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*PART 1*

*REPORT OF THE MULTISPECIES ASSESSMENT  
WORKING GROUP*

Woods Hole, 4-13 December, 1990

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## 1. INTRODUCTION

### 1.1 Participants

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### 1.2 Terms of Reference

The terms of reference (C. Res. 1990/2:5:27) are:

- a) continue the development of multispecies methods of assessment;

- b) consider how to better incorporate predation on and by 0-group fish in quantitative models of interspecies predation, particularly with regard to data to be collected in the 1991 Stomach Program;
- c) conduct medium - and long-term stochastic simulations incorporating multispecies effects, with emphasis on functional feeding relationships and stock/recruitment relationships;
- d) explore the utility of various population attributes for comparing underlying trophic mechanisms among exploited ecosystems;
- e) continue the development of multispecies models for Arctic/boreal ecosystems, focusing on problems of joint management of interacting species;
- f) conduct statistical analyses of the underlying relationships in Arctic/boreal ecosystems of cod growth to prey abundance and environmental variability, focusing on time-series data concerning:
  - i) cod growth increments,
  - ii) population abundance of cod and its prey,
  - iii) environmental conditions,
  - iv) stomach content and consumption data;
- g) for Arctic/boreal ecosystems, compile and explore existing predation data (stomach content, consumption estimates) for fish, marine mammals and birds, and make such data available in a common (disaggregated) format for future analyses;
- h) advise on the consequences for other fisheries of fishing large quantities of prey species, in particular, Norway pout and sandeel in the North Sea.

### 1.3 Overview

Since its inception, the Multispecies Working Group has had as its overriding term of reference, the continued development of analytical and simulation approaches for the incorporation of multispecies and multifleet effects into the provision of fishery management advice (Anon. 1984a; 1986; 1987; 1988; 1989a; 1990a). As a practical matter, this development has been spurred primarily by international interests in multispecies assessments of North Sea fish stocks. The original development of multispecies virtual population analysis (MSVPA) as a retrospective approach for evaluating fishing and predation mortality rates and population sizes was based on North Sea fishery problems. Similarly, the 'year of the stomach' program conducted in 1981 (and to be repeated in 1991) was focused there.

Progressive refinement of the MSVPA approach and forecasting models

based on MSVPA results have resulted in multispecies assessments for the North Sea moving from the developmental to the operational phase. Thus, for example, advice on the long-term and transitional impacts of mesh and fishing effort changes have been tendered for the North Sea system (Anon. 1988; 1989a). Similarly, estimates of natural mortality rates explicitly including predation effects are now commonly used by single-species working groups (e.g. Anon. 1991a). Refinements of the basic approach have come from additional years of stomach sampling, which have allowed for testing of the basic assumptions, as well as the inclusion of more predator stocks within the MSVPA structure (see appropriate sections of this report). Additional proposed refinements to MSVPA and forecasting include allowing for explicit spatial effects (see Recommendations), refinement in consumption and digestion data (section 8.6) and evaluation of alternative functional feeding relationships used within the model (Recommendations).

The Working Group has emphasized that rather than being parochial in its interests, its primary concern is with methodological development (Anon. 1989a). Although it is doubtful that complex tools such as MSVPA can be routinely maintained and used by the various species or area-based working groups, once such tools become operational, their care and feeding has become less demanding. Thus, the Working Group reiterates its belief that it is the logical entity for providing long-term advice when species interactions are considered, even while pursuing the primary objective of developing new methods of doing business.

From time to time the Working Group has considered multispecies/multifleet interactions in fishery systems outside of the North Sea. Work in other ecosystems has been addressed in two contexts: (1) as comparative ecosystem studies with which to evaluate detailed results from the North Sea (e.g., with the Baltic MSVPA results (Anon. 1988)), and (2) as progress reports of modeling efforts in systems such as the Barents Sea, Iceland and eastern North America (Anon. 1989a).

Given its desires to focus primarily on methodological improvements, and to maintain a wide regional perspective so as not to dilute the rather small international pool of experts in multispecies/multifishery studies, the Working Group has explored the feasibility of more intensive multispecies studies in other ecosystems. To this end a special meeting of the Multispecies Working Group was convened in Bergen, in April 1990 (Anon. 1990a).

At the special meeting of the Multispecies Working Group in Bergen (23-27 April 1990) the modelling of multispecies interactions in Arctic/Boreal Systems was reviewed (Anon. 1990a). A common ground from which cooperative studies could go forward was found and participants agreed on five recommendations in this regard, three of which were proposed as additional terms of reference for this meeting of the MSWG. The terms of reference specifically addressing multispecies aspects in arctic/boreal systems were subsequently adopted at the 78th Statutory meeting in Copenhagen

(i.e., terms of reference e, f and g in section 1.2). Thus, the current Working Group had a large number of diverse terms of reference (section 1.2), reflecting specific work in the North Sea and Arctic/Boreal systems, as well as comparative analyses incorporating Baltic Sea and North American studies. The number and diversity of terms of reference doubtlessly contributed to the significant increase in participation at the meeting (section 1.1), and, much to the dismay of ACFM, the length of this report.

Section 2 of this report details the updated MSVPA and forecasting procedures used for the North Sea. The newest version of the retrospective MSVPA package has been extended to allow for fish predators such as marine mammals, seabirds, rays, etc., for which there are no catch-at-age data. Rather, estimates of predator stock size derived outside the VPA calculation are entered into the calculations. In this regard, some explorations of the consequences of including rays and the western mackerel stock in the MSVPA calculations are undertaken. Because of the sensitivity of MSVPA results to (in some cases) rather sparse feeding data for these predators, their predation effects were not included in the MSVPA 'key run', but will be once more complete feeding data become available. The Working Group also considered approaches to the inclusion of marine mammals (section 2.9.3) and seabirds (section 8.4) within the MSVPA structure. Again, because of the lack of comparable feeding and predator stock size data, disaggregated appropriately by time and area, inclusion of bird and marine mammal effects in MSVPA was not deemed practical at this time.

The sensitivity of MSVPA and MSFOR results to assumptions of  $M_1$  (residual natural mortality values), consumption estimates, terminal fishing mortalities, and some technical simulation parameters was evaluated. Because of the large number of parameters to be evaluated (33 for MSVPA and 29 for the MSFOR model), testing the effects of modest changes of each of the parameters individually and as interactions with one another is prohibitive if all possible permutations are to be assessed. Accordingly, the Working Group used fractional factorial designs of the simulation experiments to be run. The design matrices allow all first order effects to be evaluated with a modest number of program runs (i.e., trials of MSVPA and MSFOR changing different combinations of parameters). Sensitivity analyses of MSVPA responses (especially variables related to age 1 cod abundance and mortality rates) indicated that MSVPA results were generally robust to modest variation in input parameters.

The fractional factorial method was also used to evaluate the sensitivity of predictions the long-term effects of large-scale (+50%) changes in fishing effort in North Sea fisheries, using the MSFOR model (section 4.3). MSVPA results were generally most sensitive to variation in total food consumption estimates and assumptions of  $M_1$  values. Predictions were most sensitive to recruitment estimates.

Detailed analyses of the trophic dynamics history, biomasses and

multispecies yields of the North Sea, based on the MSVPA 'key run', are given in section 3. Results are compared to analyses from single-species VPAs undertaken by various working groups (where appropriate). Two separate analyses testing the assumption of constancy of suitabilities within MSVPA are presented: for the Baltic Sea (Anon. 1990h) and North Sea MSVPAs. In these analyses the feeding data are partitioned into several sub-sets (i.e., by combinations of years). The MSVPAs are then run and suitabilities computed. The 'raw' or smoothed suitabilities are then used in a cross-validation to predict food habits data for the years not used in computing the suitabilities. These analyses again confirm the general assumption of approximate constancy of suitabilities as computed from the MSVPA analyses. Predictions of 1991 stomach contents for the five MSVPA predator stocks are based on MSFOR models, with recruitment levels based on the long-term averages. These predictions will be evaluated during the 'year of the stomach - II' program being undertaken in North Sea waters during 1991.

In section 4 various long-term equilibrium and stochastic simulations of alternative fishing strategies for the North Sea system are undertaken. A primary goal of this section was to explore the effects of large-scale changes (+50% change) in fishing effort in the several North Sea fisheries, with particular reference to the industrial demersal fishery (catching primarily sand eel and Norway pout). This specific analysis was conducted in the context of similar effort changes for all North Sea fisheries, and employed both the MSFOR and Shepherd long-term models. The sensitivity of fleet yields to variation in fleet effort was again analyzed by fractional factorial experimental designs.

Stochastic yield simulations were conducted using an empirical stock-recruitment relationship; results are compared to average historical recruitment from MSVPA. For some species, using average recruitment levels biases upward the yield estimates, since current spawning biomasses are low and recruitment has been well below the long-term average in recent years. For other stocks (e.g. herring), average SSB is currently higher than the longer-term average (including the period of the stock collapse). This results in a potential downward bias in estimated yields.

Section 5 presents analyses of the rate of growth of cod in four arctic/boreal systems (Barents Sea, Iceland, Greenland and Newfoundland), in relation to cod stock density, capelin abundance, and environmental temperature. Despite the fact that all of these factors at least partially explained the variability in cod growth observed in the time-series of cod growth data, a significant YEAR effect remained in final GLM fits. This result is perhaps explained by the relatively poor choices of environmental data with which to correlate to growth variations, or by some other yet unaccounted for factor that is not aliased by the independent variables chosen for analysis.

Time series of food and feeding data for the arctic/boreal systems are thoroughly described in section 6. These data represent the

basis for ongoing statistical and mechanistic multispecies modeling efforts currently being conducted in the arctic/boreal systems. Stomach sampling programs have been extant in the Barents Sea, Icelandic and Newfoundland systems for a number of years (in the case of the USSR, since 1947). Because of the length of the time series and intensity of these data collections, they will be important in addressing several of the proposed terms of reference for the next meeting of the Multispecies Working Group, including analyzing the variance components of stomach sampling (section 9.1), and incorporating explicit spatial effects in multispecies models (see Recommendations).

Section 7 of the report considers the potential use of multispecies size compositions (specifically from research survey trawling data) to describe the overall status of multispecies resources and factors influencing their abundance. Previous work (Anon. 1989a) has noted that the slope of the multispecies numbers or biomass at length plots for fully-recruited sizes was generally stable over time within a fishery system, but in comparative system analyses the slopes were vastly different among the ecosystems. At this meeting three sets of multispecies trawl survey data were considered: the English groundfish survey of the North Sea, Canadian trawl survey of the Grand Banks of Newfoundland and USA bottom trawl survey on Georges Bank.

The slopes of the numbers and biomass-at-length plots were much greater in the North Sea system than on the Grand Banks or on Georges Bank. Are these differing slopes inherent in the trophodynamics of the systems, or rather do they simply reflect a weighted multispecies exploitation rate? The Working Group considered alternative mechanisms contributing to the observed differences (e.g., species replacement, differing predation mortality and exploitation rates, density-dependent growth). It is clear that multispecies compositions do not in themselves yield results that are easily interpretable as indicators of multispecies interactions. What they do provide is a basis for generating testable hypotheses explaining the observed differences, and lead to a new generation of length or hybrid age-length models (section 8.5).

Section 8 of the report is traditionally where the Working Group explores new ideas and approaches to multispecies modeling and assessment problems. Accordingly, analyses presented herein should be considered speculative rather than definitive.

The current MSVPA approach allows for the computation of predation mortalities, beginning in the third calendar quarter of life of the various prey species. The problem of extending the approach to younger ages is complicated by their rapid growth and mortality dynamics, and a lack of reliable quantitative sampling of pelagic juveniles. Both length-based and hybrid age-length based approaches are proposed for extending the MSVPA to younger fish. Such models have been formulated, and it is proposed to evaluate the performance of the length-based approach relative to age-based,



by using data for 1-group fish. Such data could then be evaluated vs. length distributions of 2-group fish sampled in the IYFS data.

Section 8.2 evaluates the effects of correlations in recruitment among species, on long-term yield and biomass predictions. In general, the effect of preserving the correlation between recruitments of species in long-term forecasts is to increase the amount of correlation between the catch of individual species and fleets above the level of correlation generated by predation effects alone.

The Working Group considered the potential use of stable isotope methods to independently verify trophic structure of fishery ecosystems. The ratio of stable isotopes of nitrogen in the body tissues of marine animals increases as animals feed on higher and higher trophic levels (e.g., phytoplankton, benthos, zooplankton, fish). A long time series (1930s-1980s) of stable isotope ratio data were developed from archived scale samples of Georges Bank haddock (section 8.3). These data show a striking shift to lower trophic level feeding in recent years, perhaps indicative of significant changes in the trophic dynamics of the system. Work is underway to evaluate the utility of fish otoliths for stable isotope measurements. If the procedure can be validated, it may be an important method for verifying the proportion of 'other food' in the diets of fish predators and an independent verification of retrospective models.

The utility of currently-available seabird predation data for incorporation in fish population models is reviewed in section 8.4. Integrated data on prey composition of different bird species over the entire North Sea are at present not available. In order to explicitly account for bird-fish predation mortality ( $M_2$ ), there is a need for quantitative consumption and food composition data, disaggregated by predator and prey species, area, and quarter.

Size spectrum models of exploited fishery systems are considered in section 8.5. The utility of relating multispecies modeling to ecological size spectrum theory may be in providing an overview and as an alternative check on internal model consistencies (e.g., in terms of mass flow balances). Their elegance lies in the fact that fewer parameters need be estimated than in age-based approaches, and that basic population mechanisms are primarily size-based (e.g., growth, predation). The theory of size spectra is elaborated, and some preliminary calculations based on MSVPA size compositions are presented.

A vital parameter in MSVPA calculations is the value of total annual consumption. In section 8.6, the potential sensitivity of cod and whiting total consumption estimates to a number of assumptions of the consumption calculations are examined. More recent data on diet composition and on the application of different feeding models warrant close examination relative to MSVPA results. Significantly greater consumption by cod (particularly in older age groups) results from application of alternative evacuation, meal

size and temperature corrections. For whiting, the annual consumption was most sensitive to the choice of which year's stomach data are included in the calculations (1987 vs. other years in particular). Future experimental investigations on the effects of predator size, food type and feeding regime are warranted.

The sampling regime for the 1991 stomach sampling program is evaluated in section 9. As in 1981, bulked samples (aggregates of a number of stomach samples from predators in the same size class) will be obtained, but additional data sets on an individual fish basis are to be encouraged. The latter are needed to evaluate the variances in estimates of total stomach content and species composition. In addition to sampling of demersal phases of the various predators, special surveys of pelagic predators, particularly emphasizing o-group prey in the pelagic phase should be considered.

In response to a request from ACFM, the Working Group developed a protocol for calculating consumption of North Sea Pandalus by MSVPA predator stocks sampled in the 1981 and later-year feeding studies. These consumption estimates will be developed by applying the proportion of Pandalus in stomach samples (by predator age) to the total quarterly consumption by the predator, and multiplying by predator stock size estimated by MSVPA. Consumption estimates will be supplied to the Pandalus Working Group as soon as they are available.

Finally, this meeting of the Multispecies Working Group must be regarded as transitional. Essentially there were two rather distinct meetings conducted concurrently: one reflecting North Sea terms of reference, the other focusing on Arctic/Boreal problems. For its next meeting, the Working Group has proposed terms of reference which incorporate scientific objectives that cut across ecosystems. Thus, for example, the issue of spatial effects can be evaluated with special cases based on data from the Barents Sea, the North Sea, etc. Similarly, the issue of statistical properties of food and feeding data is of general rather than system-dependent interest. Notwithstanding these efforts to widen the regional applicability of its studies, the Multispecies Working Group nevertheless stands ready to evaluate multispecies/multifleet implications of management scenarios for the North Sea system, as requested by ACFM.

#### 1.4 Acknowledgements

The Working Group extends its thanks to the staff and administration of the Northeast Fisheries Center, Woods Hole Laboratory, for the logistical and scientific support, critical to be completion of the large and varied number of tasks undertaken. Cooperation of the data management staff in satisfying the WG's insatiable appetite for CPU time and disk space are particularly acknowledged.

The large number of projects completed by the Group could not have been undertaken without ideas, data, and working papers contributed by a number of individuals and groups, including:

- (1) fish assessment Working Groups including the Roundfish, Mackerel, Industrial and Herring Working Group for the Area South of 62°N, for quarterly disaggregated landings and sampling data;
- (2) coordinators of the ICES stomach sampling projects, for providing feeding data;
- (3) scientists and technicians in a number of institutes conducting investigations in arctic/boreal systems (e.g., Barents Sea, Iceland, Greenland, and Newfoundland) for providing data and analyses of cod growth, feeding, and environmental variations in these area; and
- (4) the various national laboratories and institutes for supporting the WG meeting in a location away from the ICES Headquarters.

## 2 MSVPA AND MULTISPECIES FORECASTS FOR THE NORTH SEA

### 2.1 The MSVPA, MSFOR and Shepherd Multispecies Programs

Since the last meeting of the MSWG the MSVPA program has been extended to include fish predators such as seals, birds, rays etc. for which no catch at age data exists. Instead of using a VPA to estimate the stock size of these predators the stock size at age must be entered directly into the calculations. Apart from this the other predators are treated in exactly the same way as the usual MSVPA predators. Given weight, total consumption and food composition at age the MSVPA is used to estimate suitabilities, prey consumption and predation mortality.

In the MSFOR the stock size at age of each of the other predators may be entered as a constant or imported from the MSVPA together with the weight at age, suitabilities and total food consumption.

The MSFOR program has been extended to include an option for preserving the between species correlation of recruitment in the forecast. Recruitment to each of the stocks is assumed to follow a lognormal distribution. A principal components analysis is used to transform the correlated recruitment time series into a system of coordinates in which they become uncorrelated. The future recruitment is generated by selecting values from the marginal distributions in the uncorrelated system and backtransforming these values to recruitment estimates. These methods are described in detail in Gislason (1991).

The output from the MSFOR has been modified to include estimates of the autocorrelation and between-species correlation of the future

yield by species and fleet and of the spawning stock biomass. The autocorrelation may be considered as a measure of the stability of the predictions, ie. the change in yield and biomass from one year to the next, while the between species correlation summarizes the interactions in the system.

The Shepherd steady state projection method was used as in the 1988 meeting of the Multispecies Working Group (Anon. 1988). That is, unsmoothed M2 values were used as input, rather than smoothed alternatives. The input data for the method was as far as possible the same as that used for MSFOR simulations. Because the Shepherd model works on annual increments, however, stock and catch weights were used for Q3 only. The M1 values adopted for the Shepherd model runs were 'tuned' so that the total natural mortality encountered by any species/age group was close (within a few percent) to that used in MSFOR simulations. There are two exceptions to this. Firstly, the total M on herring, age 1, is 1.36 in the Shepherd run as opposed to 0.97 in the MSFOR run. Secondly, the total M on sprat, age 2, in the Shepherd run is 2.203 as opposed to 1.57 in the MSFOR run. The method converged on steady state solutions for the baseline run in 17 iterations. That run is shown in Table 4.2.2.

At this Working Group meeting the Shepherd method was implemented using a program developed during the meeting. This program employs a simpler data structure than the previous incarnation and should allow relatively easy investigation of various fisheries scenarios. The new program was used successfully but is still undergoing some revision and refining; it should soon be available for general release.

Value at age data were updated to be similar to information used by the STCF Working Group on Improvements of the Exploitation Patterns of North Sea Fish Stocks (Copenhagen, 11-15 November, 1990).

## 2.2 Catch Data and Terminal Fishing Mortalities

The database was this year extended with North Sea plaice and sole and the MSVPA now comprises a total of 11 stocks.

### Herring

Quarterly catch-at-age for herring for 1989 are taken from Table 2.2.1 in Anon. (1990b) for the total North Sea. Spring spawners transferred to Division IIIa are not included. Data for 1988 have not been revised.

### Cod, Haddock, Whiting and Saithe

Quarterly catch at age data for 1989 were supplied by the chairman of the Roundfish Working Group. Revised data prior to 1989 were not available. Attention is drawn to the most recent Roundfish WG Report (Anon. 1991a) in which uncertainties in the probable level of 1989 North Sea haddock catches are discussed. Nominal landings

of this species were ca. 64,000 t whereas the Roundfish Working Group based its analysis on the assumption that 76,000 t were, in fact, landed. The data used by the Multispecies Working Group are based on the latter value.

Terminal Fs for these species were available from the 1990 Roundfish Working Group (Anon. 1991a).

For cod, haddock and whiting, the Roundfish WG over wrote the tuned terminal Fs at age 2 and below in their predictions. Instead, they used values derived from the results of RCRTINX2 analyses. A similar approach was adopted at this meeting, using MSVPA estimates of number at age in the RCRTINX2 input files.

The Roundfish WG did not estimate a value of terminal F for saithe at age 1. For their catch predictions they assumed the geometric mean abundance at age 1 in 1989. The Multispecies Working Group followed this approach and generated an "artificial" terminal F at age 1 using actual catch data and the assumed abundance.

### Sandeel

Quarterly catch at age data for 1989 were taken from the 1990 report of the Industrial Fisheries Assessment Working Group (Anon. 1990c). Total catch at age were estimated as the sum of the catch at age data for the Shetland stock and the stocks in the northern and southern North Sea. The terminal fishing mortality was selected to produce a stocks size at age in accordance with the sum of the single species assessments. The stock size at age 0 in 1989 (1 July) was selected to be equal to the average stock size at age 0 in the years 1974-1988.

### Sprat

The catch data situation has not improved relative to the situation in 1989. The same procedure as described in the 1989 report of the Working Group (Anon. 1989a) was followed to update sprat catch data for 89. The average recruitment of 1-groups in 1st quarter over the period 83-88 was used as input for the forecast. This average was backcalculated to number of 0-groups in 3rd quarter 89, which served as input.

### Mackerel

No catch statistics are available specifically for the North Sea stock of mackerel. Values for catch at age were suggested by the Mackerel Working Group (Anon. 1990d). Since then, the results of the 1990 egg survey have become available, in terms of stock size in numbers at age, at 1 July 1990, and an estimate of the mean fishing mortality of 0.205 for the ages 2 years and older for 1988 and 1989 (Iversen et al. 1991). These data were used to compute catch numbers at age for the years 1988 and 1989. At age 1,  $F=0.1025$  was used, and the catches were divided into quarters as suggested by the Mackerel Working Group. The maturity ogive was

left unchanged, since it cannot be specified for individual years. Since the age at first spawning has decreased in the later years (Iversen et al. 1991), The estimate of the spawning stock biomass in the MSVPA for the recent years is lower than indicated by the egg survey.

### Norway Pout

Quarterly catch at age data for 1989 were taken from the 1990 report of the Industrial Fisheries Working Group (Anon. 1990c). The terminal fishing mortalities were initially chosen to produce a fishing mortality at age in accordance with the single species VPA, but was later modified to take the difference between the natural mortality in the single and multispecies VPA into account. The stock size at age 0 (1 July) was selected to produce a number at age 1 (1 January 1990) in accordance with the single species VPA.

### Plaice and Sole

Yearly catch at age data were taken from the 1990 report of the Flatfish Working Group (Anon. 1991b) and split into quarters by assuming the fishing and natural mortality to be evenly distributed over the four quarters. The terminal quarterly fishing mortalities were selected in order to produce a yearly fishing mortality in accordance with the single species assessment.

## 2.3 Relative Food Composition and Rations

Feeding data for whiting in 1987 were made available since the last meeting of the Working Group, and have therefore been incorporated in the current analyses. Thus, all anticipated feeding data collected prior to the planned 1991 'year of the stomach' program have now been analyzed and incorporated into the MSVPA data files.

At the 78th Statutory Meeting of ICES, in Copenhagen, a Theme Session on consumption rate estimates (convened by H. Sparholt) identified new data and revised procedures for producing consumption estimates from at-sea stomach content data and appropriate temperature and other conversions. Because of lack of time for careful consideration of the new information, it was not possible to revise total consumption estimates in the current analyses. However, the implications of various alternative methods and models for estimating total consumption were considered in detail, including some sensitivity analyses (section 8.6). It is recognized that careful consideration of all these new data and procedures is necessary and vital to the continued development of the MSVPA implementation for the North Sea.

For the purposes of the current analyses, total consumption and food composition data were the same as in 1989 (Anon. 1989a), with the exception of the additional whiting information for 1987.

## 2.4 M1 Values

Values of natural mortality rates due to sources other than predation by MSVPA species (M1) used in the 1990 'key run' were similar to those used in the last two meetings of the Working Group (Anon. 1989a). It has been recognized earlier that estimating predation mortality rates due to predators other than the five explicitly considered in MSVPA was desirable (Anon. 1989a). As noted in section 2.1, the MSVPA program has been modified to accept estimates of predator biomass and feeding for additional stocks not analyzed in the VPA-type structure. In order to efficiently do this, M1 values must be decremented to account for the additional predation mortality accounted for by the addition of predators to the model. The sensitivity of MSVPA results to the inclusion of two 'other predator' stocks (western stock mackerel and starry ray) are considered in detail in section 2.9.

## 2.5 Feeding Relationships Used in the Runs

As in previous meetings, the Helgason-Gislason feeding relationship (i.e., assuming biomass of 'other food' to be constant) was used. Additional tests of the constancy of suitability estimates from the model, under the assumptions of the Helgason-Gislason feeding relationship, were undertaken (section 3.2).

## 2.6 Weights at Age Used

Three sets of weight-at-age data are used in the current implementation of MSVPA:

- 1) body weights in the sea;
- 2) body weights in the catch;
- 3) body weights in stomach contents.

In the case of the latter estimates, sampling plans for the 1991 stomach sampling program (Anon. 1989b; Anon. 1990g, section 9) call for improved coverage and sampling protocols to better-estimate average body weights at age in predator stomachs.

## 2.7 Results of the Key Run of MSVPA

Tables 2.7.1 a-k show the MSVPA results for the individual species included in the analysis (cod, haddock, whiting, saithe, mackerel, herring, sandeel, Norway pout, sprat, plaice and sole). The results for plaice and sole are effectively single-species results as they are not explicitly considered as predators or prey (e.g. no predation mortality rates are presented). The Tables give biomass totals, stock size in numbers and the coefficients of fishing and predation mortality, attributable in the latter case to the M2 predators (cod, haddock, whiting, saithe and mackerel). Mean values of stock in numbers, fishing mortality and the various components of natural mortality (M2 predators, "other predators",

residual) are given in Tables 2.7.2a-c for the period 1983-1988.

The MSVPA fishing mortalities for cod, haddock, whiting and saithe are of the same order, in general, as those calculated by the Roundfish Working Group (Anon. 1991a). Direct comparisons of results continue to be hindered by the fact that revisions to the catch at age data, which are made when the Roundfish Working Group finalizes its data, are not available in quarterly form for inclusion in the MSVPA database.

MSVPA fishing mortalities and the corresponding single-species values are in reasonable agreement for North Sea herring (Anon. 1990b) and for Norway pout (Anon. 1990c). This was not the case for the latter species in the previous Multispecies Working Group Report (Anon. 1989a) however, that was likely to be due to difficulties encountered by the Industrial Fisheries Working Group when they attempted an annual rather than quarterly based assessment of Norway pout. They have since reverted to a quarterly based assessment and this appears to have reconciled some of the differences between MSVPA and single species VPA.

No direct comparisons can be made between MSVPA fishing mortalities and their single-species equivalents for mackerel and sprat, as no single-species VPA is run for them. For sandeels, single-species VPAs are run on multiple stocks creating difficulties in comparing their results with MSVPA results from a composite stock.

Figures 2.7.1 a-g shows total and spawning biomass stock levels from MSVPA and to the corresponding single-species Working Group totals for cod, haddock, whiting and saithe (Anon. 1991a), herring (Anon. 1990b), and Norway pout (Anon. 1990c). A single-species VPA run by the Multispecies Working Group on the composite North Sea sandeel data is shown with 1990 MSVPA estimates.

As in previous reports, the differences between multispecies and single-species VPAs for cod, haddock, whiting and herring appear to be due mainly to differences in mean weights at age and maturity ogives. Differences in sandeel biomass totals have previously been considered to be due to variable natural mortality rates existing between years rather than constant values as used in the single-species assessments. This difference still exists. The discrepancy in biomass totals for Norway pout noted in the previous Multispecies WG Report (Anon. 1989a) has been reduced. This is due to the re-adoption of a quarterly based assessment, rather than annual, by the Industrial Fisheries Working Group in its most recent Report (Anon. 1990c).

The means of the ratio between numbers at age from MSVPA and single species Working Group estimates for the years 1983-1988 are shown in Table 2.7.3 for cod, haddock, whiting, saithe, herring and Norway pout. In general, there is good agreement except for Norway pout at age 1. This is probably due to a lower natural mortality rate at age 1 adopted in the single-species assessment than would be indicated by the inclusion of multispecies interactions. The



ratio for saithe should be 1 for all ages. Departures from this are due to differences in terminal F at age and revisions in catch at age which have not been transmitted to the Multispecies Working Group.

Table 2.7.4 gives the values of natural mortality most recently used by the single species Working Groups compared to the mean value, 1983-1988, produced by the MSVPA key run. There is good agreement between sets, apart from cod age 0 and Norway pout age 1. This reflects the uptake of MSVPA values by the single species Working Groups.

## 2.8 Sensitivity Analysis of the MSVPA

### 2.8.1 Introduction

Sensitivity of the MSVPA to small changes in its input parameters is of great interest. The hope is that those parameters that are not well known, do not have a large impact on the output of the model. The major predications of MSVPA are recruitment, stock sizes, M2s, Fs, and suitabilities. In 1986, the MSWG did a sensitivity analysis and used long term yield as predicted by MSFOR (Anon. 1986). In this section, we examine the sensitivity of six outputs from MSVPA itself to 'small' changes in 33 of the MSVPA parameters.

MSVPA response variables were chosen to give an idea of the sensitivity relationships, but do not assess the sensitivities of all response variables in the MSVPA to all parameters. The six response variables chosen are: (1) total biomass in 1974, (2) total biomass in 1989, (3) Average F for Age 1 Cod, (4) Average N for Age 1 cod, (5) average predation deaths (D) for Age 1 cod, and (6) average M2 for age 1 cod. These analyses focused on the effects of parameter variation on results for cod, primarily because of the overall importance of that species as a predator and because several important management scenarios previously assessed were intended to improve its stock status. All averages are for years 1983-1988. The 33 parameters are listed in Table 2.8.1.1 with the nominal value, lower value and upper value used in the simulation experiments. Sensitivity runs were undertaken with the nominal values of food consumption set at 150% of the levels used in the MSVPA. The lower and upper bounds in the sensitivities were set to 100% and 200% of the MSVPA values. It was felt by the Working Group that consumption levels currently used in MSVPA are minimum estimates for most species, and the higher consumption estimates used in the sensitivity runs were probably more realistic. This subject is considered in more detail in Section 8.6.

### 2.8.2 Methods

Response surface methods (Box and Draper 1987) were used to determine the sensitivities of the response variables to the parameters. The overall process is done in two steps. First, an efficient, fractional factorial design was produced for not only

the 33 MSVPA parameters in Table 2.8.1.1, but also the 29 MSFOR parameters in Table 2.8.1.2. The design was a  $2^{k-p}$  fractional factorial design determined the 'Fold-Over' method (Box and Draper 1987); Finn 1986). This produced a set of 128 experimental runs, in addition to the 'Key Run'. This set of runs allows one to determine the main effects. With the addition of axial (or star) points, a interaction terms may be tested. The star runs are determined by setting each parameter at a value of  $\pm\alpha$ , while every other parameter is set to the nominal value. The value of  $\alpha$  is  $(128)^{1/4} = +3.36359$ , where 128 is the number of fractional factorial runs made (Box and Draper 1987, p. 508).

Sensitivities are expressed as the percent change in the response variable caused by a 10% change in the parameter. A value of 10 would indicate that the response changes the same percent as the parameter. A value of 1 indicates that the response changes only one-tenth as much as the parameters.

### 2.8.3 Sensitivity of MSVPA Parameters

None of the response variables were sensitive to the technical parameters (Table 2.8.3.1; Figure 2.8.3.1). Total biomasses in 1974 and 1989 were not sensitive to any of the M1s (no sensitivities  $>3$ ). For one year old cod, N will increase 5.56% while F will decrease 3.3% with a 10% increase in Cod M1. No other M1 value had a greater than 2.5% effect on the 1 year old cod response. Biomass totals were relatively insensitive to food consumption multipliers (no value greater than 3.5). The number of one year old cod deaths will increase 7.78% for a 10% increase in cod food consumption, and cod N will increase 3.3%. Whiting food consumption was the only other predator feeding estimate that influenced one year old cod (a 2% increase in cod M2 for a 10% increase in whiting consumption). Terminal Fs had no significant effect on the MSVPA responses.

All of the significant responses appeared to be linear. For this set of MSVPA responses, the second order interaction terms were not needed.

### 2.8.4 Discussion

The six MSVPA response variables analyzed were not very sensitive to each of the 33 parameters from the MSVPA program. No sensitivity coefficient was higher than 10, and only two responses were higher than 5. Even food consumption parameters do not have a large effect. Food consumption was changed by  $\pm 33\%$  (from 150% of nominal to 100% and 200%). Even multiplying the sensitivities by 3.33 gives low overall values. The largest sensitivity is the effect of cod food consumption on 1 year old cod deaths, a change of 7.8% for a 10% change, or a 25% increase in D for a 33% increase in cod food consumption.

Although only a few of the many potential response variables from

MSVPA were analyzed in these sensitivity analyses, the runs nevertheless illustrate the damping of the responses to variations in input variables. Only two of the response variables varied by more than half of the perturbation in the input variables, and most responses were about an order of magnitude smaller than the variation in the parameters simulated. These sensitivity analysis results further strengthen the overall conclusion of the robustness of the results of the MSVPA, despite continuing uncertainties about specific input parameters.

## 2.9 Inclusion of Other Predators in MSVPA

The MSVPA has been developed to explicitly consider intra- and inter-species predation for a 9-species subset of the array in the North Sea system. Predation mortalities generated by other fish, invertebrate, bird and mammal predators were included implicitly in the 'residual' M1 mortality terms in the model. In previous meetings (e.g., Anon. 1989a) the desirability of extending the MSVPA method to explicitly include predation mortalities from other components of the ecosystem was identified, and some data and analyses for additional predators was presented.

There is increasing interest in developing methods to incorporate non-fish induced predation mortality into calculations (e.g., see section 8.4) and to include a wider array of finfish species. At this meeting some exploratory calculations were undertaken including rays and the western mackerel stock within the revised MSVPA structure (section 2.1). For several reasons discussed below, the inclusion of these 'other predators' in the final 'key run' was considered premature.

### 2.9.1 Rays (*R. radiata*)

The starry ray (*R. radiata*) is considered as an "other predator" separately in an alternative key-run. The starry ray is assigned to only one age group, age 1, with a mean weight 1.00 kg.

According to Sparholt and Vinther (1991), the biomass of starry ray in the North Sea is approximately 100,000 tonnes.

The total annual consumption is approximately 430,000 tonnes according to Vinther (1989). This corresponds to a growth efficiency of 20% for small starry rays (approximately 15-20 cm) to 0% for larger rays (45-50 cm).

The diet of starry rays is given in Table 8.4.1 of Anon. 1989a, which is based on more than 2000 stomach investigated and mainly sampled in 1983 (Vinther 1989). From this it has been deduced that rays eat 1,200 tonnes of cod, 16,500 tonnes of haddock, 4,600 tonnes of whiting and 81,250 tonnes of sand eel. The rest is taken as other food.

Enough sandeels were found in the stomach to allow a reasonable

disaggregation into length groups by quarter by assuming that the stomachs sampled in the first quarter of the year were representative also for the second quarter, and the stomachs sampled in the third quarter were representative also for the fourth quarter. These length distributions are given in Table 2.9.1.1. Sand eel ALK's taken from Daan (ed.; 1989, Table 3-I, area = ALL) were used and the results are given in Table 2.9.1.2.

The data on cod, haddock and whiting are too sparse to allow a reasonable disaggregation into size groups. The stomach content of these three species are, therefore, distributed according to the distribution in the stomach content of all five MSVPA predators in 1983. The result of this procedure is shown in Table 2.9.1.3.

### 2.9.2 Western Stock Mackerel

A substantial part of the western mackerel stock migrates into the northern part of the North Sea in the second half of the year. In recent years, considerable amounts of juvenile mackerel, presumably of the western stock have been observed in the south-eastern part of the North Sea. In the period covered by the MSVPA, the North Sea stock, which is the only one included in the model, has declined dramatically. therefore, the mackerel data as they appear in the MSVPA, is no longer representative for the total amount of mackerel in the North Sea.

Since mackerel is not eaten by any of the MSVPA species, the western stock mackerel can be introduced in the model as a predating biomass, without being assessed in the model. Estimates of the proportion of the western stock migrating into the North Sea by year and quarter, based on Norwegian tagging data (Iversen and Skagen 1989), were provided by the Mackerel Working Group (Anon. 1990d). These data were applied to the stock sizes from the assessment (Anon. 1990d) to give biomass in the North Sea by year and quarter (Table 2.9.2.1).

Stomach data were taken from the 1981 stomach sampling data base (Mehl and Westgård 1983). Because of the distribution of the western stock mackerel in the North Sea, stomach data from the northern North Seas (ICES Division IVa) were used for adult mackerel (age 3 years and older) and data from the eastern North Sea (east of 3° E) for the juveniles (ages 1 and 2). The data are shown in Table 2.9.2.2. As can be seen in Table 2.9.2.2, sampling in some quarter/age group strata was particularly sparse, and thus the veracity of predation mortality estimates derived from such data is speculative (section 2.9.4). A more detailed description of the sources of data is given in Skagen (1990a).

### 2.9.3 Other Predators Potentially to be Included

Apart from western mackerel and starry ray, determining predation mortality due to additional fish, bird and marine mammal stocks have been identified as potentially important enhancements to such modeling efforts. In the North Sea system, horse mackerel are

potentially a significant predator of pelagic juveniles of a number of species (Anon 1989a). Given their considerable seasonal biomass in the ecosystem, incorporation of their predatory effects may be quite important. However, an impediment to the inclusion of horse mackerel remains the accurate calibration of total stock size and its distributional overlap with MSVPA species, as well as associated feeding and stomach contents data.

There is also considerable interest in quantifying the impact of seabird predation on MSVPA stocks in the North Sea (section 8.4; Cornus 1990; Tasker and Hislop 1990), and vice-versa, the effects of fisheries on seabird stocks (Camphuysen 1990). In principal, seabird predation could be integrated into the analyses in a fashion similar to the methods explored for starry ray and western mackerel explored at this meeting. The practical limitations of doing so with data available at this time are explored in section 8.4.

At the Special Meeting of the Multispecies Working Group in Bergen (Anon. 1990a) the desirability of incorporating marine mammal predation into multispecies ecosystem models was emphasized. Incorporation of marine mammal predation effects may be particularly important for arctic/boreal systems wherein the marine mammal biomass potentially exerts a significant fraction of total predation mortality on some fish species. Unlike fish and seabirds, marine mammals prey primarily on adult-sized fish, rather than juveniles. Thus, marine mammals are generally regarded as more 'direct' competitors with fisheries than are most fish and bird species. Quantifying the predator biomass, feeding rate and prey species selection by marine mammal predators, at levels of precision experienced in sampling fishes, remains a daunting technical task. Incorporating predation effects based on energetics calculations of marine mammals, within the MSVPA context, is not desirable for a variety of reasons (section 8.4). Thus, there is a need for alternative model structures and improved data on predator biomasses and prey selection in order to reliably quantify the impact of marine mammal populations in the trophic economy of fishery ecosystems.

#### 2.9.4 Western Mackerel and Starry Ray Included in the MSVPA

A revised version of the key run was undertaken with western mackerel and starry ray included as predators. The M1 values were not changed accordingly. However, a test run was made with M1's from Sparholt (1990) decremented by a factor similar to the amount (in biomass) represented by the western mackerel and the starry ray in the calculation made by Sparholt. This influenced the results insignificantly and no parameter was changed by more than a few percent.

Including western mackerel and starry rays had a significant effect on the estimated M2's for haddock 0-groups (1.01 to 1.13), for herring 0-groups (0.28 to 0.65), for sprat 1-groups (0.33 to 0.59), for Norway pout 0-groups (0.29 to 0.55) and 1 groups (1.83 to

2.21), for sandeel 0-groups (0.31 to 0.62), 1-groups (0.62 to 0.90) and for 6+-groups (0.27 to 0.47; Table 2.9.4.1). All other M2 values changed very little.

Accordingly, the estimated recruitment is increased considerably for herring, sprat, Norway pout and sandeel (Table 2.9.4.2). Western mackerel has mainly eaten Norway pout and sandeels, and in some years also herring (Table 2.9.4.3). Haddock is also predated rather heavily by western mackerel. The starry ray mainly eats sandeels (Table 2.9.4.4.).

The total consumption of MSVPA fish by western mackerel and starry rays have been around 1 million tonnes per year and this is in some years as much as 50% of the amount of MSVPA fish eaten by the other five MSVPA predators (Table 2.9.4.5).

In the present meeting the western mackerel and starry ray were not included in the MSVPA key run. This was because the available data on the feeding habits of these species are still sparse, and their impact on the prey stocks is very sensitive to these data. On the other hand, this emphasizes the need for better data.

### 3 MSVPA PERSPECTIVES ON FEEDING RELATIONSHIPS

#### 3.1 Who Eats Whom?

Baseline estimates of annual consumption and feeding relationships were presented in the previous report of this Working Group along with the long-term MSFOR prediction (Figures 7.5 and 7.6 in Anon. 1989a). They are not reproduced here.

Figure 3.1.1 summarizes trends in mean biomass, yield and the predated biomass of MSVPA species for the period 1974-1989. These values are also given in Table 3.1 along with deviations from previous years' results (Anon. 1989a). The deviations are due to the updating of the MSVPA database and terminal fishing mortalities and, importantly, to the inclusion of plaice and sole in the mean biomass and total yield data. Therefore, results from the current analysis are not directly, comparable to the previous reports, although trends remain the same.

Overall mean biomass declined from 1974 (~10,700t) until the early 1980s followed by a relatively stable period (~6,100t) until 1985 since when mean biomass has increased to ca. 7,900t (Figure 3.1).

Figures 3.1.2 and 3.1.3 show mean biomass, 1974-1989 for MSVPA predators and prey respectively. Sprat has declined greatly over this period with a considerable reduction in Norway pout as well. Mackerel, as it appears in the MSVPA, has also declined greatly. The actual amount of mackerel in the North Sea is larger, however, due to the presence of the western stock (see section 2.9.2). At the same time, herring biomass has increased greatly and this is reflected in the post-1985 increase in mean total biomass (Figure 3.1.1). Other species have shown varying patterns of biomass

fluctuations. Haddock, for example, have declined and increased over a couple of cycles but with an overall decreasing trend (Figure 3.1.2) while sandeel have demonstrated a decline in biomass which has been reversed in recent years (Figure 3.1.3).

The aggregated changes have resulted in a lower mean predator biomass in recent years to ca. 40% of their value in 1974 (Table 3.1). At the same time the biomass of the MSVPA species eaten (by MSVPA predators) and the total "other food eaten" have decreased to approximately one third of their 1974 level. This relative scale of change is reflected by a decrease in the rate of consumption per predators biomass (Table 3.1). Meanwhile the ratio of the biomass of total species eaten to total North Sea yield has fallen from close to 2 in 1974 to ca. 0.70 in 1987 and 1988. (In the most recent year, 1989, the ratio is close to 1.) The likely reasons for these shifts are discussed in the previous report of this group (Anon. 1989a).

Yield has fallen from over 3 million t in each of the years 1974-1976 to slightly over 2.5 million t in 1989 (Table 3.1), although the yield/biomass ratio has varied over this period (Table 3.1).

### 3.2 Predicting Food Habits Data from MSVPA Results

One test of the appropriateness of MSVPA is its ability to predict feeding patterns of predators, and predation mortality patterns of prey. There are multiple years of observed stomach contents data for several ecosystems. The Working Group investigated how well suitabilities calculated using subsets of the total available stomach contents predicted stomach contents observed in other years.

Within MSVPA, the expected food is calculated directly from the empirically calculated suitabilities, for each unique combination of year, quarter, predator, predator age, prey, and prey age. Predicted stomach contents are calculated as the product of estimated suitabilities (for each quarter - predator - predator age - prey - prey age) X prey biomass (calculated from MSVPA), divided by the sum of products across all prey for a particular year - quarter predator - predator age group.

The Working Group was also interested in the accuracy of prediction of stomach contents from suitabilities which had been smoothed, according to algorithms investigated in several past meetings. Obtaining the predicted stomach contents using suitabilities which had been smoothed presented several problems. The suitabilities of "Other Food" have not been included in past investigations of smoothing suitabilities, because for the purposes of the Working Group the biological properties of other food are dissimilar to the properties of prey contained in MSVPA. Nonetheless, for meaningful predictions of stomach contents to be observed, the use of other food must be considered. This could best be done internal to

MSVPA, and with the suitability of 'Other Food' included in the smoothing runs. Neither was possible at the working group meeting, so the problem was addressed in other ways. A second complication was that the smoothing algorithms are applied to  $\ln(\text{suitabilities})$ , rather than to the directly estimated suitabilities. The transformation is necessary because of the log-linear size preference function assumed by the theory behind MSVPA. Retransformation of the smoothed suitabilities requires a bias correction to be applied. The bias correction term has plagued past meetings of the Working Group, and has still not proven completely tractable. The proper bias correction term takes account of the variances and covariances of all component parameter estimates of the smoothing analysis, and is not assured to be the same for all combinations of predator, prey, and age considerations. This problem, too was addressed in various ways during prediction runs.

### 3.2.1 Baltic Sea Analysis of Suitabilities

Various kinds of GLM models were used for analyzing the suitabilities estimated from the Central Baltic Sea MSVPA (Anon. 1990h). In this MSVPA we have one predator stock, cod, and four prey stocks, two herring stocks and two sprat stocks. Stomach data are available from 1977-1988. The suitability of other food was not included in the smoothing. The biomass of other food was assumed to be 1 million tonnes in the MSVPA runs used.

The models tested and the results are given in Table 3.2.1. From this table it can be seen that the simple model 2 explains 39% of the variance in the data. This model includes quarter, prey species and prey\*quarter interaction as well as weight ratio between predator and prey (wpr) and its squared value (lwrsq) as covariables, i.e. a parabolic size preference model like the one presented in the previous report of this Working Group (Anon. 1989a). The most complicated model, no. 9, included predator age as a main factor and the covariance variables were nested under prey species \* predator age. This model explained 56% of the variation, and all the effects were significant at the 0.1% level except prey species which was significant at the 5% level. This complicated model is probably overparametrized, but it is interesting to note that the estimated parameters for the lwrsq for each prey species show a monotonic decrease with cod age and thus indicating a narrowing of the size preference with cod age. The parameters estimated for lwr show a monotone increase with cod age and thus indicating a compensatory effect in the model to prevent a change in the optimal size preferred by the cod.

A plot of estimated log suitabilities vs. log weight ratios and residuals are given in Figure 3.2.1a-g, by prey species. Only for prey species 3, herring in Sub-divisions 28-29S, we see a trend in the residuals, which seems to be negative for high and low values of the log weight ratios. A clear optimum prey size preference weight ratio around 4-6 is seen. The actual top point estimated is 4.7 corresponding to a prey size preference of a given cod for



preys 110 times smaller than it self.

In order to test whether the smoothed suitabilities improved the MSVPA model, the stomach data set was split into two sets, one set containing data from 1977, 1979, 1981, 1983, 1985, and 1987 and the other set containing the alternate years. An MSVPA was then run with the say odd years stomach data, suitabilities estimated and smoothed, and these smoothed suitabilities were then used to predict the observed stomach content in the even years. A regression analysis was done between the predicted and the observed stomach content. This regression was then compared to a similar regression where the predicted stomach contents were based on the "raw" suitabilities. If the correlation improved by smoothing the suitabilities then the smoothing process have improved the MSVPA model. The correlation was however highest for the "raw" suitabilities:  $r^2 = 0.58$  for odd years to even years and  $0.57$  for even years to odd years against  $0.55$  and  $0.45$  for the smoothed estimates). The above results were based on the smoothing from model 2. However, using model 3 did not change the smoothing but decreased  $r^2$  from  $0.55$  to  $0.54$  for odd years to even years. Therefore this smoothing procedure did not improved the MSVPA model. It could however very well be that other smoothing procedures will give better results, and this ought to be tested.

The set of smoothed suitabilities did in some cases sum up to more than one. In order to avoid that in was assumed that the suitability of other food is constant and each smoothed suitability was corrected by a constant factor by cod age and quarter obtained by dividing the sum of the "raw" suitabilities with the sum of the smoothed suitabilities.

### 3.2.1.1 Alternative Scalings of Suitabilities

Another possibility is to assume that the total amount of fish in the stomachs predicted based on "raw" suitabilities by cod age and quarter (thus summing over preys and years) is the same as for the smoothed values. This procedure has as a consequence that the suitability of other food not necessarily will be the same as the "raw" suitability of other food.

This procedure was tested by taking the estimated stomach content by quarter, predator age, and prey age (from an MSVPA based on even years stomach data), multiply it with the ratio of smoothed suitabilities (from an MSVPA based on odd years stomach data) to "raw" suitabilities from even years. This "new" stomach content estimate is similar to the one estimated above if:

$$\sum^{\text{prey}} (\text{smooth}^{\text{oddyears}} * \text{biomass}) = \sum^{\text{prey}} (\text{raw}^{\text{evenyears}} * \text{biomass})$$

where  $\sum^{\text{prey}}$  is the sum over prey ages,  $\text{smooth}^{\text{oddyears}}$  is the smoothed suitabilities from odd years MSVPA and  $\text{raw}^{\text{evenyears}}$  is the suitabilities from even years MSVPA. If the observed and the predicted stomach content (by q pda py pya) were summed over years the correlation

between them was very high:  $r^2 = 0.85$ . If they were correlated without summation over years the correlation dropped to 0.35. If the raw suitabilities were used instead of the smoothed ones the correlation between the summed values increased to 0.88. Thus, the smoothing did not improve the model. The fact that summation over years of predicted and observed stomach content improved the correlation indicates that the deviation between observed and predicted in single years was due to noise in the data if trends in time can be neglected. This could of course be tested by selecting different time periods to test against each other.

Figure 3.2.2a shows a plot of observed stomach content against predicted (from odd years to even years, stomach content summed over years by  $q$  pda pya). Residuals to the regression line are given in Figure 3.2.2b.

### 3.2.1.2 GLM Models to Analyze Noise in the Data

The odd and even years stomach data sets were each used in separate MSVPA runs and the smoothing model no.2 were applied to each of set of suitabilities. The  $r^2$  of these were about 0.33 compared to 0.39 for the total stomach data set. Thus, a doubling of the stomach data increased the model by about 20%. The systematic age effect in model no.9 when applied to the total stomach set did not appear nearly as clear when applied to the two small data sets. Altogether, this means that sampling of cod stomachs in the Baltic has probably reached a level where a lot of more samples have to be taken if the precision of the MSVPA model needs to be significantly improved.

### 3.2.1.3 Bias in the Averaging Procedure of the MSVPA

According to Sparholt and Gislason (1990) the averaging procedure used in the present MSVPA of the suitabilities when stomach data from more than one year are available, gives a biased estimate of suitabilities. In the present version of MSVPA the suitabilities are calculated by year and the means are afterwards calculated. A better solution would probably be to use:

$$\text{suit} = \frac{\sum^{\text{year}}(\text{stom}) / \sum^{\text{year}}(\text{biomass})}{\sum^{\text{prey}}(\sum^{\text{year}}(\text{stom}) / \sum^{\text{year}}(\text{biomass}))}$$

where  $\sum^{\text{year}}$  is the summation over years and  $\sum^{\text{prey}}$  is the summation over prey species and age groups. This is the maximum likelihood estimator (in the sense given by Gislason and Sparre 1987) if  $\text{biomass} / \sum^{\text{prey}}(\text{biomass})$  is constant in time for all prey species and age groups. However, a general ML estimator would be nice to have, but is probably very difficult to obtain. Some bright mathematicians should have a look on this problem.

### 3.2.2 The North Sea Ecosystem

#### 3.2.2.1 Data Available

Stomach contents data were collected for all predator and quarters in 1981. Additional stomachs were analyzed in the first and third quarters of 1985, 1986, and 1987 for cod and whiting. For saithe additional stomachs were analyzed for the third quarter of 1986 and 1987. These allowed for the following combinations of years to be included in runs predicting stomach contents:

<u>Years of stomachs included in estimating the suitabilities</u>	<u>Years of stomach content predicted from the estimated suitabilities</u>
1981	1985, 1986, 1987
1981,1985	1986, 1987
1986,1987	1981, 1985
1981,1985,1986	1987
1981,1985,1987	1986
1981,1986,1987	1985
1985,1986,1987	1981

#### 3.2.2.2 Analysis Sequence

For estimations of stomach contents using the "raw" estimated suitabilities, MSVPA was used directly. The use of Other food is handled appropriately within the model, so the output estimated stomach contents can be compared directly to observed contents. The comparisons were done by regressing observed on predicted contents, both across quarters and predators within a year, and for each unique combination of predator and quarter.

The predictions based on smoothed suitabilities required additional work. First the raw suitabilities from MSVPA were smoothed, using the core smoothing model identified in past Working Group meetings (Anon. 1988; 1989a). The output smoothed suitabilities were then divided by the raw suitabilities, and their ratio multiplied by the estimated stomach contents using the raw suitabilities. This relationship was justified by the simple algebra of the relationships of each type of suitability to the total biomass of food available to the predator (the proper denominator for the predicted stomach contents, given the product of suitability and prey biomass). An additional scaling factor is necessary, however, because without including Other Food in the smoothing runs, predictions using the smoothed suitabilities may not reflect the use of other food properly. Therefore, the sum of all prey predicted to be consumed using the smoothed suitabilities was scaled to equal the sum of all prey predicted to be consumed using the raw suitabilities. This scaling does not assume that the suitability of Other food remains constant over time, but rather that other food will constitute the same fraction of the diet of a particular predator, regardless of whether the raw or smoothed suitabilities are used. This scaling ensured that the sum of

suitabilities of all prey specified in MSVPA was less than 1.0, as required by MSVPA. As long as MSVPA is not required to forecast the biomass of Other food, as well as the biomass of included species, this scaling should present few problems.

### 3.2.2.3 Results of Smoothing

The core smoothing algorithm fit using SAS PROC GLM was:

$$\ln(\text{Suit}) = Q(\text{quarter}) + P(\text{re})d(\text{ator}) + P(\text{re})y + Q*Pd + Q*Py + Pd*Py + [\ln(\text{weight predator}/\text{weight prey})]*Pd + [\ln(\text{wt ratio})]^2$$

This was the model preferred in past meetings of the Working Group, when several models were fit to the complete data set, including all predators and quarters. In the fits at this meeting, usually only cod, whiting and saithe were included as predators, and only the first and third quarters were included. Goodness of fit of the core model to each of the data sets (suitabilities based of various years of stomach data) were comparable (Table 3.2.2.3), with R<sup>2</sup> values between 0.4 and 0.5, and Root Mean Square Errors between 1.45 and 1.70. Quarter was usually not significant in the model, but the interactions of quarter with prey and/or predator usually was, so the factor was kept. Although the main effect predator was often not significantly different between cod, whiting, and sometimes saithe, the nested weight ratio slopes were highly significantly different (P < 0.001 in all cases), so that term was kept as well. Parameter estimates for the class variables (Q, Pd, PY) and slopes comparable well with estimates form previous years, and will not be considered here.

In summary, the smoothing model fit as well as expected, given past investigations, and well enough to consider using the smoothed suitabilities in forecasting predation patterns.

### 3.2.2.4 Predictions of Stomach Contents from Suitabilities

The regression tests of accuracy of predictions gave mixed results. When 3 years of stomach data are used to estimate suitabilities, and the raw estimates predict stomach contents in a fourth year, generally a quarter to a third of the variance in observed stomach contents are explained (Table 3.2.2.4a-d). Smoothing the suitabilities prior to prediction gives lower r<sup>2</sup> values in about half the cases, although the differences are often small. This result suggests that when 3 years of stomach data are available, the empirical values contain information lost in smoothing.

When the predictions based on 3 years of stomach data are examined closely, certain year-predator-quarter combinations are especially problematic. In particular, diets of cod and whiting in the third quarter of 1985 are especially hard to predict, and generally 3rd quarter cod predictions are poor. The markedly poor predictions based on raw suitabilities usually are not improved much by smoothing the suitabilities prior to prediction.

When pairs of years are used to predict other pairs of years, about one quarter of the variance in stomach contents is explained by the regressions. The predictions for 1986 and 1987, based on 1981 and 1985 are slightly poorer than the reverse. The predictions based on smoothed suitabilities are similar to those based on raw suitabilities, although the predictions for 1981 are weak. Fits are better about as often as they are worse, when predictions from raw and smoothed are examined.

When the predator by predator predictions are examined, third quarter cod and whiting stand out again as poorly predicted. First quarter whiting in 1987 are also predicted poorly. Predictions for saithe are generally good.

In summary, pairs of years predict feeding in other years only slightly worse than trios of years predict single years. Smoothing gains and loses little over using the suitabilities directly was calculated by MSVPA. The only year with complete stomach data is 1981. When suitabilities based in only those data are used to predict stomach contents in other years, 1985 is predicted very poorly. For 1986 and 1987 about 15% of the variance is captured by the predictions from raw suitabilities. When the raw suitabilities are smoothed, the variance explained increased to around 20%. When the individual predictions are examined, the same patterns of anomalous years appear. The third quarter whiting predictions are poor for all 3 years, and in 1985 the third quarter cod predictions are poor also. Predictions are generally better with smoothed than raw suitabilities, although of the several very poor predictions, only the predictions for whiting feeding in the first quarter of 1987 are improved substantially.

#### 3.2.2.5 Summary for North Sea

With 3 years of stomach contents, it is generally possible to predict about a third of the variance in diet for an independent year. With that much data, smoothing suitabilities leads to a slight loss of information, overall. For two years of data, predictions capture about a fifth to a quarter of the variance in diet, and smooth generally breaks even. With a single years data, smoothing generally improves predictions, to capture about a fifth of the total variance in diet for another year. There are some particular problematic predator-quarter combinations, particularly whiting in the third quarter.

### 3.3 Predicted Stomach Contents for 1991 - North Sea

#### 3.3.1 Method, Assumptions and Predictions

Analyses presented above and at previous meetings (Anon. 1988; 1989a) provide the analytical basis and some estimates of the prediction error associated with MSVPA calculations of suitabilities. Using a fractional cross-validation design, the analyses reveal that given the feeding data sets at hand, between a quarter and a third of the variance in stomach content can be

explained for an independent year. This is based on independent analyses for MSVPA, which includes estimates of the various recruitment levels for the prey species and the predator biomasses simultaneously.

Predicting feeding levels for an upcoming year (in this case for 1991, the 'year of the stomach - II' in the North Sea) involves not only the prediction errors associated with suitabilities, but estimates of 1991 recruitment levels and predator biomasses as well. Because of the timing of this meeting (December 1990) updated VPA estimates were available for all species included in the MSVPA that incorporated catch at age through 1989. Forecasts for 1991 obviously then involve decrementing the populations for fishing in 1990, as well as estimating 1990 and especially 1991 recruitment levels. For roundfish stocks, recruitment estimates are available for 1990 and 1991, based on young fish survey data (Anon. 1991a). Recruitment estimates for some of the other stocks are more problematical. Estimates of 1991 recruitment levels were based on average recruitment levels estimated by MSVPA (Table 2.7).

A summary of predicted food composition for the five MSVPA predators in 1991 is given in Figures 3.3.1a-e. Quarterly food compositions (integrated over all age classes in the population) are presented by quarter. In all cases the consumption of 'other food' is not presented in these calculations. Predicted feeding compositions for 1991 can be compared with similar data collected in prior years (e.g., Daan [ed.] 1989). In some cases the predicted 1991 stomach contents differ substantially from 1981 results (e.g., the proportion of herring in predator diets).

A full analyses of the veracity of these predictions awaits future meetings of the Multispecies Working Group. Detailed 1991 forecasts for diet composition and Fs at age are being maintained under lock and key by the MSWG.

#### 4 SIMULATIONS OF FISHING STRATEGIES IN THE NORTH SEA

At last years meeting (Anon. 1989a), the consequences of mesh and effort changes in 7 North Sea fleet categories were evaluated in both long- and medium-term stochastic and equilibrium simulations. Those results established the basis for evaluation the multispecies consequences of proposed 120 mm minimum mesh regulations when fishing for cod.

Terms of reference for this meeting specified evaluations of the consequences of fishing large quantities of prey species, in particular Norway pout and sandeel, in the North Sea. For the purposes of these analyses 'large quantities' was taken to represent a 50% increase in effort directed to the industrial demersal fishery. Accordingly, the Working Group used the MSFOR and Shepherd models to evaluate the multispecies effects of 50% changes in effort in that fishery.

Appropriate baseline simulations (section 4.1) were undertaken with the MSFOR and Shepherd models, to which alternative fishing scenarios were compared. Because of the general interest in the effects of such large-scale changes in effort, a systematic evaluation of 50% effort changes in all eight North Sea fleet units (now including a flatfish fleet) was evaluated (section 4.2). The sensitivity of long-term equilibrium predictions was evaluated by fractional factorial experimental designs (section 4.3). In section 4.4, the effects of using parametric stock-recruitment relationships in MSFOR predictions are compared to results employing long-term average recruitments, or correlated recruitment values among species groups.

#### 4.1 Comparisons of Equilibrium Results from MSFOR and the Shepherd Model

Tables 4.1.1 and 4.1.2 show the baseline results for the MSFOR and Shepherd models respectively. Differences between results from the MSFOR and Shepherd methods are due to 1) MSFOR using quarterly increments vs. annual increments for the Shepherd model, 2) accumulation of biomasses and yields in the Shepherd model depending on a one quarter data set (Q3) and 3) the Shepherd model having no mechanism for prey type switching. Reason (3) is the main structural difference between the two models. Reason (2), however, explains the consistently higher SSBs calculated by the Shepherd model. These values are calculated using weights in the sea in Q3 and numbers at Jan. 1st. The use of Q1 weights would reduce these figures somewhat.

There are two noteworthy differences between the two baselines. Firstly, the SSB for Norway Pout is much higher in the Shepherd run. This is explicable in terms of the stock weights used for the calculation - of the 1490 thousand tonnes of SSB, 1230 thousand tonnes is due to 1-group fish. The quarter 1 weight of 1-group Norway Pout is about half that of fish in quarter 3. Halving the contribution to the SSB from the 1-group alone would, therefore, reduce the perceived SSB level to 885 thousand tonnes. A figure similar to that calculated on a quarterly data set in MSFOR. The figures for SSB do not effect the yields and values calculated in the Shepherd model.

The second large difference between the two baselines is that although the Shepherd model projects similar discard and industrial yields of haddock (to the MSFOR model) the projected landings are only 90 thousand tonnes contrasted to 150 thousand tonnes in the MSFOR. This difference is almost certainly not due to the use of quarter 3 catch weights. Also, the total natural mortality by age on haddock, in the two procedures, is almost identical. Similarly, the baseline fishing mortalities are the same. Currently, there is no simple explanation for the discrepancy.

Apart from these two large differences it is also noticeable that the Shepherd run projects smaller herring catches. As mentioned in section 2.1, the M on age 1 herring is larger in the Shepherd run

- this, presumably is the cause of the discrepancy. Note that with the current raw M2 data set it is not possible with the Shepherd model to reduce this total M-at-age figure for herring; the large value is caused by a large M2 contribution.

Overall, despite differences between the two methods, the similarities are such as to make worthwhile the use of both methods in the sensitivity testing outlined in section 4.4.2.

#### 4.2 Consequences of Large-Scale (50%) Changes in North Sea Fisheries

For the purposes of providing advice on the effects of fishing 'large quantities' of prey species (i.e., Norway pout and sandeel), the Working Group analyzed only long-term consequences. Since the term 'large quantities' was not specifically defined, the Working Group chose to interpret this as a 50% increase in the fishing effort allocated to the Industrial Demersal fleet unit.

Given that such large increases in fleet effort would be an interesting scenario to analyze for all North Sea fleet units, results are cast in a framework of sequential 50% increases in effort for the eight fleet units. Although the results of equilibrium long-term predictions at such extreme changes from status quo effort levels are speculative, it is, nevertheless, instructive to evaluate the relative directionality in fishery and species yields and SSBs resulting from such scenarios. The effects of 50% effort increases in each of the eight North Sea fleet units are evaluated in Tables 4.2.1-4.2.7. Additionally, the sensitivity of these results to input parameters is evaluated in Section 4.3.

Both the MSFOR and Shepherd models predict substantial increases in total system yields in weight (+6% for MSFOR and +23% for the Shepherd Model), but insignificant changes in total system value (-1% and +2%, respectively), as a result of a 50% increase in Industrial Demersal Fleet effort (Table 4.2.2). Differences in long-term predictions between the two models (particularly regarding Norway pout, haddock and herring) are considered in Section 4.1. Yields (in weight) of cod, saithe, mackerel, sprat and the flatfishes remain about equal to status quo effort levels. Norway pout, sandeel and whiting yields increase. Haddock yields are predicted to remain stable by MSFOR, and to increase by the Shepherd model. The yield of whiting, saithe and haddock in the Industrial Demersal Fleet landings increases substantially on a percentage basis, but the contribution by this fleet to total landings of the three species is relatively small (Table 4.1.1). Overall, the increase in total weight of the catch is counter-balanced by the decline in revenue of some of the valuable roundfish species, as a result of landing smaller, less valuable fish (e.g., whiting, and haddock).

Both models predict substantial decreases in spawning stock biomass for sandeel, Norway Pout, and whiting, resulting from a 50% increase in Industrial Demersal effort. A slight increase in



herring SSB is also predicted. Since neither model was run assuming a functional stock-recruitment relation, the lower SSBs resulting from the strategy (e.g., for Norway pout and sandeel), had little influence on long-term results. If in fact there are positive stock-recruitment relationships for sandeel and Norway pout, then reductions in SSB resulting from the strategy will have significant negative impacts not only on yields of these two species, but on yields of their predators including cod, whiting, haddock, and especially on total system value (see Table 4.3.3.2 and particularly Figure 4.3.3.2 in the next section).

A 50% increase in fishing effort in the Roundfish fishery results in a 9-12% increase in system yield in weight and a 3-4% increase in value (Table 4.2.1). SSBs decline substantially for most roundfishes (especially cod and saithe). SSBs for Norway pout and herring increase due to lower M2s on these species.

A 50% increase in fishing effort in the Industrial Pelagic fishery results in negligible changes in total yields in weight or value, but substantial declines in SSBs for herring and sprat (Table 4.2.3).

Herring SSB declines substantially with a 50% increase in effort in the Herring fishery, but total multispecies yields change little (Table 4.2.4).

Saithe SSB declines about 35% with a 50% increase in effort in the Saithe fishery, but SSBs for haddock and Norway pout increase significantly. Total system yield in weight increases 3-5%; value 1-4% (Table 4.2.5).

A 50% increase in effort in the Mackerel fishery results in a 47-48% decrease in mackerel SSB, and a small increase in sandeel SSB (Table 4.2.6). Total multispecies yields remain virtually unchanged.

A 50% increase in the Flatfish fleet effort results in decreases in plaice and sole SSBs of 29 and 38%, respectively, and a 3% decline in system yields in value.

### 4.3 Sensitivity Analysis of Long-Term Yield Predictions

#### 4.3.1 Introduction

In order to ascertain the robustness of long-term equilibrium predictions to the various input parameters, the Working Group undertook formal sensitivity analyses of the response of various important model predictions to input data and assumptions (see section 2.8.2 for methods and Table 2.8.1.2 for MSFOR parameters used in the fractional factorial experiments).

#### 4.3.2 Sensitivity of Long Term Yield -- Analysis Protocol

The sensitivity of long-term equilibrium yields was evaluated with

respect to variations in both MSFOR parameters (Table 2.8.1.2) and MSVPA parameters used to generate the starting conditions and suitability for the forecast (Table 2.8.1.1). Because of the general convergence of MSFOR and Shepherd model predictions, a separate sensitivity analysis of Shepherd model results was not undertaken during this meeting. In the MSVPA forecasts, parameters were varied  $\pm 10\%$  from the nominal values (Table 2.8.1.2). Linear surfaces fitted to the response data were extrapolated over a wider range of variation in parameter values (e.g. Figures 4.3.3.1-4.3.3.3) to emphasize the potential importance of even small (2%) changes in the response variables to 10% variations in MSVPA and MSFOR parameters.

#### 4.3.3 Sensitivity of Long Term Yield to MSVPA and MSFOR Parameters

Table 4.3.3.1 summarizes the sensitivity coefficients of various MSVPA parameters to 13 MSVPA dependent variables (11 species yields in weight, plus total species yield in weight and value).

[It should be noted that small coefficients ( $\leq 0.4$ ) may result from the limits of numerical precision and the assumption of linear sensitivity coefficients, even where there is obviously no interaction effect present (e.g. between flatfish and other species). Thus, sensitivity coefficients  $\leq 0.4$  should be considered as 0s in Tables 4.3.3.1 and 4.3.3.2.]

Again, MSFOR predictions were not sensitive to the eight technical parameters simulated in the MSVPA model (Table 4.3.3.1). None of the MSVPA parameters had a sensitivity coefficient  $> 5$ . Generally, individual species yields were most sensitive to M1 values and food consumption levels. The highest sensitivity coefficient was saithe M1 and Norway pout yield, followed by Norway pout M1 and its own yield (4.8). Mackerel food consumption had the greatest influence on total system yield in weight (1.8).

MSFOR predictions were, in some cases, very sensitive to terminal fishing mortality rates, recruitment levels and fleet effort multipliers (Table 4.3.3.2 and Figures 4.3.3.1-4.3.3.3). The highest sensitivities overall were Norway pout yield to: Norway pout recruitment (16.4), saithe recruitment (-13), and saithe terminal F (12.9). Haddock yields were very sensitive to saithe terminal F (10.8), and saithe recruitment (-10.7). Cod yields were moderately sensitive to cod recruitment (5.8), and to a lesser extent on roundfish fleet effort (2.9).

Total multispecies yield in weight was most sensitive to Norway pout recruitment (4.5), Norway pout recruitment (3.4), saithe terminal F (3.0), and saithe recruitment (-3.0).

Total value was most dependent upon saithe terminal F (2.1), Norway pout recruitment (2.0), saithe recruitment (-1.7), and sandeel recruitment (1.7). The dependence of total value on these parameters is plotted in two-dimensional parameter space in Figures 4.3.3.1-4.3.3.3. The linear sensitivity coefficients (equivalent

to multiple linear regression slopes) are used to extrapolate the dependent variable (in this case, total value) over a range of  $\pm 30\%$  of the nominal simulated parameter values (Table 2.8.1.2). Figure 4.3.3.3 is especially illuminating, since it essentially evaluates the consequences large increases in effort in the Industrial Demersal fishery, if there are underlying positive stock-recruitment relationships for sandeel and Norway pout. A 50% increase in Industrial Demersal fishing effort results in significantly lower sandeel and Norway pout SSBs (Table 4.2.2). If S-R relations are positive for these two species, then the additive effects as suggested in Figure 4.3.3.3 indicate rather substantial declines in the total value derived from the North Sea system.

Given the general sensitivity of MSFOR results to recruitment levels (Table 4.3.3.2), it should thus be re-iterated that long-term advice must be regarded as contingent upon the validity of the underlying stock-recruitment relationship assumed in such scenarios. In Sections 4.4 and 8.2 the Working Group considers some influences of stock-recruitment dynamics on short- and long-term advice.

#### 4.4 Stochastic Simulations Incorporating Parametric Stock/Recruitment Relationships

In the current version of MSFOR, recruitment for upcoming years is either constant or stochastic, with a fixed or correlated mean (Section 8.2). Simulations were undertaken with an extension of MSVPA in which recruitment (R) can be explicitly dependent on spawning stock biomass (SSB).

For some of the stocks analyzed in the MSVPA, particularly herring and mackerel, long-standing recruitment failures have been observed and associated with very low spawning stock biomasses (SSB). Plots of historical SSB vs. recruitment indicate that some association between SSB and recruitment is likely not only for herring and mackerel, but other stocks as well.

To take the possible dependence of the recruitment on SSB into account in stochastic simulations with MSFOR, a kernel method was suggested (Skagen 1990b). Let  $SSB_k$  and  $R_k$  be the historical SSB and R in year k, and let  $SSB_a$  be the SSB in the prediction year. The recruitment predicted for year a is equal to one of the historical  $R_k$ , with probabilities dependent on the distance (by some appropriate measure) between  $SSB_k$  and  $SSB_a$ , according to a weighting function  $\varphi(SSB_a, SSB_k)$ , i.e.;

$$\text{Prob}\{R_a=R_k\} = \frac{\varphi(SSB_a, SSB_k)}{\sum_k \varphi(SSB_a, SSB_k)}$$

For the purposes of these analyses, the weighting function was assumed lognormally distributed;

$$\varphi(SSB_a, SSB_k) = \frac{1}{\sigma \sqrt{2\pi}} \frac{1}{SSB_a} \exp \left\{ -\frac{1(\log SSB_a/SSB_k - \sigma^2/2)^2}{2\sigma^2} \right\}$$

with expectation at  $SSB_a = SSB_k$ . The variance parameter of the lognormal function ( $\sigma$ ) indicates how far from an historical SSB the corresponding recruitment is expected to be. This gives a discrete probability density function for the recruitment, with the computed SSB and  $\sigma$  as parameters. This can either be used as such in the stochastic mode of MSFOR, or its expectation value can be used as a deterministic SSB-recruitment function. At this meeting, only the latter approach was used.

To obtain an appropriate value of  $\sigma$  for each species, a cross-validation of the sample statistics was performed. For each SSB-recruitment pair, the squared difference between this value, and recruitment estimated using all other SSB-recruitment pairs was computed. The  $\sigma$  was chosen that minimized the sum of squared differences. In cases wherein no minimum sum of squares could be obtained, (e.g., decreasing ssq with  $\sigma$  increasing to infinity) an SSB-independent distribution was used (i.e., giving all recruitment values equal weight).

Results of long-term stochastic simulations are compared assuming (1) constant recruitment, (2) an SSB-recruitment relation as computed above, and (3) stochastic correlated recruitment (Section 8.2; Figures 4.4.a-k). These comparisons concentrated only on the effects of the method for producing recruitment estimates for the forecasts on spawning stock biomass. Other attributes of the simulations (e.g., yields, mortality rates, etc.) were not compared for the sake of brevity. For some species, particularly cod and sprat, the average SSB predicted using the SSB-recruitment relationship is lower than the mean recruitment over the past several years. Thus, given the current depressed levels of SSB, and the assumed SSB-recruitment relationships, these stocks cannot be expected to recover to their previous levels with the exploitation and predation patterns presently included in MSFOR calculations. For some species, such as herring, the average SSB is higher than the recent average, indicating the low levels as seen during the stock collapse are no longer relevant to the scenarios.

##### 5 ANALYSIS OF COD GROWTH AND PREDATOR-PREY INTERACTIONS IN ARCTIC/BOREAL SYSTEMS

The emphasis on conducting statistical analyses of cod growth in arctic/boreal systems stems from the observation on the part of several authors that growth of cod (a ubiquitous and important component of arctic/boreal systems in the ICES area) is indeed quite variable from year to year, and that interactions with its prey are a logical energetics pathway explaining the variation in cod growth (Millar and Myers 1990; Magnusson and Pálsson 1991; Mehl

1989; Jorgensen 1989). Considerable research on the interactions between cod and prey in northern waters (and particularly the relationship between cod and capelin) have yielded variable conclusions regarding the relative influence of capelin abundance and environmental conditions on such attributes as cod growth and recruitment (Anon. 1990a; Mehl 1989; Magnusson and Pálsson 1991; Shelton et al. 1990; Millar and Myers 1990).

One of the motivations in conducting comparative multispecies analyses among arctic/boreal systems is that given the similarities in species compositions among the systems (e.g., cod, capelin, marine mammals, seabirds, etc.), there may be common functional relationships among the components which can be modeled in a consistent manner. That empirical analyses of these relationships have yielded some differing conclusions between the systems indicates either that (1) the functional responses between ecosystem components may be different among the systems, even though the species assemblages are similar, or (2) that differing conclusions regarding the strength of interactions among biological and environmental components are related to data collection and analysis methods which are not comparable among the systems. Because of the emphasis placed by the Working Group on empirical verification of multispecies models (Anon. 1990a) it was deemed critical to undertake coordinated analyses of available data as a basis for model building.

In the course of the meeting the Working Group analyzed several data sets from four Arctic/Boreal systems. Emphasis was placed on converting the data to a common format for the four systems and conducting analysis of variance to identify significant effects on annual cod growth increment. This data exploration stage was considered an important prerequisite to the possible future development of multispecies growth models, particularly those involving the effect of capelin on cod growth. There was insufficient time to complete the next step, that of specifying candidate growth models based on the results of the analysis of variance and fitting these to the data, although two growth models developed prior to the meeting were examined and fit to several of the data sets.

### 5.1 Description of Data Sets

A total of seven data sets were made available to the meeting for analyzing cod growth (Table 5.1). The primary focus was on the way that cod biomass, capelin biomass and other environmental variables may effect cod growth in the different stocks. Factors such as the effect of cod and capelin migrations, variable gear selectivity, timing of samples, spatial distribution of samples, and sample size may have important influences on measurements of cod length at age and obscure actual relationships or give rise to artifact "relationships". An attempt was made at the meeting to control for some of these factors by selecting data from certain age groups or specific areas.

Similar considerations hold for capelin biomass estimates. These estimates are of total capelin biomass at some point in the year when the survey was carried out. As a large portion of the capelin population spawns and then dies every year, prior to which extensive migrations take place over short periods, there is concern about what is an appropriate index of the availability of capelin to cod. Off Newfoundland/Labrador, there is no single time series of capelin abundance and an index had to be synthesized from several sources, introducing considerable uncertainty in this variable for the region. The development of a temperature index that is appropriate for the different regions also poses problems. These systems experience considerable seasonal and spatial variability in temperature which may not be adequately captured by an annual mean from one sampling station or a restricted area.

### 5.1.1 Barents Sea

Barents Sea cod growth, abundance and environmental data are summarized in Table 5.1 and Figures 5.1.1.1-5.1.1.13.

#### Cod Growth Data

Length at age data for the Northeast Arctic cod stock are taken from Norwegian surveys in January - March 1979-1990 (Anon. 1991c). The ages included are 3 to 8 year olds. Weights at age are mainly derived from Norwegian surveys in January - March. From 1985 onward the weights are measured directly onboard the research vessels, while earlier weights are calculated from data on length and condition factors. Here only data back to 1984 are used. For age groups 1 and 2 in 1985 - 86 the weights are taken from USSR surveys in November - December, and for 1984 the weights for ages 1 and 2 have been set to the same as in 1985 (Anon. 1991c). Weights for ages 1 and 2 in the years 1987 to 1989 are from the Norwegian surveys.

#### Population Abundance of Cod

Data on cod biomass are taken from the VPA run of the Arctic-WG (Anon. 1991c) and is given as biomass of age 3 and older.

#### Population Abundance of Capelin

Capelin biomass is the total biomass measured in September of the 1 year and older and the biomass of fish larger than 14cm which will constitute the spawning stock the next year. The years are 1973 to 1990 (Anon. 1991d).

#### Environmental Variables

The temperatures used in the analyses are annual mean temperature in 0 - 200 m in the Kola Section (70° 30'N - 72° 30'N). The mean temperatures are based on monthly measurements made by USSR. These data go back to 1921, but here only data back to 1979 are used.

### 5.1.2 Greenland

West Greenland cod growth, abundance and environmental data are summarized in Table 5.1 and Figures 5.1.2.1-5.1.2.12.

#### Cod Growth Data

Cod landings at West Greenland have been sampled regularly to obtain length and age compositions. At present age-length keys and length compositions for gears, seasons and areas are computerized back to 1976. Two time-series of size at age data from the commercial fishery were available for analysis. Both series are from the offshore trawl fishery in NAFO Div. 1C, 1D and 1E, one covering the season 1 January - 1 June in the period 1976-90, and the other covering the season 1 October - 31 December in the period 1980-89. Only mean length at age based on at least 10 age determinations have been included, which restricts the range of age groups to 5-8.

#### Population Abundance of Cod

Biomass (age 3+) of the NAFO Subarea 1 cod for the period 1975-89 were taken from the VPA run of the WG on cod stocks off East Greenland (Anon. 1990e).

#### Population Abundance of Capelin

None of the important prey stocks in the West Greenland area are assessed (capelin, sandeel) and, except for irregular cod stomach studies during the period, no information area available.

#### Environmental Variables

Observations of temperature on the top of Fylla Bank (approximately 64°N) have been made in mid-June of each year since 1950. Buch (1984) has shown that temperature trends in neighboring areas and periods were similar to those on Fylla Bank and, therefore, the Fylla Bank temperature may be a reasonable index for the area under consideration. The mean temperature of the near-surface layer (0-40 m) was used in the analyses.

### 5.1.3 Iceland

Icelandic cod growth, abundance and environmental data are summarized in Table 5.1 and Figures 5.1.3.1-5.1.3.8.

#### Cod Growth Data

The mean and standard error of length at age were made available, based on samples taken from commercial bottom trawl in June-September of each year. A region north and east of Iceland was chosen as small as possible in order to minimize problems due to regional movements of the fleet, but yet give enough data for

the analysis. The age range in the basic data set was 4-9, and the years available were from 1965 to 1989.

#### Population Abundance of Cod

The population biomass numbers at age along with the total biomass of ages 3-9 was taken from Anon. (1990f), based on the current estimates of stock size and mean weight at age in the catches.

#### Population Abundance of Capelin

The capelin biomass estimates are based on backcalculations from autumn and winter acoustic estimates, catches and a monthly natural mortality rate (Vilhjalmsson, pers. comm.). Two such series were available to the meeting, an estimate of the January and August abundances, but only the January abundance was used.

#### Environmental Variables

The only environmental variable considered was the deviation from mean temperature at 50m depth on a standard hydrographic station north of Iceland (Anon. 1990f).

#### 5.1.4 Newfoundland

Cod growth, abundance and environmental data for the Newfoundland area are summarized in Figures 5.1.4.1-5.1.4.21.

#### Cod Growth Data

Mean and standard deviation of length at age, number of fish aged and mean and standard deviation of weight at age data are available (R. Myers, Department of Fisheries and Oceans, St John's) from stratified random research trawls (C. Bishop and J. Baird, Department of Fisheries and Oceans, St John's) in the following NAFO Divisions for the specified years:

Division	Season	Years
2J	Fall	1950, 51, 53, 54, 63, 71 76-89
3K	Fall	1950-51, 52, 58, 59, 62-64, 71, 77-89
3L	Spring	1948, 50, 51, 53, 61, 63-65, 67-89
3M	Spring	1961, 64, 68, 77, 78-85
3N	Spring	1946-48, 50-53, 58-62, 64-82, 84-89
3O	Spring	1951, 52, 58-66, 68, 71, 73, 75, 76-82, 84-89
3Ps	Spring	1951, 53, 58, 59, 60, 62-65, 67-70, 72-89

Additional spring and fall data could be made available for some



areas, e.g. fall data for Div 3L.

### Population Abundance of Cod

Estimate of cod 3+ biomass in NAFO Divs. 2J3KL combined for the period 1962-89, obtained from ADAPT estimates of cod numbers at age and mean weight at age in the commercial catches (to provide greater independence with respect to research trawl length at age). The ADAPT estimates of numbers at age are tabled in Baird et al. (1990). Weights from commercial catches were extracted from Groundfish Division data files (C. Bishop and J. Baird, Department of Fisheries and Oceans, St John's) by R. Myers (Department of Fisheries and Oceans, St John's) and are prepared as SAS Data sets.

### Population Abundance of Capelin

No single time series of capelin abundance is available, however a single relative index for NAFO Divisions 2J3KL combined, covering the period 1972-89, has been put together by L. Fahrig and J. Carscadden (Department of Fisheries and Oceans, St John's) from several shorter, but overlapping time series of VPA (SCAM), acoustic and CPUE estimates.

Population abundance of other cod prey candidates include Arctic cod, sand lance, squid, shrimp, and zooplankton. During the late 1970's, when capelin abundance had declined, Arctic cod, sand lance and squid populations all appeared to have increased and may have partially compensated for the loss of capelin (Carscadden 1984). There is little in the way of abundance data for these species.

### Environmental Variables

An annual estimate of temperature anomaly at 176m (bottom) for Station 27 (47°32.8'N, 52°35.2'W) for the period 1946-89 has been compiled by R. Myers (Department of Fisheries and Oceans, St John's). Petrie et al. (1988) has shown that the temperature data at Station 27 is correlated with the temperature at Hamilton Bank (54°N, 55°W), and therefore Station 27 temperature anomalies may be reasonable indices of temperature anomalies for the NAFO regions under consideration. In order to coincide with the fall and spring trawl surveys, fall anomalies were calculated for the year November to November, and spring anomalies for the year April to April.

## 5.2 Description of Statistical Models

### 5.2.1 General Linear Models

Various general linear models were fitted to the growth and environment data. The models can be classified according to dependent variables and groups of independent variables.

Two types of dependent variables were considered: growth and standardized growth. The growth variable was simply computed as:

$$\text{delta}_{a,y} = L_{a,y} - L_{a-1,y-1}$$

The standardized growth variable was computed by calculating the mean and standard deviation of the estimated delta within an age class and then for each delta subtracting the mean and dividing by the standard deviation for the corresponding age. For Iceland and the Newfoundland stock areas weighted means and standard deviations were used in the calculation of the standardized growth variable. The weights for the Newfoundland data were based on the number of fish aged in each age class in each year and for the Icelandic data were based on estimates of the standard error of the estimates for mean length at age. These weights were also used in glm calculations. The group recognized that there is an autocorrelation in the increments because of the method of computation. Further, several of the independent variables were shown to be correlated. Since the prime purpose of the analysis was exploratory, the autocorrelation and the correlation was ignored.

The autocorrelation in the growth variables should make it difficult to detect cohort effects since successive growth parameters for a cohort will be negatively correlated. The influence will be less on the detection of effects related to year since growth increments across age within a year are not correlated. Since the standardized growth variable is standardized on age, cohort effects would have to be large in order for them to be detected since the amount of growth relative to the mean for an age class would be expected to be less for a cohort which was large at the beginning of the growth period.

For each dependent variable and each available area, season combination, two approaches were taken to investigate the effect of the environment on cod growth. The first approach involved analyses of variance computations, using age, year and cohorts as factors in all possible combinations. The second approach started by fitting a full model with all the major environmental variables, dropping nonsignificant ones ( $P > 0.1$ ) until a final model was obtained. Thereafter, a year effect was added to test whether it was significant. A significant year effect indicates the presence of an environmental effect which has not been explained by the analysis.

## 5.2.2 Growth Curve Models

### 5.2.2.1 Millar and Myers Environmentally Sensitive Growth Increment Model

The Millar and Myers (1990) model modifies the von-Bertalanffy growth curve to make the expected growth increment of a cohort in any given year a function of the environmental conditions experienced by that cohort in that year. The conventional von-Bertalanffy model can be written as

$$L_a = L_{a-1} + (L_{\infty} - L_{a-1}) (1 - \exp(-k))$$

where  $L$  is the expected length at ages  $a-1$ ,  $a$  and infinity (corresponding to subscripts  $a-1$ ,  $a$  and  $\infty$ ). Millar and Myers (1990) considered several different environmental modifications of the above equation. The modification fitting best for the Northern cod (NAFO regions 2J, 3K and 3L) data they used was one that allowed  $L_\infty$  to be environmentally dependent. The expected growth increment for a given cohort in a given year is given by the above equation, but with  $L_\infty$  replaced by the formula

$$L_\infty = L_0 + b \cdot env$$

where  $env$  is a measure of the environmental conditions. This measure may be a vector, for example, if both food availability and temperature are used.

Although the Millar and Myers model is developed by modifying expected growth increments, the Millar and Myers model fits to observed length at age data (not observed increments). This is because the length at age measurements are independent whereas the increments in successive years are correlated. The environmentally dependent expected growth increments are summed over the history of the cohort to obtain an environmentally dependent expected length at age. These are fitted to the observed length at age data.

Fitting the conventional three parameter von-Bertalanffy involves estimating parameters  $L_\infty$ ,  $a$  and  $k$ . The fit of the above environmentally dependent model involves estimating  $L_0$ ,  $a$ ,  $k$  and  $b$  (which is a vector if two or more environmental measures are used). The model is fitted in SAS, which also gives the approximate statistical significance of the environmental measures. However, it should be noted that a more reliable estimate of significance is given by the difference in residual sums of squares between the conventional three parameter von-Bertalanffy and the modified model (Seber and Wild 1989).

#### 5.2.2.2 Functional Growth Increment Model

This approach results from Anderson and Ursin (1977) growth theory and was developed by Horbowy (1983) and Horbowy and Swinder (1989). In the Anderson and Ursin growth equation

$$dw/dt = vhf w^{2/3} - kw,$$

where  $f$  is feeding level, and  $v, h, k$  are parameters. Assuming that  $f$  is constant in time interval  $(t, t+1)$  the above equation may be solved for  $w$

$$w_{t+1}^{1/3} = a f_t + \exp(-K) w_t^{1/3}$$

where  $a = vh(1 - \exp(-K))/k$ , and  $K = k/3$ . Switching to the length terms one obtains

$$l_{t+1} - \exp(-K) l_t = b f_t$$

where  $b = cvh(1 - \exp(-K))/k$  and  $c = w/l^3$ . The feeding level can be expressed as

$$f = (\text{food}/N) / (\text{food}/N + Q)$$

which leads to:

$$1/(l_{t+1} - \exp(-K) l_t) = 1/b + (Q/b) (N_t/\text{food}_t)$$

where food is available food biomass, N is stock density and Q is the search rate. Regressing  $\text{rec\_dl} = 1/(l_{t+1} - \exp(-K) l_t)$  against N or  $1/\text{food}$  or  $N/\text{food}$  can be used as a test of the influence of different variables on growth. Such analyses were undertaken for the Barents Sea and Newfoundland 3K cod growth data sets.

### 5.3 Comparison of Results Among Ecosystems

#### 5.3.1.1 Basic Analysis - Correlation Matrix and Analysis of Variance

When considering the results in this section, it must be borne in mind that the growth data has in many cases quite a high variance. In particular, for the Icelandic data, the variances are quite high on ages 8 and 9, due to sampling problems for these age groups in the north-east region. Conclusions are therefore focussed on those results which carry across regions.

Correlation matrices for all regions are displayed in Table 5.3.1.1. In the regions with capelin biomass data (all except Greenland) the correlation between capelin and capelin/cod is extremely high, ranging from 0.89 for Iceland to 0.99 for Newfoundland. This is probably due to large temporal changes in the capelin data relative to the cod data. This explains why  $1/\text{cod}$  and capelin/cod have low correlation in all regions. The Barents Sea and Newfoundland data also show a high correlation between temperature and  $1/\text{cod}$  (0.72 and 0.82 respectively).

In order to ascertain the presence or absence of environmental effects (including food availability), simple analysis of variance models were fitted to the growth increment and standardized growth increment data. Any environmental effect which varies in time should appear as a year effect in an analysis of variance. Since there is a potential for varying growth among cohorts (e.g. due to different initial sizes of juveniles), cohort factors were also fitted. In the growth increment model, an age factor was also included.

A summary of the results of these analyses for the growth increment data are presented in Table 5.3.1.2. The table shows the significance (as measured by P-levels) for each effect in various models, along with R-square values and residual degrees of freedom

for each model.

The first thing to note is that the year effect is significant in almost all models (with the notable exception of fall measurements around Greenland, which has the lowest number of observations). It is seen that cohort alone is never significant nor is it significant with the age effect. The cohort effect is in most cases significant with the year effect. However, when both age and cohort effects are in the model (especially with the year effect), these two effects are quite confounded and hard to distinguish unless a very large number of years is included in the analysis.

Conclusions based on the standardized growth are along the same lines as the above (Table 5.3.1.3). The age effect is not included in these analyses since it has been removed by the standardization. In these analyses the cohort effect is often significant when included with the year effect. This does seem to indicate that certain year classes grow faster than others, even after correcting for environmental effects.

The overwhelming presence of a year effect indicates the existence of an environmental effect. This effect should be measurable by some environmental variables. Some of the candidates are capelin biomass, cod biomass (possibly by age groups) and temperature. The effect of a high temperature is often assumed to be positive, since in the boreal regions it often indicates a flow of warmer currents with high production. However, when other environmental variables which indicate food availability are included in the model, it is not clear whether a higher temperature should lead to faster growth (higher metabolism) or slower (higher energy requirements due to faster movement).

The full model (Tables 5.1.1.4 and 5.3.1.5) includes most of the environmental variables available to the meeting: cod biomass in the form of  $1/(\text{cod biomass})$ , the biomass of the same year class in that year, the capelin biomass, the portion of the capelin biomass available per unit biomass of cod ( $\text{capelin/biomass}$ ) and temperature. A cohort effect is included and for the growth increment model an age effect is also included.

As seen in Table 5.3.1.4, the full model is somewhat too large for comfort, since the error d.f. are very few. This is partly due to the number of terms in the models and partly due to the short time series available when all the data need to be considered in one model. At this stage it must also be noted that the variable pairs: capelin with  $\text{capelin/biomass}$  on the one hand and biomass with  $\text{capelin/biomass}$  on the other are quite correlated. It is therefore hard to accept or reject models which include both variables in one of the pairs.

The similar full model for the standardized growth increments is given in Table 5.3.1.5. As in the former table, few effects are significant, with the notable exception of the paired variables in the Barents Sea and Newfoundland Div. 3L.

Backwards stepwise regression was conducted on the full models of Tables 5.3.1.4 and 5.3.1.5, dropping at each stage the least significant variable until a model was obtained which contained only variables significant at the 10% level. The results are given in Tables 5.3.1.6 and 5.3.1.7.

Inverse biomass appears in 2-3 regions, and capelin or capelin biomass appears in 4 regions. Temperature appears significant in 3 regions. An age effect is noted only in two Newfoundland areas (possibly only due to the large number of age groups in the Newfoundland data).

The year effect is in most cases significant, indicating quite strongly that there is unexplained variability in measured cod growth, which could potentially be explained by better environmental variables. It must be noted, however, that variations in time of year and area used for sampling in relation to migratory patterns can also give a strong year effect. Thus, considerations on which environmental measurements would be used must also take such factors into account when related to cod growth.

#### 5.3.1.2 Size at Age in West Greenland

In the West Greenland area size at age has decreased substantially for all age groups in both the spring and autumn (Figures 5.1.2.7-5.1.2.8). However, the analyses of the yearly length increments showed only a significant year effect in the spring data, and a general decrease in yearly length increments seems not to have occurred (Figures 5.1.2.3 and 5.1.2.4). The decrease in size at age for all age groups are therefore not the result of decreasing growth rate but due to the decreasing size of the youngest age group 5 included in the analysis. This implies that growth changes may have occurred during the period for the younger age groups.

#### 5.3.2 Growth Models

##### 5.3.2.1 Millar and Myers Model Results

The model was fitted to the Icelandic and Newfoundland region 3K cod length at age data. Due to the nonlinear least square fitting procedure (SAS proc NLIN) it was not possible to fit all possible subsets of the collection of independent (environmental) variables. Instead, two variables representing food availability and a temperature variable were explored. The two food measures were 1/cod biomass and capelin biomass/cod biomass. The former is an appropriate food measure if the amount of food available to cod is reasonably constant. The later is more appropriate if cod are largely dependent on the availability of capelin with little ability to switch to other prey types. Note that these environmental variables are functions of year only. No age specific variables (e.g. year class biomass) were used.

In fitting the models the temperature effect was modelled from age

0 onwards but the food effect was modelled from age 3 onwards since the food measures were not considered relevant for cod younger than 3. Since the Newfoundland capelin data begins in 1972 the analysis was restricted to cohorts from 1969 onwards, because it is necessary to have food availability data for age 3 and older fish. Similarly, the Icelandic data used began with the 1976 cohort because capelin biomass data begins in 1979. The fits were implemented by using each variable in the model individually and then fitting a food measure and temperature together.

The statistical significance of the environmental variables is best described by differences in residual sums of squares (Seber and Wild 1989). In particular, the conventional von-Bertalanffy fit to the Newfoundland region 3K data had a (weighted) RSS of 90,846 on 142 d.o.f. (Figure 5.3.2.1.1). The capelin biomass/cod biomass term reduced this to 75,528, a statistically significant reduction. However the 1/biomass term provided a better fit and reduced the RSS to 45,165. Including temperature with 1/biomass resulted in an additional statistically significant drop to 32,982. Figures 5.3.2.1.2 - 5.3.2.1.7 show the model fits to the length at age data for even-year cohorts between 1970 and 1980. Figures 5.3.2.1.8 - 5.3.2.1.14 show residuals. The residuals show no structure with any other variables except possibly age, where there appears to be an increasing trend from ages 3 through 5.

The fits to the Icelandic data gave a (weighted) RSS of 658 on 38 d.o.f. for the conventional von-Bertalanffy (Figure 5.3.2.1.15). The capelin biomass/cod biomass term was statistically significant and reduced the RSS to 339. The 1/biomass term managed only a minor reduction in RSS to 605 and was not statistically significant. Including temperature with capelin biomass/cod biomass gave a nonsignificant reduction in RSS to 319. The fits of the capelin biomass/cod biomass model to cohorts 1976 through 1982 are shown in Figures 5.3.2.1.16 - 5.3.2.1.22. Since temperature was not significant in the presence of the food variable it was fitted alone in the model. The temperature alone model gave a RSS of 623, indicating that temperature is not significant by itself or when included with the food variable.

A summary table of the residual sum of squares is given below:

Model	#parameters	Iceland	Newfoundland (3K)
Conventional von-Bertalanffy	3	658	90846
1/cod	4	605	45165
cap/cod	4	339	75528
temp	4	623	70862
1/cod and temp	5	599	32982
cap/cod and temp	5	319	69410

#### 5.3.2.2. Functional Growth Increment Model Results

This model was used for the analysis of two data sets: (1) Newfoundland Atlantic cod (Division 3K), and (2) Barents Sea cod. In the first data set, survey length-at-age data covering the 1977-1989 period and ages 3-13 were analyzed. First, the K value was estimated based on mean length-at-age values for the whole period. Next the increments defined as  $l_{a+1,y+1} - \exp(-K) l_{a,y}$  were calculated and ANOVA was conducted.

ANOVA shows highly significant year effect while age effect is not significant. Stock density N explains 33% of the variance of the reciprocal of mean over age increment,  $\text{rec\_dl}$ , and model is significant at 5% level (Table 5.3.2.3.1; Figure 5.3.2.3.1). Other variables such as  $1/\text{capelin}$ ,  $1/\text{temperature}$ ,  $N/\text{capelin}$  did not show any influence on cod growth.

The Barents Sea cod growth increments (data for 1979-90, ages 3-8) also show highly significant year effect and do not show age effect. The  $1/\text{capelin}$  variable explains 56% of the variance of the  $\text{rec\_dl}$  while  $1/(\text{capelin} * \text{temperature})$  explains 60% of the  $\text{rec\_dl}$  variance with models being significant at 1% level in both cases. The stock density explains only 29% of the variance and model is not significant (Table 5.3.2.3.1, Figures 5.3.2.3.2 and 5.3.2.3.3).

#### 5.4 Discussion

Particular conclusions are somewhat sensitive to the structure of the models and selection of years and ages included in the analysis. For example, the Icelandic data analysis was rerun using odd and even years and that gave somewhat different results (using the same final model which included temperature and capelin), temperature lost some significance and capelin was only significant in the odd-year run. The emphasis has been, however, on results that hold for a number of ecological systems.

The analyses indicate a strong environmental component in the measured cod growth. This is replicated in most of the systems. After fitting a model including all marginally significant environmental variables, most of the systems have a significant remaining unexplained annual variation.

This indicates that further research and better data might give significantly better growth predictions. Items of potentially great significance include identification of appropriate measures of the physical environment, especially temperature, in relation to the biological processes influencing cod abundance. [This is considered a priority concern for the development of studies under the Cod and Climate initiative] A computation of average annual abundance of capelin available to cod should be also of primary importance. This measure should take into account the overlap between the stocks and the average amount of capelin available in the region (accounting for spawning mortality and fishing).



The Millar/Myers growth curve model is seen as a method of potential great use, since environmental effects can be directly modelled into the von Bertalanffy equation, as opposed to the usual methods which assume a fixed growth model either across year classes with a different history or across years with different environmental effects. Some structure is imposed by the model, however, and further analyses of residual autocorrelations (within cohort) are needed. The current model cannot include e.g. factor effects, which may come out as significant from a linear model. The fact that a linear model indicates the presence of such effects should indicate that such terms are necessary in the growth curve models.

Here the ANOVA results were not entirely consistent with the growth curve fits. For example, the final ANOVA backwards stepwise fits did not find temperature to be significant in Newfoundland Div. 3K, but temperature was found to be significant by the growth curve model. This may be because the growth curve used temperature as an explanatory variable for growth beginning with age 0 fish, therefore increasing the probability of detecting any possible temperature effect. Another reason for differences is that the growth curve used all fish of age 3 or older in Div 3K, whereas the ANOVA's used only fish between 3 and 10 years of age.

## 6 ANALYSIS OF FOOD AND FEEDING DATA IN ARCTIC/BOREAL SYSTEMS

### 6.1 Introduction

Comparative multispecies modeling of Arctic/Boreal ecosystems requires that basic data describing the predation process be collected in a consistent manner, and that existing data be fully described and available for use in a common, disaggregated format. In this section, the stomach sampling programs (both current and historical) undertaken in the four Arctic/Boreal systems described in section 5 are reviewed in detail.

Although it was not possible to undertake detailed analyses of these feeding data at the current meeting, proposed terms of reference for the next meeting of the Multispecies Working Group include evaluation of variance components of average stomach content and species composition of prey, as well as more detailed examination of spatial overlap in predator/prey systems (see Recommendations). Because detailed stomach sampling data are available for three of the systems (see below), it is envisioned that these data will be fully integrated into the recommended analyses for the next meeting. In particular, much of the Arctic/Boreal stomach data has been collected on an individual fish basis, which is important for analyzing feeding variability (especially in relation to sampling design). Similarly, because of the variation in spatial overlap of cod and its prey (Anon. 1990a), an important contribution to modeling spatial effects explicitly will come from the examples provided by the Arctic/Boreal systems.

## 6.2 Description and Analysis of Data Sets

### 6.2.1 Barents Sea

Since 1987 the USSR and Norway have cooperated in the collection of stomach data in the Barents Sea, and a common stomach content data base is being formulated. The stomachs are worked up individually. Cod is most intensively sampled and Table 6.2.1.1 presents the number of cod-stomachs included in the data base from 1950 to 1989 by year and quarter. The bulk of the samples are from 1984 and onwards, and the 1st and 3rd quarters of the year are best covered.

All cod stomach data are available in a disaggregated format. The data file consists of two kinds of lines; one "S" line containing information on the predator and one "P" line containing information on the different prey items ("P" and "S" indicates that the line starts with a "P" or "S"). Each "S" line is followed by a "P" line for each prey category. Table 6.2.1.2 presents the data and formats by "S" and "P" lines in the file. It should be noted that the USSR and Norwegian data has different codes for filling and digestion degrees.

In addition, USSR has collected about 1 million cod stomachs in the period 1947-1983. Those data are more roughly worked up at sea (Ponomarenko and Yaragina, 1984) and are not yet fully computerized. The plan is to prepare them for computer analyses and correlate them to the more detailed quantitative data.

The stomach data are being used in the parameter estimation of the predation equations in the Barents Sea Multispecies Model (Bogstad and Tjelmeland, 1990). In addition, the data have been used in a number of USSR and Norwegian papers describing the diet and consumption of the Northeast Arctic cod stock.

The data have been used in a VPA for cod in the Barents Sea with cod cannibalism included (Skagen et al. 1990).

In addition to cod, the stomach data base also contains information on the stomach content of 8,173 haddock, 783 capelin, 1,505 herring, 184 redfish, 352 blue whiting and 2,073 polar cod. All these data have mainly been collected since 1984. In addition, there exists data on the stomach content and consumption by sea mammals and birds, but these data are not yet made available on data medium.

### 6.2.2 Iceland

A working paper introduced the sampling of stomachs in Icelandic waters since 1970 (Pálsson 1990). The feeding studies have been relatively consistent with respect to methods of sampling and analysis of the material. As a rule, the sampling has been stratified by predator length.

For most species the data have been used for a general description

of feeding habits. Only the cod data have been used for a multispecies evaluation, focusing on cod-capelin interactions (Magnusson and Pálsson 1991).

A total of 28,707 cod stomachs have been sampled on board research vessels in the period 1979-1990, with prey identification by species (Pálsson 1983). The lengths of the predators are from 7 to 129 cm and the collection has taken place 3-4 times each year, with 1,000-2,000 stomachs sampled each time. A further 7105 cod stomachs have been sampled on board commercial trawlers in the period 1981-1990 (Pálsson 1985).

Sampling of 0-group cod and larvae has been more irregular, but some 2,500 stomachs have been collected in the period 1971-1985. A further 9,144 cod stomachs were collected in 1976-1978, but prey identification was only by ecological groups (Friðgeirsson 1984; Jónsson and Friðgeirsson 1986; Pálsson 1973a; 1973b; Þóttisson 1988).

Sampling of other stomachs has been more irregular, but some data does exist for haddock, saithe, whiting, redfish, catfish, long rough dab, plaice, megrim, witch, lemon sole, capelin, blue whiting, snake blenny and sandeel (Jónsson and Friðgeirsson 1986; Pálsson 1973a; 1973b; 1983 and Steinarsson 1979).

Stomach data from common seals (218 stomachs) and grey seals (326 stomachs) are available from the years 1975-1990. Whale stomachs were collected mainly during 1967-1989, from fin whales (1,499 stomachs) and sei whales (499 stomachs) at the whaling station in Hvalfjordur. Minke whale stomachs were collected mainly in 1978, but occasional stomachs were collected in other year. The total number of stomachs is 58 from minke whales, mainly collected from animals caught in coastal NW and N Icelandic waters.

### 6.2.3. Greenland

Knowledge of food availability for cod off West Greenland is scarce. Only irregular sampling of cod stomachs has been carried out in recent years. As none of the important prey stocks (capelin, sand eel) are presently being studied with regard to their abundance and biomass, the potential changes in prey availability can not be evaluated.

### 6.2.4 Newfoundland

Cod stomachs have been collected during stratified-random surveys in NAFO Divs. 2J3K in the fall of 1978 and 1980-89 and in Div. 3L in the spring of 1979-82 and 1985-89 (G. Lilly, Department of Fisheries and Oceans, St John's). Stomachs are collected from a length-stratified sample of the cod caught in every fishing set. In addition, stomachs have been collected from hydroacoustic surveys and tagging surveys during the winter and from hydroacoustic surveys in summer. Collections from the inshore have been on a more opportunistic basis. Because of the lack of good

seasonal coverage, reliable estimates of annual food consumption and energy flow are difficult to provide. The broad pattern in predation by cod on capelin and other prey have been reviewed by Lilly (1987). Analysis of the Div. 2J3K stomach series up to 1986 has been reported in Lilly (1987), and this revealed that capelin was the major prey item of cod in most fall surveys, and that the average quantity of capelin in cod stomachs increased with capelin abundance from very low in the late 1970's to high in the mid-1980's (Lilly 1991). During years of low capelin abundance cod did not compensate by preying more intensively on other prey. There is not evidence from cod stomachs that either hyperiid amphipods or Arctic cod increased in abundance during the period of low capelin abundance (G. Lilly, Department of Fisheries and Oceans, St John's). Lilly (1990) has calculated a partial index for capelin, other prey and total fullness index for the period 1978-89.

As of August 1990, 2885 harp, 109 hooded, 19 grey, 35 harbour, 126 ringed and 32 bearded seal stomachs have been analyzed from collections from various areas off Newfoundland and Labrador (G. Stenson and I-H. Ni, Department of Fisheries and Oceans, St John's). In addition 1,600 stomachs are awaiting sorting. Of the sorted stomachs, 2,100 of the harps and 35 of the hooded contained food. Harp seal stomachs have been collected from all months October through July. Samples collected in earlier years tended to be concentrated along the northeast coast of Newfoundland although in recent years sampling from other areas, particularly Labrador, has been emphasized. Ni and Stenson (1990) provide an overall summary of the data available. The majority of the stomachs are from inshore harp seals, and these indicate that the main prey items in this region are capelin, arctic cod and invertebrates such as euphausiids and shrimp. Although cod is unimportant in these samples, it may be more important in the diet of harp seals feeding further offshore or in the diet of hooded seals which generally inhabit deeper water and dive deeper than harp seals (Stenson and Ni, Department of Fisheries and Oceans, St John's). Estimates of the population abundance of harp seals in the Northwest Atlantic are available (Ni and Stenson 1990). Pup production of the "front herd" has been most often measured with 13 annual estimates for the period 1950 to 1983. A further estimate from the March 1990 survey will soon be available. In addition to seals, humpback and minke whales are abundant and increasing in the region off Newfoundland and Labrador, and may consume considerable amounts of fish, however, data are scarce (G. Stenson, Department of Fisheries and Oceans). Feeding data for seabirds are available for the region. The best data set appears to be that for gannets on Funk Island (49° 46' N, 53° 11' W) which supports 50% of the Newfoundland population. A total of 2,281 gannet samples have been analyzed for July or August for the period 1977 to present (except for 1981) (W.A. Montevecchi, Memorial University, St John's). In general, in the sampled months, mackerel was most common, followed by herring, squid, capelin and saury, in decreasing order of importance with some variability in the rank order from year to year (Montevecchi et al. 1988).

## 7 COMPARATIVE ANALYSES OF MULTISPECIES SIZE COMPOSITIONS

A continuing objective of the Multispecies Working Group remains the development of relatively simple but robust methods with which to describe essential properties of exploited ecosystems. Research conducted by several authors (e.g. Pope and Knights (1982; Pope et al. 1988; Murawski and Idoine 1990) and preliminary analyses undertaken by the Working Group last year (Anon. 1989a) have focused on the potential utility of results from multispecies bottom trawl surveys and data from MSVPA in developing comparative ecosystem descriptions based on multispecies size compositions.

Specifically, it was noted that the slope of the multispecies numbers or biomass at length plots for fully-recruited sizes was generally stable over time within a fishery system (e.g., Anon. 1989a), but in the cases of the North Sea, Faroe Bank and Georges Bank, the slopes were vastly different among the systems. The degree to which these differences in the biomass-at-size spectra may be an inherent property of individual trophic systems, or simply a manifestation of the multispecies exploitation rate (weighted by the relative biomasses and  $F_s$  of each of the constituent species of the systems) remains unresolved. Despite the lack of consensus on the importance of various mechanisms in determining the patterns of multispecies size composition, the prospect of using relatively simple metrics such as multispecies size composition as a basis for evaluating both the status of exploitation of individual systems, and for inter-system comparisons, remains intriguing.

At this meeting the Working Group considered multispecies size compositions from three time series of bottom trawl surveys: the English groundfish survey of the North Sea, the Canadian bottom trawl survey in Newfoundland waters, and the US bottom trawl program on Georges Bank. Results of each survey program are reviewed with respect to changes in observed size composition and species distributions. These results are interpreted in light of various alternative mechanisms governing the biomass distributions at size. The overall utility of using aggregate-species biomass distributions as system-level indicators is then evaluated. The integration of these specific results with the wider body of ecological size spectrum theory is undertaken in section 8.5

### 7.1.1 North Sea - English Groundfish Survey

The English groundfish survey (EGFS) has been conducted across the North Sea since 1977. The survey typically consists of 70-100 trawl stations over a period of 30-35 days in August/September. The survey was designed to be random within depth strata across the entire North Sea area. Because of constraints (temporal and physical) the same primary trawl stations are covered each year. A recent working paper (Nicholson et al. 1989) calculated that each primary station could be minimally defined by an area of approximately 450 nm<sup>2</sup> (ie. about half of one ICES statistical

rectangle). The surveys have been well described by Harding et al. (1986). Two previous papers (Pope and Knights 1982 and Pope et al. 1988) have presented aggregate size composition for the North Sea in comparison to, respectively, Faroe Bank and Georges Bank.

Figures 7.1.1 a&b show aggregate length compositions (for 69 species) in the years 1977 to 1989 for 5cm. length groupings from 20cm. (-24cm) up to 105cm. (-109cm). Figure 7.1.1a is year X length-class X mean # per hour, Figure 7.1.1b shows the same data on a  $\text{LOG}_{10}$  scale. The numbers per hour for fish below 20cm are not shown - these figures are more variable between years as various recruitment pulses appear. Also, the survey is not believed to sample smaller fish efficiently. Not shown are the species composition changes with time. Pope et al. (1988) showed that the species composition within length classes has changed over the period of the EGFS.

Analyses of MSVPA results in terms of multispecies biomass-at-size confirm the general stability in the size distribution of the system over time in the North Sea system (Anon. 1989a).

#### 7.1.2 Newfoundland Trawl Survey

Data were presented from the stratified random trawl surveys conducted on the Grand Bank of Newfoundland (NAFO DIV 3LNO), since 1976 (Rice 1990). Biomass was aggregated across all common species, in 6 cm size categories (Figure 7.1.2a,b). Although rare species were not included in the estimation of biomass by size class and year, in all cases at least 94% of the total biomass estimated from catches was included in the analyses. Size categories lower than 18 cm were not examined, because the survey gear does not sample fish of these sizes effectively. Size categories greater than 100 cm were aggregated into a single category, because fish of such sizes were rare.

Several patterns appear to be present in the data. Two spikes of biomass appear in the lowest size groups; one in the mid 1970's and one in the mid 1980's. Both are dominated by small redfish. The first spike shows up in several size groups of redfish in 1978, but does not persist. There is some evidence that the second peak in biomass at small sizes represents increases in several species, and is progressing through the size spectrum.

In the 1970's, the slope of biomass by size group is steeper than after the early 1980's, and there is a suggestion that biomass did build first in the intermediate size groups, and later in the larger ones. However, when individual species are examined, patterns are hard to reconcile. Much more detailed analyses are necessary before sound conclusions can be drawn. In contrast to Georges Bank (Section 7.1.3), there is no evidence of an increase in elasmobranchs during periods of depressed biomass of finfish, nor were there declines of elasmobranch biomass when cod rebuilt in the larger sizes.

The Working Group discussed these figures, in the content of the information available on other systems. The Working Group noted that the data are likely to contain informative patterns, and further analyses of the size composition data are encouraged. However, some of the patterns in biomass of individual species are incongruous with the interpretations suggested by the overall patterns in the data. Careful checking of the data, and detailed analyses are necessary to ensure spurious interpretations are avoided.

### 7.1.3 Georges Bank Trawl Survey

Changes in the multispecies size and species composition on Georges Bank have been reviewed, based on the USA Northeast Fisheries Center bottom trawl survey series (Pope et al. 1988; Murawski and Idoine 1990; Figure 7.1.3a&b). Bottom trawl surveys of the USA northeast continental shelf area (including Georges Bank) have been conducted annually in the autumn since 1963; in the spring since 1968. Aggregate species catch-per-haul for autumn surveys declined steadily and significantly from 142 kg/haul (1/2 hour) in 1963 to a low of 54 kg/haul in 1969. Since that time the multispecies kg/haul index has increased steadily to levels similar to the early 1960s (e.g., 141 kg/haul in 1987). During the 1960s and early 1970s an intensive distant-water fleet fishery developed on Georges Bank, targeting a variety of groundfish and pelagic species. Concern for the status of resources on Georges Bank and elsewhere in the northwest Atlantic led to restrictive catch and effort regulations in the 1970s. The extension of coastal-state jurisdiction coincided with a rapid increase in total system biomass (as measured by aggregate species kg/haul statistics).

One important aspect of the fluctuation in biomass indices from trawl-survey catches on Georges Bank is the very apparent change in species composition of survey catches. During the 1960s, elasmobranchs (primarily spiny dogfish and skates) comprised an average of 21% in weight and 9% in numbers of trawl survey catches on Georges Bank. These proportions remained relatively stable through the mid-1970s (as the aggregate kg/haul index declined), but have since changed greatly. The proportion of elasmobranchs has increased steadily and significantly to about 75% in weight of the autumn survey catch. During the intensive distant-water fleet fishery of the 1960s and 1970s, catches of elasmobranchs were relatively high as these species were either used for human consumption or processed for industrial products. The elasmobranch species are currently fished at very low levels by USA fishermen, contributing to their improved population abundance relative to traditional target species (groundfish and flounders). If elasmobranchs and other species not intensively harvested on Georges Bank are not included in the analysis of trawl survey data, the biomass of 'marketed' finfish has declined in recent years to record-low levels, even while total-species kg/haul indices are high and stable.

The size compositions of multispecies trawl survey catches from

1963-1985 are given in Figure 7.1.3a&b. These data indicate a slight reduction in the number and proportion of relatively large fish (>50 cm) during the period of intensive distant-water fleet fishing in the mid-1960s to early 1970s. Since the mid-1970s, the number and proportion of fish in larger size categories has increased. Most of the fish >70 cm are elasmobranchs (>80%), thus the increased abundance of elasmobranchs is mostly responsible for the increasing numbers of larger fish in autumn surveys.

## 7.2 Utility of Multispecies Size Compositions as System Indicators

Although there has been some variation in the multispecies size composition within various systems, the between-year variability in multispecies size composition within systems is small when compared with the variability in size distributions among systems (Figures 7.1.1-7.1.3). In the cases of Newfoundland and Georges Bank, there are significantly greater proportions of total survey catches in the larger size intervals as compared with the North Sea system, resulting in significantly lower slopes to the multispecies size spectra. Although there is a high degree of variability from year-to-year within each system, the overall trend is striking.

It is interesting to speculate on the reasons for the vastly differing aggregate-species size distributions between the North Sea and the other two systems. Are the differences inherent in the trophodynamics of the systems, or rather do they simply reflect a weighted multispecies exploitation rate?

There are at least four potential factors which may contribute to the observed differences in multispecies size composition. First, the North Sea fisheries tend to exploit fishes at a smaller size at first capture than in the two North American fisheries systems analyzed. This would necessarily tend to increase the skew of the curve to smaller-sized individuals in the former case. Second, a consistently higher proportion of the diets of piscivorous fish are comprised of fish, as compared with higher fractions of invertebrate food for at least some predators on Georges Bank, and at Newfoundland (Ursin et al. 1985; Lilly 1991). If higher predation mortality rates of juvenile fish result from the greater reliance on fish as prey in the North Sea, then the catch curve of numbers at length should be more steeply sloped in the North Sea case. If important benthic invertebrate prey were included in the size spectra a more comparable picture among the systems may emerge.

A third set of possible factors contributing to the differences in size composition are potential differential survey biases to smaller or larger animals between the areas. If nursery grounds are not representatively sampled or the catchability of small fish is differentially low in the two North American survey series, then the slope at the lower portions of the size compositions will be lower. Finally, given that the differences in slope persist not only at the smaller sizes, but in larger sizes as well, part of the differing multispecies slopes may reflect higher multispecies



exploitation rates in the North Sea case. Exploitation rates of most roundfish stocks on Georges Bank (e.g., cod, haddock, pollock [=saithe]) are similar to those in the North Sea. However, unlike on Georges Bank, fishing mortality rates on the North Sea elasmobranch stocks are also significant (Pope et al. 1988). Thus, species compensation in the larger sizes by lightly exploited species has not occurred. In the case of Newfoundland stocks, fishing mortality rates for important stocks such as cod (Baird et al. 1990) and others are significantly lower than in the North Sea and on Georges Bank, perhaps contributing to the relatively low overall slope to the biomass at length relationship.

Given the above considerations, it is clear that multispecies size compositions (either from trawl surveys or analytical models) do not in themselves yield results that are easily interpretable as intra- or inter-system indices of multispecies interactions. What they do provide is a basis for generating testable hypotheses for the observed differences between systems, and the relative importance of various mechanisms, including overall exploitation rates, predation mortality and growth. Elucidation of the mechanisms that result in the observed differences in multispecies size compositions leads to a new set of sized-based models (perhaps every bit as complex as those currently being used for the North Sea and elsewhere). The development of age-size hybrids and completely size-based multispecies models are considered in more detail in sections 8.1 and 8.5.

## 8 FOOD FOR THOUGHT

As in previous reports of the Multispecies Working Group, Section 8 presents various ideas and work under development that may hold promise for future research approaches to assessing multispecies fishery problems. Accordingly, findings presented in this section should be considered exploratory rather than definitive in nature.

### 8.1 Size and Age Based Extensions of MSVPA

Growth, predation and fishing are basically processes working on size. Working with mean sizes by age alone, as is done in the present MSVPA/MSFOR approach will introduce bias when length distributions-at-age are wide compared to the length dynamics of the basic processes. A purely age based approach is furthermore not extendable to include proper modelling of growth, which is external in the present model. A purely size-based approach is discussed in section 8.5. This section concerns length based extensions of the present approach including a species structure. The immediate need for length based extensions is most urgent for the 0-groups due to their size spread, dynamics and extremity. The discussion below concerns only 0-groups in 3rd and 4th quarter. This means that only metamorphosed fish are included, but some gadoid species will still be pelagic in 3rd quarter.

#### 8.1.1 An Hybrid Age-Length Extension of the MSVPA/MSFOR for

### 0-Groups

The present MSVPA works in time steps of a quarter and data on stomach contents are available on a quarterly basis. This means that mean numbers of predators are calculated on a quarterly basis and the availability of food must be calculated on the same basis.

A length extension of the 0-group phase based on a continuous length based model within quarters has been proposed (Beyer and Degnbol 1990). The basic idea is to treat each length interval of 0-groups as separate units similarly to the species/age units used for other ages. 0-groups are growing through length groups in a quarter. The mean number of 0-groups present in a certain length group in a quarter can be calculated using

- 1) the total number present at the end of the quarter (from MSVPA backcalculations of age 1 to 1/1 (4th quarter) or from backcalculating 0-groups through the subsequent quarter (3rd quarter)).
- 2) a length distribution at the end of the quarter from surveys - for instance IYFS of 1-groups - or from backcalculating length frequencies through the subsequent quarter.
- 3) a growth rate estimate - for instance from single otolith growth increment measurements.
- 4) a mortality estimate.

The mortality estimate is calculated iteratively as M1+M2 utilizing the same iterative approach as used for the MSVPA in general.

The requirements for implementation are that all data concerning 0-groups (distributions in survey catches and stomach contents of predators) are available on a length basis.

It may also be required to distinguish between pelagic and demersal stages in a hybrid approach which means that data must be available on a demersal and pelagic basis separately.

It is difficult to test the model. A proper test would be to compare predicted length distributions in 3rd quarter with length distributions measured during surveys. The lack of proper (non-biased) sampling gear for 0-groups, especially in the pelagic phase, may make such comparisons uncertain. It is suggested that the basic approach of the model can be tested by applying it on 1-groups, using the length distributions of 2-groups in IYFS as the starting point for backcalculations of length distributions of 1-groups and subsequently comparing these with groundfish surveys during the year.

#### 8.1.2 Length-Based Extension for All Ages

This hybrid approach could in principle be extended to cover the whole range of MSVPA species and ages (e.g., Mesnil and Shepherd 1990). An explicit inclusion of length would allow inclusion of growth modelling and would allow the addition of a dynamic element to suitabilities so that suitabilities are dependent on the size structure of prey and predator cohorts. The information needed for such an approach is partly available insofar as all catch data and stomach contents data are collected on a size basis initially to be converted to age later. Length frequencies in the sea are also available from regular surveys in most quarters. The problems are mainly associated with estimation: the degrees of freedom will be reduced as another dimension is added.

## 8.2 The Effect of Correlation Between Recruitment on Long-Term Predictions

Due to interactions among juveniles and to common responses to environmental variables it is likely that recruitment to one stock will be related to the recruitment to other stocks. A large year class of herring may thus be more likely if the recruitment to sprat is at a low level.

The correlation matrix of the MSVPA estimates of log recruitment at age 0 (1 July) is given in Table 8.2.1. Correlations above a level of app. 0.6 (12 d.f.) are significant at the 5% level. Only 5 out of 55 correlations in Table 8.2.1 meet this criterion suggesting that this result may be due to chance. However, assuming that the correlations nevertheless represent an estimate of the interactions, i.e. that they would be confirmed by additional years of data, it is possible to study the effect of preserving them in the long term predictions. One way of doing this is to perform a principal components analysis (PCA). A PCA transforms the 11 time series of recruitment into a new system of coordinates in which they are represented by 11 new uncorrelated time-series (the principal components scores). If recruitment to each of the stocks is assumed to follow a lognormal distribution log recruitment will be normally distributed and so will the principal component scores. Selecting values at random from the normally distributed principal component scores and backtransforming them to log recruitment estimates will generate estimates of recruitment in which the historic correlation is preserved. Further details on the method may be found in Gislason (1991).

Tables 8.2.2 and 8.2.3 contain the results of two long-term (2250 year) runs with the MSFOR in which recruitment was assumed to be stochastic and all other parameters were held constant. In one of the runs the recruitments were selected at random from the (assumed) lognormal distribution of recruitment without taking the between species correlation of recruitment into account. The results of this run in terms of the correlation between the catch of individual fleets, the catch of individual species and the spawning stock biomasses represents the effect of multispecies interactions. Table 8.2.2.a shows the between-species correlation

of the catch. As expected, the catch of saithe is negatively correlated with the catch of prey species like Norway pout and haddock and the catch of mackerel is negatively correlated with the catch of its main fish prey sandeel. For sole and plaice which do not interact with other species the correlation is found to be negligible. The remaining correlations are more difficult to explain, with the exception of cod and whiting they are all positive. Whiting, cod and haddock are thus positively correlated with sandeel, Norway pout and sprat. The explanation for this apparently contradictory result could be that cannibalism is reduced when the abundance of other suitable prey is high. The same effect is reflected in the catch by fleet (Table 8.2.3.a). Except for the fisheries for saithe and mackerel the fleet catches are all positively correlated.

Introducing correlation between recruitment changes this result dramatically even though the average yield only changes insignificantly (Table 8.2.4). Table 8.2.2.b shows that the most of the correlations have increased considerably and some have even gone from negative to positive. Whiting has thus become positively correlated with cod. Saithe is still negatively correlated to Norway pout and haddock, but a fairly strong positive correlation to herring has been created. Positive correlations above 0.5 are now found between cod and sandeel, whiting and sprat, Norway pout and sprat and between sandeel and Norway pout. Saithe and mackerel still show negative correlations with many of the other species, but whiting and herring are also negatively correlated to most of the other species.

In general the effect of preserving the correlation between recruitment in the long-term forecast is to increase the amount of correlation between the catch of individual species and fleets above the level of correlation generated by predation.

### 8.3 Stable Isotope Methods for Analyzing Trophic Structure

The Working Group considered a presentation by Drs. Sam Wainright and Brian Fry of the Marine Biological Laboratory in Woods Hole, concerning the use of secondary methods to independently verify trophic structure of marine ecosystems. These studies have the potential for retrospectively evaluating changes in the trophic economies of such systems, based on time-series of archived aging materials from fish. The ratio of the stable isotopes of nitrogen,  $^{15}\text{N}$  and  $^{14}\text{N}$ , denoted by  $\delta^{15}\text{N}$ , is often used as an indicator of trophic level in ecological studies (Fry 1988). This trophic relationship is based on laboratory rearing studies, where animals have  $\delta^{15}\text{N}$  values of about 3.5% higher than their diets. Ongoing studies of the Georges Bank fishery ecosystem have used published reports of the gut contents seven species of commercially important fish and scale samples from these species, coupled with stable isotope values ( $\delta^{15}\text{N}$ ) of major prey items, to examine feeding relations among these demersal fish species of the ecosystem. Scale samples from the archived collection (time series) maintained at the

National Marine Fisheries Service Laboratory in Woods Hole were used to analyze historical changes in isotopic ratios. Values of  $\delta^{15}\text{N}$  predicted from gut contents of predators agreed well with measured  $\delta^{15}\text{N}$  values for four species: yellowtail flounder, Limanda ferruginea, haddock, windowpane flounder, Scophthalmus aquosus, and witch flounder, Glyptocephalus cynoglossus, all of which occupy the third or fourth trophic level (Figure 8.3.1; trophic level one is denoted as primary production). Summer flounder (Paralichthys dentatus, which was predicted to occupy trophic level 4.5 because of its piscivorous diet, instead had the same  $\delta^{15}\text{N}$  value (and by inference the same trophic level) as windowpane flounder. The American plaice, Hippoglossoides platessoides, and winter flounder, Pseudopleuronectes americanus, which were predicted to occupy trophic level three, based on gut content analysis, but instead had  $\delta^{15}\text{N}$  values of trophic level 3.5. It is concluded that while stomach content analyses and anecdotal observations have suggested that these species occupy differing trophic positions, ranging from opportunistic generalists to piscivores, stable isotope analysis suggests smaller differences in their overall trophic positions. Stable isotope analysis measures assimilated diet integrated over the life of the fish, while stomach contents reveal short-term diet composition. Comparison of these two methods therefore may very well be useful in determining current and past trophic positions, particularly given the inherent limitations of each of these methods, with respect to accounting for spatial and temporal variation in diet composition.

Archived scale samples for haddock are available for the Georges Bank system for nearly 60 years (1930s to present). Analyses of isotopic ratios from this archive suggest a general decrease in the trophic level of haddock since the 1930s, with shorter-term variations superimposed on the overall trends (Figure 8.3.2). Low  $\delta^{15}\text{N}$  values in the early 1950s coincide with a period of high water temperatures. Overall, the decline in trophic level of haddock suggests that either its position within the Georges Bank food web has changes, or that the entire trophic economy (including haddock) has changes over the 60-year period. Although causal relationships for this shift remain speculative, the stable isotope data point to significant changes in the Georges Bank system over the past 60 years. That these changes may be a secondary effect of the harvesting history of the ecosystem make such retrospective analyses indeed a potentially important tool to independently verify mechanistic models such as MSVPA, which are to date calibrated on landings data and sporadic (although intensive) stomach content information.

The retrospective analyses of stable isotope ratios in fish have, to date, used only scale samples, although there is no theoretical reason why archived otolith data could not be used as well. Given the large collections of archived otolith (and to some extent scale) data available in the ICES area, the technique holds some promise for re-constructing the trophic ecology of exploited systems.

#### 8.4 Seabird Predation on North Sea Fish Stocks

Data on consumption and food composition of seabirds were presented in two Working Papers (Cornus 1990; Tasker and Hislop 1990). The available information suggests that consumption of fish by seabirds is, on a total North Sea scale, small compared with predation by the MSVPA predators. For instance, Table 8.4.1 (from Tasker and Hislop 1990) provides preliminary estimates of the energy requirements transformed to weight equivalents for four important species by quarter and subarea of the North Sea. Although this table indicates that at least 250 thousand tonnes of fish might be consumed, this figure includes discards and offal provided by the fisheries. The table also shows that consumption by seabirds is by not evenly spread over different areas in the North Sea and also that it changes markedly by season. Therefore, birds may have a considerable impact on local fish populations and vice versa as indicated by the recent failures in breeding success by the Shetland bird populations.

Integrated data on the prey composition of different bird species over the entire North Sea are at present not available, although local studies indicate that the food taken by seabirds varies considerably between areas and seasons. As an example, the length distributions of sandeel taken by guillemots during different months and at different locations is shown in Figure 8.4.1.

At present, seabird predation is implicitly included in MSVPA to the extent that they represent a component of the 'other' natural mortality (M1). However, the estimated predation rates are rather crude, because biomasses eaten are allocated to prey age classes according to the proportions found in some fish predators. The available evidence does not allow a more precise estimation procedure, but even when more detailed data were available, any revision would probably have minor effects on the ultimate results of the MSVPA. Also, the present type of multispecies assessment would probably be irrelevant in terms of the focal interactions between fisheries and birds. Such problems might only be addressed if some kind of spatial resolution is introduced in the MSVPA model. One way of addressing this problem might be to develop a general two compartment model, which can be used to single out any particular area from the remainder of the North Sea depending on the specific question one might want to answer. Such an approach would require migration parameters for all components of the MSVPA as well as detailed consumption information for the areas considered separately.

The Working Group acknowledged the attempts by ornithologists to investigate the interactions between seabirds, fish stocks and fisheries (Camphuysen 1990). However, in order to allow an integrated analysis of such interactions, there is an urgent need for quantitative consumption and food composition data for the total North Sea seabird populations, disaggregated by species, area and quarter.

## 8.5 Size Spectrum Models of Multispecies Systems

The importance of body-size in describing ecosystems properties was recognized already in the 1920s (Platt 1985). Size was considered by Haldane (1928) as the single most important attribute to an organism. Size is also implicitly used as a key variable in the hybrid of Andersen and Ursin's (1977) predator-prey selection model and VPA, i.e. in MSVPA.

Relating multispecies modelling to ecological size spectrum theory may in the first instance provide overview (which otherwise is difficult to achieve) and at the same time serve as an alternative check on internal model consistency (eg in terms of mass flow balances).

Interpretation of multispecies size compositions in terms of size spectra may provide insight into the consequences of different management regimes and facilitates the development of simple tools for system comparison. The need for general systems interpretations is also apparent when environmental aspects are becoming an increasingly important part of the tasks for fishery biologists. Size-based multispecies modelling further improves the possibilities for relating to mainstream ecological theory developing outside the community of fishery biology.

The present section (see Silvert and Platt 1980; Platt et al. 1981; Peterson and Wroblewski 1984 for background and Beyer 1990 for details) serves only as a first introduction to the theory of size spectra in relation to multispecies modelling and to the formulation of possible developments integrating the two approaches. The considerations here are entirely based on steady state conditions. The study of the behavior of spectra in transient situations is of high relevance to management but the well-defined beginning point (i.e. the equations for continuity and mass balance) then takes the form of partial integro-differential equations. It is when the spectra are assumed to remain constant with time (i.e. steady state) that simplified descriptions of the size-dynamics are obtained.

### 8.5.1 Concepts and Relations

All animals are lumped together by size and treated as one 'species' in a size-structured system. Numbers and biomass are described by density functions. Let  $n(w)$  denote the number density and  $b(w) = w n(w)$  the biomass density at size  $w$ . This means that the number of fish in a small weight interval  $(w, w+dw)$  is  $n(w)dw$  with biomass  $b(w)dw$ . Catch and yield rates in the infinitesimal size-interval is obtained by multiplying with  $F(w)$ , the rate of fishing mortality at size  $w$ . Integrating over a size-interval gives total numbers, biomass etc. for that particular window in the steady state spectrum (Figure 8.5.1.1).

A quantification of the vital rates at size is needed for obtaining

a mechanistic description of the density functions. For simplifications, the system is assumed to have a continuous and constant rate of recruitment ( $R$ ) occurring as input to the left of the spectrum. Reproductive losses are incorporated in  $g(w)=dw/dt$ , the growth rate at size  $w$ . The governing equation for number density then takes the form (Figure 8.5.1.2):

$$(1) \quad d(g(w)n(w))/dw = -Z(w)n(w) \quad \text{or}$$

$$(2) \quad n(w) = c_0 * 1/g(w) * \exp \left[ - \int Z(w)/g(w) dw \right]$$

where  $c_0$  is a constant. Note that it is not,  $Z(w)$ , the instantaneous rate of total mortality at size  $w$  which is the essential parameter of mortality in size-specific theory but rather the physiological rate of mortality,  $Z(w)/g(w)$ , i.e. the rate ratio of mortality to growth (see Beyer 1989). The integral gives size-specific cumulative mortality and the exponential factor represents survival which is proportional to  $g(w)n(w)$ , the rate of growing out of size  $w$ .

If the vital rates,  $g(w)$  and  $Z(w)$ , are known as explicit functions of size then the slopes of the number and biomass spectra at size  $w$  can be obtained directly from Eq (1) (Figure 8.5.1.3). The spectra are usually presented on a logarithmic scale. If  $b(w)w = n(w)w^2$ , the biomass in log weight classes is almost constant (Sheldon et al. 1972; 1973) then the spectra for log-densities become straight lines with slopes of ca -2 for numbers and -1 for biomass.

Requiring mass balance in the predation process, however, implies that  $M_2(w)$ , the predation mortality at size  $w$  is related to the rate of food consumption of the predators. The formulation requires a specification of size selection (i.e. a SUIT model) and the resulting predation mortality at size, in general, depends on the number density. This makes it more difficult to obtain the number density from Eq. (2) because the integral also depends on  $n(w)$ .

### 8.5.2 Logical Consequences in Case of Allometric Growth at Size

In ecological particle size theory growth at size is usually described by a simple allometric model :

$$(3) \quad g(w) = Hw^{1-m} \quad ; \quad m \approx 1/4$$

The biomass spectrum becomes

$$(4) \quad \ln b(w) = \text{constant} + m \ln w - H^{-1} \int w^{m-1} Z(w) dw$$



$$(5) \quad \text{slope}_{\text{bio}}(w) = m - H^{-1}w^m Z(w)$$

Hence, the biomass spectrum becomes a straight line only if the rate of total mortality is proportional to  $w^m$ , i.e. to  $G(w) = g(w)/w$ , the specific or instantaneous rate of growth.

#### Constant rate of total mortality

If mortality is considered constant as in classical fish population dynamics,  $Z = F + M$ , the result is a convex biomass spectrum (Figure 8.5.2.1) because the slope decreases with increasing size:

$$(6) \quad \ln b(w) = \text{constant} + m \ln w - (F+M)/Hm * w^m$$

$$(7) \quad \text{slope}_{\text{bio}}(w) = m - (F+M)w^m/H \quad ; \quad m \approx 1/4$$

The absolute value of the first term will increase by a factor of more than 3 when the weight increases by a factor of 100.

The absolute values of the slope of the spectrum at a specific size, that are obtained in the new steady states as the fishing mortality progressively increases, are also increasing. These considerations strictly deal with equilibrium situations and not with the more interesting situations of transient behavior. The rate of recruitment is also considered constant independently of the fishing effort. Finally, natural mortality is considered constant at any size which in general is inconsistent with the size-specific rate of food consumption implied by the allometric growth model.

#### Predation mortality in non-exploited systems

The rate of food consumption underlying allometric growth is:

$$(8) \quad i(w) = hw^{1-m} \quad ; \quad e = g(w)/i(w) = h/H$$

where  $e$  denotes the gross production efficiency. Assuming that a predator eats prey of a specific fraction,  $1/p$ , of its own size (e.g. Ursin 1973) and the spectrum can be described by a straight line (i.e. allometric density models) then it follows from mass balance (Peterson and Wroblewski 1984 and Beyer 1989 Ex. 10) that the predation mortality is proportional to the specific rate of food consumption (Figure 8.5.2.2):

$$(9) \quad M_2(w) = qw^{-m} \quad ; \quad e q/H = p^{1-q/H}$$

The biomass spectrum becomes a straight line:

$$(10) \quad \ln b(w) = \text{constant} + (m - q/H) \ln w$$

$$(11) \quad \text{slope}_{\text{bio}} = m - q/H$$

Note in particular that it is  $q/H$ , the instantaneous rate ratio of mortality to growth that determines the slope of the spectrum in steady state. This ratio is determined from the transient equation of mass balance given in Eq. (9):  $e \cdot \text{ratio} = p^{1-\text{ratio}}$ .

As an example, let the ratio of predator weight to prey weight be 1000 (i.e.  $p = 1000$ ) and the gross production efficiency 10% (i.e.  $e = .1$ ). The slope of the biomass spectrum becomes  $m - q/H \approx 0.25 - 1.30 = -1.05$ . The absolute value of the slope is thus a little more than one in agreement with Sheldon's findings that the biomass in log-weight classes should decrease slightly. A predator-prey weight ratio of  $p=100$  is perhaps more representative than  $p=1000$  for many predators. If  $p=100$  then  $q/H=1.42$  (assuming a gross production efficiency of 10%) and the slope of the biomass spectrum becomes  $-1.17$ .

It may be noted that the result of a predation mortality proportional to the specific rate of food consumption still is valid when the predator select prey according to a log-normal suitability (Beyer 1990, Appendix 1).

#### Predation mortality in exploited systems

If the total mortality has the form

$$(12) \quad Z(w) = F + M_1 + M_2(w)$$

the predation mortality is specified by

$$(13) \quad M_2(w) = b(pw)/b(w) * p^{1-m} w^{-mh}$$

and the equation for the biomass spectrum,

$$(14) \quad \ln b(w) = \text{constant} + m \ln w - (M_1 + F)/Hm w^m - \int M_2(w)/(Hw^{1-m}) dw$$

$$(15) \quad \text{slope}_{\text{BIO}}(w) = m - w^m(M_1 + F)/H - h/H * p^{1-m} b(pw)/b(w)$$

It is not a trivial matter to solve Eqs (13) and (14). The ratio of biomass densities and, hence, the predation mortality become a function of all the parameters involved:

$$b(pw)/b(w) = f(w; p, M_1, F, H, h, m) = a_0 + a_1 w^{b_1} + \dots ?$$

This problem of computing the density arises the moment other causes of mortality than predation are introduced. The fishing mortality and other-causes natural mortality may be described in

any way (through eg power functions). The major problem is how to deal with the b-ratio in the integral. When this problem is solved the slope can be obtained directly from Eq (14).

### 8.5.3 Utility and Perspectives for Research

The main benefits from utilizing spectrum theory in multispecies modelling are that the dynamics of a complex system can be described through comparatively few parameters and that the system is described in a consistent way in terms of vital rates and mass balance.

Spectrum theory can serve as a means of formulating research hypothesis concerning the shape of the spectra in different systems with different vital rates, predation functions and exploitation patterns. The relative simplicity (few parameters) of the description of spectra makes such intersystem comparisons possible. It is similarly possible to use the shape of the spectrum to monitor changes in a system as exploitation patterns are changed or other external forces such as environmental degradation are changing the system. The latter comparisons can, though, not be made on basis of the steady state theory presented here.

In connection with the MSVPA data spectrum theory can be used to check internal consistency and consequences on a systems level of alternative hypothesis concerning essential submodels (ration, preferences, compensatory changes in preference and growth etc.).

A first step is to formulate a hypothesis concerning the shape of the spectrum to be expected on basis of the input parameters and certain results from the MSVPA : recruitment, weight at age, food rations, fishing patterns,  $M_2$ 's,  $M_1$ 's, suitabilities. The basic parameters :  $H$ ,  $h$ ,  $m$ ,  $p$  (as  $\mu$  and  $\sigma$ ) can be estimated on basis of these parameters. The internal consistency of the MSVPA in terms of vital rates and mass balance can then be checked by comparing the expected spectrum with the spectrum produced as number and biomass density output from the MSVPA.

The next step could be to go back into stomach data as they are available originally, on a size class basis, and similarly size distributions of predators and prey in the sea from survey data. This kind of data is needed both to overcome the problems when using data from an age-structured model such as MSVPA that sizes are derived from age which means that interval sizes are decreasing with size on a linear scale. Size data are also needed in order to be able to work with proper size distributions at age which is essential for approximations to a continuous model.

Once the proper orders of magnitude for all parameters have been established the spectrum model can be used as a tool for studying possible compensatory mechanisms in the model such as changes in suitabilities or growth rates with changing slope.

The overall strategy for this size-based model development is that there is no need to complicate things more than necessary. However, the spectrum approach do offer a great variety of possible extensions and elaborations. One may, for example, separately consider pelagic and demersal systems or other effects of spatial distributions in the sea. Animals of the same size may further be classified into entities based on development stages (eg juvenile and adults), predation strategy, taxa, age or whatever is appropriate for the objective of study. The size spectrum may be extended at both ends to cover mammals as well as invertebrates etc. The lacking applicability to elucidating systems dynamics clearly constitutes an important limitation of steady state considerations. The study of transient behavior and its relation to inferring the flow structures among the size classes based on MSVPA and survey data (and other time series of psd's (particle size distributions) at given locations (Platt et.al. 1981)) is a promising field of research. The important point from a modelling point of view is that whether ecological psd theory is used to describe cohorts, populations or communities and irrespectively of the level of complexity, the beginning point is the same and well defined: the quantification of the vital rates at the individual level.

#### 8.5.4 Applications of Spectrum Theory Using MSVPA Data

Biomass spectrum and the relation between weight and vital rates has been calculated and is presented in Figures 8.5.4.1-8.5.4.6. Averages by size class have been calculated as mean values of species/age groups at size weighted by stock numbers. The growth rate is calculated as weight difference between size groups divided by difference in mean age.

The biomass spectrum has an overall slope of -1.25, but is not strictly linear. Power relations have been calculated by nonlinear regression and results are presented on the figures where pertinent for subsequent calculations.

As an approximation to the North Sea situation F has been assumed to be 0.5 /yr and M1 0.2 /yr for all sizes. Predation mortality is

$$M2 = 1.108 * W^{-0.251} \text{ /yr} \quad ; \quad Q = 1.08$$

and growth :

$$g(w) = 4.08 * W^{0.666} \text{ g/yr} \quad ; \quad H = 4.08, m = 0.33$$

p increases from about 100 (W=10 g) to 2000 (w= 10kg). This increase may be artificial due to the non-inclusion of other food in the size model. This introduces a systematic bias in the lower end of the predator range.

Using Eq (15) in sect. 8.5.2 in an approximation with  $m=1/3$ ,

$H=4.08$ ,  $h/H \approx 10$ ,  $M1+F=0.7$  and  $b(w) \approx W^{1.25}$ :

$$\text{slope}_{\text{BIO}}(W) = 0.33 - 0.172 * W^{0.33} - 10p^{-0.58}$$

This gives a slope of  $-0.73$  for  $W=10$  g and  $p=100$  and a slope of  $-1.53$  for  $W=1000$ g and  $p=1000$ . This is in good accordance with the increasing slope and the increase in  $p$  seen in Figures 8.5.4.1. and 8.5.4.6.

If  $M1+F$  was to be disregarded ( $=0$ ) then we would expect a linear spectrum with slope  $m-q/H = 0.33-0.272 = 0.05!$  This indicates the importance of including  $M1$  and  $F$  : we can not expect the slope to be constant by size and the results of the MSVPA do make sense when utilized in a spectrum context. These explorations are indicative, but more thorough work is needed before definite conclusions of balance in the MSVPA data can be drawn.

### 8.6 Analyses of Consumption Estimates and Models in MSVPA

The estimates of quarterly consumption per individual predator age have not been changed since the Working Group meeting in 1986 (Anon. 1987). The quarterly rations for the gadoid predators used since 1986 were mainly based on the results presented in the Report of the Meeting of the Coordinators of the Stomach Sampling Project 1981 (Anon. 1984b). For cod, whiting and haddock a modified version of the Daan's model had been applied, whereas consumption estimates of saithe and mackerel were based on an exponential stomach evacuation model. In recent years several experiments have been conducted with cod (Bromley 1991, dos Santos 1990) and whiting (Bromley 1988, Robb 1990) and the discussion about the most adequate evacuation/consumption-model (Daan-type, linear, "general" or exponential) is still going on.

The model presently applied to the gadoid predators and its parameters are briefly reviewed at the beginning of this section since some part of this information was not included in the Working Group's reports so far. Secondly, some implications of the choice of a certain model and the choice of certain parameter estimates from different investigations on the resulting consumption estimates of cod and whiting are outlined.

#### Model presently applied to gadoid predators :

$$C = A * W^{2/3}$$

$$A = \frac{91 * 2 * \phi}{\delta o * e^{0.096(T_o-T)} * q^{2/3}}$$

$C$  = quarterly Consumption per individual  
 $W$  = weight of predator in the quarter  
 $91$  = days per quarter  
 $2$  = constant from Daan's original model  
 $\phi$  = feeding level

from  $S = \phi * L^3$   
 with  $S$  = mean stomach  
 content  
 and  $L$  = length

$\delta_0$  = constant from Daan's model relating digestion time (D) with the length of the fish (L) according to:

$$D = \delta_0 * L \quad \text{or} \quad \delta_0 = D/L$$

$T_0$  = temperature of the experiments from which D and  $\delta_0$  were derived;

T = mean temperature in the quarter considered (see Anon 1987);

q = constant from the length-weight-relationship with length cubed;

0.096 = constant from Ursin et al. (1985).

The following parameters had been chosen:

Cod : all parameters from Daan (1973),  $\phi$ -values given in Anon (1987)

Whiting : parameters were derived from experiments presented in Hislop et al. (1983) :

L-mean = 33.5cm (midpoint of range)

D = 2.5 days

$T_0$  = 11.5°C (midpoint of range)

$\delta_0$  = 0.0746

Haddock : A-values for haddock were chosen somewhat below those for whiting assuming that haddock is more sluggish than whiting. The A-value of the third quarter had been taken as 86% of that for whiting. The A-values for the other quarters had been derived from this value correcting for the temperature deviation between quarters.

#### Implications of Model Type and Key Parameters on Consumption Estimates

Table 8.6.1 summarizes some of the properties of consumption models being currently in the discussion. The major implication of the choice of a certain theoretical model is the dependency of consumption on predator size, which is partly predetermined by the model.

As far as only the effect of stomach content on consumption is considered, the Daan model and the exponential model imply the strongest increase of predation with predator size. It is, however, assumed in all cases that the stomach content increases in proportion to the predator weight (or length cubed), following Daan (1973).

For the Daan model, however, as a part of the theory the digestion time increases linearly with length of the fish, giving an overall proportionality of consumption to the length squared. The size effect of the general model depends on the choice of the power  $b$ , which is either made by experiments (Jones 1974) or by physiological considerations (see Jobling 1981).

The overall size effect based on four different studies (see Table 8.6.1) shows a variation of the power ranging from 1.8 to 4.6. If the experimental meal size in dos Santos work is kept in a fixed proportion of the predator weight, however, the power reduces to 3. In Bromley's model the number of empty stomachs in the field data has to be considered, which might show a trend with length of the fish (In the North Sea cod data it decreases with length in the 2nd and 4th quarter).

In all approaches evacuation/consumption is assumed to be an exponential function of temperature, with instantaneous coefficients ranging from 0.081 to 0.11. The currently used value (0.096) is actually the arithmetic mean of several independent estimates including Jones's 0.081 and also values obtained from other species like flounder and trout (Ursin et al. 1985). The mean is remarkably close to dos Santos's estimate.

The effect of temperature on the estimated food consumption is considerable. The present version uses different temperatures for particular species and quarters referring to the mean temperature in the distribution area of the individual species. An overall increase in temperature in all quarters of  $1^{\circ}\text{C}$  leads to a 10% increase of consumption ( $2^{\circ}\text{C} \rightarrow 21\%$ ).

The type of food also has a strong effect on the estimated consumption. The digestion constants obtained from dos Santos (1990) vary by a factor of 2.6. The estimated consumption will vary by the same factor depending on the constant chosen, all other parameters (stomach content, temperature etc) being constant.

In some models, e.g. dos Santos (1990), the experimental meal size is treated as a parameter of the digestion model. This parameter becomes a problem, when the digestion model is used for the estimation of consumption, since it can hardly be related to something observable in the field. Meal size also cannot be related to a time scale, since it refers to one particular experiment, whatever the duration of evacuation has been. It has, however, a strong impact on the estimated consumption. Doubling the meal size in dos Santos's model raises the estimated consumption by a factor of 1.5.

#### Problems in the Whiting Digestion Data Currently Used:

It was demonstrated in Bromley's (1988) and Robb's (1990) studies on whiting evacuation, that the evacuation time increases strongly with increasing meal size. An extreme example from Robb's work might illustrate this: A fish of 17cm needs 11.3 days at  $7^{\circ}\text{C}$  to

empty its stomach, when fed 12 times the average stomach content observed in the sea (in 1981).

A more realistic digestion constant for whiting can be derived from an experiment, in which the initial meal size equals approximately the daily ration in the field, if it is further assumed that the daily ration should not exceed 3% of the predator weight. The daily ration can be estimated using Daan's model and the stomach content data from the 1981 sampling program. From the experiments of Jones (1974) and Bromley (1988) the following data combination can be derived, which closely matches these conditions:

$D = 1.1$  days,  $L = 22$ cm,  $T = 10.6^{\circ}\text{C}$ ,  $\delta o = 0.045$

These parameters nearly double the calculated consumption.

#### Problems in the Whiting Stomach Data Currently Used:

For the years 1985, 1986 and 1987 additional stomachs of whiting have been sampled, mainly during the first and third quarter (Figures 8.6.1 and 8.6.2). In these three years the average stomach contents of almost all age groups were significantly higher than in 1981: about 2 times in I/1985 and I/1987 and about 2.5 times in I/1986. From these results it appears, that either the 1981 (and 1986?) data were exceptional, or that the stomach content level varies considerably from year to year.

Higher stomach content levels raise the consumption estimates proportionally in case of the exponential and the Daan model. If a higher level of stomach content shall be introduced into the calculations of whiting consumption, the approximation of  $\delta o$  ( $=0.045$ , see above) has to be revised, since it depends on the 1981 stomach content level. For two reasons it was decided to apply the estimate of  $\delta o$  ( $=0.06$ ) from Daan's experiments with cod also for whiting: 1) this estimate does not refer to a certain experimental meal size, since it is based on a multiple meal experiment 2) the treatment of cod and whiting remains consistent.

#### Alternative Scenarios for the Estimation Consumption of Cod and Whiting:

Some of the new experimental results for cod and whiting have been applied to the 1981 stomach content data, to assess the impact of different parameter estimates and models on the yearly consumption by age group. For whiting also the effect of a higher stomach content level (1987) was studied.

##### Cod scenarios:

- "Bromley" : based on results in Bromley (1991); food type sprat; predator size correction from Bromley (1991); correction for empty stomachs according to data in Daan (1989); temperature correction based on Anon. (1987).



- "dos Santos" : Consumption based on exponential evacuation model and parameter estimates from dos Santos (1990), stomach content levels (mean values) as in key run (1981 data) smoothed according to Anon. (1987), food type: mixture of krill (25%) prawn (25%) herring (25%) and capelin (25%), Meal size twice the average stomach content in the sea; temperature correction from dos Santos (1990)

#### Whiting scenarios:

- "1987" : Consumption calculated with Daan's method; digestion parameters as estimated for cod fed with multiple meals (it is assumed that whiting and cod of the same size have the same evacuation time) based on Daan (1973); stomach content level in first and third quarter based on 1987 data, values for the second and fourth quarter were adjusted in proportion to the relative differences between quarters in 1981.

- "Jones" : Consumption based on method and parameter estimates of Jones (1974), stomach content levels (mean values) as in option "1987"; results are biased (overestimated), since the average stomach content is raised to the power (0.51) instead of raising the individual stomach content values to the power before averaging.

As can be expected from the theoretical considerations above, the main differences between the different models concern the rate of increase of consumption per fish with age (Figures 8.6.3 and 8.6.4). The dos Santos model for cod and the Jones model for whiting predict the steepest increases. Both models predict higher consumption for large predators and lower consumption for small predators, when compared with the presently used Daan model. The slope of the Bromley model is very similar to that of the Daan model, although the theory predicts a more gentle increase of consumption with age for the Bromley model. This is explained with a decreasing fraction of empty stomachs in three quarters of the year. Consumption levels are not directly comparable between the scenarios, since the food types and feeding regimes vary between the studies. Daan fed multiple alternating meals of sprat and Crangon, Bromley used single meals of sprat, dos Santos gave single meals of different fish and crustacean species.

The main deviations between different models, however, occur beyond the size range, which is covered with experiments: in the three studies on cod considered here, fish size varied between 30 and 66cm. This corresponds to ages 2 and 3 at the beginning of the year or ages 1 and 2 at the end of the year.

The whiting data are limited, in the experiments of Hislop et al. (1983) and Bromley (1988) only a single size group (27-40cm and 28cm resp.) was used, Jones's experiments were mainly carried out with haddock, ranging from 14 to 40 cm. This size range would be sufficient for whiting, but is doubtful, whether digestion parameters of mainly benthos feeding haddock are representative for

whiting, which prefers fish prey.

### Conclusions and Recommendations for Further Experiments:

It can be concluded that the temperature effect is quite thoroughly investigated and future research should focus on other aspects like predator size, food type and feeding regime. Experiments should preferably be designed in order to relate average stomach content and food intake directly.

## 9 SAMPLING STRATEGIES FOR THE 1991 "YEAR OF THE STOMACH" PROGRAM

The Working Group addressed several aspects of the sampling strategy to be followed in the 1991 program, which had remained unresolved during the meeting of the Planning Group in 1989 (Anon. 1989b) because they required a more extensive discussion from the theoretical point of view. This section provides the necessary feedback to the coordinators of the program so that a final manual can be drawn up in early January 1991 (Anon. 1990g; Appendices A and B).

### 9.1 Bulked vs Individual Stomach Samples

The advantages and disadvantages of sampling strategies aimed at individual or grouped stomachs are well understood. Both the collection of individual stomachs on board and the analysis of individual stomachs in the laboratory are consuming vastly more time than when samples are grouped. In contrast, the detailed information provided by individual stomachs is potentially more useful than the average figures obtained from grouped samples, because such data can be used to analyze the sampling variances and the associated uncertainty in the consumption data. In addition, some stomach evacuation models may require estimates of the distribution of stomach content weights among individuals. However, despite frequent pleas for individual stomach content data and the availability of several data sets for e.g. whiting, saithe and cod, so far very little use has been made from such data to evaluate the inherent variances and distributional properties. This is a pity, because in that case the appropriate sampling scheme might be better evaluated.

One obvious reason for changing to individual stomach content sampling during the 1991 program would be if such information could be transformed into an estimate of the uncertainty related to the predation part of the MSVPA. However, in that case one runs into similar problems as when trying to estimate uncertainty related to the catch at age part of the VPA. Uncertainty enters the calculations at different levels and in different forms. E.g., food consumption data are calculated on the basis of weighing factors for individual samples, which are based on catch rates during trawl surveys, and at some stage information by size class is transformed into information by age class by means of ALK's. At each of these

steps new uncertainty is introduced and at present, there seems no model available by which the variation in individual stomachs could be integrated into an evaluation of uncertainty related to the input for MSVPA. Probably, such information would rather be used in a more qualitative study of some sampling problems related to feeding studies and one can argue that there is no need to integrate such studies with the program proposed for 1991, which already draws very heavily upon the available resources and should not be unnecessarily overloaded.

Therefore, the WG decided that the strategy of taking grouped samples should be sustained in 1991. This is not to say that it would not be useful to collect additional data sets on an individual basis, when that would be feasible, and such studies should certainly be encouraged. In addition, more effort should be put into evaluating the existing data sets (see proposed terms of reference for the next Working Group meeting).

An important aspect of the problem of computing the variance of stomach content and feeding level is the fact that stomach samples derived from research vessel or commercial vessels are not simple random samples, but rather represent cluster samples, stratified by the sampling design (Cochran 1977). In a stratified cluster sample, the individuals selected for sampling may not be representative of the population as a whole, as in simple or stratified random sampling. For example, stomach sampling is usually stratified by a number of variables such as region, season, predator size and time of day. The fish selected for stomach sampling may not be truly random samples since sampling quotas (by the above stratification variables) may be filled when a large 'cluster' of fish is encountered. The correlations among individuals within a cluster may impart significant sampling bias. For example, the similarity of prey composition between individuals taken in the same trawl tow is probably much greater than between individuals from adjacent trawl tows. How the total sample is selected is critical to the actual biases imparted by the clustering effect.

The variance of a parameter estimated by single stage cluster sampling with equal sized clusters is given by:

$$V(X_{cl}) \approx \{[(1-f)S^2]/nM\}\{1 + (M-1)\rho\}$$

Where;

- M = Number of Clusters in Population
- n = Number of Clusters Sampled
- S<sup>2</sup> = Finite Population Correction
- ρ = Intracluster Correlation Coefficient

Note that variance increases as intracluster correlation increases and that variance will be underestimated if intracluster correlation is ignored. If intracluster correlation is moderate to high, it is more efficient to draw more samples and sample fewer

fish per haul. Little information is gained by intensive sampling at any site where intracluster correlation is high. The actual design of stomach sampling programs is more complicated than the simple case described above, due to (1) unequal-sized clusters, (2) M is unknown and must be estimated, (3) the usual design is a 2 Stage Cluster Sample (e.g., clustering of tows, and fish within tows), and (4) a ratio estimator (biased) is required if individual stomachs not identified (as in the 1981 and 1991 North Sea studies).

Because of possible cluster correlation between the stomach contents of individuals within hauls, a general strategy to take smaller samples from more hauls would seem advantageous. However, since the number of stations fished is fixed by other requirements and since all hauls are sampled, this is not a realistic option to improve data collection in the North Sea program. It was agreed that a basic sample size of 10 fish per size class, with adjustments for certain cases where total sampling intensity is likely to exceed or remain considerably below the overall target, should be maintained (Appendix A; Anon. 1990g). Issues concerning the variances of stomach sampling data are included as proposed terms of reference for the next WG meeting (see Recommendations).

## 9.2 0-Group Predators and Prey

The inclusion of a part of the western stock of mackerel in the MSVPA for the North Sea (see sections 2.9.2 and 2.9.4) clearly demonstrates the need for additional data on predation by adult fish on 0-groups in the 3rd and 4th quarters. According to the available data western mackerel in some years accounts for up to one half of the total fish predation in weight (section 2.9.2). During the 1991 sampling program, stomachs will mainly be collected during bottom trawl surveys and no effort has beforehand been allocated to sampling pelagic fish predators such as mackerel, horse mackerel, herring etc. by pelagic trawling. No specific program for sampling of the 0-group phase has been planned, although there are at least two research vessels that will undertake such research, so far. If a better understanding of the role of predation on 0-groups in quarters 3 and 4 is to be achieved it will be necessary to collect such samples. It is therefore recommended that stomachs samples and information on the spatial distribution of pelagic species and 0-groups should be collected during the joint acoustic summer survey in the North Sea. The procedures for collecting these samples should be agreed upon at the forthcoming meeting of the stomach sample coordinators.

In addition it should be considered to make special studies with the purpose of investigating whether there are differences in the food composition of predators caught by in the water column by pelagic trawl and close to the bottom by bottom trawl.

In order to study the importance of predation and cannibalism among 0-groups special surveys should be designed. As it will be impossible to reach an areal coverage which will allow the results

to be used to quantify the processes on an overall North Sea scale the surveys should concentrate on improving the understanding of the processes rather than on collecting data for direct use in existing models.

## 10. CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

(1) The consequences of fishing large quantities of prey species on other North Sea fisheries were evaluated in the context of large changes in fishing effort (+50%) for all eight of the nominal North Sea fleets. Although the results of equilibrium long-term predictions at such extreme changes from status quo effort levels are speculative, it is, nevertheless, instructive to evaluate the relative directionality in fishery yields of such scenarios. A 50% increase in fishing effort in the Industrial Demersal Fishery (targeting sandeel and Norway Pout) is predicted to result in substantial increases in total system yields in weight (+6% for MSFOR and +23% for the Shepherd Model), but insignificant changes in total system value (-1% and +2%, respectively). SSBs for Norway pout, sandeel and whiting will decline substantially. If there are positive stock-recruitment relationships for Norway pout and sandeel, then the scenario could potentially result in lower long-term yields of Norway pout and sandeel, as well as for cod, whiting, and haddock, and total system yield in weight and value.

(2) The incorporation of parametric stock-recruitment relationships in the multispecies forecasting procedure (MSFOR) results in significant differences in the time trajectories and levels of stock biomasses, recruitment and yields to North Sea Fish Stocks as compared to using long-term average recruitment levels, or correlated species recruitments. For stocks such as cod and sprat, currently having average recruitment levels above the long-term mean, the parametric S/R relationships result in lower average predicted SSBs. For stocks, such as herring, that have increased greatly in abundance following stock collapse, inclusion of the S/R relation in model predictions results in higher long-term predictions of SSB than using long-term means.

(3) The MSFOR prediction model has been used, in conjunction with long-term average recruitment estimates, to forecast consumption by MSVPA predators in the North Sea during 1991. Predictions for 1991 differ, in some cases quite dramatically, from food composition estimates for previous years, due to the changing status of important prey resources (e.g. herring) and associated predator stock sizes. These predictions will be evaluated against feeding data collected in the intensive 1991 'Year of the Stomach' project, and serve as a test of the utility of the method for making short-term predictions. The robustness of these predictions will be evaluated in future MSWG meetings.

- (4) Studies conducted at this meeting of the Multispecies Working Group substantiate the assumption of the relative constancy of the suitability of prey species/age groups to predators, not only in the North Sea System, but in the Baltic as well. Models predicting prey species consumption by predators are statistically significant, explaining about a half of the total variance in the case of the North Sea, and substantially more in the Baltic. The remaining sources of model variance probably lie in the variability in the basic feeding data, and the assumptions of a uniform spatial dimension in the MSVPA.
- (5) Several analyses were undertaken to evaluate the effects of various assumed digestion models on consumption levels used in MSVPA. Example calculations for whiting indicate substantial differences in total consumption (ration), depending on the year of data used (1981 vs. 1987), and gastric evacuation model. There is a need to resolve these differences, and in some cases, to conduct additional experiments to estimate appropriate ration levels for MSVPA.
- (6) There were significant correlations among species in the matrix of annual recruitment values produced by MSVPA. Positively correlated species are obviously responding in a similar fashion to environmental variability, the influence of spawning stock biomass, or predation mortalities. Negative correlations among species perhaps indicate predation effects. In general, the effect of preserving the correlation between species recruitments in long-term forecasts is to increase the amount of correlation between the catch of individual species and fleets above the level of correlation generated by predation effects alone.
- (7) Statistical analyses of the influence of prey (capelin) biomass, cod stock size and temperature on the growth rates of cod were undertaken for four Boreal/Arctic ecosystems. No single model was obtained for explaining cod growth across the Boreal/Arctic fishery ecosystems evaluated.
- (8) There were significant residual YEAR effects remaining after accounting for cod growth variations due to prey, temperature and cod stock size fluctuations in the Boreal/Arctic systems. Although some results are sensitive to variability of input data, these conclusions imply that either the data sets do not contain adequate descriptions of these variables as they relate to cod growth, or there are other, yet unexplained, factors influencing measured cod growth in Boreal/Arctic ecosystems.
- (9) In all areas the variances of total stomach content and species composition of food habits are not well understood, but are of considerable importance in evaluating sources of error in feeding model performance. These aspects were beyond the scope of this meeting, but are considered a priority for future analyses of the MSWG.
- (10) The extension of MSVPA to consider predation on 0-group fish

younger than six months is complicated by the growth dynamics of these young fish (i.e., rapid growth and death rates). This requires either a time step significantly shorter than quarterly (as in the current MSVPA), or the use of size-based growth and mortality dynamics in the earliest phase. The meeting considered several potential approaches for dealing with this matter, and the adequacy of size-based data for the young fish. It was agreed that extending our understanding of predation influences on recruitment dynamics to younger fish, by adaptation of the MSVPA was a worthwhile goal. However, current data bases (sampling of 0-group fish in stomachs by fine-scale length increment) was currently inadequate. Further, there are probably many 0-group predators that will not be sampled in the 1991 'year of the stomach' program. It was agreed that development of hybrid age-size, and fully sized-based versions of MSVPA should be pursued, and in the short term, that such models could be validated with size/age data for age 1 fish.

(11) The Working Group considered three time series of multispecies size compositions from research vessel sampling. Although each area (Grand Banks of Newfoundland, North Sea, Georges Bank) exhibited characteristic signals in the slope of the log-numbers at length (multispecies size compositions), the slopes generally differed greatly between systems. It was concluded that although multispecies size compositions do not in themselves yield results that are easily interpretable as indices of multispecies interactions, they do provide a basis for generating testable hypotheses for mechanisms accounting for the observed patterns. Further elucidation of these mechanisms leads to a new set of size-based models, some of which were examined by the Working Group.

(12) The use of stable isotope methods based on collections of hard parts from archival samples is considered to be a promising method for evaluating large-scale changes in trophic systems (such as the variable proportion of 'other food' in fish predator stomachs) and perhaps as an external check on the adequacy of integrated stomach sampling programs. Laboratories maintaining archival collections of fish scales and otoliths are encouraged to make such data available for cooperative studies to evaluate the efficacy of the method, and its use in comparative ecosystem studies.

(13) The ability to incorporate the effects of 'external' predators (e.g., rays, seabirds, marine mammals, etc.) on the MSVPA system is critically dependent on the quality of estimates of predator abundance and average consumption, over the period of interest. Although some general calculations on the relative importance of such predators can be derived from thermodynamic (energy) properties, these calculations are not a substitute for those based on synoptic evaluations of feeding frequency, diet composition and predator abundance. The evaluation of the significance of predation by these species ultimately will depend on obtaining such data. Organizations interested in evaluating interactions among these components and fisheries are encouraged to develop data collection programs that will produce these estimates, at an

adequate level of precision and spatial disaggregation.

### Recommendations

- (1) An important result emerging from the analysis of cod growth is that even when cod abundance, prey density and temperature were considered as independent variables, a significant YEAR effect remained unexplained in most areas. Possibly, the measurements of prey abundance and temperature do not adequately describe the prey stock availability to the cod or the average temperature which influences the stock. Clearly, more research on these topics is warranted. These results are specifically referred to the Study Group on Cod Stock Fluctuations (Hamburg, 16-18 April, 1991) for consideration in developing long-term data sets for the Cod and Climate program, and as a general model for such studies.
- (2) Evaluations of alternative digestion models, data and temperature corrections indicate the need to reconcile the very different consumption estimates resulting for some predators in the MSVPA. Given the sensitivity of some MSVPA calculations (including age/size effects) to digestion models chosen, researchers involved in such studies are encouraged to conduct analyses under a wide range of predator sizes and conditions of meal size and frequency, and temperature conditions likely to be encountered in the field. These experiments are considered vital to the calibration of the MSVPA method.
- (3) The stomach sampling program for the North Sea in 1991 should, to the extent practicable, maintain methods comparable with those used in 1981. Additional sampling effort should be directed at extending sampling to pelagic predators such as mackerel and horse mackerel. Research is particularly encouraged on the topics of (a) obtaining individual stomach data for the purposes of developing measures of variability, and (b) studies of within 0-group predation and cannibalism in the pelagic phase as extensions of recruitment research in the North Sea.
- (4) Based on the results of the Special Meeting of the Multispecies Working Group held in Bergen (Anon. 1990a), and this meeting, it is clear that further analysis of existing feeding data bases are needed in order to evaluate the statistical properties of estimates of total ration and species composition of diets. Such analyses are proposed for the next meeting of the Multispecies Working Group (see below), but an efficient analysis of such factors will require substantial pre-processing of existing feeding data. Therefore, it is recommended that a three-day Study Group be convened, at a time and place to be agreed, for the purpose of deciding upon common data-base formats and appropriate software to expedite such analyses at the next meeting of the Multispecies Working Group.
- (5) The next meeting of the Multispecies Working Group should be convened in 18 months time (June, 1992) with suggested terms of



reference to include:

(a) continue the development of multispecies methods of assessment;

(b) evaluate the statistical properties of food and feeding data, with particular reference to variability in total food consumption and species composition and emphasizing the potential implications on such estimates of sampling design. Such analyses should be undertaken for the diversity of ecosystems currently being studied by ICES member countries;

(c) Consider the importance of and strategies for explicitly including spatial effects in multispecies/multifleet assessment models;

(d) evaluate the effect of alternative functional feeding relationships (include predator/prey switching) on multispecies retrospective analyses and predictive models;

(e) conduct evaluations of the multispecies/multifleet implications of management scenarios, as requested by ACFM.

(6) Contingent on the full implementation of the new computer facilities, the venue of the next meeting of the Multispecies Working Group is recommended to be the ICES Headquarters.

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Table 2.7.1a. Output from MSVPA 'Key Run' for cod.

FISHING MORTALITY		COD								
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
1	0.0849	0.1443	0.0583	0.2297	0.1169	0.1874	0.1526	0.1648	0.2489	
2	0.8232	0.7620	0.9777	0.8617	1.0642	0.8384	0.9026	1.0109	0.9528	
3	0.7227	0.8045	0.8611	0.7256	0.9515	0.9290	0.9340	0.9705	1.2308	
4	0.7090	0.6647	0.8004	0.5828	0.8109	0.5376	0.7314	0.7204	0.7822	
5	0.7119	0.7908	0.6128	0.5707	0.9616	0.7341	0.5716	0.6791	0.7777	
6	0.7030	0.6803	0.9125	0.4547	0.7490	0.5437	0.6006	0.6426	0.8429	
7	0.6559	0.7473	0.8659	0.5549	0.7347	0.6595	0.7195	0.7286	0.6895	
8	0.7221	0.5414	0.4969	0.6117	0.8708	0.5083	0.7091	0.6326	0.7229	
9	1.1287	0.9462	0.4604	0.5342	1.0076	0.7728	0.6285	0.6881	0.6889	
10	0.6956	0.9239	0.9486	0.3930	0.7991	0.7382	0.7010	0.6972	0.5803	
11	0.6000	0.6002	0.6002	0.6002	0.8013	0.6334	1.1465	0.2155	0.9520	
MEAN F (UNWEIGHTED) FOR AGES 2 TO 8										
	0.7211	0.7130	0.7896	0.6232	0.8775	0.6787	0.7384	0.7692	0.8570	

FISHING MORTALITY		COD						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
1	0.1661	0.2331	0.1501	0.2189	0.1591	0.1666	0.1244	
2	1.0738	0.9802	0.9858	0.8393	0.8775	0.8266	0.6066	
3	1.1524	0.9773	0.9175	1.1302	0.7650	1.0943	0.7836	
4	0.8534	0.7347	0.8256	0.9052	0.8954	1.0388	0.7843	
5	0.7756	0.7104	0.7146	0.8173	0.7058	0.8054	1.0103	
6	0.7773	0.7509	0.6909	0.9319	0.8254	0.8493	0.8063	
7	0.7147	0.7478	0.7318	0.8806	0.9291	0.6581	0.8283	
8	0.7248	0.8125	0.8228	0.9614	0.8980	0.8876	0.6313	
9	0.5950	0.8319	0.6580	0.6749	1.0962	0.5737	0.9413	
10	0.5203	0.9318	0.4289	1.1788	1.1538	0.7110	0.5933	
11	0.5592	0.9567	0.9504	0.2490	0.7490	2.2243	0.8002	
MEAN F (UNWEIGHTED) FOR AGES 2 TO 8								
	0.8674	0.8163	0.8127	0.9237	0.8423	0.8800	0.7787	

Mortality of 0-group is for 3rd and 4th quarter only  
 NORTH SEA DATA 1974 - 1989 (MULTISPECIES WORKING GROUP 1990)  
 WITH STOMACH CONTENT DATA FOR COD, WHITING, MACKEREL, SAITHE AND HADDOCK  
 MULTISPECIES VPA

STOCK NUMBERS		COD								
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	
0	0.	0.	0.	0.	0.	0.	0.	0.	0.	
1	301295.	455083.	216581.	819773.	498675.	512712.	1033451.	397202.	654332.	
2	122397.	111025.	178802.	91433.	289571.	180010.	175738.	357852.	117794.	
3	24064.	34697.	35443.	46797.	26537.	68345.	53354.	48671.	86407.	
4	32031.	8405.	11887.	11535.	17321.	7775.	20766.	15856.	13810.	
5	9434.	12907.	3540.	4371.	5273.	6303.	3718.	8182.	6317.	
6	1993.	3790.	4792.	1570.	2022.	1650.	2477.	1719.	3397.	
7	948.	808.	1572.	1575.	816.	783.	785.	1112.	740.	
8	793.	403.	313.	541.	740.	320.	331.	313.	439.	
9	514.	316.	192.	156.	240.	254.	158.	134.	136.	
10	164.	136.	100.	99.	75.	72.	96.	69.	55.	
11	433.	121.	80.	58.	87.	49.	38.	115.	41.	
TOTAL STOCK BIOMASS ON 1. JANUARY										
	326852.	286501.	285834.	264072.	354909.	321595.	357853.	428080.	353066.	
SPAWNING STOCK BIOMASS ON 1. JANUARY										
	169050.	141636.	118048.	99707.	114236.	102727.	117677.	129139.	132387.	

STOCK NUMBERS		COD						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.	0.	0.	0.	0.	0.	0.	
1	323233.	602206.	130898.	555011.	256075.	216655.	332540.	
2	215960.	111199.	219023.	48019.	208325.	99462.	82632.	
3	30225.	49795.	28978.	57055.	14521.	61619.	30965.	
4	19155.	7189.	14564.	8936.	14375.	5251.	16271.	
5	5172.	6680.	2823.	5222.	2959.	4807.	1521.	
6	2376.	1950.	2688.	1131.	1888.	1196.	1759.	
7	1197.	894.	753.	1103.	365.	677.	419.	
8	304.	480.	347.	297.	374.	118.	287.	
9	175.	121.	174.	125.	93.	125.	40.	
10	56.	79.	43.	74.	52.	25.	58.	
11	47.	40.	37.	63.	30.	15.	16.	
TOTAL STOCK BIOMASS ON 1. JANUARY								
	314282.	262117.	274797.	225906.	243044.	223837.	195628.	
SPAWNING STOCK BIOMASS ON 1. JANUARY								
	116391.	98318.	94112.	89586.	78725.	76383.	75757.	



Table 2.7.1b. Output from MSVPA 'Key Run' for haddock.

FISHING MORTALITY		HADDOCK									
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982		
0	0.0162	0.0163	0.0255	0.0204	0.0288	0.0468	0.0480	0.0606	0.0352		
1	0.3705	0.3588	0.3399	0.3270	0.5414	0.1690	0.2295	0.1923	0.2235		
2	0.9230	1.0307	0.8442	0.9897	0.8250	1.0076	0.8045	0.4637	0.4532		
3	0.9454	1.2967	1.4226	1.0455	1.0662	1.4384	1.2147	0.9263	0.8227		
4	0.9951	1.1344	0.8063	1.2886	1.1223	1.0030	1.1066	0.9948	0.8815		
5	0.7066	1.0292	1.3840	1.0605	1.1203	0.9785	0.7142	0.6365	0.6028		
6	0.9456	0.6719	1.1574	1.0559	1.0425	1.0525	0.9547	0.3063	0.4952		
7	1.1369	1.3393	0.3565	0.9248	1.1366	0.5698	1.0123	0.8919	0.3858		
8	0.7418	1.1622	0.6443	0.4003	0.6845	1.0224	0.6238	0.6712	0.9329		
9	0.2758	0.8873	1.2244	0.4800	0.6746	0.5594	1.5070	0.9143	0.2543		
10	1.1548	2.5651	3.0570	1.0046	0.2421	0.3850	0.8787	0.9086	0.5853		
11	0.9000	0.9000	0.9000	0.9000	1.0643	0.9522	1.0033	0.8952	0.8874		
MEAN F (UNWEIGHTED) FOR AGES 2 TO 6			0.9031	1.0326	1.1229	1.0880	1.0353	1.0960	0.9589	0.6655	0.6511

FISHING MORTALITY		HADDOCK							
AGE	1983	1984	1985	1986	1987	1988	1989		
0	0.0344	0.0077	0.0174	0.0028	0.0040	0.0024	0.0031		
1	0.2060	0.1676	0.3433	0.2059	0.1482	0.1473	0.0987		
2	0.6577	0.6595	0.6481	1.1348	0.8489	0.8358	0.4334		
3	1.0427	0.9343	0.9509	1.3221	1.0549	1.2309	1.1204		
4	1.1498	1.0721	1.0978	1.3022	1.0433	1.2408	1.1158		
5	1.2335	1.1591	0.9465	1.0225	0.8300	1.1957	0.9617		
6	0.7892	1.0167	0.9905	0.6612	1.0741	0.7525	0.9677		
7	0.3685	0.6849	0.8272	0.9903	0.6856	0.7379	0.9384		
8	0.1402	0.1700	0.5408	0.7635	1.3422	0.4320	0.6633		
9	0.5377	0.0945	0.1727	0.5822	0.7311	1.1015	0.4972		
10	0.9710	0.6036	0.0849	0.4241	0.5476	0.9110	0.4393		
11	0.9354	0.9522	0.9343	0.9713	1.0653	1.6004	0.7002		
MEAN F (UNWEIGHTED) FOR AGES 2 TO 6			0.9746	0.9683	0.9268	1.0886	0.9702	1.0512	0.9139

1 Mortality of 0-group is for 3rd and 4th quarter only  
NORTH SEA DATA 1974 - 1989 (MULTISPECIES WORKING GROUP 1990)

STOCK NUMBERS		HADDOCK									
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982		
0	0.	0.	0.	0.	0.	0.	0.	0.	0.		
1	12027495.	20038872.	2108913.	2441401.	4608750.	5420217.	8581164.	3040436.	4118549.		
2	350276.	1280748.	2219937.	199338.	309572.	452849.	836163.	1403271.	298539.		
3	596263.	91006.	306621.	642524.	49597.	90682.	110327.	251208.	578953.		
4	92040.	176740.	19017.	56534.	171185.	13114.	16253.	24939.	75394.		
5	3933.	27519.	46091.	6886.	12636.	45234.	3904.	4361.	7479.		
6	2343.	1584.	8033.	9434.	1948.	3367.	13897.	1562.	1885.		
7	16911.	745.	662.	2067.	562.	562.	962.	4380.	941.		
8	491.	4442.	160.	380.	671.	706.	260.	286.	1470.		
9	99.	192.	1138.	69.	208.	277.	208.	114.	120.		
10	51.	62.	65.	274.	35.	87.	130.	38.	37.		
11	15.	20.	6.	4.	114.	33.	69.	66.	19.		
TOTAL STOCK BIOMASS ON 1. JANUARY			1024080.	1507183.	708701.	457201.	440920.	464895.	699852.	551974.	548402.
SPAWNING STOCK BIOMASS ON 1. JANUARY			253523.	226408.	269819.	225706.	131816.	98657.	110960.	175489.	218102.

STOCK NUMBERS		HADDOCK							
AGE	1983	1984	1985	1986	1987	1988	1989		
0	0.	0.	0.	0.	0.	0.	0.		
1	2663441.	10097809.	4696848.	4927975.	7669836.	1202747.	2702928.		
2	604987.	407595.	1525728.	364767.	499766.	1182236.	136292.		
3	124898.	209401.	143622.	542194.	79868.	147735.	350362.		
4	191365.	33718.	62904.	42644.	110531.	21653.	33069.		
5	25279.	49145.	9376.	17048.	9430.	31709.	5098.		
6	3344.	6015.	12605.	2973.	5014.	3362.	7845.		
7	940.	1243.	1782.	3833.	1257.	1402.	1297.		
8	524.	533.	513.	638.	1166.	518.	549.		
9	473.	373.	368.	245.	243.	249.	275.		
10	76.	226.	278.	253.	112.	96.	68.		
11	25.	34.	149.	303.	189.	63.	53.		
TOTAL STOCK BIOMASS ON 1. JANUARY			437994.	774913.	660675.	585925.	623451.	388426.	335970.
SPAWNING STOCK BIOMASS ON 1. JANUARY			186515.	145608.	186650.	208834.	124188.	150926.	131256.



Table 2.7.1c. Output from MSVPA 'Key Run' for whiting.

FISHING MORTALITY		WHITING							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.0545	0.0558	0.0716	0.0844	0.0589	0.0421	0.0628	0.1206	0.0311
1	0.4356	0.2467	0.2244	0.4746	0.1781	0.2887	0.1252	0.1966	0.2408
2	0.9134	0.7933	1.0077	0.5584	0.4271	0.5330	0.4446	0.3316	0.3365
3	1.0831	1.0786	1.2689	0.9286	0.7231	0.8252	0.8237	0.7667	0.5232
4	0.9719	1.0766	1.1311	1.0309	0.8851	0.7498	1.0314	1.0035	0.7293
5	1.0631	1.0578	0.8265	0.8665	0.7549	0.9572	1.1850	1.0611	0.9394
6	1.9986	0.9721	1.2721	1.0494	1.1821	1.0286	1.4541	1.4086	1.2135
7	1.1648	1.0853	0.7455	0.8360	1.6045	0.9029	1.1571	1.3727	0.9564
8	0.8891	1.2307	0.6574	2.2173	1.7511	1.0046	1.9675	1.0598	1.3312
9	2.3431	1.4816	0.7125	0.3927	0.7077	0.5364	0.7599	0.7375	0.7571
10	1.2000	1.2013	1.2000	1.2000	1.3731	1.0093	1.3711	1.1593	0.9852
MEAN F (UNWEIGHTED) FOR AGES 2 TO 6									
	1.2060	0.9957	1.1013	0.8868	0.7945	0.8188	0.9878	0.9143	0.7484

  

FISHING MORTALITY		WHITING					
AGE	1983	1984	1985	1986	1987	1988	1989
0	0.1623	0.0567	0.0363	0.0480	0.0154	0.0505	0.0164
1	0.2920	0.3237	0.2667	0.3588	0.1590	0.2349	0.1258
2	0.4719	0.5126	0.3326	0.4070	0.4355	0.4690	0.2204
3	0.7339	0.8551	0.6373	0.6648	0.7830	0.6995	0.7342
4	0.7653	1.0819	0.9181	1.2663	1.3399	0.9040	0.8534
5	0.9483	1.0704	1.0347	1.0623	1.3654	1.1152	0.9756
6	1.0243	1.3474	1.1862	1.4931	1.5274	1.3519	1.5770
7	1.2792	1.2323	1.3219	1.6293	1.7855	0.5316	1.3513
8	1.3788	1.4108	2.4063	1.5693	2.2163	0.7286	1.4753
9	1.2543	2.2000	2.9464	1.8968	1.0138	2.2352	1.2402
10	1.0352	1.1693	1.4022	1.1711	1.2521	2.7003	1.2402
MEAN F (UNWEIGHTED) FOR AGES 2 TO 6							
	0.7887	0.9735	0.8218	0.9787	1.0902	0.9079	0.8721

Mortality of 0-group is for 3rd and 4th quarter only  
1 NORTH SEA DATA 1974 - 1989 (MULTISPECIES WORKING GROUP 1990)  
WITH STOMACH CONTENT DATA FOR COD, WHITING, MACKEREL, SAITHE AND HADDOCK  
MULTISPECIES VPA

  

STOCK NUMBERS		WHITING							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	3576914.	7211268.	4623431.	4633804.	5153250.	5592004.	5334748.	2511417.	2104447.
2	2035323.	908594.	2208861.	1375829.	1071364.	1445472.	1383734.	1568125.	541285.
3	414941.	520430.	271127.	529454.	516078.	451197.	547059.	574901.	697871.
4	59279.	96641.	124875.	53981.	147552.	176525.	139145.	169235.	185473.
5	8338.	16818.	25144.	30816.	14678.	46346.	63313.	37701.	46645.
6	1569.	2265.	4632.	8730.	10268.	5466.	14076.	15329.	10277.
7	9253.	170.	688.	1043.	2455.	2532.	1570.	2643.	3001.
8	654.	2364.	47.	267.	370.	404.	840.	404.	548.
9	63.	220.	565.	20.	24.	53.	121.	96.	115.
10	29.	7.	54.	301.	14.	14.	32.	62.	54.
TOTAL STOCK BIOMASS ON 1. JANUARY									
	508073.	542469.	563756.	496848.	499771.	568835.	569966.	489004.	376966.
SPAWNING STOCK BIOMASS ON 1. JANUARY									
	363565.	283080.	381188.	322250.	310189.	360282.	370960.	386152.	298507.

  

STOCK NUMBERS		WHITING					
AGE	1983	1984	1985	1986	1987	1988	1989
0	0.	0.	0.	0.	0.	0.	0.
1	1932199.	2524187.	2185302.	3817404.	3237277.	4256103.	5662790.
2	570370.	495043.	699448.	592798.	1036688.	1057767.	1118572.
3	244890.	227968.	195654.	326949.	263089.	449477.	441310.
4	286106.	82200.	68974.	73578.	120233.	87014.	160683.
5	67264.	100933.	21357.	21090.	15909.	24343.	27120.
6	14338.	20602.	27512.	6033.	5799.	3246.	6363.
7	2439.	4131.	4310.	6771.	1093.	1020.	679.
8	944.	556.	986.	941.	1087.	150.	491.
9	119.	195.	111.	73.	160.	97.	59.
10	62.	37.	22.	6.	12.	50.	11.
TOTAL STOCK BIOMASS ON 1. JANUARY							
	318960.	283376.	257926.	328743.	357564.	430476.	516027.
SPAWNING STOCK BIOMASS ON 1. JANUARY							
	246190.	190811.	175079.	190313.	234832.	272169.	308285.



94 Table 2.7.1d. Output from MSVPA 'Key Run' for saithe.

FISHING MORTALITY		SAITHE								
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
1	0.0084	0.0004	0.0025	0.0865	0.0040	0.0047	0.0105	0.0299	0.0051	
2	0.0628	0.1570	0.1851	0.1559	0.1482	0.2489	0.1368	0.1664	0.1925	
3	0.4493	0.3820	0.7373	0.1822	0.2648	0.2086	0.2784	0.1537	0.3709	
4	0.5093	0.7734	0.8045	0.5541	0.5442	0.4052	0.2985	0.3100	0.4716	
5	0.3654	0.6987	0.9158	0.9566	0.5684	0.4809	0.5714	0.3318	0.7203	
6	0.5982	0.5340	0.6985	0.6970	0.4310	0.3764	0.5905	0.5662	0.5817	
7	0.6762	0.5344	0.5773	0.3690	0.2859	0.4490	0.5299	0.5808	0.5152	
8	0.5064	0.5327	0.5992	0.4659	0.2787	0.3928	0.3757	0.8200	0.5460	
9	0.4223	0.2889	0.3977	0.3519	0.2679	0.2262	0.4527	0.4476	0.6676	
10	0.3670	0.2679	0.4258	0.2796	0.2582	0.1808	0.3467	0.4449	0.3792	
11	0.3462	0.2054	0.4350	0.2193	0.2693	0.2438	0.3525	0.5492	0.3173	
12	0.3604	0.3720	0.5041	0.4843	0.2676	0.2673	0.2451	0.7133	0.3771	
13	0.6820	0.4149	0.4618	0.3713	0.5597	0.1554	0.2913	0.5458	0.4700	
14	0.3096	0.4015	0.6969	0.6188	0.3972	0.2768	0.2316	0.6813	0.6040	
15	0.2823	0.3001	0.3000	0.3001	0.3572	0.2401	0.3432	0.6202	0.4982	
MEAN F (UNWEIGHTED) FOR AGES 3 TO 6		0.4806	0.5970	0.7890	0.5975	0.4521	0.3678	0.4347	0.3404	0.5361

FISHING MORTALITY		SAITHE						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
1	0.0004	0.0002	0.0027	0.0005	0.0109	0.0001	0.0256	
2	0.1422	0.1027	0.0150	0.0589	0.1895	0.0198	0.0530	
3	0.3010	0.5982	0.5821	0.2319	0.4114	0.1464	0.1041	
4	0.5206	0.8089	1.1412	1.4715	0.7183	0.3732	0.4341	
5	0.7577	0.7289	0.7758	1.2092	1.0174	0.6141	0.6223	
6	0.7863	1.0476	0.7099	0.8567	0.5975	0.5687	0.4371	
7	1.0530	0.5364	0.5804	0.5613	0.6001	0.4735	0.4462	
8	0.8044	0.7903	0.3303	0.4688	0.7510	0.3041	0.4962	
9	0.8387	0.3754	0.3709	0.3306	0.9197	0.4500	0.4372	
10	0.4230	0.4164	0.1864	0.3598	0.5727	0.5188	0.4371	
11	0.4409	0.2438	0.2840	0.2410	0.3571	0.8522	0.2855	
12	0.3427	0.2797	0.2410	0.5160	0.3033	0.5049	0.4372	
13	0.4688	0.2107	0.1328	0.1964	0.4378	0.2422	0.4372	
14	0.3429	0.4298	0.2649	0.2712	0.3231	0.3874	0.4372	
15	0.5233	0.3352	0.1951	0.3772	0.3652	0.4002	0.4372	
MEAN F (UNWEIGHTED) FOR AGES 3 TO 6		0.5914	0.7959	0.8022	0.9423	0.6861	0.4256	0.3994

STOCK NUMBERS		SAITHE								
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	
0	0.	0.	0.	0.	0.	0.	0.	0.	0.	
1	480217.	189974.	121082.	128060.	117309.	257191.	160210.	198451.	339214.	
2	266144.	389869.	155472.	98883.	96161.	95664.	209586.	129794.	157686.	
3	184041.	204639.	272831.	105780.	69271.	67887.	61064.	149660.	89978.	
4	87464.	96146.	114351.	106863.	72179.	43518.	45117.	37846.	105077.	
5	44580.	43030.	36324.	41879.	50272.	34295.	23759.	27405.	22727.	
6	50205.	25327.	17517.	11901.	13173.	23314.	17359.	10985.	16102.	
7	32388.	22598.	12156.	7133.	4853.	7008.	13101.	7875.	5106.	
8	13889.	13485.	10842.	5587.	4038.	2985.	3662.	6314.	3607.	
9	4547.	6853.	6481.	4875.	2871.	2502.	1650.	2059.	2277.	
10	2891.	2441.	4203.	3565.	2808.	1798.	1634.	859.	1078.	
11	1546.	1640.	1529.	2248.	2207.	1775.	1229.	946.	451.	
12	805.	895.	1093.	810.	1478.	1380.	1139.	707.	447.	
13	293.	460.	505.	541.	409.	926.	865.	730.	284.	
14	124.	121.	249.	261.	305.	191.	649.	529.	346.	
15	121.	189.	169.	258.	269.	472.	283.	753.	436.	
TOTAL STOCK BIOMASS ON 1. JANUARY		796562.	745712.	702200.	493741.	410943.	368157.	364133.	386408.	410152.
SPAWNING STOCK BIOMASS ON 1. JANUARY		445530.	359002.	295398.	237388.	218637.	212565.	199636.	174532.	161104.

STOCK NUMBERS		SAITHE						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.	0.	0.	0.	0.	0.	0.	
1	477635.	395511.	139072.	193172.	236646.	257663.	230004.	
2	276299.	390901.	323750.	113561.	158079.	191655.	210943.	
3	106499.	196231.	288810.	261110.	87653.	107082.	153843.	
4	50838.	64529.	88332.	132121.	169531.	47562.	75733.	
5	53684.	24732.	23528.	23102.	24835.	67677.	26811.	
6	9055.	20603.	9769.	8868.	5645.	7351.	29983.	
7	7369.	3377.	5917.	3933.	3083.	2543.	3408.	
8	2497.	2105.	1617.	2711.	1837.	1385.	1296.	
9	1711.	915.	782.	951.	1389.	710.	837.	
10	956.	605.	514.	442.	560.	453.	370.	
11	604.	513.	327.	350.	252.	258.	221.	
12	269.	318.	329.	201.	200.	88.	159.	
13	251.	156.	197.	212.	98.	121.	44.	
14	145.	129.	104.	141.	142.	52.	78.	
15	301.	204.	210.	148.	204.	187.	61.	
TOTAL STOCK BIOMASS ON 1. JANUARY		414511.	475691.	533508.	523516.	435570.	372796.	435354.
SPAWNING STOCK BIOMASS ON 1. JANUARY		170740.	138057.	119125.	122352.	119191.	147268.	155078.





Table 2.7.1e. Output from MSVPA 'Key Run' for mackerel.

FISHING MORTALITY		MACKEREL							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0067	0.0242	0.0102	0.0075	0.0000	0.0000	0.0225	0.0214	0.0213
2	0.1097	0.0277	0.1913	0.0881	0.0638	0.0199	0.0673	0.0567	0.0154
3	0.0773	0.1253	0.2521	0.2171	0.2130	0.1118	0.1084	0.1790	0.0969
4	0.1822	0.1855	0.1414	0.2987	0.2163	0.2322	0.1849	0.1933	0.1936
5	0.2353	0.1784	0.2069	0.1326	0.2322	0.2605	0.3069	0.0637	0.2146
6	0.2200	0.2870	0.1715	0.2347	0.1056	0.1695	0.3172	0.2401	0.1463
7	0.1028	0.1759	0.2677	0.4314	0.0290	0.0951	0.2640	0.3502	0.2173
8	0.2421	0.4229	0.3154	0.4726	0.3831	0.1357	0.2670	0.2712	0.2531
9	0.0901	0.3785	0.2713	0.5571	0.2931	0.0699	0.3009	0.2555	0.2030
10	0.0457	0.1914	0.3590	0.4699	0.5174	0.2668	0.1614	0.2426	0.2091
11	0.0395	0.0593	0.2143	0.6721	0.0867	0.3302	0.2967	0.1346	0.1670
12	0.1426	0.0620	0.0764	0.3752	0.1338	0.2380	0.4097	0.5412	0.1839
13	0.1280	0.1005	0.0324	0.1536	0.4120	0.4075	0.2347	0.3196	0.4367
14	0.0280	0.0890	0.0895	0.0337	0.1582	0.2897	0.6391	0.7945	0.5504
15	0.6790	0.3602	0.2535	0.4059	0.5713	0.2927	0.2914	1.4402	0.4108
MEAN F (UNWEIGHTED) FOR AGES 4 TO 8			0.2206	0.3140	0.1932	0.1691	0.2697	0.2577	0.2178

FISHING MORTALITY		MACKEREL						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
1	0.0072	0.0032	0.1275	0.1347	0.0074	0.1025	0.1025	
2	0.1076	0.1572	0.1327	1.1626	0.0251	0.2047	0.2050	
3	0.2686	0.6671	0.6369	0.6659	0.0461	0.2050	0.2050	
4	0.3102	0.6328	1.1842	1.4912	0.0910	0.2051	0.2050	
5	0.2176	0.6979	0.9272	0.8154	0.3548	0.2048	0.2051	
6	0.1019	0.5180	1.5102	0.4270	0.1003	0.2054	0.2053	
7	0.2258	0.3897	0.6411	1.6279	0.0593	0.2055	0.2038	
8	0.3384	0.3512	0.4802	0.3089	0.8492	0.2050	0.2053	
9	0.2262	0.4616	0.7991	0.7769	0.2344	0.1967	0.2049	
10	0.2396	0.3762	0.7919	0.9827	0.1016	0.2049	0.1988	
11	0.1771	0.2596	0.4835	1.0696	0.1525	0.2054	0.2048	
12	0.2091	0.2605	0.4664	0.7879	0.1228	0.0213	0.2038	
13	0.1318	0.1753	0.5666	0.5230	0.1030	0.1646	0.2065	
14	0.8826	0.1255	0.2706	0.9047	0.0409	0.1281	0.2067	
15	0.7472	0.6811	2.0661	0.3660	0.7412	0.0649	0.2061	
MEAN F (UNWEIGHTED) FOR AGES 4 TO 8		0.5179	0.9486	0.9341	0.2909	0.2051	0.2049	

STOCK NUMBERS		MACKEREL							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	482857.	555876.	295323.	170096.	35627.	113443.	141402.	202225.	215885.
2	198957.	412837.	467017.	251598.	145315.	30664.	95467.	119127.	170387.
3	350778.	153458.	345633.	331960.	198283.	117338.	25873.	76824.	96879.
4	264678.	279468.	116525.	231206.	229966.	137921.	90308.	19982.	55286.
5	1269717.	189865.	199822.	87071.	147610.	159433.	98669.	64070.	16137.
6	256380.	863747.	136722.	139840.	65639.	100722.	105753.	62482.	43375.
7	84956.	177094.	557940.	99131.	95183.	50836.	73177.	66283.	37393.
8	82761.	65976.	127838.	367441.	55427.	79582.	39785.	48371.	40195.
9	40921.	55917.	37202.	80265.	197154.	32523.	59803.	26221.	31743.
10	12335.	32186.	32961.	24411.	39576.	126584.	26103.	38096.	17479.
11	8908.	10143.	22876.	19814.	13133.	20305.	83439.	19119.	25727.
12	7752.	7371.	8228.	15892.	8708.	10365.	12561.	53380.	14383.
13	8578.	5786.	5962.	6561.	9399.	6557.	7032.	7178.	26741.
14	37346.	6496.	4503.	4968.	4843.	5358.	3755.	4786.	4488.
15	48613.	78213.	15406.	8312.	8045.	9948.	9672.	2142.	4336.
TOTAL STOCK BIOMASS ON 1. JANUARY		888796.	747588.	613281.	449935.	360053.	304193.	251046.	224961.
SPAWNING STOCK BIOMASS ON 1. JANUARY		715375.	533033.	458639.	363912.	313654.	265579.	189136.	145685.

STOCK NUMBERS		MACKEREL						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.	0.	0.	0.	0.	0.	0.	
1	26621.	8860.	61187.	30190.	76276.	219720.	134270.	
2	182974.	22749.	7602.	46361.	22710.	65168.	170691.	
3	133107.	141422.	16732.	5730.	12476.	19063.	45705.	
4	68705.	87576.	62467.	7617.	2534.	10254.	13367.	
5	38395.	43362.	40032.	16452.	1476.	1991.	7189.	
6	11998.	26584.	18572.	13633.	6265.	891.	1397.	
7	30041.	9326.	13631.	3530.	7656.	4878.	624.	
8	24987.	20630.	5436.	6179.	597.	6210.	3419.	
9	26737.	15332.	12497.	2895.	3905.	220.	4355.	
10	22301.	18354.	8317.	4838.	1146.	2659.	155.	
11	12206.	15106.	10844.	3243.	1559.	891.	1865.	
12	18737.	8800.	5756.	10029.	958.	1152.	624.	
13	10300.	13085.	5837.	5414.	2253.	729.	970.	
14	14873.	7770.	9451.	2851.	2762.	1749.	532.	
15	3761.	9383.	6621.	15397.	1683.	11803.	4422.	
TOTAL STOCK BIOMASS ON 1. JANUARY		161058.	97308.	56645.	29979.	58218.	76509.	
SPAWNING STOCK BIOMASS ON 1. JANUARY		118420.	86397.	42761.	15726.	21637.	17099.	



Table 2.7.1f. Output from MSVPA 'Key Run' for herring.

FISHING MORTALITY		HERRING							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.0737	0.1010	0.0973	0.0737	0.0365	0.0665	0.0707	0.3943	0.3358
1	0.4500	0.5430	0.2021	0.1674	0.1220	0.1082	0.0510	0.1502	0.1939
2	0.9706	1.2470	1.2467	0.1419	0.0180	0.0788	0.2661	0.2833	0.2116
3	0.8937	1.4280	1.4381	0.9823	0.0318	0.0569	0.3602	0.2600	0.4634
4	0.9545	1.2577	1.6051	0.4139	0.0674	0.0735	0.2499	0.2631	0.2287
5	1.1160	1.7975	1.2799	0.9309	0.0182	0.0342	0.2068	0.3476	0.1290
6	0.9864	1.2023	1.0633	0.3966	0.0551	0.0136	0.0467	0.3521	0.1196
7	0.7642	2.0489	1.5734	0.7310	0.0300	0.3154	0.1250	0.6210	0.1802
8	0.7802	2.0003	2.3972	1.0526	0.1731	0.1151	0.2301	0.8495	0.1946
9	1.0001	1.0003	0.3602	0.0010	0.0003	0.0120	0.0022	0.3000	0.0387
MEAN F (UNWEIGHTED) FOR AGES 3 TO 6	0.9876	1.4214	1.3466	0.6810	0.0431	0.0445	0.2159	0.3057	0.2352

FISHING MORTALITY		HERRING						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.3980	0.1088	0.0363	0.0132	0.0847	0.0794	0.0981	
1	0.1433	0.0689	0.1997	0.1430	0.2296	0.2442	0.3843	
2	0.2689	0.2475	0.3401	0.3662	0.3493	0.3368	0.2589	
3	0.3172	0.3718	0.6004	0.4443	0.4364	0.4102	0.4624	
4	0.4176	0.4926	0.6450	0.5010	0.5036	0.4846	0.5625	
5	0.2600	0.5615	0.6294	0.4525	0.5188	0.5188	0.5081	
6	0.2895	0.3256	0.6553	0.6756	0.4932	0.5125	0.5047	
7	0.3191	0.5300	0.5187	0.7064	0.5828	0.4520	0.4902	
8	0.3796	0.4217	0.5396	0.7030	0.5924	0.7857	0.4362	
9	0.3302	0.3146	0.4608	0.4702	0.1864	0.5794	0.2729	
MEAN F (UNWEIGHTED) FOR AGES 3 TO 6	0.3211	0.4379	0.6325	0.5183	0.4880	0.4815	0.5094	

Mortality of 0-group is for 3rd and 4th quarter only  
 1 NORTH SEA DATA 1974 - 1989 (MULTISPECIES WORKING GROUP 1990)  
 WITH STOMACH CONTENT DATA FOR COD, WHITING, MACKEREL, SAITHE AND HADDOCK

MULTISPECIES VPA

STOCK NUMBERS		HERRING							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	4892224.	8503174.	1509029.	1423791.	2296971.	2321756.	5799039.	6744966.	9827970.
2	1632704.	985452.	1703234.	421000.	410786.	692175.	739010.	1825115.	1947065.
3	754842.	407046.	185841.	311600.	227554.	242798.	390739.	338590.	764089.
4	227025.	215559.	71082.	32891.	86003.	162550.	165181.	199089.	183734.
5	89594.	72678.	51212.	12032.	18384.	67632.	127271.	108639.	127902.
6	39582.	25886.	10603.	12518.	4174.	15856.	57433.	91172.	67217.
7	10024.	10928.	5861.	2924.	6858.	3216.	12824.	44038.	50670.
8	3687.	4224.	1274.	1099.	1274.	6022.	2123.	10241.	21415.
9	1678.	2291.	1402.	1092.	3639.	9150.	50000.	4629.	30599.
TOTAL STOCK BIOMASS ON 1. JANUARY	325198.	273132.	189141.	94724.	103031.	148222.	237264.	328953.	430840.
SPAWNING STOCK BIOMASS ON 1. JANUARY	221184.	143740.	123768.	65956.	64068.	101153.	147168.	197366.	258873.

STOCK NUMBERS		HERRING						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.	0.	0.	0.	0.	0.	0.	
1	15506593.	14002755.	12547595.	21722894.	26742228.	15661770.	10710647.	
2	3263134.	5897475.	6000509.	4890806.	9367444.	9646960.	5578383.	
3	988948.	1581579.	2989603.	2694954.	2207157.	4235450.	4380827.	
4	343562.	536208.	828628.	1253675.	1311551.	1123018.	2113990.	
5	123618.	192112.	279874.	370206.	649894.	678848.	588759.	
6	99043.	84279.	96990.	131803.	208748.	342379.	357798.	
7	49502.	61925.	51601.	41946.	57007.	108792.	173497.	
8	38290.	32554.	32981.	27795.	18727.	28800.	62644.	
9	45626.	69834.	45010.	40033.	50004.	19005.	38165.	
TOTAL STOCK BIOMASS ON 1. JANUARY	657460.	948300.	1153434.	1222002.	1629356.	1759592.	1562718.	
SPAWNING STOCK BIOMASS ON 1. JANUARY	380829.	616612.	836349.	825607.	1048502.	1303948.	1279390.	



Table 2.7.1g. Output from MSVPA 'Key Run' for sandeel.

FISHING MORTALITY		SANDEEL								
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	
0	0.0105	0.0142	0.0173	0.0334	0.1092	0.0958	0.0602	0.1024	0.1507	
1	0.1680	0.1216	0.2022	0.3107	0.4302	0.2277	0.4456	0.3463	0.3367	
2	0.1430	0.2747	0.4868	0.4370	0.7061	0.8992	0.7610	0.8690	0.8859	
3	0.0501	0.3872	0.3225	0.7719	0.3834	0.6980	0.9730	0.5473	1.2549	
4	0.2657	0.1434	0.4067	0.3950	0.4903	0.6107	0.5272	0.8306	1.2644	
5	0.2704	0.3554	0.1350	0.7873	0.2395	0.8751	0.4735	0.9858	0.8193	
6	0.5356	0.3218	0.4943	0.8245	0.8851	0.8966	1.0637	0.8321	0.8154	
MEAN F (UNWEIGHTED) FOR AGES 1 TO 2		0.1555	0.1982	0.3445	0.3739	0.5681	0.5635	0.6033	0.6076	0.6113

FISHING MORTALITY		SANDEEL						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.0401	0.0248	0.0210	0.0230	0.0098	0.0162	0.0065	
1	0.2237	0.5259	0.2266	0.1168	0.3187	0.3683	0.3198	
2	0.7981	0.2817	1.5106	0.3641	0.3829	1.1540	0.9759	
3	0.7269	1.6980	1.2285	0.4734	0.1892	0.5829	0.7819	
4	0.4000	0.6016	0.6198	0.2485	0.1321	0.5376	0.2485	
5	0.5589	0.5868	1.7635	0.1105	0.1320	0.6559	0.0369	
6	0.8465	1.1292	1.2958	0.3277	0.0285	0.6900	0.0236	
MEAN F (UNWEIGHTED) FOR AGES 1 TO 2		0.5109	0.4038	0.8686	0.2405	0.3508	0.7611	0.6479

Mortality of 0-group is for 3rd and 4th quarter only  
 NORTH SEA DATA 1974 - 1989 (MULTISPECIES WORKING GROUP 1990)  
 WITH STOMACH CONTENT DATA FOR COD, WHITING, MACKEREL, SAITHE AND HADDOCK  
 MULTISPECIES VPA

STOCK NUMBERS		SANDEEL								
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	
0	0.	0.	0.	0.	0.	0.	0.	0.	0.	
1	499805472.	617610368.	379693536.	393469344.	414137472.	304211648.	316836544.	159773360.	411248608.	
2	65993940.	55485768.	80575448.	41679556.	58388572.	64147928.	58644656.	48179032.	22810078.	
3	24994828.	17821486.	14205056.	16058503.	10239758.	12146663.	11329995.	11443344.	7929778.	
4	13410953.	12066436.	6252925.	5266567.	4051257.	3992818.	3515640.	2434199.	3630826.	
5	1638863.	2900475.	2858398.	1196915.	1282746.	1051342.	982384.	870686.	414449.	
6	346568.	467394.	754475.	963568.	267329.	582612.	257801.	355886.	173472.	
TOTAL STOCK BIOMASS ON 1. JANUARY		3293718.	3544214.	2696266.	2339751.	2462719.	2119156.	2084394.	1347222.	2035073.
SPAWNING STOCK BIOMASS ON 1. JANUARY		1344476.	1135534.	1215461.	805221.	847583.	932731.	848731.	724106.	431204.

STOCK NUMBERS		SANDEEL						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.	0.	0.	0.	0.	0.	0.	
1	114350752.	358677248.	127692664.	486924576.	246872288.	84666432.	626642176.	
2	99346448.	27978222.	76364192.	32309496.	164684720.	68195360.	14848534.	
3	4370547.	20869242.	10749024.	8599059.	12045370.	59611276.	9893740.	
4	1318702.	1254122.	2349670.	1924610.	3346495.	6241965.	19653230.	
5	435928.	421968.	368253.	679078.	843276.	1654443.	1760055.	
6	110481.	157473.	162021.	63391.	877329.	604749.	911340.	
TOTAL STOCK BIOMASS ON 1. JANUARY		1533635.	2026687.	1474311.	2403298.	2876997.	2074589.	3195994.
SPAWNING STOCK BIOMASS ON 1. JANUARY		1087667.	627846.	976310.	504292.	1914195.	1744390.	752090.

Table 2.7.1g. (Continued).

AGE	PREDATION MORTALITY		SANDEEL						
	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.5623	0.5552	0.4908	0.4161	0.4180	0.4165	0.4665	0.3395	0.3217
1	1.5402	1.4251	1.5173	1.1073	0.9449	0.9290	0.9484	1.1103	0.5939
2	0.7162	0.6379	0.6762	0.5169	0.4141	0.3847	0.4234	0.4853	0.3164
3	0.2882	0.2702	0.2798	0.2153	0.1684	0.1519	0.1749	0.2107	0.1491
4	0.9057	0.9370	0.8868	0.6575	0.4988	0.4317	0.5087	0.5798	0.4953
5	0.6049	0.8082	0.7673	0.5567	0.4140	0.3472	0.3921	0.4777	0.3870
6	1.1250	1.2464	1.0953	0.7775	0.5536	0.4523	0.5283	0.5820	0.5976

AGE	PREDATION MORTALITY		SANDEEL				
	1983	1984	1985	1986	1987	1988	1989
0	0.2901	0.3293	0.2752	0.3388	0.3377	0.2836	0.4267
1	0.6942	0.5310	0.6577	0.4773	0.4778	0.8826	0.6333
2	0.3122	0.2249	0.2232	0.1726	0.1833	0.3265	0.2689
3	0.1315	0.0960	0.1015	0.0804	0.0782	0.1367	0.1210
4	0.3795	0.2638	0.2615	0.2167	0.2123	0.3684	0.3624
5	0.3170	0.2004	0.2089	0.1559	0.1497	0.2935	0.2416
6	0.4187	0.2491	0.2198	0.1885	0.1799	0.3517	0.3297

Table 2.7.1h. Output from MSVPA 'Key Run' for Norway pout.

FISHING MORTALITY			N. POUT						
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.0318	0.0372	0.0303	0.0167	0.0103	0.0102	0.0087	0.1780	0.0076
1	0.8212	0.5785	0.4292	0.4227	0.3555	0.3979	0.5126	0.4241	0.4310
2	2.7515	1.2153	1.6950	0.6455	1.0530	1.6138	1.9811	1.0762	1.6180
3	2.1940	0.9460	0.8510	1.6777	0.7415	0.8312	1.3690	4.3131	0.8248
MEAN F (UNWEIGHTED) FOR AGES 1 TO 2			1.0621	0.5341	0.7042	1.0058	1.2468	0.7501	1.0245

  

FISHING MORTALITY			N. POUT					
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.0227	0.0197	0.0053	0.0459	0.0047	0.0305	0.0733	
1	0.4634	0.6682	0.6671	0.3112	0.4028	0.2220	0.5060	
2	1.2263	2.0059	1.7725	1.6082	0.6060	1.7161	1.2442	
3	1.0869	1.1508	1.5701	0.7562	0.2835	0.0554	0.7388	
MEAN F (UNWEIGHTED) FOR AGES 1 TO 2			1.2198	0.9597	0.5044	0.9690	0.8751	

Mortality of 0-group is for 3rd and 4th quarter only  
1 NORTH SEA DATA 1974 - 1989 (MULTISPECIES WORKING GROUP 1990)  
WITH STOMACH CONTENT DATA FOR COD, WHITING, MACKEREL, SAITHE AND HADDOCK  
MULTISPECIES VPA

BIOMASS OF OTHER FOOD ASSUMED TO REMAIN CONSTANT

STOCK NUMBERS			N. POUT								
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982		
0	0.	0.	0.	0.	0.	0.	0.	0.	0.		
1	247043200.	166712016.	235857280.	169683968.	85833504.	117938696.	131416504.	63923052.	157542480.		
2	3110103.	8206573.	5883211.	10639070.	10176887.	5302937.	10118375.	11311718.	2886031.		
3	638988.	45145.	581254.	261062.	1447038.	852781.	279465.	387925.	923788.		
TOTAL STOCK BIOMASS ON 1. JANUARY			1978386.	1464224.	1956948.	1553773.	955320.	1058361.	1251320.	771327.	1304810.
SPAWNING STOCK BIOMASS ON 1. JANUARY			1039622.	830718.	1060691.	908974.	629153.	610194.	751938.	528419.	706148.

  

STOCK NUMBERS			N. POUT						
AGE	1983	1984	1985	1986	1987	1988	1989		
0	0.	0.	0.	0.	0.	0.	0.		
1	130844408.	106964736.	95524640.	108345408.	98349152.	41070852.	80696368.		
2	12108098.	11393872.	5609905.	2865464.	4422288.	4619026.	1915375.		
3	159647.	1053399.	449103.	254898.	158654.	624133.	170591.		
TOTAL STOCK BIOMASS ON 1. JANUARY			1289295.	1128349.	878365.	902329.	859368.	448285.	666043.
SPAWNING STOCK BIOMASS ON 1. JANUARY			792087.	721883.	515372.	490616.	485641.	292216.	359397.

1 NORTH SEA DATA 1974 - 1989 (MULTISPECIES WORKING GROUP 1990)  
WITH STOMACH CONTENT DATA FOR COD, WHITING, MACKEREL, SAITHE AND HADDOCK  
MULTISPECIES VPA

BIOMASS OF OTHER FOOD ASSUMED TO REMAIN CONSTANT

PREDATION MORTALITY			N. POUT						
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.2739	0.3208	0.3135	0.2966	0.2777	0.2234	0.2643	0.2840	0.2740
1	1.8339	2.0161	1.9202	1.6416	1.6790	1.3088	1.1902	1.9237	1.3847
2	0.9209	0.8886	0.8223	0.8071	0.8914	0.7595	0.6431	0.9011	0.7314
3	0.9748	0.9838	0.8983	0.8749	0.9973	0.8363	0.6896	0.9768	0.7773

  

PREDATION MORTALITY			N. POUT					
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.1999	0.2722	0.2973	0.3357	0.3687	0.2921	0.4039	
1	1.2275	1.5297	2.0895	2.1374	1.9056	2.0934	2.2524	
2	0.6689	0.6347	0.7824	0.8178	0.8763	1.0356	0.9722	
3	0.6760	0.6265	0.8681	0.9225	0.9193	1.1914	1.0411	



Table 2.7.1i. Output from MSVPA 'Key Run' for sprat.

FISHING MORTALITY		SPRAT							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.0065	0.0021	0.0159	0.0068	0.0022	0.0039	0.0076	0.0089	0.0030
1	0.1013	0.2287	0.2676	0.1669	0.5060	0.3428	0.4280	0.4714	0.6916
2	0.4708	0.6147	0.5835	0.5703	0.5368	0.7155	0.6375	1.2967	1.0891
3	0.8707	1.5892	3.1683	0.5242	2.1957	1.8236	1.6906	0.6394	1.7698
4	2.8642	1.8860	2.5453	4.3208	1.3908	1.7110	1.8581	0.3918	0.4663
MEAN F (UNWEIGHTED) FOR AGES 1 TO 3									
	0.4809	0.8108	1.3398	0.4205	1.0795	0.9606	0.9187	0.8025	1.1835

FISHING MORTALITY		SPRAT					
AGE	1983	1984	1985	1986	1987	1988	1989
0	0.0027	0.0032	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.9382	0.3007	0.1346	0.0143	0.0472	0.8466	0.6615
2	1.0453	1.2776	0.4941	0.1126	0.0896	0.2097	0.2554
3	1.6507	2.1113	0.6361	0.4250	0.1806	0.1998	0.3542
4	1.8924	2.0810	1.0180	0.6371	0.3596	0.6221	0.5486
MEAN F (UNWEIGHTED) FOR AGES 1 TO 3							
	1.2114	1.2299	0.4216	0.1840	0.1058	0.4187	0.4237

Mortality of 0-group is for 3rd and 4th quarter only  
 1 NORTH SEA DATA 1974 - 1989 (MULTISPECIES WORKING GROUP 1990)  
 WITH STOMACH CONTENT DATA FOR COD, WHITING, MACKEREL, SAITHE AND HADDOCK  
 MULTISPECIES VPA

BIOMASS OF OTHER FOOD ASSUMED TO REMAIN CONSTANT

STOCK NUMBERS		SPRAT							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	365518400.	219252816.	295185408.	159250224.	146600976.	261823632.	99989128.	62124924.	31966702.
2	47214280.	110036672.	53119224.	72789432.	42459612.	28504554.	61126900.	20051312.	13396731.
3	3010755.	7830263.	11275492.	5716310.	8533012.	4308877.	2379418.	3916904.	899061.
4	408354.	522839.	671522.	173240.	1373246.	349509.	239356.	159758.	663046.
TOTAL STOCK BIOMASS ON 1. JANUARY									
	1424603.	1615264.	1415548.	1111378.	901091.	1011787.	806960.	393956.	223124.
SPAWNING STOCK BIOMASS ON 1. JANUARY									
	437703.	1023281.	618548.	681402.	505268.	304863.	536989.	226219.	136813.

STOCK NUMBERS		SPRAT					
AGE	1983	1984	1985	1986	1987	1988	1989
0	0.	0.	0.	0.	0.	0.	0.
1	15769140.	47430820.	25593100.	23943134.	100552656.	14430279.	19108370.
2	6059361.	2439326.	13494457.	9117278.	9052252.	38376040.	2276773.
3	936792.	524141.	133338.	1910608.	1481422.	1578617.	5770813.
4	58788.	71427.	28855.	31836.	627988.	539004.	510424.
TOTAL STOCK BIOMASS ON 1. JANUARY							
	107366.	157451.	181089.	168614.	381319.	385869.	170032.
SPAWNING STOCK BIOMASS ON 1. JANUARY							
	64789.	29387.	111988.	103967.	109827.	346907.	118440.

Table 2.7.1i. (Continued).

PREDATION MORTALITY		SPRAT							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.1129	0.1290	0.1169	0.1354	0.1232	0.1133	0.1305	0.0887	0.0877
1	0.4893	0.5791	0.5225	0.5451	0.5217	0.5020	0.5688	0.4527	0.3615
2	0.7660	1.1037	1.0861	1.0135	1.1912	1.2081	1.5504	1.2479	1.0111
3	0.4325	0.3907	0.5112	0.4677	0.5405	0.5967	0.6344	0.7779	0.5020
4	0.5445	0.5882	0.7135	0.7818	0.8652	1.0024	1.1717	1.2570	1.0622

PREDATION MORTALITY		SPRAT						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.0657	0.0727	0.0506	0.0606	0.0675	0.0627	0.1019	
1	0.3181	0.3463	0.2875	0.3484	0.3060	0.3899	0.5226	
2	0.8422	1.0689	0.9006	1.1445	1.0967	1.1248	1.9913	
3	0.4583	0.4057	0.4524	0.4117	0.4682	0.5327	0.6214	
4	0.7441	0.7811	0.6806	0.7963	0.7461	0.9283	1.2723	

Table 2.7.1j. Output from MSVPA 'Key Run' for plaice.

FISHING MORTALITY		PLAICE							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0037	0.0030	0.0092	0.0072	0.0028	0.0032	0.0016	0.0006	0.0035
2	0.0448	0.0746	0.1230	0.2319	0.1638	0.1729	0.1889	0.1975	0.1436
3	0.4768	0.1669	0.2696	0.2059	0.3793	0.4875	0.6548	0.5672	0.6921
4	0.6220	0.4334	0.3770	0.3435	0.3815	0.5113	0.6030	0.5803	0.6534
5	0.5229	0.5113	0.3069	0.5786	0.4213	0.6020	0.4721	0.5477	0.5663
6	0.3789	0.5105	0.3389	0.3056	0.4579	0.6190	0.4196	0.4026	0.4735
7	0.2916	0.3895	0.3811	0.3094	0.2967	0.5761	0.3952	0.3660	0.4079
8	0.3605	0.3271	0.3331	0.3317	0.2578	0.3111	0.3575	0.3783	0.3276
9	0.3614	0.3711	0.2392	0.3252	0.2350	0.3176	0.1993	0.3198	0.3305
10	0.3691	0.3275	0.2801	0.2173	0.2582	0.3318	0.2172	0.2031	0.3809
11	0.4302	0.2313	0.3160	0.2615	0.1736	0.3238	0.1953	0.2507	0.2241
12	0.3315	0.4980	0.1631	0.3065	0.1662	0.2277	0.3122	0.2330	0.2287
13	0.3123	0.2834	0.5151	0.1110	0.2248	0.2669	0.1165	0.3213	0.2242
14	0.2417	0.3303	0.1394	0.4794	0.0916	0.3366	0.1460	0.1597	0.3188
15	0.4400	0.4380	0.3310	0.2910	0.2530	0.3822	0.2611	0.3231	0.3642
MEAN F (UNWEIGHTED) FOR AGES 3 TO 8			0.3344	0.3458	0.3657	0.5178	0.4837	0.4737	0.5201

FISHING MORTALITY		PLAICE					
AGE	1983	1984	1985	1986	1987	1988	1989
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0022	0.0002	0.0003	0.0013	0.0000	0.0000	0.0010
2	0.1482	0.1372	0.1541	0.1666	0.0975	0.0534	0.0830
3	0.5288	0.5183	0.4634	0.5272	0.4432	0.3664	0.4361
4	0.7398	0.4441	0.7072	0.5507	0.6693	0.5476	0.5002
5	0.5625	0.6124	0.4703	0.7305	0.7066	0.7675	0.7054
6	0.4768	0.4915	0.4900	0.6748	0.5908	0.7853	0.6122
7	0.3986	0.4128	0.4352	0.5413	0.5826	0.7385	0.6713
8	0.3675	0.4545	0.3840	0.5006	0.3962	0.7578	0.6653
9	0.2692	0.3832	0.3702	0.4900	0.3733	0.6915	0.5622
10	0.3349	0.2699	0.3464	0.4650	0.4710	0.6598	0.7283
11	0.3515	0.2169	0.1850	0.4297	0.3466	0.6234	0.6973
12	0.3544	0.2853	0.2474	0.2697	0.3512	0.7127	0.8703
13	0.2636	0.1930	0.2640	0.2661	0.1654	0.5765	0.6784
14	0.1818	0.1958	0.2129	0.3403	0.1188	0.2615	0.7073
15	0.4112	0.3401	0.3532	0.4882	0.3762	0.6534	0.7074
MEAN F (UNWEIGHTED) FOR AGES 3 TO 8			0.4917	0.5875	0.5648	0.6605	0.5984

STOCK NUMBERS		PLAICE							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	453903.	337082.	321074.	466840.	423753.	437195.	652058.	413209.	1007667.
2	484500.	409177.	304076.	287851.	419367.	382345.	394343.	589080.	373648.
3	165497.	419193.	343623.	243301.	206548.	322132.	291044.	295396.	437512.
4	136695.	92960.	320986.	237444.	179182.	127902.	179011.	136815.	151576.
5	103318.	66402.	54533.	199225.	152384.	110712.	69404.	88629.	69294.
6	62131.	55417.	36033.	36305.	101070.	90475.	54870.	39169.	46375.
7	32848.	38489.	30096.	23232.	24199.	57852.	44085.	32634.	23695.
8	21952.	22205.	23592.	18602.	15427.	16276.	29424.	26869.	20478.
9	19820.	13851.	14487.	15299.	12080.	10787.	10789.	18620.	16655.
10	14097.	12495.	8647.	10320.	10001.	8641.	7104.	7999.	12236.
11	35944.	8819.	8149.	5913.	7514.	6990.	5611.	5173.	5907.
12	7046.	21153.	6332.	5376.	4119.	5715.	4176.	4575.	3643.
13	7996.	4576.	11632.	4867.	3580.	3156.	4118.	3030.	2994.
14	7223.	5294.	3119.	6288.	3941.	2587.	2187.	3317.	1988.
15	11024.	12334.	9833.	7586.	11845.	8506.	5516.	4957.	6889.
TOTAL STOCK BIOMASS ON 1. JANUARY			437619.	449915.	450719.	448798.	451235.	438777.	514042.
SPAWNING STOCK BIOMASS ON 1. JANUARY			315754.	320448.	319195.	304395.	277320.	280668.	270401.

STOCK NUMBERS		PLAICE					
AGE	1983	1984	1985	1986	1987	1988	1989
0	0.	0.	0.	0.	0.	0.	0.
1	571360.	595426.	505733.	1303600.	387765.	669638.	1319345.
2	908619.	515839.	538662.	457492.	1177961.	350864.	605912.
3	292878.	708880.	406892.	417796.	350433.	966886.	300964.
4	198139.	156166.	381974.	231620.	223135.	203559.	606500.
5	71356.	85552.	90637.	170408.	120829.	103387.	106520.
6	35588.	36788.	41961.	51241.	74269.	53937.	43422.
7	26136.	19990.	20361.	23261.	23612.	37222.	22253.
8	14259.	15874.	11970.	11922.	12249.	11932.	16094.
9	13353.	8935.	9118.	7377.	6539.	7457.	5060.
10	10829.	9231.	5511.	5697.	4089.	4074.	3379.
11	7565.	7010.	6377.	3526.	3238.	2310.	1905.
12	4272.	4816.	5106.	4796.	2076.	2072.	1121.
13	2623.	2712.	3277.	3607.	3313.	1322.	919.
14	2165.	1823.	2023.	2277.	2501.	2541.	672.
15	3268.	4586.	3722.	3327.	3869.	3797.	3195.
TOTAL STOCK BIOMASS ON 1. JANUARY			524627.	617742.	591120.	604983.	699756.
SPAWNING STOCK BIOMASS ON 1. JANUARY			343632.	323811.	371005.	347623.	403342.

Table 2.7.1k. Output from MSVPA 'Key Run' for sole.

FISHING MORTALITY		SOLE							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0010	0.0066	0.0096	0.0132	0.0006	0.0008	0.0044	0.0030	0.0185
2	0.1845	0.2748	0.1032	0.2608	0.2352	0.2259	0.1291	0.2509	0.2316
3	0.5718	0.5367	0.5549	0.5263	0.5655	0.6577	0.5591	0.5285	0.6801
4	0.5940	0.6231	0.4869	0.5954	0.4920	0.6176	0.5871	0.6056	0.5713
5	0.4491	0.4173	0.4994	0.4590	0.4944	0.4206	0.5604	0.5247	0.6420
6	0.4430	0.4153	0.3076	0.3069	0.4585	0.4201	0.3281	0.5389	0.5872
7	0.3905	0.2922	0.3335	0.1409	0.4907	0.3069	0.5000	0.3293	0.4490
8	0.2713	0.3602	0.3028	0.2942	0.3862	0.3991	0.3859	0.3412	0.3279
9	0.1642	0.3091	0.2540	0.2004	0.2480	0.2311	0.2791	0.3326	0.3666
10	0.2671	0.1223	0.1753	0.1728	0.2032	0.2097	0.0663	0.2119	0.3567
11	0.3134	0.1508	0.1276	0.1026	0.2641	0.2228	0.3179	0.1626	0.2198
12	0.0760	0.3972	0.0990	0.0988	0.1700	0.1819	0.0978	0.1737	0.1449
13	0.0241	0.0212	0.4675	0.0988	0.1051	0.1881	0.1031	0.2242	0.3057
14	0.2072	0.0733	0.0376	0.5535	0.0750	0.0881	0.0737	0.0497	0.0369
15	0.3840	0.3060	0.2840	0.3120	0.4160	0.4942	0.3652	0.5102	0.4202
MEAN F (UNWEIGHTED) FOR AGES 2 TO 8									
	0.4149	0.4171	0.3698	0.3691	0.4461	0.4354	0.4357	0.4456	0.4985

  

FISHING MORTALITY		SOLE						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
1	0.0029	0.0029	0.0022	0.0025	0.0017	0.0001	0.0020	
2	0.3110	0.2904	0.3136	0.1487	0.2477	0.3032	0.2941	
3	0.5994	0.7229	0.7415	0.6292	0.5294	0.6956	0.7743	
4	0.6904	0.6822	0.7790	0.6883	0.6581	0.7807	0.7563	
5	0.3409	0.6088	0.5992	0.6884	0.5268	0.6764	0.5132	
6	0.4907	0.7595	0.4696	0.7605	0.5849	0.5982	0.5272	
7	0.4455	0.5689	0.4378	0.5503	0.4281	0.5721	0.4111	
8	0.4549	0.4031	0.4714	0.3849	0.3834	0.4266	0.4431	
9	0.3136	0.4166	0.4081	0.6835	0.5859	0.3631	0.3631	
10	0.2791	0.2961	0.2459	0.7810	0.5766	0.4399	0.2471	
11	0.4783	0.2837	0.3580	0.7914	0.4642	0.2972	1.2833	
12	0.0582	0.2666	0.3972	0.5597	0.7621	0.3843	0.5192	
13	0.0332	0.0662	0.2451	0.4452	0.4015	0.4678	0.3411	
14	0.4277	0.0660	0.0869	0.4198	0.3222	0.0739	0.5512	
15	0.3191	0.3431	0.4052	0.7814	0.7114	0.3912	0.5512	
MEAN F (UNWEIGHTED) FOR AGES 2 TO 8								
	0.4761	0.5765	0.5446	0.5500	0.4798	0.5790	0.5313	

  

STOCK NUMBERS		SOLE							
AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982
0	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	110510.	42055.	113508.	139855.	46796.	11546.	152835.	148226.	151561.
2	95491.	99898.	37803.	101721.	124893.	42317.	10439.	137688.	133720.
3	51721.	71849.	68670.	30853.	70912.	89321.	30549.	8301.	96937.
4	12810.	26420.	38012.	35675.	16494.	36449.	41870.	15804.	4428.
5	20408.	6400.	12820.	21136.	17798.	9125.	17785.	21062.	7804.
6	5619.	11785.	3815.	7040.	12085.	9823.	5422.	9189.	11278.
7	5127.	3265.	7039.	2538.	4687.	6914.	5839.	3534.	4850.
8	2896.	3140.	2206.	4563.	1994.	2596.	4602.	3205.	2300.
9	2770.	1998.	1982.	1474.	3076.	1226.	1576.	2831.	2061.
10	2717.	2127.	1327.	1391.	1092.	2172.	881.	1079.	1837.
11	9189.	1882.	1703.	1008.	1059.	806.	1594.	746.	790.
12	1487.	6078.	1465.	1356.	823.	736.	584.	1049.	574.
13	1407.	1247.	3697.	1200.	1112.	628.	555.	479.	798.
14	1705.	1243.	1105.	2096.	984.	906.	471.	453.	346.
15	4602.	3757.	3278.	2851.	2705.	1844.	2017.	867.	962.
TOTAL STOCK BIOMASS ON 1. JANUARY									
	60838.	58456.	53637.	57502.	58517.	49880.	43995.	50790.	60798.
SPAWNING STOCK BIOMASS ON 1. JANUARY									
	41943.	42368.	42669.	36269.	38692.	43379.	34891.	24103.	34499.

  

STOCK NUMBERS		SOLE						
AGE	1983	1984	1985	1986	1987	1988	1989	
0	0.	0.	0.	0.	0.	0.	0.	
1	141328.	69409.	78412.	154262.	58366.	208788.	60237.	
2	134621.	127510.	62623.	70794.	139229.	52725.	188910.	
3	95979.	89251.	86293.	41411.	55208.	98340.	35229.	
4	44432.	47689.	39196.	37199.	19973.	29419.	44384.	
5	2263.	20158.	21813.	16274.	16911.	9359.	12194.	
6	3716.	1456.	9922.	10841.	7398.	9035.	4305.	
7	5672.	2058.	616.	5613.	4585.	3730.	4495.	
8	2801.	3288.	1054.	360.	2929.	2704.	1905.	
9	1499.	1608.	1988.	596.	222.	1806.	1597.	
10	1293.	992.	959.	1196.	272.	112.	1137.	
11	1164.	885.	667.	679.	496.	138.	65.	
12	574.	653.	603.	422.	278.	282.	93.	
13	449.	490.	452.	367.	218.	118.	174.	
14	532.	393.	415.	320.	213.	132.	67.	
15	882.	877.	839.	587.	343.	359.	232.	
TOTAL STOCK BIOMASS ON 1. JANUARY								
	66132.	64624.	55397.	50585.	51807.	55888.	58552.	
SPAWNING STOCK BIOMASS ON 1. JANUARY								
	40219.	43302.	42709.	32961.	29397.	38067.	29093.	

Table 2.7.2a. Values of M1 and mean values (1983-1988) of M2, total natural mortality fishing mortality, and stock in numbers ('000) at age. Last age is a + group. Stock numbers on 1 January (0-group 1 July). 0-group mortality rates are expressed on a half year basis.

Age	M1		M2	Total Natural Mortality	Fishing Mortality	Numbers
	Residual Mortality	"Other" Predators				
<u>Cod</u>						
0	0.1	0.36	0.444	0.904	-	847102
1	0.2	0.28	0.333	0.813	0.182	347346
2	0.2	0.07	0.089	0.359	0.931	150331
3	0.2	-	0.045	0.245	1.006	40365
4	0.2	-	-	0.200	0.876	11578
5	0.2	-	-	0.200	0.755	4611
6	0.2	-	-	0.200	0.804	1872
7	0.2	-	-	0.200	0.777	832
8	0.2	-	-	0.200	0.851	320
9	0.2	-	-	0.200	0.738	135
10	0.2	-	-	0.200	0.821	55
11	0.2	-	-	0.200	0.948	39
<u>Saithe</u>						
0	0.1	-	-	0.100	-	267464
1	0.2	-	-	0.200	0.002	283283
2	0.2	-	-	0.200	0.088	242374
3	0.2	-	-	0.200	0.378	174564
4	0.2	-	-	0.200	0.839	92152
5	0.2	-	-	0.200	0.851	36260
6	0.2	-	-	0.200	0.761	10215
7	0.2	-	-	0.200	0.634	4370
8	0.2	-	-	0.200	0.575	2025
9	0.2	-	-	0.200	0.547	1076
10	0.2	-	-	0.200	0.413	588
11	0.2	-	-	0.200	0.411	384
12	0.2	-	-	0.200	0.364	234
13	0.2	-	-	0.200	0.281	173
14	0.2	-	-	0.200	0.337	119
15	0.2	-	-	0.200	0.366	209
<u>Whiting</u>						
0	0.1	0.28	0.665	1.045	0.061	11014459
1	0.2	0.36	0.452	1.012	0.273	2992079
2	0.2	0.12	0.097	0.417	0.438	742019
3	0.2	0.08	0.058	0.338	0.729	284671
4	0.2	0.03	0.036	0.266	1.046	119684
5	0.2	0.01	0.019	0.229	1.099	41816
6	0.2	-	0.015	0.215	1.322	12922
7	0.2	-	-	0.200	1.297	3294
8	0.2	-	-	0.200	1.618	777
9	0.2	-	-	0.200	1.924	126
10	0.2	-	-	0.200	1.456	32

Table 2.7.2b. Values of M1 and mean values (1983-1988) of M2, total natural mortality fishing mortality, and stock in numbers ('000) at age. Last age is a + group. Stock numbers on 1 January (0-group 1 July). 0-group mortality rates are expressed on a half year basis.

Age	M1		M2	Total Natural Mortality	Fishing Mortality	Numbers
	Residual Mortality	"Other" Predators				
<u>Haddock</u>						
0	0.1	0.52	1.019	1.639	0.011	26120120
1	0.2	0.52	1.187	1.907	0.203	5209776
2	0.2	0.11	0.075	0.385	0.797	764180
3	0.2	0.03	0.034	0.264	1.089	207953
4	0.2	-	0.007	0.207	1.151	77136
5	0.2	-	0.002	0.202	1.064	23664
6	0.2	-	-	0.200	0.881	5552
7	0.2	-	-	0.200	0.716	1743
8	0.2	-	-	0.200	0.565	649
9	0.2	-	-	0.200	0.537	325
10	0.2	-	-	0.200	0.590	174
11	0.2	-	-	0.200	1.076	127
<u>Mackerel</u>						
0	0.08	-	-	0.080	0.000	95304
1	0.15	-	-	0.150	0.064	70476
2	0.15	-	-	0.150	0.298	57927
3	0.15	-	-	0.150	0.415	54755
4	0.15	-	-	0.150	0.652	39859
5	0.15	-	-	0.150	0.536	23618
6	0.15	-	-	0.150	0.477	12991
7	0.15	-	-	0.150	0.525	11510
8	0.15	-	-	0.150	0.422	10673
9	0.15	-	-	0.150	0.449	10264
10	0.15	-	-	0.150	0.449	9602
11	0.15	-	-	0.150	0.391	7308
12	0.15	-	-	0.150	0.311	7572
13	0.15	-	-	0.150	0.277	6270
14	0.15	-	-	0.150	0.392	6576
15	0.15	-	-	0.150	0.778	8108
<u>Herring</u>						
0	0.05	0.17	0.279	0.499	0.120	30917424
1	0.1	0.22	0.450	0.770	0.171	17697306
2	0.1	0.11	0.236	0.446	0.318	6511055
3	0.1	0.05	0.123	0.273	0.430	2449615
4	0.1	0.03	0.029	0.159	0.507	899440
5	0.1	0.01	0.012	0.122	0.490	382425
6	0.1	-	0.069	0.169	0.492	160540
7	0.1	-	-	0.100	0.518	61795
8	0.1	-	-	0.100	0.570	29858
9	0.1	-	-	0.100	0.390	44919

Table 2.7.2c. Values of M1 and mean values (1983-1988) of M2, total natural mortality fishing mortality, and stock in numbers ('000) at age. Last age is a + group. Stock numbers on 1 January (0-group 1 July). 0-group mortality rates are expressed on a half year basis.

Age	M1		M2	Total Natural Mortality	Fishing Mortality	Numbers
	Residual Mortality	"Other" Predators				
<u>Sprat</u>						
0	0.1	0.22	0.063	0.383	0.001	56509220
1	0.2	0.41	0.333	0.943	0.380	37953188
2	0.2	0.36	1.303	1.863	0.538	13089787
3	0.2	0.30	0.455	0.955	0.867	1094153
4	0.2	0.26	0.779	1.239	1.102	226316
<u>Norway Pout</u>						
0	0.1	0.30	0.294	0.694	0.021	179827216
1	0.2	0.55	1.831	2.581	0.456	96849864
2	0.2	0.44	0.803	1.443	1.489	6836442
3	0.2	0.34	0.867	1.407	0.817	449972
<u>Sandeel</u>						
0	0.1	0.16	0.309	0.569	0.022	574055552
1	0.2	0.29	0.620	1.110	0.297	236530672
2	0.2	0.25	0.240	0.690	0.749	78146408
3	0.2	0.19	0.104	0.494	0.816	19374086
4	0.2	0.16	0.284	0.644	0.423	2739261
5	0.2	0.14	0.221	0.561	0.634	733824
6	0.2	0.11	0.268	0.578	0.720	329241

Table 2.7.3 The mean of the ratio between numbers on the MSVPA and the single species VPA's for the years 1983-1988. (ratio is MSVPA/SSVPA). SSVPA values are from 1990 Working Group reports.

Age	Cod	Whiting	Saithe	Haddock	Herring	Norway Pout
1	1.10	1.25	0.95	1.45	0.94	2.06
2	1.04	0.99	0.96	1.09	1.18	0.97
3	1.06	1.01	0.97	1.06	1.10	1.26
4	1.06	1.03	0.98	0.99	1.26	-
5	1.05	1.02	0.99	1.04	0.96	-
6	1.06	1.03	0.99	1.05	1.01	-
7	1.06	1.07	0.97	1.10	0.95	-
8	1.06	1.00	1.01	1.21	0.90	-



Table 2.7.4 Natural mortalities used by the single species working groups in their most recent reports compared to total M from MSVPA key run averaged over the period 1983-1988.

Age	Cod		Haddock		Whiting		Saithe	
	SS	MS	SS	MS	SS	MS	SS	MS
0	1.35	0.90	1.03	1.64	1.28	1.05	0.1	0.1
1	0.80	0.81	1.65	1.91	0.95	1.01	0.2	0.2
2	0.35	0.36	0.40	0.39	0.45	0.42	0.2	0.2
3	0.25	0.25	0.25	0.26	0.35	0.34	0.2	0.2
4	0.20	0.20	0.25	0.21	0.30	0.27	0.2	0.2
5	0.20	0.20	0.20	0.20	0.25	0.23	0.2	0.2
6	0.20	0.20	0.20	0.20	0.25	0.22	0.2	0.2
7	0.20	0.20	0.20	0.20	0.20	0.20	0.2	0.2
8	0.20	0.20	0.20	0.20	0.20	0.20	0.2	0.2
9	0.20	0.20	0.20	0.20	0.20	0.20	0.2	0.2
10	0.20	0.20	0.20	0.20	0.20	0.20	0.2	0.2
11	0.20	0.20	0.20	0.20	0.20	-	0.2	0.2

  

Age	Herring		Norway Pout		Sandeel		Sprat	
	SS	MS	SS	MS	SS	MS	SS	MS
0	0.5	0.50	0.8	0.64	0.8	0.57	-	0.38
1	1.0	0.77	1.6	2.58	1.2	1.11	-	0.94
2	0.3	0.45	1.6	1.44	0.6	0.69	-	1.86
3	0.2	0.27	1.6	1.40	0.6	0.49	-	0.96
4	0.1	0.16	-	-	0.6	0.64	-	1.24
5	0.1	0.12	-	-	0.6	0.56	-	-
6	0.1	0.17	-	-	0.6	0.58	-	-
7	0.1	0.10	-	-	-	-	-	-
8	0.1	0.10	-	-	-	-	-	-
9	0.1	0.10	-	-	-	-	-	-

Table 2.8.1.1 MSVPA parameters used in the sensitivity analyses.

#	Variable Name	Nominal Value	Lower Value	Upper Value
1	MIXSUI	0.30	0.27	0.33
2	MIXM2	0.30	0.27	0.33
3	EPFSF1	0.1E-5	0.099E-5	0.11E-5
4	EPFMS2	0.1E-5	0.099E-5	0.11E-5
5	EPSUI	0.1E-5	0.099E-5	0.11E-5
6	OTHER FOOD	30.0E+6	15.0E+6	45.0E+6
7	Lower Limit WS/W	0.1E-5	0.1E-6	0.1E-4
8	Upper Limit WS/W	0.1E+7	0.1E+6	0.1E+8
9	COD M1 Multiplier	1	0.9	1.1
10	WHITING M1 Multiplier	1	0.9	1.1
11	SAITHE M1 Multiplier	1	0.9	1.1
12	MACKEREL M1 Multiplier	1	0.9	1.1
13	HADDOCK M1 Multiplier	1	0.9	1.1
14	HERRING M1 Multiplier	1	0.9	1.1
15	SPRAT M1 Multiplier	1	0.9	1.1
16	N. POUT M1 Multiplier	1	0.9	1.1
17	SANDEEL M1 Multiplier	1	0.9	1.1
18	PLAICE M1 Multiplier	1	0.9	1.1
19	SOLE M1 Multiplier	1	0.9	1.1
20	COD Food Consumption	1.5	1.0	2.0
21	WHITING Food Consumption	1.5	1.0	2.0
22	SAITHE Food Consumption	1.5	1.0	2.0
23	MACKEREL Food Consumption	1.5	1.0	2.0
24	HADDOCK Food Consumption	1.5	1.0	2.0
25	COD Terminal F	1	0.9	1.1
26	WHITING Terminal F	1	0.9	1.1
27	SAITHE Terminal F	1	0.9	1.1
28	MACKEREL Terminal F	1	0.9	1.1
29	HADDOCK Terminal F	1	0.9	1.1
30	HERRING Terminal F	1	0.9	1.1
31	SPRAT Terminal F	1	0.9	1.1
32	N. POUT Terminal F	1	0.9	1.1
33	SANDEEL Terminal F	1	0.9	1.1

Table 2.8.1.2 MSFOR parameters used in the sensitivity analyses.

#	Variable Name	Nominal Value	Lower Value	Upper Value
34	COD Terminal F	1	0.9	1.1
35	WHITING Terminal F	1	0.9	1.1
36	SAITHE Terminal F	1	0.9	1.1
37	MACKEREL Terminal F	1	0.9	1.1
38	HADDOCK Terminal F	1	0.9	1.1
39	HERRING Terminal F	1	0.9	1.1
40	SPRAT Terminal F	1	0.9	1.1
41	N. POUT Terminal F	1	0.9	1.1
42	SANDEEL Terminal F	1	0.9	1.1
43	PLAICE Terminal F	1	0.9	1.1
44	SOLE Terminal F	1	0.9	1.1
45	COD Recruitment	1	0.9	1.1
46	WHITING Recruitment	1	0.9	1.1
47	SAITHE Recruitment	1	0.9	1.1
48	MACKEREL Recruitment	1	0.9	1.1
49	HADDOCK Recruitment	1	0.9	1.1
50	HERRING Recruitment	1	0.9	1.1
51	SPRAT Recruitment	1	0.9	1.1
52	N. POUT Recruitment	1	0.9	1.1
53	SANDEEL Recruitment	1	0.9	1.1
54	PLAICE Recruitment	1	0.9	1.1
55	SOLE Recruitment	1	0.9	1.1
56	Roundfish Fleet F	1	0.9	1.1
57	Indust. Dem. Fleet F	1	0.9	1.1
58	Indust. Pel. Fleet F	1	0.9	1.1
59	Herring Fleet F	1	0.9	1.1
60	Saithe Fleet F	1	0.9	1.1
61	Mackerel Fleet F	1	0.9	1.1
62	Flatfish Fleet F	1	0.9	1.1

Table 2.8.3.1. Relative sensitivities of MSVPA responses to MSVPA parameters. Sensitivities are expressed as the percent change in the response variable (% of mean) caused by a 10% change in the parameter. Mean catch, F, N, D and M2 are from simultaion runs used to produce the sensitivity coefficients (e.g., the fractional factorial design experiments). TOTBIOM is total biomass (t) in the MSVPA year indicated, N is population numbers ('000), D is predation deaths ('000), and M2 is predation mortality rate.

	TOTBIOM74	TOTBIOM89	COD 1-Year-Old (Mean for 83-88)			
			F	N	D	M2
(Means)	14389948	8946703	0.176	402033	126105	0.451
MIXSUI	0.0	0.0	0.0	0.0	0.0	0.0
MIXM2	0.0	0.0	0.0	0.0	0.0	0.0
EPFSF1	0.0	0.0	0.0	0.0	0.0	0.0
EPFMS2	0.0	0.0	0.0	0.0	0.0	0.0
EPSUI	0.0	0.0	0.0	0.0	0.0	0.0
OTHFood	0.0	0.0	0.0	0.0	0.0	0.0
LLimWSW	0.0	0.0	0.0	0.0	0.0	0.0
ULimWSW	0.0	0.0	0.0	0.0	0.0	0.0
CODM1	0.2	0.0	-3.1	5.6	2.5	0.0
WHITGM1	0.4	0.3	0.0	0.5	1.4	1.1
SAITNM1	0.9	0.1	0.0	0.0	0.0	0.0
MACKLM1	2.4	0.0	0.0	0.0	0.1	0.0
HADDKM1	0.2	0.1	0.0	0.0	-0.1	0.0
HERRGM1	0.0	0.2	0.0	0.0	0.0	0.0
SPRATM1	0.7	0.0	0.0	-0.2	-0.7	-0.5
NPOUTM1	0.6	0.3	0.0	0.0	-0.1	0.0
SamdeM1	1.3	0.9	0.0	-0.1	-0.2	-0.1
PLAICM1	0.1	0.1	0.0	0.0	0.0	0.0
SOLEM1	0.0	0.0	0.0	0.0	0.0	0.0
CODFC	0.5	0.2	-1.0	3.3	7.8	5.7
WHITGFC	1.1	1.7	0.0	0.7	2.3	1.7
SAITHFC	1.7	1.2	0.0	0.0	-0.1	0.0
MACKLFC	3.3	0.2	0.0	0.0	0.0	0.0
HADDKFC	0.1	0.0	0.0	0.0	0.0	0.0
CODTFM	0.0	0.0	0.0	0.0	0.0	0.0
WHITTFM	0.0	0.0	0.0	0.0	0.0	0.0
SATHTFM	0.0	0.0	0.0	0.0	0.0	0.0
MACKTFM	-0.1	0.0	0.0	0.0	0.0	0.0
HADDTFM	0.0	0.0	0.0	0.0	0.0	0.0
HERRTFM	0.0	0.0	0.0	0.0	0.0	0.0
SPRTTFM	0.0	0.0	0.0	0.0	0.0	0.0
N.PTTFM	0.0	0.0	0.0	0.0	0.0	0.0
SANDTFM	0.1	0.0	0.0	0.0	0.0	0.0

Table 2.9.1.1. The length distribution of sand eel found in the stomachs of starry rays.

Length (cm)	Quarter 1	Quarter 3
≤5	0	0
5-7	4	10
7-10	205	416
10-15	5773	567
15-20	3005	568
20-25	66	6
25-30	2	0
>30	0	0

Table 2.9.1.2 The age distribution of sand eel found in the stomachs of rays in weight fractions.

Age	Quarter 1+2	$\bar{w}$	Quarter 3+4	$\bar{w}$
0	-	-	0.0439	2.82
1	0.0591	4.84	0.0476	13.47
2	0.1242	10.32	0.0741	12.17
3	0.0017	30.82	0.0154	15.01
4	0.0023	35.4	0.0070	17.53
5	0.0007	32.6	0.0005	32.6
6+	0.0010	37.98	0.0005	33.1
Other food*	0.7592		0.7592	

\*not including cod, whiting or haddock.

Table 2.9.1.3. The stomach content of R. radiata in weight fractions (sand eel not included).

Age/Quarter	Cod			Haddock			Whiting		
	1/2	3	4	1/2	3	4	1/2	3	4
0	-	0.0021	0.0020	-	0.0318	0.0283	-	0.0102	0.0103
1	0.0028	0.0007	0.0008	0.0384	0.0066	0.0101	0.0107	0.0005	0.0004
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6+	0	0	0	0	0	0	0	0	0
Other food* is 0.7592 in all quarters.									

\*not including sandeels.

Table 2.9.2.1. Biomass of Western mackerel in the North Sea (tonnes x 10<sup>-3</sup>).

Year	Juveniles (Age 1-2)				Adults (Age 3+)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1974	-	-	-	-	-	-	1628	225
1975	-	-	-	-	-	-	3043	373
1976	-	-	-	-	-	-	531	160
1977	-	-	-	-	-	-	188	155
1978	-	-	-	-	-	-	400	161
1979	-	-	-	-	-	-	992	308
1980	-	-	-	-	241	99	1123	560
1981	-	-	-	-	207	85	1069	656
1982	26	47	175	168	193	79	1009	625
1983	60	39	242	227	235	96	1227	759
1984	6	13	313	85	318	131	1688	1062
1985	4	91	287	281	284	117	1497	936
1986	66	86	645	836	218	90	1271	1424
1987	18	46	242	292	269	110	1549	1721
1988	23	76	356	422	226	95	1077	1490
1989	42	55	407	522	207	129	941	1299

Table 2.9.2.2. Diet of Western Mackerel in the North Sea.

Unit: 0/00 by weight

Predator age: Quarter:	1-2 YEARS				3 YEARS AND OLDER				
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Prey:									
Haddock	0-gr:	0	0	0	0	0	12	0	
Herring	0-ring:	0	0	81	0	0	0	6	
Sprat	1-gr:	0	208	5	0	0	0	0	
Sprat	2-gr:	0	0	2	0	0	0	0	
Norw. pout	0-gr:	0	0	1	0	0	170	110	
Norw. pout	1-gr:	0	0	0	0	0	0	68	
Sandeel		0	0	0	0	0	0	0	
Sandeel	0-gr:	0	0	2	65	0	0	161	
Sandeel	1-gr:	0	270	0	0	106	64	4	
Total mean weight per stomach:									
		1.51	1.50	1.88	1.26	6.99	8.25	3.36	4.30
No. of stomachs:									
		31	78	370	52	36	319	644	231
Area: North Sea E of 3 E Northern North Sea (Ices IVa)									

Table 2.9.4.1. Mean M2 (over years 1983-88) in the key run, and when other predators are included.

Age	Key run	Incl. others	Age	Key run	Incl. others
Cod			Whiting		
0	0.44408	0.47496	0	0.66574	0.70087
1	0.33281	0.38245	1	0.45218	0.51011
2	0.08917	0.09047	2	0.09657	0.09879
3	0.04541	0.04569	3	0.05784	0.05869
4+	0	0	4	0.03561	0.03574
			5	0.01890	0.01895
			6	0.01537	0.01536
			7+	0	0
-----			-----		
Haddock			Herring		
0	1.01910	1.12682	0	0.27949	0.65063
1	1.18662	1.32646	1	0.45011	0.46914
2	0.07459	0.07577	2	0.23567	0.23919
3	0.03383	0.03469	3	0.12302	0.12470
4	0.00716	0.00721	4	0.02901	0.02902
5	0.00158	0.00158	5	0.01213	0.01204
6+	0	0	6	0.06940	0.06848
			7+	0	0
-----			-----		
Sprat			Norway pout		
0	0.06330	0.06134	0	0.29432	0.54998
1	0.33269	0.53481	1	1.83053	2.21333
2	1.02961	1.06726	2	0.80261	0.84669
3	0.45483	0.48751	3	0.86732	0.85854
4	0.77943	0.78373			
-----			-----		
Sandeel			-----		
0	0.30911	0.61559			
1	0.62007	0.90050			
2	0.24044	0.29580			
3	0.10406	0.16260			
4	0.28370	0.35890			
5	0.22090	0.24036			
6	0.26794	0.47565			



Table 2.9.4.2. Recruitment (mean value over the years 1983-88), in the key run of MSVPA, and with other predators included. Numbers in millions.

	Key Run		Incl. other predators	
	0-gr	1-gr	0-gr	1-gr
Cod	847	347	897	323
Whiting	11014	2992	11275	2734
Saithe	267	283	267	283
Mackerel	95	70	95	70
Haddock	26120	5210	30863	4824
Herring	30917	17697	43803	16028
Sprat	56509	37953	54069	36254
Norway pout	179827	96849	253003	97850
Sandeel	544055	236530	884890	260893
Plaice	838	672	838	672
Sole	110	118	110	118

Table 2.9.4.3. Total biomass (metric tonnes) of various MSVPA species consumed by western mackerel in a revised 'key run' including western mackerel and starry ray as 'other predators'.

TOTAL BIOMASSES CONSUMED BY PREDATORS, COMPARED TO AVERAGE STOCK BIOMASS OF PREDATOR

PREDATOR W\_MACKEREL

Prey	Cod	Whiting	Saithe	Mackerel	Haddock	Herring	Sprat	N. Pout	Sandeel
1974	0.	0.	0.	0.	81035.	123.	0.	366846.	528591.
1975	0.	0.	0.	0.	20897.	299.	0.	1068583.	772014.
1976	0.	0.	0.	0.	5528.	119.	0.	178114.	137366.
1977	0.	0.	0.	0.	3475.	190.	0.	57135.	46687.
1978	0.	0.	0.	0.	8659.	208.	0.	89360.	77458.
1979	0.	0.	0.	0.	27887.	852.	0.	226221.	200560.
1980	0.	0.	0.	0.	17000.	1951.	0.	237422.	233670.
1981	0.	0.	0.	0.	19403.	3531.	0.	379681.	307363.
1982	0.	0.	0.	0.	14760.	52966.	12865.	456499.	349624.
1983	0.	0.	0.	0.	43990.	50582.	8777.	434295.	416891.
1984	0.	0.	0.	0.	31167.	21180.	5553.	464053.	385945.
1985	0.	0.	0.	0.	23679.	114959.	44693.	330469.	584610.
1986	0.	0.	0.	0.	30718.	229903.	14299.	407176.	535848.
1987	0.	0.	0.	0.	8575.	72498.	43941.	420849.	319926.
1988	0.	0.	0.	0.	9779.	78508.	28800.	275135.	498238.
1989	0.	0.	0.	0.	12432.	97071.	7036.	211291.	493216.

PREDATOR W\_MACKEREL

Prey	Plaice	Sole	Total	Other Food	Ave. Biomass
1974	0.	0.	977395.	1529248.	442769.
1975	0.	0.	1861791.	2929943.	841922.
1976	0.	0.	321128.	743961.	195792.
1977	0.	0.	107486.	328847.	89983.
1978	0.	0.	175685.	566260.	141257.
1979	0.	0.	455520.	1185477.	305261.
1980	0.	0.	490044.	2113888.	491198.
1981	0.	0.	709978.	1949702.	513514.
1982	0.	0.	886714.	2908892.	697052.
1983	0.	0.	954537.	3253653.	778935.
1984	0.	0.	907099.	3485681.	837533.
1985	0.	0.	1098409.	3683572.	849438.
1986	0.	0.	1218023.	4290638.	1033217.
1987	0.	0.	865788.	4561390.	1072346.
1988	0.	0.	890460.	3896305.	921879.
1989	0.	0.	811046.	3622822.	854968.

Table 2.9.4.4 Total biomass (metric tonnes) of various MSVPA species consumed by starry ray in a revised 'key-run' including western mackerel and starry ray as 'other predators'.

TOTAL BIOMASSES CONSUMED BY PREDATORS, COMPARED TO AVERAGE STOCK BIOMASS OF PREDATOR

PREDATOR RAJA RADIATA

Prey	Cod	Whiting	Saithe	Mackerel	Haddock	Herring	Sprat	N. Pout	Sandeel
1974	848.	8047.	0.	0.	42383.	0.	0.	0.	122053.
1975	976.	10159.	0.	0.	50809.	0.	0.	0.	118463.
1976	1133.	9548.	0.	0.	7801.	0.	0.	0.	107097.
1977	2275.	9901.	0.	0.	11584.	0.	0.	0.	99354.
1978	1437.	10569.	0.	0.	19266.	0.	0.	0.	100308.
1979	1846.	10861.	0.	0.	24354.	0.	0.	0.	92760.
1980	2463.	8433.	0.	0.	33728.	0.	0.	0.	82414.
1981	1420.	4985.	0.	0.	13335.	0.	0.	0.	68964.
1982	1713.	4066.	0.	0.	16461.	0.	0.	0.	97024.
1983	1204.	4601.	0.	0.	16511.	0.	0.	0.	81271.
1984	1425.	4720.	0.	0.	35413.	0.	0.	0.	89886.
1985	720.	5954.	0.	0.	16214.	0.	0.	0.	77455.
1986	1352.	6691.	0.	0.	16362.	0.	0.	0.	128602.
1987	626.	6374.	0.	0.	22288.	0.	0.	0.	141157.
1988	743.	9760.	0.	0.	5359.	0.	0.	0.	105592.
1989	795.	9321.	0.	0.	9120.	0.	0.	0.	146285.

PREDATOR RAJA RADIATA

Prey	Plaice	Sole	Total	Other Food	Ave. Biomass
1974	0.	0.	173332.	256669.	100000.
1975	0.	0.	180407.	249594.	100000.
1976	0.	0.	125579.	304421.	100000.
1977	0.	0.	123118.	306887.	100000.
1978	0.	0.	131581.	298419.	100000.
1979	0.	0.	130021.	299979.	100000.
1980	0.	0.	127033.	302962.	100000.
1981	0.	0.	88703.	341297.	100000.
1982	0.	0.	119263.	310737.	100000.
1983	0.	0.	103587.	326413.	100000.
1984	0.	0.	131444.	298556.	100000.
1985	0.	0.	100342.	329658.	100000.
1986	0.	0.	153007.	276993.	100000.
1987	0.	0.	170446.	259554.	100000.
1988	0.	0.	121453.	308547.	100000.
1989	0.	0.	165520.	264480.	100000.

Table 2.9.4.5. Total biomass (metric tonnes) of various MSVPA species consumed by all predators in a revised 'key-run' including western mackerel and starry ray as 'other predators'.

TOTAL BIOMASSES CONSUMED BY ALL PREDATORS, COMPARED TO TOTAL STOCK BIOMASS AND TOTAL YIELD

Year	-----MSVPA Species-----					-----Other Predators-----			
	Total Biomass	Average Biomass	Total Yield	Total Fish Eaten	Tot. Oth. Mortality	Tot. Oth. Food Eaten	Average Biomass	Total Fish Eaten	Tot. Oth. Food Eaten
1974	10679626.	10475205.	3157578.	6070088.	4696800.	9264407.	542769.	1150726.	1785917.
1975	10892950.	10075370.	3272390.	5625039.	4375788.	7319503.	941922.	2042198.	3179536.
1976	9320740.	8226153.	3276642.	4557712.	3430269.	6161708.	295792.	446707.	1048382.
1977	7559039.	6903842.	2634517.	3481252.	2852471.	5684589.	189983.	230600.	635733.
1978	6785943.	6435570.	2667848.	2875189.	2778400.	5267880.	241577.	307265.	864679.
1979	6569734.	6600272.	2577154.	2770470.	2970013.	5460052.	405261.	585541.	1485456.
1980	6936427.	6051199.	2740117.	2535076.	2430433.	4966439.	591198.	617082.	2416850.
1981	5323446.	5637819.	2559357.	2307355.	2517682.	4596980.	613514.	798681.	2290999.
1982	6469914.	6239044.	2539892.	2273221.	2533510.	3680578.	797052.	1005977.	3219628.
1983	5787030.	6207701.	2510925.	2020922.	2635077.	4228913.	878935.	1058124.	3580066.
1984	6773350.	6521019.	2769138.	1860043.	2506865.	3993927.	937533.	1039342.	3784237.
1985	6115351.	6268320.	2699711.	1901641.	2473331.	3750549.	949438.	1198751.	4013231.
1986	7039601.	7839822.	2150914.	2165758.	3090610.	3781774.	1133217.	1371030.	4167631.
1987	7965542.	8101266.	2613729.	1801776.	2746333.	2851872.	1172346.	1036234.	4820944.
1988	6778501.	7279631.	2770275.	1885533.	2580776.	3055947.	1021879.	1011914.	4304852.
1989	7994581.	7808601.	2571609.	2323777.	2641928.	3208085.	954968.	976566.	3387302.

Table 3.1 Total biomasses consumed by all predators, compared to total stock biomass, total predator biomass, total yield, and residual natural mortality in terms of biomass (1,000 t). Second figure refers to deviation of 1989 results in percent of 1989 results.

Year	Average biomass		Total Yield		Total VPA species eaten (TVSE)		Total oth. food eaten (TOFE)		Average predator biomass (APDB)		Yield Av. biom.		TVSE Av. biom.		TOFE Av. biom.		TVSE APDB	
1974	10723	4	3158	4	6192	1	8954	-2	3370	0	0.29	1	0.58	-2	0.84	-5	1.84	2
1975	10192	3	3272	4	5707	1	7356	-2	3201	0	0.32	0	0.56	-2	0.72	-5	1.78	2
1976	8498	4	3277	4	4725	1	6004	-2	2568	0	0.39	0	0.56	-2	0.71	-5	1.84	1
1977	7153	5	2635	5	3633	-1	5522	-2	2104	0	0.37	1	0.51	-5	0.77	-6	1.73	-1
1978	6660	5	2668	5	3006	1	5126	-2	1896	-1	0.40	0	0.45	-4	0.77	-7	1.59	1
1979	6778	5	2577	7	2873	1	5362	-3	1913	-1	0.38	2	0.42	-4	0.79	-7	1.50	2
1980	6143	5	2740	5	2608	1	4984	-2	1966	-1	0.45	0	0.42	-4	0.81	-7	1.33	2
1981	5579	5	2559	6	2349	2	4559	-3	1810	-1	0.46	0	0.42	-4	0.82	-8	1.30	3
1982	6180	6	2540	7	2293	-2	3706	-3	1629	-2	0.41	1	0.37	-7	0.60	-8	1.41	0
1983	6100	5	2511	7	2019	-2	4209	-4	1587	-2	0.41	2	0.33	-7	0.69	-8	1.27	0
1984	6431	3	2769	7	1847	-4	4061	-4	1631	-3	0.43	4	0.29	-7	0.63	-7	1.13	-1
1985	6146	5	2700	7	1906	-3	3758	-12	1558	-7	0.44	2	0.31	-8	0.61	-16	1.22	5
1986	7806	7	2151	9	2188	-11	3869	-13	1484	-11	0.28	2	0.28	-16	0.50	-19	1.47	0
1987	8085	7	2614	7	1784	-25	3005	-15	1336	-19	0.32	0	0.22	-29	0.37	-21	1.34	-7
1988	7122		2770		1865		3087		1338		0.39		0.26		0.43		1.39	
1989	7888		2572		2398		3094		1438		0.33		0.30		0.39		1.67	
Mean	7343		2720		2962		4791		1927		0.38		0.39		0.65		1.49	
CV	0.21		0.11		0.49		0.35		0.33		0.15		0.30		0.25		0.16	

Table 3.2.1. GLM models for smoothing suitabilities from the Central Baltic MSVPA. Dependent variable is log (suit). Lwr (log weight ratio) and lwrsq (log weight ratio squared) are continuous variables.

Model	Model	df	r <sup>2</sup>	F	All Parameters Significant at 0.1%
no.1 q py lwr lwrsq	8		0.31	61	yes
no.2 q py py*q lwr lwrsq	17		0.39	40	yes
no.3 q py py*q lwr lwrsq wpd	18		0.42	42	yes
no.4 q py py*q lwr(pda) lwrsq	25		0.42	30	yes
no.5 q py py*q lwr(pda) lwrsq wpd	26		0.42	29	wpd=34%
no.6 q py pda py*q lwr(pda) lwrsq wpd	34		0.43	23	q=4.4% pda=1.6%
no.7 q py pda py*q lwr(pda) lwrsq(pda)	41		0.44	20	pda=0.4%
no.8 q py pda py*q lwr(py*pda) lwrsq(pda)	68		0.47	13	yes
no.9 q py pda py*q lwr(py*pda) lwrsq(py*pda)	95		0.56	13	py=3.6%

wpd= log weight of predator  
q= quarter  
py= prey species  
pda= predator age

Table 3.2.2.3 Results of smoothing runs for suitabilities from MSVPA runs including various combinations of stomach contents data. Core model for smoothing included terms for Quarter (Q), predator species (PD), prey species (PY), Q\*PD, Q\*PY, and PD\*PY interactions, the log weight ratio of predator to prey (nested, for separate slopes for predators) and the log weight ratio squared.

Years of Stomach Data Included	r <sup>2</sup> of Model	Root MSE	Non-Significant Terms (Type III SS)
81	0.447	1.534	-
81,85	0.496	1.446	Q
86,87	0.412	1.697	Q, Q*PD
81,85,86	0.448	1.521	Q, PD
81,86,87*	0.474	1.500	PD
81,85,87	0.508	1.461	Q, PD
85,86,87**	0.483	1.576	-

\* only 2 predators included; saithe deleted

\*\*all 4 quarters and all 5 predators included.

Table 3.2.2.4.a Regression of diets observed in specified years (test years) on diets predicted by suitabilities using stomach data in other years. (Figures in brackets are not significant at the 1% level).

Years Used Estimating SUIT	Test Years	Quarter	Predator	----- r <sup>2</sup> -----		--- Slope ---		N
				Raw	Smoothed	Raw	Smoothed	
81,85,86	87	1/3	All	0.30	0.28	0.546	0.724	657
		1	Cod	0.48	0.15	0.726	0.355	166
		1	Whiting	0.20	0.27	0.638	0.583	119
		3	Cod	0.10	0.28	0.207	0.662	179
		3	Whiting	0.16	0.26	0.496	0.681	131
		3	Saithe	0.47	0.39	0.802	1.115	58
81,86,87	85	1/3	All	0.12	0.23	0.235	0.431	594
		1	Cod	0.31	0.43	0.627	0.766	164
		1	Whiting	0.77	0.82	1.223	1.051	117
		3	Cod	<0.01>	0.04	-	0.099	185
		3	Whiting	0.10	<0.02>	0.183	-	125
81,85,87	86	1/3	All	0.22	0.23	0.596	0.812	670
		1	Cod	0.35	0.39	0.997	0.865	166
		1	Whiting	0.64	0.75	1.091	1.080	120
		3	Cod	0.10	<0.03>	0.336	-	183
		3	Whiting	0.40	0.19	0.746	0.502	127
		3	Saithe	0.76	0.51	1.677	1.325	70
85,86,87	81	1/3	All	0.32	0.17	0.387	0.458	619
		1	Cod	0.27	0.12	0.436	0.344	162
		1	Whiting	0.26	0.30	0.442	0.346	101
		3	Cod	0.15	0.24	0.844	1.162	168
		3	Whiting	<0.04>	0.09	-	0.327	133
		3	Saithe	0.57	0.23	0.257	0.109	55



Table 3.2.2.4.b

Years Used Estimating SUIT	Test Year	Quarter	Predator	----- r2 -----		---- Slope ----		N	
				Raw	Smoothed	Raw	Smoothed		
81,85	86	1/3	All	0.17	0.20	0.495	0.815	628	
		1	Cod	0.33	0.37	0.926	0.851	163	
		1	Whiting	0.34	0.77	0.761	1.076	117	
		3	Cod	0.09	<0.03>	0.302	-	172	
		3	Whiting	0.15	0.14	0.492	0.443	121	
		3	Saithe	0.72	0.44	2.380	1.971	81	
	87	1/3	All	0.20	0.27	0.408	0.732	628	
		1	Cod	0.45	0.21	0.728	0.501	163	
		1	Whiting	0.09	0.16	0.406	0.472	117	
		3	Cod	0.06	0.34	0.134	0.650	172	
		3	Whiting	<0.02>	0.05	-	0.280	121	
		3	Saithe	0.69	0.59	1.240	2.094	81	
	86,87	81	1/3	All	0.25	0.15	0.438	0.277	584
			1	Cod	0.31	0.18	0.484	0.452	148
1			Whiting	0.26	0.29	0.434	0.496	95	
3			Cod	0.30	0.16	0.790	0.337	158	
3			Whiting	0.04	<0.03>	0.177	-	124	
3			Saithe	0.57	0.30	0.258	0.153	55	
85		1/3	All	0.28	0.25	0.437	0.386	527	
		1	Cod	0.40	0.43	0.579	0.575	147	
		1	Whiting	0.82	0.87	1.010	0.957	96	
		3	Cod	0.05	<0.00>	0.113	-	158	
		3	Whiting	0.12	<0.03>	0.195	-	124	

Table 3.2.2.4.c

Years Used Estimating SUIT	Test Years	Quarter	Predator	----- r <sup>2</sup> -----		---- Slope ----		N
				Raw	Smoothed	Raw	Smoothed	
81	85	1/3	All	0.03	0.20	0.093	0.381	490
		1	Cod	0.14	0.46	0.444	0.860	141
		1	Whiting	0.31	0.78	0.763	1.164	107
		3	Cod	<0.00>	0.05	-	0.102	143
		3	Whiting	<0.03>	<0.04>	-	-	96
		3	Saithe	0.75	0.44	2.430	1.954	81
	86	1/3	All	0.17	0.27	0.317	0.683	542
		1	Cod	0.17	0.43	0.617	0.918	141
		1	Whiting	0.18	0.70	0.485	1.087	107
		3	Cod	0.32	0.23	0.243	0.520	143
		3	Whiting	<0.02>	<0.01>	-	-	96
		3	Saithe	0.75	0.44	2.430	1.954	81
	87	1/3	All	0.12	0.18	0.238	0.484	543
		1	Cod	0.42	0.24	0.627	0.501	141
		1	Whiting	<0.02>	0.35	-	0.888	107
		3	Cod	<0.03>	0.15	-	0.276	144
		3	Whiting	<0.01>	<0.01>	-	-	96
		3	Saithe	0.69	0.58	1.222	2.052	51

Table 3.2.2.4d Regression of diets observed in 1985/86/87 by prey and predator species on diets predicted by suitabilities using stomach data for 1981. (Figures in brackets are not significant at the 1% level).

Quarter	Predator	Prey	r <sup>2</sup>		
1	Cod	Cod	0.54		
		Whiting	0.44		
		Haddock	0.47		
		Herring	<0.00>		
		Sprat	<0.01>		
		Norway pout	0.47		
	Whiting	Sandeel	0.41		
		Cod	0.23		
		Whiting	<0.03>		
		Haddock	<0.00>		
		Herring	0.81		
		Sprat	0.05		
		Norway pout	0.25		
		Sandeel	0.90		
		3	Cod	Cod	0.08
				Whiting	0.75
Haddock	<0.00>				
Herring	<0.01>				
Sprat	0.22				
Norway pout	0.74				
Whiting	Sandeel		0.63		
	Cod		0.99		
	Whiting		0.66		
	Haddock		0.70		
	Herring		<0.01>		
	Sprat		<0.00>		
	Norway pout		<0.01>		
	Sandeel		0.29		
	Saithe		Cod	0.18	
			Whiting	0.59	
Haddock			0.44		
Norway pout			0.77		
Sandeel		<0.02>			

Table 4.1.1 Baseline long-term predictions using MSFOR. All weights in thousands of tonnes, values in millions of ECUs.

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	109	309	110	31	198	724	296	819	1348	342	34	
Fishery Yield (Weight)												
												TOTAL
RF - HC	265	79	87	0	150	0	0	0	0	0	0	581
RF - DISC	0	53	0	0	117	0	0	0	0	0	0	170
IND - DEM	0	60	5	0	18	0	0	474	1000	0	0	1556
IND - PEL	0	10	0	0	0	215	250	0	0	0	0	475
HERRING -	0	0	0	0	0	208	0	0	0	0	0	208
SAITHE	0	0	71	0	0	0	0	0	0	0	0	71
MACKEREL	0	0	0	35	0	0	0	0	0	0	0	35
FLATFISH	0	0	0	0	0	0	0	0	0	163	20	183
TOTAL	265	202	163	35	285	423	250	474	1000	163	19	3279
Fishery Value												
												TOTAL
RF - HC	329	85	63	0	152	0	0	0	0	0	0	628
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	4	0	0	1	0	0	33	70	0	0	109
IND - PEL	0	1	0	0	0	15	17	0	0	0	0	33
HERRING -	0	0	0	0	0	69	0	0	0	0	0	69
SAITHE	0	0	51	0	0	0	0	0	0	0	0	51
MACKEREL	0	0	0	18	0	0	0	0	0	0	0	18
FLATFISH	0	0	0	0	0	0	0	0	0	193	122	315
TOTAL	329	90	114	18	153	84	17	33	70	193	122	1223

Table 4.1.2 Baseline predictions using the Shepherd Model.  
All weights in thousands of tonnes, values in millions of ECUs.

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	129	396	126	40	141	591	319	1490	1850	341	33	
Fishery Yield (Weight)												
												TOTAL
RF - HC	270	79	92	0	90	0	0	0	0	0	0	532
RF - DISC	0	54	0	0	113	0	0	0	0	0	0	167
IND - DEM	0	80	5	0	23	0	0	574	776	0	0	1456
IND - PEL	0	15	0	0	0	162	265	0	0	0	0	443
HERRING -	0	0	0	0	0	129	0	0	0	0	0	129
SAITHE	0	0	75	0	0	0	0	0	0	0	0	75
MACKEREL	0	0	0	37	0	0	0	0	0	0	0	37
FLATFISH	0	0	0	0	0	0	0	0	0	163	19	182
TOTAL	270	228	172	37	226	291	265	574	776	163	19	3021
FISHERY VALUE												
												TOTAL
RF - HC	335	86	66	0	90	0	0	0	0	0	0	577
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	6	0	0	2	0	0	40	54	0	0	102
IND - PEL	0	1	0	0	0	11	19	0	0	0	0	31
HERRING -	0	0	0	0	0	41	0	0	0	0	0	41
SAITHE	0	0	54	0	0	0	0	0	0	0	0	54
MACKEREL	0	0	0	19	0	0	0	0	0	0	0	19
FLATFISH	0	0	0	0	0	0	0	0	0	192	120	312
TOTAL	335	92	120	19	92	52	19	40	54	192	120	1135

Table 4.2.1a. Percent deviations in MSFOR predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Roundfish Human Consumption and Discard Fisheries, as compared to baseline runs (Table 4.1.1).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	-58	-8	-39	0	-8	11	1	19	1	0	0	
<b>Fishery Yield (Weight)</b>												
												TOTAL
RF - HC	6	8	10	0	18	0	0	0	0	0	0	10
RF - DISC	0	47	0	0	79	0	0	0	0	0	0	69
IND - DEM	0	-2	-20	0	17	0	0	36	1	0	0	12
IND - PEL	0	0	0	0	0	10	1	0	0	0	0	5
HERRING -	0	0	0	0	0	13	0	0	0	0	0	13
SAITHE	0	0	-23	0	0	0	0	0	0	0	0	-23
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	6	15	-5	0	43	11	1	36	1	0	0	12
<b>Fishery Value</b>												
												TOTAL
RF - HC	1	7	8	0	13	0	0	0	0	0	0	6
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	36	1	0	0	12
IND - PEL	0	0	0	0	0	13	6	0	0	0	0	6
HERRING -	0	0	0	0	0	14	0	0	0	0	0	14
SAITHE	0	0	-24	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	1	7	-6	0	12	14	6	36	1	0	0	4

Table 4.2.1b. Percent deviations in SHEPHERD MODEL predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Roundfish Human Consumption and Discard Fisheries, as compared to baseline runs (Table 4.1.2).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	-53	-6	-38	0	-14	9	0	7	1	0	0	
<b>Fishery Yield (Weight)</b>												
												TOTAL
RF - HC	9	12	11	0	9	0	0	0	0	0	0	10
RF - DISC	0	45	0	0	59	0	0	0	0	0	0	54
IND - DEM	0	-2	-16	0	3	0	0	17	1	0	0	7
IND - PEL	0	0	0	0	0	7	0	0	0	0	0	7
HERRING -	0	0	0	0	0	10	0	0	0	0	0	10
SAITHE	0	0	-22	0	0	0	0	0	0	0	0	-22
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	9	14	-4	0	34	9	0	17	1	0	0	9
<b>FISHERY VALUE</b>												
												TOTAL
RF - HC	5	10	10	0	5	0	0	0	0	0	0	6
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	-2	-15	0	3	0	0	17	1	0	0	7
IND - PEL	0	0	0	0	0	7	0	0	0	0	0	7
HERRING -	0	0	0	0	0	12	0	0	0	0	0	12
SAITHE	0	0	-23	0	0	0	0	0	0	0	0	-23
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	5	9	-5	0	5	11	0	17	1	0	0	3

Table 4.2.2a. Percent deviations in MSFOR predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Industrial Demersal Fishery, as compared to baseline runs (Table 4.1.1).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	-1	-10	-3	0	-4	3	1	-12	-28	0	0	
Fishery Yield (Weight)												
												TOTAL
RF - HC	-1	-16	-2	0	-5	0	0	0	0	0	0	-4
RF - DISC	0	-8	0	0	-3	0	0	0	0	0	0	-4
IND - DEM	0	40	40	0	44	0	0	15	11	0	0	14
IND - PEL	0	0	0	0	0	2	1	0	0	0	0	2
HERRING -	0	0	0	0	0	2	0	0	0	0	0	2
SAITHE	0	0	-1	0	0	0	0	0	0	0	0	-1
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	-1	3	-1	0	0	2	1	15	11	0	0	6
Fishery Value												
												TOTAL
RF - HC	-1	-16	-3	0	-5	0	0	0	0	0	0	-4
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	50	0	0	100	0	0	15	11	0	0	14
IND - PEL	0	0	0	0	0	0	6	0	0	0	0	3
HERRING -	0	0	0	0	0	3	0	0	0	0	0	3
SAITHE	0	0	-2	0	0	0	0	0	0	0	0	-2
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	-1	-13	-2	0	-5	2	6	15	11	0	0	-1

Table 4.2.2b. Percent deviations in SHEPHERD MODEL predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Industrial Demersal Fishery, as compared to baseline runs (Table 4.1.2).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	0	-7	-2	0	1	5	2	-4	-21	0	0	
Fishery Yield (Weight)												
												TOTAL
RF - HC	1	-13	-2	0	1	0	0	0	0	0	0	-2
RF - DISC	0	-5	0	0	2	0	0	0	0	0	0	<1
IND - DEM	0	44	48	0	52	0	0	32	19	0	0	26
IND - PEL	0	-2	0	0	0	4	1	0	0	0	0	2
HERRING -	0	0	0	0	0	5	0	0	0	0	0	5
SAITHE	0	0	-2	0	0	0	0	0	0	0	0	-2
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	9	0	0	7	4	2	32	19	0	0	23
FISHERY VALUE												
												TOTAL
RF - HC	1	-14	-2	0	1	0	0	0	0	0	0	-2
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	44	50	0	52	0	0	32	19	0	0	26
IND - PEL	0	-2	0	0	0	4	1	0	0	0	0	2
HERRING -	0	0	0	0	0	5	0	0	0	0	0	5
SAITHE	0	0	-2	0	0	0	0	0	0	0	0	-2
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	1	-10	-2	0	1	5	1	33	18	0	0	2

Table 4.2.3a. Percent deviations in MSFOR predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the **Industrial Pelagic Fishery**, as compared to baseline runs (Table 4.1.1).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	-1	-3	0	0	-2	-24	-24	0	0	0	0	
<b>Fishery Yield (Weight)</b>												
												TOTAL
RF - HC	-1	-4	0	0	-2	0	0	0	0	0	0	-2
RF - DISC	0	-2	0	0	-2	0	0	0	0	0	0	-2
IND - DEM	0	-3	0	0	0	0	0	-1	0	0	0	0
IND - PEL	0	50	0	0	0	18	21	0	0	0	0	20
HERRING -	0	0	0	0	0	-27	0	0	0	0	0	-27
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	-1	0	0	0	-2	-4	21	-1	0	0	0	1
<b>Fishery Value</b>												
												TOTAL
RF - HC	-1	-4	0	0	-2	0	0	0	0	0	0	-1
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	0	0	0	0
IND - PEL	0	0	0	0	0	20	24	0	0	0	0	21
HERRING -	0	0	0	0	0	-30	0	0	0	0	0	-30
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	-1	-3	0	0	-2	-21	24	0	0	0	0	-2

Table 4.2.3b. Percent deviations in SHEPHERD MODEL predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the **Industrial Pelagic Fishery**, as compared to baseline runs (Table 4.1.2).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	0	-1	0	0	1	-21	-20	0	1	0	0	
<b>Fishery Yield (Weight)</b>												
												TOTAL
RF - HC	0	-2	0	0	1	0	0	0	0	0	0	<1
RF - DISC	0	-1	0	0	1	0	0	0	0	0	0	<1
IND - DEM	0	-1	0	0	0	0	0	0	0	0	0	-1
IND - PEL	0	49	0	0	0	23	30	0	0	0	0	28
HERRING -	0	0	0	0	0	-23	0	0	0	0	0	-23
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	2	0	0	1	3	30	0	1	0	0	3
<b>FISHERY VALUE</b>												
												TOTAL
RF - HC	0	-2	0	0	1	0	0	0	0	0	0	<1
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	-1	0	0	0	0	0	0	0	0	0	-1
IND - PEL	0	49	0	0	0	23	30	0	0	0	0	28
HERRING -	0	0	0	0	0	-26	0	0	0	0	0	-26
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	-1	0	0	1	-15	30	0	0	0	0	<1

Table 4.2.4a. Percent deviations in MSFOR predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Herring Fishery, as compared to baseline runs (Table 4.1.1).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	0	0	0	0	0	-18	0	0	0	0	0	
Fishery Yield (Weight)												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	0	0	0	0
IND - PEL	0	0	0	0	0	-15	0	0	0	0	0	-7
HERRING -	0	0	0	0	0	18	0	0	0	0	0	18
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	0	0	1	0	0	0	0	0	<1
Fishery Value												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	0	0	0	0
IND - PEL	0	0	0	0	0	-13	0	0	0	0	0	-6
HERRING -	0	0	0	0	0	14	0	0	0	0	0	13
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	0	0	8	0	0	0	0	0	<1

Table 4.2.4b. Percent deviations in SHEPHERD MODEL predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Herring Fishery, as compared to baseline runs (Table 4.1.2).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	0	0	0	0	0	-15	0	0	0	0	0	
Fishery Yield (Weight)												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	0	0	0	0
IND - PEL	0	0	0	0	0	-13	0	0	0	0	0	-13
HERRING -	0	0	0	0	0	24	0	0	0	0	0	24
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	0	0	3	0	0	0	0	0	<1
FISHERY VALUE												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	0	0	0	0
IND - PEL	0	0	0	0	0	-13	0	0	0	0	0	-13
HERRING -	0	0	0	0	0	19	0	0	0	0	0	19
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	0	0	12	0	0	0	0	0	1



Table 4.2.5a. Percent deviations in MSFOR predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Saithe Fishery, as compared to baseline runs (Table 4.1.1).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	4	1	-35	0	19	2	0	12	-1	0	0	
Fishery Yield (Weight)												
												TOTAL
RF - HC	3	1	-24	0	18	0	0	0	0	0	0	3
RF - DISC	0	2	0	0	17	0	0	0	0	0	0	12
IND - DEM	0	13	0	0	11	0	0	23	0	0	0	7
IND - PEL	0	0	0	0	0	1	0	0	0	0	0	1
HERRING -	0	0	0	0	0	2	0	0	0	0	0	2
SAITHE	0	0	18	0	0	0	0	0	0	0	0	18
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	3	1	-5	0	18	2	0	23	0	0	0	5
Fishery Value												
												TOTAL
RF - HC	3	1	-25	0	18	0	0	0	0	0	0	4
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	24	0	0	0	6
IND - PEL	0	0	0	0	0	0	6	0	0	0	0	3
HERRING -	0	0	0	0	0	1	0	0	0	0	0	1
SAITHE	0	0	18	0	0	0	0	0	0	0	0	18
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	3	1	-6	0	18	2	6	24	0	0	0	4

Table 4.2.5b. Percent deviations in SHEPHERD MODEL predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Saithe Fishery, as compared to baseline runs (Table 4.1.2).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	1	0	-33	0	14	1	0	5	-1	0	0	
Fishery Yield (Weight)												
												TOTAL
RF - HC	1	0	-23	0	15	0	0	0	0	0	0	2
RF - DISC	0	0	0	0	9	0	0	0	0	0	0	9
IND - DEM	0	0	-16	0	5	0	0	13	0	0	0	5
IND - PEL	0	0	0	0	0	1	0	0	0	0	0	1
HERRING -	0	0	0	0	0	1	0	0	0	0	0	1
SAITHE	0	0	19	0	0	0	0	0	0	0	0	19
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	1	0	-5	0	11	1	0	13	0	0	0	3
FISHERY VALUE												
												TOTAL
RF - HC	1	0	-24	0	15	0	0	0	0	0	0	<1
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	-15	0	4	0	0	13	0	0	0	5
IND - PEL	0	0	0	0	0	1	0	0	0	0	0	1
HERRING -	0	0	0	0	0	1	0	0	0	0	0	1
SAITHE	0	0	19	0	0	0	0	0	0	0	0	19
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	1	0	-5	0	14	1	0	13	0	0	0	1

Table 4.2.6a. Percent deviations in MSFOR predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Mackerel Fishery, as compared to baseline runs (Table 4.1.1).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	2	0	0	-48	1	2	1	0	4	0	0	
Fishery Yield (Weight)												
												TOTAL
RF - HC	1	0	0	0	0	0	0	0	0	0	0	1
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	1
IND - DEM	0	0	0	0	0	0	0	1	3	0	0	2
IND - PEL	0	0	0	0	0	1	1	0	0	0	0	1
HERRING -	0	0	0	0	0	2	0	0	0	0	0	2
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	3	0	0	0	0	0	0	0	3
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	1	0	0	3	0	2	1	1	3	0	0	2
Fishery Value												
												TOTAL
RF - HC	1	0	0	0	0	0	0	0	0	0	0	1
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	3	0	0	3
IND - PEL	0	0	0	0	0	0	6	0	0	0	0	3
HERRING -	0	0	0	0	0	1	0	0	0	0	0	1
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	6	0	0	0	0	0	0	0	6
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	1	0	0	6	0	2	6	0	3	0	0	1

Table 4.2.6b. Percent deviations in SHEPHERD MODEL predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Mackerel Fishery, as compared to baseline runs (Table 4.1.2).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	0	0	0	-47	-1	1	1	0	3	0	0	
Fishery Yield (Weight)												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	3	0	0	2
IND - PEL	0	0	0	0	0	1	1	0	0	0	0	1
HERRING -	0	0	0	0	0	0	0	0	0	0	0	0
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	4	0	0	0	0	0	0	0	4
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	4	0	1	1	0	3	0	0	1
FISHERY VALUE												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	3	0	0	3
IND - PEL	0	0	0	0	0	1	1	0	0	0	0	1
HERRING -	0	0	0	0	0	1	0	0	0	0	0	1
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	3	0	0	0	0	0	0	0	3
FLATFISH	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	3	0	1	1	0	3	0	0	1

Table 4.2.7a. Percent deviations in MSFOR predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Flatfish Fishery, as compared to baseline runs (Table 4.1.1).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	0	0	0	0	0	0	0	0	0	-29	-38	
<b>Fishery Yield (Weight)</b>												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	0	0	0	0
IND - PEL	0	0	0	0	0	0	0	0	0	0	0	0
HERRING -	0	0	0	0	0	0	0	0	0	0	0	0
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	-4	-10	-4
TOTAL	0	0	0	0	0	0	0	0	0	-4	-10	<1
<b>Fishery Value</b>												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	0	0	0	0
IND - PEL	0	0	0	0	0	0	0	0	0	0	0	0
HERRING -	0	0	0	0	0	0	0	0	0	0	0	0
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	-11	-8	-10
TOTAL	0	0	0	0	0	0	0	0	0	-11	-8	-3

Table 4.2.7b. Percent deviations in SHEPHERD MODEL predictions of fishery and species yields and SSBs (thousands of tonnes) and yields in value (millions of ECUs) contingent upon a 50% increase in effort in the Flatfish Fishery, as compared to baseline runs (Table 4.1.2).

SPECIES >	COD	WHI	SAI	MAC	HAD	HER	SPR	NOP	AMM	PLE	SOL	
SSB	0	0	0	0	0	0	0	0	0	-28	-38	
<b>Fishery Yield (Weight)</b>												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	0	0	0	0
IND - PEL	0	0	0	0	0	0	0	0	0	0	0	0
HERRING -	0	0	0	0	0	0	0	0	0	0	0	0
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	-4	-5	-4
TOTAL	0	0	0	0	0	0	0	0	0	-4	-5	<1
<b>FISHERY VALUE</b>												
												TOTAL
RF - HC	0	0	0	0	0	0	0	0	0	0	0	0
RF - DISC	0	0	0	0	0	0	0	0	0	0	0	0
IND - DEM	0	0	0	0	0	0	0	0	0	0	0	0
IND - PEL	0	0	0	0	0	0	0	0	0	0	0	0
HERRING -	0	0	0	0	0	0	0	0	0	0	0	0
SAITHE	0	0	0	0	0	0	0	0	0	0	0	0
MACKEREL	0	0	0	0	0	0	0	0	0	0	0	0
FLATFISH	0	0	0	0	0	0	0	0	0	-11	-7	-9
TOTAL	0	0	0	0	0	0	0	0	0	-10	-8	-3

Table 4.3.3.1. Relative Sensitivities of Long Term Yields to MSVPA Parameters. Sensitivities are expressed as the percent change in the response variable (% of mean) caused by a 10% change in the parameter. Mean catches and total value are based on averages computed from the simulations used in the fractional factorial experiments.

	Long Term Yields (Weight)						
	Cod	Whiting	Saithe	Macker	Haddock	Herring	Sprat
Mean Catch	269422	201789	163039	34542	302167	422441	274291
MIXSUI	0.3	-0.1	-0.3	0.2	0.6	0.4	0.1
MIXM2	0.1	0.2	-0.4	-0.1	0.0	-0.4	0.3
EPFSF1	0.1	-0.1	0.4	-0.1	-0.3	0.3	0.2
EPFMS2	-0.2	0.3	0.4	-0.1	-1.0	-0.2	-0.3
EPSUI	-0.4	-0.1	0.4	0.1	-1.9	-0.4	-0.2
OTHFood	0.1	0.0	0.1	0.0	0.0	0.0	0.0
LLimWSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ULimWSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CODM1	-1.6	0.1	0.4	0.0	-1.6	-0.4	-0.2
WHITGM1	0.1	-0.5	0.4	0.0	-0.6	0.1	0.6
SAITNM1	0.5	0.3	-1.3	0.0	3.8	0.2	0.4
MACKLM1	1.0	0.1	-0.4	1.0	0.0	1.0	0.7
HADDKM1	-0.2	-0.4	-0.4	0.0	-2.9	-0.1	0.6
HERRGM1	0.1	0.2	-0.5	0.0	0.0	-1.1	-0.7
SPRATM1	-0.1	-0.1	0.4	0.0	-0.4	0.1	-0.9
NPOUTM1	-0.3	0.2	0.4	0.0	-2.6	-0.4	-0.2
Sandem1	0.1	-0.4	-0.4	0.0	1.0	0.1	0.2
PLAICM1	0.0	0.1	-0.4	0.0	0.4	-0.4	-0.3
SOLEM1	-0.1	-0.2	0.4	0.0	-0.2	0.2	0.7
CODFC	-0.7	0.1	0.1	0.0	-0.6	-0.8	-0.1
WHITGFC	-0.5	0.0	0.1	0.0	-1.1	-0.8	0.3
SAITHFC	0.6	0.0	0.1	0.0	3.0	0.1	-0.2
MACKLFC	1.3	0.2	-0.1	0.0	0.9	1.4	2.2
HADDHFC	0.1	0.0	-0.1	0.0	0.3	0.0	0.0
CODTFM	-0.2	0.0	0.4	-0.1	0.1	-0.4	-0.8
WHITTFM	-0.1	-0.3	0.4	-0.1	-0.4	-0.1	0.7
SATHTFM	-0.1	0.2	-0.4	-0.1	0.1	-0.1	-0.1
MACKTFM	0.4	0.1	-0.4	-0.1	1.8	0.3	0.0
HADDTFM	0.2	-0.3	-0.4	0.1	1.1	0.2	0.3
HERRTFM	-0.1	0.1	-0.4	0.1	0.4	-0.3	-0.2
SPRTTFM	0.0	-0.2	0.4	0.1	0.0	0.4	0.2
N.PTTFM	0.0	0.3	0.5	0.1	0.2	0.1	0.4
SANDTFM	0.1	0.3	0.4	0.1	0.5	0.0	0.5

Table 4.3.3.1. (continued).

Mean Catch	Long Term Yields (Biomass)				Total	Total Value
	N. Pout	Sandeel	Plaice	Sole		
	516625	1075352	162701	19561	3445888	1248821
MIXSUI	1.0	-0.1	-0.3	-0.2	0.4	0.1
MIXM2	1.1	-0.9	0.4	-0.5	0.1	0.0
EPFSF1	0.3	-0.4	-0.4	0.4	0.2	0.0
EPEMS2	-1.1	0.4	0.4	0.5	-0.3	-0.1
EPSUI	-1.6	0.8	0.4	0.5	-0.4	-0.2
OTHFood	0.2	0.2	-0.1	0.1	0.1	0.0
LLimWSW	0.0	0.0	0.0	0.0	0.0	0.0
ULimWSW	0.0	0.0	0.0	0.0	0.0	0.0
CODM1	-1.7	0.4	-0.4	-0.5	-0.6	-0.8
WHITGM1	0.4	0.5	0.4	-0.4	0.0	0.0
SAITNM1	4.9	0.3	-0.4	0.5	1.0	0.7
MACKLM1	0.1	3.3	0.4	0.4	1.1	0.6
HADDKM1	0.2	1.0	0.4	0.4	-0.1	-0.4
HERRGM1	1.8	0.4	-0.4	0.5	0.0	0.0
SPRATM1	0.5	-0.3	0.4	-0.4	0.1	0.0
NPOUTM1	-4.8	-0.7	-0.4	-0.5	-1.1	-0.7
Sandem1	1.3	-3.1	0.4	0.5	-0.5	0.1
PLAICM1	-0.3	-1.1	-1.6	0.4	-0.3	-0.3
SOLEM1	-1.5	0.8	0.4	-1.2	-0.1	-0.2
CODFC	-0.3	-0.5	-0.1	-0.1	-0.5	-0.4
WHITGFC	-0.6	-1.0	-0.1	-0.1	-0.7	-0.4
SAITHFC	2.2	-0.4	0.1	-0.1	0.6	0.6
MACKLFC	0.9	3.5	-0.1	0.1	1.8	0.8
HADDKFC	-0.1	-0.3	0.1	0.1	0.0	0.1
CODTFM	0.1	-1.1	0.4	0.4	-0.2	0.1
WHITTFM	-1.3	-0.6	-0.4	0.5	-0.2	-0.1
SATHTFM	-0.3	-0.9	0.4	-0.4	-0.1	0.0
MACKTFM	1.8	-0.7	-0.4	-0.5	0.4	0.2
HADDTFM	1.6	-0.4	-0.4	-0.5	0.4	0.2
HERRTFM	-0.1	0.4	0.4	-0.4	-0.1	0.0
SPRTTFM	-1.4	0.9	-0.4	0.5	-0.1	0.0
N.PTTFM	0.2	0.5	0.4	0.4	0.1	0.2
SANDTFM	0.6	0.5	0.4	0.4	0.2	0.2

Table 4.3.3.2. Relative Sensitivities of Long Term Yields to MSFOR Parameters. Sensitivities are expressed as the percent change in the response variable (% of mean) caused by a 10% change in the parameter. Mean catches (t) and total value (ECUs) are based on simulation runs used in the fractional factorial experiments.

	Long Term Yields (Weight)						
	Cod	Whiting	Saithe	Mackl	Haddock	Herring	Sprat
Mean Catch	269422	201789	163039	34542	302167	4221441	274291
CODTFF	1.5	1.0	0.4	0.1	1.5	0.5	-0.7
WHITFFF	0.7	2.4	-0.4	0.1	4.1	1.9	0.5
SATHFFF	2.0	0.0	-2.3	0.1	10.8	1.1	0.3
MACKFFF	0.6	0.2	-0.4	0.9	1.8	1.0	0.5
HADDFFF	-0.2	0.3	-0.4	-0.1	0.3	-0.1	-0.1
HERRFFF	-0.3	-0.4	0.4	-0.1	-0.6	0.3	0.5
SPRTFFF	-0.4	-0.2	0.4	-0.1	-0.6	-0.7	4.4
N.PTFFF	0.2	0.0	-0.4	0.0	1.6	0.4	0.2
SANDFFF	-0.3	-0.1	-0.4	0.0	0.1	-0.3	-0.3
PLAITFF	-0.1	-0.3	0.4	0.0	-0.4	0.0	-0.4
SOLEFFF	-0.2	0.0	0.4	0.0	-0.3	-0.3	0.3
CODRecr	5.8	-0.7	0.4	0.0	-1.0	-1.2	-0.7
WHITNGR	-1.5	2.9	0.4	0.0	-4.2	-3.4	-2.3
SAITHER	-1.7	-0.5	7.8	0.0	-10.7	-1.1	-0.4
MACKRLR	-0.3	-0.4	-0.4	8.3	0.9	-0.3	-0.3
HADDCKR	0.1	0.3	0.4	0.0	8.2	0.0	-0.2
HERRNGR	0.2	0.1	0.4	0.0	-0.2	9.0	0.3
SPRATR	0.6	0.8	-0.4	0.0	1.2	1.0	8.9
N.POUTR	1.4	0.4	-0.4	0.0	6.9	1.3	1.1
SANDELR	1.2	1.5	-0.4	0.0	2.3	1.1	0.2
PLAICER	0.0	0.2	-0.4	0.0	0.1	0.0	0.4
SOLERec	0.1	-0.2	0.4	0.0	-0.6	0.1	0.2
RONDFLf	2.9	2.6	-0.5	0.0	6.9	1.7	-0.2
IDEMFLf	-0.1	0.5	-0.5	0.1	-0.1	0.6	0.8
IPELFLf	-0.1	0.2	-0.4	0.1	0.2	-0.1	4.6
HERRFLf	0.1	-0.2	0.4	0.1	-0.4	0.6	0.2
SAITFLf	0.6	0.0	0.5	0.1	2.3	-0.1	-0.2
MACKFLf	0.2	0.4	0.4	0.8	-1.3	0.3	0.1
FLATFLf	-0.1	-0.1	0.4	-0.1	-0.8	0.3	0.2

Table 4.3.3.2. (Continued).

	N.	Pout	Long Term Yields (Weight)			Total	Total Value
			Sandeel	Plaice	Sole		
Mean Catch	516625	1075352	162701	19561	3445888	1248821	
CODTFF	-1.5	-0.8	-0.4	0.5	0.1	0.6	
WHITTFF	1.2	-0.6	0.4	-0.4	1.1	0.8	
SATHTFF	12.9	-0.9	-0.4	-0.5	3.0	2.1	
MACKTFF	2.0	1.6	-0.4	-0.5	1.0	0.4	
HADDTFF	1.1	0.7	0.4	-0.4	0.2	-0.7	
HERRTFF	-1.3	0.7	-0.4	0.5	-0.2	-0.3	
SPRTTFF	0.1	0.2	0.4	0.4	0.1	0.0	
N. PTTFF	4.9	1.0	0.4	0.5	1.1	0.5	
SANDTFF	-0.4	3.2	-0.4	0.4	0.6	-0.1	
PIAITFF	-1.9	0.7	-0.6	-0.5	-0.3	-0.5	
SOLETFF	-0.3	0.2	-0.4	-1.6	-0.2	-0.4	
CODRecr	0.2	-0.9	-0.4	-0.4	0.1	1.1	
WHITNGR	-3.0	-4.2	0.4	-0.5	-2.4	-1.3	
SAITHER	-13.0	-0.9	-0.4	0.4	-3.0	-1.7	
MACKRLR	0.9	-3.0	0.4	0.5	-0.5	0.1	
HADDCKR	-1.8	-1.0	-0.4	-0.5	0.0	0.9	
HERRNGR	0.4	0.8	0.4	-0.4	1.3	0.7	
SPRATR	1.8	0.5	-0.4	0.5	1.3	0.6	
N. POUTR	16.4	0.5	0.4	0.4	3.4	2.0	
SANDELR	1.3	11.6	0.4	0.4	4.5	1.7	
PLAICER	1.5	-0.8	7.7	0.5	0.6	1.2	
SOLERec	0.5	-0.3	0.4	7.7	0.2	0.8	
RONDFLf	6.3	-1.0	-0.4	-0.5	2.0	1.3	
IDEMFLf	3.4	2.7	0.4	-0.4	1.7	-0.1	
IPELFLf	1.2	-0.6	-0.4	0.5	0.6	-0.2	
HERRFLf	-0.2	-0.3	0.4	0.4	0.1	0.1	
SAITFLf	3.2	-0.9	0.4	0.5	0.6	0.6	
MACKFLf	-1.6	1.4	0.4	0.5	0.0	0.0	
FLATFLf	0.1	0.9	-1.5	-0.9	0.0	-0.7	

Table 5.1 Years and age ranges in data sets. Column 1=variables column 2-8=area/subarea. Table gives maximum year and age range.

Independent variable		Barents	Greenland		Iceland	Newfoundland		
		sea	Spring	Fall	NE	2J	3K	3L
Cod biomass	Years	79-90		75-89	78-90	62-89	62-89	62-89
	Ages summed	3-		3-12+	3- 9	3-13	3-13	3-13
Capelin		73-79			78-89	72-89	72-89	72-89
Temperature		21-89		73-89	72-90	46-89	46-89	46-89
Cod lengths	Years	79-90	76-90	80-89	65-89	see Section 5.1.4		5.1.4
	Age range	3- 8	5- 8	5- 8	4- 9	1+	1+	1+



Table 5.3.1.1 Correlations between variables.

Table 5.3.1.1a Barents Sea.

	1/COD	CAPELIN	CAP/COD	TEMP
1/COD	1.00	-0.28	-0.12	0.72
CAPELIN	-0.28	1.00	0.97	-0.50
CAP/COD	-0.12	0.97	1.00	-0.22
TEMP	0.72	-0.50	-0.22	1.00

5.3.1.1b Greenland, spring: the correlation between 1/COD and TEMP is 0.28.

5.3.1.1c Greenland, autumn: the correlation between 1/COD and TEMP is 0.26.

Table 5.3.1.1d Iceland, North-East

	1/COD	CAPELIN	CAP/COD	TEMP
1/COD	1.00	-0.21	0.24	-0.36
CAPELIN	-0.21	1.00	0.89	0.25
CAP/COD	0.24	0.89	1.00	0.06
TEMP	-0.36	0.25	0.06	1.00

Table 5.3.1.1e Newfoundland 2J, 3K and 3L

	1/COD	CAPELIN	CAP/COD	TEMP
1/COD	1.00	-0.17	-0.10	0.82
CAPELIN	-0.17	1.00	0.99	-0.40
CAP/COD	-0.10	0.99	1.00	-0.31
TEMP	0.82	-0.40	-0.31	1.00

Table 5.3.1.2 Description of models with classification variables.  
Significance levels and degrees of freedom.  
Dependent variable: growth.

Independent variable	Barents sea	Greenland Spring	Greenland Fall	Iceland NE	Newfoundland		
					2J	3K	3L
Cohort	-	-	-	-	-	-	-
d.f./R2	40/.12	19/.25	13/.34	46/.15	66/.10	66/.08	64/.11
Age	-	-	-	**	***	***	***
d.f./R2	50/.00	29/.13	20/.15	69/.09	77/.48	77/.31	75/.28
Year	***	***	-	***	**	**	***
d.f./R2	44/.67	20/.72	15/.38	48/.77	72/.24	72/.24	70/.56
Age	-	**	-	***	***	***	***
Year	***	***	-	***	***	***	***
d.f./R2	40/.68	18/.81	13/.53	46/.84	66/.73	66/.54	64/.77
Age	-	-	-	*	***	***	***
Cohort	-	-	-	-	-	-	-
d.f./R2	36/.13	17/.47	11/.43	44/.47	60/.62	60/.45	58/.43
Year	***	***	-	***	***	***	***
Cohort	-	***	-	*	***	**	***
d.f./R2	30/.72	9/.97	6/.71	23/.92	55/.65	55/.51	53/.80
Age	-	-	-	-	***	-	-
Cohort	-	**	-	-	-	-	-
Year	***	***	-	***	***	-	***
d.f./R2	27/.73	8/.97	5/.71	22/.93	50/.78	50/.58	48/.81
N	55	32	22	72	84	84	81

- : 0.10 < P  
\* : 0.05 < P < 0.10  
\*\* : 0.01 < P < 0.05  
\*\*\* : < P < 0.01

Table 5.3.1.3 Description of models with classification variables. Significance levels and degrees of freedom. Dependent variable: scaled growth.

Independent Variable	Barents		Greenland		Iceland	Newfoundland		
	Sea	Spring	Fall	NE	2J	3K	3L	
Cohort	-	-	-	-	-	-	-	-
d.f./R2	40/.13	19/.33	13/.23	65/0.18	66/0.27	66/0.20	64/0.19	
Year	***	***	-	***	***	***	***	
d.f./R2	44/.73	20/.72	15/.47	67/0.52	72/0.81	72/0.34	70/0.64	
Year	***	***	-	***	***	-+	***	
Cohort	-	**	-	-	-	-	-	
d.f./R2	30/.78	9/.96	6/.64	42/0.67	55/0.61	55/0.40	53/0.70	

+ p= 0.106

++ Age 9 excluded in the analysis.

- : 0.10 < P

\* : 0.05 < P < 0.10

\*\* : 0.01 < P < 0.05

\*\*\* : < P < 0.01

Table 5.3.1.4 Description of full models. Significance levels and degrees of freedom. A blank entry means that the term was not entered into the model (see text). Dependent variable: growth.

Independent Variable	Barents		Greenland		Iceland	Newfoundland		
	Sea	Spring	Fall	NE	2J	3K	3L	
1/Biomass	***	-	-	-	-	-	**	
Year class bio.							-	
Capelin	***						***	
Capelin/Biomass	***						***	
Temperature	***	-	-	**			-	
Cohort	-	-	-	-			-	
Age	-	-	-	-	***		-	
d.f. error	32	15	9	9	27	49	47	
R2	.62	.50	.47	.81	.74	.55	.62	

+ The capelin biomass variable used in section 5.3 for the Barents Sea models, is the winter spawning biomass predicted from the capelin biomass estimates from the september survey the previous year.

++ Ages 8 and 9 excluded from the analysis

- : 0.10 < P

\* : 0.05 < P < 0.10

\*\* : 0.01 < P < 0.05

\*\*\* : < P < 0.01

Table 5.3.1.5 Description of full models. Significance levels and degrees of freedom. A blank entry means that the term was not entered into the model (see text). Dependent variable: scaled growth.

Independent Variable	Barents Sea	Greenland		Iceland <sup>+</sup> NE	Newfoundland		
		Spring	Fall		2J	3K	3L
1/Biomass	***	-	-	-	-	*	-
Year class bio.				-	-	-	**
Capelin	***			-	-	-	***
Capelin/Biomass	***			-	-	-	***
Temperature	***	-	-	**	-	-	-
Cohort	-	-	-	-	-	-	-
d.f. error	36	17	11	18	55	55	53
R2	.68	.37	.28	0.66	0.48	0.35	0.43

+ Age 9 excluded from the analysis

- : 0.10 < P  
 \* : 0.05 < P < 0.10  
 \*\* : 0.01 < P < 0.05  
 \*\*\* : < P < 0.01

Table 5.3.1.6 Description of final models resulting from backwards stepwise regression. Significance levels and degrees of freedom. A blank entry means that the term was not entered into the model (see text). Dependent variable: growth.

Independent Variable	Barents Sea	Greenland		Iceland NE	Newfoundland		
		Spring	Fall		2J	3K	3L
1/Biomass	***	/	/	/	/	***	***
Year class bio.				/	/	/	/
Capelin	***			**	/	/	***
Capelin/Biomass	***			/	/	*	***
Temperature	***	/	/	***	***	/	/
Cohort	/	/	/	/	/		***
Age	/	/	/	/	***	***	/
d.f. error	50			30	69	75	61
R2	.54			.47	.66	.46	.52
Significance of year	**	***	-	***	***	-	***

/ : Term eliminated  
 \* : 0.05 < P < 0.10  
 \*\* : 0.01 < P < 0.05  
 \*\*\* : < P < 0.01

Table 5.3.1.7 Description of final models resulting from backwards stepwise regression. Significance levels and degrees of freedom. A blank entry means that the term was not entered into the model (see text). Dependent variable: scaled growth.

Independent Variable	Greenland			Iceland+ NE	Newfoundland		
	Barents Sea	Spring	Fall		2J	3K	3L
1/Biomass	***	/	/	/	/	**	/
Year class bio.				/	/	/	/
Capelin	***			*	/	***	***
Capelin/Biomass	***			/	/	/	/
Temperature	***	/	/	***	***	/	/
Cohort	/	/	/	/	/	/	/
d.f. error	50			41	75	81	80
R2	.61			.38	.29	.23	.17
Significance of year	**	***	-	**	***	-	***

+age 9 excluded

/ : 0.10 < Term eliminated  
 \* : 0.05 < P < 0.10  
 \*\* : 0.01 < P < 0.05  
 \*\*\* : < P < 0.01

Table 5.3.2.3.1. The explained variance of rec\_dl and significance level of the models

Explanatory variable		Explained variance (%)	Significance level (%)
COD3K	N	33	5
ARCTIC COD	N	29	9
	1/capelin	56	1
	1/temperature	16	-
	N/capelin	50	1
	N/(capelin*temperature)	54	1
	1/(capelin*temperature)	60	0.5

Table 6.2.1.1. The number of cod stomachs included in the USSR-Norwegian stomach content data base by year and quarter.

Year	Quarter				Total
	1	2	3	4	
1950	-	-	141	-	141
1951	-	-	-	49	49
1952	-	24	150	472	646
1956	108	124	370	379	981
1957	82	186	93	161	522
1958	98	39	165	152	454
1973	-	-	174	-	174
1975	-	-	199	-	199
1980	-	-	593	-	593
1981	-	185	200	-	385
1982	832	-	-	-	832
1984	1087	346	1009	1289	3731
1985	1882	512	1271	488	4153
1986	1847	471	2952	652	5922
1987	1654	921	2015	1325	5915
1988	2408	252	1150	1428	5238
1989	2835	686	1687	250	5458
Total	12833	3746	12169	6645	35393

Table 6.2.1.2. Type of data and format of data in the cod stomach contents file from the Barents Sea.

Data	S-line Format	Data	P-line Format
S	A1	P	A1
Country	A2	Prey code	
Ship	A2	(10-digit NoDC)	A10
Station	I4	Length code	
O	X1	(ICES-stom.-progr.)	X1,I5
Position	X1, A10	Digestion degree	X1,I1
Depth	X2, I4	No. of prey items	X1,I6
Gear	X1, A2		
Length	X2, F5.1		
Weight	X1, F6.3		
Age	X2, I2		
Filling degree	I3		
No. of fish per			
Haul of eq. length	I3		
Duration	2I2		

Table 8.2.1. Long-term MSFOR predictions. Correlation between MSVPA estimates of recruitment (0-group, 1 July).

CORRELLATION MATRIX OF LOGGED RECRUITMENT

	COD	WHITING	SAITHE	MACKEREL	HADDOCK	HERRING	SPRAT	N. POUT	SANDEEL	PLAICE
COD	1.000	0.395	-0.085	0.108	0.305	-0.437	0.461	0.379	0.625	0.055
WHITING	0.395	1.000	-0.550	0.575	-0.074	-0.656	0.593	-0.026	0.419	-0.253
SAITHE	-0.085	-0.550	1.000	-0.356	0.127	0.661	-0.523	-0.160	-0.289	0.341
MACKEREL	0.108	0.575	-0.356	1.000	-0.128	-0.342	0.358	0.223	0.196	-0.238
HADDOCK	0.305	-0.074	0.127	-0.128	1.000	0.273	0.296	0.222	0.417	-0.125
HERRING	-0.437	-0.656	0.661	-0.342	0.273	1.000	-0.757	-0.380	-0.400	0.457
SPRAT	0.461	0.593	-0.523	0.358	0.296	-0.757	1.000	0.526	0.545	-0.717
N. POUT	0.379	-0.026	-0.160	0.223	0.222	-0.380	0.526	1.000	0.591	-0.209
SANDEEL	0.625	0.419	-0.289	0.196	0.417	-0.400	0.545	0.591	1.000	0.082
PLAICE	0.055	-0.253	0.341	-0.238	-0.125	0.457	-0.717	-0.209	0.082	1.000
SOLE	-0.045	-0.316	0.017	0.055	-0.430	0.287	-0.504	-0.077	-0.344	0.325

CORRELLATION MATRIX OF LOGGED RECRUITMENT

	SOLE
COD	-0.045
WHITING	-0.316
SAITHE	0.017
MACKEREL	0.055
HADDOCK	-0.430
HERRING	0.287
SPRAT	-0.504
N. POUT	-0.077
SANDEEL	-0.344
PLAICE	0.325
SOLE	1.000

Table 8.2.2. Long-term MSFOR predictions. Correlation between catch in tonnes by species.

A. Stochastic Recruitment

CORRELATION BETWEEN SPECIES OF CATCH IN TONNES  
NUMBER OF YEARS: 2250

SPECIES/SPECIES												
SPECIES	NO.	1	2	3	4	5	6	7	8	9	10	11
COD	1	1.00	-0.13	-0.04	-0.09	0.10	0.05	0.04	0.08	0.08	-0.01	0.02
WHITING	2	-0.13	1.00	-0.08	-0.06	0.21	0.16	0.14	0.25	0.29	0.05	0.00
SAITHE	3	-0.04	-0.08	1.00	0.02	-0.26	-0.02	0.01	-0.35	0.01	0.02	0.02
MACKEREL	4	-0.09	-0.06	0.02	1.00	0.02	0.01	-0.04	-0.08	-0.20	0.03	-0.02
HADDOCK	5	0.10	0.21	-0.26	0.02	1.00	0.10	0.05	0.29	0.04	0.03	-0.05
HERRING	6	0.05	0.16	-0.02	0.01	0.10	1.00	0.04	0.11	0.07	-0.01	0.02
SPRAT	7	0.04	0.14	0.01	-0.04	0.05	0.04	1.00	0.05	0.06	0.04	-0.01
N. POUT	8	0.08	0.25	-0.35	-0.08	0.29	0.11	0.05	1.00	0.15	0.04	-0.05
SANDEEL	9	0.08	0.29	0.01	-0.20	0.04	0.07	0.06	0.15	1.00	0.02	0.01
PLAICE	10	-0.01	0.05	0.02	0.03	0.03	-0.01	0.04	0.04	0.02	1.00	0.02
SOLE	11	0.02	0.00	0.02	-0.02	-0.05	0.02	-0.01	-0.05	0.01	0.02	1.00

B. Stochastic Correlated Recruitment

CORRELATION BETWEEN SPECIES OF CATCH IN TONNES  
NUMBER OF YEARS: 2250

SPECIES/SPECIES												
SPECIES	NO.	1	2	3	4	5	6	7	8	9	10	11
COD	1	1.00	0.38	-0.05	0.02	0.46	-0.22	0.32	0.31	0.53	-0.04	-0.04
WHITING	2	0.38	1.00	-0.26	0.28	0.28	-0.31	0.55	0.37	0.47	-0.18	-0.16
SAITHE	3	-0.05	-0.26	1.00	-0.24	-0.12	0.45	-0.07	-0.35	0.01	0.34	-0.03
MACKEREL	4	0.02	0.28	-0.24	1.00	-0.02	-0.20	0.11	0.12	-0.20	-0.20	0.12
HADDOCK	5	0.46	0.28	-0.12	-0.02	1.00	0.10	0.29	0.41	0.40	-0.12	-0.16
HERRING	6	-0.22	-0.31	0.45	-0.20	0.10	1.00	-0.19	-0.18	-0.06	0.32	0.14
SPRAT	7	0.32	0.55	-0.07	0.11	0.29	-0.19	1.00	0.50	0.31	-0.05	-0.03
N. POUT	8	0.31	0.37	-0.35	0.12	0.41	-0.18	0.50	1.00	0.51	-0.09	0.03
SANDEEL	9	0.53	0.47	0.01	-0.20	0.40	-0.06	0.31	0.51	1.00	0.11	-0.11
PLAICE	10	-0.04	-0.18	0.34	-0.20	-0.12	0.32	-0.05	-0.09	0.11	1.00	0.21
SOLE	11	-0.04	-0.16	-0.03	0.12	-0.16	0.14	-0.03	0.03	-0.11	0.21	1.00



Table 8.2.3. Long-term MSFOR predictions. Correlation between catch in tonnes by fleet.

A. Stochastic Recruitment

LONGTERM MULTI SPECIES PREDICTION, STOCHASTIC RECRUITMENT

CORRELATION BETWEEN FLEETS OF CATCH IN TONNES  
NUMBER OF YEARS: 2250

FLEET/FLEET	FLEET	NO.	1	2	3	4	5	6	7	8
RF85LAND.	1	1.00	0.43	0.09	0.08	0.12	-0.02	-0.02	0.02	
RF85DISC.	2	0.43	1.00	0.29	0.11	0.09	-0.26	-0.01	0.01	
INDUST. DEM.	3	0.09	0.29	1.00	0.11	0.10	-0.15	-0.20	0.03	
INDUST. PEL.	4	0.08	0.11	0.11	1.00	0.30	0.00	-0.03	0.03	
HERRING	5	0.12	0.09	0.10	0.30	1.00	-0.02	0.01	0.00	
SAITHE	6	-0.02	-0.26	-0.15	0.00	-0.02	1.00	0.02	0.02	
MACKEREL	7	-0.02	-0.01	-0.20	-0.03	0.01	0.02	1.00	0.02	
FLATFISH	8	0.02	0.01	0.03	0.03	0.00	0.02	0.02	1.00	

B. Stochastic Correlated Recruitment

LONGTERM MULTI SP. PREDICTION, STOCH. CORR. RECRUITMENT

CORRELATION BETWEEN FLEETS OF CATCH IN TONNES  
NUMBER OF YEARS: 2250

FLEET/FLEET	FLEET	NO.	1	2	3	4	5	6	7	8
RF85LAND.	1	1.00	0.52	0.42	0.26	-0.03	0.03	0.01	-0.13	
RF85DISC.	2	0.52	1.00	0.60	0.42	0.05	-0.16	0.00	-0.08	
INDUST. DEM.	3	0.42	0.60	1.00	0.39	-0.11	-0.15	-0.08	0.02	
INDUST. PEL.	4	0.26	0.42	0.39	1.00	0.24	0.11	0.02	0.07	
HERRING	5	-0.03	0.05	-0.11	0.24	1.00	0.48	-0.21	0.34	
SAITHE	6	0.03	-0.16	-0.15	0.11	0.48	1.00	-0.25	0.31	
MACKEREL	7	0.01	0.00	-0.08	0.02	-0.21	-0.25	1.00	-0.17	
FLATFISH	8	-0.13	-0.08	0.02	0.07	0.34	0.31	-0.17	1.00	

Table 8.2.4. Long-term MSFOR predictions.

## A. Stochastic Recruitment

AVERAGE TOTAL BIOMASS, SSB, RECRUITMENT, AV. BIOMASS AND CATCH BY SPECIES

SPECIES	TOTAL BIOMASS	SSB	RECRUITMENT	AV. BIOMASS	CATCH
COD	334665.	108856.	1339531.	281317.	264388.
WHITING	457026.	306791.	13083345.	400658.	200549.
SAITHE	374267.	108966.	255251.	350083.	163615.
MACKEREL	89745.	30986.	162967.	106502.	34431.
HADDOCK	735754.	218478.	27570520.	593042.	309874.
HERRING	1000981.	751537.	20742818.	1212806.	439459.
SPRAT	647881.	341742.	166039776.	719910.	285019.
N. POUT	1347957.	854649.	247685152.	1402521.	514232.
SANDEEL	2849119.	1426487.	670333248.	2910975.	1047749.
PLAICE	548338.	337757.	659205.	446709.	161221.
SOLE	53192.	33972.	114498.	42032.	19938.
TOTAL	8438926.	4520221.	1147986432.	8466554.	3440476.

## B. Stochastic Correlated Recruitment

LONGTERM MULTI SP. PREDICTION, STOCH. CORR. RECRUITMENT

AVERAGE TOTAL BIOMASS, SSB, RECRUITMENT, AV. BIOMASS AND CATCH BY SPECIES

SPECIES	TOTAL BIOMASS	SSB	RECRUITMENT	AV. BIOMASS	CATCH
COD	342461.	111368.	1332267.	287903.	270714.
WHITING	460062.	308651.	13067525.	403057.	201431.
SAITHE	369154.	107470.	251757.	345305.	161374.
MACKEREL	86117.	29641.	156623.	102236.	33030.
HADDOCK	766270.	230645.	27542058.	619678.	326803.
HERRING	963866.	725257.	20189822.	1168059.	424334.
SPRAT	579758.	293542.	154861936.	641343.	247283.
N. POUT	1356152.	861175.	247487872.	1413256.	521135.
SANDEEL	2845619.	1407463.	684634560.	2897618.	1038658.
PLAICE	556445.	342763.	669261.	453312.	163612.
SOLE	50407.	32189.	108588.	39833.	18893.
TOTAL	8376312.	4450164.	1150302336.	8371599.	3407268.

Table 8.4.1. Estimated food intake of North Sea Populations of four seabird species in each quarter and sub-area, expressed in terms of weight (tonnes). Assumed calorific values of prey: Gannet and Fulmar; 9.2, Guillemot; 8.5, Kittiwake; 5.9.

AREA	QUARTERLY PERIOD				Annual
	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	
GANNET (9.2 kJ/g)					
Shetland	1900	2880	1600	35	5615
IVa W	1345	1240	825	250	3660
IVa E	215	60	60	10	345
IVb W	2215	2350	3155	2090	9810
IVb E	470	100	255	365	1190
IVc	205	45	125	220	595
Total	6350	5875	6020	2970	21215
FULMAR * (9.2 kJ/g)					
Shetland	6720	5550	9710	2605	24585
IVa W	16315	13940	8525	18115	56895
IVa E	2905	2040	3375	1150	9470
IVb W	2910	2110	7385	6555	18960
IVb E	1625	1570	2070	3440	8705
IVc	360	475	1900	240	2975
Total	30835	25685	32965	32105	121590
GUILLEMOT (8.5 kJ/g)					
Shetland	1765	6685	2245	530	11225
IVa W	5980	22580	18845	3100	50505
IVa E	235	120	2995	955	4305
IVb W	4500	9150	17220	9440	40310
IVb E	1060	265	845	1380	3550
IVc	1735	130	90	2110	4065
Total	15275	38930	42240	17515	113960
KITTIWAKE (5.9 KJ/g)					
Shetland	725	1725	425	255	3130
IVa W	13230	9485	5525	6090	34330
IVa E	2135	260	100	2090	4585
IVb W	3635	9205	6425	7400	26665
IVb E	4550	385	90	535	5560
IVc	1210	320	80	920	2530
Total	25485	21380	12645	17290	76800

\* Includes unknown fraction of discards and offal

Table 8.6.1. Comparison of models currently used to estimate consumption by fish.

Theoretical Model Basis	Individual food particles	Total stomach content	Total stomach content	Total stomach content	
Evacuation model	Linear $dS/dt = \# \text{ particles}$	Linear $dS/dt = -R$	General $dS/dt = -RS^b$	Exponential $dS/dt = -RS$	
Consumption Model	Daan per day $C = 2S/D$  D = digestion time	Bajkov/Bromley < ----- F = RE E = % full	Jones per hour F=RS <sup>b</sup> {b = 0.46} <sup>***</sup>	Eggers/Elliot & Persson -----> F = RS	
Effect of predator size on consumption via stomach content $S = \phi L^3$	$C \sim L^3$	$C \sim L^0$	$C \sim L^{3b}$ $C \sim L^{1.38}$	$C \sim L^3$	
Experimental Basis	Daan (1973) cod	Bromley (1989) cod	Jones (1974) cod haddock whiting	Dos Santos (1990) cod	
Effect of predator size on consumption via digestion coefficient	$D = \delta L^*$ $C \sim L^{-1}$	$R \sim W^{0.59}$ $C \sim L^{1.8}$	$R \sim L^{1.4}$ $C \sim L^{1.4}$	$R \sim (W/W_0)^{0.54}$ $(R \sim L^{1.6})$	
Type of experiment	theory*	feeding	evacuation	evacuation	
size range	1241g*	6-3600g	800-3000g	57-438g	262-2066g
Combined size effect of stomach content and digestion coefficient	$C \sim L^2$	$C \sim L^{1.8}$	$C \sim L^{2.8}$	$C \sim L^3$ (~ L <sup>4.6</sup> ) **	
Temperature $C \sim e^{k(T-T_0)}$	k = 0.096 ****	-----	k = 0.081	k = 0.110	

\* D ~ weight of food particle/surface of food particle, only one size class was used for estimation of  $\delta$  (including fish of 700-1470 g).

\*\* only if meal size ( $W_0$ ) remains constant.

\*\*\* This particular value is an experimental result based on evacuation and feeding experiments.

\*\*\*\* This value is based on Ursin 1985, and used in the 1986 working group meeting.

L = length of predator

F = feeding rate [g/h]

R = constant [1/t]

S = stomach content at time t

b = constant [0 < b < 1]

T = environmental temperature

C = consumption [g/day]

W = weight of predator

$\delta$  = constant [see text]

$W_0$  = meal size in experiment

t = time

$T_0$  = experimental temperature