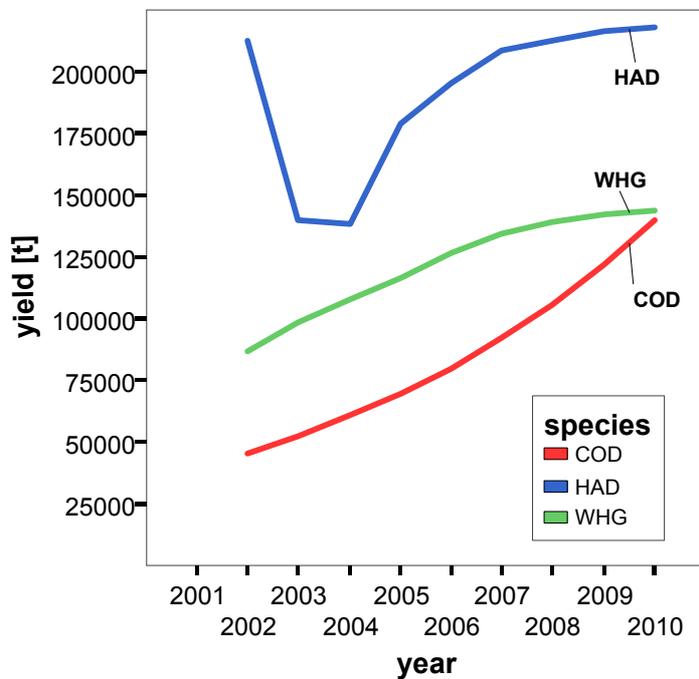


Figure 6.7 HCR Prediction scenario 3: Annual yield of whiting, haddock and cod.

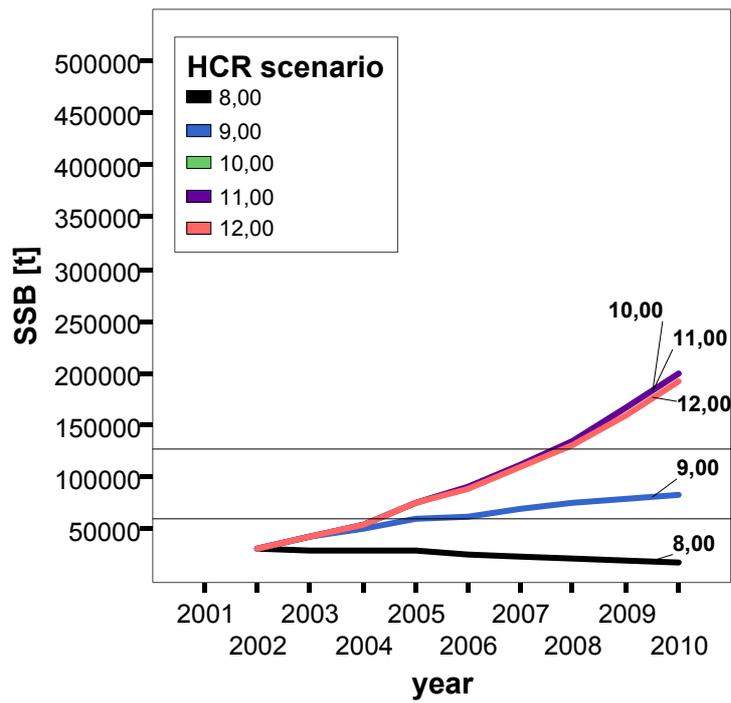


Figure 6.8 HCR Prediction scenarios 8 - 12: SSB cod; cod B_{pa} and B_{lim} are represented as horizontal lines.

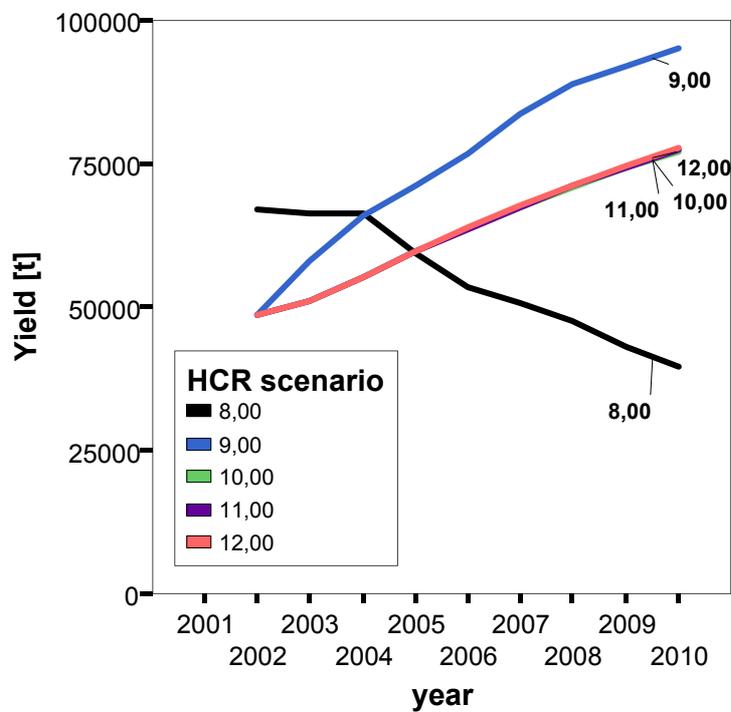


Figure 6.9 HCR Prediction scenarios 8 - 12: Annual yield cod

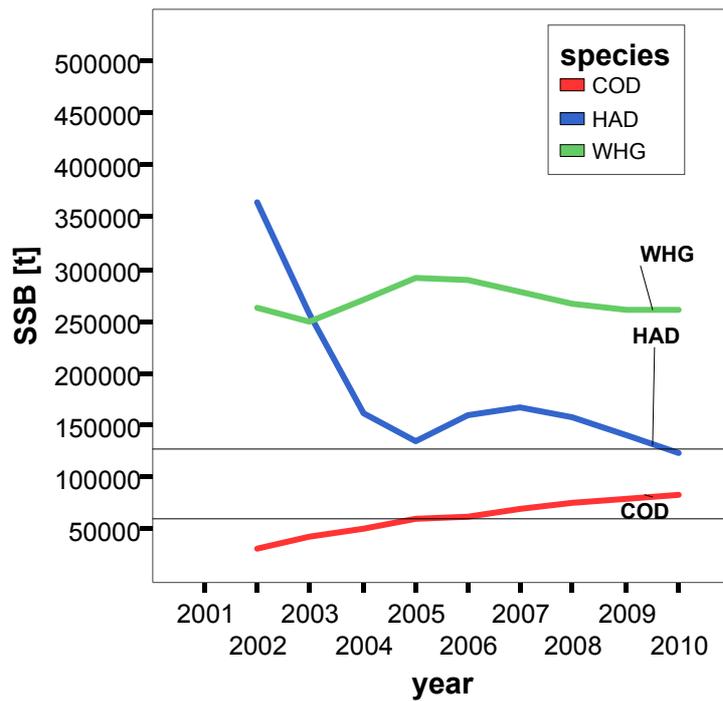


Figure 6.10 HCR Prediction scenarios 9: SSB cod; cod B_{pa} and B_{lim} are represented as horizontal lines.

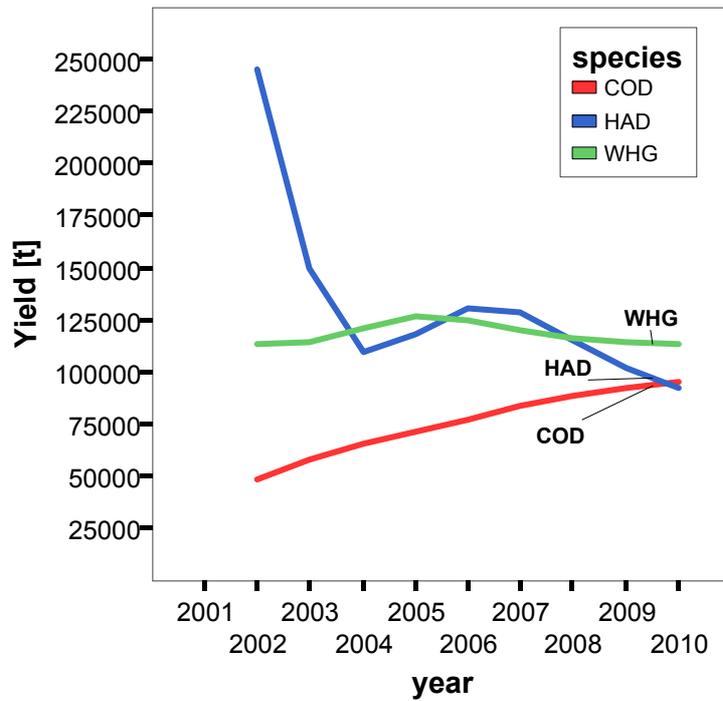


Figure 6.11 HCR Prediction scenario 9: Annual yield of whiting, haddock and cod.

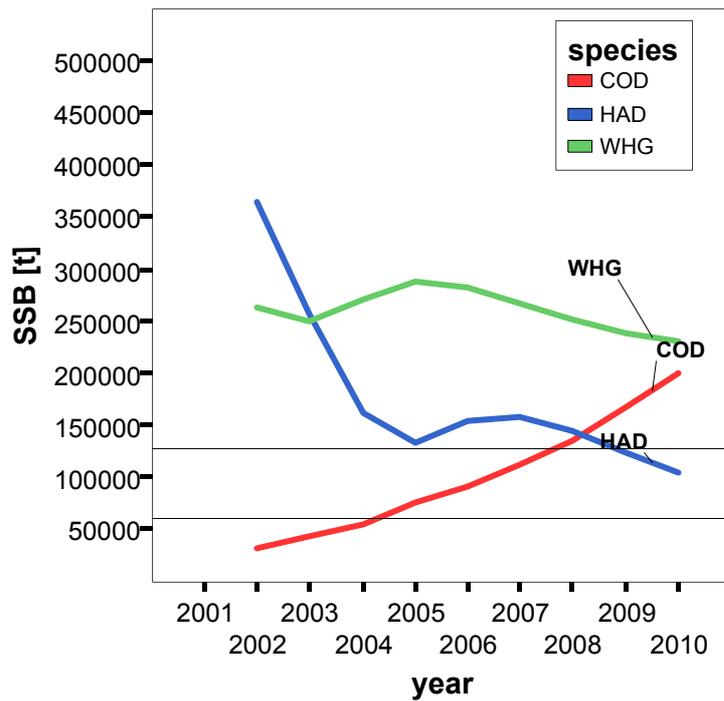


Figure 6.12 HCR Prediction scenarios 10: SSB cod; cod B_{pa} and B_{lim} are represented as horizontal lines.

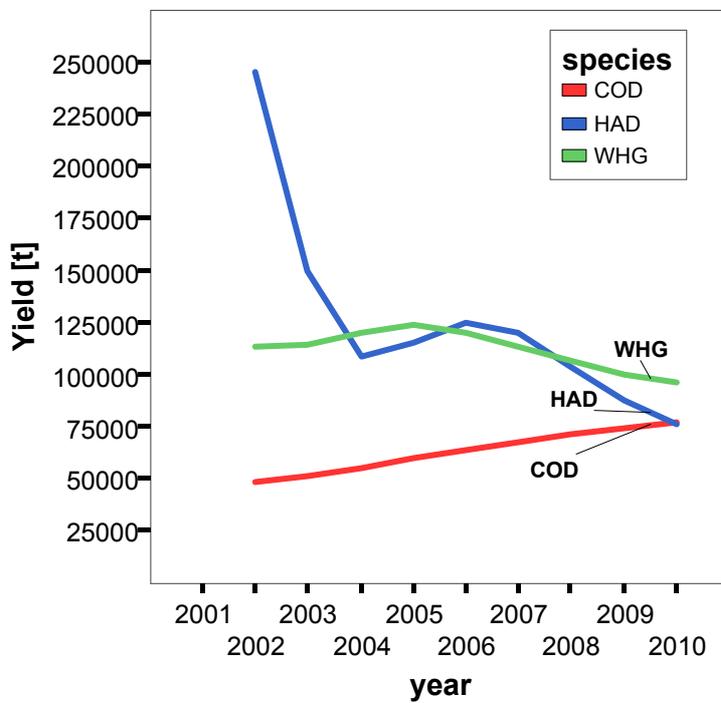


Figure 6.13 HCR Prediction scenario 10: Annual yield of whiting, haddock and cod.

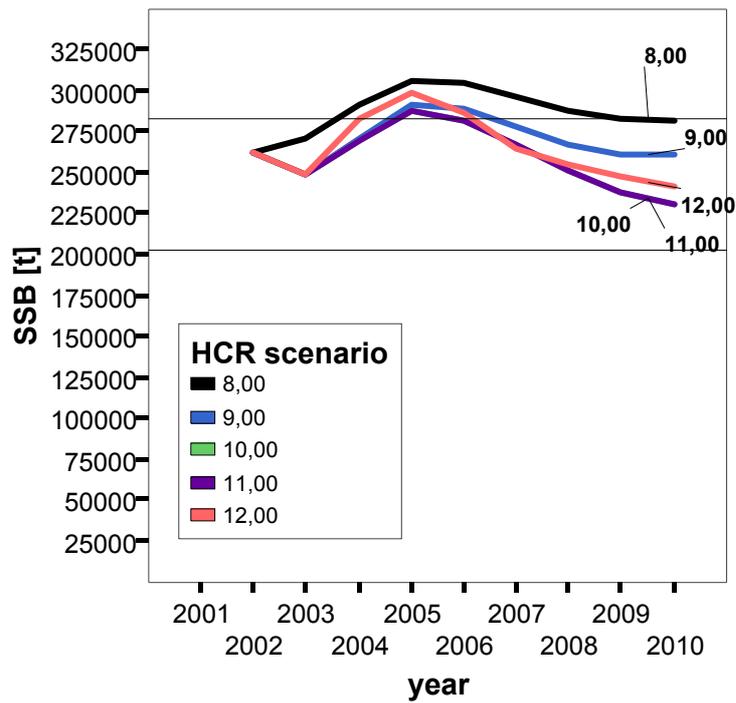


Figure 6.14 HCR Prediction scenarios 8 - 10: SSB whiting; whiting B_{pa} and B_{lim} are represented as horizontal lines.

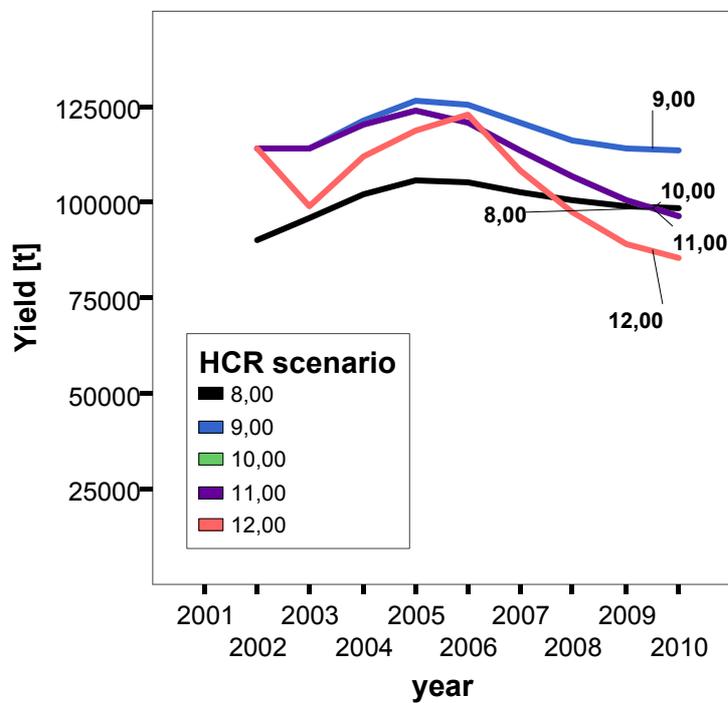


Figure 6.15 HCR Prediction scenarios 8 - 10: Annual yield whiting.

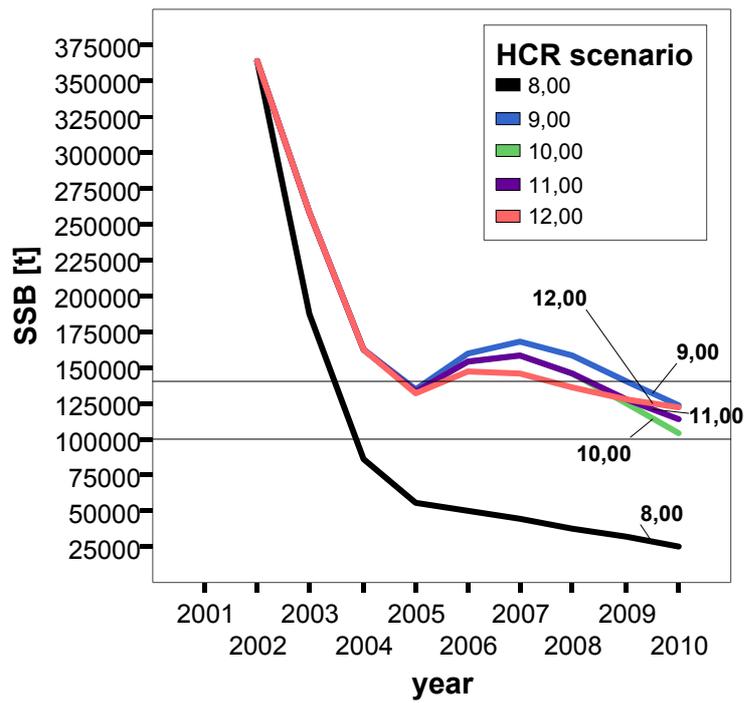


Figure 6.16 HCR Prediction scenarios 8 - 10: SSB haddock; haddock B_{pa} and B_{lim} are represented as horizontal lines.

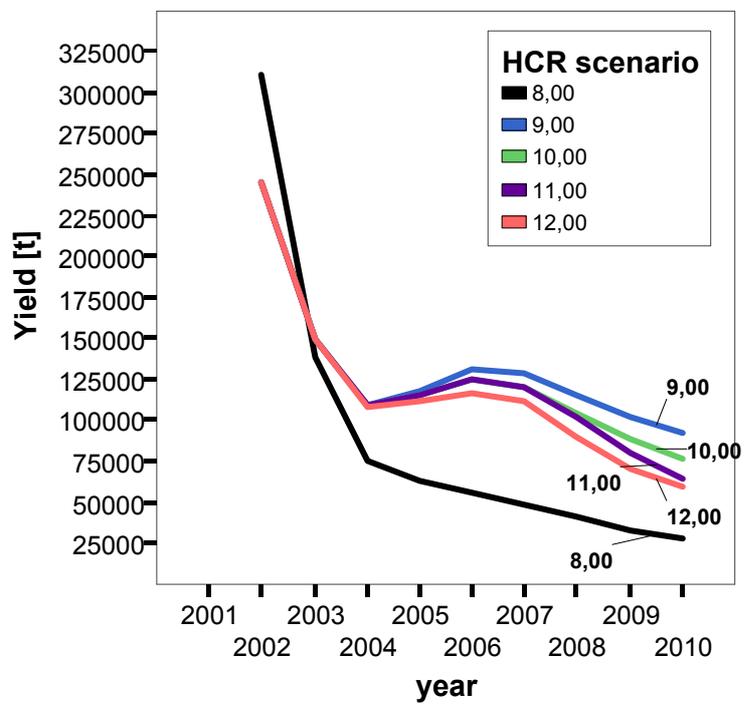


Figure 6.17 HCR Prediction scenarios 8 - 10: Annual yield haddock.

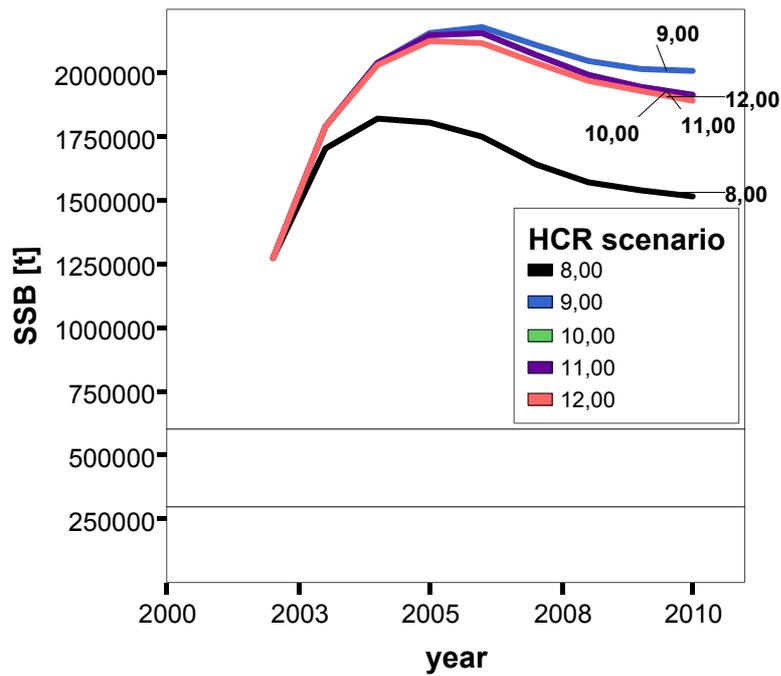


Figure 6.18 HCR Prediction scenarios 8 - 10: SSB herring; herring B_{pa} and B_{lim} are represented as horizontal lines.

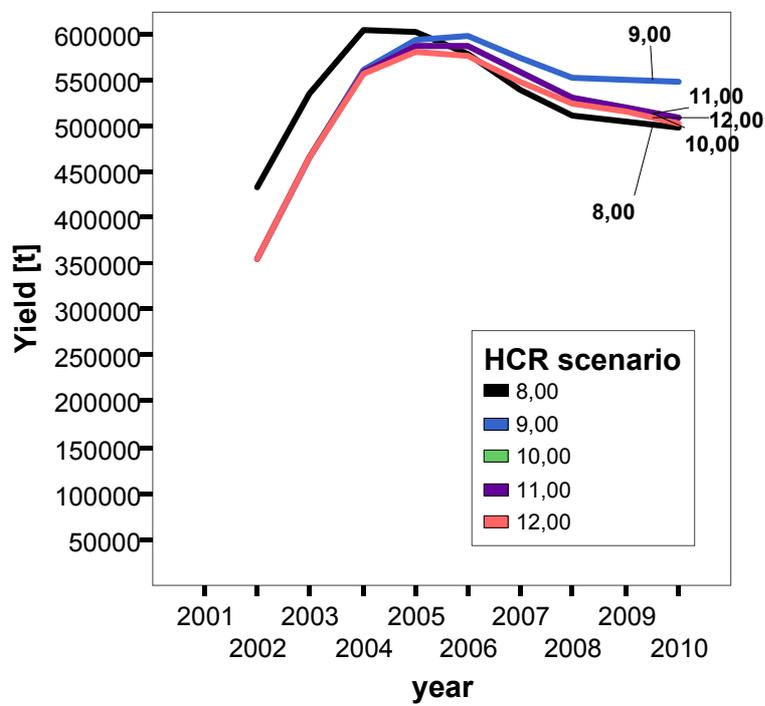


Figure 6.19 HCR Prediction scenarios 8 - 10: Annual yield herring.

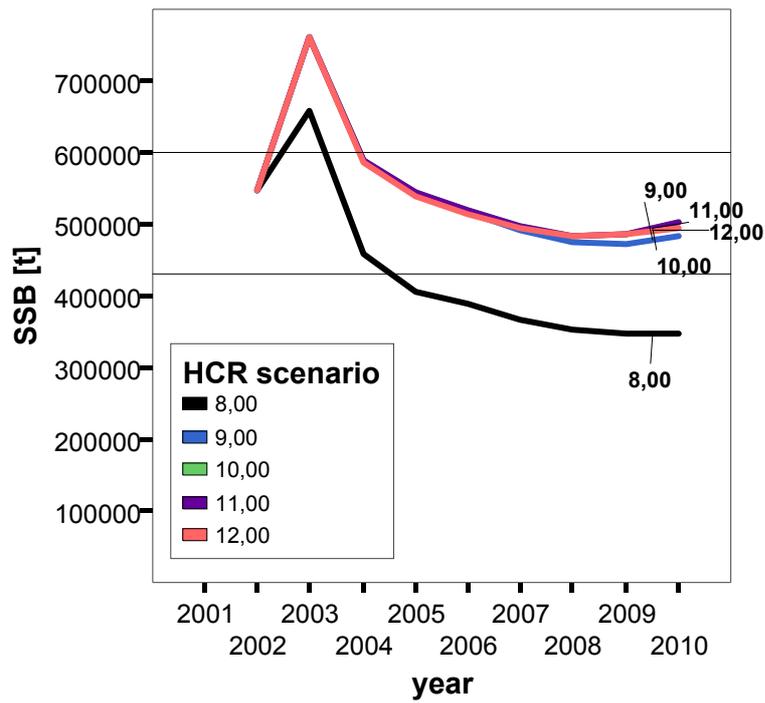


Figure 6.20 HCR Prediction scenarios 8 - 10: SSB sandeel; sandeel B_{pa} and B_{lim} are represented as horizontal lines.

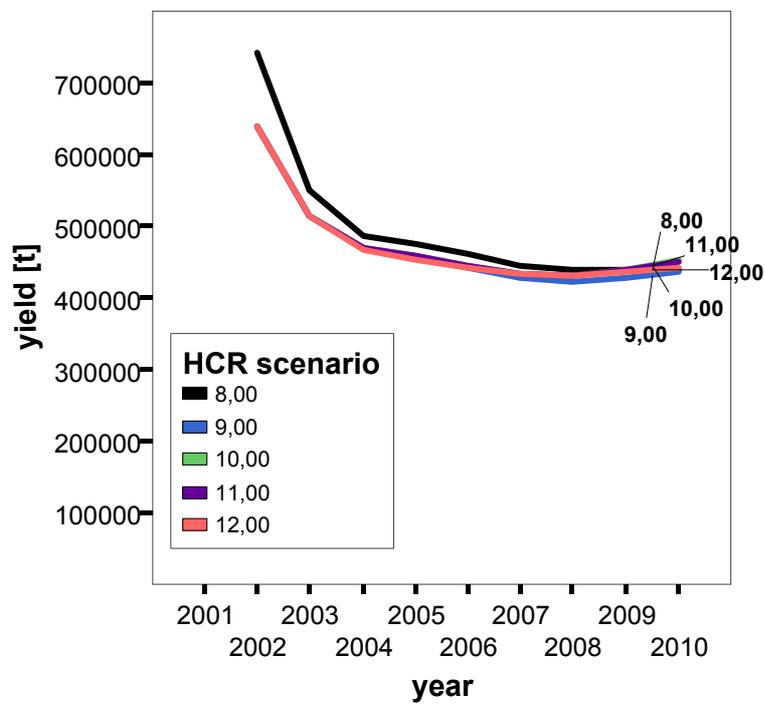


Figure 6.21 HCR Prediction scenarios 8 - 10: Annual yield sandeel.

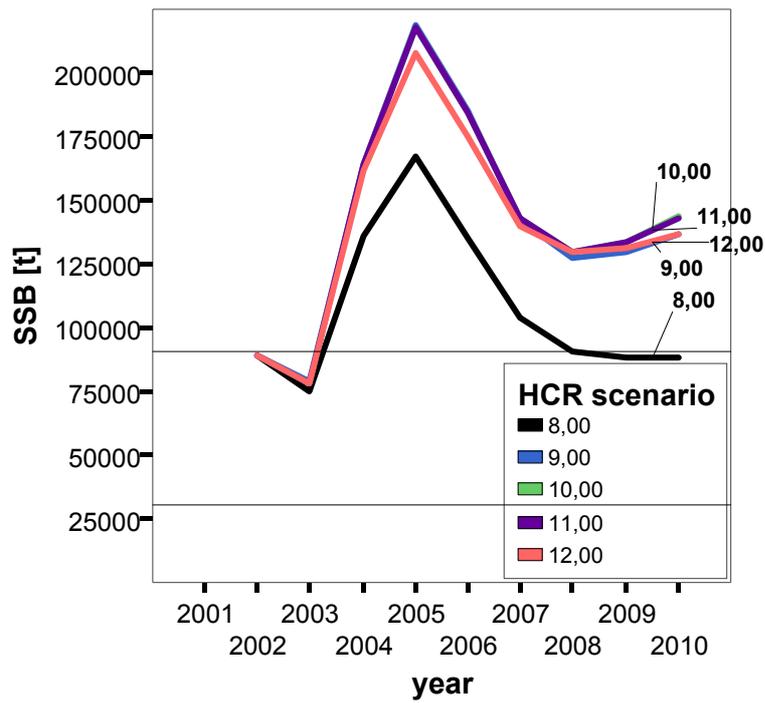


Figure 6.22 HCR Prediction scenarios 8 - 10: SSB Norway pout; Norway pout B_{pa} and B_{lim} are represented as horizontal lines.

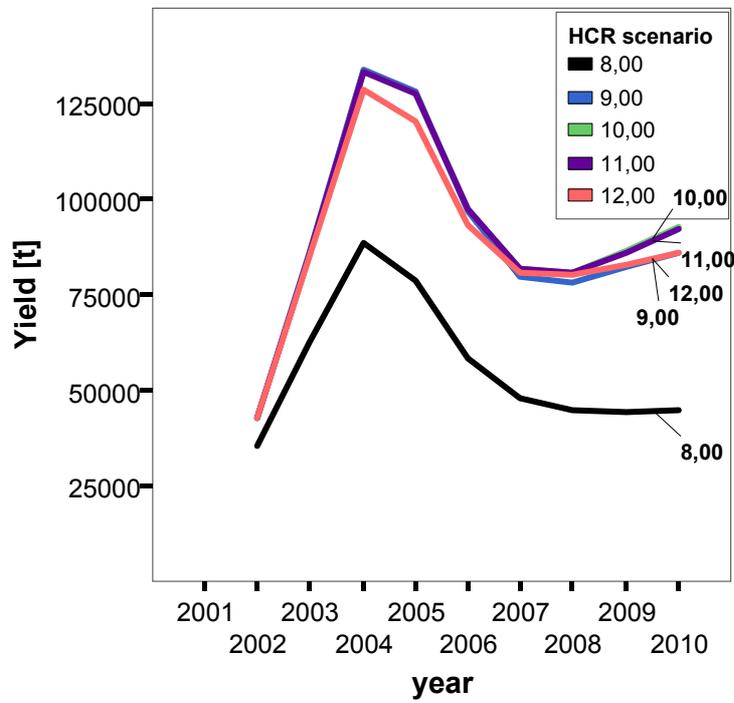


Figure 6.23 HCR Prediction scenarios 8 - 10: Annual yield Norway pout.

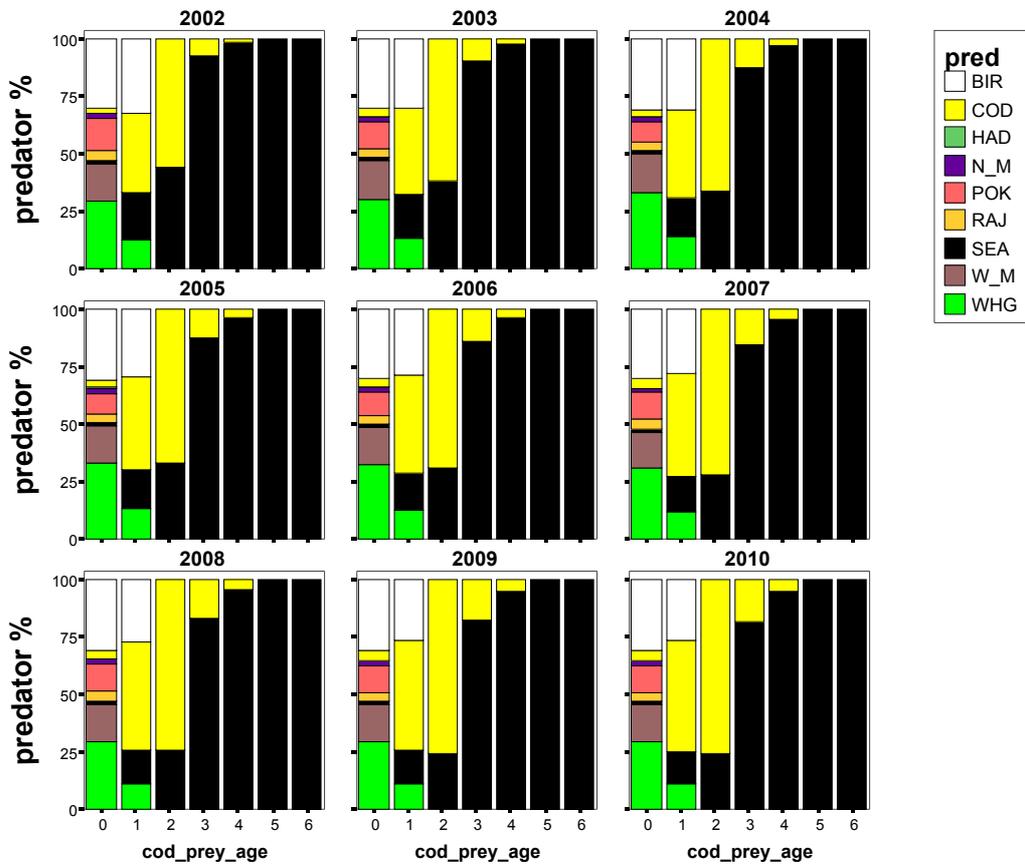


Figure 6.24 HCR Prediction scenario 9: Relative shares of predators in the total number of cod eaten by all predators.

7 EVALUATION OF PROGRESS BY SGGROMAT

ToR c) review the data sources collated by SGGROMAT for the construction, by quarter, of historical stock lengths and weights-at-age for North Sea MSVPA species.

Part of the work of SGGROMAT consists of an assessment of the availability of data on length and weight-at-age, maturity, condition and fecundity. This is a large undertaking which is due to be completed by the end of 2004. Progress made so far appears to have been limited to the creation of guidelines on filling in standardised tables and identifying likely contributors (ICES 2003c). This 'meta-data' compilation process is nearing completion for an example stock (North Sea Herring), but no material was available in time for consideration by this SG. These biological data are essential for the implementation of process models for e.g. growth and maturity, in both the single and multispecies context, and an inventory of data availability and location would clearly be useful. The completion of this exercise is therefore encouraged by SGMSNS.

8 MASS BALANCE TROPHO-DYNAMIC MODELS

TOR d) Review the developments in representing ecological linkages and management objectives within North Sea mass balance tropho-dynamic models.

8.1 Data requirements of Ecopath with Ecosim in comparison to MSVPA

Ecopath with Ecosim (EwE) software is a widely used tool for modelling food webs and carrying out analysis of ecosystem dynamics (e.g. Pauly et al. 2000). The approach is founded on a static description of the whole system, aggregated into user-defined ecologically functional groups.

The Ecopath approach differs from more traditional multispecies models (e.g. MSVPA) in that it does NOT require (i) representation of individual species, (ii) age structure of species (iii) quarterly catch data, (iv) quarterly stomach content data. For each of the functional groups the parameters required are average annual estimates of: total mortality (production/biomass), consumption rate (consumption/biomass), population biomass, biomass trends, diet composition, and landings, discards, costs and price data for each defined fishing fleet.

8.2 Review of Ecopath ecosystem models of the North Sea

At present, 3 published Ecopath models exist for the North Sea. Based on the 1981 'year of the stomach' data, Christensen (1995) constructed two models, a 24 box model and a 29 box model incorporating more detailed, size based plankton groups. Neither model included fisheries catches. Mackinson (2002a), constructed a detailed historical representation of the North Sea in the 1880s which includes 49 boxes, with catch data for five different fishing fleets. The model has been used in an examination of the utility of Ecosim's harvest policy analysis routine (which optimises biomasses to achieve an economic or biological 'objective function' (Mackinson 2002b).

An unpublished 32-box model of the North Sea in 1974 was constructed by Christensen for comparisons between Ecosim and MSVPA in a study undertaken by DIFRES and the Fisheries Centre-UBC (Christensen, Vinther, Gislason and others). The model also includes spatial representation of functional groups. To our knowledge, there has been no further progress than that reported in the previous meeting of this group (ICES 2002b).

8.3 Modelling the North Sea in 1991

CEFAS is presently engaged in the construction of a revised, more detailed EwE model of the North Sea. This work was stimulated by perceived shortcomings in previous models with regard to: Structural representation in relation to ecological linkages and management objectives

- Representation of fishing fleets landings, discards and economics
- Spatial representation of functional groups, fleets and their interactions
- Data credibility, sensitivity testing and derivation of predator-prey interaction parameters.

1991 was chosen so as to maximise the use of extensive fish diet composition data collected during the 1991 'year of the stomach', and because stock assessment data for the period 1991-2003 can be used in parameterising dynamic

(Ecosim) simulations. In addition, detailed information on fishery catches, disaggregated by fleet, were available from ICES for 1991.

Recent ecosystem modelling work using EwE (presented at this meeting: Mackinson *et al.* in press, Pinnegar *et al.* in press, Blanchard *et al.* 2002), has explored the sensitivities of this approach. Ecopath models, and Ecosim scenarios based on these, were shown to be particularly sensitive to model aggregation (the number of compartments, and whether particular parts of the ecosystem were emphasised, e.g. fish or marine mammals). In addition the completeness of the diet composition matrix (and hence the quality of the stomach content data) was shown to greatly affect model dynamics. The type of functional response assumed (the relationship between predator feeding rate and prey availability), can also greatly impact Ecosystem outputs and model dynamics.

Lessons learnt from this work are being applied to the North Sea 1991 model, the future development of which is described in Figure 8.1.

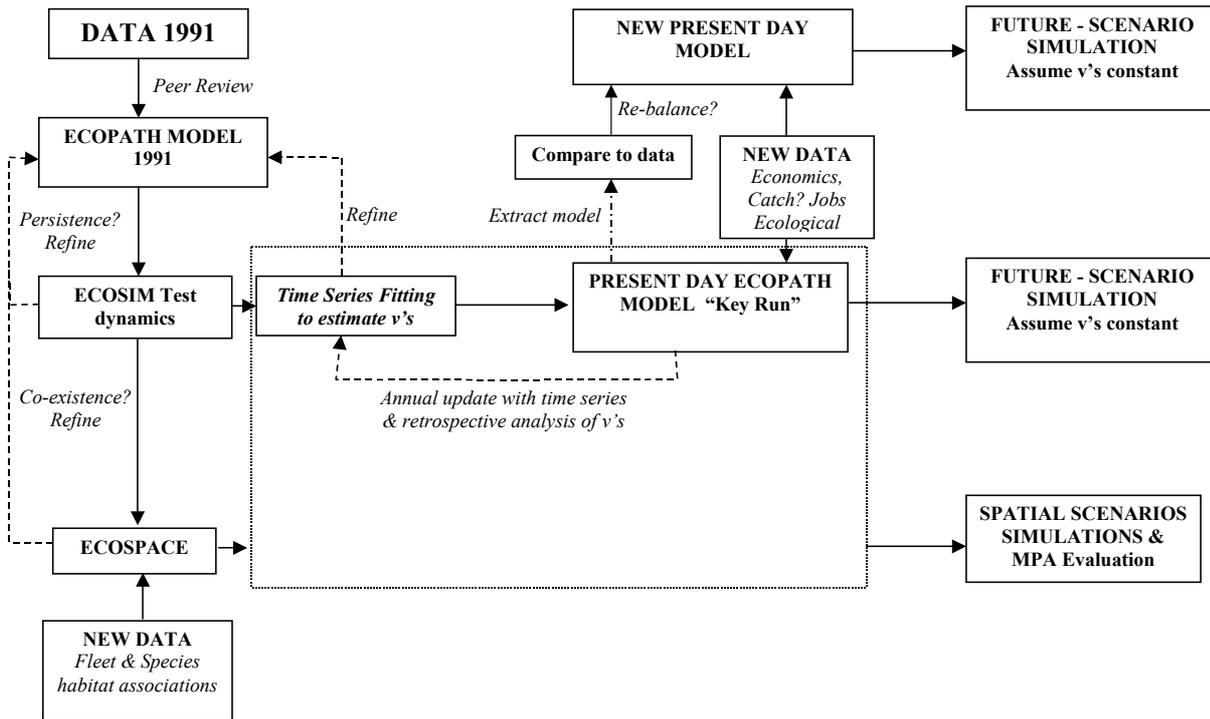


Figure 8.1 Conceptual overview of the development and application of the North Sea 1991 Ecopath Model.

Since 2002, work has been focussed on defining model structure and obtaining basic input parameters. Data for the 71 functional groups (Table 8.1) has been collated and will be reviewed by appropriate experts. Landings, discards and economic data have been compiled for the 18 fishing fleets specified in the model.

Table 8.1 Summary of functional groups in 1991 North Sea model.

| Meta-Group | Number of functional groups |
|--------------------------------------|-----------------------------|
| Marine Mammals | 3 |
| Birds | 1 |
| Fish (7 split adult-juvenile groups) | 46 |
| Invertebrates | 14 |
| Autoheterotrophs | 2 |
| Autotrophs | 2 |
| Dead things | 3 |

Work during the forthcoming year will concentrate on completion of the basic input parameters, scientific reviewing, testing of temporal dynamics and parameter refinement.

9 OTHER MODELLING APPROACHES

9.1 Gadget, Bormicon & Fleksibest

BORMICON (BOReal MIgration and CONsumption model - Stefánsson & Pálsson, 1997) was developed in 1995 for multiple interacting stocks in the waters around Iceland. A single-species variant of BORMICON named Fleksibest (Frøysa *et al.* 2002) was specifically designed to be an assessment tool and has been applied to northeast arctic cod at recent meetings of the ICES arctic fisheries working group.

The main difference between Fleksibest and Bormicon is that Fleksibest estimates parameters in separable models for fishing mortalities while Bormicon in principle treats the fishing fleet as another predator. The model framework is being further developed under an EU project (*dst²*), and under the new name GADGET (Globally applicable Area-Disaggregated General marine Ecosystem evaluation Tool). (Anon 2002).

Gadget is a flexible framework, rather than a single model, with many different functions (sub-models) are available for growth, consumption, migration, fleet selectivity etc. Gadget is both an age and length structured modelling approach although most biological processes such as growth, maturation and mortalities are primarily related to length. Gadget allows users to include several species or individual stocks, multiple areas with migration between areas, multiple commercial and survey fleets. Gadget takes a model specification and in the first instance runs a simulation without use of real-world data. The program then compares modelled outputs with actual data and produces numeric likelihood scores measuring how well the model matches the inputted data sets. Different error distributions (e.g. normal, multinomial) can be assumed for different data sets, where necessary. Gadget optimises to an 'overall likelihood score' using a combination of Simulated Annealing and Hooke & Jeeves minimisation.

Since the model in principle is a simulation model specified through parameters, the observed data are used to fit the model to data, and not for calculations within the model itself. Accordingly, it can use a variety of data, and can work even when data are not complete. However, lack of essential data limits which parameters can be estimated. Therefore, Gadget allows the user to specify the formulation of parametric process models in many cases, and the user is free to choose which parameters to estimate and which to consider known. Gadget is particularly useful in situations where there is very little age data available. It has, for example, been used for the assessment of redfish and shrimps in Iceland (Björnsson & Sigurdsson 2003), and there are plans for a model for wolffish (*Anarrhichas* spp).

Although Gadget was primarily designed for Icelandic waters, work is in progress to implement it for other areas. There is currently a four species model available for Iceland (cod, capelin, shrimp and seals) and also a cod model for Iceland which includes cannibalism (it is parameterised in the same way as a 2 species model). There is a 3 species model for the Celtic Sea (ICES are VIIe-k), which includes cod, whiting, blue whiting, and which will be expanded in 2003 to cover hake and mackerel. Fleksibest, although basically a single-species model, also includes cod cannibalism (and a lookup table of capelin biomasses) in the Barents Sea, although predation links within this model are formulated in a different way to the standard Gadget approach. Single-species Gadget formulations have been developed for herring in the North Sea and Northern Shelf anglerfish. Gadget/Fleksibest is operated within a UNIX/Linux platform and scripts have been developed (at IMR) to provide the types of output familiar to ICES assessment groups (see ICES arctic WG).

Gadget essentially deals with predation in a very similar way to the MULTSPEC model (Bogstad *et al.* 1995), but different to MSVPA. The consumption of a prey is dependent on the length of both the predator and the prey, and the amount of the prey available, as a proportion of the total amount of food available. The consumption is given by equation 1 below:

$$(1) \quad C = \frac{M\psi F}{\sum_{prey} F}$$

The parameter F gives the amount of a given prey that is consumed by the predator, which is obtained by multiplying the biomass of the prey by the suitability (see below). The summation over prey is over all length groups of all prey types (including non-modelled prey, given as "otherfood"). M represents the maximum possible consumption for the predator and ψ gives the "feeding level" which is the fraction of the available food that the predator is consuming. M is defined by

$$(2) \quad M = m_0 e^{(m_1 T - m_2 T^3)} L^{m_3}$$

where:

L is the length of the predator

H is the half feeding value

T is the temperature

$$(3) \quad \psi = \frac{\sum_{prey} F}{H + \sum_{prey} F}$$

Equation 3 defines the “feeding level”, ψ . This is governed by the total amount of prey available and the ‘half feeding value’ H . The value of H is the density of prey required to allow the predator to consume prey at half the maximum consumption level.

Currently there are 5 suitability functions possible within Gadget: (1) a constant suitability function, where there is no dependence on either the length of the predator or the length of the prey; (2) ‘straight-line suitability’ where there is no dependence on the length of the predator, and a linear dependence on the length of the prey [used to model fishing vessels]; (3) a suitability function that has no dependence on the length of the predator, and a logarithmic dependence on the length of the prey; (4) a suitability function that has a logarithmic dependence on both the length of the predator and the length of the prey; and (5) The ‘Andersen and Ursin suitability function’; a more general suitability function that is dependant on the ratio of the predator length to the prey length.

Gadget input files can now be generated ‘automatically’ once data have been entered into a ‘data-warehouse’, and there are plans to develop Gadget models for the Bay of Biscay and Mediterranean.

9.2 SMS Stochastic-multispecies-model

A stochastic multispecies model is under development at DIFRES. The model is based on the ideas of Andersen and Ursin (1977) and the ICES MSVPA (Gislason and Helgason 1985). In contrast to MSVPA the new model treats catch, survey data and relative stomach contents observations as stochastic variables subject to random variation. The purpose of developing a stochastic model is to obtain the uncertainties of biological parameters such as biomass, fishing and predation mortality rates and food preference parameters. Further, the stochastic approach enables that statistical tests of relevant biological hypotheses can be carried out. For instance ‘are predation mortalities by age significantly different over years or can single-species models be applied?’

Both the stochastic catch and survey models are age-based models for which fishing mortalities are assumed to be semi separable and catchabilities by age constant during the period considered. Both type observations are assumed to be log-normal distributed ignoring possible correlations. The probability distributions of relative stomach contents observations for North Sea roundfish predator species collected by ICES in 1991 have been analysed by bootstrap (Vinther and Lewy 2003). The variance structure applied is similar to that of the Dirichlet distribution. The expected value of relative stomach content of a prey species has been modelled using the same formula as used in the MSVPA. However, in the present model suitability parameters have been further modelled using the Andersen and Ursin model distinguishing between the species-specific vulnerability and size dependent parameters. The stomach content model is length-based in contrast to the MSVPA because the predation process almost certainly depend on length rather than age.

The model has been implemented using AD Model Builder. Analyses has been carried out using data for the North Sea including the same VPA species as for MSVPA for the period 1974-2000 and preliminary results have been obtained.

9.3 MSFIV

Predation rates within MSFOR are fixed and conditional upon age whereas in reality they are far more likely to be functions of size (Frøysa et al. 2002, Floeter & Temming, 2003). MSFIV is a length-based multispecies projection

program developed at CEFAS, which addresses some of the shortcomings of MSFOR and was developed primarily to test the robustness of single-species reference points in a multispecies context.

Within MSFIV, a new suite of predation functions were developed from ecological theory and parameterised using the 1981 and 1991 Year of the Stomach data. These functions pave the way for inclusion of variable growth rates and examination of their effect upon stocks and their rebuilding potential. Ecologically important concepts such as spatial overlap of predators and prey, density dependent range expansion and size based predation were also incorporated into this model (Macall 1990, Larsen & Gislason 1992, Rindorf et al. 1998). Multispecies stock recruit functions were parameterised and incorporated, as were technical interactions within the fisheries.

In MSFIV the suitability of a prey item to a particular predator is governed by three attributes:

- (1) physiological and behavioural characteristics which will make species more or less “ideal”, e.g. shoaling or hiding, spines or camouflage etc.;
- (2) the ability of predators to catch and handle particular prey, i.e. a “predatoriness” factor.
- (3) the size spectrum of preferred prey items. No predator will eat items larger than itself, and there will be an optimum size.

The feeding functions defined (above) place much less reliance upon specific “suitabilities” for each age of predator on each age of prey. The resulting MSFIV model is designed to be more ecologically realistic than MSFOR. Sensitivity analyses revealed parameterisation problems for some of the predator-prey relationships leading to instability in prey forecasts. This appears to be the result of insufficient data for some interactions (chiefly saithe predating on herring).

A potentially important result from investigations using MSFIV is that spatial processes have the potential to reverse the long-held belief that multispecies issues become less important as stock size decreases. As population numbers decline, fish tend to become spatially concentrated into what are usually considered refuges from predation. However, for some prey species within the North Sea (e.g. herring), the contracted prey population sits within the home-range of a major predator (e.g. saithe) and thus the per-capita predation risk may actually increase. This may go some way to explain the phenomena of “negative switching” observed and commented on for the North Sea (a prey stock becomes more heavily predated as it declines). This has important implications for area based management regimes.

10 SEABIRDS AND MARINE MAMMALS

The study group welcomed the commitment stated both by the ICES Working Group on Seabird Ecology (WGSE) and the Working Group on Marine Mammal Ecology (WGMME) (ICES 2003d,e) to devise a process to construct time-series of: (1) abundance in the North Sea by quarter and year since 1963; and (2) consumption rates and dietary composition by species and size class for selected periods by quarter and year. This information is required by SGMSNS in order to provide a more accurate 4M key-run of the multispecies model of the North Sea in 2005.

In the following section of this report, SGMSNS have attempted to provide additional guidance to WGSE and WGMME with respect to the overall format and nature of the information required for input into 4M or other multispecies/ecosystem models.

10.1 Data required from WGSE and WGMME

- For marine mammals, population numbers in ICES area IV, by year and quarter. If there are known differences in the diet-at-age, then it would be beneficial to split the population numbers accordingly (e.g. juveniles and adults).
- For seabirds, population numbers in ICES area IV by year and quarter, – ideally by species or functional group.
- Diet by predator (and age categories) and quarter (although the quarters need not be in the same year). Diet data should be disaggregated by prey species and size (length or age). Diet composition should also be a relative estimate, i.e. % weight or volume, if only numbers of prey items consumed are available, then these will need to be converted (either by WGSE and WGMME or SGMSNS) to biomass using published weight-length relationships. Diet should ideally represent the whole North Sea population since it is difficult for SGMSNS to use data from one colony or region which may not be representative of the whole of the North Sea. Ideally the diet should not be given as an average over a longer period. Point observations are necessary for estimating the model food

'suitabilities'. When it is impossible to give diet for a particularly quarter of a year, diet should be given for a relatively short period of time.

- Consumption per individual per quarter (a single estimate). If the population numbers are split into separate age categories (e.g. juveniles and adults) or species, then separate estimates will be required for each group.
- For seabirds (if possible), there should ideally be some separation between prey taken as discards from fishing vessels (i.e. dead) and those taken live. Or at least SGMSNS would appreciate some estimate of the proportion of prey taken as discards and those taken live.

10.2 Marine mammals

In the current key-run of 4M (reported in section 3 of this report), grey seals are the only marine mammals which have been considered and population numbers were based on estimates for the period 1974-1995, updated by assuming that the stock has increased by 6% per year (F. Larsen, pers. comm). Clearly it would be beneficial to update the model with observed grey seal population estimates and also, where available, utilise more recent stomach content data.

WGMME report that grey seal counts have been made annually since the 1960s in the largest colonies in the UK (over 90% of the North Sea population). Estimates of pup production in the UK grey seal population are mainly obtained from annual aerial surveys of all the main breeding sites and useful additional data are available through the annual report of the UK Special Committee on Seals (SCOS). The diets of grey seals were examined in UK colonies/haul-outs in 1985 on a quarterly basis (Hammond *et al.* 1994a, 1994b). A further study was carried out on the east coast of Scotland in the mid-1990s (Hall 1999). Large-scale dietary surveys are currently being carried out as part of a doctoral study, covering most UK colonies.

WGMME and SCOS have suggested that the population of harbour seals in the North Sea may be substantial (c. 34495 animals) although severely impacted in 1988 and 2002 by outbreaks of phocine distemper virus. Clearly such a large population might inflict considerable predation mortality on North Sea fish stocks, and consequently it would be beneficial to include this species in the next key-run of 4M. Harbour seals spend the largest proportion of their time on land during moult (in August) and they are therefore visible to be counted in aerial surveys. Harbour seal counts in the Wadden Sea and eastern England started in the early 1970s, but counts at colonies along the Scottish coast started later and (with the exception of the Inner Moray Firth) have not been annual. Harbour seal diet has been studied by Pierce *et al.* (1991) and Tollitt and Thompson (1996) in the Moray Firth in northeast Scotland. Hall *et al.* (1998) and Brown *et al.* (2001), respectively, conducted seasonal studies for harbour seal diet in the Wash and the Shetlands.

WGMME stated (ICES 2003d) that there has only been one estimate of cetacean abundance in the North Sea, that of SCANS in 1994 (Hammond *et al.* 2002). A further survey is planned in 2004 or 2005 and Scheidat *et al.* (2003) conducted aerial surveys in May to August 2002 to examine the distribution of harbour porpoises in German North Sea and Baltic waters. In the North Sea densities of harbour porpoise were highest in the northeastern part of the survey area, closest to the Danish border. There is very little information on the foods of the principal cetacean species occurring in the North Sea; what little there is can be found in published literature (e.g. Santos *et al.* 1995; Aarefjord & Bjørge 1995, Olsen & Holst 2001).

11 SEABIRDS

In the current key-run of 4M (reported in section 3 of this report), seabirds are incorporated only as an aggregate fish-eating seabird predator. In 2002 WGMSNS requested that the Working Group on Seabird Ecology [WGSE] construct time-series by year and quarter for individual species (fulmar, gannet, European shag, great-black backed gull, herring gull, black-legged kittiwake, common guillemot, razorbill and Atlantic puffin), feeding within the North Sea area since 1963.

Numbers of breeding seabirds around the North Sea have recently been re-evaluated (ICES 2002c). A large part of this revision has been the result of *Seabird 2000*, a joint British and Irish project. The majority of colonies appear to have declined since the last censuses that took place between 1985-1987. This is contrary to the situation perceived by the Multispecies Assessment Working Group (MAWG) in 1997. Overall, the number of MSVPA seabirds at breeding colonies has decreased from 4 million to 3.4 million birds between the two large censuses (approximately 14 years). This equates to a yearly decrease of 1.18%.

Seabird numbers as used within 4M are based upon counts of breeding birds at colonies round the North Sea and therefore generally represent numbers in the spring and early summer months. Previously, the Multispecies Assessment

Working Group attempted to account for the numbers of non-breeding birds and breeding birds absent from the colony at the time of census by multiplying by 1.5. These counts were assumed to hold for 2nd and 3rd quarters while numbers in the 1st and 4th quarters were estimated by comparing total food consumption in quarters one and two, and in quarters four and three, respectively. This procedure results in smaller population sizes in the winter months.

WGSE (ICES 2001) gave wintering population estimates for the North Sea which were up to 6 times larger than the breeding population. Basing seabird population size on breeding numbers alone may therefore severely underestimate consumption rates. WGSE (ICES 2003e) suggest that in 2004 they will estimate trends in abundance during the three non-breeding seasons using a seasonal key derived by Tasker and Furness (1996).

In the current 4M key-run, dietary information for seabirds was obtained from Hunt & Furness (1996). WGSE will review additional dietary information derived from studies carried out after 1993, in particular WGSE will examine whether changes in seabird diets can be detected through time in the North Sea.

12 RECOMMENDATIONS AND FURTHER WORK

SGMSNS has addressed its terms of reference and the group felt that it has been both a useful and stimulating forum for discussion and work. In 2002 WKMSNS recommended that two further meetings be held, and the workshop culminating in this report is the first of these under the new guise of SGMSNS. The group concurs with the original recommendation, and requests that one further meeting now be held (in March 2005) – the suggested terms of reference for which are given in Section 12.4. After the 2005 meeting ICES should review the future for multispecies assessment and whether a new ICES study or working group needs to be created and what appropriate terms of reference might be.

The 2003 Study Group focused primarily on new developments in the 4M software, applying 4M to evaluate single-species precautionary reference points, and an evaluation of the cod recovery plan taking into account biological interactions. A new key-run of 4M was prepared using updated fishery and survey data. Progress towards, and sensitivities of, other multispecies modelling approaches (notably Ecopath with Ecosim, Bormicon/Gadget, SMS, MSFIV) were discussed.

SGMSNS suggested that future meetings might benefit from the wider involvement of modelling groups from outside of the North Sea area. Substantial progress is being made in developing multispecies models and software in other ICES countries. SGMSNS felt that it would be beneficial to hold some sort of joint event whereby ideas might be exchanged, and the wider role of multispecies assessment and advice within ICES be discussed.

12.1 Specific Recommendations for work on 4M

Whilst a new key-run of the North Sea 4M package has been produced by SGMSNS there are still a number of modest extensions to the model that could be made in the short-term. Brief details of these activities are presented below.

Although the MSVPA and its successor 4M have provided a major breakthrough in the understanding of the interactions between fish species in the North Sea, they have several shortcomings. Being basically a VPA and relying on catch statistics for estimates of the stock abundance in absolute terms, this approach is not fully adequate for estimating the dynamics of stocks before they enter the fishery. In particular, for stocks where discards of undersized fish are not included, the basis for estimates of predation mortality at the youngest age may be unreliable.

During simulation exercises at SGMSNS this year, it became apparent that predation pressure exerted on 0-group fish can cause anomalies or innate discrepancies in resulting population and recruitment estimates. Notably, it was found that excluding grey-gurnard from the model resulted in much lower estimates and no overall trend in M for 0-group cod (see Section 2). Similarly, western mackerel were also shown to be a consumer of 0-group fish and obtain 73% (by weight) of food from 0-group Norway-pout in quarter 4, thereby greatly affecting population estimates for this species.

Clearly we cannot simply dismiss the possibility that these effects are both real and important, since for example, gurnard often occur at frontal regions where 0-group fish are locally very abundant. However, it would seem sensible to investigate further.

- SGMSNS recommend as a matter of urgency, that new 4M runs be completed whereby all 0-group fish is treated as 'other food' and all species recruit at age 1.
- SGMSNS recommend that both the limitations of the model framework and the available stomach data be considered further (in the context of understanding predation on 0-group fish).

North Sea mackerel was originally included as a full MSVPA species, and shown to be an important predator in the North Sea system. However, mackerel was later dropped as a VPA species from the 4M model as the size of its population declined markedly in the 1970s.

Today, the total population of mackerel is treated as two stocks of “other predators”, a North Sea component and a western stock component. Diets of North Sea mackerel and western mackerel were treated differently and big discrepancies were observed between the 1981 and 1991 data. Due to changes in computing systems, for some time the 1981 mackerel stomach data could not be used in 4M, however this problem has now been resolved and a usable dataset has been recovered.

- SGMSNS recommend that before the 2005 meeting, the 1981 mackerel stomach data be used in the revised 4M model key-run.

Substantial populations of marine mammals and fish-eating seabirds exist in the North Sea (see section 10), and it is thought that these animals may impart substantial predation mortality on certain fish stocks. Data on marine mammals (grey seals) and seabirds have not been properly updated since the 1997 key-run of MSVPA. WGSE and WGMME have committed themselves in 2004 to providing new and updated estimates for population sizes, consumption rates and diet composition. SGMSNS view it as particularly important to obtain information on harbour seals which are currently not considered at all in the 4M model.

- SGMSNS recommend that before the 2005 meeting, the new data provided by WGSE and WGMME be uploaded, and used in the revised 4M model key-run.

SGMSNS acknowledge and appreciate the work initiated by the ICES Working Group on Fish Ecology (WGFE) to improve consumption estimates for MSVPA predators. This undoubtedly will lead to an improvement of overall model parameterisation in the future.

- SGMSNS recommend that revised estimates of food ration for cod, haddock, whiting, mackerel, horse mackerel and saithe be prepared and applied.

Further specific recommendations concerning the 4M model include:

- An evaluation of the optimisation package developed for SGMSNS 2003 (WD 3) and others, in order to explore sensitivity and examine how such tools might be used for evaluation of the existing single-species reference point and evaluation of additional “multispecies” reference points.

12.2 General Recommendations for multispecies modelling work.

Modelling may significantly enhance our understanding of potential ecosystem impacts of fisheries and the past two decades have seen an explosive growth in the number and type of multispecies models directed at fisheries questions (reviewed in Hollowed et al., 2000; Whipple et al., 2000). It is prudent to examine approaches that provide alternative views of the nature and of species interactions not only the MSVPA/4M approach.

Multispecies modelling approaches which have emerged in recent years have included:

- age structured models (e.g. MSVPA & 4M)
- length or age/length structured models (e.g. Gadget & SMS)
- biomass dynamic models (e.g. Ecosim)
- Bayesian models (e.g. Hammond & Ellis 2002)
- individual based models.

- SGMSNS recommend that as a supplementary term-of-reference for the March 2005 meeting, the group review the final report of the EU Framework V project 'DST²' (due to end in December 2003) and progress described therein, concerning Gadget/Bormicon.
- SGMSNS recommends that at the 2005 meeting, time-series-tuning be carried out on the 1991 Ecopath Mass-balance model of the North Sea (see section 8). This will result in a model can be used in parallel with MSVPA for future scenario testing at the level of the whole ecosystem.
- SGMSNS recommends that the ICES Working Group on Fish Ecology (WGFE) develop and maintain a meta-database comparable to that produced by WGSE listing all North Sea fish stomach data sources, including data on non-commercial species. This would undoubtedly be of great utility for all future modelling exercises.

12.3 Ideas for the future direction of multispecies field work in the North Sea

Mathematical models are used to distil a complicated system into a simpler one. Our ability to model the real world depends on our ability to collect adequate data. It is important to acknowledge that smart models cannot substitute for bad (or a lack of) data. It may take hours to develop a mathematical model and months to implement it on a computer, but it may take decades to collect an adequate time-series of quality fisheries data (Sparre & Hart, 2002).

Essential data requirements of all multispecies/ecosystem models are basic data on who's eating who, how much, when and where. We consider that the most pressing data needs requiring field investigations to support development of multispecies/ecosystem modelling are:

1. Updated stomach data

It is important to recognise that all current modelling efforts are dependent upon stomach data which was collected 12 and 22 years ago. There have been marked changes in the composition of the North Sea fish assemblage over this period with many non-commercial and small species increasing in abundance while traditional target species have declined (see Jennings *et al.* 2002). It is very likely that gross changes have occurred in the North Sea food-web since the last 'year of the stomach', and in order to validate current multispecies projections for the North Sea (which are forced to rely on projected diet compositions), it would be beneficial to hold a further large-scale or smaller targeted stomach sampling exercises. Such exercises are inevitably very expensive although they could be piggy-backed onto current groundfish surveys of the North Sea. Certain predators are now becoming important e.g. grey-gurnard and horse mackerel which have only been sampled once (in the 1991 'year of the stomach'. Sampling level of mackerel and saithe stomachs has also been relatively modest and multispecies assessment would benefit from new sampling of these species.

2. Spatial resolution

Focus on spatio-temporal scales of species distribution, habitat associations and movements.

3. Behavioural dynamics of predator-prey interactions

The mechanisms of predator-prey interactions, including qualitative and quantitative investigations leading to hypotheses on predator-prey dynamics. Such investigations are wedded to the issue of spatial resolution and include addressing spatial association/overlap of predators and prey and investigations to see whether spatial overlap has changed in the North Sea over the 40-year MSVPA period.

4. Specific studies providing independent data for validating models

Methods exist which to some extent allow the independent validation of model predictions. For example analyses of stable isotopes (of nitrogen, carbon and sulphur) can be used to reconstruct aquatic food webs, whilst also making it possible to examine whether predator diets have changed markedly over long periods of time. Wainright *et al.* 1993 demonstrated, based on analyses of archived scale samples, that the diet of haddock on Georges Bank, Canada changed markedly over the course of the 20th Century. Fish of similar size now feed at a much lower trophic level than they did 100 years ago, in response to changes in the abundance of their main prey and/or discarding practices.

5. *Focus on lower end of food web*

There is a particular requirement for size-based sampling of non-target species for which little information is presently available (right down to micro-plankton and meiofauna etc). Also included are investigations on critical transition stages of fishes. Estimation of gear and species-specific catchabilities are required to provide area density estimates of biomass.

6. *Behavioural dynamics of fishing fleets*

Spatially resolved data on fishing fleet effort allocation, landings, by-catch composition and discarding rates.

It is imperative that planning such field investigations includes development of data storage systems that facilitate wide distribution of the data in an easily accessible format.

12.4 **Future terms of reference**

It is requested that there be one further meeting of SGMSNS, to be held in **spring (March) 2005**. This will permit 2 years of additional data (2002 and 2003) to be incorporated into a revised, and 'definitive', 4M model key-run. By holding the meeting in March, this will also allow findings and recommendations to be considered at the spring meeting of ACFM in 2005.

The **Study Group on Multispecies Assessment in the North Sea [SGMSNS]** (Co-Chairs: Morten Vinther (Denmark) and Ewen Bell (UK)) should meet at ICES Headquarters/ Charlottenlund Castle, Copenhagen for 5 days during March 2005 to:

- (a) prepare a 'definitive' and fully revised 4M model key-run, incorporating any revisions in consumption rates or other available data.
- (b) re-evaluate the importance of mackerel as an MSVPA predator in the North Sea.
- (c) incorporate the biomass data, consumption rates and diet compositions provided by WGSE and WGMME for marine mammals and seabirds. Evaluate the importance of newly introduced predators (e.g. harbour seals), and whether these affect 4M outputs.
- (d) re-examine the issue of whether 0-group fish can adequately be modelled using the 4M or other multispecies modelling approaches.
- (e) address 'applied' and specific questions posed by ICES.
- (f) Perform a data fitting exercise using the North Sea 1991 EwE model. The fitting exercise will require input (survey CPUE) and output data (MSVPA estimated biomasses) from the updated 4M key-run (TORa).
- (g) examine the need within ICES and develop a strategy for multispecies stock assessment and subsequent multispecies advice on management issues. Consider whether a new ICES study or working group needs to be created and if so, what appropriate terms of reference might be and what geographic area it might focus on.

SGMSNS should report for the attention of the Resource Management Committee, the Living Resources Committee and ACFM and ACE.

13 **WORKING DOCUMENTS PRESENTED TO THE WORKSHOP**

Three working documents were presented to the study group:

Working document, WD1

Kempf, A., Floeter, J. and Temming, A. (2003) Sensitivity of 4M predictions to the use of different stomach data sets, a case study on a potential North Sea gadoid recovery plan. 56 pp.
An extended summary of parts of the study is presented in Appendix 2.

Working document, WD2

Vinther, M. (2003) 4M-HCR, Harvest Control Rules and 4M forecast.
See section 2 and sec 6 for more information

Working document, WD3

Vinther, M. (2003) 4M-Optim, objective functions and 4M forecast
See section 2 for more information

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APPENDIX 1

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APPENDIX 2

Sensitivity of 4M predictions to the use of different stomach data sets, a case study on a potential North Sea gadoid recovery plan

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Introduction

One of the critical assumptions in MSVPA theory is that suitability coefficients (suits) are time invariant. However, there are several potential causes for suits to vary over space and/or time. For example, suits may change because of prey switching or variable spatial overlap (Hilden 1988). If the assumption of constant suits is not valid, the results of MSVPA and MSFOR may be affected due to not accounting for either random or systematic suit changes in the model. This could lead to biased results of a yet unknown magnitude in hindcasts as well as in predictions.

In this paper we assessed the directions and magnitudes of changes in the 4M results, which occur due to the application of independent stomach data sets and hence analyse the implications of the assumption of constant suitabilities for 4M stock projections. Scenario predictions with both stomach data sets were performed to assess the consequences of using a particular stomach data set in the context of a “Gadoid Recovery Plan”.

Materials and Methods

Data

In this analysis the catch-at-age data used in keyrun 2002 (ICES, 2002) were available from ICES area IV (North Sea) for the years 1963 to 2000. Western and North Sea mackerel (*scomber scombrus*) was implemented as “Other predator”. The stomach data stem mainly from the years 1981 and 1991, the so called “Years of the stomach” (Daan 1989; Hislop et al. 1997). Two independent suit matrices can be calculated from those data. In addition, cod, whiting and saithe stomach content data from the 1st and 3rd quarters of the years 1985 to 1987 (Anon. 1988) were used in this analysis. Detailed descriptions of sampling and stomach content analysis procedures can be found in Robb (1991).

If not stated otherwise all other input data were the same as in the keyrun 2002 (ICES 2002). These are namely data for consumption rates, proportion mature, mean weights, M1 and terminal F.

Analyses of the influence of different stomach data sets on MSVPA results

Two model runs were carried out with the operation “VPA” in multi species mode with 4M. Both model runs differed in the choice of the stomach data set otherwise they were completely identical. For one model run only the 1981 stomach data were used, for the other one only the 1991 stomach data. Differing from keyrun 2002, the stomach data for Western and North Sea mackerel from the year 1981 were included in the data set. All other options were used as in keyrun 2002.

Analysis of suit matrices

Weighted average suits were calculated over prey age groups, separately for every quarter, predator, predator age group and prey species (e.g., cod age group 1 eating sandeel age groups 1-4 → weighted average suit for cod age group 1 eating sandeel). As a weighting factor the magnitude of an interaction was chosen. The intention was to accentuate suits of dominant interactions. For every predator prey interaction the weighted average 1991 suit was subtracted from its 1981 counterpart, i.e., the 1981 suit matrix was defined as the baseline for this analysis.

Analyses of the impact of different stomach data sets on stock biomasses

The calculated stock biomasses for the first quarters of the years 1981 and 1991 and the calculated recruitment biomass, i.e., the stock biomasses of age group zero in the 3rd quarters, were extracted from the two model results. The proportional differences in calculated stock and recruitment biomasses were calculated. Again, the model run with the 1981 stomach data set was taken as the baseline and the 1981 values were set to 100%.

Analyses of the influence of different stomach data sets on 4M predictions

To create the input data for the predictions three model runs were carried out with the operation “VPA” in multi species mode with different stomach data sets:

- one model run with the 1981 stomach data only (Run 1981)
- one model run with the 1991 stomach data only (Run 1991)
- one model run with all available stomach data (1981, 1985-87, 1991) as in the keyrun 2002 (Run 2002).

All other input data were used identically in the three runs and the calculation time period was 1963 to 2000. The eight VPA species (cod, whiting, haddock, herring, sprat, N. pout, sandeel and saithe) were included. All “Other Predators” were excluded. The biomass for “Other Food” was set constant. The consumption rates were provided externally and recruitment of all VPA species occurred in age group zero in the 3rd quarter of a year. A VPA tuning for all three runs was carried out simultaneously according to the method described in Vinther (2001). The same tuning fleets and options as in the single-species assessment for ICES Area IV were used (ICES, 1999, 2000).

Afterwards, the operation “Prepare Prediction” in 4M was executed for all runs separately. The VPA year 1999 was chosen as a reference year. Predicted recruitment were calculated as constant arithmetic mean values over the VPA years 1997 to 1999. The future F-Patterns were also calculated as mean values from the VPA years 1997 to 1999. The time period for the calculation of mean values of other parameters (such as M1, weight in the sea etc.) was limited to the years 1993 to 1999.

The future F pattern found with the help of the operation “Prepare Prediction” in 4M was subject to another manipulation. In order to simulate scenarios of a “Gadoid recovery plan”, the future coefficients of fishing mortality were reduced by 10, 50 and 90 percent for cod, whiting and haddock simultaneously in each of the three runs.

After finishing the operation “Prepare Prediction” two analyses (analysis I and analysis II) were carried out to analyse the influence of the different stomach data sets on 4M prediction.

In analysis I altogether 12 forecasts were carried out, deploying various combinations of suit matrices and fishing pressure reduction levels. Thus, the runs of analysis I only differed in the choice of the suit matrix. All other parameters were held artificially identical, using the results from the operation “Prepare prediction” of run 2002 also for run 1981 and run 1991. The forecasted time period was limited to the years 2000 to 2015. Recruitment was held constant (taken from year 1999 of the run 2002) and all additional options were chosen as in the VPAs carried out for the calculation of the suit matrices. The developments of the predicted annual yields were displayed on line charts.

In analysis II the F pattern for the different fishing pressure reductions, the stock numbers in the first quarter of the first forecast year and recruitment were taken directly from the three preparation runs as input to the forecasts. Everything else was carried out as described for analysis I.

Results

Comparison of suit matrices 1981 and 1991

The suit matrix 1991 and the suit matrix 1981 differ clearly for all predator species. The absolute differences can reach up to +/- 0.8 at maximum (e.g., interaction saithe age group 3 feeds upon haddock in 1st quarter). Since suits can reach a maximum value of 1, this suggests large changes in suitability. Although these are extreme cases, differences in the range of +/- 0.2 and +/- 0.5 appear frequently for all predator species. However, differences under +/-0.2 constitute the predominant fraction. Besides these, systematic patterns in suit changes occur. In such cases all predator age groups show suit changes in the same direction. For example, all age groups of whiting have a considerably stronger tendency towards cannibalism in the 1st quarter 1991 than in 1981. Cod, however, shows the weakest tendency towards these patterns.

Changes in stock biomass due to different stomach data sets

Between the model runs with the 1981 and 1991 stomach data set large proportional differences in the calculated 1st quarter (1981) stock biomasses and recruitment biomass occur (Fig. 1). In most cases higher stock biomasses are calculated with the 1991 stomach data set. Negative proportional differences, which imply a higher stock biomass under the use of the 1981 stomach data set, are in the minority. The predominant magnitude of differences is between 50 and 100 percent, but differences up to 250% (N.pout age group 3) occur. Cod shows the lowest differences. Similar to the

calculated stock biomasses of the older age groups, in most cases the calculated recruitment biomass is considerably higher in the model run with the 1991 stomach data. Only herring shows a higher recruitment under use of the 1981 stomach data set. The differences between the two runs are mostly in the range of 50 to 100 percent. Remarkably, for cod a 720 % higher recruitment biomass in the MSVPA year 1981 is calculated with the 1991 stomach data set.

The proportional fraction of “Other Food” in the 1981 and 1991 stomach data sets

The stomach data sets 1981 and 1991 are different with respect to the proportional fraction of “Other Food” in many cases. The bulk of the differences are in the range of 10 -30 %. Sometimes, however, differences up to 80 % can be observed (e.g.; age groups 4-5 of saithe in the 4th quarter (Fig 2)) Regarding systematic trends, it can be recognized that for most predator species the 1981 proportional fraction of “Other Food” is higher than in the 1991 stomach data, especially in saithe. Except for the saithe age groups 4 and 5 in the 2nd quarter, the proportional fractions of “Other Food” are always considerably higher in the 1981 stomach data set (Fig. 2). This tendency can be observed in a weaker form for all predators but haddock (Kempf 2003). and causes systematic higher predation mortalities for VPA prey species under use of the 1991 stomach data set than under use of the 1981 stomach data set.

Differences in the predicted yield development (Analysis I and II)

Although the Analysis I runs only differ with respect to the suit matrix used, large differences in the predicted yield development within the years 2000 to 2015 occur. When reducing the fishing pressure on cod, whiting and haddock, the differences between the runs stay almost in the same ranges for all scenarios. Although the model runs are different in the absolute yield numbers for almost all species, most of them do not differ with respect to direction of the future yield development. However, Norway pout represents an exception: While up to the year 2015 a steadily increasing yield is predicted in run 1981, the run 1991 and run 2002 predict diminishing yields. For cod, whiting, herring and N. pout run 1991 predicts considerably smaller future annual yields than run 1981 even in the first years of the calculation time period (e.g. fig. 3, up to 50 % lower for cod and whiting). Run 2002 mostly predicts yields lying between those of run 1981 and run 1991. Only for cod does the predicted yield of run 2002 represent the mean value of run 1981 and run 1991. Otherwise run 2002 calculates values which are closer to the predictions of run 1981 or run 1991.

When contrasting the predictions from Analyses I and II, although the differences in the input data are greater in Analysis II, the predicted yields from the three Analysis II runs converge e.g., fig. 4, cod and whiting). But the larger the reduction of fishing pressure on cod, whiting and haddock becomes, the bigger are the differences between the three runs in Analysis II (e.g., with no reduction of fishing pressure the 2015 yield predictions for cod differ by 15% between Run 1981 and Run 1991, but this increases to 60% difference at 90% reduction of fishing pressure). However, even in these scenarios of drastic fishing reduction, the differences between the three runs remain at a lower level than in Analysis I. Herring is the only species for that the differences in predicted yield reach similar dimensions in both Analyses I and II (yield in run 81 is up to three times higher than predicted in run 91).

Discussion

Our analysis has revealed substantial differences in parts of the suitability matrix depending on the stomach data set used. The observed differences can to some extent be attributed to insufficient data quality and subsequent variability. A number of suitabilities is actually based on very small sample sizes of stomachs supporting them (e.g., for saithe age group 3 only 1 stomach was sampled in 1981 in the 1st quarter). The relationship between sample size and suitability variability was also systematically investigated and showed a clear negative correlation (Kempf 2003).

However, our analysis also revealed a number of examples of systematic shifts in suitabilities referring to predator age prey age combinations which were well represented in the stomach data base. These systematic changes are of more concern, since they may reflect either prey switching behaviour or changes in the predator prey overlap patterns. In the first case the suitability depends on the prey abundance while in the second case overlap patterns may vary with stock size, year class strength and hydrography. These processes can potentially induce both year to year variability as well as trends on the decadal scale.

The present implementation of 4M uses a pooled suit matrix that is generated from all available stomach data. With this approach systematic changes can not be addressed properly, however, the variability in suitabilities due to low sample numbers may be dampened to some extent. To resolve the systematic effects, investigations into variations of predator prey overlap as well as additional stomach sampling programs should be undertaken. With this additional information a dynamic process based food selection model could be developed for 4M.

Our analysis revealed pronounced differences in the amount of the fraction of other food in several MSVPA predator stomachs between 1981 and 1991. Higher amounts of other food translate into lower predation mortalities and hence lower estimates of stock numbers for the VPA-species and vice versa. Pronounced fluctuations or trends in the abundance of relevant other food populations may indirectly cause mortality fluctuations of VPA-species, which can not be considered in assessments or predictions.

Both systematic suitability changes as well as changes in the amount of other food are considered to be real and sufficiently supported by the two independent data sets. It can therefore be assumed, that such changes occur quite frequently in reality, however without additional samples they remain invisible. We performed specific simulations (analysis I) to demonstrate the magnitude of the effects of such invisible changes on the basis of the two available stomach data sets. In this analysis future recruitment values were assumed to be known exactly from independent sources and therefore set identical in both runs (one with 1981 stomachs, one with 1991 stomachs). The resulting effects on predicted yield levels in the context of a gadoid recovery scenario were substantial and demonstrate the relevance of these processes. The presented actual numbers, however, should not be considered to reflect reality.

Contrary to these theoretical scenarios on the effects of unaccounted changes in the feeding patterns, in standard 4M forecasts recruitment values are taken from the respective retrospective runs to keep the recruitment levels internally consistent with the F and M patterns applied. The observed differences in predicted yield levels were much lower than in analysis I. However, even by applying this procedure, the use of a particular stomach data set leads for some species to deviations in the predicted yield levels. Nevertheless, the predicted trends were rather similar in these comparative runs. Also the cod recovery scenarios that were made with recruitment values from the respective runs but different stomach content data sets revealed rather consistent trends.

In the present ICES fisheries assessment the SSVPA and its derivatives are still the preferred management tools. Only a mean value of the calculated M2 values for every species age group is taken from the MSVPA results as input for SSVPA calculations. Thus, the demonstrated uncertainties of the North Sea MSVPA are only significant for the current ICES fisheries assessment methods, when the M2 values also exhibit wide confidence intervals because of the potentially wrong assumption of constant suits.

ICES (1997) pointed out in their analysis of differences between Run 1981 and Run 1991, that the dependence of partial M2's on the used stomach data set is only small compared to the magnitude of variability in the suitabilities. It was argued subsequently that M2's can be taken from the MSVPA for single-species assessment without great risk. However, as also stated in ICES (1997) for prey populations the total predation mortality resulting from all model predators together is more relevant than the partial M2's. In the model runs carried out for this study large absolute differences in these cumulative M2's were found especially for young age groups (up to a difference of 1.2 with the most differences around 0.3, Tab. 1). Again, the variations may reflect either year to year effects or even trends. If a constant M2-value is applied the potential effects of the real M2-fluctuations are not accounted for in the yield predictions.

Table 1

Differences in cumulative M2's between Run 1981 and Run 1991 for the year 2000 as an example.

| species | age group | Run 1981 | Run 1991 |
|---------|-----------|----------|----------|
| cod | 0 | 0,64 | 1,72 |
| cod | 1 | 0,30 | 0,16 |
| whiting | 0 | 1,42 | 2,64 |
| whiting | 1 | 0,45 | 0,2 |
| haddock | 0 | 1,74 | 1,41 |
| haddock | 1 | 1,63 | 0,9 |

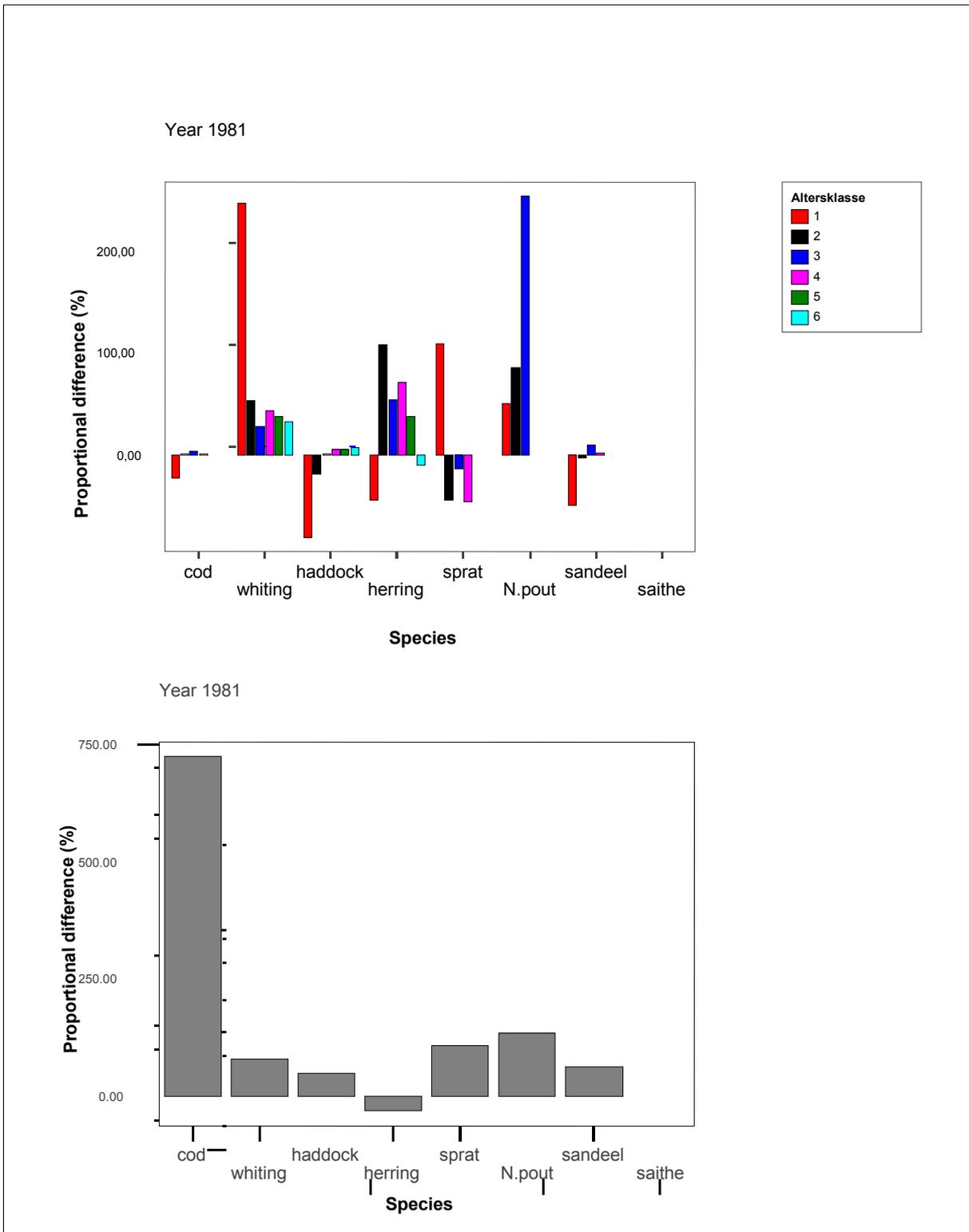


Figure 1

Proportional difference in the calculated 1st quarter stock biomass (upper figure) and recruitment biomass (lower figure) for the MSVPA year 1981 between the 1981 and 1991 model run. The calculated stock biomasses with the stomach data set 1981 was set as 100 percent. Positive differences imply a higher biomass in the 1991 model run. Negative differences imply a higher biomass in the 1981 model run.

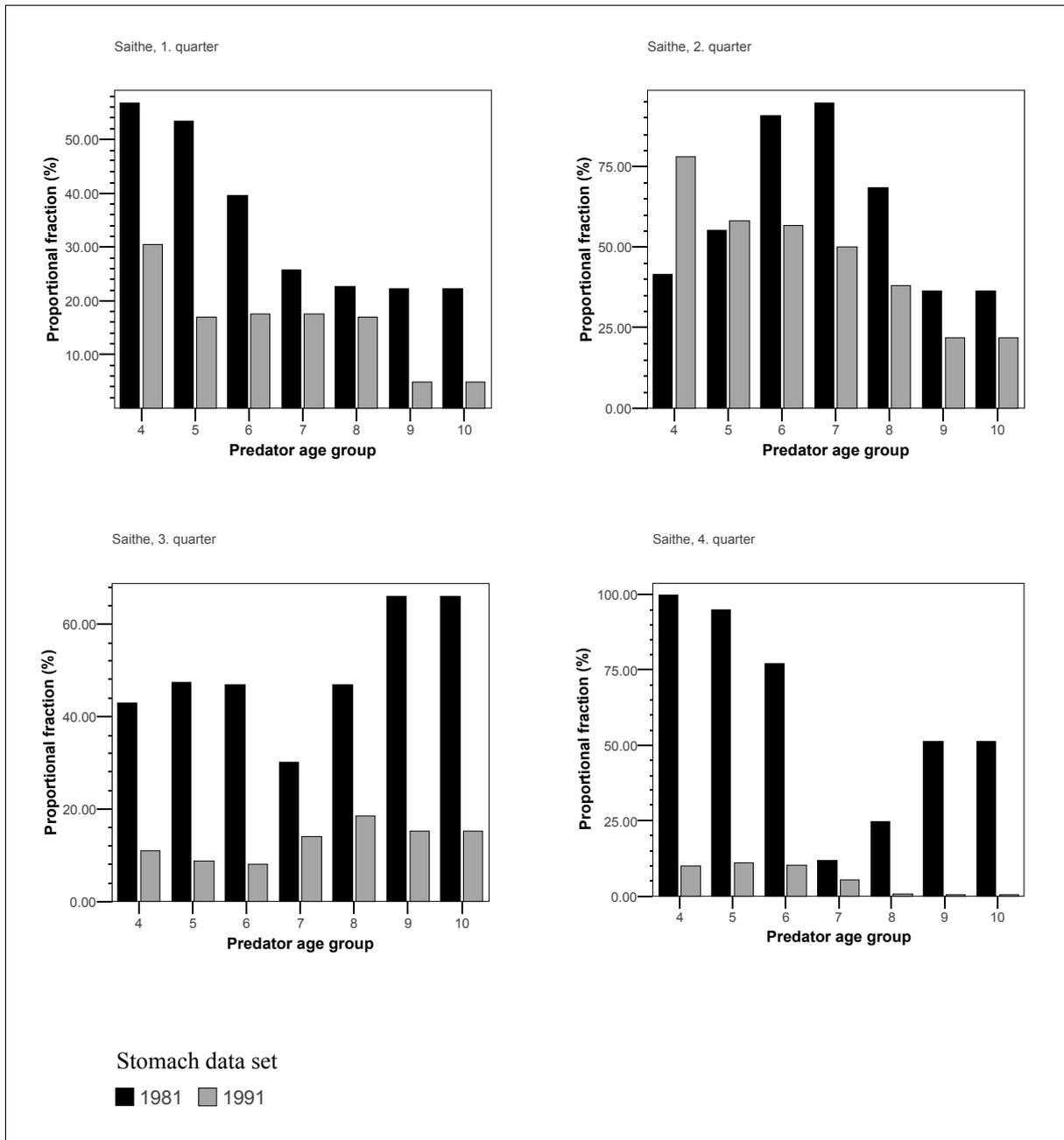


Figure 2 Differences in the proportional fraction of „Other Food“ in the diet of saithe between the stomach data set 1981 and 1991. Age groups with a proportional “Other Food” fraction of 100 percent in both stomach data sets are not plotted.

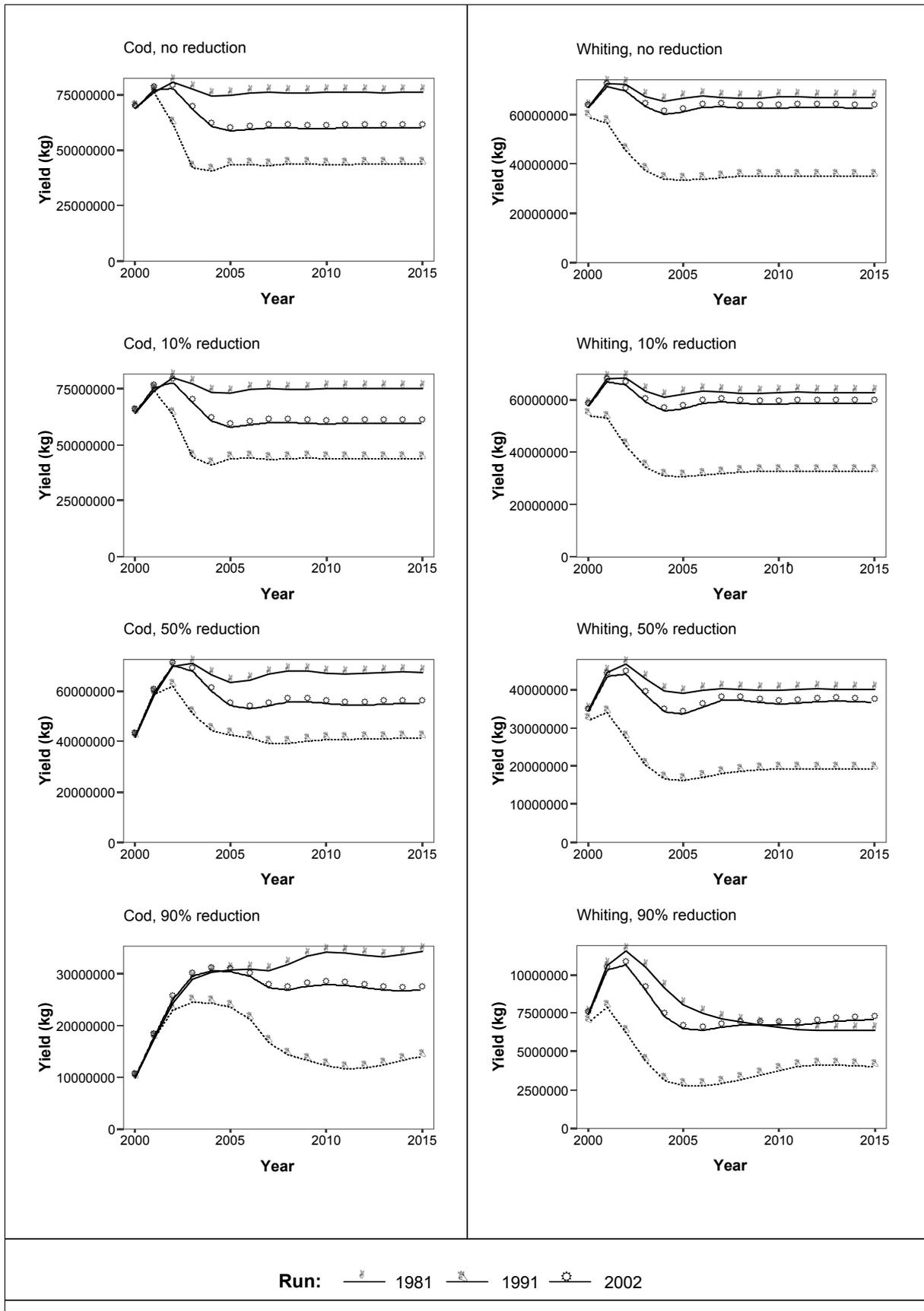


Figure 3 Differences between the runs in the development of the future annual yield for divers fishing pressure reduction scenarios. The runs are different according to the used suit matrix.

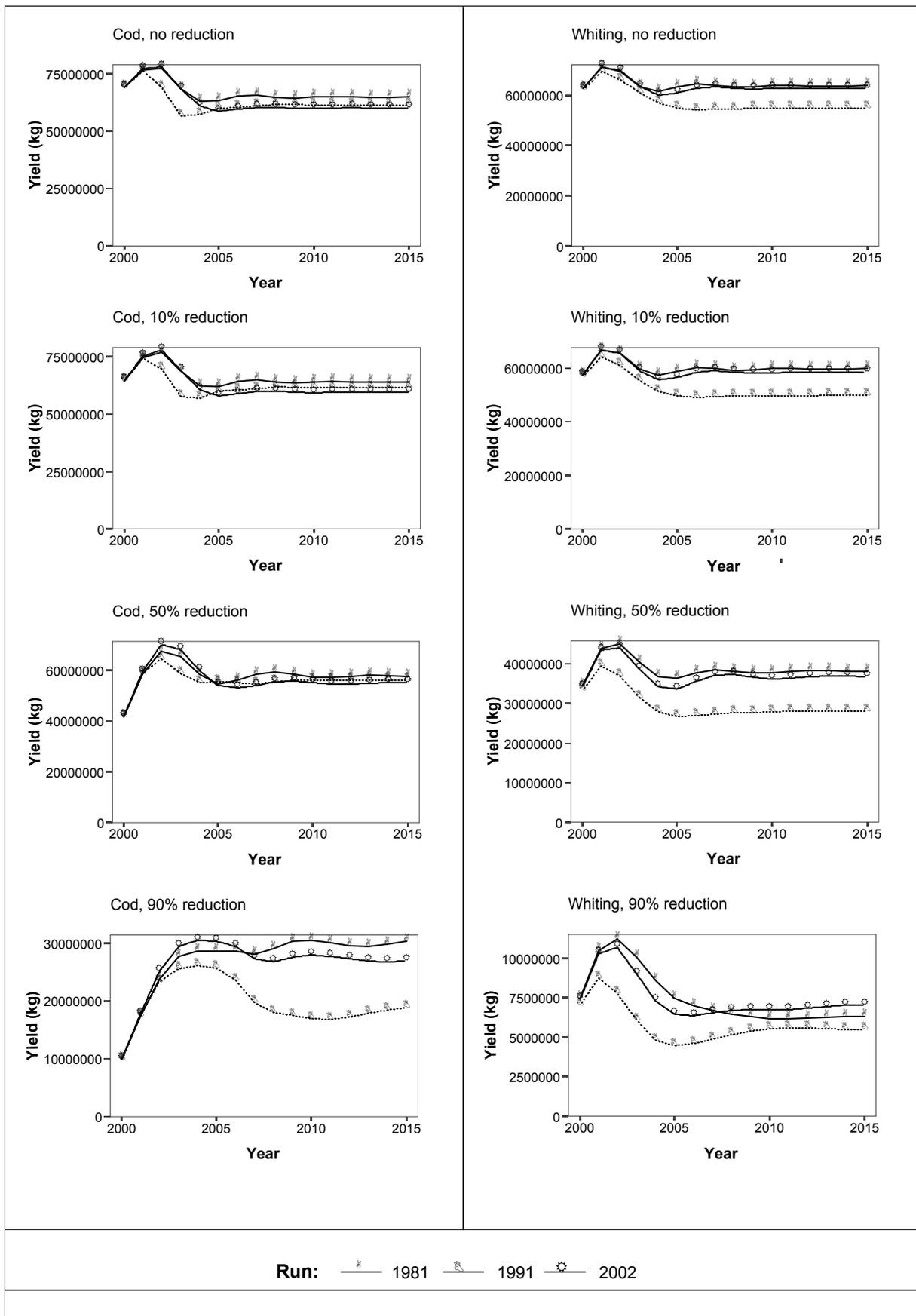


Figure 4 Differences between the runs in the development of the future annual yield for divers fishing pressure reduction scenarios. The runs are different according to the used suit matrix, the recruitment levels, the used f patterns, and the stock biomass in the 1st quarter of the first prediction year.

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