Working Group on Multispecies Assessment Methods (WGSAM; outputs from 2023 meeting)

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ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

Contents

i Executive summary

The Working Group on Multispecies Assessment Methods (WGSAM) aims to advance the operational use of knowledge on predator-prey interactions for advice on fisheries and ecosystem management. Key runs of multispecies and ecosystem models provided by WGSAM are integral to this mission. They serve as a robust component of ecosystem science that seamlessly integrates into the ICES advice.

This report presents an update of the multispecies SMS key-run model for the North Sea and its review by the working group based on established review criteria. The updated model extends to input time-series to 2022 and includes a more extensive revision of the time-series of marine birds and grey seal population numbers. Additional improvements of this key-run include (i) one extra year of grey seal diet data (i.e., 1985, 2002, 2010); (ii) plaice is now a prey species, although predation is at the moment limited to grey seal; (iii) improved compilation of fish diet data including estimation of variance of the estimated prey proportions. WGSAM recommends the use of natural mortality estimates from the North Sea SMS key-run for use in single species stock assessment models of North Sea haddock, herring, Norway pout, sandeel (estimates are disaggregated for the southern and northern North Sea), sprat, and whiting. The SMS key-run continues to assume a single North Sea cod stock in contrast to the recent split into three components which makes assimilation of the natural mortality estimates into the new cod assessments problematic. More work is needed to harmonise the new fish stomachs with the old ones before they could be integrated in the North Sea key-run.

ii Expert group information

Expert group name	Working Group on Multispecies Assessment Methods (WGSAM)
Expert group cycle	Multiannual
Year cycle started	2022
Reporting year in cycle	2/3
Chairs	Valerio Bartolino, Sweden
	Michael Spence, UK
Meeting venue and dates	9-13 October 2023, Edinburgh, UK (19 participants)

1 North Sea SMS key-run review

1.1 Review

1.1.1 Is the model appropriate for the problem?

The stochastic multispecies model (SMS, Lewy and Vinther 2004) model provides natural mortality estimates by age and year as input to single species stock assessments. The 2023 key-run provides natural mortality estimates for the assessments of haddock, herring, Norway pout, southern North Sea sandeel, northern North Sea sandeel, sprat, and whiting. Natural mortality estimates are only used as input for the historic part of single species models and no forecast is needed. M estimates by age and quarter are a direct output of the SMS model. However, an assumption is needed for residual mortalities M1 while the predation mortalities M2 are estimated (M = M1+M2). The model provides estimates for the years 1974 to 2022.

The North Sea SMS model is in general parameterized for the North Sea. See the Assumptions and Parameterization Section below for specifics on handling modelled stocks ranging beyond the North Sea.

Predators include both assessed species (i.e., cod, haddock, saithe, whiting, mackerel) and species with given input population size (North Sea horse mackerel, western horse mackerel, grey gurnard, starry ray, hake, fulmar, gannet, great black backed gull, guillemot, herring gull, kittiwake, puffin, razorbill, grey seal, harbour porpoise). The assessed predators are parametrised using a combination of commercial and survey data (i.e., same input as for the single species assessments) except saithe and mackerel which are closely tuned to the ICES stock assessment by using number-at-age from the single species assessment models as input of SMS.

Overall, the model is appropriate to provide information on natural mortalities as input for the assessments of haddock, herring, Norway pout, southern North Sea sandeel, northern North Sea sandeel, sprat, and whiting. The 2023 North Sea SMS key-run is primarily an update of the 2020 key-run by: 1) extension of the input data and their update when the single species stock assessment input data were revised through benchmarks or inter-benchmarks, 2) complete revision of the grey seal and birds time-series, 3) update of the diet calculation from the stomach data. Overall, the model structure and main assumptions are consistent with the previous key-run. The model remains appropriate in relation to the purpose of providing predation mortality estimates.

1.1.2 Is the scientific basis of the model sound?

The SMS model is an established and reviewed modelling framework (i.e., ICES WGSAM 2016, 2021) that has previously been applied in the North Sea to provide input for assessments of commercially important stocks (e.g., North Sea cod and herring). The Baltic SMS model was reviewed by ICES WGSAM (2019, 2023), ICES WKMULTBAL (2012), and ICES WGSAM (2012). Single species implementations of SMS are also used for the stock assessment of some of the stocks in the Greater North Sea ecoregion (i.e., sandeel, sprat).

1.1.3 Is the input data quality and parameterization sufficient for the problem?

Data quality

SMS uses the same data as used for input to the single species assessments (catch at age, mean weights, proportion mature, survey indices) or uses some output from the single stock assessments as in the case of saithe and mackerel. These data have been benchmarked and therefore no further review on these data has been carried out. However, changes to input data since the 2020 SMS North Sea key-run include:

- **Update of "single-species data"** (catch-at-age numbers, individual mean weights in the stock and in the catch, proportion of mature fish, survey indices, etc.) with use of the most recent ICES assessment input data. The most important changes or differences include:
    - Whiting: during the 2022 stock assessment (ICES WGNSSK 2022) the working group changed the age range from 0-8+ to 0-6+ to achieve a satisfactory model. Assessment data using the old age range are not available from WGNSSK, such that SMS has to change to the new 0-6+ age range. The change in the plus group explains the apparent change in mean weight for age 6 (which now has become a plus group).
    - Haddock: mean weights-at-age in the sea has changed considerably since 2020 key-run. The SMS mean weights are copied correctly from the ICES assessment, but these are now considerably lower than the values used by ICES in 2019. This stock was benchmarked in 2022 (ICES WKNSCS 2023), and the age range was changed from age 0-10+ to 0-8+. In addition, prior to the 2022 benchmark stock weights-at-age were assumed to be the same as catch weights-at-age. Now, stock weights-at-age are derived by applying correction factors (calculated from comparing mean weights-at-age in the catch data to survey data from NS-IBTS Q1 and UK-SCOWCGFS Q1) to the mean catch weights-at-age. Input data available from WGNSSK is given for 0-15+ age range, whereas SMS uses ages 0-10+. Decreasing the SMS age range to follow the ICES assessment is possible, however this would result in a very large plus group for, which there is insufficient data to get a proper and year-dependent size distribution. SMS scales the annual mean weight to the quarterly mean weights applied by the old MSVPA dataset (as explained in section 3.1.3 for cod Stock Annex). To maintain this approach and to maintain the wider 0-10+ age range, the 2023 key-run uses the catch mean weight (as in previous years) as the basis for the calculation of the mean stock weight at age. The resulting values of mean weights-at-age are shown in the below figures. These are almost identical to the previous key-run, however with some changes for individual years, probably due to the benchmark revision of data. Proportion of mature for age 2 shows a substantial increase and are in line with recent stock assessment input data.
    - Sandeel: Catches of age 0 in quarter 4 were an error in the 2020 key-run. This error had no effect as F in quarter 4 was assumed to be zero and therefore not calculated. The catch and weight-at-age in the catch time-series are both updated. Differences are more relevant in the weight-at-age for both the north and southern sandeel. Weight at age in the stock for both northern and southern sandeel are nearly identical with the previous key-run for Q1 and Q4 while larger differences are noticeable for Q2-3. Using this time-series, the mean weight in the sea is now calculated in accordance with the stock Annex, with the only difference that the mean weight in the sea of age 1+ was estimated from a smooth function on the available mean weight at age in the catch (the former Stock Annex prescribed to use a simple mean).

- Hake: There was a 2022 benchmark (ICES WKANGHAKE 2023) for Hake so 2023 values for SMS were updated. SMS does not use data on the 0-25 cm hakes as it is assumed that the juveniles are mainly distributed in the southern part of the stock distribution area, outside the North Sea. This correction was however not done this year. In addition, data used (catch by area) to calculate the proportion of the stock within the North Sea has been changed at the benchmark. With the corrected calculation and updated data for stock distribution, the stock numbers used in 2023 are slightly higher than the values used in 2020, mainly due to the benchmark upward revision of stock numbers. Stock size by quarter is provided by the ICES assessment, so the apparent largest difference in stock numbers in quarters 3 and 4 is due to the assessment output (and not because of changes in the assumptions in SMS). Mean weights at age are quite the same for the smaller size (ages) while differences are visible for age6+.
- Cod: proportion of mature cod (smoothed time-series) shows a minor change for ages 2-5 compared to the previous key-run input. Also, the proportion of cod in the North Sea presents moderate differences. Northern horse mackerel: the time-series stock numbers show a general downward revision for all ages compared to the previous key-run and the weight at age 6+ show a minor decrease.
- Update of other predators' numbers: for A. radiata, G. gurnards, western horse mackerel there are only small changes in the numbers.

- **Update of marine bird numbers:**

  The proportion of birds in each quarter remained the same as in the 2020 key-run but the time-series of absolute estimates were revised for all the marine bird species based on Dierschke *et al.* (2022).

- **Update of the grey seal numbers:**

  Grey seal numbers were last updated in 2011 and previous updates following the 2011 key-run assumed a stable seal population after 2009 based on the old impression at that time that the seal population was levelling off. The following assessments of the seal population carried on by OSPAR proved this assumption to be wrong as the North Sea grey seal population has been steadily increasing until present.

  Moreover, lack of proper documentation prevented to reconstruct the quarterly old time-series of seal used in the previous key-runs. Documentation was insufficient to reconstruct both the long-term trends and the seasonal patterns in the old time-series.

  These reasons provided strong justification for an update of the seal time-series used for the 2023 key-run. Hence, the working group decided for a new calculation based on up to date information and estimates (SMS stock annex).

  Scaling of seal numbers from the monitored colonies to the rest of the UK coast were anchored to estimates from five years (1985, 2002, 2010, 2019, 2022). Overall, these years cover the period of observations and scale estimates from monitored colonies but it is noted that they are derived from personal communication with seal experts and not from published information. It is surprising that the scaling in those five years is very similar in absolute terms while the number of estimated seals has increased four-folds from the mid-1980s to the 2020s.

  Extrapolation prior 1984 follows exponential growth consistently with the old time-series.

  Inclusion of seals from other North Sea areas outside the UK is appropriate and without specific information is based on the simplest assumption that the total population scale to

the proportion of pups counted in these areas. A single multiplier is used over the whole time-series which is probably a crude but the only possible assumption without additional information. However, it is noted that the majority of grey seals are on the UK coast and the impact of this correction, is marginal.

Considering the lack of information to explain seasonal differences in the seal numbers in the old time-series, it seems appropriate to keep the estimates constant in between breeding seasons. Moreover, the number of seals is expected to be relatively stable from one season to another given the many age classes and their high survival except for the pups.

- **Update stomach data:**

  The compilation of the diet data from individual fish stomachs as input for the key-run was based on the 'FishStomach' R package (https://github.com/MortenVinther/FishStomachs). The results are in general consistent with the diet data used for the 2020 key-run and minor difference in the diet are reported as follows: increase of southern sandeel in the 1995 diet of harbour porpoise and in the diet of mackerel, decrease of sprat in the diet of northern horse-mackerel, increase of herring in the 1986–1987 saithe's diet. The new procedure represents an important improvement in terms of transparency and replicability of the diet data compilation. The procedure and imputation criteria to prepare the diet data input to the key-run are documented in https://github.com/ices-eg/wg_WGSAM/tree/master/Stomach_compilation/NorthSea. Moreover, the new approach allows estimation of variance of the estimated prey proportions from the observed stomachs which can be used as input to SMS.

  An updated stomach database has been made available for the ICES community (https://stomachdata.ices.dk/inventory), which, among other things, contains a range of newly analysed fish stomachs from the North Sea that could potentially be relevant for the SMS key-run. Justification for not including the new fish stomachs is well supported by a lack of consistency (i.e., small spatial coverage, different coverage of the taxonomic groups included in the otherfood) between this new data source and old stomach data already included in the model (see WD03).

- **Update of the grey seal diet:**

  The 2023 key-run includes an update of the grey seal stomachs (see SMS stock annex) with (1) the addition of stomachs from 2010–2011 (only 1985 and 2002 were available for the previous key-run) and (2) a new calculation of the main prey length and of the otherfood component.

  Seal diet composition was derived from otolith-based estimates of prey length which were then converted to prey weight using species specific length-weight relationship. Information from the prey-size (expressed in weight) composition was first pulled across regions to guarantee a sufficient number of samples and then scaled to total consumption estimates by quarter provided by seal experts. The pulling of the samples across regions is weighted for the consumption by region to avoid bias in the size distribution. The approach is meaningful and the procedure to scale diet size composition to the consumption by species formally correct. When the number of diet samples is <5 in a quarter, imputation is done by borrowing information from an adjacent quarter (borrowing is limited with quarter 1-2 and 3-4).

  Sandeel consumption by grey seal was split between the northern and southern sandeel, following the SMS definition, according to area-based consumption estimates from seal experts. This is a clear improvement compared to the previous assumption that all sandeel consumed by grey seal were from the northern sandeel stock.

Overall, the quality of data used in SMS is considered as good as possible to provide input to the model. That the model uses key input from the single species assessments can be seen as strength because these data have been already through a full benchmark process in ICES.

Assumptions and parameterization

Assumptions regarding stock distributions are as follows:

- The stock definition of North Sea cod in the ICES assessment has changed. Advice is now given on three sub-stocks (ICES WKBCOD 2023). The SMS definition of the cod stock remains the same as in the previous key-run, where cod represents ICES area 4. Therefore, Ms on cod are no longer directly comparable to those in the ICES single-species assessments. Further, the 2021 benchmark introduced an adjustment on cod natural mortality of ages 3+ from 2011 to account for migration to the West of Scotland area, which was not included in the assessment area (citation). This ad hoc solution has been used to fix retrospective patterns in the stock assessment due to an overestimation of the catch of large individuals which had moved outside the assessment area. SMS also has this additional mortality on stock from 2011.
- Previously, plaice was not considered as prey in SMS. The stock was benchmarked in 2022 and difficulties were encountered during the benchmark regarding the natural mortality assumption (changed from M=0.1 for all ages and years to age varying M estimated from weights at age, ICES WKNSCS 2023). It was suggested at the benchmark that trying to estimate natural mortality in SMS would help the scientists to trust the estimates of M to use in the plaice assessment. Therefore, it was decided to incorporate plaice as a prey in SMS in the 2023 key-run (refer to the SMS stock annex for details). Given that grey seal diet data was re-extracted for the 2023 key-run, plaice was added to the list of prey to extract in grey seal diet data. In 2010–2011, 3816 tonnes of plaice were estimated to be consumed by grey seals, which represents around 4% of grey seal diet in that period and is of the same order of magnitude than haddock consumption. The predation of fish such as cod, and haddock on plaice was not incorporated yet. Plaice is normally considered 'other food' for these fish species and their contribution to the plaice predation mortality is likely substantial. As a result, at the moment only grey seal predation is considered for the estimation of M2 for plaice, which is considered insufficient to capture temporal dynamics of predation mortality for this flatfish.

See 2020 key-run review (ICES WGSAM 2021) for other consideration on model assumptions.

Overall, the parameterization and assumptions are consistent with scientific knowledge.

1.1.4 Does model output compare well with observations?

In this review report we reproduce only a few diagnostic plots as they are relevant to support the review text. Diagnostic plots for all the comparison are available at https://ices-eg.github.io/wg_WGSAM /NorthSeaKeyRun_2023/HTML/NS_2023_key_run.html

Catch data

The SMS key-run is generally able to reproduce the annual catches for the modelled species (Figure 1.1.4.1). Some more pronounced differences are found from the mid-1980s until early 2000s for the southern and northern sandeel stocks and from the mid-1990s until mid-2000s for sprat.

The highest observed peaks in the annual catches are also underestimated for some stocks (i.e., cod in 1980, herring in 1987–1989, mackerel in 2014, saithe in 1975 and 1985) but the model is overall able to reproduce both the long-term pattern as well as the interannual variability of fisheries yields.

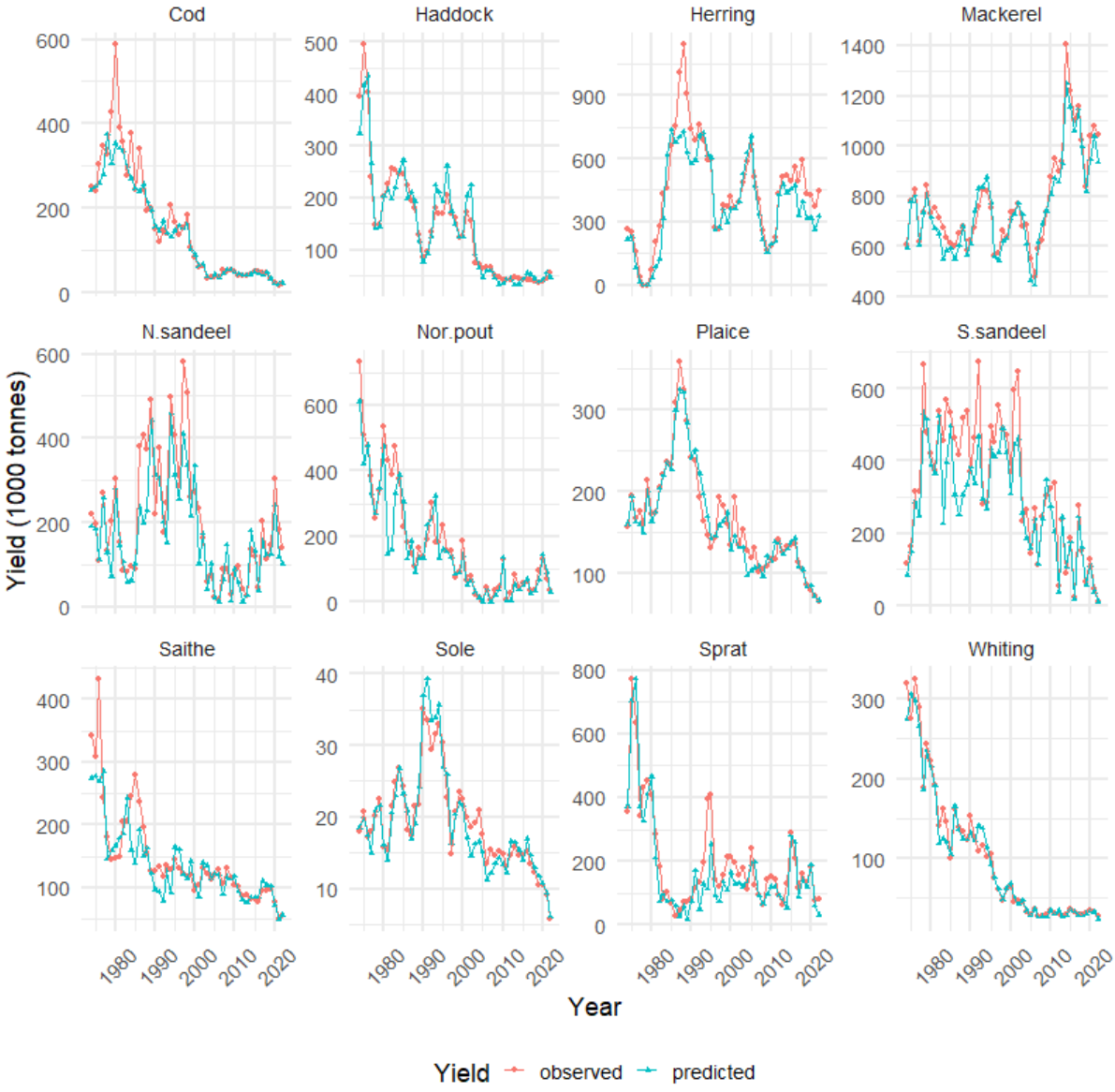


Figure 1.1.4.1. SMS North Sea model fits (predicted) to catch data (observed).

When looking into more details by species and age, an underestimation of catch weight for longer lived species is often more pronounced for the youngest and/or oldest ages (examples see figures 1.1.4.2 and 1.1.4.3). Information for catch at age is more uncertain for these age groups than for ages where the bulk of landings is observed.

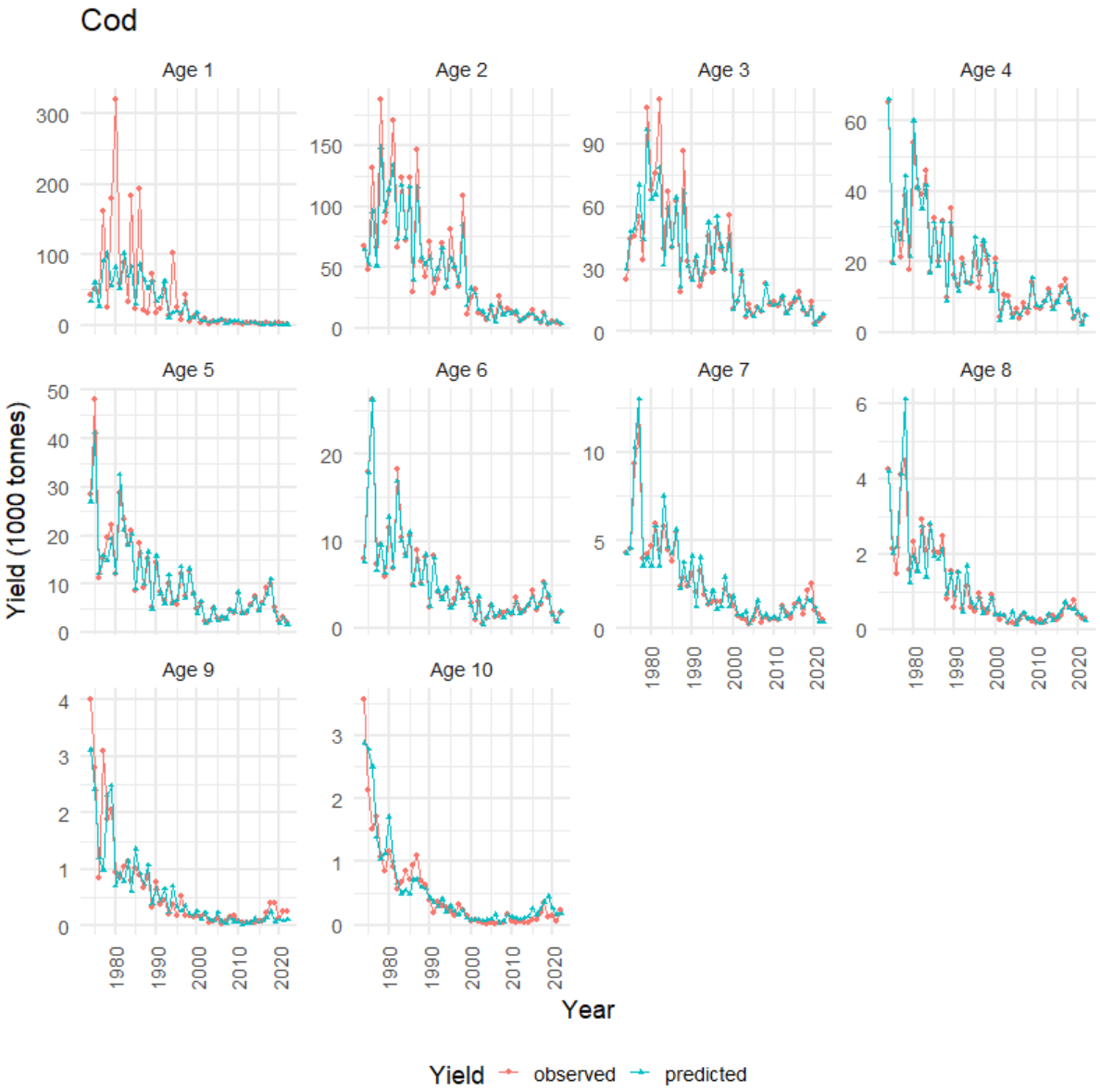


Figure 1.1.4.2. Cod. Observed and SMS predicted catch weight by age.

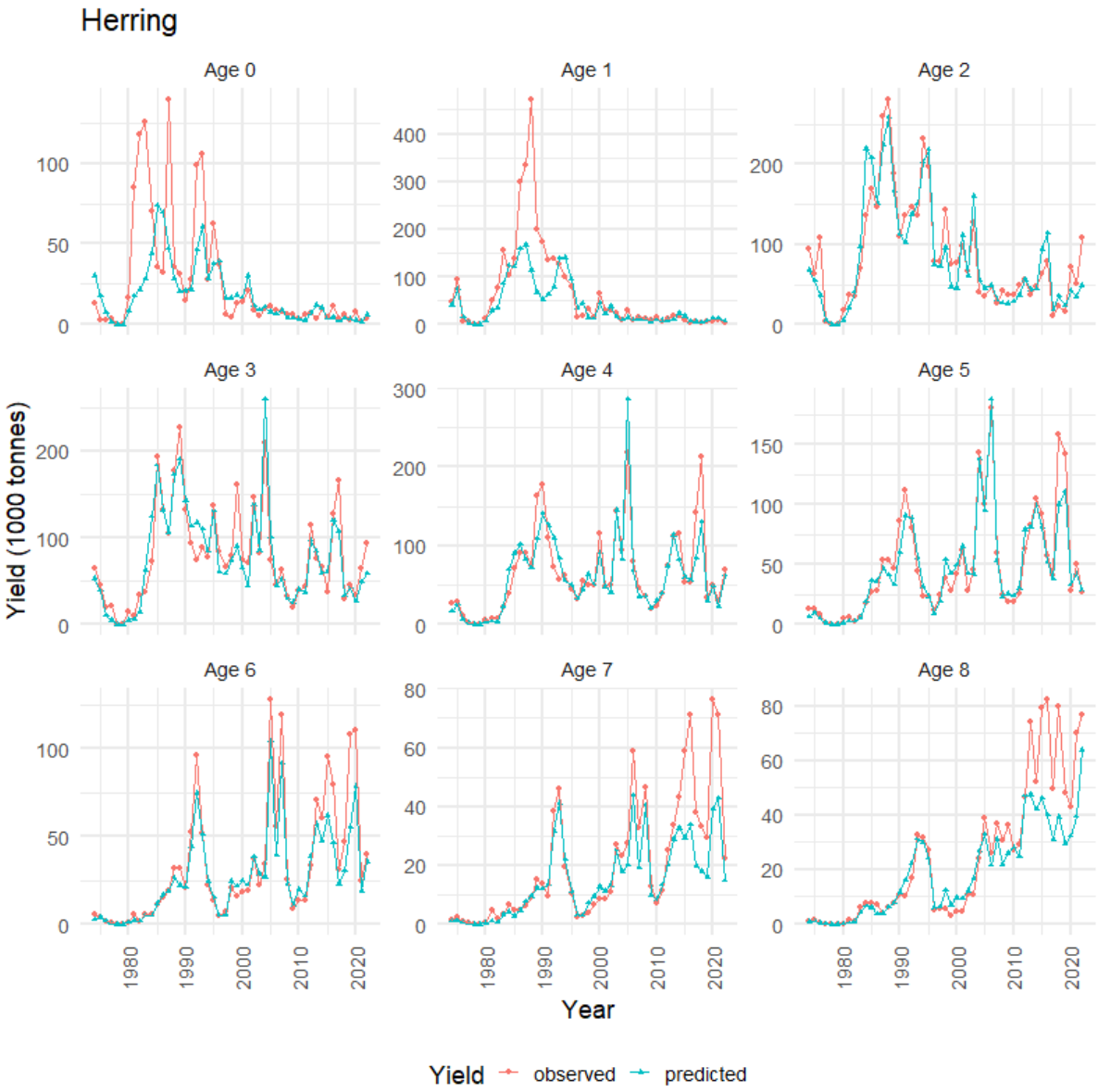


Figure 1.1.4.3. Herring. Observed and SMS predicted catch weight by age.

Survey data

The model fits age specific time-series from multiple surveys carried out throughout the North Sea. Whenever possible the same survey time-series used in the single species assessments were used for the key-run. The goodness of fit is highly variable among the stocks, surveys and ages. It is difficult to provide a systematic evaluation of the fitting. Patterns in the residuals both along ages and years exist but do not seem particularly different from the previous key-runs. Among the most visible patterns it is worth to mention those for haddock in quarters 3+4 with strong positive residuals for multiple ages and years in the beginning of the time-series while in recent years negative residuals dominate (Figure 1.1.4.4). Another example is plaice which shows strong year and age effects (Figure 1.1.4.5). For other species residual patterns are less pronounced.

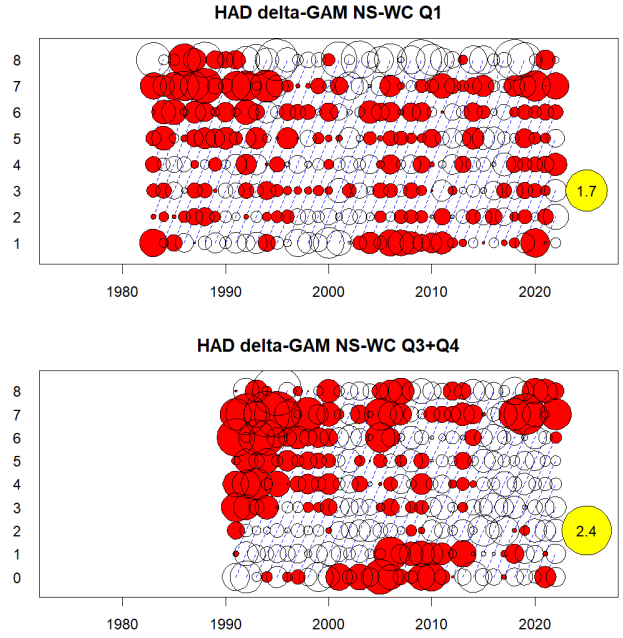


Figure 1.1.4.4 Haddock. Survey observations Residuals, log(Survey observed CPUE) - log(expected CPUE). Red is positive, White is negative.

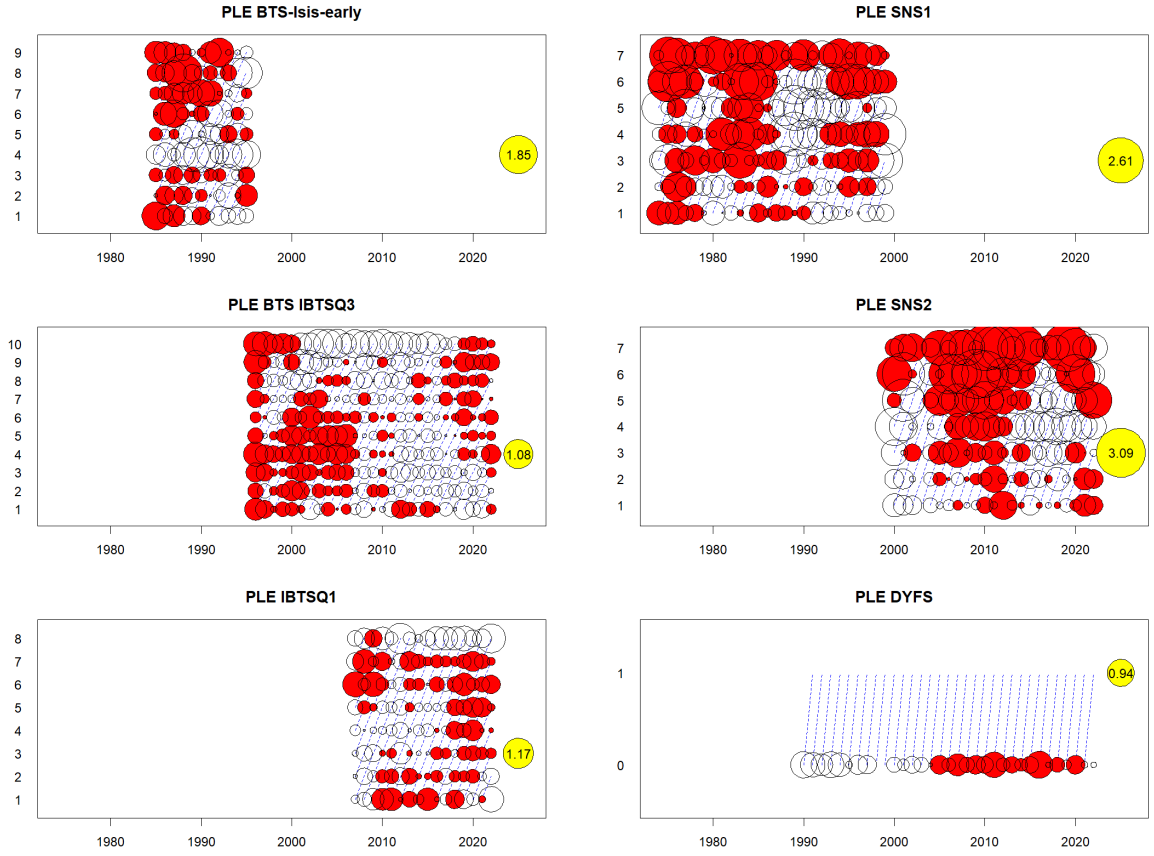


Figure 1.1.4.5 Plaice Survey observations Residuals, log(Survey observed CPUE) - log(expected CPUE). Red is positive, White is negative.

Stomach data

SMS is generally able to predict the patterns observed in stomach samples (based on the ObsEst plots). The SMS model is run with a quarterly time step and input data (incl. stomach data) are fitted on a quarterly basis and for different predator size classes. However, for convenience, and aware of the limits of such simplification, the fitting of the stomach data has been evaluated by the expert group on an annual basis and all predator size classes combined (comparisons for all predators are available at https://ices-eg.github.io/wg_WGSAM/NorthSeaKey-run2023_Supp-Plots.html.

Overall, the species composition in the stomach data appears rather stable in time, which is also largely due to the fact that stomachs are available from few years (for fish predators mainly between 1981 and 1991). On an annual basis, the species composition in the stomachs appears well represented in the model. For many of the main predators, other food (otherfood in figures) represents a considerable proportion of the total diet, especially for smaller length categories. For instance, approx. 3/4 or more of the cod diet is consistently composed of otherfood (Figure 1.1.4.6). Some more pronounced differences between observed and modelled diet emerge when interannual variability in species composition increases, as is the case for saithe (i.e. otherfood is approx. 60% in 1981 but around 30% in 1991 because of the increasing contribution of herring and/or a decrease in available otherfood like Euphausiids, Figure 1.1.4.7). The assumption of a constant otherfood biomass and availability of prey (i.e. constant predator-prey overlap) could contribute to the smaller variability over years predicted than observed in some cases (other examples can be found for grey gurnards or harbour porpoise). A systematic over or underestimation of modelled fish prey vs. otherfood overall years was only visible for herring gull (Figure 1.1.4.8). Reasons are unclear, however, the predator only has a minor contribution to total predation mortalities. When stomach data are available from a single year only but the model diet visibly departs from the observations (i.e., western horse mackerel), reasons are likely due to inter-seasonal variability in prey abundance and/or predator-prey overlap, and/or simply observation variability coming from the data and/or the overall fit to catch, survey and stomach data suggests some deviations from observed diet compositions. (Figure 1.1.4.9).

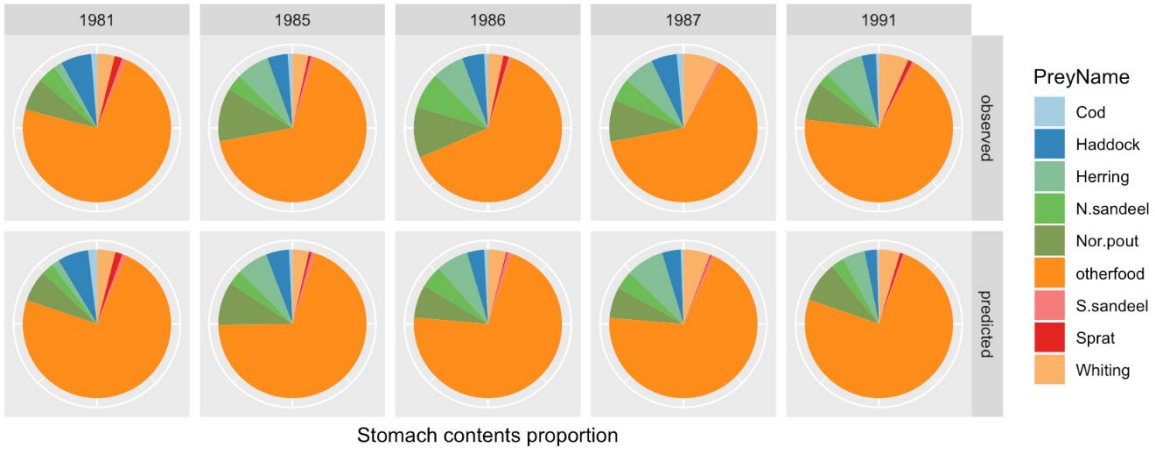


Figure 1.1.4.6. Input (top row) and SMS predicted (bottom) diet composition for cod.

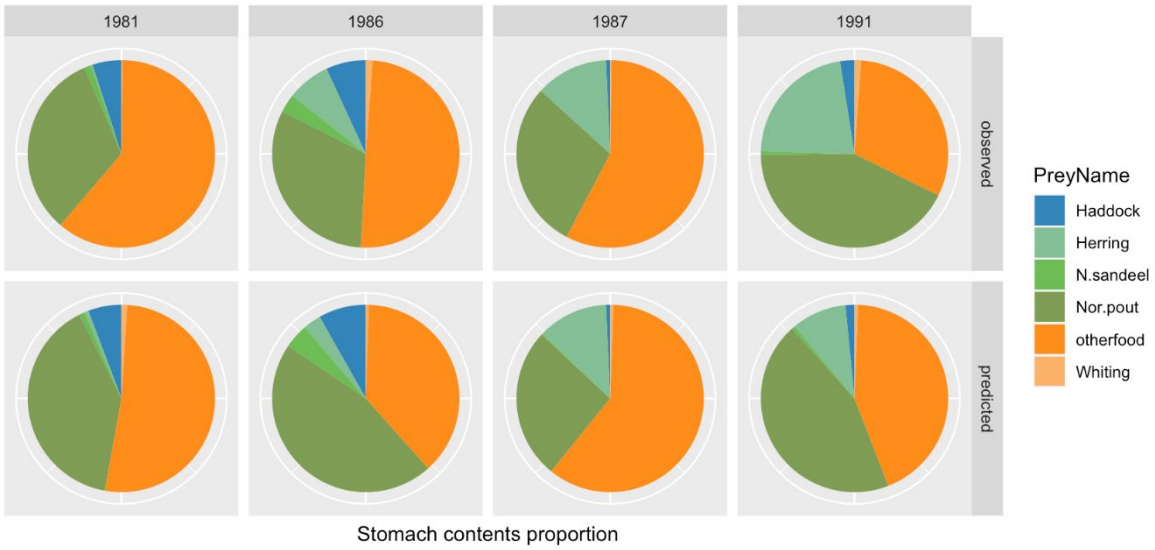


Figure 1.1.4.7. Input (top row) and SMS predicted (bottom row) diet composition for saithe.

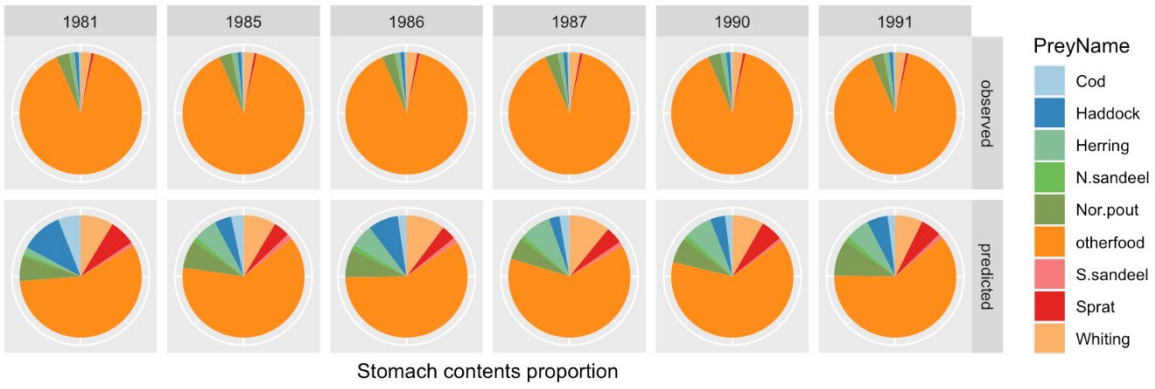


Figure 1.1.4.8. Input (top row) and SMS predicted (bottom row) diet composition for herring gull.

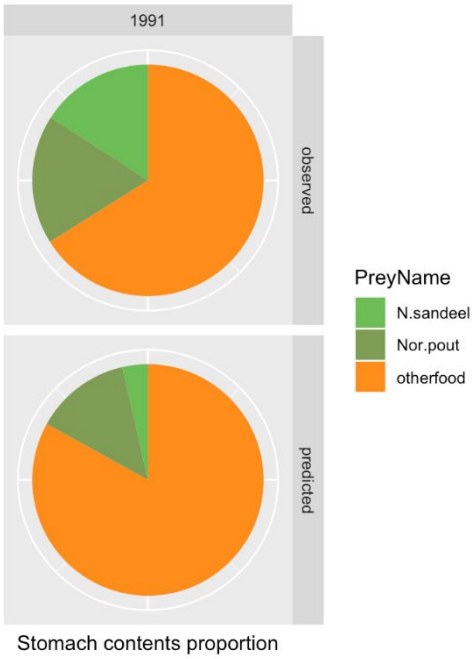


Figure 1.1.4.9. Input (top) and SMS predicted (bottom) diet composition for western horse mackerel.

As expected, M2 shows a general decrease with the age of the prey. Some exceptions are found for the age 0 of some prey species (e.g., N sandeel, Norway pout), where predation mortality for age 0 in quarter 3 is smaller than the predation mortality in quarter 4. This is probably linked to the uncertainties of estimating mean weight of 0-groups, but it has also to do with changes in the importance of predators between quarters (e.g., horse mackerel, whiting, saithe).

1.1.5 Sensitivity and uncertainty

Many processes, abundances and parameters that are included in SMS are highly uncertain. Here we consider components with high uncertainty that we expect to have a strong effect on the model outcomes. In addition, we describe the uncertainty, sensitivity and robustness tests covered in the current key-run. In this key-run, a retrospective analysis (5-year peel of all input data) was conducted and the effect on the SSB, F, Recruitment and M2 by age was considered. The robustness of the model to an adjustment on cod natural mortality to account for migration to the West of Scotland area (sometime referred as "magic M") was tested by means of a retrospective analysis. The effect of adding plaice as a prey species to the model was tested by assuming two different relationships between age and background mortality for plaice. Different methods for a calculation of alpha0 were used, and their effect on the model outcomes were considered. The uncertainty analysis of the estimates (CV) was unfortunately not possible this year due to changes in the model builder procedure.

Diets and Dirichlet distributions, alpha0 calculation

Variance in the stomach content observations is modelled via a Dirichlet distribution. A species-specific parameter linking the sampling level and variance is estimated by the model. Changes to this year's key-run included how alpha0, which is related to the precision of the Dirichlet distribution in the likelihood component. Previously this value was fitted within the SMS

framework, however this year it was input following a bootstrapping exercise. Previously SMS was fitted to averages of stomach estimates, and therefore there was no information included regarding the variance in stomach samples, or effort in the estimates, possibly leading to over-fitting of the stomach data.

The likelihood component of the stomach data accounts for uncertainty in SMS in two ways. Uncertainty caused by errors in the model, how the model doesn't exactly describe reality, and uncertainty in the observation process. The previous formulation of SMS only accounted for uncertainty in the model, meaning that uncertainty in the observation process could be ignored, leading to potentially overfitting of the stomach data. By fixing alpha0, as done this year, only uncertainty in the observation process is accounted for, potentially weighting the stomach data too much. An alternative approach, where alpha0 is fitted but has a maximum value account for both observation uncertainty and uncertainty in the model. This approach was tested, however there was issues during the fitting procedure, and it was decided to stick to the approach of fixingalpha0. Sensitivity analysis of the two procedures, "alpha_0" and "alpha_max", show that the results do not change using the two procedures.

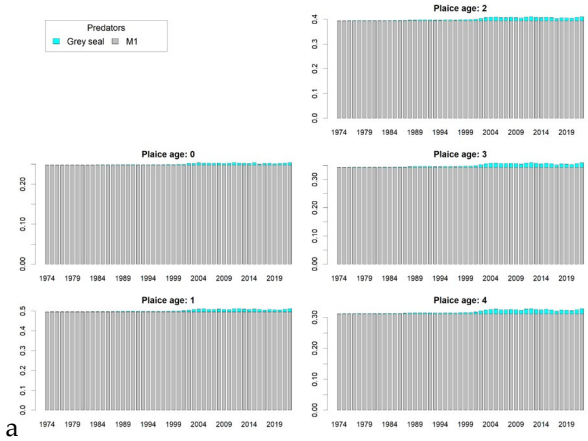
Additional M on cod

The 2023 SMS keyrun follows several assumptions used in the cod stock assessment model prior 2023 (i.e., single stock assumption, north-west distribution limited to the North Sea excluding the West of Scotland area) including the adjustment on the M of age3+ from 2011 to correct for migration outside the North Sea. A comparison of a retrospective analysis including and excluding an additional M showed that removing the additional mortality did not improve the fit of the model.

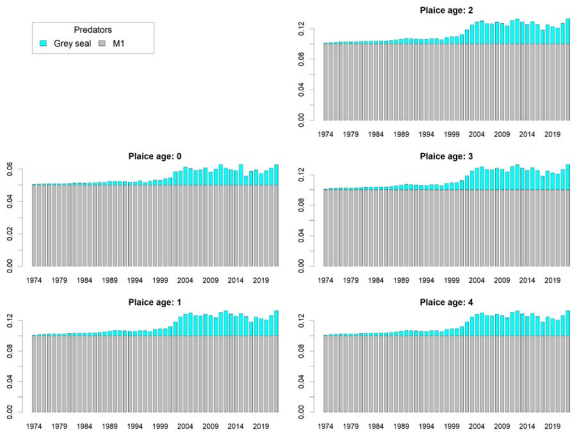
Plaice as a prey species

By default, M1 for plaice, which represents the background mortality from other sources than predation, was set to the age varying M currently used in the single species assessment. As a robustness test, SMS was also run with the M1 used prior to the benchmark, i.e., M1=0.1 for all ages and years. The rationale behind the test was that if shifting to a very low M1 value does not have an effect on the estimates of the model that do not consider plaice, adding plaice to the model does not have a strong effect on the model outcomes.

The estimated M2 varies depending on the value of M1, with M2 increasing with a lower M1 (Figure 1.1.5.1). The value of M1+M2 varies also with M1 indicating that M2 for plaice is sensitive to the value for M1. Due to the sensitivity to M1 values and the absence of fish predation of plaice in the model, the estimated M2 values were considered unreliable by the review group. The plaice M2 values were therefore considered unfit for use in the plaice single species assessment model. Additional work is required in the next key-run to make good estimates of M2 for plaice.


Predators
Grey seal
M1
Plaice age: 0
Plaice age: 1
Plaice age: 2
Plaice age: 3
Plaice age: 4

a


Predators
Grey seal
M1
Plaice age: 0
Plaice age: 1
Plaice age: 2
Plaice age: 3
Plaice age: 4

b

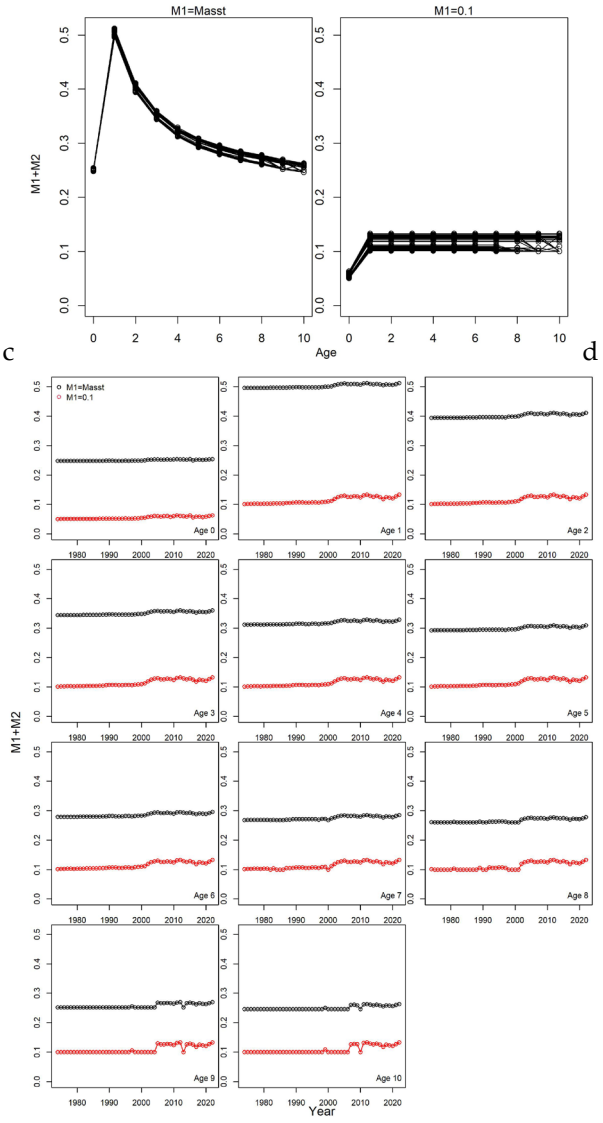


Figure 1.5.1. Estimated natural mortality (M1+M2) when M1 is from the assessment (a), when M1=0.1 (b), and comparison of M1+M2 across ages (c), and years (d).

Retrospective analysis

Five years of the input data were peeled off year by year, after which SMS was run and the effect on the predicted M2, SSB, F and R values was examined.

Overall, retrospective patterns in M2 were small except for the second peel for herring, haddock and Norway pout, where the model predicted different M2s. The SSB for all species except Norway pout were similar for all retrospective fits, however the second peel for Norway pout it was considerably different.

Uncertainty in SSB, Recruitment, and M2

Uncertainty analysis of the SSB, recruitment and M2 estimates (CV) was unfortunately not possible this year due to changes in the model builder.

1.1.6 Comparison with previous key-run

The SMS methodology has been reviewed in ICES WKMULTBAL (2012) and in several WGSAM (i.e., 2016, 2019).

Comparison with the previously reviewed and approved 2020 key-run was part of the 2023 WGSAM review and is summarized here. Most results were comparable between key-runs and differences in results were mainly attributable to changes in SMS. The main differences between the two key-runs are highlighted below.

Changes in SSB, F and Recruits since last key-run

For most of the species, the times series of F, SSB and recruits from the new key-run are very close to those of the 2020 key-run.

Cod presents a lower SSB and higher F between 2010 and 2022 compared to the previous key-run. Recruitment for the whole time-series is estimated lower in the 2023 key-run. These differences result mainly from the changes in the ICES assessment and the inclusion of the additional M1 to take assumed migration of cod age 3+ to area 6.a into account.

Increased whiting SSB and decreased F between the 2020 and 2023 key-runs are significant and are due to changes done at the ICES benchmark. These changes are consistent with the ICES assessment.

For northern sandeel, SSB, F and recruitment differ between the key-runs probably due to the benchmark on sandeel stocks in 2022/2023, the longer commercial CPUE time-series in the 2023 key-run, and probably the decrease in M2 due to the seal diet being split between northern and southern sandeel in this key-run.

Recruitment, F and SSB are very different for plaice in the two key-runs. This is partly due to the plaice benchmark.

Changes in M2 since last key-run

Large differences in M2 are observed for cod between the 2023 and the 2020 key-runs. Age 0 predation is lower in the 2023 key-run due to a reduction in M2 from mainly grey gurnards, and an increase in M2 from birds and A. radiate. Predation mortality of age 1 and 2 cod is slightly lower in the 2023 key-run up to year 2000 and higher in the remaining time period due to the upward revision of the whiting population. Age 3 M2 is larger in the 2023 run due to the change in seal population numbers and revision of seal diet data.

The two key-runs show similar estimates of M2. The largest change is seen for age 0, with a lower M2 in the most recent key-run, apparently from all predators.

Predation mortalities of herring follows the same trends in the two key-runs, despite some annual differences. The most consistent changes are a lower M2 for age 0–1 and a higher M2 for ages 2–4 in the 2023 key-run. For age 4, the increase in M2 is due to a higher partial M2 from saithe and harbour porpoise.

M2 for northern sandeel is generally lower in the 2023 key-run, mainly due to the split of sandeels in the grey seal diet from entirely northern sandeel into a northern and southern sandeel.

M2 for southern sandeel for ages 2-4 are larger in the 2023 key-run, due to southern sandeel now being a prey for grey seals.

For Norway pout, M2 for age 0 is estimated slightly lower in the new key-run, mainly due to a smaller partial M from hake.

For sprat, M2 for ages 2+ are higher in the 2023 run, mainly due to a higher M2 from mackerel, where the input weighting of diet has changed the overall weighting of the likelihood components.

Plaice has now become a prey species for grey seals, however the estimated M2 (max 0.015) is small and time is needed to validate the plaice M2s for use in the single species assessment.

1.2 Review recommendations

WGSAM accepts the model output from SMS as key-run with the settings given in the Stock Annex (Annex 3)

Key-run summary sheet

AREA	NORTH SEA
Model name	SMS
Type of model	Age–length structured statistical estimation model
Run year	2023
Predatory species	Assessed species: Cod, haddock, saithe, whiting, mackerel Species with given input population size: North Sea horse mackerel, western horse mackerel, grey gurnard, starry ray, hake, fulmar, gannet, great black backed gull, guillemot, herring gull, kittiwake, puffin, razorbill, grey seal, harbour porpoise
Prey species	Cod, haddock, herring, Norway pout, southern North Sea sandeel, northern North Sea sandeel, sprat, whiting
Time range	1974–2022
Time step	Quarterly
Area structure	North Sea, ICES sub-division 4
Stomach data	Fish species: 1981, 1985, 1986, 1987, 1991, 2005, 2013 Grey seals: 1985, 2002 Harbour porpoise: Decadal 1985, 1995, 2005
Purpose of key-run	Making historic data on natural mortality available and multispecies dynamics
Model changes since last key-run	None
Output available at	Sharepoint: …/data/NS_2023_key_run.html https://github.com/ices-eg/wg_WGSAM/NorthSeaKeyRun_2023
Further details in	Report of the Working Group on Multispecies Assessment Methods 2023

WGSAM considers the key-run as currently best possible run with SMS to provide natural mortality estimates. WGSAM recommends to use these values as input to single species stock assessments. The full time-series should be used and not only an update for the years after the last key-run in 2020.

A number of recommendations steam from this review:

- The new stomach database and its associated data should ideally be used in future SMS key-runs (including both the Baltic and North Sea), however new methods need to be

developed to harmonise the new samples with those that occurred in the 1980s and in the Year of the Stomach (1991). Potential solutions could be (i) to redefine the likelihood function to use individual observations, rather than the average diet, (ii) to work towards multiarea key-run models that would be inherently better to handle data spatial fragmentation in the sampling, or (iii) using statistical models to standardize the stomach data for changes in the spatial distribution, predator size, quarter, or other sampling variables. Currently, the new stomach database is still continuously being updated with new and old data collected over the years, and as the number of samples among years increase, this should represent a strong incentive to use the full time-series of samples for future key-runs.

- From the review it emerged that it would be beneficial that modellers in WGSAM are better supported by the stock assessment working groups in the preparation, maintenance and documentation of the time-series input for the North Sea key-run. That would help to consolidate the input data and would provide the relevant information to interpret changes in between key-run well in advance of the working group meeting and key-run review.
- Similarly, the review suggests that update of time-series for birds would largely benefit from contribution by bird experts (i.e., JWGBIRD).
- The harbour porpoise numbers time-series is assumed constant at 0.2 million individuals which is an obsolute assumption as suggested by the decreasing trend over the last decade presented by OSPAR (Abundance and Distribution of Cetaceans (ospar.org)). It is relevant to re-evaluate and update this rough estimate in preparation of the next key-run. To our knowledge there are no population number estimates available for harbour porpoise, but possibly trends could be incorporated.
- Visualisation of the model output is abundant and informative, and it has been improving considerably through the years. However, the richness of model output can make review of model fitting difficult at time, especially for data components like the diet data which are characterise by numerous dimensions. In this respect, it would be useful to explore the possibility to develop summary visual diagnostics that could inform about model fitting to the diet data simultaneously across multiple predators.

1.3 References

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WD03 why the new fish stomach data from the North Sea were not included in the 2023 SMS key-run.

Annex 1: List of participants

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Annex 2: WGSAM resolution

The **Working Group on Multispecies Assessment Methods** (WGSAM), chaired by Valerio Bartolino Sweden; and Michael Spence, UK, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2022	10-14 October	Woods Hole, USA	Reports on keyrun reviews to be provided after each review is complete	Incoming co-chair: Michael Spence (UK) Outgoing co-chair: Sarah Gaichas (USA)
Year 2023	9-13 October	Edinburgh, UK	Reports on any keyrun reviews that are completed	
Year 2024			Final report by Date to SCICOM	

ToR descriptors

ToR	Description	Background	Science Plan Codes	Duration	Expected Deliverables
a	Regional updates: Review further progress and deliver key updates on multispecies modelling and ecosystem data analysis contributing to modeling throughout the ICES region	This ToR acts to increase the speed of communication of new results across the ICES area	5.1; 5.2; 6.1	3 years	Report on further progress and key updates. Review and collaborate with appropriate EGs to revise sections on "species interactions" in the Fisheries Overviews
b	Key-runs: Parametrisation of multispecies and ecosystem key-run models for different ICES regions. This includes standard update (limited to inclusion of recent data), extensive update (incl. new data and processes), and new key-runs.	Key-runs are models checked against high quality criteria, which are developed to contribute to a variety of operational objectives as part of the ICES advice, i.e. provide information on natural mortality for inclusion in single species assessments, estimates of multispecies reference points, large operating ecosystem models for MSE, etc.	5.1; 5.2; 6.1	3 years	Report on output of multispecies models including stock biomass and numbers and natural mortalities for use by single species assessment groups and external users.
c	Skill assessment: Establish and apply methods to assess the skill of multispecies	This work is aimed at assessing the performance of models intended for	5.1; 6.1; 6.3	3 years	Report on technical requirements for cross-models standardisation and comparison. Manuscript(s) on skill

	models intended for operational advice	strategic or tactical management advice. Evaluation will require work towards standardisation for cross-model comparison. This ToR will also deal with evaluation of methods for model calibration and data weighting in the context of multispecies modelling.			assessment of wide array of multispecies models based on a large simulation study.
d	Multi-model advice: Evaluate methods for generating advice by comparing and/or combining multiple models	This work is aimed at addressing structural uncertainty in advice arising from multiple models	5.1; 6.1; 6.3	3 years	Report on methods for comparing models and for constructing model ensembles. Report on case examples from both simulation testing and real studies
e	MSE: Evaluate methods and applications for multispecies and ecosystem advice, including evaluation of management procedures and estimation of biological reference points under the uncertainties of climate change.	This ToR looks for multispecies and ecosystem approaches to understand the resistance and resilience of ecosystems to a warming environment and to perturbations related to the effects of climate change. Through the use of simulations, alternative management strategies and exploitation regimes can be evaluated for robustness to uncertainties related to climate change.	2.5; 5.2; 6.1	3 years	Review methods to evaluate populations and ecosystem resilience. Review of methods for management strategy evaluation which incorporate the effects and uncertainties of climate change

Summary of the Work Plan

Year 1	All ToRs, update keyrun Baltic Sea (coupled with data preparation workshop for the Baltic Sea benchmark), keyrun Georges Bank multi-model (dedicated workshop)
Year 2	All ToRs
Year 3	All ToRs

Supporting information

Priority	The current activities of this Group will lead ICES into issues related to the ecosystem effects of fisheries under multiple sources of uncertainties incl. climate change. The activities will provide information (e.g., natural mortality estimates, performance of indicators, multispecies reference points) and tools (e.g., multi-model ensembles, keyrun models) valuable for the implementation of an integrated advice and the application of a precautionary approach in several North Atlantic ecosystems. Consequently, these activities are considered to have a high priority.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 20–25 members and guests. Expertise in ecosystem dynamics, trophic interactions, modelling and fish stock assessment from across the whole ICES region.
Secretariat facilities	Standard EG support.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	ACOM, assessment Expert Groups.
Linkages to other committees or groups	WGMIXFISH, WGDIM, WGBIFS, IBTSWG, WGECO, all IEASG groups, WKCLIMAD.
Linkages to other organizations	None

Annex 3: Stock Annex for the ICES North Sea SMS configuration

Working Group	Working Group on Multispecies Assessment Methods (WGSAM)
Date	December 2023 (after the WGSAM 2023 meeting in October)
Predatory species	Assessed species: Cod, haddock, saithe, whiting, mackerel
	Species with given input population size: North Sea horse mackerel, western horse mackerel, grey gurnard, starry ray, hake, fulmar, gannet, great black backed gull, guillemot, herring gull, kittiwake, puffin, razorbill, grey seal, harbour porpoise.
Prey species	Assessed species: Cod, haddock, herring, Norway pout, southern North Sea sandeel, northern North Sea sandeel, sprat, whiting
Stock Assessor	Morten Vinther

Summary

SMS (Lewy and Vinther, 2004) is a stock assessment model including biological interaction estimated from a parameterised size-dependent food selection function. The model is formulated and fitted to observations of total catches, survey cpue and stomach contents for the North Sea. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix.

In the present SMS analysis, the following predator and prey stocks were available: predators and prey (cod, whiting, haddock), prey only (herring, sprat, northern and southern sandeel, Norway pout), predator only (saithe, mackerel), no predator–prey interactions (sole and plaice) and 'external predators' (eight species of seabirds, starry ray, grey gurnard, North Sea horse-mackerel, western horse-mackerel, hake, grey seals and harbour porpoise). The population dynamics of all species except 'external predators' were estimated within the model.

2023 key run

The 2023 key run added three years of data, 2020–2022, to the time-series since 1974. This includes both new and revised data from benchmarked ICES assessments. The full time-series of sea bird abundance was revised; the old time-series had not been updated since 2011. An update of the population number of grey seals was also made and new grey seal diet data for 2010 were applied for the first time. Sandeels eaten by grey seals are now divided between the Northern and Southern stock (just the Northern stock in the 2020 key run). Plaice has become a prey species in SMS (eaten by grey seals).

With respect to methodology, fish diets were recompiled with the R-package FishStomachs (with similar results as in the 2020 key run). The new approach also estimates the variance of the estimated prey proportions. These estimated uncertainties are now used as input to SMS, where such uncertainties were previously estimated within SMS.

2020 key run

A key run for the North Sea SMS model, including data for the period 1974–2019 was produced at the 2020 WGSAM. This key run replaced the 2017 key run. The 2020 key run includes revision and updates to the input data as produced by the ICES assessments, but no major modifications of the configuration of the model.

2017 key run

A key run for the North Sea SMS model, including data for the period 1974–2016 was produced at the 2017 WGSAM. This key run replaced the key 2014 key run. The 2017 key run includes revision and updates to the input data and a few modifications of the structure of the model.

All assessment models for the individual stocks were updated with the most recent data and stock numbers were corrected where the stock area did not correspond to the key run area (the North Sea proper, Division 4). New estimates of quarterly mean weight-at-age in the stock were produced for stocks where this information was not available from the stock assessments. These values were lower than previous estimates and this increased the range of age groups of cod consumed by marine mammals to also include significant impacts on cod of age 3. To improve the inclusion of mackerel in the model, this species was included as a fully modelled predator in the model, and the proportion of the mackerel stock, which occurs in the North Sea in each quarter, was reviewed, and new estimates were produced. Consumption (ration) of the main fish predators, including mackerel and horse mackerel, was revised to reflect the most recent knowledge of evacuation rates leading to changes for mackerel and horse mackerel (lower

consumption rates). Finally, the quarterly overlap of the species with sandeel was evaluated and adapted to better mirror the stomach contents observed. Diet data for the predatory fish were bias corrected to take into account that evacuation rate is a function of prey energy density, prey armament and ambient temperature. This correction gave in general lower diet proportion of the SMS prey fish and a higher proportion of "other food" compared to the observed stomach contents which previously have been used directly as diet. Diet data for harbour porpoise were corrected for differences in residence time of otoliths from different species and size of the prey and the resulting consumption showed a larger contribution from sandeel and herring while whiting was less important than previously estimated.

Model description

The SMS model (Lewy and Vinther, 2004) is a stock assessment model including biological interaction estimated from a parameterised size-dependent food selection function. The model is formulated and fitted to observations of total catches, survey cpue and stomach contents for the main stocks in the North Sea. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix.

The following predator and prey stocks are available:

- predators and prey (cod, whiting, haddock);
- prey only (herring, sprat, northern and southern sandeel, Norway pout);
- predator only (saithe and mackerel);
- no predator-prey interactions (sole and plaice); and
- 'external predators' (eight seabird species, starry ray, grey gurnard, North Sea horse-mackerel, western horse-mackerel, hake, grey seals and harbour porpoise).

The population dynamics of all stocks except 'external predators' are estimated within the model.

A detailed description of the model can be found in Appendix 1.

Where to find Input and output, the SMS program and R-scripts

The SMS model has a comprehensive set of input and output data which cannot all be presented in this StockAnnex. Parts of these data are presented in this StockAnnex, but full input and input data and software can be found at the WGSAM Sharepoint and on Github https://github.com/ices-eg/wg_WGSAM.

The **GitHub** include several directories:

- NortSeaKeyRun_2014: The SMS North Sea key run made at the 2014 WGSAM, including data for the period 1974–2013. The version here has been corrected in 2015 for an input error.
- NortSeaKeyRun_2017: The SMS North Sea key run made at the 2017 WGSAM, including data for 1974–2016.

- NortSeaKeyRun_2020: The SMS North Sea key run made at the 2020 WGSAM, including data for 1974–2019.
- NortSeaKeyRun_2022: The SMS North Sea key run made at the 2023 WGSAM, including data for 1974–2022.
- input_output: Detailed presentation of input and output file for the 2023 key run. Includes a zip files with all graphics and tables, and a HTML document which shows the same tables and figures in a more user-friendly way.
- SMS_ADMB: AD Model Builder source code for the SMS North Sea program
- SMS_R_prog: R scripts for preparing, running and presenting results from an SMS run
- SMS_Stomachs: R scripts for compilation of stomach contents observations into population diet

The "**input_output**" and the HTML file directory found at GitHub above has data organised as outlined below:

- Input
  - c.obs: plots of observed catch numbers-at-age from this and previous key runs
  - OtherPredators: plots of stock size of external predators from this and previous key runs
  - West: plots of mean weight-at-age in the sea from this and previous key runs
  - Weca: plots of mean weight-at-age in the catch from this and previous key runs
  - M1: plots of residual natural mortality-at-age from this and previous key runs
  - PropMat: plots of proportion mature-at-age in the sea from this and previous key runs
  - prop.in: plots of the proportion of the population (stock) within the North Sea area in the sea, from this and previous key runs
  - ALK: Age Length Keys for converting number at age to number at length.
  - Ration: plots of consumption (food ration) at age from this and previous key runs
  - Stomachs: Plots of relative stomach contents as used in SMS
    - OldNew: plots of relative stomach contents weight before and after recompilation
  - Tables
    - +Tables with most of the variables listed above
- Parameters
  - Figures plots
    - Catchability Estimated: catchability of survey cpue
    - Dirichlet_alpha0: concentration parameter ($\alpha 0$) for diet obs.
    - Survey_observation: Variance of survey catch per unit effort observations.
    - Vulnerability: Predator-prey vulnerability
    - + Various overview tables for SMS parameters
  - Tables +More details on parameters
- Output
  - Comparisons

        - Summary: Comparison of stock summaries from this and previous key runs
        - M2: Comparison of M2 values from this and previous key runs
        - SSB_R Comparison: of estimated stock recruitment relation from this and previous key runs
    - ExploiPattern: Estimated exploitation pattern (relative F)
    - PartialM2
        - Annually Plots of M2 by year for each age group of prey species, showing the partial M2 from each predator
        - Quarterly Plots of M2 by year for each age group of prey species, showing the partial M2 from each predator
    - Stock summary: Plots of stock summaries
    - WhoEatsWhom
        - Plots of biomass eaten by various combinations of predator and preys.
        - CSV files with the same information (on three aggregation levels).
    - Tables, with F at age, M2 and M=M1+M2 at age, N at age and stock summary
- Diagnostics
    - Residuals
        - Catch at age observation residuals
        - Survey at age observation residuals
        - Stomachs
            - Raw_resid residuals (Observed-predicted) for diet presented in various plots
            - ObsEst Observed and predicted diet
            - Comp_resid Compositional residuals (Trijoulet *et al.* 2023)
            - Stan_resid Standardised residuals
    - Retrospective (retrospective analysis 2018 to 2022)
        - Summary Plots of stock summaries,
        - M2 Plots of predation mortality (M2) at age

Input data

The description of input data is divided into four main sections:

Analytical assessment stocks: Stocks for which analytical age-based assessments are done by ICES or can be done from data available from ICES. Data input are similar to those applied by ICES "single-species" assessments used for TAC advice, with some additional data.

External predator stocks: Stocks for which stock numbers are assumed known and given as input to SMS.

Diet and ration data: Diet data and food ration data for all predators (analytical stocks and external predators) derived from observed stomach contents data.

Additional data: Miscellaneous data.

Analytical assessment stocks

This group of stocks includes:

Cod;
Haddock;
Whiting;
Saithe;
Mackerel;
Herring;
Northern sandeel;
Southern sandeel;
Sprat;
Norway pout;
Plaice;
Sole.

"Single-species" input data, by default given by quarterly time steps, include

- Catch-at-age in numbers (file canum.in);
- Proportion of the catch-at-age landed (file proportion_landed.in);
- Mean weight-at-age in the catch (file weca.in);
- Mean weight-at-age in the stock (file west.in);
- Proportion mature-at-age (file propmat.in);
- Proportion of M and F before spawning (file proportion_M_and_F_before_spawning.in);
- M, single-species natural mortality-at-age (file natmor.in);
- Survey catch-at-age and effort (file fleet_catch.in).

SMS uses quarterly time steps, so input catch data should preferably also be given by quarter. Most of the ICES North Sea stock assessments are however done using annual time steps (see table below).

Table 2.1.1. Overview of "dynamic" stocks used in SMS and their basis from ICES single-species advice.

Species	SMS		ICES Assessment			
	Species code	Max age	Stock area	First year	Age range (data)	time step
Cod	COD	10+	North Sea, eastern English Channel, Skagerrak	1963	1–15	year
Whiting	WHG	6+	North Sea and eastern English Channel	1978	0-6	year
Haddock	HAD	10+	North Sea, West of Scotland, Skagerrak	1965	0–15	year
Saithe	POK	10+	North Sea, Rockall and West of Scotland, Skagerrak and Kattegat	1967	3–10	year
Herring	HER	9+	North Sea, Skagerrak and Kattegat, eastern English Channel	1947	0–8	year
Northern sandeel	NSA	4+	Mix of sandeel stocks	1986	0–4	semester
Southern sandeel	SSA	4+	Mix of sandeel stocks	1983	0–4	semester
Sprat	SPR	3+	North Sea, Skagerrak and Kattegat	1974	0–3	quarter
Norway pout	NOP	3	North Sea, Skagerrak, and Kattegat	1984	0–3	quarter
Plaice	PLE	10+	North Sea, Skagerrak	1957	1–15	year
Sole	SOL	10+	North Sea	1957	1–10	year

Quarterly catch data

Quarterly catch-at-age numbers for cod, whiting, haddock, saithe and herring were provided by ICES assessment groups up to 2003. However, such data have not routinely been reported since. Most stock data before 2013 did not include discards, as those were not considered in the ICES assessment. In addition, stock areas for the ICES assessments have changed for many stocks since 2003. For example, haddock area 6.a (West of Scotland) was joined with the previously used stock area North Sea and Skagerrak in 2014. These changes in stock areas and discards' addition make it almost impossible to use the older time-series of catches.

Some quarterly catch data, including discards, can be found in the ICES InterCatch database. InterCatch data include national catch information used to derive the total international catch data for ICES stock advice. For each year, stock and nation (and fleet) a total annual catch weight is provided often divided into landings and discards. In addition, national catch-at-age in numbers and mean weight by the year or quarter can optionally be provided using the same aggregation level as for the total catch weight. InterCatch data include quarterly catch data, but only for the most recent years.

Table 2.1.3. Year range for quarterly data from assessment reports or produced by the stock coordinator (*).

Stock	Year range
Herring	2005–2022*
Northern sandeel	1982–2022*
Southern sandeel	1982–2022*
Sprat	1974–2022
Norway pout	1982–2022

Unfortunately, the quarterly catches provided did not appear to be updated back in time in response to e.g. benchmark decisions on changes in the stock area. Further, discards were not consistently reported in the time period. Hence, the quarterly catch data could not be used for whiting, haddock, saithe, mackerel, plaice and sole. Annual catch data as provided for the ICES single-species assessment are therefore used for cod, whiting, haddock, saithe, mackerel, plaice and sole. Data by quarter were available from assessments or stock coordinators for herring, sandeel stocks, sprat and Norway pout (Table 2.1.3).

For stocks with annual catch data it is assumed that annual F is distributed equally over the year, that is $F^{3}_{Y,A2,q}$ in the F model is set to the same value for all quarters (see Appendix 1, equation 3 for details).

For some stocks, annual catch data are divided into landings and discards, and in some cases also industrial bycatch (Table 2.1.1). The proportion of the catch-at-age landed as used in SMS is derived by year and age from landings (landings and industrial bycatch) and discards (and BMS) number-at-age. This proportion is assumed the same for all quarters.

Proportion of the stock within the North Sea.

SMS includes several stocks where the distribution area is larger than the North Sea (ICES subarea 4), while predation mortality is calculated only for the North Sea. The abundances of both predators and prey within the North Sea are calculated from abundance in the full distribution area and an assumed proportion of the stock within the North Sea, ideally by year, quarter and age. M for the stock distribution area outside the North Sea is assumed to be the same as within the North Sea. Likewise, the estimate of F is assumed to be the same within the full stock distribution area.

The NS-IBTS survey covers the North Sea, Kattegat and Skagerrak and in addition the English Channel since quarter 1, 2007), **and provides data to assess the distribution of cod, whiting, Norway pout and plaice.** The distribution areas for haddock and saithe are larger than the area covered by IBTS and are not used to estimate distribution for these two stocks. For herring, IBTS data do not separate between the North Sea and the Western Baltic stocks, which both are found in high proportions in the Kattegat and Skagerrak.

The distributions of the cod and whiting stocks were determined from the IBTS quarter 1 and quarter 3 survey data. Average cpue by species, year, quarter, age and ICES rectangle and were downloaded from the ICES DATRAS database (data type "cpue per age per subarea", survey NS-IBTS, quarters 1 and 3).

The proportion of the stock within the North Sea area was calculated from:

- Mean cpue within each ICES roundish area, year and quarter is calculated as a simple mean of the "cpue per age per subarea" (subarea=ICES rectangle).
- An index for stock abundance per area (North Sea, Skagerrak, Kattegat and English Channel) is calculated as the sum of average roundfish area cpue, weighted by the area (km^2) of the roundfish areas.
- The proportion of the stock within the North Sea is finally calculated by year and quarter from the index per area.

The smoothed value and potential significant trend of the proportions [0;1] within the North Sea was subsequently analysed by a gam model (beta distributed data on (0,1) with logit link function) with the proportion as a function of (spline smooth) of year.

The full data set of data for "proportion within the North Sea" can be found in the folder: input_output/input/prop.in (see section 2 for details).

Cod

Change in stock definition and M1

ICES has split the "North Sea cod" (distribution areas: North Sea, Skagerrak, English Channel) into three sub-stocks "Southern", "NorthWestern" and "Viking" (Figure 3.1-1); (ICES WKBCOD, 2023). The three sub-stocks include the area West of Scotland (subdivision 6.aN) which was earlier assessed separately. ICES assesses the sub-stocks simultaneously in a multi-stock-SAM model, where it is assumed that a given sub-stock is within its stock area in quarter 1 (~ at spawning time) and that the sub-stocks mix within other quarters. The SMS model cannot emulate that! ICES is still maintaining the catch at age data for the old stock definition, which allows a continuation of the old cod stock definition in SMS. The "old" data includes ages 0-10+, while the age ranges are truncated to 0-6+ in the three sub-stocks data.

The 2021 cod benchmark introduced an *ad hoc* adjustment on natural mortality of ages 3+ from 2011 to mimic an assumed 15% migration to the West of Scotland area, which was not included in the assessment area. M1 used for SMS is adjusted using the same approach:

$$M1_{\text{adj},a,y} = M1_{a,y} - \ln(1-\alpha)$$

where α (15%) is the migration rate as a proportion.

The full data set of data for "M1" and the changes since the previous key run can be found in the folder: input_output/input/M1 (see section 2 for details).

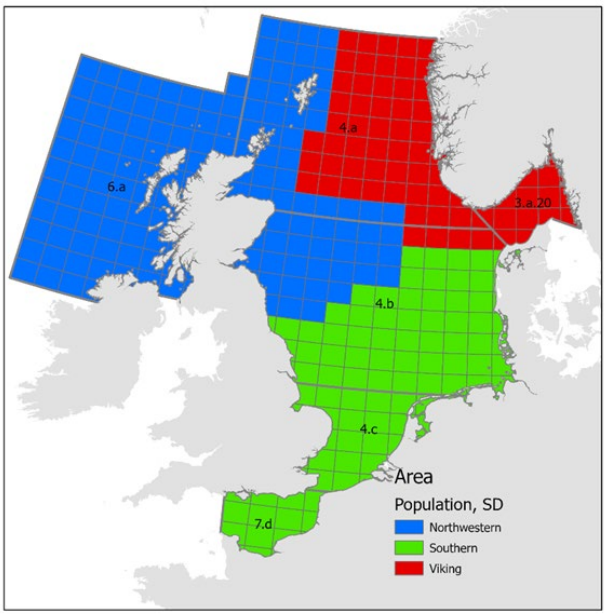

Figure 3.1-1 ICES cod assessment with stock area for three sub-stocks.

Catch data

Annual catch data (catch-at-age in number and mean weight-at-age, for landings and discards and combined) are available from the ICES Assessment Working Group for the North Sea Stocks (ICES, WGNSSK 2023).

The full data set of catch at age data and the changes since the previous key run can be found in the folder: input_output/input/c.obs (see section 2 for details).

Survey data

Survey data are modified from the data used by the (three sub-stock) single-species assessment. The SMS version is based on the same two gam models (quarter 1 and quarter 3-4) as applied by ICES WGNSSK, which fit survey data for the whole distribution area. The indices for used SMS are however calculated for the area within the old stock area (e.g. excluding area 6.a). The table below shows the resulting survey data, where alfa and beta are the timing of the survey, given as a proportion of the year.

	Name	Years	Ages	alfa and beta	Source
1	Q1, Gam	1983–2023	1–7	0.125-0.125	WGNSSK 2023
2	Q34, Gam	1992–2022	0-7	0.75-075	WGNSSK 2023

Biological data

Proportion mature ("raw" data from quarter 1 surveys) and single-species natural mortality (M) data are available from WGNSSK 2023. SMS uses smoothed values of proportion mature. This smoothing is done outside before used in SMS while WGNSSK uses proportion mature fitted within the SAM model. M1 values are adjusted as mentioned at the beginning of this cod-section.

The single-species assessment assumes that the mean weight-at-age in the stock is equal to the mean weight-at-age observed during the quarter 1 survey. This set of mean weights is estimated for all the sub-stocks individually. In SMS it is assumed that the mean weight-at-age for age 2 and younger is constant over the years. Data from the old North Sea MSVPA (ICES CM 1997/Assess:16) are used for these younger ages. MSVPA data provide weights by age and quarter, but the weights do not change between years. For age 3 and older, the ratio between weight per quarter (and age) as specified in MSVPA data are maintained, but raised to the annual mean weight in the catch used by single-species assessment (excluding area 6.a data). Raising is done from the simple mean of quarterly mean weights and the annual single-species mean weight in a given year.

The full data set of data for "mean weight at age in the sea" and the changes since the previous key run can be found in the folder: input_output/input/West (see section 2 for details).

Stock distribution

The observed proportion of the stock within and outside the North Sea is shown for Quarter 1 (Figure 3.1-2) and quarter 3 (Figure 3.1-3) and Figure 3.1-4 shows the observed proportion within the North Sea (excluding the English Channel data, as those exist only for the last 13 years) and the fitted proportion assuming a smooth temporal change. There is a highly significant trend for age 1 and age 2 in quarter 1. In quarter 3, the trend for age 3 is statistically significant, but the temporal change in proportion is limited. Even though it is not statistical significant, the trend for age 1 and age 2 in quarter 3 follows the general trend for the same age groups in quarter 1 ()

The proportion of cod stock within the Eastern Channel based on survey data cannot be determined for a longer time-series. Available data suggest a proportion below 5%. The commercial

catch of cod is mainly determined by the individual TACs for three areas North Sea, Skagerrak and the English Channel (east and western combined), however catch data reported to ICES (WGNSSK 2017) show that 4% of the cod stock catch has been taken from the Eastern Channel for the years 2007–2016. This proportion, if it is representing the stock distribution, is small and therefore ignored for SMS purposes.

For Quarter 1, the fitted survey proportions for ages 1 to 5+ are used to exclude cod in the Skagerrak/Kattegat from the SMS consumption model. For quarter 3, only data back to 1991 are available. The difference between the fitted proportions by quarter for age 1 and older is quite small (Figure 3.1-6), and therefore the Quarter 1 proportions are assumed to apply also to quarter 3. For age 0 in quarter 3, the observations are highly variable and it is therefore assumed that the proportion of age 0 in quarter 3 follows the proportion of age 1 in quarter 1. The full data set of data for "proportion within the North Sea" and the changes since the previous key run can be found in the folder: input_output/input/prop.in (see section 2 for details). The proportions are assumed to be the same for all quarters.

Figure 3.1-2. Stock distribution, Cod quarter 1. Please note that data for the English Channel has just been available since 2007.

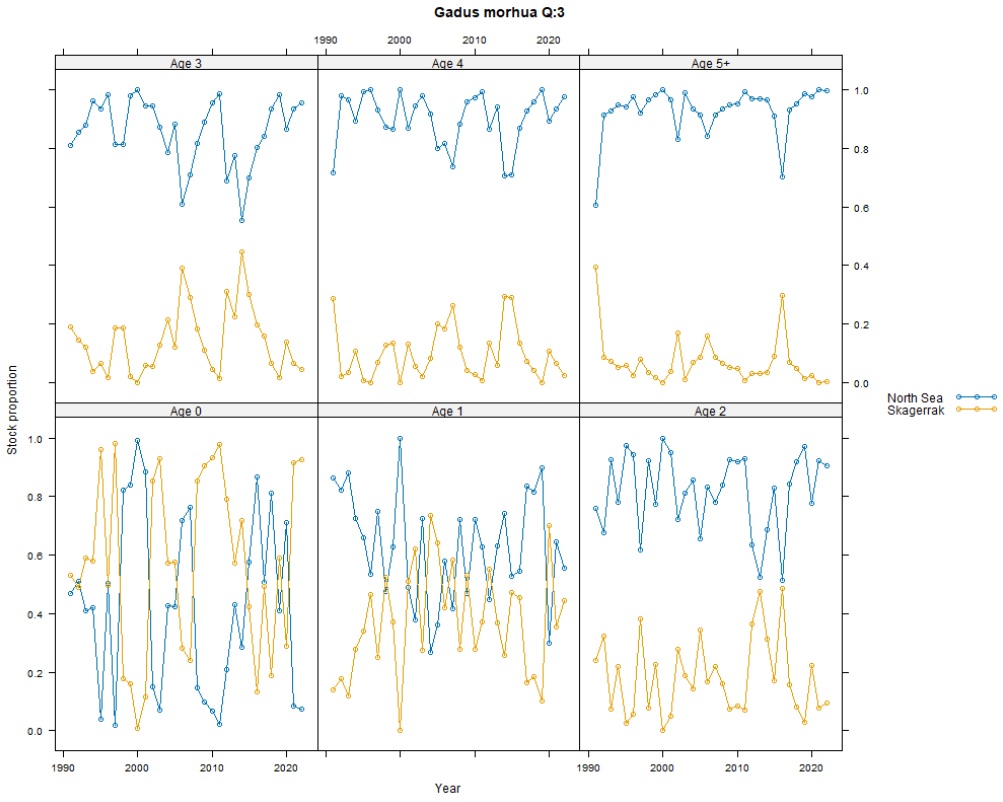

Figure 3.1-3. Stock distribution, Cod quarter 3.

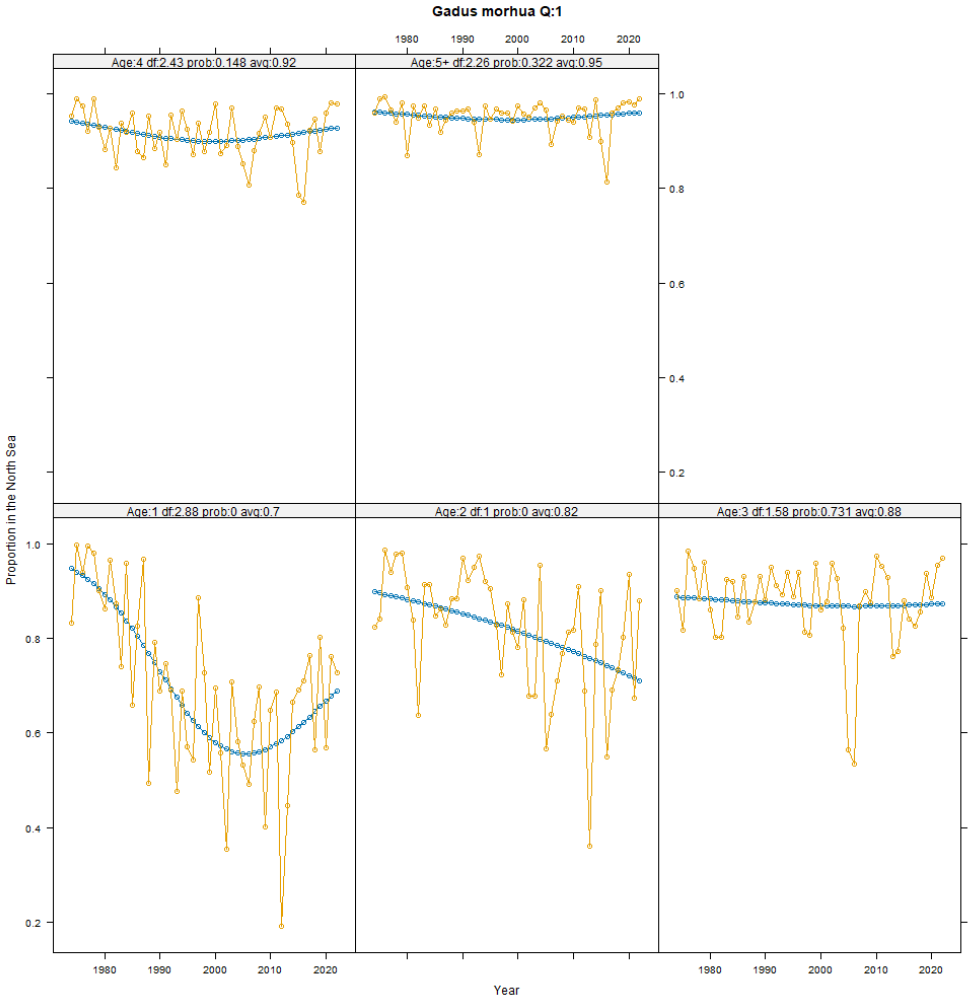

Figure 3.1-4. Observed and fitted proportion of the cod stock (North Sea & Skagerrak data) within the North Sea. For each age, the degree of freedom for the fit, the significance of the fit and the average proportion are shown.

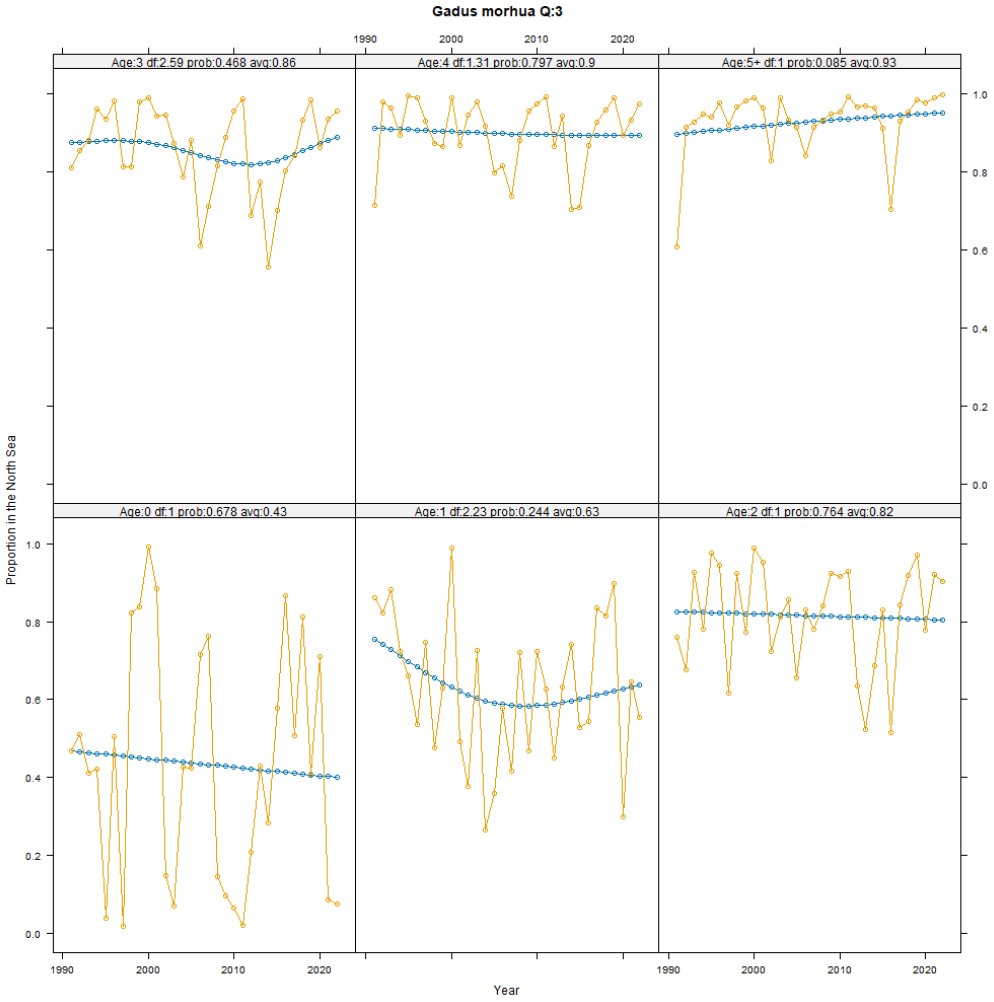

Figure 3.1-5. Observed and fitted proportion of the cod stock (North Sea & Skagerrak data) within the North Sea. For each age, the degree of freedom for the fit, the significance of the fit and the average proportion are shown.

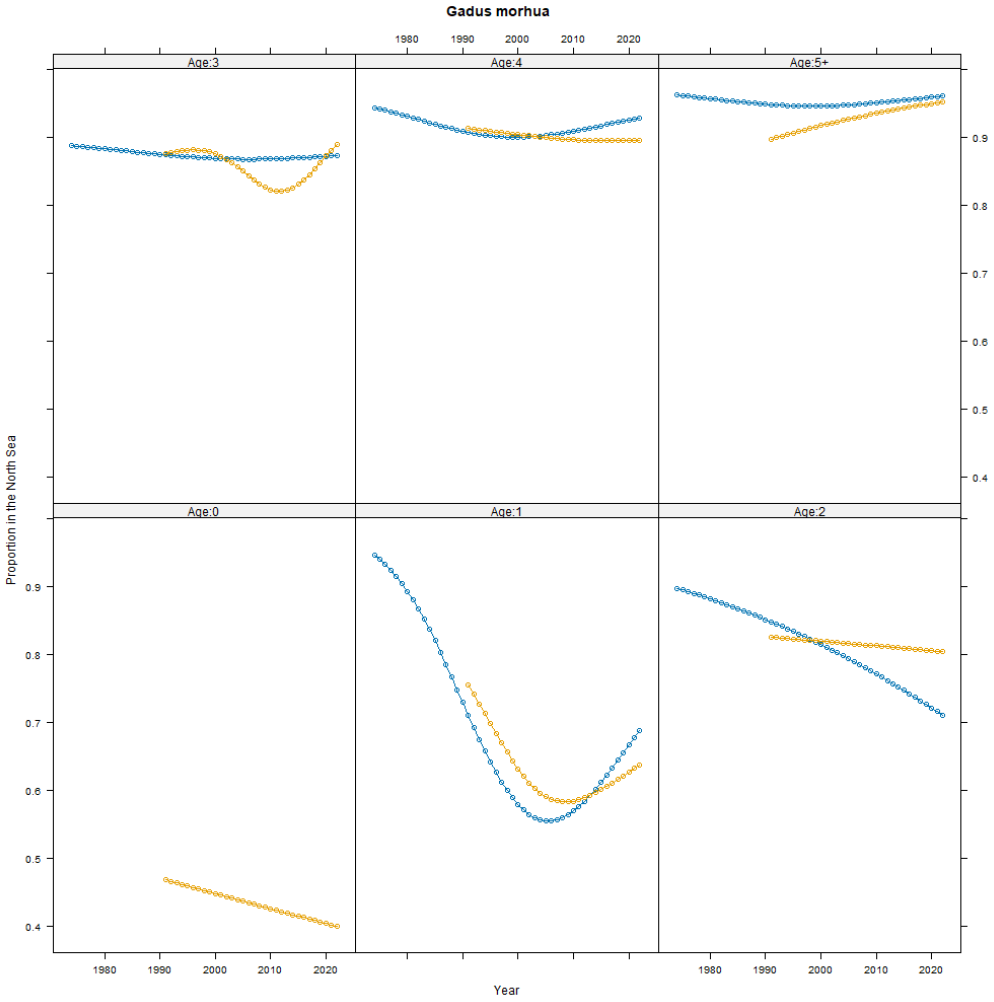

Figure 3.1-6. Fitted proportion of the cod stock (North Sea & Skagerrak data) within the North Sea for quarter 1 (1974–2022, blue line) and quarter 3 (1991–2022).

Whiting

The ICES single species assessment includes whiting in the North Sea (ICES Sub-area 4) and eastern English Channel (ICES Division 7.d). The most recent benchmark for this stock was conducted in January 2018. An interbenchmark was carried out in 2021 to assess the impact of new natural mortality estimates on the assessment. The assessment method was changed again in 2022. For the 2023 assessment, the WGNSSK SAM model was updated with a plus group at age 6 (previously age 8) and F averaged across ages 2 to 5 (previously 2 to 6).

Catch data

Annual catch-at-age data are available from the ICES assessment (WGNSSK 2023) since 1978. Catch data 1974–1977 from MSVPA (ICES CM 1997/Assess:16) were not updated. It is assumed that the proportion landed for the period 1974–1977 is equal to the average proportion landed 1987–1992. See the "**input_output**" (sec 1) for the detailed data set.

Survey data

Survey data are copied from the single-species assessment.

	Name	Years	Ages	alfa and beta	Source
1	IBTS Q1	1983–2023	1–5	0–0.25	WGNSSK 2023
2	IBTS Q3	1991–2022	0–5	0.5–0.75	WGNSSK 2023

Biological data

Proportion mature data are copied from the single-species input.

The single-species assessment provides estimates of annual mean weight-at-age in the stock in quarter 1 based on IBTS Q1 observations. This set of mean weights is considerably lower than the previously used mean weights based on annual mean weight-at-age in the catch, especially for the youngest ages. The new mean weight included some very low weights ("outliers" ?). The lowest 10% percentiles of the mean weights were raised to the 10% percentiles of the observations for a given age-quarter combination. Mean weight-at-age in the stock used in SMS for age 0 was derived as for cod for ages 0–2. Mean weights-at-age for ages 3 and older were assumed equal to the mean weight in the stock but applying a quarter specific correction for other quarters. See the "**input_output**" (sec 1) for the detailed data set. The new set of mean weights are same for ages 0-5, and higher for ages 6+ due to the change in the plus group.

Stock distribution

Survey data for the English Channel are only available for Quarter 1 since 2007 (Figure 3.1.7) but show that the proportion within the Channel is variable but low, and decreasing with age. Estimates of commercial catches within each area (WGNSSK 2017) show that the proportion of catches from the North Sea decreases from around 90% in 1995 to around 75% in 2015, but the trend is not statistically significant. Based on the short survey time-series and commercial catch statistics, it is assumed that 90% of the ICES (North Sea & Eastern English Channel) whiting stock is situated within the North Sea. This is assumed for all years, quarters and ages in SMS.

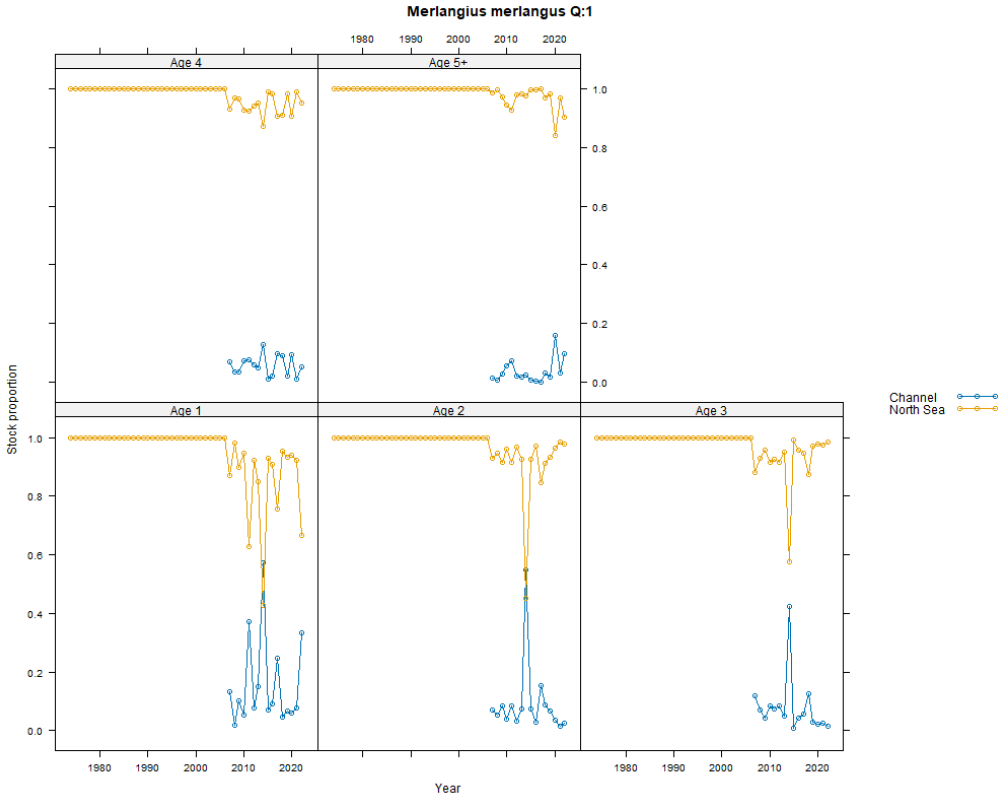

Figure 3.1.7. Stock distribution, Whiting quarter 1. Please note that data for the English Channel were available since 2007.

Haddock

The age range of haddock used in the ICES assessment was changed at the 2022 Benchmark from ages 0-10+ to age 0-8+. Data (except mean weight at age in the sea) are however maintained for the age range 0-15+. The age range used in SMS (0-10+) was maintained due to a better resolution of data by age, avoiding the very large 8+ group used by the single species assessment.

Catch data

Annual catch-at-age data are available from the assessment (WGNSSK, 2023) since 1965, and were used in SMS. See the "**input_output**" (sec 1) for the detailed data set.

Survey data

Survey data are copied from the single-species assessment.

	NAME	YEARS	AGES	ALFA AND BETA	SOURCE
1	IBTS Q1	1983–2022	1–5	0–0.25	WGNSSK 2023
2	IBTS Q3	1983–2022	0–5	0.5–0.75	WGNSSK 2023

IBTS Q1 data were in SMS split into two time-series, 1974-1988 and 1989-2020 for a better model fit.

Biological data

Proportion mature data are copied from the single-species input (WGNSSK 2023).

The single-species assessment assumes that the mean weight-at-age in the stock is equal to the mean weight-at-age in the catch, however adjusted by applying correction factors (calculated

from comparing mean weights-at-age in the catch data to survey data from NS-IBTS Q1 and UK-SCOWCGFS Q1). However, it is not described how this adjustment is done.

Mean weight-at-age in the stock used in SMS for ages 0–2 and for ages 3-10+ was derived as for cod. See the "**input_output**" (sec 1) for the detailed data set.

Stock distribution

Survey data for Area 6 are not analysed here to derive stock distributions. Catch data (WGNSSK 2023) show that 12% of the catches are taken "West of Scotland". For SMS, it is assumed that 88% of the stock is within the North Sea for all years, quarters and ages. For age 1 and older, a variable but small proportion is found in Skagerrak/Kattegat. This proportion is however ignored in SMS.

Saithe

Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2023) since 1967, and were used in SMS.

Survey data

Survey data (fleet 1) are copied from the single-species assessment. With this tuning fleet only, the SMS assessment gives a rather different assessment result compared with the ICES single-species assessment. The ICES assessment makes use of a combined (commercial cpue) biomass index, which cannot be used in SMS. To get a more consistent SMS assessment the stock numbers estimated by ICES single-species assessment were used as survey data (fleet 2). Saithe in SMS acts as a predator only and the stock dynamic of other SMS species does not affect saithe, which makes it possible to use this approach to get a more consistent (compared to the ICES assessment) result. A CV of 0.5 (rlnorm(x, meanlog=0, sdlog=0.5)) was assumed for this artificial index for all ages and years. This relatively high CV should simulate the quite high uncertainties in the ICES assessment.

Name	Years	Ages	alfa and beta	Source
Stock assessment N	1974–2022	3–9	0–0	WGNSSK 2023

Biological data

Proportion mature and M are copied from the single-species input (WGNSSK 2023).

The single-species assessment assumes that the mean weight-at-age in the stock is equal to the mean weight-at-age in the catch. Mean weight-at-age in the stock used in SMS for ages 0–2 was derived as for cod. Mean weights-at-age for ages 3 and older were assumed equal to mean weight in the catch. See the "**input_output**" (sec 1) for the detailed data set.

Stock distribution

90.6% of saithe are assumed present in the North Sea following the historical distribution of TAC between areas 6 and 4+3.

Mackerel

The ICES assessment of this Northeast Atlantic mackerel is conducted with data from 1980 for age 0–12+ (WGWIDE 2023). Given the wide stock area of the mackerel, mackerel found in the North Sea constitutes a low and variable proportion of the full stock. The inclusion of mackerel as one assessed stock rather than two external predators (western and North Sea mackerel) was made in the 2017 key run and follows the decisions made at the mackerel benchmarks, that mackerel in Northeast Atlantic is one stock (with three spawning components: western, southern, and North Sea). However, ICES concluded in 2023 that the Northeast Atlantic mackerel has no distinct spawning components.

Catch data

Annual catch numbers and mean weight-at-age in the catch are copied from the ICES assessment (WGWIDE 2023).

For the period before 1980 (1974–1979) estimates of total catch weight are provided by WGWIDE

Year	Total catch weight (tonnes)
1974	607 586
1975	784 014
1976	828 235
1977	620 247
1978	736 726
1979	843 155

Catch-at-age and quarter for the period 1974–1979 are derived from single-species stock numbers in 1980 (WGWIDE 2017) assuming a similar exploitation pattern as in 1980–1984 estimated by the single-species assessment and the total catch weight 1974–1979. Mean weight-at-age in the catch 1974–1979 was similarly derived from the mean of observed mean weight 1980–1984.

Survey data

The mackerel assessment uses an SSB index (from egg sampling) and tagging data (which cannot be handled by SMS) in addition to two cpue indices. Due to uncertain catch-at-age data in the first half of the time-series and other issues, the assessment is highly sensitive to the survey data

used in the assessment. To get an assessment result, that is close to the single-species output, estimated stock numbers from the single-species assessment are used as cpue indices in the SMS model. A CV of 0.4 (rlnorm(x, meanlog=0, sdlog=0.4)) was assumed for this artificial index for all ages and years.

	Name	Years	Ages	alfa and beta	Source
2	Stock assessment N	1980–2022	1–9	0–0	WGWIDE 2023

Biological data

Constant quarterly mean weight-at-age data in the sea are copied from the MSVPA input data (ICES CM 1997/Assess:16) and as the basis for all years. The plus group (10+) mean weight is calculated as a simple mean of ages 10–12 in the MSVPA data. Where annual catch mean weight is available (1980–2021) from the assessment (WGWIDE 2023), these were used to scale the year independent MSVPA data in a similar way as for cod (Figure 3.1.1-7).

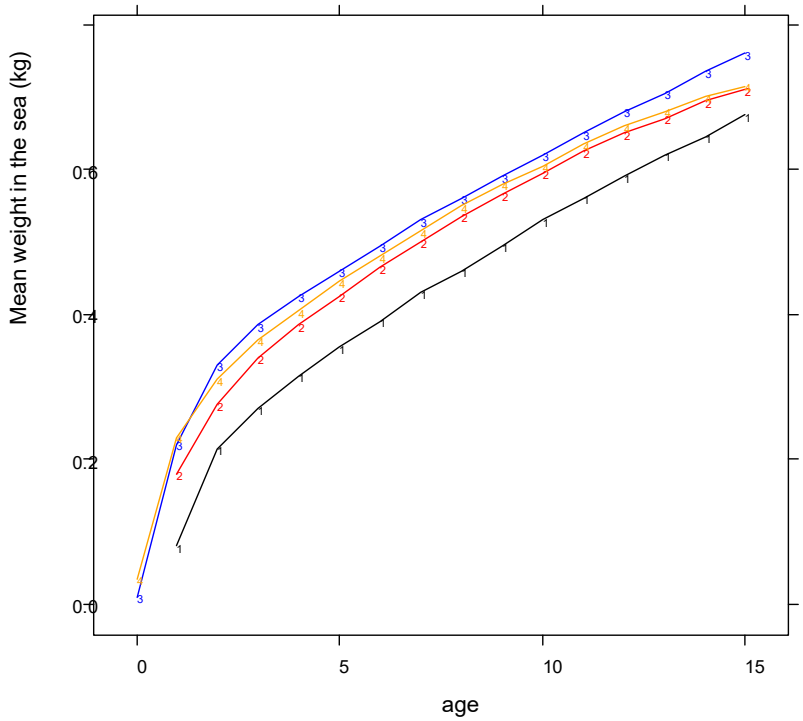

Figure 3.1.1-7. Mean weight-at-age in the sea by quarter as used in MSVPA (ICES CM 1997/Assess:16) and used as the basis for SMS input.

Proportion mature and natural mortality (M) data are copied from the ICES assessment (1980–) and the 1980 values are copied to 1974–1979.

Stock distribution

Historically, information on the proportion of the mackerel stocks (at that time the western and North Sea stocks) which was inside the North Sea was provided by the relevant assessment working groups (see Table 3-1 and Table 3-1 below). However, data have not been updated by the assessment working groups since 1997. The proportion of the stock by spawning component (Western and Southern) can be estimated from the egg survey data (Table 3-3) and an additional assumption on the relative size of the North Sea component, which not has been surveyed at the same time (Table 3-4).

WGSAM (2017) reviewed the historical information from catch distribution together with the reported proportions. In later years, the proportion of the catches of the Northeast Atlantic mackerel taken in the North Sea has decreased and the majority of the catches seem to have been taken in areas north of the North Sea (Figure 3.1.8). The proportion of the catch within the North Sea has however increased in 2018 and 2019.

Table 3-1. Percentage of the west mackerel stock to be present in the North Sea. Data from: Table 7.4 ICES CM 1990/Assess:19 for juveniles, age group 1 and 2; Table 2 from ICES CM 1989/H:20 for 3+ for the period 1974–1985; and Table 12.3 from ICES CM 1997/Assess:3.

	Q1			Q2			Q3			Q4		
	Age			Age			Age			Age		
	1	2	>2	1	2	>2	1	2	>2	1	2	>2
year	0	0	0	0	0	0	0	0	30	0	0	5
1974												
1975	0	0	0	0	0	0	0	0	70	0	0	10
1976	0	0	0	0	0	0	0	0	15	0	0	5
1977	0	0	0	0	0	0	0	0	5	0	0	5
1978	0	0	0	0	0	0	0	0	10	0	0	5
1979	0	0	0	0	0	0	0	0	25	0	0	10
1980	0	0	10	0	0	5	0	0	40	0	0	25
1981	0	0	10	0	0	5	0	0	45	0	0	35
1982	0	5	10	5	5	5	10	10	45	10	10	35
1983	0	5	10	10	5	5	10	20	45	10	20	35
1984	0	5	10	15	5	5	25	30	45	25	30	35
1985	0	5	10	20	5	5	30	80	45	30	100	35
1986–1989	0	20	20	40	20	10	60	100	50	60	70	70
1990–1997	0	10	10	20	10	5	30	50	50	30	70	70

Table 3-2. Percentage of the North Sea mackerel component to be present in the North Sea. Data from: Figure app 1–2 ICES CM 1985/Assess:7 for the period 1974–1984; Figure 9.1 and 9.2 ICES CM 1986/Assess:12 for period 1985; and Table 8.3 ICES CM 1987/Assess:11 for 1986–1997.

	Q1			Q2			Q3			Q4		
	Age			Age			Age			Age		
	1	2	>2	1	2	>2	1	2	>2	1	2	>2
year 1974	70	70	30	70	70	90	80	80	80	85	85	55
1975-1984	70	70	30	70	70	90	80	80	80	85	85	55
1985	95	95	45	95	95	80	80	80	80	90	90	65
1986-1997	100	80	80	100	100	100	100	100	50	100	80	70

Table 3-3. SSB (kt) derived from the mackerel egg surveys for the Southern, Western and combined survey area. Data from WGWIDE 2020, Table 8.6.1.1.1

	SSB (kt) by component				Proportion by component		
Year	Western	Southern	Combined		Western	Southern	Combined
1992	3367.2	507.2	3874.5		86.9%	13.1%	100%
1995	3396	370.4	3766.4		90.2%	9.8%	100%
1998	3315.8	882.9	4198.6		79.0%	21.0%	100%
2001	2816.4	417.5	3233.8		87.1%	12.9%	100%
2004	2797.6	309.2	3106.8		90.0%	10.0%	100%
2007	3038.3	744.7	3783		80.3%	19.7%	100%
2010	3884.4	926.3	4810.8		80.7%	19.3%	100%
2013	3927.9	904	4831.9		81.3%	18.7%	100%
2016	3076.8	447.3	3524.1		87.3%	12.7%	100%
2019	2290.8	796.7	3087.5		74.2%	25.8%	100%

Table 3-4. WGSAM 2017 estimates of relative contribution from the North Sea, Western and Southern components estimated from the egg-survey data (1989, 1992, 1995, 1998, 2001, 2004, 2007, 2010, 2013 and 2016) and assumptions about the relative contributions from the North Sea component. Data for the period before 1989 are copied from Table 2.4.4.2 ICES CM 2005/ACFM:08.

YEAR	NORTH SEA	WESTERN	SOUTHERN
1974	0.221	0.651	0.128
1975	0.205	0.668	0.128
1976	0.201	0.671	0.128
1977	0.177	0.695	0.128
1978	0.136	0.736	0.128
1979	0.125	0.747	0.128
1980	0.116	0.756	0.128
1981	0.081	0.786	0.133
1982	0.080	0.792	0.128
1983	0.074	0.798	0.128
1984	0.037	0.835	0.128
1985	0.037	0.835	0.128
1986	0.037	0.835	0.128
1987	0.037	0.835	0.128
1988	0.037	0.835	0.128
1989	0.037	0.835	0.128
1990	0.037	0.835	0.128

Year	North Sea	Western	Southern
1991	0.037	0.835	0.128
1992	0.037	0.835	0.128
1993	0.037	0.835	0.128
1994	0.037	0.835	0.128
1995	0.029	0.842	0.129
1996	0.029	0.842	0.129
1997	0.029	0.842	0.129
1998	0.029	0.764	0.207
1999	0.029	0.764	0.207
2000	0.029	0.764	0.207
2001	0.029	0.847	0.124
2002	0.029	0.847	0.124
2003	0.029	0.847	0.124
2004	0.029	0.872	0.099
2005	0.029	0.872	0.099
2006	0.029	0.872	0.099
2007	0.029	0.858	0.113
2008	0.029	0.858	0.113
2009	0.029	0.858	0.113
2010	0.029	0.777	0.194
2011	0.029	0.777	0.194
2012	0.029	0.777	0.194
2013	0.029	0.748	0.223
2014	0.029	0.748	0.223
2015	0.029	0.748	0.223
2016	0.038	0.856	0.105
2017-2022*	0.038	0.856	0.105

*Assumed equal to 2016.

Using the available proportion of the stock by component (Table 3-3) and the proportion of each component within the North Sea, it is possible to calculate the proportion of Northeast Atlantic mackerel within the North Sea (Figure 3.1-8).

For the key run in 2020, data from WGSAM 2017 were not updated. It is assumed that the stock distribution in 2017–2019 is the same as for 2016. The key run in 2023 made the same assumptions for the years 2020–2022.

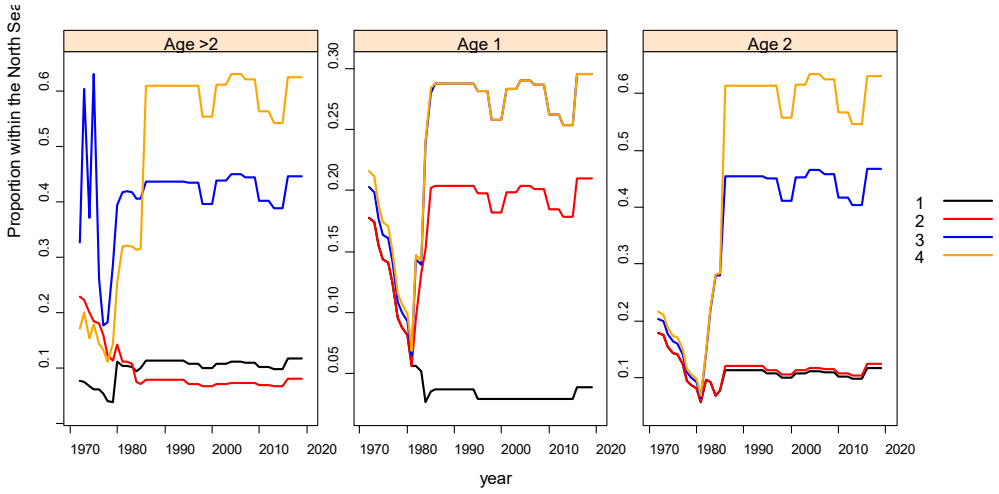

Figure 3.1-8. Preliminary estimate of the proportion of the Northeast Atlantic Mackerel stock by age group and quarter (1–4) within the North Sea calculated from stock distributions presented in Table 3.4–Table 3.6.

This proportion presented in the figure assumes however that the proportions of the various components have been constant since 1997, which is not the case. The spatial catch distribution shows a northerly and easterly expansion of the catch areas (WGWIDE 2020) which is also reflected in the catch proportion from the North Sea (Figure 3.1.10). The contribution of North Sea catches has roughly been halved in the period 2000–2016, followed by an increase. Using the proportion caught in the North Sea as an indicator of the proportion of the total stock within the North Sea since 2000, the proportion estimated (Figure 3.1-9) becomes smaller for the period since 2000 (Figure 3.1.11), however increased in the most recent years.

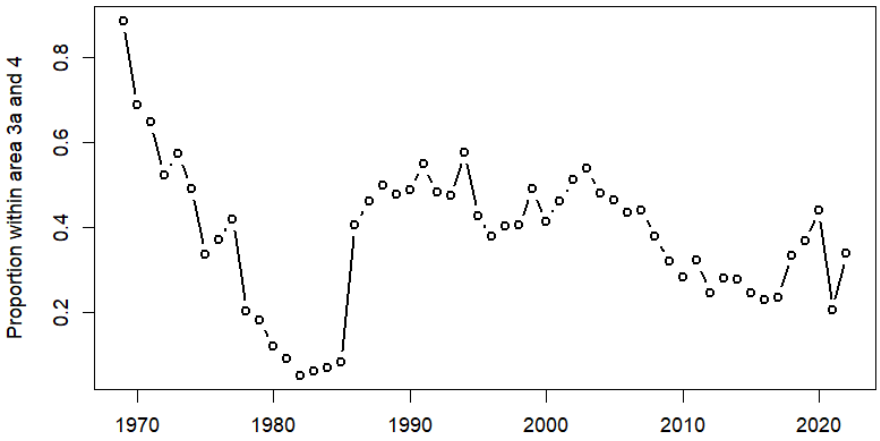

Figure 3.1-9. Proportion of mackerel catches in the North Sea. Data from WGWIDE 2023.

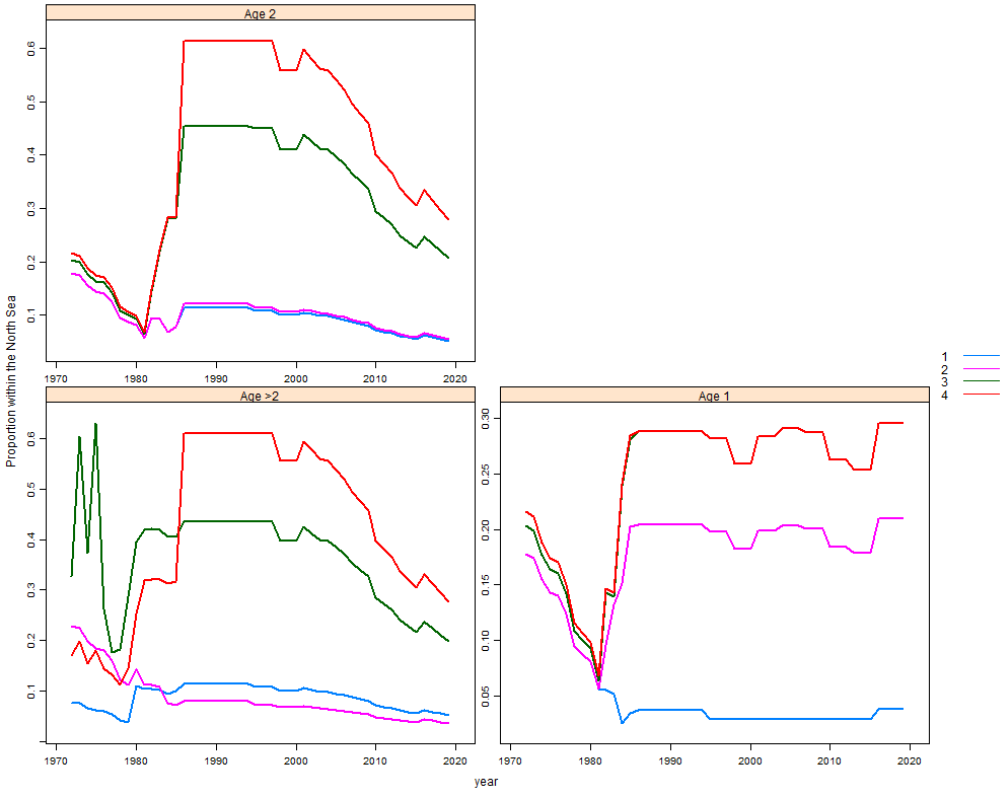

Figure 3.1-10. Estimate of proportion of the Northeast Atlantic Mackerel stock by age group and quarter (1–4) within the North Sea.

WGSAM, 2020 concluded to use the proportion of the stock within the North Sea as presented in Figure 3.1-10. It was recognised that this estimate is based on a series of assumptions, however the estimate seems the best available. Data from 2019 were used for the year 2020–2022 in the 2023 key run,

Herring

Catch data

Annual catches exist for the period since 1947 (HAWG 2023). Quarterly data, 2005–2016 are available from the stock coordinator (Norbert Rohlf) and the 2007 key run (1974–2004). The quarterly data, 2017–2022 were copied from HAWG reports. The existing quarterly data were adjusted such that the sum of quarterly catch numbers summed up to the annual numbers used by HAWG.

Survey data

Survey data are copied from the single-species assessment (survey 1-3).

	Name	Years	Ages	alfa and beta	Source
1	HERAS Q2	1989–2022	1–8	0.54–0.56	HAWG 2023
2	IBTS Q1	1984–2023	1–1	0.10-0.10	HAWG 2023
4	MIK	1992–2023	0–0	0–0	HAWG 2023

Sandeel

The ICES sandeel assessments (2023) for the North Sea area include six individually assessed stocks. Ideally, SMS should follow the same division to provide relevant natural mortalities for sandeel in the different stocks. However, using all stocks separately would give problems with limited catch-at-age and diet data availability for some of the stocks. Instead, sandeels in SMS are divided using the previously used Northern and Southern sandeel areas (Figure 3.1-11).

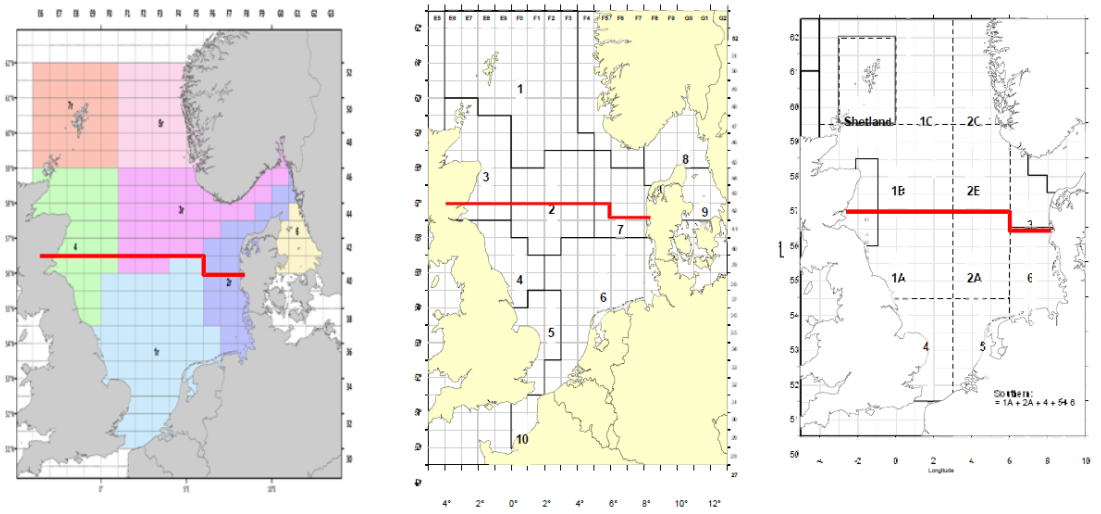

Figure 3.1-11. Sandeel stock and data compilation areas: The left plot shows the stock areas as applied by ICES in 2017. The red line shows the division between the previously used "Northern" and "Southern" sandeel areas. The plot in the middle shows the ICES roundish areas, which are used as strata in the compilation of stomach content data. The right plot shows the northern and southern areas with sampling areas.

Catch data since 1983 are available by ICES rectangle (HAWG 2023.) and were aggregated into the two stocks. Data from 1974–1982 are available from the 1999 ICES assessment, where

assessment data were aggregated into a Northern and Southern stock. The available time-series of mean weights in the catch of ages 1-4 is shown below.

Figure 3.1-12. Observed mean weight at age in the catch in quarter 2 and 3 for the Northern (NSA) and Southern (SSA) sandeel. The red line is a loess smoother used for estimating mean weight at age in the stock.

In the estimation of sandeel as prey, it is assumed that sandeel found in stomachs from fish sampled in roundfish area 1, 2, 3 and 7 are northern sandeel and southern sandeel are from roundfish areas 4, 5 and 6. This split aligns fairly well with the two stock areas (Figure 3.1-11).

Estimating mean weight in the stock is a special concern for sandeel, as the weight of one year olds and older fish in the catch in the months from July onwards is likely to be biased towards lower mean weights due to differences in the onset of burying of large and small sandeel (Pedersen *et al.*, 1999; Rindorf *et al.*, 2016). The duration and start of the fishing season have also changed considerably over the years such that the quarterly mean weight at age in the catch may differ from the mean weight at age in the stock. Moreover, weight in the catch of the 0-group is highly variable as the 0-group fishery only occurs in parts of the time-series and the exact timing of it varies.

The stock mean weight of sandeel age 1+ in quarters 2 and 3 were estimated from a loess smother of the full time-series of mean catch weight in the first and second half year, respectively. Quarter 1 mean weight was estimated as 79% of that in quarter 2 to reflect the recorded difference in condition between the two quarters (Rindorf *et al.*, 2016). Quarter 4 mean weight was estimated as 89% of that in quarter 3, accounting for half the condition loss between quarter 3 and quarter

1 (Rindorf *et al.*, 2016). The mean weight of 0-groups in quarter 4 was estimated as the long-term average weight of 0-group in the catch the second half year. The mean weight of the 0-group in quarter 3 is assumed to be half of the mean weight in quarter 4. This procedure was used as the mean weight of 0-groups in catches in quarter 3 was substantially higher than that observed in the stomachs, indicating that the fisheries selection may exclude smaller individuals.

Survey data

Survey data are derived from the same observations used in the single-species assessments in areas 1–3 using the same model but deriving sandeel survey indices for the northern and southern North Sea (Casper Berg, pers. comm.) In addition to this, three commercial time-series were used to mimic the use of effort tuning of F in the sandeel assessment. These commercial cpue time-series replace the effort time-series used by the ICES single-species effort.

Northern Sandeel surveys:

	Name	Years	Ages	alfa and beta	Source
1	Dredge survey	2004–2022	0–1	0.75–1	Casper Berg
2	Commercial 1. half year	1983–1998	1–3	0.25–0.5	HAWG 2023,Anna Rindorf
3	Commercial 1. half year	1999–2022	1–3	0.25–0.5	HAWG 2023,Anna Rindorf
4	Commercial 2. half year	1976–2004	1–3	0.25–0.5	Sandeel assessment 2005
5	Acoustic survey SA 3	2009-2022	1-4	0.25-0.5	HAWG 2023

Southern Sandeel surveys:

	Name	Years	Ages	alfa and beta	Source
1	Dredge survey	2004–2022	0–1	0.75–1	Casper Berg
2	Commercial 1. half year	1983–1998	1–3	0.25–0.5	HAWG 2023,Anna Rindorf
3	Commercial 1. half year	1999–2009	1–3	0.25–0.5	HAWG 2023,Anna Rindorf
5	Commercial 1. half year	2010–2022	1–3	0.25–0.5	HAWG 2023,Anna Rindorf

Sprat

The ICES North Sea sprat stock was merged with the sprat stock in the Kattegat and Skagerrak at the 2017 benchmark. The single-species sprat assessment (HAWG 2023) uses a single-species version of SMS with quarterly time steps, which gives data similar to the data used in the multispecies SMS. The single-species assessment uses however, a life cycle year from July to June, which is different to the calendar year used in SMS multispecies. To correct for that, year, quarter and age in single-species data are transformed into multispecies data by the following rule:

If singles-species quarter is Q1 or Q2 then multispecies Quarter=single-species Q + 2

If singles-species quarter is Q3 or Q4 then {

multispecies Quarter=single-species Q – 2

multispecies Year=single-species Year + 1

multispecies Age=single-species Age + 1

}

Catch data

Quarterly catch data are copied from the single-species assessment (HAWG 2023), using the above-mentioned data transformation of year, quarter and age.

Survey data

Survey data are copied from the single-species assessment (survey 1–3).

	Name	Years	Ages	Source
1	IBTS Q1	1983–2023	0–3+	HAWG 2023
2	HERAS Q2	2006–2022	1–3+	HAWG 2023
3	IBTS Q3	1992–2022	1–3+	HAWG 2023

Biological data

Proportion mature and stock mean weight data are copied from single-species data.

Stock distribution

The proportions of the sprat stock observed within the North Sea were estimated using the distribution of biomass between the two areas from the HERAS (acoustic) survey. The distribution in this survey corresponded well with the distribution of catches in the given year (Figure 3.1-13). The landings distribution is a biased estimator in the years with very low catches (TAC) in the North, e.g. the mid-eighties, and WGSAM decided to use the HERAS data as the basis for stock proportions. The HERAS survey does not provide information before 2004. The data were smoothed and used to predict the distribution of the stock before 2004 (Figure 3.1-14). The same distribution was used for all ages and quarters (Figure 3.1-15).

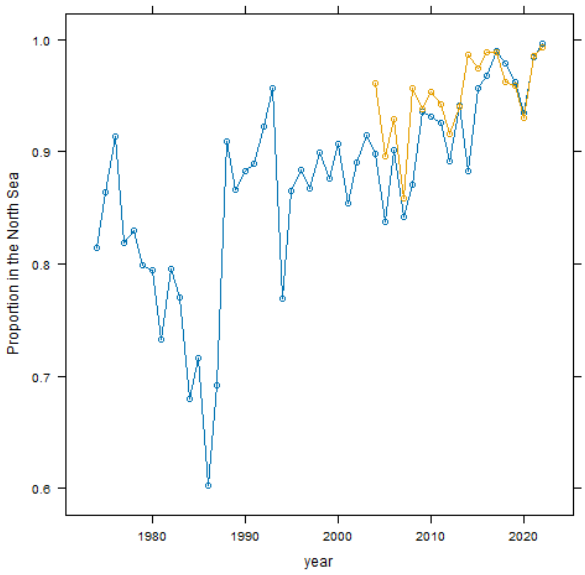

Figure 3.1-13. The proportion of the sprat stock (North Sea, Kattegat and Skagerrak data) within the North Sea estimated from landings statistics (1974–2022) and the HERAS survey (2004–2022).

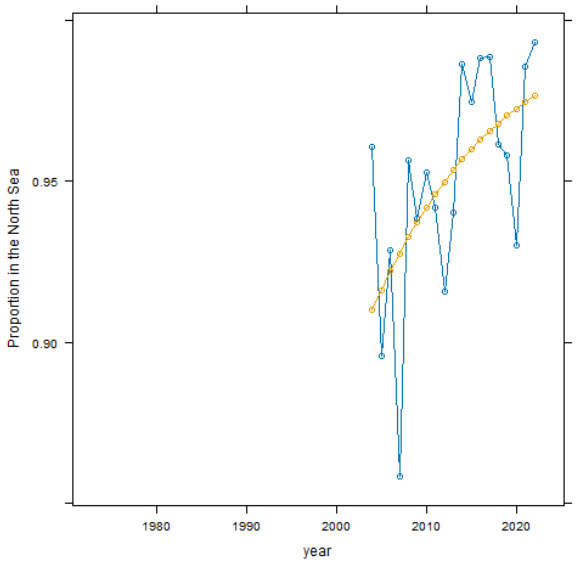

Figure 3.1-14. Observed and fitted proportion of the sprat stock (North Sea, Kattegat and Skagerrak data) within the North Sea with data from the HERAS survey.

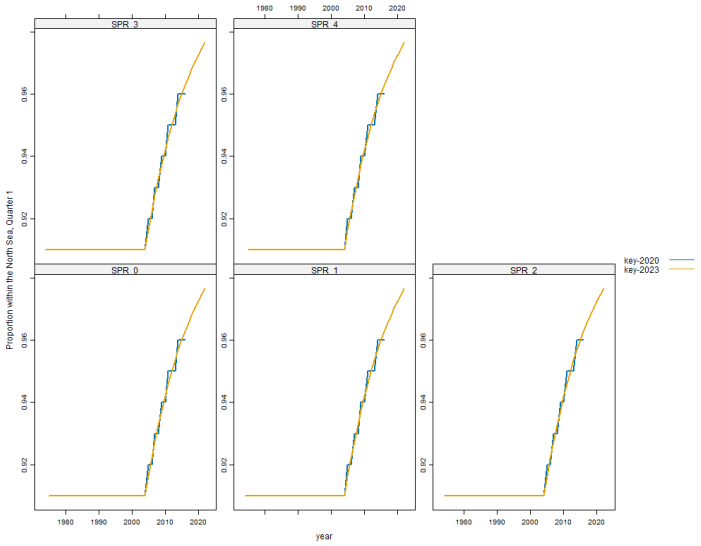

Figure 3.1-15. The proportion of the sprat stock (North Sea, Kattegat and Skagerrak data) within the North Sea as applied in SMS.

Norway pout

The single-species sprat assessment (WGNSSK 2023) uses quarterly data for the period since 1974. To accommodate mortality due to spawning stress, the oldest age group (age 3) in the SMS model run is not a plus group (i.e., all Norway pout die when turning four years old).

Catch data

Quarterly catch data are copied from the single-species assessment (download from stockassessment.org)

Survey data

Survey data are copied from the single-species assessment.

	Name	Years	Ages	alfa and beta	Source
1	EGFS	1992-2022	0–1	0.5–0.75	WGNSSK 2023
2	SGFS	1998–2022	0–1	0.5–0.75	WGNSSK 2023
3	IBTS Q1	1984–2023	1–3	0.0–0.0	WGNSSK 2023
4	IBTS Q3	1991–2022	2–3	0.5–0.75	WGNSSK 2023

Biological data

Proportion mature, stock mean weight and M data are copied from single-species data.

Plaice

Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2023) since 1957, and were used in SMS.

Survey data

Survey data are copied from the single-species assessment.

	Name	Years	Ages	alfa and beta	Source
1	BTS-Isis-early	1985–1995	1–9	0.50–0.75	WGNSSK 2023
2	BTS-IBTSQ3	1996–2022	1–10	0.50–0.75	WGNSSK 2023
3	SNS1	1974–1999	1–7	0.50–0.75	WGNSSK 2023
4	SNS2	2000–2022	1–7	0.50–0.75	WGNSSK 2023
5	DYFS	1990–2022	0-0	0.50–0.75	WGNSSK 2023
6	IBTS Q1	2007–2022	1–8	0.0–0.25	WGNSSK 2023

Biological data

Proportion mature data are copied from the single-species input (WGNSSK 2023).

The single-species assessment assumes that the mean weight-at-age in the stock is equal to the mean weight-at-age in the catch. Mean weight-at-age in the stock used in SMS for ages 0–2 was derived as for cod. Mean weights-at-age for ages 3 and older were assumed equal to mean weight in the catch.

Plaice became a prey species (eaten by grey seals) in the 2023 key run. An age-dependent natural mortality was adopted in the 2022 plaice benchmark. These values are estimated based on the Peterson-Wroblewski method based on the stock weight at age, and are kept constant for the entire assessment period. The M values from WGNSSK were used for both M and M1 in SMS. This ignores the fact that the natural mortality from grey seals is assumed already to be included.

Sole

Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2023) since 1957, and were used in SMS.

Survey data

Survey data are copied from the single-species assessment (survey 1–3).

	Name	Years	Ages	alfa and beta	Source
1	BTS	1985–2022	1–10	0.50-0.75	WGNSSK 2023
2	SNS	1974–2022	1–6	0.50–0.75	WGNSSK 2023

Biological data

Proportion mature data are copied from the single-species input (WGNSSK 2023).

The single-species assessment assumes that the mean weight-at-age in the stock is equal to the mean weight-at-age in the catch. Mean weight-at-age in the stock used in SMS for ages 0–2 was derived as for cod. Mean weights-at-age for ages 3 and older were assumed equal to mean weight in the catch.

External predators

The "external predator" group includes predators for which the stock numbers are given by input. The list of species includes:

- Birds
  - Fulmar
  - Guillemot
  - Herring Gull
  - Kittiwake
  - GBB. Gull
  - Gannet
  - Puffin
  - Razorbill
- Fish
  - Starry ray
  - Grey gurnards
  - Western horse mackerel
  - North Sea horse mackerel
  - Hake
- Mammals
  - Grey seal
  - Harbour porpoise

Time-series of their abundance can be found in the "**input_output**" in the directory input\OtherPredators.

Birds

Marine bird abundance estimates were based on the numbers published by Dierschke *et al.* (2022). They provide counts of numbers of breeding pairs at breeding colonies from 1991–2020 for Greater North Sea for OSPAR regions II a, b, d, e and f (of which areas II a, b, d and f correspond to ICES area 4). They did not provide abundances outside the breeding season and we

therefore estimated abundances outside the breeding season based on the numbers in the breeding season (see WD04 for calculations). Also, prior to 1991 and after 2020, abundances were estimated based on the assumed trends for these periods in the 2019 key Run.

We use the numbers as reported by Dierschke *et al.*, (2022), summed over OSPAR subregions IIa, IIb, IId and IIf, for the quarters that fall inside the breeding seasons. For the quarters that fall outside of the breeding season, we calculated bird abundances based on abundance ratios between the abundance in the different quarters in the SMS 2020 key run compared to abundances in quarter 2 (as this is for all species the height of the breeding season).

From 2021–2022 we use the same abundances as for 2020, for the years prior to 1991, when there is no data available (in the 2019 SMS key run the values were based on linear or logistic regression back through time) we use the relative changes in abundance such as were used for the 2019 key run (ICES, 2011) between 1974–1990, as a ratio of the abundance in 1991.

Starry rays and grey gurnards

The time-series of grey gurnard and starry ray (*Amblyraja radiata*) are estimated from IBTS cpue by length, scaling the time-series cpue index to a "known" average biomass. For starry ray, an average biomass of 100 kt over the years 1977–1988 is suggested by Sparholt and Vinther (1991). Sparholt (1990) estimated the average biomass of grey gurnards, 1983–1985, in the range of 48 kt (IYFS Q1 data) to 146 kt (EFGS Q3). Another estimate (Daan *et al.*, 1990) estimated the average biomass of grey gurnards to 205 kt based on EGFS Q3 data 1977–1986, using the method of Sparholt.

The stock number per length class, year and quarter is derived from a generalized linear model of cpue (number per hour) assuming a Poisson distribution and using a log-link function. Cpue was modelled by individual size classes from the explanatory variables: year, quarter, roundfish area and gear. Data were extracted from ICES DATRAS (data type: cpue per length per haul) for the period since 1974. Quarter 1 data were used for the whole period; quarter 3 since 1991 and quarter 2 and quarter 4 for the period 1991–1997. Data from the early part of the time-series seem not to have recorded starry ray or gurnards even though it was noted that all species were recorded. All records from individual cruises (year, quarter and vessel) with no recorded catch of starry ray or gurnards in any haul were excluded from the analysis.

The total average biomass is divided into size classes from the average observed cpue and the mean weight in the years 1991–1997 where data exist for all four quarters. By using this method it is assumed that catchability is independent of size, which is probably not the case for smaller individuals. The average stock estimate in thousands of tonnes by size classes is shown in the table below.

Size cm group	Species	
	Grey gurnard	Starry ray
00–10	0.04	-
10–20	22.52	0.39
20–30	124.04	4.11
30–99	58.40	95.50
All	205.00	100.00

The model "year-effects" for starry ray are more uncertain for the period before 1981 and these data were finally allocated to one year, "pre-1981". The year effect for "pre-1981" was used for a stock estimate for 1974–1981.

For both species, the published biomass estimates are very uncertain and they are not used directly in SMS. For starry ray it is assumed that the stock has an average biomass of 100 kt over the years 1982–2013. The final year, 2013, was used in the 2014 key-run and this year has been maintained as there are recent trends in the biomass. For grey gurnards, an average biomass of 205 kt is assumed for the years 1977–2013, where the year range is chosen mainly for stability reasons.

Horse mackerel

ICES considers horse mackerel (*Trachurus trachurus*) in the Northeast Atlantic to be separated into three stocks. The southern stock is found in the Atlantic waters of the Iberian Peninsula, the North Sea stock in the eastern English Channel and North Sea area, and the western stock on the northeast Continental Shelf of Europe, stretching from the Bay of Biscay in the south to Norway in the north. ICES makes an analytical (absolute) assessment of the western stock using the Stock Synthesis (SS3) model, while the North Sea stock is assessed from survey indices and an absolute stock biomass is not estimated. Stock abundance by length group for the western stock were extracted from the ICES assessment (WGWIDE, 2023).

Previously, ICES has stated that about 7% of the combined western and North Sea mackerel stock resides in the North Sea. WGSAM 2017 decided to assume that the North Sea stock development followed that of the western stock and total North Sea horse mackerel biomass was therefore 7.5% of the biomass of the western mackerel. Lately, an increasing proportion of the North Sea horse mackerel was caught in fisheries in the English Channel in the 4th quarter. However, this change in quarter 4 distribution does not necessarily reflect changes in quarter 2 and 3 distribution, and as these are the quarters where the main feeding takes place. Therefore, WGSAM considered that North Sea horse mackerel were all present in the North Sea.

The western horse mackerel stock assessment reports have previously reported the proportion of western horse mackerel entering the North Sea in each quarter (Table 3-5).

Table 3-5. Percentage of the western horse mackerel stock entering the North Sea by quarter. Sources: Table 12.3 in ICES CM 2000/ACFM:5 for 1998; Table 12.2 in ICES CM 1999/ACFM:6 for 1997; Table 12.x in ICES CM 1998/Assess:6 for 1996; Table 12.5 in ICES CM 1997/Assess:3 for 1995; Table 12.5 in ICES CM 1996/Asess:7 for 1994; Table 18.5 in ICES CM 1995/Assess:2 for 1993; Table 16.5 in ICES CM 1993/Assess:19 for 1992; Table 13.5 in ICES CM 1992/assess:17 for 1991).

	Age 1–4				age >4			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1974–1985	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	5	10
1987	0	0	0	0	0	0	5	40
1988	0	0	0	0	0	0	5	40
1989	0	0	0	0	0	0	5	40
1990	0	0	0	0	0	0	5	40
1991	0	0	0	0	0	0	5	40
1992	0	0	0	0	0	0	10	55
1993	0	0	0	0	0	0	5	65
1994	0	0	0	0	0	0	5	65
1995	0	0	0	0	0	0	5	65
1996	0	0	0	0	1	0	0	10
1997	0	0	0	0	1	0	0	50
1998–2016	0	0	0	0	1	0	0	10

This information has not been available since 1998, but the proportion of western stock horse mackerel caught in the North Sea (all horse mackerel caught in Subarea 4a) is still reported (Table 3-5). Based on these data, it was decided to assume that 10% of the western horse mackerel stock was present in the North Sea in quarter 4. In quarters 2 and 3, no western horse mackerel were present in the North Sea. In quarter 1, horse mackerel are not feeding and hence it is not relevant to know their abundance in the North Sea. Age 4 horse mackerel in quarter 3 and 4 has a mean length of around 25 cm according to the SS3 assessment, and this length was used to calculate the stock numbers of the western stock within the North Sea from the SS3 estimate of stock abundance at size.

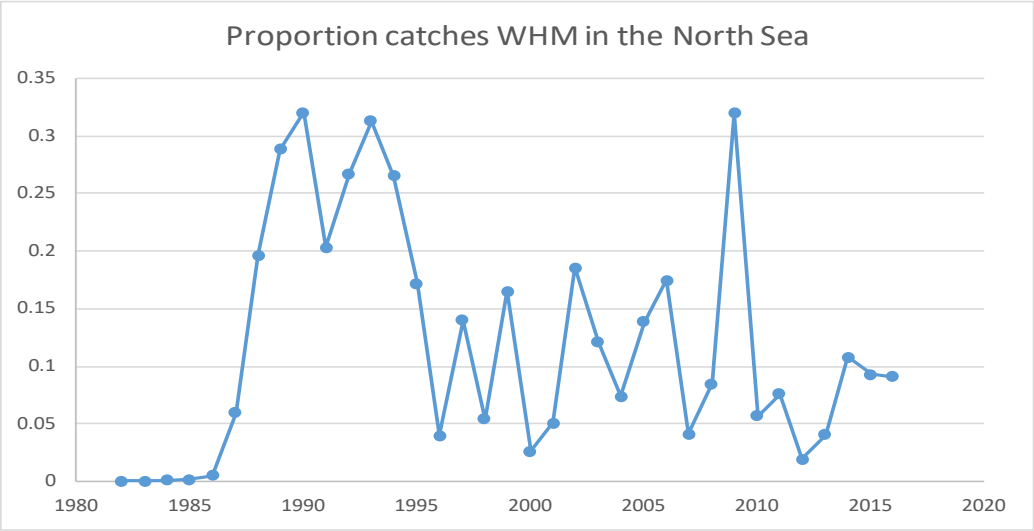

Figure 3.2-16. Proportion of western horse mackerel catches in the North Sea (data from WGWIDE 2017).

Hake

Hake was included in the 2014 key run as an "external predator" due to the increasing stock size and higher relative abundance in the North Sea. The ICES assessment for "northern hake" (Hake in Division 3a, Subareas 4, 6 and 7 and Divisions 8a,b,d) includes all sea areas from the northern Bay of Biscay up to the Norwegian Sea. The proportion of the stock within the North Sea is estimated from the proportion of landings. Landings data (Table 9.1, WGBIE 2020) provides data by area since 2013. Before that, landings data for the North Sea area were combined for areas 3, 4, 5 and 6. Landings weight from the North Sea (area 4), 1974–2012 was estimated from the combined landings and the average proportion of the landings within area 4 from estimated from available data, 2013–2019. The final proportion of landings within the North Sea (Figure 3.2-2) shows a steep increase in landings from the North Sea in 2002–2007.

The ICES assessment of hake was benchmarked in 2022, which changed considerably the absolute levels of F and stock sized.

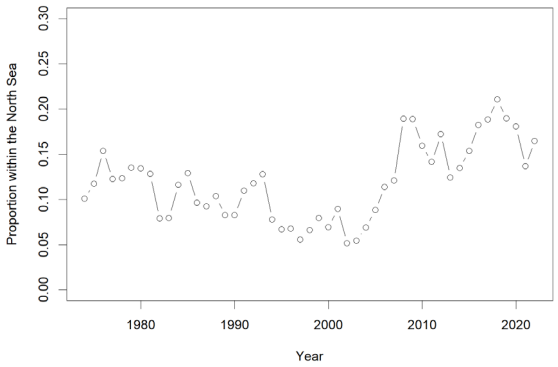

Figure 3.2-17. Proportion of landings within the North Sea from the stock of "northern hake" estimated from landings weights derived from Table 9.1 in ICES WGBIE, 2023.

Quarterly landings data by area since 2013 are available from ICES InterCatch data on the WGBIE 2023 SharePoint. The quarterly distributions of landings from the North Sea are shown in Table 3-6. Percentage of total landings of hake from the North Sea by quarter (Q1-Q4), and percentage of total annual landings weight from the North Sea by year.

Table 3-6. Percentage of total landings of hake from the North Sea by quarter (Q1-Q4), and percentage of total annual landings weight from the North Sea by year.

	Q1	Q2	Q3	Q4	% North Sea
2013	9.2	18.1	19.7	15.0	12.8
2014	4.8	13.8	18.1	16.9	13.9
2015	7.1	13.7	20.9	14.9	15.8
2016	8.9	15.0	22.1	19.2	18.9
2017	8.8	13.9	26.3	21.4	19.6
2018	6.2	12.7	27.5	17.8	21.9
2019	6.2	12.9	21.4	17.5	19.8
2020	8.4	15.3	25.5	19.5	18.9
2021	5.3	14.4	20.4	14.2	14.8
2022	11.0	20.5	44.3	24.2	18.1
Average	7.6	15.0	24.6	18.1	17.4
Scaled average	43.5	86.1	141.3	103.6	100.0

The ICES assessment for "northern hake" is an ss3 assessment which provides quarterly abundances by length class for the period since 1978.

Stock numbers present in the North Sea were calculated from the ss3 quarterly stock number estimate and the assumption that the stock distribution follows the landings distribution by quarter for the years 2013–2022 (Table 3-6). For the years before 2013, the stock numbers in the North Sea were calculated from the total ss3 quarterly estimates multiplied by the annual landings proportion (Figure 3.2-2) and the "scaled average" from Table 3.6. The number of hake in the North Sea in the years 1974–1977 is assumed to be the same as for 1978.

Stomach data are available from hake larger than 20 cm, and fish smaller than this was not included in the stock numbers in the North Sea. This is probably realistic as spawning and juveniles are found mainly outside the North Sea.

The stock distributions are based on landings statistics which might give a biased result. However, even though there is a comprehensive survey coverage in the stock distribution area, commercial catches are probably a better source than the high number of surveys where each survey is only covering a small part of the distribution area, using its own gear and survey period.

ICES (2017), concluded with respect to hake distribution based on survey data that:

– In recent year, changes in the distribution of hake occurred at the northern limits of its distribution: west and north of Scotland, northern North Sea and Skagerrak.

– As no shift in the centre of gravity of the population has been observed in other areas, the changes in distributions is related to an expansion of the population towards the north and not to a shift in the overall distribution of the two stocks considered. –

Results still need to be taken with caution as:

- The trawl surveys mainly sample small hakes, as the adult are mainly distributed along the slopes.

- Not all areas were surveyed over the whole period investigated.

The size classes of hake were changed for the 2020 key run to follow the size classes used for stomach contents.

See the detailed input stock number and biomass in the "**input_output**".

A swept area estimate of Hake in the North Sea (Staby, 2018) estimated from IBTS Q1 and IBTS Q3 data (Figure 3.2-3) shows a similar biomass development in the North Sea since 1997, as the biomass used in SMS.

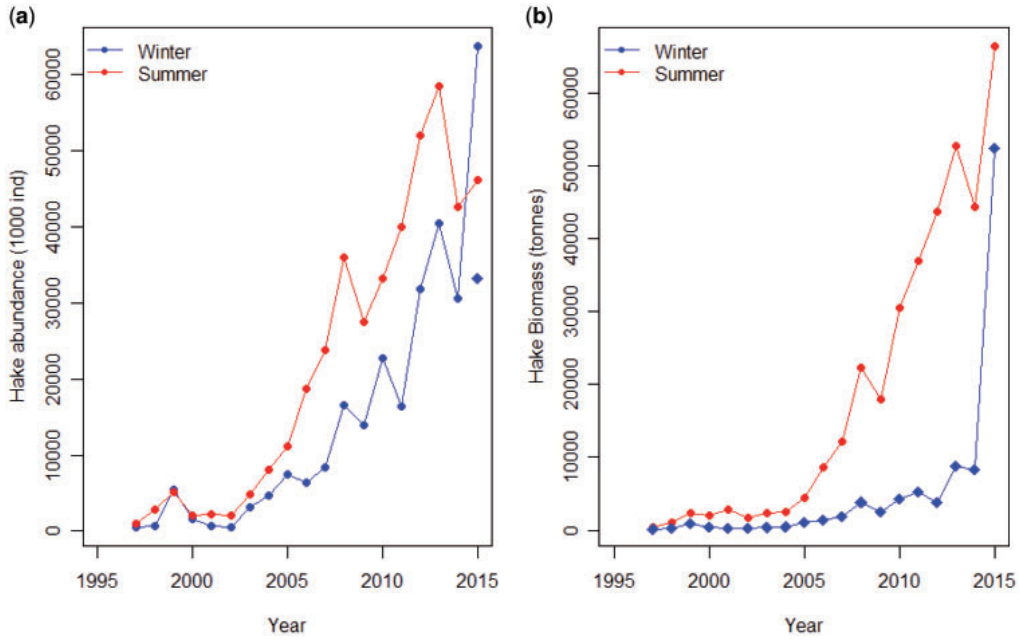

Figure 3.2-18. Swept area estimate of Hake in the North Sea from IBTS Q1 and Q3 data (copied from Staby, 2018).

Grey seal

Most recent grey seal numbers come from Thomas (2021) and include estimates for the period 1984–2020. Seal numbers from 2021–2022 were obtained via personal communication (Phil Hammond, SMRU). Seal estimates are given for the beginning of the breeding season, which corresponds to quarter 4, and relate to seals associated with the regularly monitored colonies. A multiplier is required to account for the seals that breed outside these colonies. Multipliers on the grey seal estimates to account for non-monitored colonies were made available for the years 1985, 2002, 2010, 2019, 2022 (pers. comm. Phil Hammond (SMRU)). Estimates for 1984–2022, were therefore extrapolated to the full British colonies following a linear regression between the scaled estimates. Numbers prior to 1984 are predicted following a linear regression on the log scale so that the population is assumed to have an exponential growth in the period 1984-1990 (using 1984–1990 to estimate parameters, similar method as for the 2020 keyrun). These estimates relate to seals on the British side of the North Sea. Even though these are the largest colonies, some colonies exist notably along the Netherlands and the southern Norwegian coast.

ICES (2022) provides pup counts for different areas of the North Sea from recent surveys (2017, 2019, 2020, or 2021). The colonies in the North Sea were extracted, and the proportion of the pup counts outside the UK was estimated and resulted in a proportion of around 0.044. A multiplier of around 1.044 was applied to the British grey seal population estimates to extrapolate the numbers to the entire North Sea grey seal population in quarter 4. For quarters 1-3, we assume the same population estimates as in the quarter 4 the year before. A full analysis on grey seal numbers is available in the WD01 part of the 2023 WGSAM report.

Harbour porpoise

The abundance of cetaceans in the North Sea is monitored during aerial and boat-based sightings surveys, with corrections to take account of the detectability of the animals (Hammond *et al.*, 2002). Harbour porpoise population size was assumed to be constant over the period and set to the average of the number of porpoises in the North Sea proper in the two SCANs years (224 100).

Diet and ration data

Seabirds

Average bird diet data of ten species for the most recent 25 years were estimated as part of the BECAUSE project, 2004–2007. For each bird species, estimated data include biomass eaten for each prey species and the minimum, mean and maximum length of the prey. There were no further data on size or age distribution available.

Mammals

Data on grey seals

Seal diet data derived from scats were sampled in 1985, 2002, and 2010–2011 at haul-out sites around the UK coast. This data was re-extracted by the SMRU this year to include the most recent data (2010–2011) and plaice as prey (Phil Hammond pers. comm.). The way the seal diet data was obtained is described in detail in Hammond and Wilson (2016). The data included seal consumption per fish stock that are considered in SMS (cod, whiting, haddock, herring, sandeel, norway pout, sprat, plaice) in tonnes per year, quarter (Q1-4), and regions of the North Sea (regions 1-4, Shetland, Orkney and northern North Sea, central North Sea, and southern North Sea respectively). The data also included outputs from otolith experiments as estimated fish length in the diet given otolith size (per year, region, and quarter).

Each fish length sample is converted to weight using length-weight relationship parameters from Coull (1989). The fish weights (weighted by the total consumption per region and quarter) are summed across regions such that the weight consumed is given per species, length bin, quarter, and year. Weights are then converted to proportion consumed per length bin, and these proportions are multiplied by the total grey seal consumption (in weight) per species and quarter to obtain the weight of prey consumed per length bin. The biomass of other food eaten by grey seals is derived from the total grey seal consumption per quarter and year. The number of scat samples per quarter and year is used to give information on uncertainty in the diet data.

Few assumptions were made while handling grey seal diet, as follows:

- Sprat was added to other food because of the small total consumption in each year and the lack of length samples.
- If there are less than 5 length bins for a prey in one quarter and year, the length distribution from the adjacent quarter is added to these samples. This "borrowing" is made between quarters 1-2 and quarters 3-4. The 5 samples threshold was chosen after realizing that in few instances only 1-3 samples were available despite fish being consumed. We assume these are not representative of the real length distribution in the diet. The borrowing between quarters was chosen so that it might keep a distinction between spawning seasons, e.g., spring, autumn.
- The diet in 1985 and 2010-2011 is given for a set of years e.g., 1983, 1985, 1988, and 2010-2011. In SMS, we assume the diet is in the year where there is the largest number of samples, i.e., 1985, and 2010.

The code for the analysis is available on the WGSAM GitHub repository.

Sandeel in the North Sea area is managed as six individually assessed stocks. Given the lack of input data at the correct spatial scale, two sandeel stocks are considered in SMS and split into northern and southern North Sea stocks. In the previous SMS keyruns, the total grey seal predation was attributed entirely to the northern sandeel stock. In the 2023 keyrun, the proportion of sandeel consumed by grey seals was extracted from the diet data with the assumption that the northern areas correspond to Shetland, Orkney and northern North Sea, and the southern area to the central North Sea, and the southern North Sea. This resulted in the proportions in the table below. These proportions are used to split the diet data between northern and southern sandeel. The code to extract the proportions is also available on the WGSAM repository.

Proportion of sandeel consumed per area.

	1985 North	1985 South	2002 North	2002 South	2010 North	2010 South
Quarter 1	0.879	0.121	0.795	0.205	0.598	0.402
Quarter 2	0.892	0.108	0.781	0.219	0.657	0.343
Quarter 3	0.844	0.156	0.776	0.224	0.669	0.331
Quarter 4	0.820	0.180	0.805	0.195	0.637	0.363

The resulting size distribution for sandeels in grey seal diet suggests that a considerable proportion of the diet in 1985 consisted of sandeels greater than 20cm in length. Because sandeels caught by the fishery are generally smaller than this, there is some uncertainty about whether these sandeels are *Ammodytes marinus*, and it has been suggested that they may instead be a different sandeel species such as *Hyperoplus lanceolatus*. To avoid this problem, sandeels larger than 20 cm were assumed to be 'other food'. Net consumption was assumed to be 5.5 kg per seal per day.

Data on harbour porpoise

Decadal diet composition (proportion per species and 1 cm length group) was derived from Danish and UK samples assuming that DK and UK samples each represented 50% of the population except in the 1980s when only Danish samples were available (Table 2.3.1). Unfortunately, the number of stomachs was too low to allow quarterly diet composition to be estimated, and all diets were assumed to be derived from their 3rd quarter, as this is the quarter where fish recruits in the SMS model and as such have the full size range of fish sizes. Stomach data from each decade were assigned to the years, 1985, 1995 and 2005 respectively. Daily consumption was set to 2.4 kg (Sophie Smout, University of St. Andrews, pers. Comm.).

Table 2.3.1. Number of harbour porpoise stomachs analysed per country and decade.

Decade	UK	Denmark
1980–1989	0	40
1990–1999	46	62
2000–2009	56	10

In 2011 and 2014/2015, no corrections for differences in evacuation times between prey were applied. In 2017, the data were corrected to account for the fact that the residence time of otoliths in the stomach of harbour porpoise depends on the otolith size. A simple model describing this relationship as a power function of otolith length was suggested by Ross *et al.* (2016). Using this model, the bias originating from differential residence time of fish prey otoliths was remedied by applying the correction factor $l_o^{-1.5}$ to the observed numbers of the six prey fish cod, whiting, Norway pout, sandeel, herring and sprat by length class. *Lo* is the otolith length, which was calculated from the otolith length–total fish length relationships compiled by Leopold *et al.* (2001). The two datasets from the UK and DK were merged for each of the three decades 1985–1994, 1995–2004, and 2005–2014, giving equal weight to the data from the two countries.

The corrected size distributions of the six fish species were scaled to the fraction of the food (mass) requirement of the harbour porpoise population in the North sea constituted by these species (i.e. 87.0%, 82.2% and 69.8% of total food requirement for the decades 1985–1994, 1995–2004, and 2005–2014, respectively). Weight–length relationships from the 3rd quarter. The correction compared to previous result in a 50% increase in herring, a 267% increase in sandeel, a 54% decrease for whiting and smaller changes for other species (Figure 3.3.1).

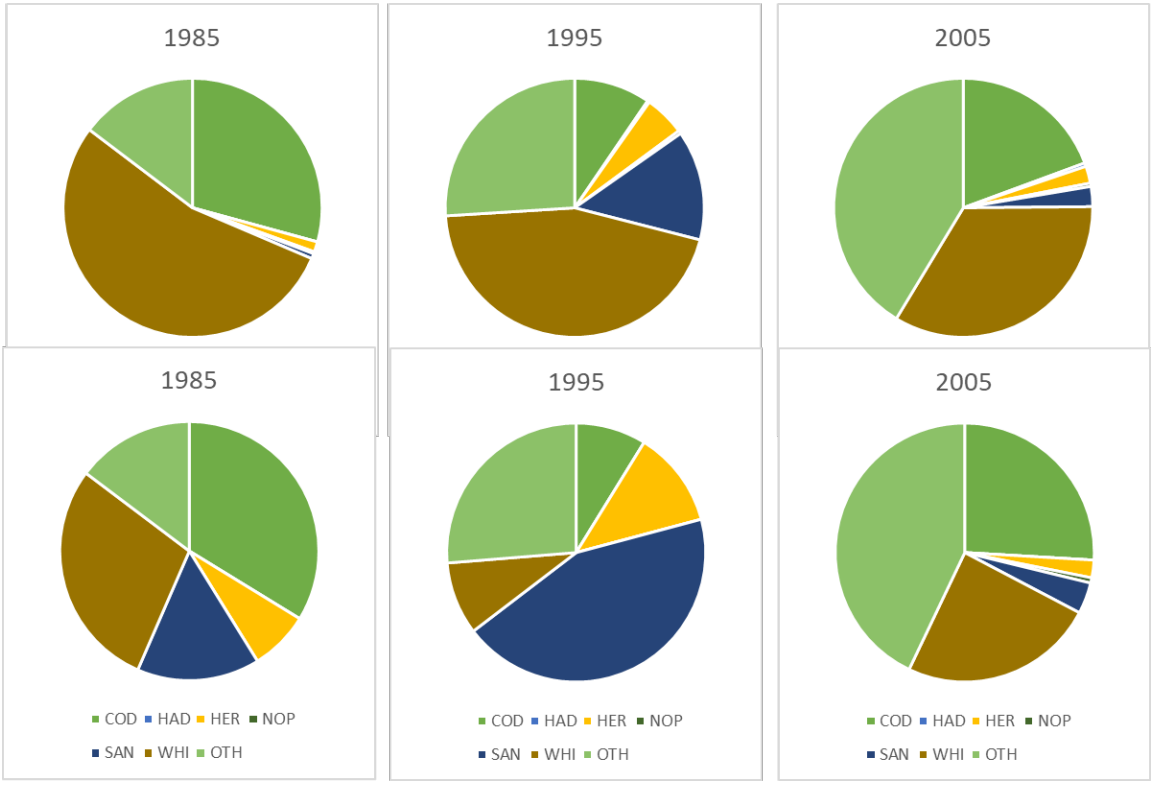

Figure 3.3-19. Harbour porpoise stomach content recorded (top) and consumption rates after correcting for differences in residence times (bottom).

Fish stomach data

An international stomach sampling programme was initiated in 1981 to collect stomach contents data from economical important piscivorous fish species in the North Sea. The sampling program was under the auspices of ICES with the purpose of collecting data on "who eats whom" of the exploited fish in the North Sea for use in fish stock assessment. Stomachs were sampled from saithe, cod, haddock, whiting and mackerel. Stomach sampling continued in the period 1981 to 1991 with the inclusion of more fish species. The highest sampling intensity was in 1981 and 1991. Further information on the background for the ICES stomach sampling project is given in Daan (1989); ICES, 1989 and ICES, 1997.

Stomach contents data are available from ICES (https://www.ices.dk/data/data-portals/Pages/Stomach-content.aspx)

Most of the sampled stomachs have been pooled into size classes at sampling time, e.g. saithe 300–400 mm in the 1981 sampling, such that information on the individual fish does not exist. Similarly, the size of prey item was pooled within size classes, e.g. herring 150–200 mm, in the first quantification of stomach contents data. The size distribution and mean length of the individual size classes (and they differ between sampling years) was derived from the size distribution of fish in the sea (or actually in the trawl) estimated from IBTS 1991–1997 data. For plaice data from beam trawl surveys were used as well. Sandeel are not caught during IBTS and data from the Danish commercial fishery 1987–2003 were used instead for this prey species.

Both the sandeel fishery and IBTS (and BTS) use trawls with a small mesh size, but nevertheless, fish smaller than 5–7 cm are hardly caught. As data are not available to correct for this underrepresentation of the smallest fish, it is ignored in the SMS run, such that the size distribution used by SMS has probably fewer very small fish compared to the size distribution in the sea.

Compilation of stomach contents data into diet

The compilation of the individual stomach samples from trawl hauls into the average diet of the North Sea predators basically follows the technique given by ICES (1993). The average "population" diet or food ration is basically calculated from a stratified mean of the individual stomach content samples, weighted by the strata density of the predator and the area of the strata. This seems simple, but incomplete and patchy sampling makes it often necessary to use a series of *ad hoc* solutions.

The compilation of stomach contents for the 2023 keyrun was done using the FishStomachs R-package (available from https://github.com/MortenVinther/FishStomachs).

The FishStomachs package defines data structures suitable for stomach data, and provides the necessary methods to compile observed stomach data into population diet and biomass eaten, used for multispecies models. The methods applied for a set of observations are stored within the data output to document the compilation steps taken.

The stomach contents compilation followed the steps outlined below:

1. Read and check data from the agreed exchange format;
2. Bias correct to take into account variable evacuation rate;
3. Assign size classes for predators and preys;
4. Bias correct to take into account regurgitated stomachs within sample units;
5. Aggregate stomachs contents within sample_id and size classes.
6. Allocate unidentified or partly identified prey items;
7. Calculate population diet and food ration from a weighted average.

In addition, FishStomachs make it possible to estimate uncertainties of the estimated diet from bootstrapping of individual samples. Bootstrapping is made between step 5 and 6 in the steps above. This approach and the use of the estimated uncertainties are described further in the WD05 "Estimating uncertainties of diet data for use in Stochastic Multispecies Models (SMS)" on the WGSAM 2023 SharePoint.

Even with the use of FishStomachs, the data compilation is too comprehensive to be described here in detail. The R-code for data compilation is available at the WGSAM GitHub (see section 2)

Estimation of food ration from stomach contents data

Food rations (evacuation rate of stomach contents) are estimated from the observed stomach contents and using the methods suggested by Andersen and Beyer (2005a,b). This model takes into account the differences in evacuation rates between prey types due to their energy density and their resistance to digestion (armament).

Food rations were estimated as part of the 2020 key run and has not been updated using the FishStomachs R-package.

Ration I (per hour) by prey group (i) for an individual stomach or a pool of stomachs is calculated from:

$$R = \sum_i \rho M_i b_i \; e^{\delta T} \; L^{\lambda} \; E^{-\xi} \; K \left(\frac{N_A}{N_F} \right)^{\alpha - 1} \; S^{\alpha}$$

M= armament of individual prey (group) i

b=proportion of prey (group) i

T= temperature (OC)

L= length (cm) of the predator

E= average energy density (kJ/g wet weight) of the stomach (or of the pooled stomach sample)

N= Number of stomachs in the sample, total (A) and with food (F)

S = average stomach contents in grams

rho, delta, lambda, my and K = parameters to the model

Table 3-7. Parameter values of the generic cylinder model of gastric evacuation.

SPECIES	RHO	LAMBDA	DELTA	MY	ALFA	K
Cod	0.00224	1.30	0.083	-0.85	0.5	0.85
Haddock	0.00191	1.30	0.083	-0.85	0.5	0.85
Saithe	0.00171	1.35	0.081	-0.85	0.5	0.85
Whiting	0.00171	1.35	0.081	-0.85	0.5	0.85
Mackerel	0.00174	1.30	0.080	-0.85	0.5	0.85

The estimated rations by individual strata (year, quarter, predator and predator size class used in sampling) are combined into one equation for ration from mean weight (ration=a*W^b) where "a" and "b" are dependent on quarter (Table 3-8).

Table 3-8. Parameters for estimating quarterly ratio ɔn= a*W^b).

Species	Quarter	a	b	Species	Quarter	a	b
01 Fulmar	1	34.420	0.000	11 W.horse mac	1	0.000	0.000
	2	28.720	0.000		2	0.000	0.000
	3	27.091	0.000		3	4.507	1.765
	4	34.420	0.000		4	1.573	1.035
02 Guillemot	1	32.456	0.000	12 N.horse mac	1	0.000	0.000
	2	32.258	0.000		2	3.155	1.765
	3	32.828	0.000		3	4.507	1.765
	4	32.148	0.000		4	1.573	1.035
03 Her. Gull	1	28.550	0.000	13 Grey seal	1	477.855	0.000
	2	33.688	0.000		2	438.480	0.000
	3	36.829	0.000		3	382.284	0.000
	4	62.300	0.000		4	708.882	0.000
04 Kittiwake	1	21.865	0.000	14 H. porpoise	1	219.000	0.000
	2	20.971	0.000		2	219.000	0.000
	3	20.971	0.000		3	219.000	0.000
	4	21.865	0.000		4	219.000	0.000
05 GBB. Gull	1	42.956	0.000	15 Hake	1	0.772	0.761
	2	43.412	0.000		2	2.180	0.802
	3	44.178	0.000		3	1.302	0.825
	4	48.950	0.000		4	1.527	0.766
06 Gannet	1	84.200	0.000	16 Cod	1	0.900	0.786
	2	89.900	0.000		2	1.212	0.786
	3	89.900	0.000		3	1.247	0.786
	4	84.200	0.000		4	1.390	0.786
07 Puffin	1	14.950	0.000	17 Whiting	1	0.426	0.683
	2	15.084	0.000		2	0.455	0.683
	3	15.084	0.000		3	0.679	0.683
	4	14.950	0.000		4	0.574	0.683
08 Razorbill	1	20.116	0.000	18 Haddock	1	0.323	0.714
	2	20.916	0.000		2	0.446	0.714
	3	21.159	0.000		3	0.594	0.714
	4	20.116	0.000		4	0.588	0.714
09 A. radiata	1	0.198	0.548	19 Saithe	1	0.394	1.045
	2	0.186	0.509		2	1.139	1.045
	3	0.236	0.463		3	0.604	1.045
	4	0.420	0.593		4	0.706	1.045
10 G. gurnards	1	0.423	0.867	20 Mackerel	1	0.101	1.443
	2	0.702	0.790		2	1.283	1.443
	3	0.786	0.702		3	1.444	1.443
	4	0.592	0.771		4	0.220	1.443

Calculated consumption rates expressed as daily ration per kg body weight (Figure 3.3-2) generally decreased with the size of the predator with the exception of mackerel, saithe and horse mackerel, where consumption increased with predator size. All three species feed mostly on zooplankton at small ages, and the estimates may be a result of an underestimation of zooplankton consumption. This should have a limited effect on fish consumption (the amount eaten will be smaller but the relative contribution of fish will be higher).

The consumption in percent body weight for hake was assumed to be the same as for saithe at a similar weight and North Sea horse mackerel consumption was assumed identical to that of western horse mackerel. Following the estimation of all daily consumption rates, daily consumption in weight for each predator age group was estimated using the actual weight-at-age in the stock of that age group. Previously, a constant ration in weight was used for each age group, but given the recent decrease in the mean weight of predators (particularly saithe but also cod), this practice was changed. Similarly, all mean weights-at-age in the stock of prey fish were updated with annually observed values to account for recent persistent changes in mean weight-at-age of forage fish.

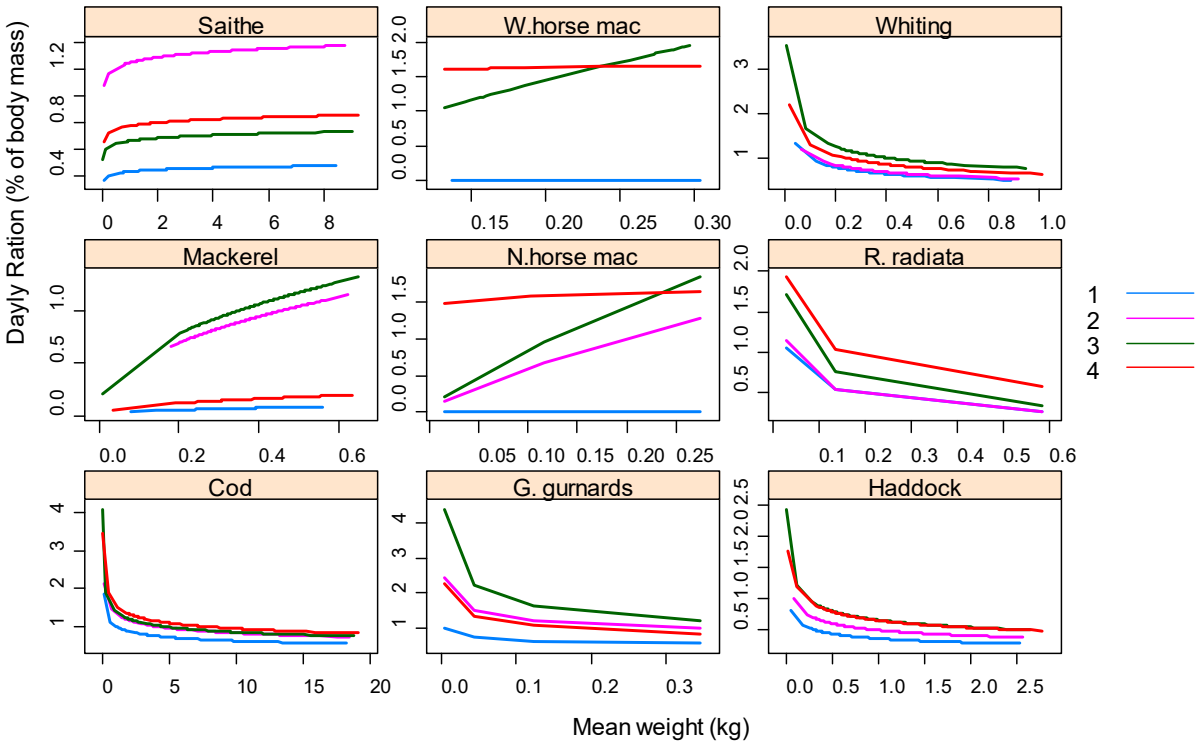

Figure 3.3-20. Daily consumption rates as used in SMS calculated from the method of Andersen. Colours show quarter of the year.

New stomach data

New data for mackerel were collected in 2013. Unfortunately, the length of the prey items was not recorded, and therefore, the data cannot be used directly by SMS.

Moreover, an updated stomach database has been made available for the ICES community (https://stomachdata.ices.dk/inventory), which, among other things, contains a range of newly analysed fish stomachs from the North Sea that could potentially be relevant for the SMS key-run. However, WGSAM decided against using the new data in the 2023 key-run based on several factors: 1) the data was not available until the week of WGSAM, and there was therefore not sufficient time to properly analyse and quality check the data. 2) The geographical distribution of the new stomach data was not comparable to the other data already used in SMS (see Figure for an example of sample distribution of mackerel stomachs), and since SMS uses an average diet per year and season, there was concerns that without an intermediate standardisation the limited sampling distribution would not be representative of the predator-prey interactions in the entire spatial domain of the model. 3) Many of the newly analysed samples had substantial amounts of unidentified organic matter in their stomach which risks to have an inconsistent treatment of the otherfood category (WD03).

Other input data

In addition to the data mentioned above SMS uses data on predator–prey overlap, length–weight relations, residual natural mortality (M1) and age–length keys (ALK). Detailed data can be found in the "**input_output**".

Predator–prey overlap

Predator–prey species overlap is a quarter dependent parameter used in the calculation of food suitability (see equation 8 in Appendix 1). By default the spatial overlap is set to one, but it can also be estimated within SMS for a few combinations. "Spatial overlap" does also include vertical overlap, e.g. sandeel as prey when they are available in the water column (mainly quarter 2 and 3) and buried in the sediment (mainly quarter 4 and 1). For some seabirds (fulmar, kittiwake, gannet and razorbill) the spatial overlap is set to 20 for quarter 2 and 3 to reflect the high proportions of sandeel in their (or their chicks') diet. The value 20 was chosen based on a few trial runs, where 20 gave a sufficient fit to data.

Length–weight relations

Conversion from length into weight is used for some SMS configuration. The parameters values are shown below.

Table 3-9. Length (mm) weight (kg) relation parameters: Weight=a*length^b.

Species	a	b	source
G. gurnards	6.20000e-09	3.10000	Coull *et al* 1989
horse mac	1.05000e-08	2.96220	Silva *et al* 2013
Hake	6.59000e-09	3.01700	Fishbase
Cod	2.04750e-08	2.85710	Coull *et al* 1989
Whiting	1.05090e-08	2.94560	Coull *et al* 1989
Haddock	1.82120e-08	2.82680	Coull *et al* 1989
Saithe	2.83220e-08	2.73740	Coull *et al* 1989
Mackerel	3.81000e-09	3.21000	Coull *et al* 1989
Herring	6.03000e-09	3.09040	Coull *et al* 1989
Sandeel	2.66875e-09	3.06000	Stock coordinator
Nor. Pout	7.50000e-09	3.02440	Silva *et al* 2013
Sprat	8.72900e-10	3.47460	Stock coordinator
Plaice	1.51000e-08	2.88760	Silva *et al* 2013
Sole	8.00000e-09	3.04999	Silva *et al* 2013

Age to length conversion keys

SAM is an age–length based model, where stock dynamic (N, F, M2, etc.) is by age classes while predation is calculated on the basis of the sizes of predators and preys. This means that e.g. stock numbers-at-age has to be converted into stock number-at-size class for the calculation of M2.

For each species, age and quarter the proportion of stock numbers by size classes used at the 1991 stomach sampling are derived from the derived from the size distribution of fish in the sea (or actually in the trawl) estimated from IBTS 1991–1997 data. Sandeel are not caught during IBTS and data from the Danish commercial fishery 1987–2003 were used instead for this species. For both data sources, data from several years were combined into one average quarterly size distribution. Both the sandeel fishery and IBTS use trawls with a small mesh size, but nevertheless, fish smaller than 5–7 cm are hardly caught. As data are not available to correct for this bias, it is ignored in the SMS run, such that the size distribution used, has probably fewer very small fish compared to the size distribution in the sea.

An example of the age–length conversion keys is shown in the table below. Bar charts with age–length can be found in the "**input_output**".

Table 3-10. Example of age–length conversion key: Whiting. The table shows the percentage of a given size class for a given age and quarter.

		Size class (lower limit in mm)													All
		50	60	70	80	100	120	150	200	250	300	350	400	500	
Age	Quarter														
0	3	2.0	8.1	16.8	35.9	21.1		5.2	.	.	.	.	.	.	100.0
	4	.	1.0	2.0	5.0	15.3	31.0	42.7	3.0	.	.	.	.	.	100.0
1	1	.	.	1.0	2.0	3.8	31.4	50.8	11.1	.	.	.	.	.	100.0
	2	.	.	.	.	2.0	14.8	67.5	15.7	.	.	.	.	.	100.0
	3	.	.	.	.	1.0	2.0	28.6	59.4	9.0	.	.	.	.	100.0
	4	.	.	.	.	.	2.0	11.4	70.3	16.3	.	.	.	.	100.0
2	1	.	.	.	.	.	.	4.1	62.4	32.1	1.4	.	.	.	100.0
	2	.	.	.	.	.	0.1	6.6	63.6	28.6	1.2	.	.	.	100.0
	3	.	.	.	.	.	0.0	0.7	31.8	59.9	7.6	.	.	.	100.0
	4	.	.	.	.	.	.	0.1	34.2	56.1	9.5	.	.	.	100.0
3	1	.	.	.	.	.	.	0.2	16.2	66.2	17.4	.	.	.	100.0
	2	.	.	.	.	.	.	.	17.2	67.5	15.3	.	.	.	100.0
	3	.	.	.	.	.	.	0.2	7.8	60.8	27.6	3.5	.	.	100.0
	4	.	.	.	.	.	.	0.0	3.6	60.8	31.3	4.3	.	.	100.0
4	1	.	.	.	.	.	.	0.2	4.0	49.6	39.3	6.9	.	.	100.0
	2	.	.	.	.	.	.	.	4.6	58.4	31.2	5.8	.	.	100.0
	3	.	.	.	.	.	.	.	2.2	38.7	45.4	11.9	1.9	.	100.0
	4	.	.	.	.	.	.	.	1.9	47.4	37.1	11.3	2.3	.	100.0
5	1	.	.	.	.	.	.	.	0.8	39.9	42.6	14.2	2.4	.	100.0
	2	.	.	.	.	.	.	.	3.1	46.8	36.1	11.4	2.7	.	100.0
	3	.	.	.	.	.	.	.	0.6	32.0	48.8	14.2	4.4	.	100.0
	4	.	.	.	.	.	.	.	.	44.3	42.1	10.5	3.1	.	100.0
6	1	.	.	.	.	.	.	.	0.2	38.6	45.0	11.1	5.1	.	100.0
	2	.	.	.	.	.	.	.	4.1	43.7	37.5	11.2	3.6	.	100.0
	3	.	.	.	.	.	.	.	.	34.3	42.2	18.3	5.1	.	100.0
	4	.	.	.	.	.	.	.	0.7	43.9	46.0	7.0	2.4	.	100.0
7	1	.	.	.	.	.	.	.	.	25.5	58.0	9.7	6.7	.	100.0
	2	.	.	.	.	.	.	.	.	28.0	48.1	17.6	6.4	.	100.0
	3	.	.	.	.	.	.	.	.	1.7	76.1	14.6	7.6	.	100.0
	4	.	.	.	.	.	.	.	.	25.8	60.2	10.6	3.4	.	100.0
8	1	.	.	.	.	.	.	.	.	32.3	44.2	14.8	5.8	2.9	100.0
	2	.	.	.	.	.	.	.	.	19.0	49.0	26.9	5.0	.	100.0
	3	.	.	.	.	.	.	.	.	22.0	47.8	22.2	8.0	.	100.0
	4	.	.	.	.	.	.	.	.	.	70.5	26.4	1.1	2.1	100.0

Residual natural mortality (M1)

M1 (residual natural mortality) by quarter is set to 0.05 for the species cod, whiting, haddock, saithe, the two sandeel stocks, Norway pout, sprat and 0.0375 for mackerel, and 0.025 for herring, plaice and sole. M1 for non-prey species is the annual natural mortality (M) used in the single-species assessment divided into 4 quarters. For cod M1 is adjusted for age 3+ to mimic migration from the North Sea to the area West of Scotland.

Model configuration

The configuration of the SMS model aims firstly to mimic the configuration of ICES single-species assessment models and secondly to configure options for predation mortality as concluded at the last key run, or modified during the present WGSAM meeting. Appendix 2 presents the SMS configuration (option files) used for the 2023 key run.

Fishing mortality

SMS uses a separable F model while most of the ICES single-species models use a more flexible model for F (e.g. SAM using random walk F). In addition, some models use types of abundances indices (e.g. SSB or tagging data) and estimate process noise, which have not been implemented in SMS. The SMS single-species assessment will therefore not be able to replicate the ICES single-species output with the same M values as used by ICES WG. Section 3 gives an overview of changes made in the ICES single species assessment (e.g. during ICES Benchmarks) and how these changes are handled **by** SMS.

Configuring predation mortality options

The SMS model has two options for size preferences of predators: either prey are taken according to their abundance in the environment (no size selection) within the observed predator–prey size range; or it can be assumed that a predator has a preferred prey size ratio and that a prey twice as big as the preferred size is as attractive as another half the prey size (log-normal distribution). In 2011, sensible size preferences could only be estimated for around half the fish species and the parameters for the remaining predators were close to the bounds. This corresponds to a situation where the data do not contain sufficient information to estimate the size preference parameters. This was also the case for grey seals. For harbour porpoise, modelling size selection as non-uniform resulted in a greater preference and hence natural mortality of 1-year old cod and a lower consumption of 0- and 2-year old cod. Predicted recruitments, Fs and SSBs were virtually identical. The likelihood of the model was improved by 10 with two 2 parameters added, which indicated a statistically significant improvement of the fit (X^2 test). Inspection of the fit revealed, however, that the size distribution in the diet predicted with size selection was substantially narrower than the observed.

WGSAM 2011 considered that size selection should either be for all predators or none, or at least consistent within groups such as fish and mammals. Given that the model likelihood was only slightly improved by introducing size selection, that fitting parameters close to their bounds may give unwanted results inside the model (for technical reasons) and that the fits of the diets themselves were not improved for all species, it was decided to use uniform selection for all predator species, as done since the 2007 key run. This practice was continued in the 2020 and 2023 key runs, such that model options for predation mortality have been kept constant since the 2014 key run, except for harbour porpoise.

With the change in mean weight-at-age for cod in the 2017 key run, cod at age 3 obtained a smaller mean weight which gave a steep increase in M2 for age 3, as the diet data show that harbour porpoise can eat the (now smaller) age 3 cod. WGSAM 2017 discussed this issue a lot and concluded that the available diet data for harbour porpoise were not sufficient to justify such an increase in M2. Technically, the configuration of size selection was changed from "uniform size selection" to "Constraint uniform size selection" (see equation 13 in Appendix 1) such that the harbour porpoise could not eat cod older than2 years (implemented by a predator:prey size

range). For the other preys eaten by porpoise the constrains in size selection were set to the observed value such that the size selection model in practise was not change for these preys.

SMS estimates the variance of diet observation from an assumed relation between sampling level of stomachs and variance (see Appendix 1, equation 25). As an alternative, the variance can be estimated from bootstrapping outside SMS and used as input to SMS. This reduces the number of parameters in the model and is a first step towards separation observation and process noise. See WD05 "Estimating uncertainties of diet data for use in Stochastic Multispecies Models (SMS)" for more details. At the WGSAM it was decided to use input values of variance of diet data for the predators grey gurnards, horse mackerel, A. radiata, cod, whiting, haddock, saithe, and mackerel. Diet data for the seven species of seabirds are based on expert knowledge, rather than a documented compilation of available observations into a diet composition. To reflect high uncertainties for such data, it was decided to put a lower limit on the within SMS estimates of variance. Technically, this was done by setting an upper limit on α_0 at 5 for sea birds.

Results of the 2023 North Sea SMS key run

Changes of input data to the new key run and ICES benchmarks for some of the stocks since the 2020 key run have produced stock summaries (recruitment, mean F and SSB) from the 2023 key run that is somewhat different from the summaries from the 2020 key run. However, the new estimated predation mortalities (M2) are fairly consistent with the M2 values from the previous key run.

Results from the previous key runs in 2014, 2017, 2020 can be found on https://github.com/ices-eg/wg_WGSAM (see section 2)

Key run summary sheet

AREA	NORTH SEA
Model name	SMS
Type of model	Age–length structured statistical estimation model
Run year	2023
Predatory species	Assessed species: Cod, haddock, saithe, whiting, mackerel Species with given input population size: North Sea horse mackerel, western horse mackerel, grey gurnard, starry ray, hake, fulmar, gannet, great black backed gull, guillemot, herring gull, kittiwake, puffin, razorbill, grey seal, harbour porpoise
Prey species	Cod, haddock, herring, Norway pout, southern North Sea sandeel, northern North Sea sandeel, sprat, whiting and plaice
Time range	1974–2022.
Time step	Quarterly
Area structure	North Sea
Stomach data	Fish species: 1981, 1985, 1986, 1987, 1991, 2005, 2013 Grey seals: 1985, 2002, 2010 Harbour porpoise: Decadal 1985, 1995, 2005
Purpose of key run	Making historic data on natural mortality available and multispecies dynamic
Model changes since last key run	All time-series updated. Addition of diet data for Grey seals in 2010. Updated dated population size of seabirds and grey seals. Recompilation of diet data for the main fish predators and use of externally estimates of uncertainties of diet data as input to SMS
Output available at	Sharepoint/data/North_Sea_key_run and https://github.com/ices-eg/wg_WGSAM
Further details in	Report of the Working Group on Multispecies Assessment Methods 2023

Results of the 2023 key run

The input and output from the model are comprehensive and cannot all be presented in this StockAnnex.

Detailed input- and output data on ASCII and HTML files, and presented on graphs can be downloaded from WGSAM SharePoint/data/North_Sea_key_run or from https://github.com/ices-eg/wg_WGSAM . See section 2 for more details on access to the full data set.

Model diagnostics

The population dynamics of all species except 'external predators' were estimated within the model. The key-run converged and the uncertainties of parameters were obtained from the inverse Hessian matrix.

Parameter overview

The SMS estimates a large number of parameters (see Appendix 1 for an overview of input, parameters and estimated variables). Out the total number of parameters (1839) only 126 relates to predation (Table 5-1). The rest (1713) are considered as "single species" assessment parameters.

All "recruiting" year classes to the model are estimated individually either as 0-groups (parameter "recruitment, stock N at youngest age" inTable 5-1) or at older age in the first year of the model (parameter, "stock number in the first year"). In addition a stock recruitment model is fitted for each species to get stock number estimate for some stocks without additional data sources, which requires some parameters

SMS uses a separable model for F with an estimated year, season, and age effect. The year effect (parameter, "year effect in separable model for F" in Table 5-1) includes one parameter for each species and year in the model, except for the first year in a separable year range where a constant value is used. This sums up to 550 parameters. The parameter "age effect in separable model for F" includes the age effect parameters for each group of ages, species and year range. Likewise the parameter "season effect in separable model for F" have a set of season parameters for each year range. The number of season parameters (40) is low, as a constant value is assumed for the species with annual catch data.

The sub-model for survey indices requires 100 parameters for the age based catchability and 73 parameters for the estimate of the variance of survey observations (Table 5-1).

117 parameters out of a total of 126 parameters related to predation are used to parameterize predator - prey vulnerabilities (Table 5-1). The vulnerability parameters are estimated with a low CV for the predators cod, whiting, haddock and saithe with a high number of stomachs sampled (Table 5-2).

Table 5-11. Number of parameters estimated by group of data.

Parameter	Catch	N-initial	Predation	Survey	all
Catch observation uncertanty	60	0	0	0	60
F-age effect	179	0	0	0	179
F-season effect	40	0	0	0	40
F-year effect	555	0	0	0	555
N first age	0	588	0	0	588
N first year	0	88	0	0	88
Other food	0	0	3	0	3
Spatial overlap	0	0	6	0	6
SSB-Rec parameter	0	17	0	0	17
SSB-Rec uncertanty	0	12	0	0	12
Stomach variance	0	0	11	0	11
Survey catchability	0	0	0	100	100
Survey observation uncertanty	0	0	0	73	73
Vulnerability	0	0	117	0	117
all	834	705	137	173	1849

Table 5-12.

Table Parameter overview. CV of predator – prey vulnerability parameter

Predator	Cod	Whiting	Haddock	Herring	N.sandeel	S.sandeel	Nor.pout	Sprat	Plaice
Fulmar	27	26	42	25	27	27	25	25	
Guillemot		26	46	27	25	24		27	
Her.Gull	33	22	23	22	43	43	22	22	
Kittiwake	32	31	32	30	23	22		29	
GBB.Gull	24	23	23	22	25	25	22	23	
Gannet	32			20	30	29		33	
Puffin				32	23	23		32	
Razorbill		32		28	34	34	32	25	
A.radiata	52	60			38	50	40		
G.gurnards	21	14	36	50	14	13	15	34	
W.horse.mac					40		47		
N.horse.mac		42		39	74			47	
Grey.seal	16	24	19	31	13	17	28		23
H.porpoise	29	25		47	45	50	99		
Hake		113		68			32		
Cod	9	7	6	6	11	12	6	11	

Whiting	23	16	16	15	16	16	13	14
Haddock					13	73	16	
Saithe		21	15	17	19		12	
Mackerel				21	20	18	18	17

Key diagnostics

Key diagnostics (Table 5-3) show a reasonable fit for catch and survey indices data for most species. For Norway pout and sprat the fit to catch data is poor; however better for survey indices. The two sandeel stocks show a reasonable fit to catch data in the main fishing season (quarter 2) but the fit is poor for quarter 3. Stock–recruitment relationships are estimated quite well (reasonable sigma value) for the stocks except for haddock.

Detailed diagnostics

As described in section 2, several diagnostic plots area available in the "**input_output**" directory, as also shown below:

- Diagnostics
  - Residuals
    - Catch at age observation residuals
    - Survey at age observation residuals
    - Stomachs
      - Raw_resid residuals (Observed-predicted) for diet presented in various plots
      - ObsEst Observed and predicted diet
      - Comp_resid Compositional residuals (Trijoulet *et al.* 2023)
      - Stan_resid Standardised residuals
  - Retrospective (retrospective analysis 2018 to 2022)
    - Summary Plots of stock summaries,
    - M2 Plots of predation mortality (M2) at age

Table 5-13. SMS model diagnostics.

November 20, 2023 18:59:01 run time:291 seconds

objective function (negative log likelihood): -6439.23
Number of parameters: 1893
Number of observations used in likelihood: 16975
Maximum gradient: 0.0493262
Akaike information criterion (AIC): -9092.45
Number of observations used in the likelihood:

	Catch	CPUE	S/R	Stomach	Sum	
Species: 1, Fulmar	0	0	0	144	144	0
Species: 2, Guillemot	0	0	0	144	144	0
Species: 3, Her.Gull	0	0	0	168	168	0
Species: 4, Kittiwake	0	0	0	132	132	0
Species: 5, GBB.Gull	0	0	0	204	204	0
Species: 6, Gannet	0	0	0	96	96	0
Species: 7, Puffin	0	0	0	96	96	0
Species: 8, Razorbill	0	0	0	132	132	0
Species: 9, A.radiata	0	0	0	64	64	0
Species:10, G.gurnards	0	0	0	137	137	0
Species:11, W.horse.mac	0	0	0	14	14	0
Species:12, N.horse.mac	0	0	0	36	36	0
Species:13, Grey.seal	0	0	0	105	105	0
Species:14, H.porpoise	0	0	0	19	19	0
Species:15, Hake	0	0	0	33	33	0
Species:16, Cod	490	528	49	864	1931	0
Species:17, Whiting	294	392	49	617	1352	0
Species:18, Haddock	490	608	49	132	1279	0
Species:19, Saithe	392	343	46	215	996	0
Species:20, Mackerel	490	387	49	112	1038	0
Species:21, Herring	1666	336	49	0	2051	0
Species:22, N.sandeel	882	243	49	0	1174	0
Species:23, S.sandeel	882	158	49	0	1089	0
Species:24, Nor.pout	686	296	49	0	1031	0
Species:25, Sprat	588	267	49	0	904	0
Species:26, Plaice	490	864	47	0	1401	0
Species:27, Sole	490	668	47	0	1205	0
Sum	7840	5090	581	3464	16975	0

unweighted objective function contributions:

	Catch	CPUE	SSB/R	stomach	Sum
Fulmar	0.0	0.0	0.0	-223.6	-224
Guillemot	0.0	0.0	0.0	-196.5	-197
Her.Gull	0.0	0.0	0.0	-304.4	-304
Kittiwake	0.0	0.0	0.0	-188.4	-188
GBB.Gull	0.0	0.0	0.0	-352.2	-352

Gannet	0.0	0.0	0.0	-71.0	-71
Puffin	0.0	0.0	0.0	-58.2	-58
Razorbill	0.0	0.0	0.0	-97.4	-97
A.radiata	0.0	0.0	0.0	-38.6	-39
G.gurnards	0.0	0.0	0.0	-14.7	-15
W.horse.mac	0.0	0.0	0.0	1.9	2
N.horse.mac	0.0	0.0	0.0	-14.0	-14
Grey.seal	0.0	0.0	0.0	-226.7	-227
H.porpoise	0.0	0.0	0.0	-22.3	-22
Hake	0.0	0.0	0.0	-16.9	-17
Cod	-443.7	-138.0	-8.8	-1481.5	-2072
Whiting	-187.0	-192.7	-30.2	-534.0	-944
Haddock	-121.7	-183.2	18.2	-62.2	-349
Saithe	-322.0	-73.4	-24.6	-19.1	-439
Mackerel	-457.9	-75.6	-8.3	-88.4	-630
Herring	266.3	-193.1	-12.2	0.0	61
N.sandeel	156.0	54.2	13.0	0.0	223
S.sandeel	97.0	-23.0	3.9	0.0	78
Nor.pout	285.8	-36.4	-7.6	0.0	242
Sprat	223.4	-53.2	-3.7	0.0	167
Plaice	-407.2	-145.6	-27.5	0.0	-580
Sole	-440.0	25.7	-6.6	0.0	-421
Sum	-1350.8	-1034.3	-94.3	-4008.0	-6487

contribution by fleet:

Species:16, Cod

COD Quarter 1	total:-103.024	mean: -0.368
COD NS cod indices Q3 & Q4	total: -35.000	mean: -0.141

Species:17, Whiting

WHG IBTS-Q1	total:-100.347	mean: -0.502
WHG IBTS-Q3	total: -92.338	mean: -0.481

Species:18, Haddock

HAD delta-GAM NS-WC Q1	total:-120.916	mean: -0.378
HAD delta-GAM NS-WC Q3+Q4	total: -62.330	mean: -0.216

Species:19, Saithe

POK N with noise	total: -73.424	mean: -0.214

Species:20, Mackerel

MAC N with noise	total: -75.633	mean: -0.195

Species:21, Herring

HER HERAS	total:-157.321	mean: -0.596
HER IBTS-Q1	total: -23.564	mean: -0.589
HER IBTS0	total: -12.220	mean: -0.394

Species:22, N.sandeel

NSA 78redge	total: 9.423	mean: 0.248
NSA Commercial 1983-1998	total: 1.888	mean: 0.031

```
NSA Commercial 1999-2022      total:   5.930   mean:   0.099
NSA Commercial old            total:  20.186   mean:   0.696
NSA acoustic SA 1R            total:  16.781   mean:   0.300

Species:23, S.sandeel
SSA 79redge                    total:  11.649   mean:   0.307
SSA Commercial 1983-2002      total: -19.265   mean:  -0.321
SSA Commercial 2003-2022      total: -15.338   mean:  -0.256

Species:24, Nor.pout
NOP EGFSQ3                    total:   1.171   mean:   0.019
NOP IBTSQ1                    total: -35.065   mean:  -0.292
NOP IBTSQ3                    total:   0.524   mean:   0.008
NOP SGFSQ3                    total:  -2.997   mean:  -0.060

Species:25, Sprat
SPR Acoustic                  total:  -9.128   mean:  -0.179
SPR IBTS Q1                   total:  11.543   mean:   0.094
SPR IBTS Q3                   total: -55.576   mean:  -0.598

Species:26, Plaice
PLE BTS-Isis-early            total:  -4.666   mean:  -0.047
PLE BTS IBTSQ3                total:-159.517   mean:  -0.591
PLE IBTSQ1                    total: -71.089   mean:  -0.555
PLE SNS1                      total:  50.693   mean:   0.279
PLE SNS2                      total:  46.424   mean:   0.301
PLE DYFS                      total:  -7.434   mean:  -0.240

Species:27, Sole
SOL BTS                       total: -76.343   mean:  -0.201
SOL SNS                       total: 102.044   mean:   0.354


F, Year effect:
```

	sp.16	sp.17	sp.18	sp.19	sp.20	sp.21	sp.22	sp.23	sp.24	sp.25	sp.26	sp.27
1974:	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1975:	1.053	1.025	1.238	1.178	1.327	1.655	1.415	1.532	0.658	2.434	1.185	1.016
1976:	1.161	0.934	1.125	1.274	1.502	0.975	1.191	3.772	0.628	2.208	0.949	0.946
1977:	1.127	0.798	1.082	1.629	1.174	0.232	2.825	3.887	0.428	2.206	1.037	0.860
1978:	1.322	0.592	1.161	0.966	1.482	5.007	1.441	5.911	0.493	1.523	0.946	1.055
1979:	1.072	0.710	1.180	1.030	1.829	5.007	0.524	7.077	0.507	0.891	1.434	1.038
1980:	1.226	0.627	1.103	1.201	1.000	0.145	1.636	5.250	0.544	2.200	1.143	1.042
1981:	1.228	0.637	0.804	1.104	1.039	0.223	1.185	6.080	0.427	1.980	1.189	1.035
1982:	1.304	0.524	0.773	1.086	1.037	0.191	1.038	6.598	0.467	1.189	1.317	1.165
1983:	1.315	0.716	1.024	1.590	0.889	1.000	0.424	3.694	0.593	2.394	1.260	1.099
1984:	1.233	0.796	1.210	1.309	0.917	1.552	0.405	4.646	0.635	1.103	1.314	1.258
1985:	1.237	0.636	1.000	1.326	0.815	1.771	0.678	8.154	1.034	1.174	1.207	1.179
1986:	1.342	0.893	1.036	1.628	0.764	1.501	1.718	3.130	0.421	2.244	1.503	1.287
1987:	1.299	0.716	1.167	1.389	0.834	1.340	1.206	2.201	0.686	0.498	1.532	1.056
1988:	1.308	0.631	1.147	1.602	0.910	1.283	1.872	4.200	0.393	1.442	1.615	1.079
1989:	1.346	0.519	1.129	1.479	0.776	1.098	4.304	5.233	0.491	0.493	1.435	0.891
1990:	1.280	0.550	1.057	1.278	0.838	1.050	3.487	6.917	0.444	1.614	1.000	1.000
1991:	1.271	1.000	1.092	1.183	1.002	1.188	2.601	4.787	0.664	1.736	1.171	1.114

1992:	1.233	1.204	0.959	1.000	1.167	1.629	1.391	4.269	0.357	0.692	1.239	1.091
1993:	1.000	1.352	1.191	1.438	1.324	2.125	0.965	3.810	0.741	1.446	1.194	1.183
1994:	0.954	1.183	1.072	1.013	1.434	1.923	3.986	3.464	0.465	0.790	1.199	1.264
1995:	0.907	0.890	0.954	1.292	1.363	2.003	1.490	2.889	0.272	1.778	1.141	1.186
1996:	0.971	0.809	1.131	1.116	1.010	0.816	1.601	4.806	0.313	1.385	1.295	1.682
1997:	0.934	0.712	0.858	0.799	0.985	0.764	1.572	2.604	0.286	1.054	1.449	1.422
1998:	1.242	0.622	0.928	0.822	1.120	1.000	2.045	4.114	0.234	1.775	1.242	1.518
1999:	1.251	0.850	1.161	1.126	1.149	0.746	1.467	6.873	0.326	1.131	1.261	1.357
2000:	1.255	0.745	1.000	0.800	1.371	0.775	1.938	4.687	0.294	1.392	0.921	1.496
2001:	0.889	0.445	0.811	0.613	1.545	0.599	1.162	8.171	0.124	1.799	1.126	1.248
2002:	1.176	0.395	0.735	0.844	1.854	0.558	3.218	5.028	0.296	1.638	1.056	1.246
2003:	0.740	0.562	0.398	0.907	1.781	0.614	1.795	7.175	1.000	1.581	0.938	1.227
2004:	0.785	0.476	0.433	0.655	1.000	0.656	4.198	6.022	0.698	1.578	0.656	1.210
2005:	0.781	0.453	0.461	0.747	0.715	0.838	1.000	1.000	5.007	1.158	0.646	1.304
2006:	0.801	0.591	0.728	0.716	0.581	0.668	0.372	1.043	0.876	1.892	0.627	1.115
2007:	1.000	1.000	0.659	0.594	0.656	0.593	1.180	0.480	5.007	1.068	1.000	1.129
2008:	1.094	0.970	0.437	0.882	0.586	0.414	4.223	0.685	0.378	0.968	0.746	0.966
2009:	1.088	0.894	0.398	0.911	0.534	0.243	0.383	1.244	0.344	0.566	0.834	1.109
2010:	0.930	0.871	0.431	0.941	0.493	0.284	1.060	0.331	0.882	0.653	0.731	1.240
2011:	0.697	0.738	0.403	0.888	0.460	0.273	0.923	0.314	0.044	0.822	0.901	1.086
2012:	0.649	0.779	0.349	0.819	0.403	0.518	0.313	0.091	0.085	0.907	0.872	1.231
2013:	0.607	0.680	0.308	0.746	0.401	0.614	0.686	1.163	0.732	0.945	0.761	1.129
2014:	0.582	0.737	0.485	0.755	0.506	0.595	3.146	0.544	0.793	0.256	0.811	1.101
2015:	0.602	0.930	0.737	0.792	0.468	0.647	1.620	0.538	0.672	1.088	0.883	1.051
2016:	0.611	0.837	0.598	0.787	0.440	0.626	0.898	0.060	1.052	2.450	1.011	1.265
2017:	0.673	0.643	0.536	0.934	0.483	0.460	1.015	0.703	0.405	0.745	0.817	1.291
2018:	0.967	0.617	0.510	0.924	0.450	0.569	1.070	1.023	0.859	0.957	0.919	1.316
2019:	0.822	0.672	0.507	0.948	0.400	0.502	1.191	0.653	1.018	0.702	0.725	1.473
2020:	0.610	0.564	0.402	0.711	0.507	0.564	1.384	0.610	1.270	0.972	0.717	1.097
2021:	0.383	0.417	0.259	0.503	0.616	0.492	1.024	0.224	1.002	0.526	0.571	0.751
2022:	0.437	0.261	0.143	0.484	0.655	0.665	1.718	0.042	0.624	0.170	0.526	0.468

F, season effect:

Cod

Please note: Season effects are copied from input file

age: 1

1974-1992: 0.250 0.250 0.250 0.250

1993-2006: 0.250 0.250 0.250 0.250

2007-2022: 0.250 0.250 0.250 0.250

age: 2

1974-1992: 0.250 0.250 0.250 0.250

1993-2006: 0.250 0.250 0.250 0.250

2007-2022: 0.250 0.250 0.250 0.250

age: 3

1974-1992: 0.250 0.250 0.250 0.250

1993-2006: 0.250 0.250 0.250 0.250

2007-2022: 0.250 0.250 0.250 0.250

age: 5 - 10

1974-1992: 0.250 0.250 0.250 0.250

1993-2006: 0.250 0.250 0.250 0.250

2007-2022: 0.250 0.250 0.250 0.250

Whiting

```
Please note: Season effects are copied from input file
age: 0
    1974-1990:   0.000 0.000 0.500 0.500
    1991-2006:   0.000 0.000 0.500 0.500
    2007-2022:   0.000 0.000 0.500 0.500
age: 1
    1974-1990:   0.250 0.250 0.250 0.250
    1991-2006:   0.250 0.250 0.250 0.250
    2007-2022:   0.250 0.250 0.250 0.250
age: 2
    1974-1990:   0.250 0.250 0.250 0.250
    1991-2006:   0.250 0.250 0.250 0.250
    2007-2022:   0.250 0.250 0.250 0.250
age: 3 - 6
    1974-1990:   0.250 0.250 0.250 0.250
    1991-2006:   0.250 0.250 0.250 0.250
    2007-2022:   0.250 0.250 0.250 0.250

Haddock
Please note: Season effects are copied from input file
age: 0
    1974-1984:   0.000 0.000 0.500 0.500
    1985-1999:   0.000 0.000 0.500 0.500
    2000-2022:   0.000 0.000 0.500 0.500
age: 1
    1974-1984:   0.250 0.250 0.250 0.250
    1985-1999:   0.250 0.250 0.250 0.250
    2000-2022:   0.250 0.250 0.250 0.250
age: 2 - 10
    1974-1984:   0.250 0.250 0.250 0.250
    1985-1999:   0.250 0.250 0.250 0.250
    2000-2022:   0.250 0.250 0.250 0.250

Saithe
Please note: Season effects are copied from input file
age: 3
    1974-1991:   0.250 0.250 0.250 0.250
    1992-2022:   0.250 0.250 0.250 0.250
age: 4 - 10
    1974-1991:   0.250 0.250 0.250 0.250
    1992-2022:   0.250 0.250 0.250 0.250

Mackerel
Please note: Season effects are copied from input file
age: 1
    1974-1979:   0.250 0.250 0.250 0.250
    1980-2003:   0.250 0.250 0.250 0.250
    2004-2022:   0.250 0.250 0.250 0.250
age: 2
    1974-1979:   0.250 0.250 0.250 0.250
    1980-2003:   0.250 0.250 0.250 0.250
    2004-2022:   0.250 0.250 0.250 0.250
age: 4 - 10
```

```
    1974-1979:   0.250 0.250 0.250 0.250
    1980-2003:   0.250 0.250 0.250 0.250
    2004-2022:   0.250 0.250 0.250 0.250

Herring
age: 0
    1974-1982:   0.000 0.000 0.920 0.500
    1983-1997:   0.000 0.000 1.233 0.500
    1998-2022:   0.000 0.000 0.552 0.500
age: 1 - 8
    1974-1982:   0.081 0.054 0.136 0.250
    1983-1997:   0.085 0.095 0.242 0.250
    1998-2022:   0.067 0.137 0.360 0.250

N.sandeel
age: 0
    1974-2004:   0.000 0.000 1.000 0.000
    2005-2022:   0.000 0.000 1.000 0.000
age: 1
    1974-2004:   0.000 3.682 0.500 0.000
    2005-2022:   0.000 11.153 0.500 0.000
age: 2 - 4
    1974-2004:   0.000 5.836 0.500 0.000
    2005-2022:   0.000 11.130 0.500 0.000

S.sandeel
age: 0
    1974-2004:   0.000 0.000 1.000 0.000
    2005-2022:   0.000 0.000 1.000 0.000
age: 1
    1974-2004:   0.000 3.398 0.500 0.000
    2005-2022:   0.000 8.015 0.500 0.000
age: 2 - 4
    1974-2004:   0.000 3.323 0.500 0.000
    2005-2022:   0.000 11.694 0.500 0.000

Nor.pout
age: 0
    1974-2002:   0.000 0.000 0.026 0.500
    2003-2022:   0.000 0.000 0.038 0.500
age: 1
    1974-2002:   0.066 0.048 0.165 0.250
    2003-2022:   0.002 0.020 0.113 0.250
age: 3
    1974-2002:   0.096 0.128 0.131 0.250
    2003-2022:   0.005 0.036 0.117 0.250

Sprat
age: 1
    1974-2022:   0.018 0.000 0.286 0.250
age: 2
    1974-2022:   0.041 0.000 0.144 0.250
age: 3
```

1974-2022: 0.062 0.000 0.114 0.250

Plaice
Please note: Season effects are copied from input file
age: 1
1974-1989: 0.250 0.250 0.250 0.250
1990-2006: 0.250 0.250 0.250 0.250
2007-2022: 0.250 0.250 0.250 0.250
age: 2 – 10
1974-1989: 0.250 0.250 0.250 0.250
1990-2006: 0.250 0.250 0.250 0.250
2007-2022: 0.250 0.250 0.250 0.250

Sole
Please note: Season effects are copied from input file
age: 1 – 10
1974-1989: 0.250 0.250 0.250 0.250
1990-2022: 0.250 0.250 0.250 0.250

F, age effect:

	0	1	2	3	4	5	6	7	8	9	10
Cod											
1974-1992:	0.000	0.334	0.759	0.781	0.660	0.593	0.593	0.637	0.599	0.667	0.667
1993-2006:	0.000	0.180	0.807	1.074	0.996	0.905	0.817	0.889	0.841	0.936	0.936
2007-2022:	0.000	0.083	0.375	0.694	0.719	0.773	0.695	0.563	0.388	0.166	0.166
Whiting											
1974-1990:	0.037	0.186	0.488	0.822	1.036	1.159	1.159				
1991-2006:	0.017	0.097	0.263	0.388	0.423	0.331	0.331				
2007-2022:	0.002	0.040	0.108	0.189	0.230	0.228	0.228				
Haddock											
1974-1984:	0.034	0.158	0.525	0.867	0.836	0.835	0.810	0.704	0.704	0.704	0.704
1985-1999:	0.018	0.167	0.678	0.921	0.969	0.967	0.821	0.747	0.747	0.747	0.747
2000-2022:	0.008	0.120	0.505	0.944	1.160	1.157	1.028	1.165	1.165	1.165	1.165
Saithe											
1974-1991:	0.000	0.000	0.000	0.386	0.516	0.486	0.417	0.385	0.347	0.347	0.347
1992-2022:	0.000	0.000	0.000	0.167	0.436	0.548	0.551	0.508	0.450	0.450	0.450
Mackerel											
1974-1979:	0.000	0.024	0.041	0.068	0.117	0.117	0.124	0.129	0.129	0.129	0.129
1980-2003:	0.000	0.033	0.078	0.129	0.186	0.216	0.232	0.278	0.278	0.278	0.278
2004-2022:	0.000	0.019	0.073	0.170	0.260	0.365	0.449	0.586	0.586	0.586	0.586
Herring											
1974-1982:	0.351	1.158	1.594	1.584	1.315	1.346	1.346	1.346	1.346		
1983-1997:	0.081	0.285	0.404	0.464	0.536	0.501	0.501	0.501	0.501		
1998-2022:	0.091	0.093	0.221	0.355	0.481	0.700	0.700	0.700	0.700		
N.sandeel											
1974-2004:	0.021	0.052	0.039	0.026	0.026						
2005-2022:	0.001	0.016	0.036	0.034	0.034						
S.sandeel											
1974-2004:	0.001	0.022	0.039	0.046	0.046						
2005-2022:	0.001	0.051	0.061	0.092	0.092						
Nor.pout											
1974-2002:	0.142	2.287	7.100	7.100							
2003-2022:	0.011	0.838	3.854	3.854							

Sprat

1974-2022: 0.000 0.796 2.219 2.219

Plaice

1974-1989: 0.000 0.107 0.242 0.285 0.312 0.310 0.275 0.226 0.226 0.226 0.226

1990-2006: 0.000 0.075 0.325 0.383 0.423 0.445 0.431 0.291 0.291 0.291 0.291

2007-2022: 0.000 0.064 0.199 0.251 0.296 0.289 0.234 0.135 0.135 0.135 0.135

Sole

1974-1989: 0.000 0.002 0.201 0.569 0.595 0.485 0.449 0.350 0.350 0.350 0.350

1990-2022: 0.000 0.017 0.190 0.420 0.512 0.521 0.484 0.437 0.437 0.437 0.437

sqrt(catch variance) ~ CV:

Cod

6 0.605

2 0.143

3 0.143

4 0.143

6 0.143

6 0.143

6 0.259

8 0.259

9 0.566

10 0.566

Whiting

6 1.200

6 0.242

2 0.242

3 0.242

4 0.242

6 0.403

6 0.403

Haddock

6 0.891

6 0.523

2 0.280

3 0.280

4 0.280

6 0.280

6 0.409

6 0.409

8	0.893
9	0.893
10	0.893

Saithe

3	0.497
4	0.497
6	0.202
6	0.202
6	0.202
8	0.233
9	0.233
10	0.233

Mackerel

6	0.482
2	0.433
3	0.202
4	0.202
6	0.202
6	0.202
6	0.202
8	0.202
9	0.202
10	0.202

Herring

	season			
age	1	2	3	4
0			0.879	0.915
1	0.861	0.703	0.678	0.603
2	0.861	0.703	0.678	0.603
3	0.861	0.703	0.678	0.603
4	0.861	0.703	0.678	0.603
5	0.861	0.703	0.678	0.603
6	0.861	0.703	0.678	0.603
7	0.861	0.703	0.678	0.603
8	0.897	0.788	0.430	0.931

N.sandeel

	season			
age	1	2	3	4
6			1.414	

1	0.526	1.366
2	0.526	1.366
3	0.526	1.366
4	1.341	1.414

S.sandeel

	season			
age	1	2	3	4
6			1.414	
1		0.376	0.993	
2		0.376	0.993	
3		0.376	0.993	
4		0.754	1.344	

Nor.pout

	season			
age	1	2	3	4
0			1.414	1.208
1	1.035	0.748	0.650	0.672
2	1.035	0.748	0.650	0.672
3	1.380	1.082	1.157	1.414

Sprat

	season			
age	1	2	3	4
1	1.243		0.883	0.717
2	1.243		0.883	0.717
3	1.414		0.956	1.232

Plaice

6	0.421
2	0.243
3	0.252
4	0.252
6	0.252
6	0.252
6	0.252
8	0.252
9	0.252
10	0.252

Sole

6	1.414

```
 2       0.398
 3       0.187
 4       0.187

 6       0.187
 6       0.187
 6       0.187

 8       0.187
 9       0.187
10       0.187
```

Survey catchability:

Cod	age 0	age 1	age 2	age 3	age 4	age 5	age 6	age 7	age 8	age 9	age 10
COD Quarter 1		0.806	4.213	6.834	9.874	9.874	9.874	9.874			
COD NS cod indices Q3 & Q4	0.126	2.139	4.184	6.026	7.759	7.759	7.759	7.759			
Whiting											
WHG IBTS-Q1		1.374	4.006	4.233	3.345	3.345					
WHG IBTS-Q3	0.760	4.015	4.301	3.372	2.963	2.963					
Haddock											
HAD delta-GAM NS-WC Q1		36.157	60.995	66.369	46.275	46.275	46.275	46.275	46.275		
HAD delta-GAM NS-WC Q3+Q4	19.733	66.705	59.098	59.098	59.098	59.098	59.098	59.098	59.098		
Saithe											
POK N with noise				0.974	0.974	0.974	0.974	0.974	0.974	0.974	
Mackerel											
MAC N with noise		1.079	1.079	1.079	1.079	1.079	1.079	1.079	1.079	1.079	
Herring											
HER HERAS		1.210	1.054	1.275	1.275	1.275	1.275	1.275	1.275		
HER IBTS-Q1		13.184									
HER IBTS0	0.399										
N.sandeel											
NSA 87redge	36.963	46.486									
NSA Commercial 1983-1998		0.863	0.946	0.582							
NSA Commercial 1999-2022		1.875	3.403	3.028							
NSA Commercial old	1.957										
NSA acoustic SA 1R		3.279	8.265	11.790	11.790						
S.sandeel											
SSA dregde	0.240	0.975									
SSA Commercial 1983-2002		0.460	0.861	0.966							
SSA Commercial 2003-2022		0.796	1.272	2.096							
Nor.pout											
NOP EGFSQ3	0.386	2.908									
NOP IBTSQ1		0.970	2.833	7.577							
NOP IBTSQ3			4.803	7.307							
NOP SGFSQ3	0.920	2.950									
Sprat											
SPR Acoustic		10.172	19.457	25.391							
SPR IBTS Q1		4.027	10.961	12.718							
SPR IBTS Q3		7.716	9.331	5.332							
Plaice											
PLE BTS-Isis-early		1.483	1.680	0.858	0.177	0.177	0.177	0.177	0.177	0.177	

PLE BTS IBTSQ3		3.173	4.556	5.552	7.106	7.106	7.106	7.106	7.106	7.106
7.106										
PLE IBTSQ1		0.069	0.516	1.124	1.442	1.737	1.737	1.737	1.737	
PLE SNS1		16.967	10.883	3.562	0.977	0.175	0.175	0.175		
PLE SNS2		7.545	2.251	1.090	0.396	0.396	0.396	0.396		
PLE DYFS	0.679									
Sole										
SOL BTS		25.491	23.116	17.762	15.316	15.316	15.316	15.316	15.316	15.316
15.316										
SOL SNS		1.859	0.762	0.245	0.245	0.245	0.245			

sqrt(Survey variance) ~ CV:

Cod	age 0	age 1	age 2	age 3	age 4	age 5	age 6	age 7	age 8	age 9	age
10											
COD Quarter 1		0.53	0.31	0.43	0.43	0.43	0.43	0.43			
COD NS cod indices Q3 & Q4	1.32	0.50	0.46	0.46	0.46	0.46	0.46	0.46			
Whiting											
WHG IBTS-Q1		0.47	0.34	0.34	0.34	0.34					
WHG IBTS-Q3	0.74	0.41	0.31	0.31	0.31	0.31					
Haddock											
HAD delta-GAM NS-WC Q1		0.40	0.42	0.42	0.42	0.42	0.42	0.42	0.42		
HAD delta-GAM NS-WC Q3+Q4	0.52	0.37	0.37	0.53	0.53	0.53	0.53	0.53	0.53		
Saithe											
POK N with noise				0.49	0.49	0.49	0.49	0.49	0.49	0.49	
Mackerel											
MAC N with noise		0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
Herring											
HER HERAS		0.47	0.24	0.34	0.34	0.34	0.34	0.34	0.34		
HER IBTS-Q1		0.34									
HER IBTS0	0.41										
N.sandeel											
NSA 88redge	0.67	0.90									
NSA Commercial 1983-1998		0.63	0.63	0.63							
NSA Commercial 1999-2022		0.65	0.68	0.68							
NSA Commercial old	1.22										
NSA acoustic SA 1R		0.75	0.75	0.75	1.08						
S.sandeel											
SSA 88redge	0.73	0.93									
SSA Commercial 1983-2002		0.59	0.38	0.38							
SSA Commercial 2003-2022		0.47	0.47	0.47							
Nor.pout											
NOP EGFSQ3	0.92	0.41									
NOP IBTSQ1		0.55	0.41	0.41							
NOP IBTSQ3			0.47	0.80							
NOP SGFSQ3	0.82	0.40									
Sprat											
SPR Acoustic		0.48	0.52	0.52							
SPR IBTS Q1		0.72	0.64	0.64							
SPR IBTS Q3		0.45	0.29	0.29							
Plaice											
PLE BTS-Isis-early		0.45	0.45	0.73	0.73	0.58	0.58	0.58	0.58	0.58	
PLE BTS IBTSQ3		0.30	0.24	0.36	0.36	0.36	0.36	0.36	0.36	0.36	
0.36											

PLE IBTSQ1	0.35	0.35	0.23	0.23	0.43	0.43	0.43	0.43	
PLE SNS1	0.41	0.41	0.92	0.92	1.15	1.15	1.15		
PLE SNS2	0.38	0.38	0.82	0.82	1.37	1.37	1.37		
PLE DYFS	0.48								
Sole									
SOL BTS	0.47	0.40	0.40	0.40	0.40	0.40	0.66	0.66	0.66
0.66									
SOL SNS	0.63	0.66	0.66	1.15	1.15	1.15			

Recruit-SSB		alfa	beta	var	sd
Cod	Hockey stick -break.:	42.635	8.600e+04	0.222	0.471
Whiting	Hockey stick -break.:	112.177	1.200e+05	0.084	0.290
Haddock	Geometric mean:	14.770		1.039	1.019
Saithe	Geometric mean:	12.089		0.126	0.355
Mackerel	Geometric mean:	15.243		0.263	0.512
Herring	Ricker:	52.305	8.290e-07	0.224	0.473
N.sandeel	Ricker:	1011.603	1.558e-06	0.627	0.792
S.sandeel	Ricker:	1102.784	2.304e-06	0.431	0.657
Nor.pout	Hockey stick -break.:	960.887	8.000e+04	0.249	0.499
Sprat	Hockey stick -break.:	1019.358	9.400e+04	0.309	0.556
Plaice	Ricker:	9.283	1.026e-06	0.114	0.338
Sole	Ricker:	6.607	2.400e-05	0.278	0.527

Multispecies parameters

stomach content variance model: Dirichlet distribution

Other food Suitability slope:

Fulmar	0.0000
Guillemot	0.0000
Her.Gull	0.0000
Kittiwake	0.0000
GBB.Gull	0.0000
Gannet	0.0000
Puffin	0.0000
Razorbill	0.0000
A.radiata	0.0988
G.gurnards	0.0000
W.horse.mac	0.0000
N.horse.mac	0.0000
Grey.seal	0.0000
H.porpoise	0.0000
Hake	0.0000
Cod	0.0000
Whiting	-0.5933
Haddock	0.0000
Saithe	-0.2812
Mackerel	0.0000

Stomach variance:	value	internal	max alfa0
Fulmar	0.120	0.120 limit	5.000
Guillemot	0.120	0.120 limit	5.000
Her.Gull	0.120	0.120 limit	5.000
Kittiwake	0.120	0.120 limit	5.000
GBB.Gull	0.120	0.120 limit	5.000
Gannet	0.120	0.120 limit	5.000
Puffin	0.120	0.120 limit	5.000
Razorbill	0.120	0.120 limit	5.000
A.radiata	0.000	0.000	39.970 input
G.gurnards	0.000	0.000	99.170 input
W.horse.mac	0.000	0.000	10.590 input
N.horse.mac	0.000	0.000	10.770 input
Grey.seal	51.603	51.603	50.603
H.porpoise	0.186	0.186	17.571
Hake	0.046	0.046	1.322
Cod	0.000	0.000	222.900 input
Whiting	0.000	0.000	167.480 input
Haddock	0.000	0.000	66.830 input
Saithe	0.000	0.000	121.820 input
Mackerel	0.000	0.000	234.330 input

Retrospective analysis for M2

The retrospective analysis of M2 shows a consistent estimate of predation mortalities (Figure 5.1-1 to Figure 5.1-8) with the terminal year in the range 2019–2022, however with quite different M2 values for Norway pout when 2021 is the terminal year. The 2021 run illustrates the "Achilles heel" with such a complex model; if one of the stocks is "wrong", it affects the M2 for a range of other species as well.

A closer look at the retro2021 run showed that F is estimated much lower and SSB much higher for Norway pout. This much larger biomass results in a lower M2. The diagnostics do not indicate that something has gone really wrong with the fit. The likelihoods are quite comparable, but 2021 has a poorer fit to catches and survey cpue (see table below). The catch residuals for retro 2021 show consistent (all) very high and negative catch residuals for age 3 in quarter 4, something you only see when the optimizer has cannot make progress , but the Maximum gradient is 0.0009 indicating a good fit

Table. Likelihood contributions from the retrospective runs.

Label	Species	catch	CPUE	SSB.Rec	neg_log likelihood
2018	Nor.pout	262.9	-32.2	-4.6	230.3
2019	Nor.pout	269.2	-32.0	-5.0	236.8
2020	Nor.pout	276.9	-35.1	-6.3	241.2
2021	Nor.pout	339.5	-15.9	1.9	323.8
2022	Nor.pout	285.8	-36.4	-7.6	248.7

Plots of retrospective summary plots (not shown here, but can be found on the SharePoint). Show some instability (F is consistently estimated slightly lower and SSB higher) for cod in year 2019.

As for all other retrospective assessment analyses, this analysis also shows that values (M2) in the terminal years of the time-series have larger uncertainties; however, this uncertainty is not huge. Compared to most ICES single species models, the retrospective patterns from SMS are actually quite small!

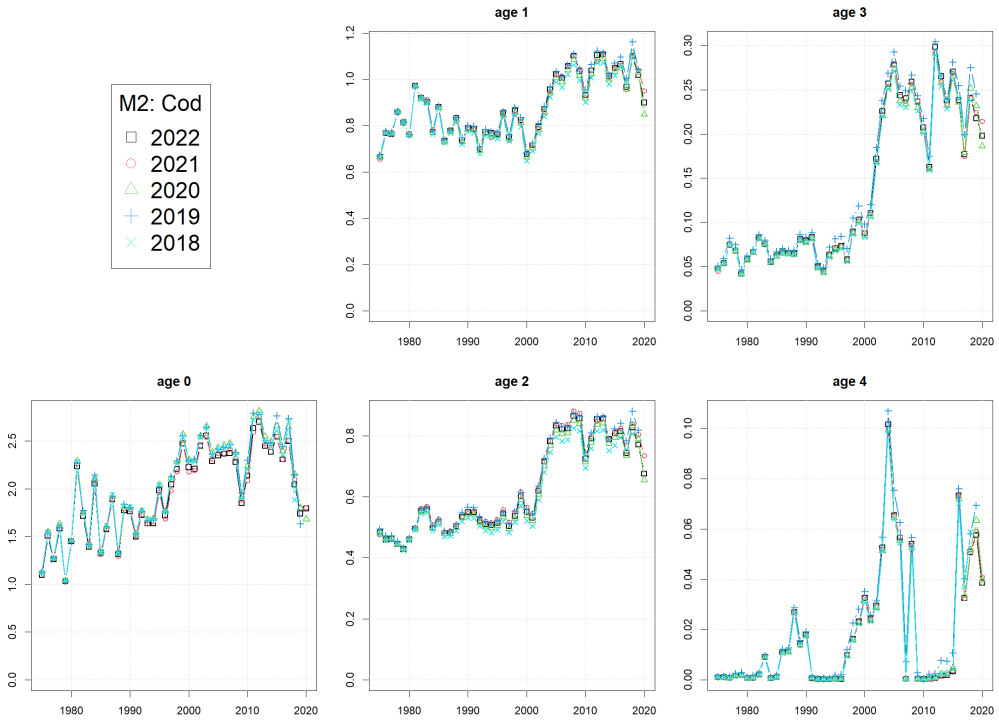

Figure 5.1-21. Retrospective analysis of M2 for cod.

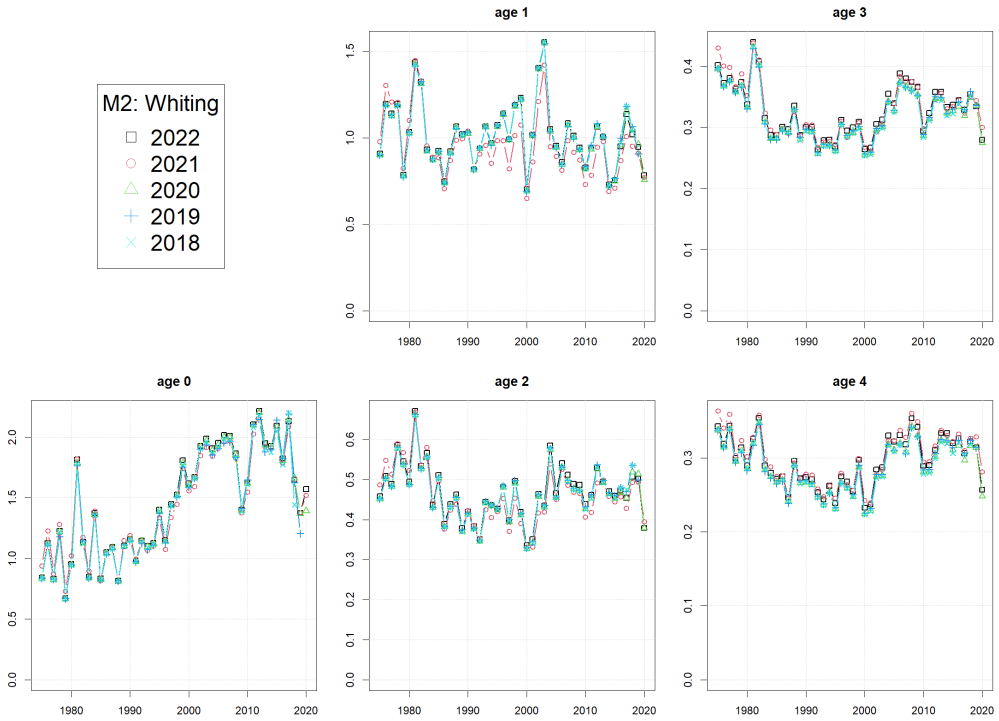

Figure 5.1-22. Retrospective analysis of M2 for whiting.

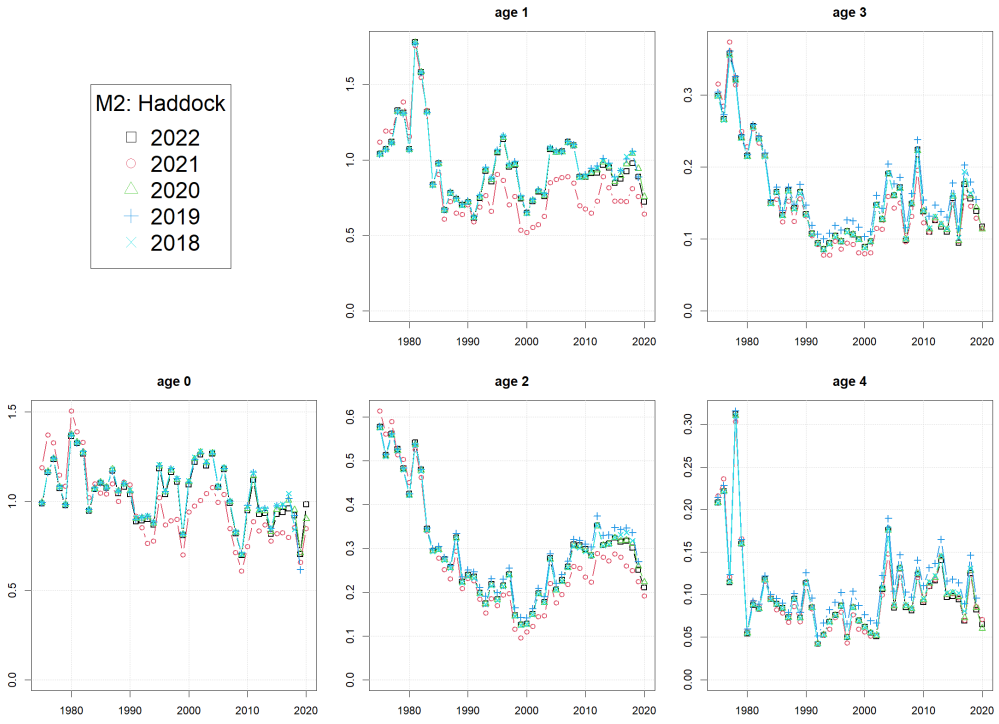

Figure 5.1-23. Retrospective analysis of M2 for haddock.

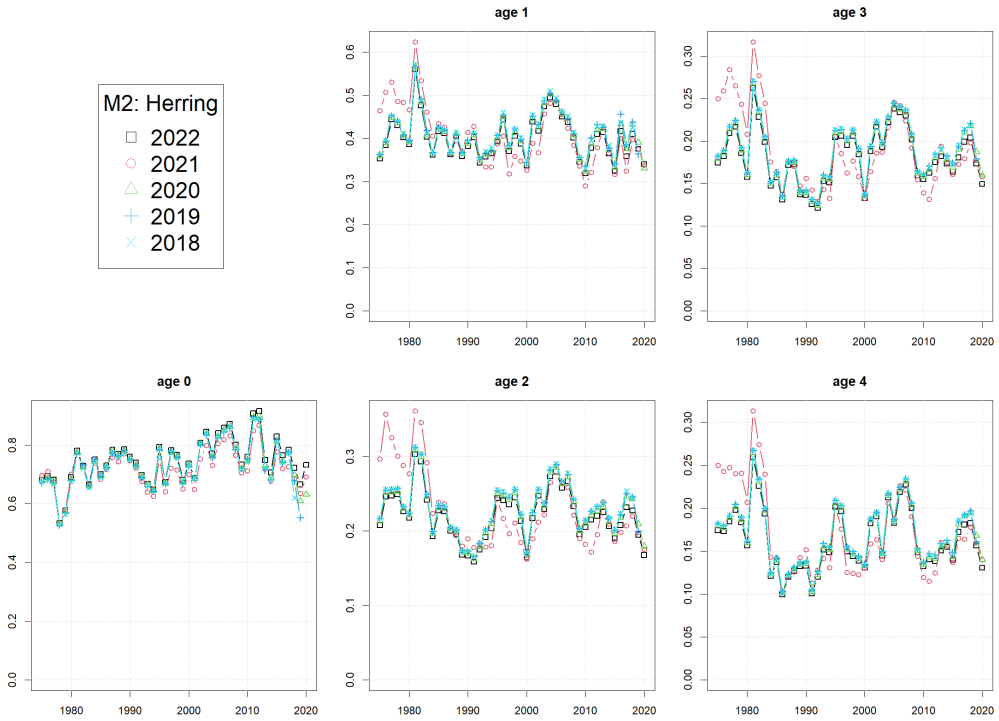

Figure 5.1-24. Retrospective analysis of M2 for herring.

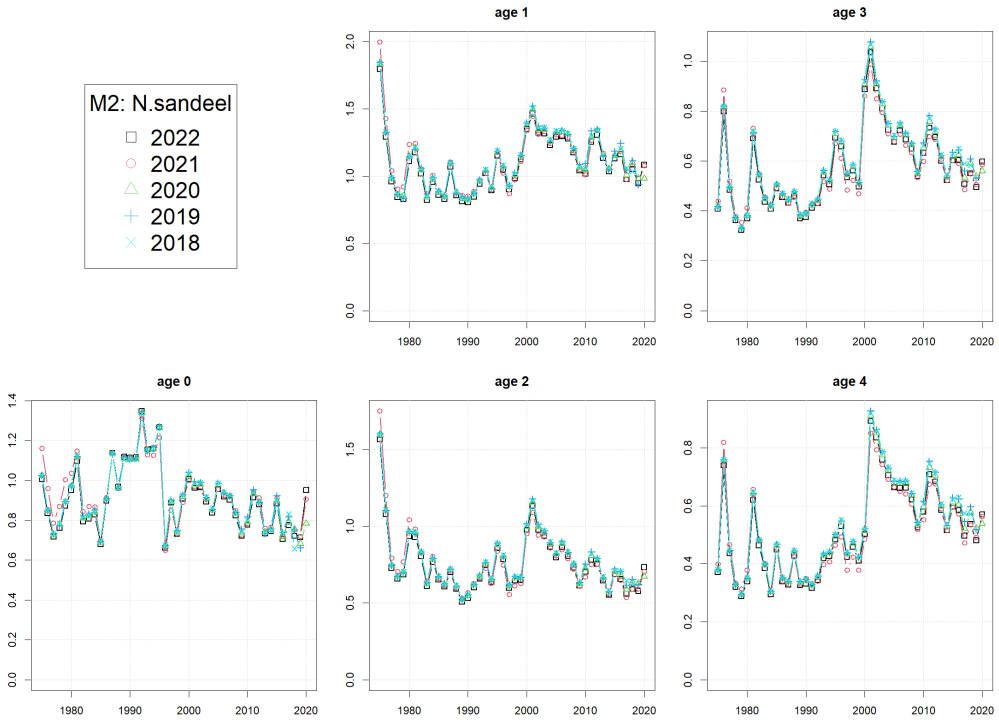

Figure 5.1-25. Retrospective analysis of M2 for northern sandeel

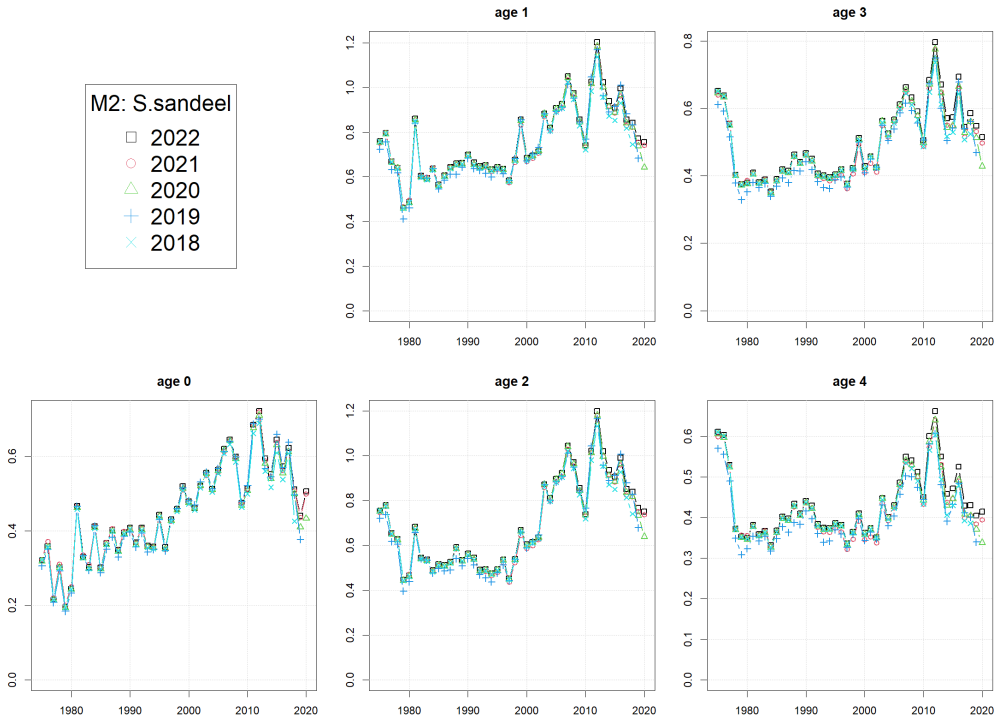

Figure 5.1-26. Retrospective analysis of M2 for southern sandeel.

Figure 5.1-27. Retrospective analysis of M2 for Norway pout.

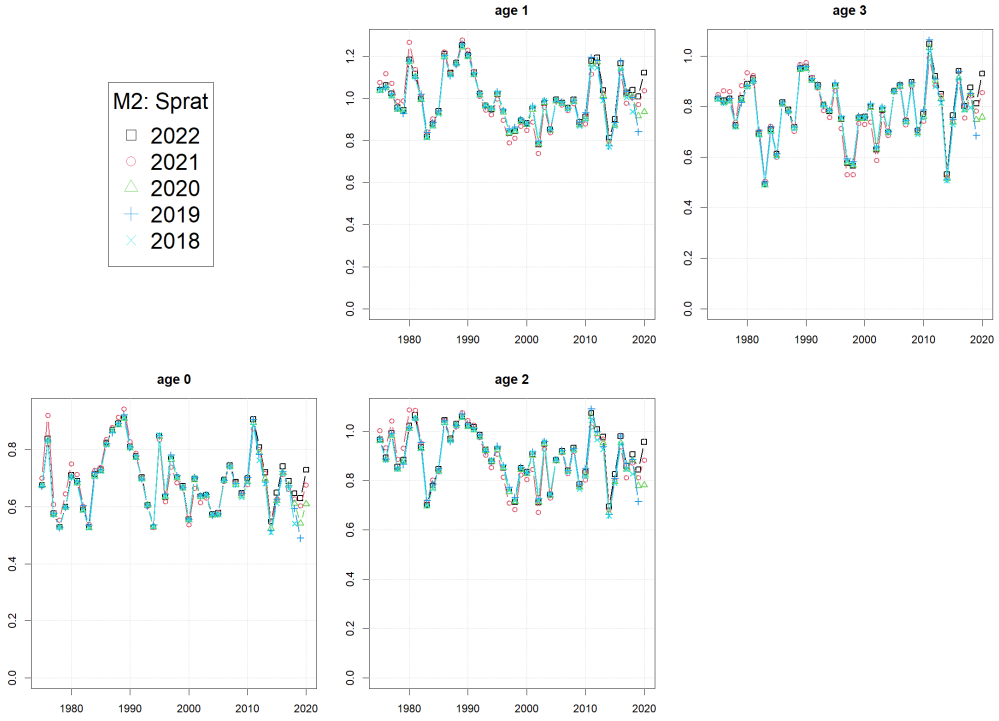

Figure 5.1-28. Retrospective analysis of M2 for sprat.

Stock summary results

The stock summaries are presented in Figure 5.1-9 to Figure 5.1-19.

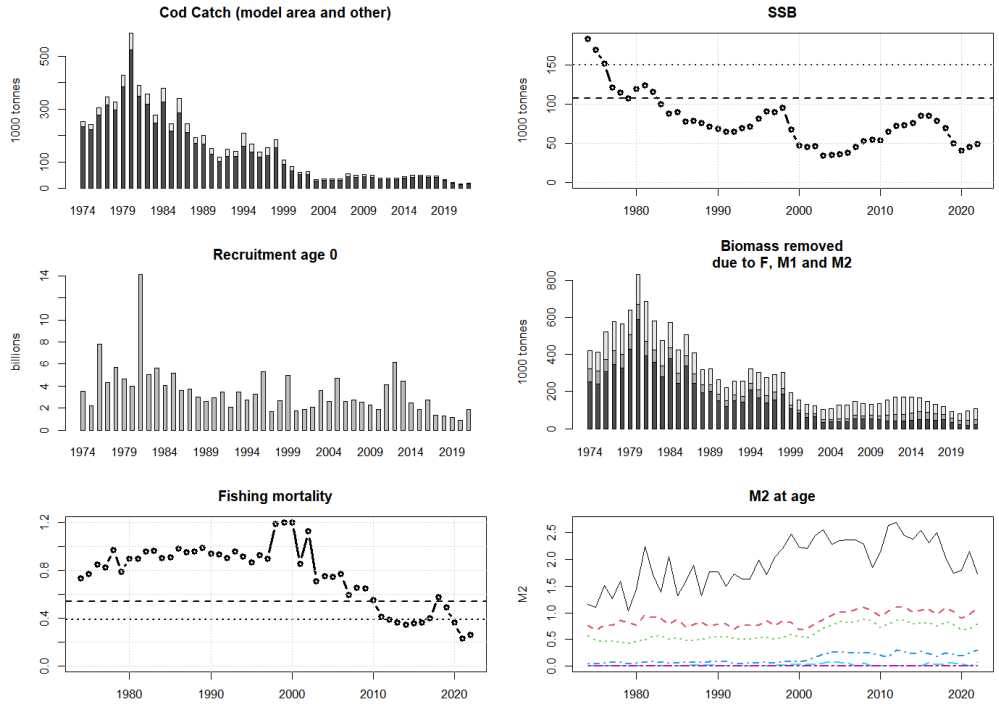

Figure 5.1-29. SMS output for cod. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

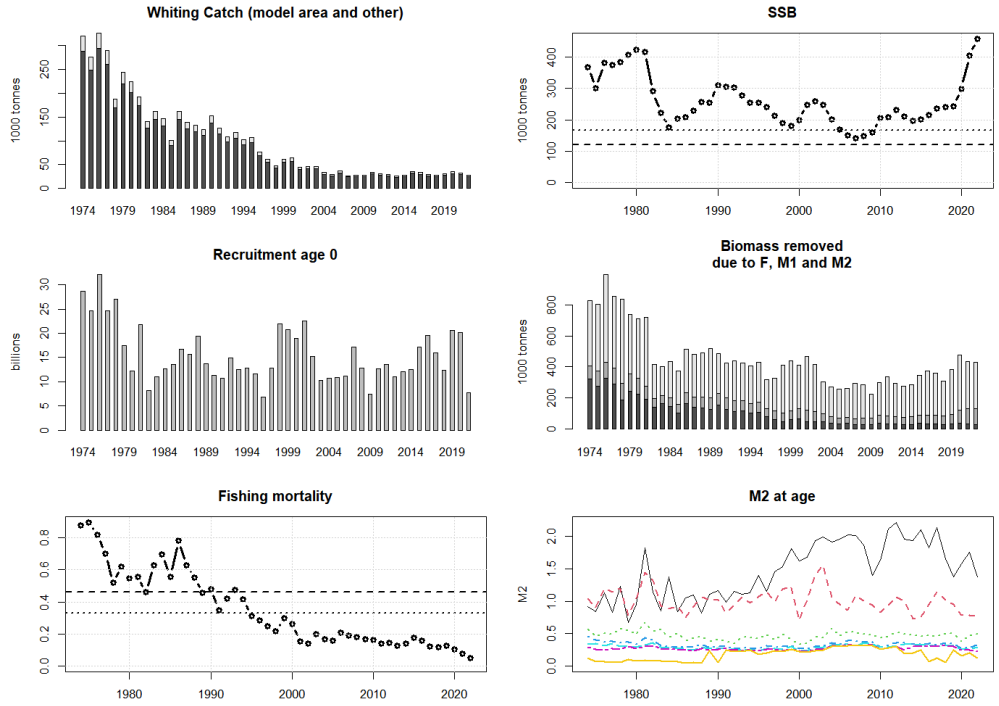

Figure 5.1-30. SMS output for whiting. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

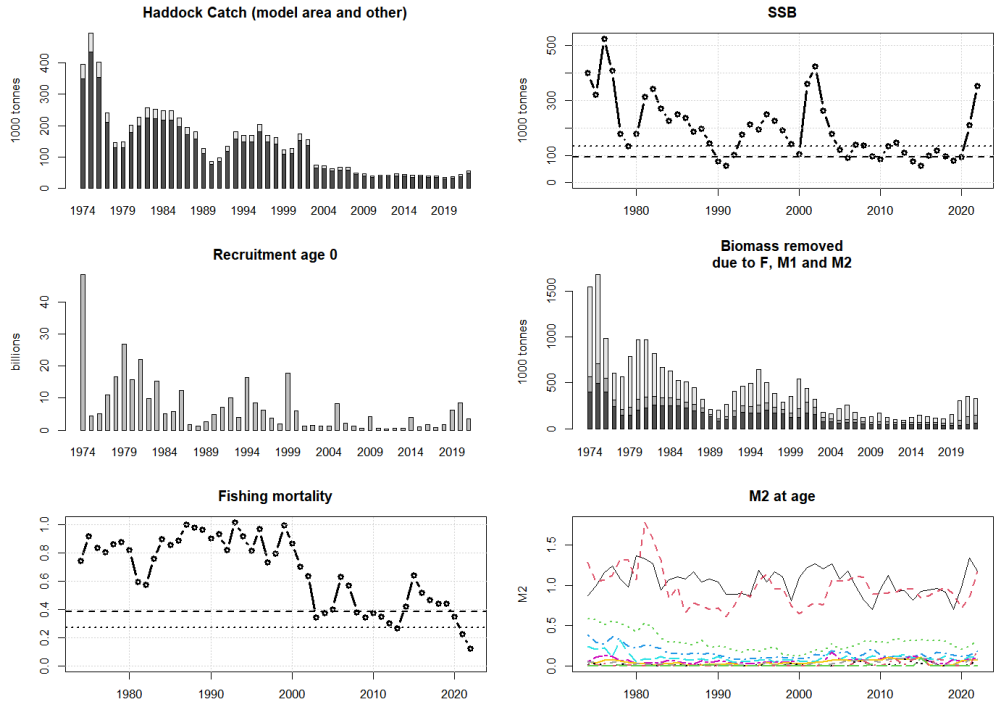

Figure 5.1-31. SMS output for haddock. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

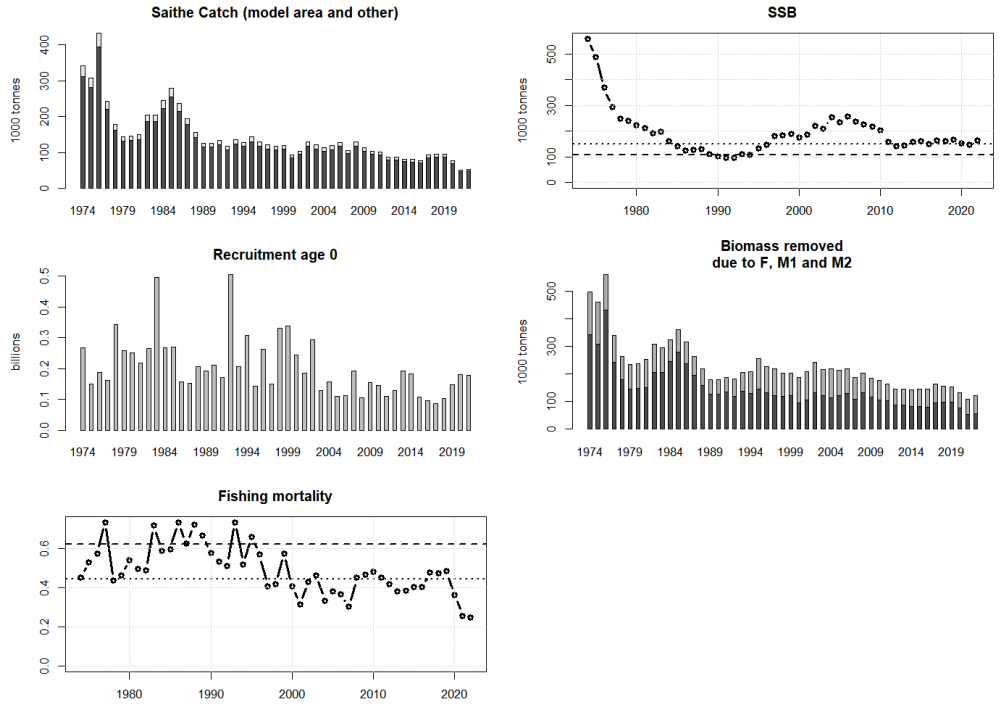

Figure 5.1-32. SMS output for saithe. Catch weight, Recruitment, F, SSB and Biomass removed due to fishery (F).

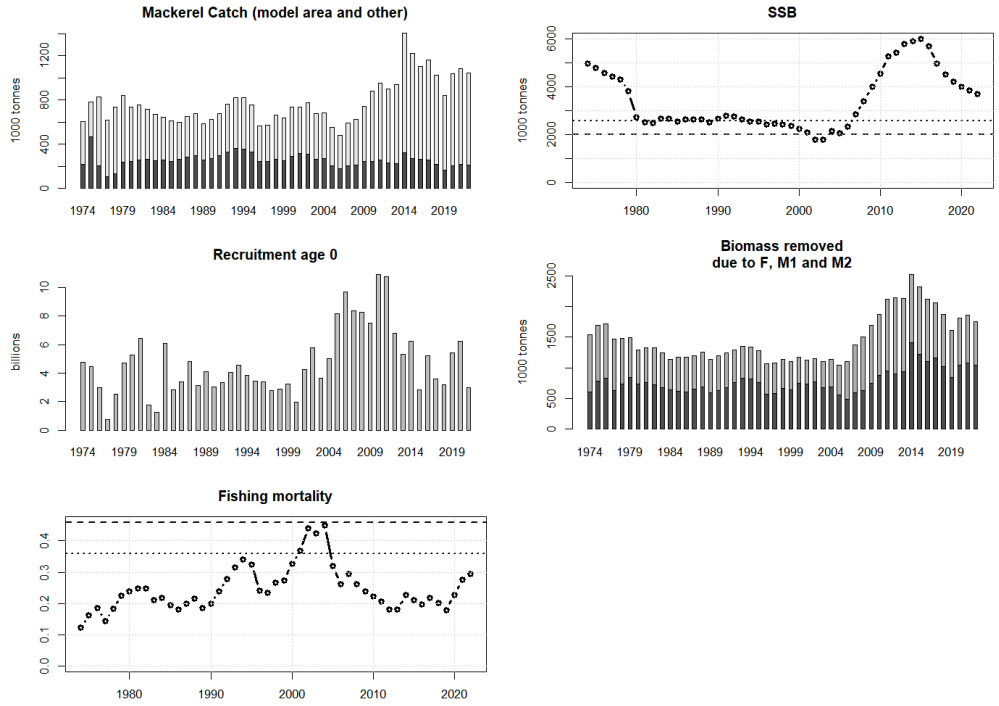

Figure 5.1-33. SMS output for Mackerel. Catch weight, Recruitment, F, SSB and Biomass removed due to fishery (F).

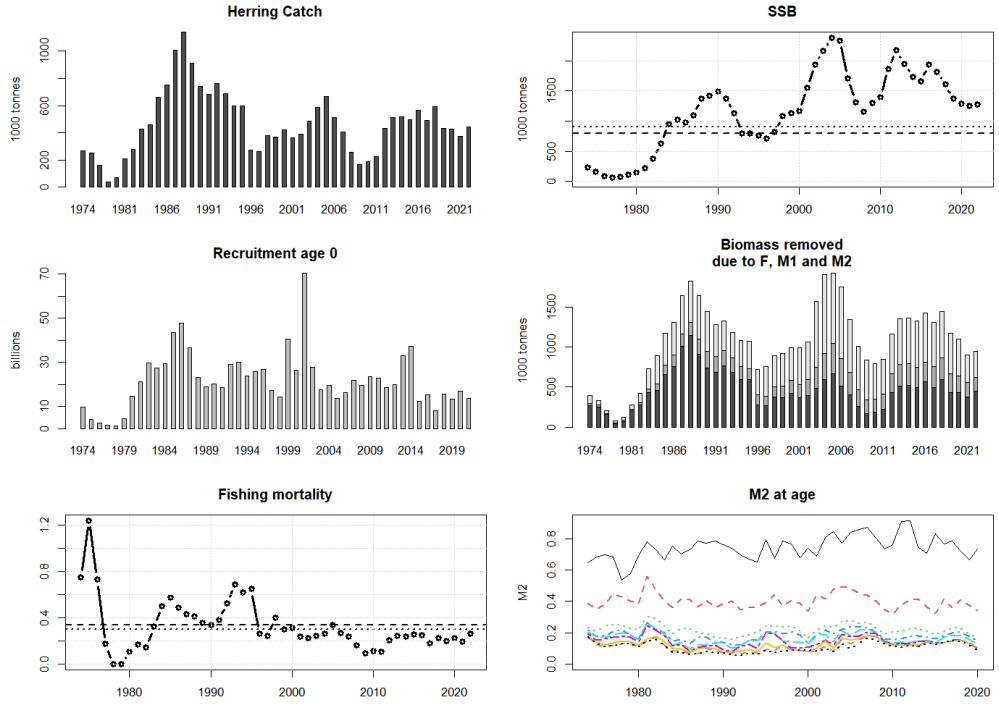

Figure 5.1-34. SMS output for Herring. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

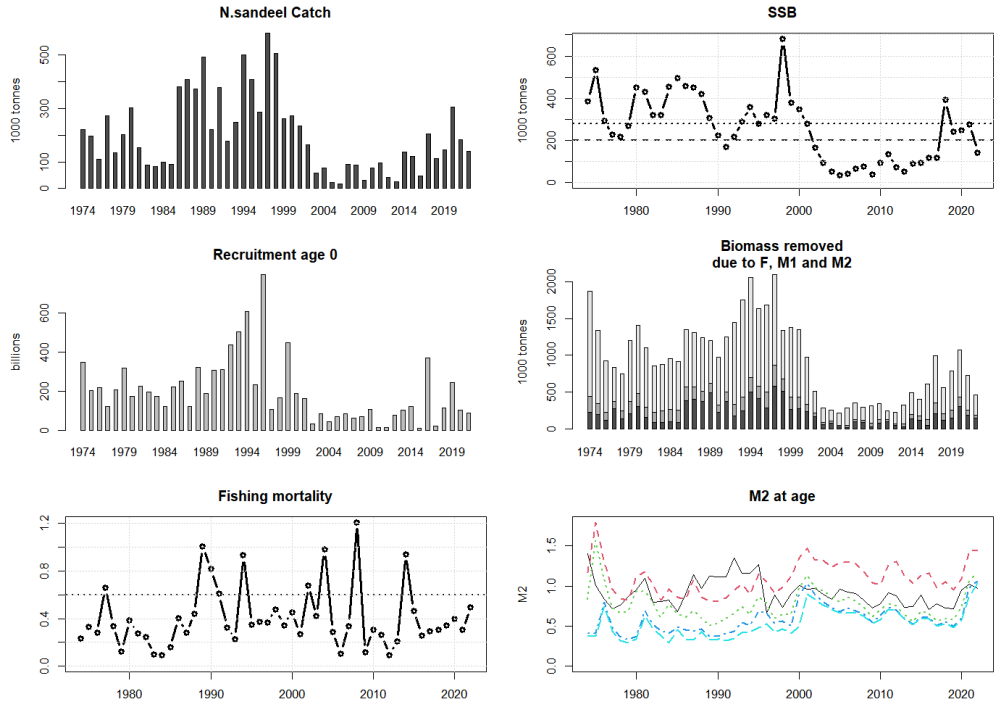

Figure 5.1-35. SMS output for Northern Sandeel. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

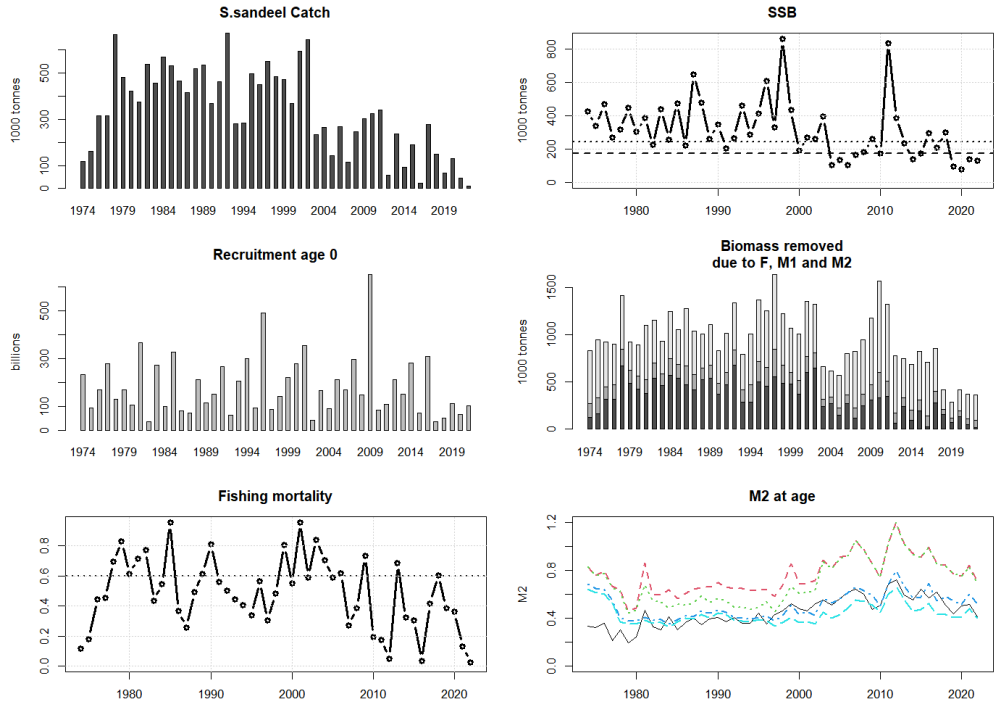

Figure 5.1-36. SMS output for Southern Sandeel. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

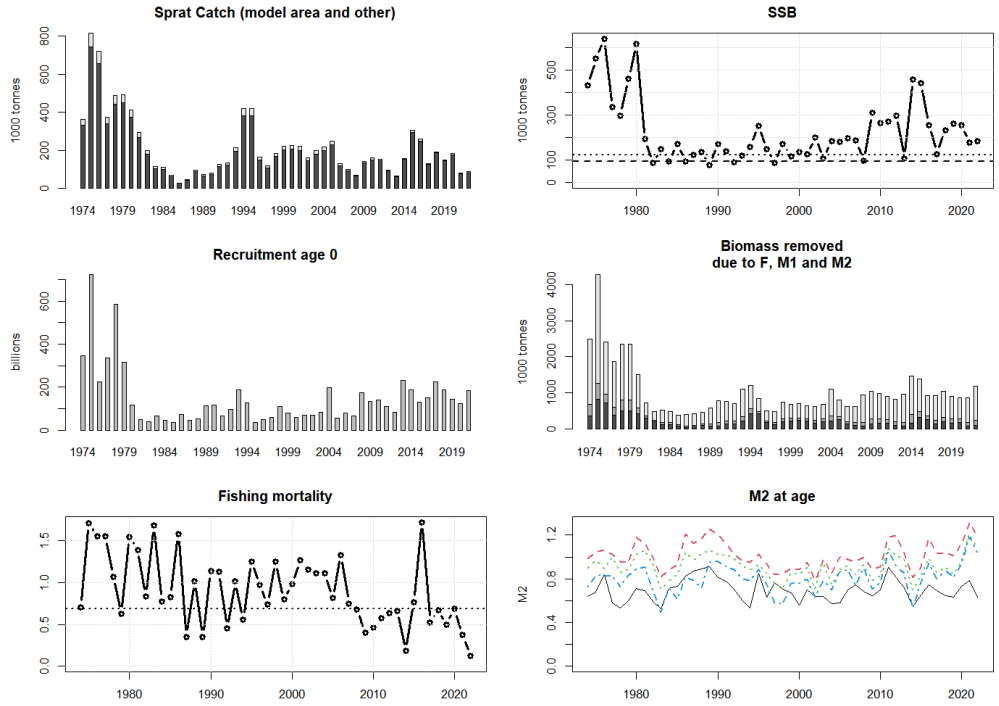

Figure 5.1-37. SMS output for Sprat. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

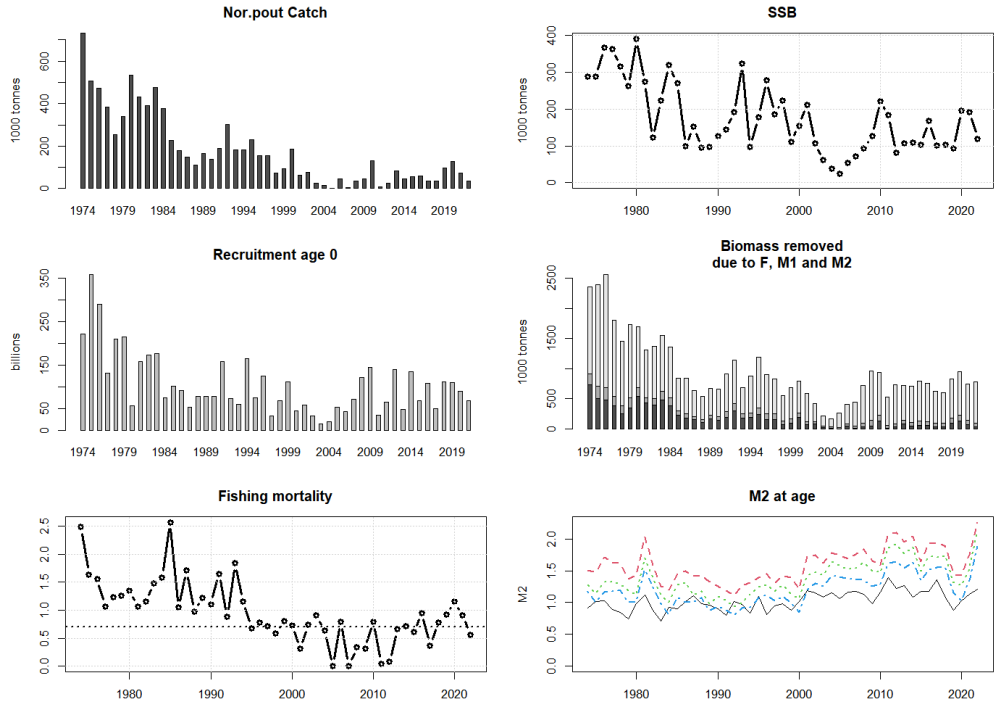

Figure 5.1-38. SMS output for Norway pout. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

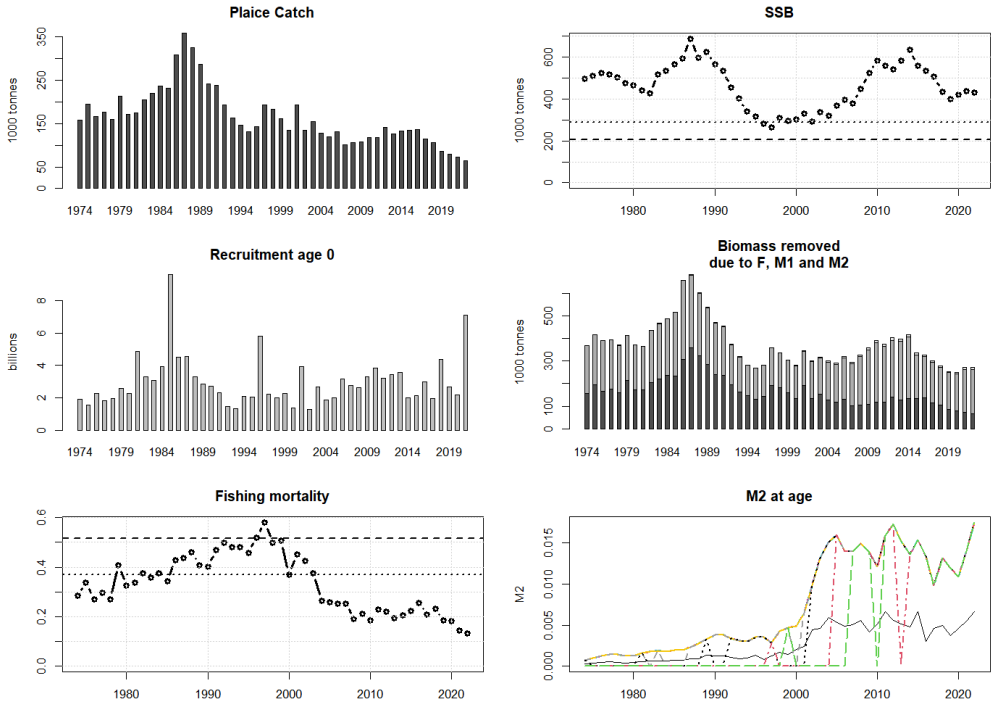

Figure 5.1-39. SMS output for Plaice. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

Who eats whom

Eaten biomass by predator

Biomass of eaten SMS prey species biomass decreased from more than 6 million tons in the mid-seventies to around 3.5 million tonnes in recent years (Figure 5.1-20).

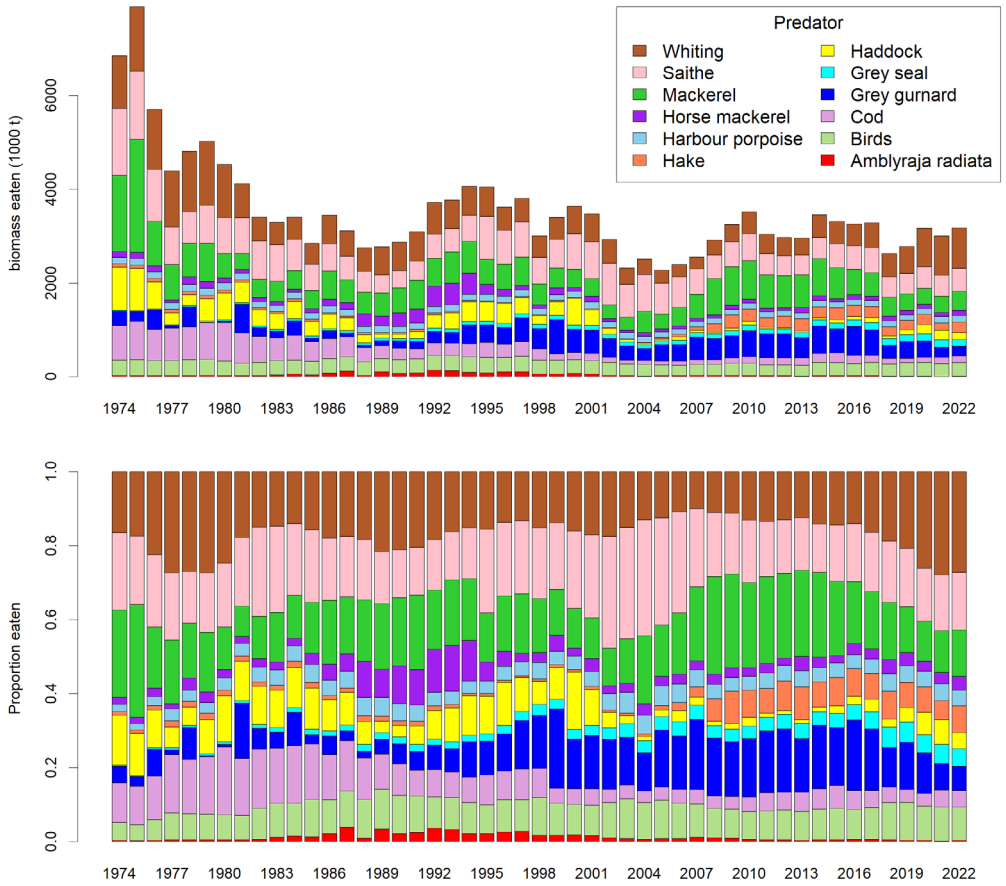

Figure 5.1-40. Eaten total biomass of all prey species by individual predator (groups). Upper figure shows the absolute weight eaten and the lower figure shows the relative weight eaten.

Eaten biomass by prey

The eaten biomass of the individual SMS prey species (Figure 5.1-21) follows in general the prey stock sizes.

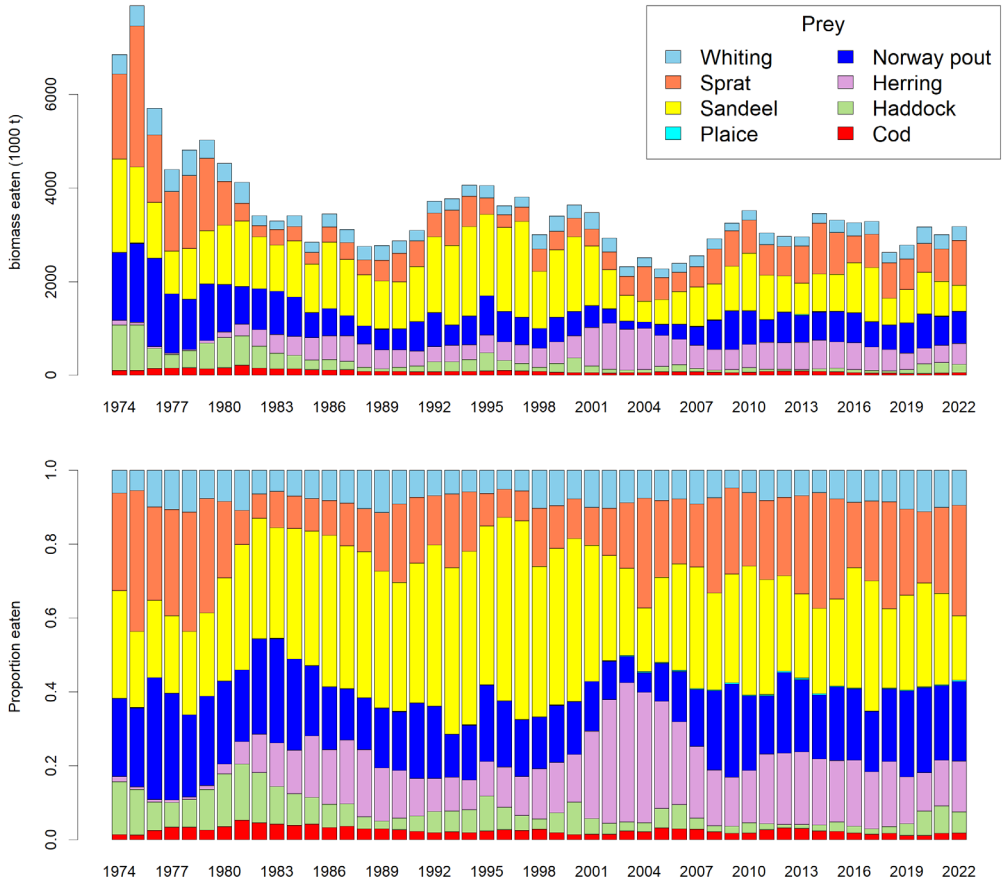

Figure 5.1-41. Eaten biomass of the individual prey species. Upper figure shows the absolute weight eaten and the lower figure shows relative weight eaten.

Eaten biomass by individual prey species

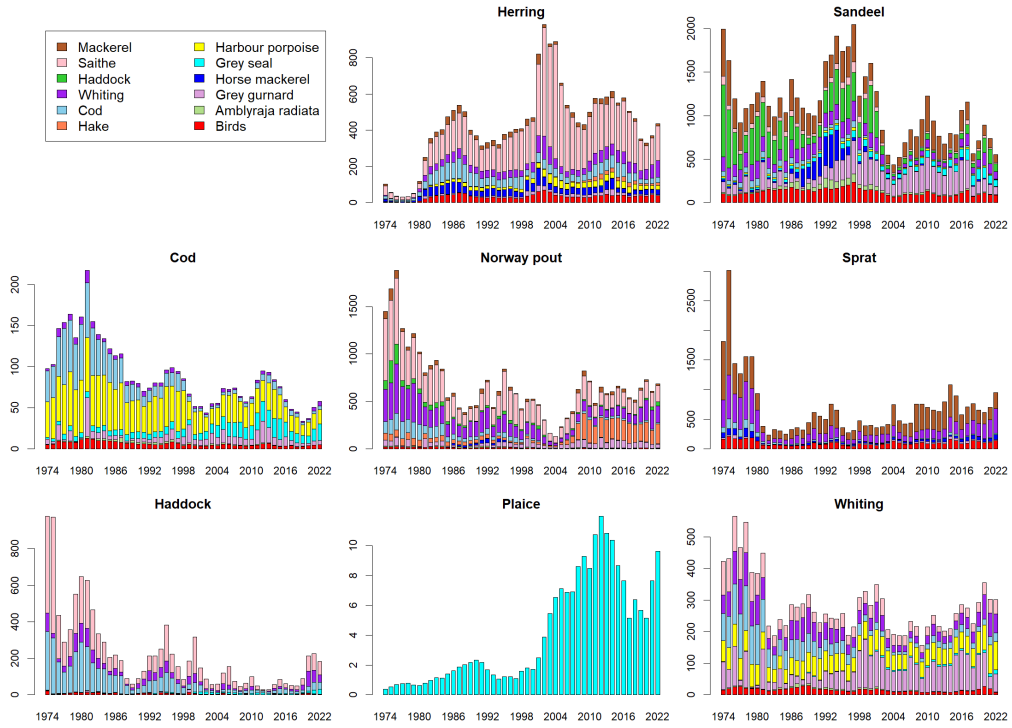

Figure 5.1-42. Eaten biomass (1000 tonnes) of the individual prey species by predator (groups).

Predation mortalities (M2)

The overall picture of M2 at-age (sum of quarterly M2 values) is highly variable between species (Figure 5.1-23 to Figure 5.1-30). For cod and whiting, the steep increase in abundance of the predator grey gurnard has led to an increase in M2 of 0-group fish in recent years. Further, the mortality of 2 and 3-years old cod has increased substantially as a result of the recent increase in grey seal abundance. Haddock natural mortality particularly of age 2 fish decreased over time until around year 2000, with the decrease in the biomass of large cod and saithe. This is followed by an increase in MS mainly due to the increasing grey seal and saithe populations. Herring M2 has been variable over the years but with no clear temporal trend

The two sandeel stocks show markedly different patterns in the main predators, with cod, mackerel, whiting, saithe, seabirds and in later years, grey seals all exerting a significant impact on northern sandeel whereas grey gurnards, mackerel, whiting and seabirds are the main predators on southern sandeel. Natural mortality of Norway pout increased slightly in the late 1990s due to the increasing abundance of hake. The M2 of sprat is fairly stable over the years, despite large changes abundance of the main predator species mackerel and whiting.

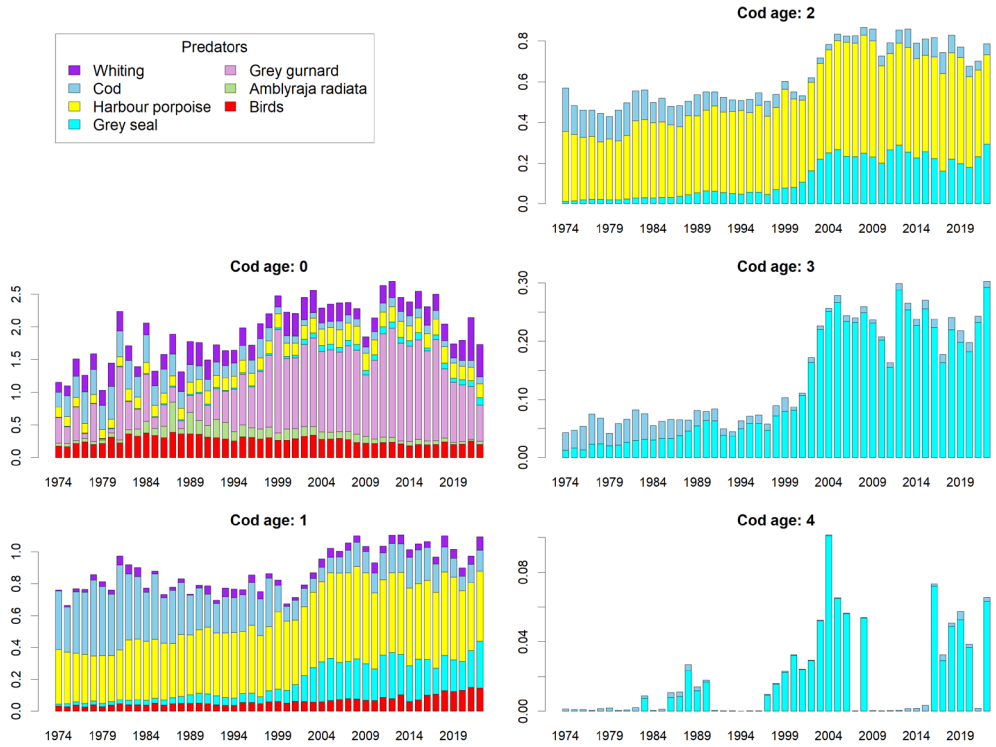

Figure 5.1-43. Predation mortality (M2) by prey species and age inflicted by predator species.

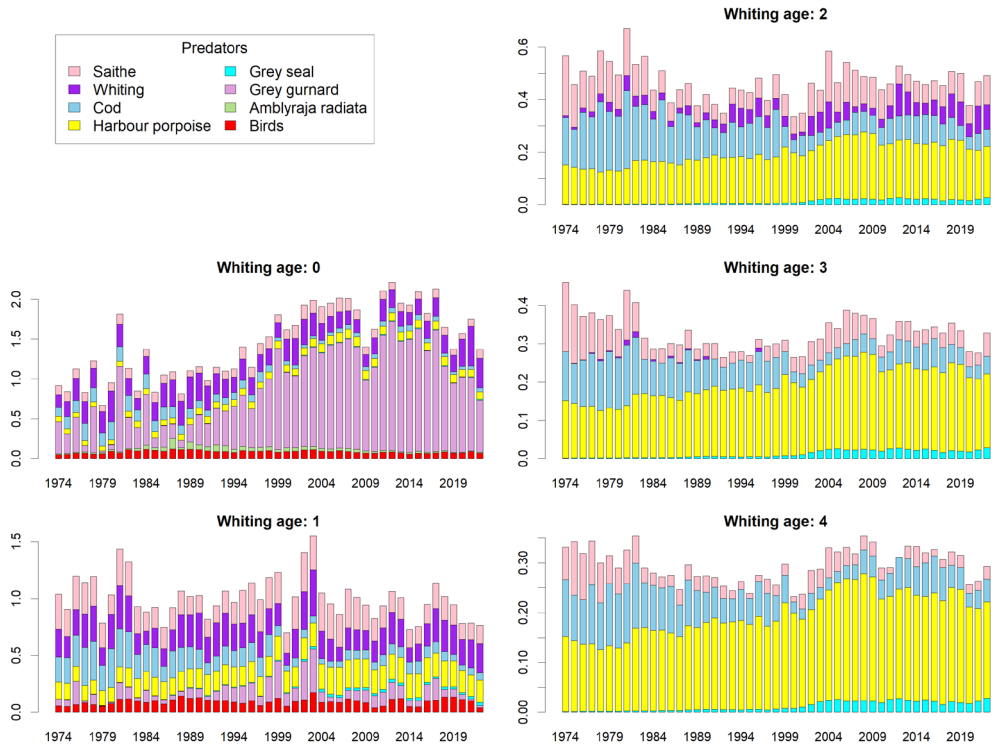

Figure 5.1-44. Predation mortality (M2) by prey species and age inflicted by predator species.

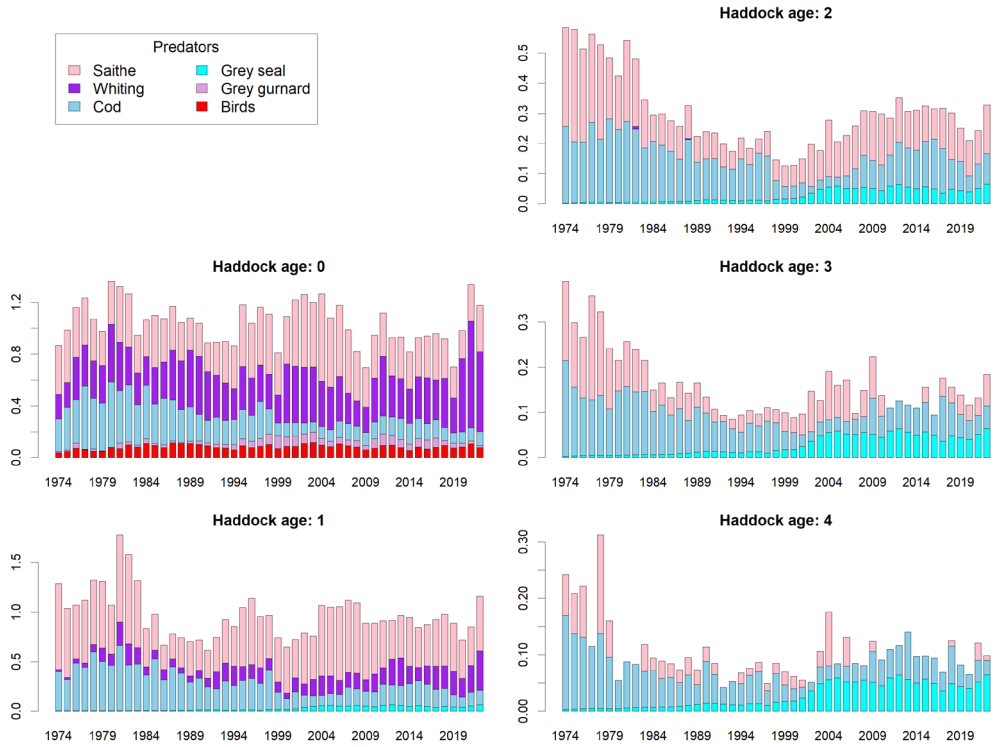

Figure 5.1-45. Predation mortality (M2) by prey species and age inflicted by predator species.

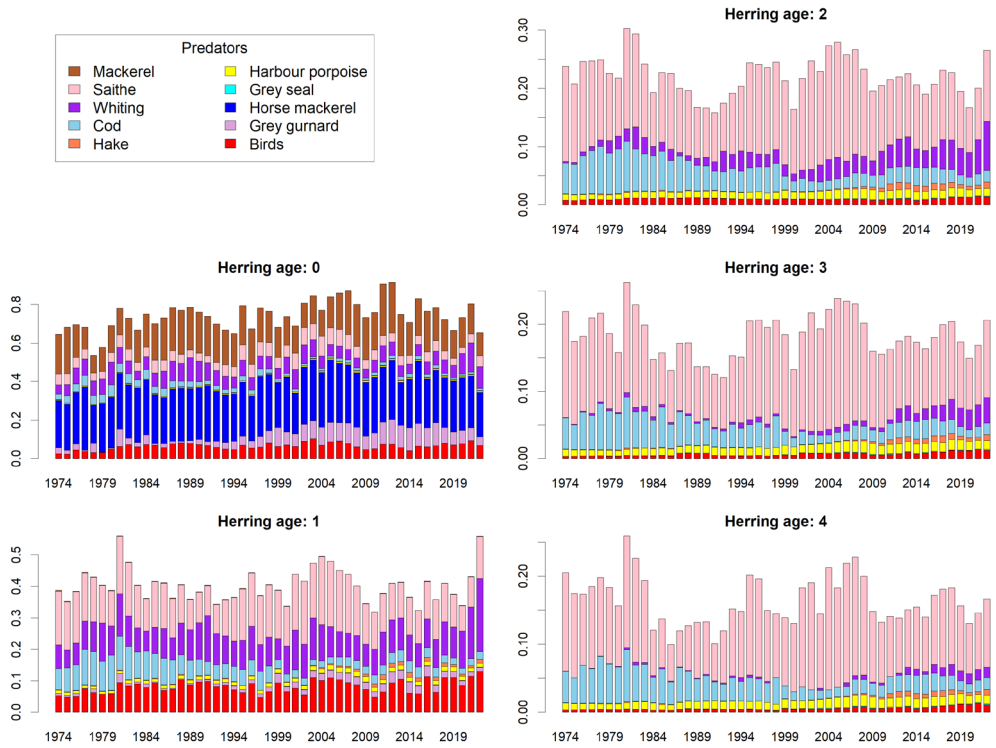

Figure 5.1-46.Predation mortality (M2) by prey species and age inflicted by predator species.

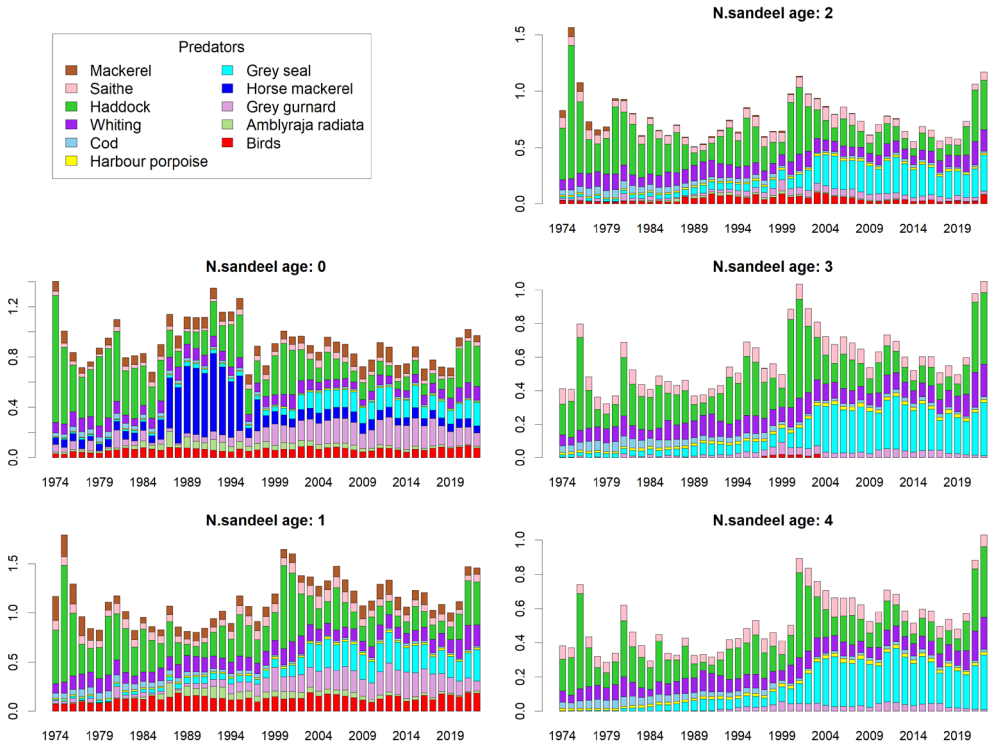

Figure 5.1-47. Predation mortality (M2) by prey species and age inflicted by predator species.

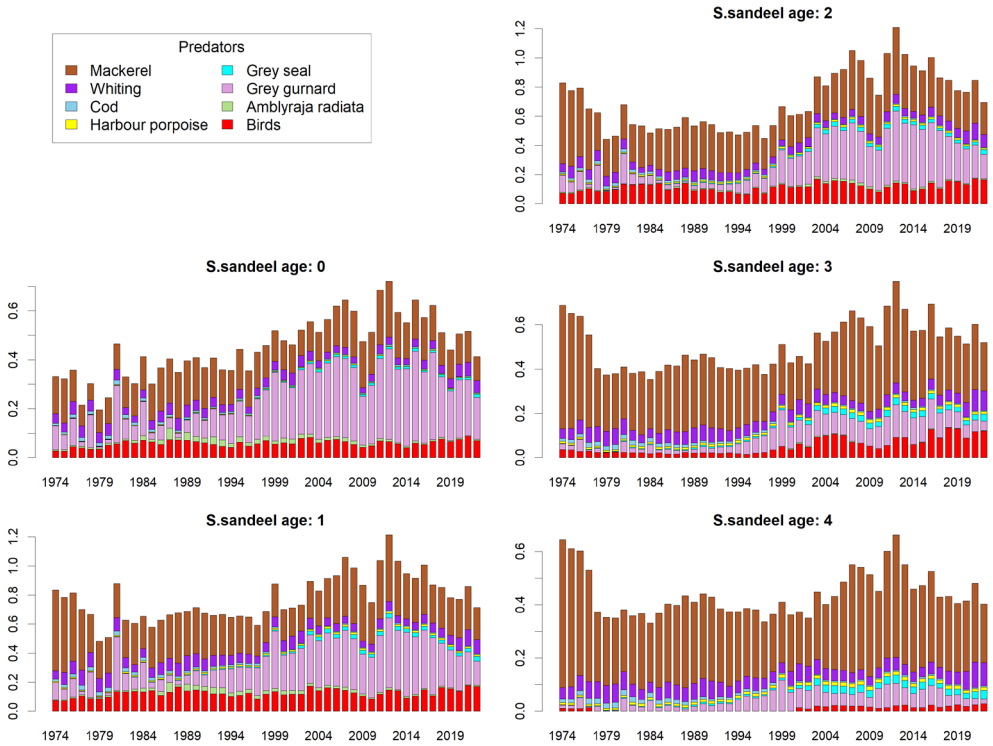

Figure 5.1-48. Predation mortality (M2) by prey species and age inflicted by predator species.

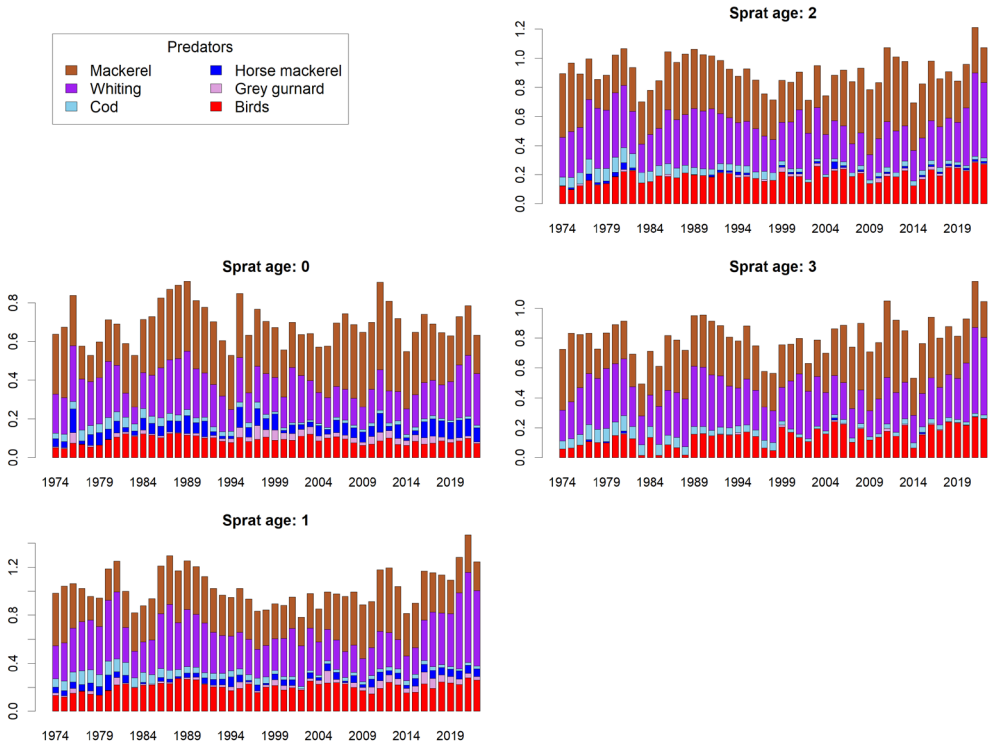

Figure 5.1-49. Predation mortality (M2) by prey species and age inflicted by predator species.

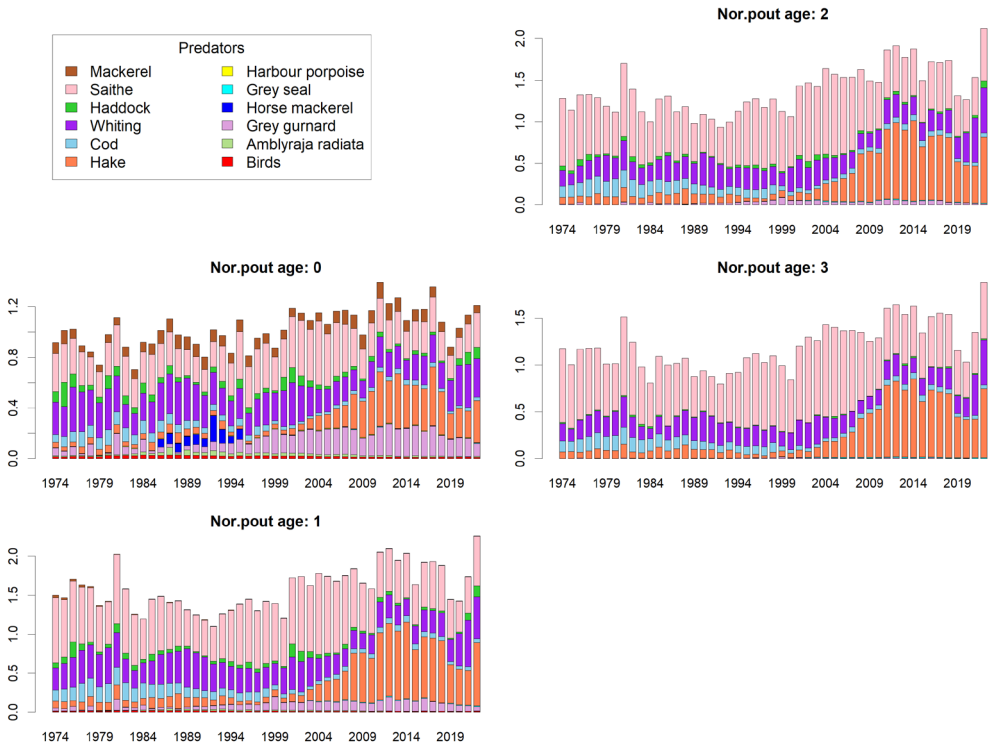

Figure 5.1-50. Predation mortality (M2) by prey species and age inflicted by predator species.

Natural mortalities (M1+M2)

This section tables the sum of estimated predation mortalities (M2) and the residual natural mortality (M1) given as input to SMS. Natural mortalities (M=M1+M2) estimated by SMS are used as input to the ICES stock assessment. If M values are used, WGSAM does not recommend updating existing (old) data series of natural mortality by simply adding M values for the latest three years.

Table 5-14. Natural mortalities (sum of quarterly M1+M2) as estimated by SMS.

Cod : Natural mortality (sum of quarterly M1+M2)

Year/Age	0	1	2	3	4	5	6	7	8	9	10
1974	1.252	0.961	0.768	0.243	0.201	0.200	0.200	0.200	0.200	0.200	0.200
1975	1.198	0.865	0.683	0.247	0.201	0.200	0.200	0.200	0.200	0.200	0.200
1976	1.610	0.968	0.661	0.254	0.201	0.200	0.200	0.200	0.200	0.200	0.200
1977	1.361	0.964	0.661	0.275	0.201	0.200	0.200	0.200	0.200	0.200	0.200
1978	1.686	1.058	0.645	0.268	0.202	0.200	0.200	0.200	0.200	0.200	0.200
1979	1.132	1.013	0.628	0.242	0.202	0.200	0.200	0.200	0.200	0.200	0.200
1980	1.549	0.961	0.661	0.258	0.201	0.200	0.200	0.200	0.200	0.200	0.200
1981	2.339	1.172	0.696	0.266	0.201	0.200	0.200	0.200	0.200	0.200	0.200
1982	1.816	1.120	0.755	0.282	0.202	0.200	0.200	0.200	0.200	0.200	0.200
1983	1.491	1.102	0.758	0.275	0.209	0.200	0.200	0.200	0.200	0.200	0.200
1984	2.156	0.972	0.699	0.255	0.201	0.200	0.200	0.200	0.200	0.200	0.200
1985	1.427	1.080	0.718	0.262	0.201	0.200	0.200	0.200	0.200	0.200	0.200
1986	1.677	0.933	0.680	0.266	0.211	0.200	0.200	0.200	0.200	0.200	0.200
1987	1.988	0.978	0.683	0.265	0.211	0.200	0.200	0.200	0.200	0.200	0.200
1988	1.414	1.031	0.704	0.265	0.227	0.200	0.200	0.200	0.200	0.200	0.200
1989	1.875	0.935	0.735	0.281	0.214	0.200	0.200	0.200	0.200	0.200	0.200
1990	1.865	0.990	0.749	0.279	0.218	0.200	0.200	0.200	0.200	0.200	0.200
1991	1.597	0.986	0.749	0.283	0.201	0.200	0.200	0.200	0.200	0.200	0.200
1992	1.826	0.897	0.723	0.250	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1993	1.738	0.972	0.711	0.245	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1994	1.739	0.967	0.707	0.263	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1995	2.084	0.963	0.715	0.271	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1996	1.822	1.055	0.745	0.273	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1997	2.146	0.950	0.705	0.258	0.210	0.200	0.200	0.200	0.200	0.200	0.200
1998	2.303	1.064	0.738	0.289	0.216	0.200	0.200	0.200	0.200	0.200	0.200
1999	2.576	1.023	0.802	0.303	0.223	0.200	0.200	0.200	0.200	0.200	0.200
2000	2.329	0.875	0.750	0.287	0.233	0.200	0.200	0.200	0.200	0.200	0.200
2001	2.311	0.915	0.732	0.310	0.224	0.200	0.200	0.200	0.200	0.200	0.200
2002	2.551	0.993	0.820	0.372	0.229	0.200	0.200	0.200	0.200	0.200	0.200
2003	2.659	1.070	0.915	0.426	0.252	0.200	0.200	0.200	0.200	0.200	0.200
2004	2.393	1.155	0.983	0.457	0.302	0.200	0.200	0.200	0.200	0.200	0.200

2005	2.448	1.222	1.034	0.479	0.265	0.200	0.200	0.200	0.200	0.200	0.200
2006	2.467	1.205	1.023	0.444	0.256	0.200	0.200	0.200	0.200	0.200	0.200
2007	2.474	1.256	1.025	0.440	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2008	2.382	1.301	1.066	0.459	0.254	0.200	0.200	0.200	0.200	0.200	0.200
2009	1.951	1.234	1.058	0.437	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2010	2.239	1.132	0.925	0.407	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2011	2.735	1.238	0.991	0.516	0.353	0.353	0.353	0.353	0.353	0.353	0.353
2012	2.801	1.305	1.054	0.652	0.353	0.353	0.353	0.353	0.353	0.353	0.353
2013	2.550	1.307	1.057	0.618	0.354	0.353	0.353	0.353	0.353	0.353	0.353
2014	2.485	1.215	0.989	0.591	0.355	0.354	0.353	0.353	0.353	0.353	0.353
2015	2.644	1.250	1.009	0.623	0.356	0.355	0.354	0.353	0.353	0.353	0.353
2016	2.409	1.264	1.015	0.591	0.426	0.353	0.353	0.353	0.353	0.353	0.353
2017	2.600	1.167	0.944	0.530	0.385	0.354	0.353	0.353	0.353	0.353	0.353
2018	2.146	1.300	1.028	0.594	0.404	0.353	0.353	0.353	0.353	0.353	0.353
2019	1.841	1.218	0.971	0.571	0.410	0.353	0.353	0.353	0.353	0.353	0.353
2020	1.894	1.099	0.876	0.551	0.391	0.353	0.353	0.353	0.353	0.353	0.353
2021	2.247	1.174	0.900	0.596	0.355	0.353	0.353	0.353	0.353	0.353	0.353
2022	1.832	1.293	0.986	0.656	0.418	0.353	0.353	0.353	0.353	0.353	0.353

Whiting : Natural mortality (sum of quarterly M1+M2)

Year/Age	0	1	2	3	4	5	6
1974	1.017	1.239	0.768	0.661	0.532	0.491	0.319
1975	0.940	1.108	0.658	0.602	0.542	0.462	0.270
1976	1.229	1.396	0.708	0.573	0.519	0.445	0.268
1977	0.930	1.341	0.690	0.581	0.544	0.475	0.258
1978	1.326	1.396	0.786	0.564	0.500	0.458	0.262
1979	0.770	0.985	0.745	0.574	0.514	0.500	0.297
1980	1.052	1.233	0.695	0.538	0.490	0.468	0.285
1981	1.915	1.636	0.871	0.640	0.526	0.507	0.289
1982	1.235	1.522	0.734	0.608	0.554	0.519	0.280
1983	0.948	1.130	0.766	0.515	0.489	0.474	0.283
1984	1.474	1.081	0.637	0.487	0.480	0.456	0.270
1985	0.933	1.125	0.711	0.488	0.472	0.456	0.273
1986	1.151	0.947	0.588	0.501	0.475	0.446	0.251
1987	1.193	1.121	0.638	0.497	0.446	0.431	0.256
1988	0.915	1.265	0.662	0.536	0.496	0.468	0.242
1989	1.205	1.218	0.578	0.487	0.472	0.452	0.434
1990	1.257	1.226	0.620	0.501	0.474	0.458	0.257
1991	1.080	1.017	0.583	0.501	0.471	0.471	0.450
1992	1.248	1.138	0.550	0.464	0.454	0.444	0.427
1993	1.201	1.265	0.644	0.479	0.444	0.438	0.427

1994	1.227	1.168	0.636	0.480	0.462	0.444	0.444
1995	1.501	1.272	0.627	0.469	0.439	0.435	0.377
1996	1.249	1.338	0.682	0.512	0.475	0.455	0.399
1997	1.547	1.191	0.598	0.494	0.468	0.454	0.436
1998	1.628	1.386	0.696	0.500	0.455	0.437	0.422
1999	1.910	1.431	0.619	0.510	0.497	0.474	0.458
2000	1.717	0.901	0.535	0.465	0.433	0.433	0.430
2001	1.772	1.216	0.550	0.467	0.437	0.427	0.414
2002	2.028	1.605	0.663	0.506	0.484	0.455	0.437
2003	2.086	1.752	0.635	0.513	0.487	0.462	0.443
2004	2.006	1.248	0.785	0.555	0.530	0.526	0.503
2005	2.053	1.154	0.666	0.540	0.522	0.502	0.500
2006	2.116	1.059	0.741	0.588	0.531	0.531	0.516
2007	2.111	1.283	0.712	0.580	0.518	0.518	0.514
2008	1.966	1.210	0.689	0.574	0.554	0.516	0.516
2009	1.501	1.143	0.686	0.566	0.542	0.533	0.513
2010	1.725	1.026	0.638	0.495	0.489	0.461	0.461
2011	2.207	1.137	0.661	0.523	0.490	0.479	0.479
2012	2.316	1.263	0.729	0.558	0.511	0.500	0.500
2013	2.050	1.206	0.695	0.558	0.534	0.447	0.395
2014	2.026	0.928	0.671	0.533	0.533	0.508	0.403
2015	2.195	0.955	0.659	0.537	0.520	0.508	0.448
2016	1.925	1.149	0.673	0.544	0.526	0.516	0.272
2017	2.231	1.336	0.654	0.529	0.507	0.501	0.325
2018	1.747	1.220	0.707	0.554	0.522	0.513	0.258
2019	1.476	1.146	0.701	0.534	0.514	0.500	0.442
2020	1.671	0.982	0.579	0.480	0.457	0.449	0.355
2021	1.851	0.984	0.669	0.476	0.463	0.452	0.405
2022	1.472	0.964	0.692	0.528	0.493	0.423	0.323

Haddock : Natural mortality (sum of quarterly M1+M2)

Year/Age	0	1	2	3	4	5	6	7	8	9	10
1974	0.968	1.486	0.785	0.591	0.442	0.258	0.259	0.258	0.220	0.208	0.202
1975	1.086	1.240	0.778	0.499	0.408	0.309	0.241	0.241	0.241	0.208	0.200
1976	1.262	1.272	0.714	0.466	0.422	0.333	0.272	0.204	0.205	0.231	0.200
1977	1.334	1.319	0.762	0.558	0.315	0.315	0.279	0.244	0.203	0.202	0.215
1978	1.172	1.526	0.727	0.523	0.513	0.265	0.265	0.248	0.217	0.200	0.215
1979	1.075	1.512	0.683	0.442	0.360	0.277	0.244	0.214	0.214	0.212	0.205
1980	1.465	1.272	0.625	0.415	0.254	0.231	0.237	0.230	0.206	0.206	0.202
1981	1.424	1.980	0.742	0.457	0.288	0.240	0.225	0.225	0.205	0.203	0.203
1982	1.366	1.782	0.680	0.440	0.283	0.239	0.211	0.206	0.210	0.200	0.200

1983	1.046	1.519	0.544	0.416	0.318	0.250	0.225	0.229	0.204	0.207	0.203
1984	1.166	1.035	0.495	0.349	0.295	0.272	0.227	0.221	0.202	0.200	0.202
1985	1.202	1.175	0.498	0.365	0.289	0.258	0.245	0.213	0.206	0.201	0.201
1986	1.175	0.867	0.475	0.333	0.284	0.240	0.214	0.222	0.205	0.211	0.200
1987	1.270	0.980	0.457	0.367	0.273	0.225	0.209	0.209	0.209	0.209	0.201
1988	1.145	0.942	0.525	0.343	0.295	0.264	0.210	0.208	0.210	0.220	0.201
1989	1.180	0.901	0.424	0.365	0.273	0.242	0.230	0.208	0.204	0.204	0.220
1990	1.139	0.920	0.439	0.334	0.314	0.266	0.220	0.211	0.205	0.201	0.201
1991	0.987	0.815	0.435	0.307	0.285	0.258	0.227	0.219	0.206	0.201	0.200
1992	0.993	0.946	0.399	0.294	0.242	0.227	0.230	0.207	0.202	0.200	0.200
1993	0.998	1.125	0.374	0.285	0.253	0.240	0.213	0.213	0.202	0.204	0.201
1994	0.967	1.056	0.418	0.294	0.268	0.230	0.205	0.205	0.205	0.201	0.200
1995	1.283	1.247	0.384	0.304	0.276	0.233	0.214	0.204	0.209	0.205	0.200
1996	1.138	1.338	0.415	0.296	0.287	0.244	0.244	0.244	0.201	0.202	0.200
1997	1.262	1.155	0.441	0.310	0.250	0.250	0.223	0.213	0.203	0.200	0.200
1998	1.208	1.165	0.346	0.306	0.285	0.246	0.235	0.211	0.205	0.205	0.200
1999	0.909	0.944	0.326	0.299	0.270	0.263	0.240	0.233	0.233	0.202	0.200
2000	1.193	0.848	0.328	0.289	0.262	0.230	0.228	0.207	0.210	0.201	0.200
2001	1.320	0.924	0.350	0.296	0.255	0.239	0.239	0.215	0.200	0.202	0.200
2002	1.361	0.989	0.398	0.347	0.251	0.246	0.244	0.245	0.202	0.200	0.200
2003	1.300	0.958	0.377	0.327	0.306	0.259	0.257	0.203	0.201	0.201	0.200
2004	1.366	1.270	0.478	0.391	0.376	0.369	0.270	0.228	0.202	0.200	0.200
2005	1.179	1.251	0.406	0.360	0.285	0.285	0.281	0.238	0.203	0.202	0.200
2006	1.278	1.257	0.427	0.372	0.331	0.276	0.274	0.274	0.206	0.201	0.200
2007	1.089	1.319	0.459	0.298	0.285	0.280	0.267	0.267	0.267	0.245	0.201
2008	0.919	1.295	0.509	0.349	0.281	0.273	0.273	0.270	0.247	0.268	0.200
2009	0.797	1.086	0.507	0.424	0.324	0.269	0.269	0.269	0.208	0.207	0.224
2010	1.048	1.088	0.498	0.338	0.291	0.291	0.272	0.243	0.204	0.203	0.202
2011	1.219	1.111	0.484	0.310	0.310	0.310	0.310	0.286	0.218	0.243	0.201
2012	1.028	1.114	0.552	0.326	0.317	0.293	0.293	0.303	0.213	0.285	0.201
2013	1.033	1.166	0.507	0.317	0.341	0.293	0.283	0.287	0.293	0.216	0.202
2014	0.917	1.149	0.511	0.309	0.297	0.330	0.282	0.282	0.242	0.282	0.202
2015	1.028	1.046	0.524	0.356	0.298	0.298	0.308	0.298	0.230	0.298	0.298
2016	1.039	1.073	0.516	0.294	0.294	0.262	0.223	0.294	0.283	0.212	0.207
2017	1.059	1.124	0.517	0.376	0.269	0.229	0.204	0.214	0.214	0.288	0.203
2018	1.020	1.177	0.502	0.356	0.325	0.225	0.214	0.209	0.203	0.265	0.203
2019	0.803	1.088	0.451	0.339	0.282	0.282	0.220	0.237	0.205	0.205	0.205
2020	1.082	0.922	0.410	0.317	0.265	0.258	0.265	0.204	0.200	0.200	0.200
2021	1.439	1.053	0.443	0.332	0.321	0.288	0.274	0.281	0.213	0.208	0.203
2022	1.277	1.362	0.528	0.385	0.299	0.291	0.283	0.283	0.283	0.378	0.200

Herring : Natural mortality (sum of quarterly M1+M2)

Year/Age	0	1	2	3	4	5	6	7	8
1974	0.695	0.487	0.338	0.319	0.305	0.294	0.281	0.275	0.275
1975	0.732	0.453	0.308	0.275	0.274	0.255	0.237	0.226	0.230
1976	0.745	0.484	0.346	0.282	0.273	0.262	0.225	0.213	0.213
1977	0.731	0.544	0.347	0.310	0.285	0.272	0.235	0.222	0.215
1978	0.584	0.531	0.349	0.317	0.298	0.280	0.247	0.229	0.228
1979	0.627	0.503	0.326	0.286	0.283	0.274	0.244	0.237	0.231
1980	0.740	0.487	0.318	0.258	0.257	0.239	0.219	0.211	0.211
1981	0.830	0.661	0.403	0.363	0.359	0.344	0.263	0.252	0.250
1982	0.779	0.577	0.393	0.329	0.326	0.318	0.277	0.270	0.259
1983	0.716	0.503	0.342	0.299	0.294	0.282	0.243	0.221	0.221
1984	0.801	0.462	0.293	0.248	0.221	0.215	0.199	0.189	0.174
1985	0.750	0.517	0.327	0.258	0.237	0.229	0.196	0.182	0.175
1986	0.780	0.512	0.326	0.231	0.199	0.181	0.176	0.166	0.162
1987	0.834	0.463	0.300	0.272	0.220	0.206	0.197	0.167	0.163
1988	0.820	0.505	0.296	0.272	0.227	0.214	0.206	0.202	0.178
1989	0.835	0.459	0.268	0.237	0.232	0.219	0.196	0.187	0.169
1990	0.810	0.482	0.267	0.237	0.233	0.194	0.179	0.176	0.168
1991	0.789	0.503	0.259	0.226	0.201	0.179	0.174	0.168	0.155
1992	0.748	0.444	0.275	0.221	0.220	0.214	0.184	0.168	0.156
1993	0.718	0.458	0.292	0.253	0.252	0.225	0.193	0.177	0.169
1994	0.699	0.465	0.304	0.251	0.248	0.201	0.180	0.170	0.165
1995	0.844	0.493	0.344	0.305	0.302	0.299	0.232	0.191	0.187
1996	0.724	0.544	0.341	0.306	0.296	0.296	0.205	0.187	0.175
1997	0.832	0.471	0.336	0.296	0.249	0.247	0.223	0.215	0.185
1998	0.816	0.505	0.345	0.306	0.244	0.204	0.192	0.192	0.187
1999	0.731	0.488	0.313	0.284	0.239	0.201	0.190	0.189	0.189
2000	0.787	0.438	0.265	0.233	0.231	0.205	0.181	0.178	0.189
2001	0.737	0.539	0.317	0.288	0.283	0.225	0.200	0.189	0.184
2002	0.857	0.518	0.347	0.317	0.291	0.253	0.248	0.211	0.198
2003	0.895	0.574	0.329	0.293	0.245	0.220	0.204	0.183	0.178
2004	0.821	0.595	0.373	0.323	0.312	0.291	0.267	0.255	0.231
2005	0.890	0.580	0.379	0.339	0.283	0.274	0.252	0.228	0.199
2006	0.910	0.551	0.358	0.334	0.319	0.282	0.263	0.257	0.236
2007	0.922	0.539	0.367	0.330	0.328	0.302	0.287	0.275	0.265
2008	0.851	0.502	0.333	0.302	0.300	0.294	0.278	0.277	0.255
2009	0.783	0.446	0.296	0.260	0.248	0.243	0.238	0.238	0.232
2010	0.810	0.419	0.305	0.255	0.233	0.225	0.223	0.223	0.211
2011	0.958	0.478	0.315	0.263	0.241	0.233	0.220	0.216	0.209
2012	0.966	0.510	0.320	0.275	0.238	0.230	0.222	0.225	0.222
2013	0.799	0.515	0.325	0.282	0.251	0.244	0.221	0.210	0.213

2014	0.756	0.466	0.307	0.274	0.255	0.247	0.242	0.242	0.234
2015	0.879	0.424	0.290	0.264	0.240	0.236	0.228	0.228	0.224
2016	0.816	0.517	0.308	0.281	0.272	0.239	0.237	0.237	0.239
2017	0.834	0.458	0.332	0.299	0.281	0.254	0.247	0.247	0.248
2018	0.772	0.510	0.327	0.304	0.283	0.255	0.252	0.252	0.246
2019	0.715	0.475	0.295	0.274	0.256	0.234	0.228	0.228	0.218
2020	0.782	0.440	0.267	0.249	0.231	0.208	0.207	0.201	0.189
2021	0.853	0.531	0.301	0.269	0.246	0.229	0.218	0.214	0.204
2022	0.704	0.659	0.366	0.306	0.266	0.261	0.252	0.245	0.232

N.sandeel : Natural mortality (sum of quarterly M1+M2)

Year/Age	0	1	2	3	4
1974	1.503	1.370	1.029	0.611	0.582
1975	1.107	1.995	1.766	0.608	0.571
1976	0.935	1.493	1.279	0.999	0.940
1977	0.817	1.161	0.929	0.684	0.636
1978	0.862	1.042	0.858	0.563	0.520
1979	0.972	1.028	0.885	0.523	0.488
1980	1.050	1.311	1.135	0.570	0.540
1981	1.196	1.375	1.129	0.891	0.822
1982	0.894	1.217	1.006	0.726	0.664
1983	0.909	1.022	0.810	0.636	0.585
1984	0.928	1.155	0.966	0.609	0.494
1985	0.780	1.061	0.853	0.690	0.649
1986	0.999	1.030	0.809	0.655	0.539
1987	1.238	1.270	0.902	0.633	0.528
1988	1.069	1.058	0.794	0.661	0.629
1989	1.219	1.013	0.708	0.570	0.526
1990	1.213	1.004	0.733	0.576	0.532
1991	1.217	1.047	0.800	0.612	0.516
1992	1.448	1.144	0.857	0.631	0.544
1993	1.257	1.220	0.944	0.742	0.619
1994	1.260	1.094	0.839	0.707	0.627
1995	1.366	1.351	1.057	0.892	0.683
1996	0.762	1.246	0.984	0.859	0.730
1997	0.988	1.102	0.800	0.734	0.624
1998	0.831	1.184	0.845	0.761	0.659
1999	1.009	1.325	0.848	0.698	0.611
2000	1.107	1.550	1.177	1.088	0.702
2001	1.062	1.664	1.334	1.236	1.093
2002	1.065	1.524	1.178	1.091	1.036

2003	0.994	1.517	1.138	1.010	0.960
2004	0.937	1.430	1.066	0.925	0.906
2005	1.057	1.491	0.998	0.876	0.863
2006	1.019	1.495	1.062	0.922	0.861
2007	1.002	1.479	1.006	0.886	0.862
2008	0.924	1.374	0.932	0.849	0.822
2009	0.823	1.242	0.813	0.739	0.725
2010	0.877	1.218	0.905	0.832	0.780
2011	1.015	1.453	0.981	0.933	0.908
2012	0.979	1.507	0.956	0.895	0.884
2013	0.833	1.334	0.846	0.801	0.785
2014	0.846	1.233	0.755	0.722	0.715
2015	0.984	1.332	0.888	0.803	0.797
2016	0.807	1.363	0.857	0.803	0.785
2017	0.876	1.176	0.760	0.709	0.697
2018	0.822	1.253	0.792	0.750	0.737
2019	0.814	1.146	0.778	0.696	0.681
2020	1.052	1.282	0.933	0.797	0.770
2021	1.120	1.638	1.264	1.179	1.082
2022	1.072	1.648	1.371	1.255	1.231

S.sandeel : Natural mortality (sum of quarterly M1+M2)

Year/Age	0	1	2	3	4
1974	0.432	1.033	1.031	0.886	0.843
1975	0.421	0.959	0.955	0.851	0.811
1976	0.458	0.997	0.979	0.838	0.803
1977	0.315	0.869	0.854	0.754	0.729
1978	0.402	0.840	0.826	0.602	0.572
1979	0.294	0.660	0.645	0.574	0.552
1980	0.345	0.687	0.666	0.579	0.550
1981	0.566	1.061	0.882	0.609	0.581
1982	0.430	0.803	0.745	0.581	0.558
1983	0.402	0.793	0.736	0.589	0.566
1984	0.512	0.838	0.688	0.553	0.531
1985	0.401	0.765	0.716	0.590	0.568
1986	0.467	0.807	0.712	0.619	0.602
1987	0.503	0.844	0.727	0.614	0.597
1988	0.449	0.860	0.791	0.663	0.633
1989	0.495	0.863	0.735	0.641	0.610
1990	0.508	0.900	0.763	0.667	0.641
1991	0.469	0.863	0.745	0.651	0.629

1992	0.507	0.848	0.691	0.606	0.584
1993	0.459	0.852	0.693	0.602	0.574
1994	0.456	0.834	0.674	0.595	0.573
1995	0.542	0.843	0.692	0.604	0.586
1996	0.455	0.836	0.737	0.619	0.581
1997	0.530	0.784	0.652	0.577	0.536
1998	0.559	0.876	0.739	0.623	0.564
1999	0.619	1.057	0.868	0.712	0.610
2000	0.579	0.885	0.805	0.628	0.562
2001	0.561	0.895	0.815	0.657	0.573
2002	0.621	0.914	0.835	0.624	0.550
2003	0.655	1.083	1.073	0.763	0.648
2004	0.612	1.020	1.010	0.725	0.601
2005	0.663	1.107	1.097	0.767	0.631
2006	0.719	1.126	1.123	0.811	0.686
2007	0.744	1.250	1.246	0.863	0.750
2008	0.699	1.175	1.171	0.832	0.740
2009	0.575	1.057	1.055	0.791	0.713
2010	0.613	0.941	0.939	0.705	0.650
2011	0.784	1.226	1.223	0.884	0.801
2012	0.821	1.404	1.400	0.996	0.862
2013	0.694	1.224	1.220	0.870	0.750
2014	0.651	1.139	1.137	0.771	0.658
2015	0.744	1.109	1.107	0.774	0.671
2016	0.673	1.195	1.192	0.893	0.725
2017	0.722	1.056	1.052	0.745	0.629
2018	0.611	1.043	1.038	0.785	0.630
2019	0.540	0.972	0.968	0.748	0.604
2020	0.605	0.955	0.950	0.714	0.614
2021	0.615	1.043	1.034	0.802	0.680
2022	0.512	0.907	0.896	0.720	0.603

Nor.pout : Natural mortality (sum of quarterly M1+M2)

Year/Age	**0**	**1**	**2**	**3**
1974	1.016	1.701	1.481	1.375
1975	1.111	1.670	1.342	1.201
1976	1.123	1.910	1.522	1.368
1977	0.991	1.831	1.526	1.379
1978	0.941	1.812	1.491	1.383
1979	0.840	1.572	1.386	1.210
1980	1.078	1.626	1.319	1.213

1981	1.215	2.232	1.899	1.713
1982	0.981	1.783	1.591	1.444
1983	0.805	1.456	1.322	1.179
1984	1.019	1.398	1.198	1.008
1985	1.007	1.652	1.474	1.290
1986	1.111	1.691	1.510	1.200
1987	1.204	1.611	1.321	1.215
1988	1.077	1.634	1.381	1.270
1989	1.061	1.519	1.180	1.079
1990	1.004	1.451	1.291	1.137
1991	0.901	1.388	1.230	1.078
1992	1.116	1.303	1.136	0.995
1993	1.072	1.462	1.197	1.112
1994	0.933	1.513	1.330	1.120
1995	1.197	1.593	1.441	1.276
1996	0.911	1.653	1.479	1.320
1997	1.051	1.506	1.376	1.227
1998	1.087	1.623	1.473	1.298
1999	0.975	1.598	1.326	1.192
2000	1.113	1.410	1.262	1.042
2001	1.287	1.927	1.630	1.403
2002	1.250	1.942	1.668	1.497
2003	1.188	1.825	1.622	1.459
2004	1.251	1.984	1.839	1.630
2005	1.160	1.945	1.771	1.603
2006	1.265	1.884	1.732	1.565
2007	1.271	1.958	1.736	1.569
2008	1.235	2.042	1.829	1.547
2009	1.077	1.860	1.693	1.453
2010	1.268	1.784	1.675	1.491
2011	1.493	2.260	2.063	1.806
2012	1.323	2.303	2.112	1.844
2013	1.369	2.149	1.973	1.739
2014	1.189	2.242	2.075	1.829
2015	1.277	1.838	1.695	1.542
2016	1.279	2.125	1.918	1.719
2017	1.457	2.134	1.912	1.755
2018	1.178	2.085	1.934	1.741
2019	0.981	1.648	1.512	1.354
2020	1.128	1.630	1.467	1.232
2021	1.234	1.941	1.734	1.548
2022	1.309	2.464	2.321	2.084

Sprat : Natural mortality (sum of quarterly M1+M2)

Year/Age	0	1	2	3
1974	0.738	1.182	1.094	0.924
1975	0.775	1.241	1.167	1.031
1976	0.939	1.261	1.093	1.023
1977	0.678	1.224	1.194	1.031
1978	0.629	1.157	1.057	0.926
1979	0.700	1.143	1.084	1.033
1980	0.811	1.386	1.223	1.088
1981	0.790	1.318	1.266	1.111
1982	0.690	1.199	1.136	0.892
1983	0.628	1.019	0.901	0.693
1984	0.814	1.080	0.980	0.910
1985	0.830	1.139	1.047	0.812
1986	0.925	1.411	1.246	1.017
1987	0.971	1.322	1.172	0.987
1988	0.992	1.371	1.230	0.918
1989	1.013	1.453	1.261	1.151
1990	0.911	1.406	1.226	1.155
1991	0.878	1.323	1.217	1.112
1992	0.803	1.223	1.185	1.084
1993	0.706	1.166	1.125	1.006
1994	0.629	1.148	1.078	0.982
1995	0.948	1.221	1.128	1.081
1996	0.734	1.137	1.052	0.949
1997	0.868	1.035	0.956	0.777
1998	0.803	1.045	0.914	0.765
1999	0.773	1.096	1.050	0.956
2000	0.656	1.082	1.036	0.959
2001	0.798	1.151	1.107	0.999
2002	0.736	0.982	0.912	0.829
2003	0.741	1.179	1.150	0.987
2004	0.674	1.053	0.943	0.898
2005	0.678	1.194	1.085	1.062
2006	0.795	1.178	1.119	1.084
2007	0.845	1.156	1.040	0.941
2008	0.787	1.194	1.133	1.097
2009	0.748	1.087	0.985	0.906
2010	0.799	1.114	1.033	0.970
2011	1.007	1.378	1.274	1.248
2012	0.909	1.394	1.209	1.119

2013	0.821	1.239	1.178	1.049
2014	0.648	1.013	0.895	0.731
2015	0.749	1.102	1.026	0.964
2016	0.842	1.367	1.181	1.141
2017	0.790	1.227	1.059	1.001
2018	0.747	1.240	1.107	1.075
2019	0.730	1.210	1.044	1.013
2020	0.830	1.322	1.157	1.130
2021	0.886	1.519	1.411	1.381
2022	0.734	1.389	1.274	1.244

Plaice : Natural mortality (sum of quarterly M1+M2)

Year/Age	0	1	2	3	4	5	6	7	8	9	10
1974	0.248	0.496	0.394	0.344	0.312	0.292	0.279	0.268	0.261	0.252	0.246
1975	0.248	0.496	0.395	0.344	0.312	0.293	0.279	0.269	0.260	0.252	0.246
1976	0.248	0.496	0.395	0.344	0.312	0.293	0.279	0.269	0.260	0.252	0.246
1977	0.248	0.496	0.395	0.344	0.313	0.293	0.279	0.269	0.260	0.252	0.246
1978	0.248	0.496	0.395	0.344	0.313	0.293	0.279	0.269	0.260	0.252	0.246
1979	0.248	0.496	0.395	0.344	0.312	0.293	0.279	0.269	0.260	0.252	0.246
1980	0.248	0.496	0.395	0.344	0.312	0.293	0.279	0.269	0.260	0.252	0.246
1981	0.248	0.496	0.395	0.344	0.313	0.293	0.280	0.269	0.262	0.252	0.246
1982	0.248	0.497	0.395	0.345	0.313	0.293	0.280	0.268	0.260	0.252	0.246
1983	0.248	0.497	0.395	0.345	0.313	0.293	0.280	0.269	0.260	0.252	0.246
1984	0.248	0.497	0.395	0.345	0.313	0.293	0.280	0.268	0.260	0.252	0.246
1985	0.248	0.497	0.396	0.345	0.313	0.294	0.280	0.268	0.260	0.252	0.246
1986	0.248	0.497	0.396	0.345	0.313	0.294	0.280	0.268	0.260	0.252	0.246
1987	0.248	0.497	0.396	0.345	0.314	0.294	0.280	0.270	0.260	0.252	0.246
1988	0.248	0.498	0.396	0.346	0.314	0.294	0.281	0.270	0.260	0.252	0.246
1989	0.249	0.498	0.397	0.346	0.314	0.295	0.281	0.271	0.263	0.252	0.246
1990	0.249	0.499	0.397	0.347	0.315	0.295	0.282	0.271	0.260	0.252	0.246
1991	0.249	0.499	0.397	0.347	0.315	0.295	0.282	0.271	0.260	0.252	0.246
1992	0.248	0.498	0.397	0.346	0.315	0.295	0.281	0.271	0.263	0.252	0.246
1993	0.248	0.498	0.397	0.346	0.314	0.295	0.281	0.271	0.263	0.252	0.246
1994	0.248	0.498	0.397	0.346	0.314	0.295	0.281	0.271	0.263	0.252	0.246
1995	0.249	0.498	0.397	0.346	0.315	0.295	0.282	0.271	0.264	0.252	0.246
1996	0.248	0.498	0.397	0.346	0.315	0.295	0.282	0.271	0.264	0.252	0.246
1997	0.249	0.498	0.396	0.346	0.314	0.294	0.281	0.270	0.263	0.255	0.246
1998	0.249	0.499	0.398	0.347	0.315	0.296	0.282	0.272	0.260	0.252	0.246
1999	0.249	0.500	0.398	0.348	0.316	0.296	0.283	0.272	0.260	0.252	0.250
2000	0.249	0.500	0.398	0.348	0.316	0.296	0.283	0.268	0.260	0.252	0.246
2001	0.250	0.501	0.400	0.349	0.318	0.298	0.284	0.274	0.260	0.252	0.246

2002	0.252	0.505	0.403	0.353	0.321	0.301	0.288	0.277	0.270	0.252	0.246
2003	0.252	0.508	0.407	0.356	0.324	0.305	0.291	0.281	0.273	0.252	0.246
2004	0.253	0.510	0.409	0.358	0.326	0.307	0.293	0.283	0.275	0.252	0.246
2005	0.253	0.511	0.410	0.359	0.327	0.308	0.294	0.284	0.276	0.268	0.246
2006	0.252	0.509	0.408	0.357	0.325	0.306	0.292	0.282	0.274	0.266	0.246
2007	0.252	0.509	0.408	0.357	0.325	0.306	0.292	0.282	0.274	0.266	0.260
2008	0.253	0.510	0.409	0.358	0.326	0.307	0.293	0.283	0.275	0.267	0.261
2009	0.252	0.509	0.407	0.357	0.325	0.305	0.292	0.281	0.274	0.266	0.259
2010	0.253	0.507	0.406	0.355	0.323	0.304	0.290	0.280	0.272	0.265	0.246
2011	0.254	0.511	0.410	0.359	0.327	0.308	0.294	0.284	0.276	0.268	0.262
2012	0.253	0.512	0.411	0.360	0.329	0.309	0.295	0.285	0.277	0.270	0.263
2013	0.253	0.510	0.409	0.358	0.326	0.307	0.293	0.283	0.275	0.252	0.261
2014	0.252	0.508	0.407	0.356	0.325	0.305	0.292	0.281	0.274	0.266	0.259
2015	0.254	0.510	0.409	0.358	0.327	0.307	0.293	0.283	0.275	0.268	0.261
2016	0.250	0.508	0.407	0.356	0.325	0.305	0.291	0.281	0.273	0.266	0.259
2017	0.252	0.505	0.403	0.353	0.321	0.301	0.288	0.277	0.270	0.262	0.255
2018	0.252	0.508	0.407	0.356	0.324	0.305	0.291	0.281	0.273	0.266	0.259
2019	0.251	0.507	0.406	0.355	0.323	0.304	0.290	0.280	0.272	0.264	0.258
2020	0.252	0.506	0.404	0.354	0.322	0.302	0.289	0.278	0.271	0.263	0.256
2021	0.253	0.509	0.408	0.357	0.325	0.306	0.292	0.282	0.274	0.266	0.260
2022	0.254	0.512	0.411	0.360	0.329	0.309	0.296	0.285	0.278	0.270	0.263

Changes made during key runs

Since the last key run in 2020, WGSAM 2023 made been several changes in input data to the SMS:

- Update of "single-species data" (catch-at-age numbers, mean weights, proportion mature, survey indices, etc.) with use of the most recent ICES assessment input data. The most important changes are:
  - WGNSSK has changed the age range for whiting to 0-6+ (from 0-8+). Data are not available for the full age range and ages 0-6+ are now used by SMS.
  - Cod was benchmarked in 2022/2023 with new stock area and new 3-substock model in the ICES assessment, which SMS cannot emulate. SMS uses the old (and still updated) dataset for the old assessment area.
  - Haddock was benchmarked in 2022/2023 with some changes in data and truncation of the age range. Data with the full age range are however available such that the old SMS age range was maintained for haddock.
  - Update of the full time-series of sandeels (benchmarked in 2022/2023). Some changes in mean weights and catch at age numbers have been made by ICES. SMS now follows the StockAnnex in the compilation of mean weights at age in the sea.
- Update and re-estimation of population numbers of the seven species of seabirds. The old time-series has not been updated since 2011.
- Update of population number of grey seals and addition of grey seal diet data for 2010. Sandeel eaten by grey seals are now divided between the Northern and Southern stock (assumed just Northern stock in the 2020 key run).
- Plaice has become a prey species in SMS (eaten by grey seals).
- Recompilation of diet data for the major predator fish using the FishStomachs R-package.
- Calculation and use of input variance of diet data in the SMS.

The main changes made from the 2017 to the 2020 key run were:

- Update of "single-species data" (catch-at-age numbers, mean weights, proportion mature, survey indices, etc.) with use of the most recent ICES assessment input data. The most important changes are:
  - Whiting benchmark with mean weight at age in the sea derived from survey data, whereas mean weights from the catches were used previously. This gives lower mean weight at ages for the youngest ages and higher mean weight for the oldest ages compared to the 2017 key run.
  - Sprat benchmark with inclusion of subdivision 3a in the stock area and re-estimation of historical catch data.
  - Mackerel benchmark with new stock size estimate.
- Re-estimation of the Hake stock within the North Sea.
- Re-estimation of horse mackerel and their proportion of the stock within the North Sea

The main changes made from the 2014 to the 2017 key run were:

- Inclusion of mackerel as a dynamic species, which replaces the "external predators" North Sea mackerel and Western stock mackerel. With both approaches the

proportion of the North Atlantic mackerel within the North Sea needs to be known. In lack of a documented time-series for that, WGSAM made their own estimate of stock distribution, where used in SMS.

- Re-calculation of "single-species data" for the two sandeel stocks, as the present ICES stock areas for sandeel fit poorly into the northern and southern sandeel areas used in SMS.
- Update of consumption estimates (daily ration) of fish predators, particularly mackerel and horse mackerel using updated parameter for the evacuation model.
- Bias correction of diet estimate from observed stomach contents taking variable evacuation rate of prey species, stomach fullness and temperature into account for the fish stocks (cod, whiting, haddock saithe and mackerel) and taking variable evacuation rates of otolith (sizes) into account for harbour porpoise.
- Inclusion of distribution of fish stocks making calculations of M2 based only on the predator and prey stock numbers within the North Sea area.

The following sections describes the changes in the main output variable between the 2020 key run and the new 2023 key run.

Changes by species

Cod

The main differences for cod between the two key runs are F and SSB in the terminal years with a lower F and higher SSB in the 2023 key run (Figure 6.1-1, upper panel).. This result is mainly from the changes in the ICES assessment and the inclusion of the additional M1 to take assumed migration of cod age 3+ to area 6.a into account. Recruitment for the whole time-series is estimated lower in the 2023 key run.

Age 0 predation is lower in the 2023 key run (Figure 6.1-1, lower panel). A comparison with the M2 from the 2020 key run shows a reduction in M2 from mainly grey gurnards, and an increase in M2 from birds and *A. radiate*. The reduction in M2 form gurnards is probably due to the new (input) uncertainties on diet data. Relative to the vulnerability of "other food" for gurnard, the vulnerability of cod is reduce from 39 to 7.5 between the two key runs. Predation mortality of age 1 and 2 cod is slightly lower in the 2023 key run up to year 2000 and higher in the remaining time period. This seems to be due to the upward revision of the whiting population. Age 3 M2 is larger in the 2023 run due to the change in seal population numbers and revision of seal diet data.

Whiting

The ICES benchmark of the whiting assessment and truncation of the age range gave a considerably higher SSB and lower F in both the ICES assessment and SMS (Figure 6.1-2, upper panel).

These changes in population numbers are reflected in M2 for whiting (Figure 6.1-2), however the two key-runs' estimates of M2 are quite similar. The largest change is seen for age 0, with a lower M2 in the most recent key run, apparently from all predators.

Haddock

Recruitment, F, SSB and predation at age of haddock are largely the same between the two key runs (Figure 6.1-3).

Saithe

The two saithe assessments are quite similar (Figure 6.1-4) and show the same changes in in the ICES single species assessment.

Mackerel

Like the saithe assessment, the mackerel assessment (Figure 6.1-5) show the same small changes as seen in the ICES assessments.

Herring

The two herring assessments are similar (Figure 6.1-6) for the main output, recruitment, F and SSB (Figure 6.1-6, upper panel).

Predation mortalities of herring follows the same trends in the two key runs, even though with some differences by year (Figure 6.1-6, lower panel). The most consistent changes are a lower M2 for age 0-1 and a higher M2 for ages 2- 4 in the 2023 key run. For age 4, the increase in M2 is due to a higher partial M2 from saithe and harbour porpoise.

Northern sandeel

The two assessments are quite different (Figure 6.1-7) both with respect to the stock summary and predation mortality. The sandeel stocks in the North Sea were benchmarked in 2022/2023 which mainly changed the mean weight at ages in the catch (and thereby the catch at age). In addition, the 2020 key run used very short time-series of commercial CPUE which probably resulted in overfitting (very small observation variance). This is not the case for the 2023 key run.

M2 is generally lower in the 2023 run, mainly due to the split of sandeels in the grey seal diet from entirely Northern sandeel into a Northern and Southern sandeel.

Southern sandeel

The 2023 key run results (F, SSB and recruitment) for Southern sandeel (Figure 6.1-8) are quite similar between the two key runs. M2 for age 2+ is larger in the 2023 key run, as Southern sandeel has now become a prey for grey seals.

Norway pout

The assessment result for Norway pout are quite similar for the two key runs (Figure 6.1-9. M2 for age 0 and recruitment are estimated slightly lower in the new key run, mainly due to a smaller partial M from hake.

Sprat

The ICES sprat assessment is highly uncertain and there are also considerable changes in the M2 results from the two key runs (Figure 6.1-10). M2 for ages 0–1 are consistently estimated between the two runs, but M2 for ages 2-3 are higher in the 2023 run. Compared with the partial M2 from the 2020 key run, this change is mainly due to a higher M2 from mackerel, where the input weighting of diet has changed the overall weighting of the likelihood components.

Plaice

Recruitment, F and SSB (Figure 6.1-11) are very different for the two key runs. This is due to the plaice benchmark, but also because the plaice assessment done by SMS at the last key run did not get much attention, as plaice was neither a predator nor a prey. Plaice has now become a prey species for grey seals, however the estimated M2 (max 0.015) is too small to influence the stock dynamic.

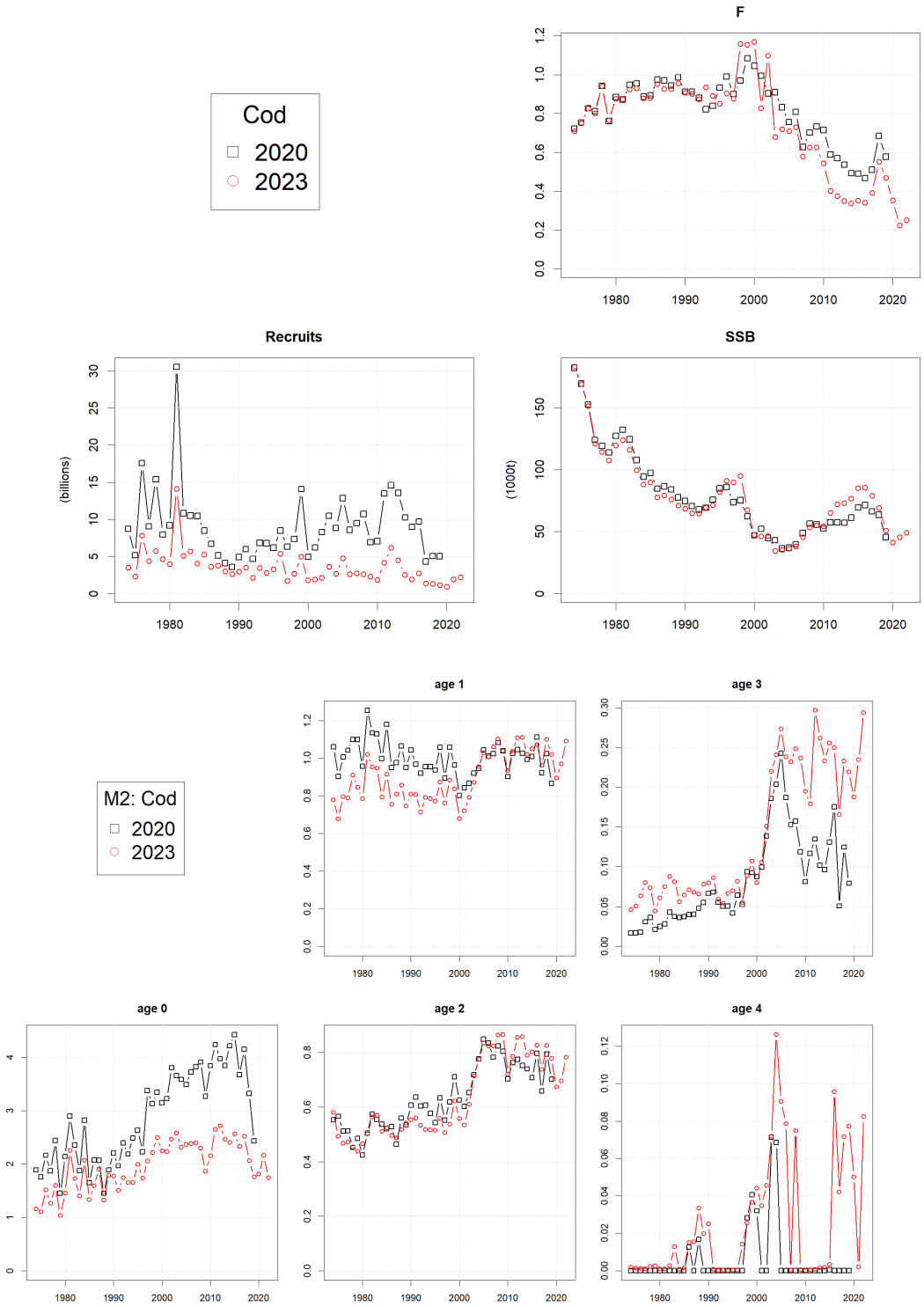

Figure 6.1-51. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of cod from the 2020 and 2023 key runs.

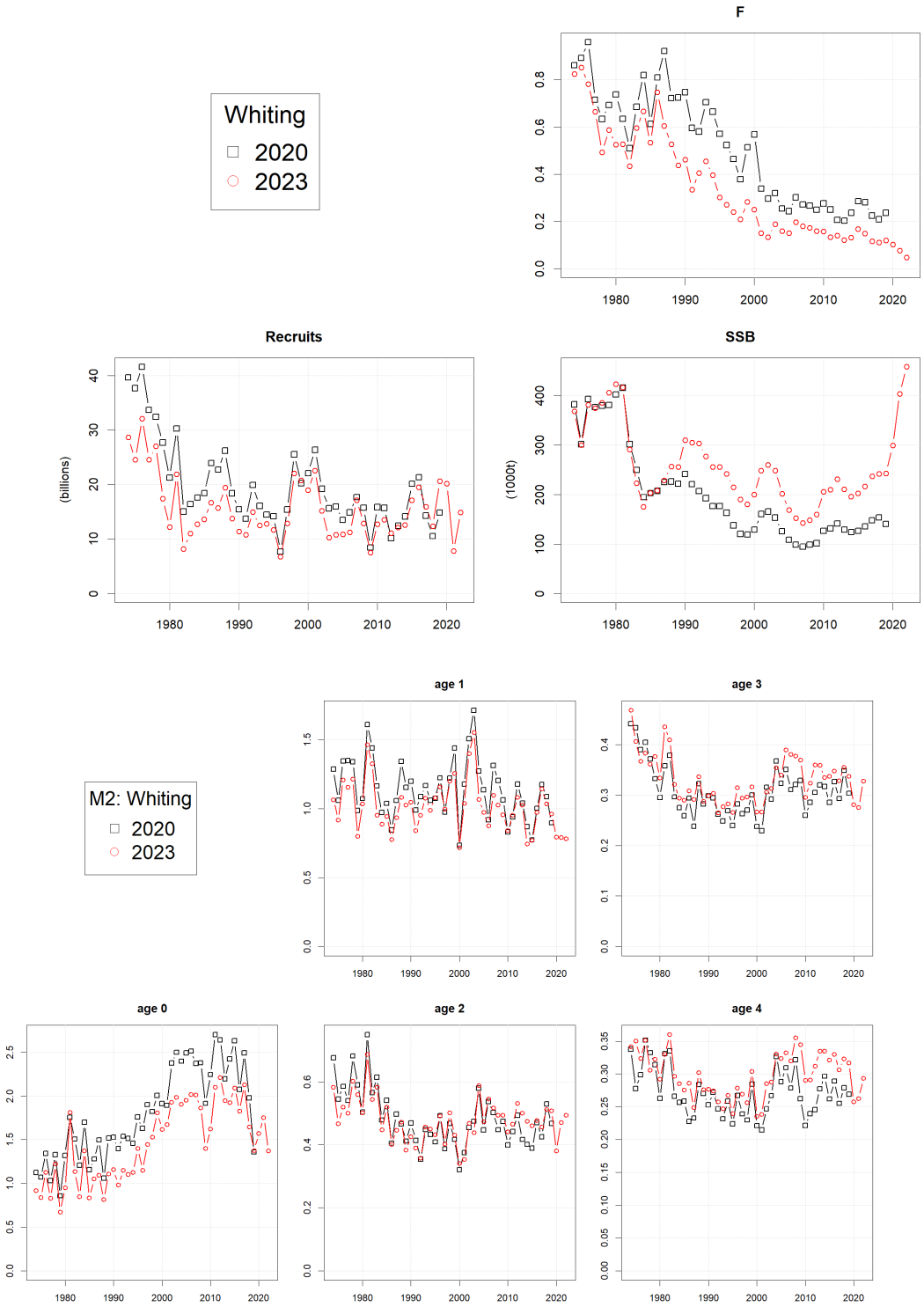

Figure 6.1-52. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of whiting from the 2020 and 2023 key runs.

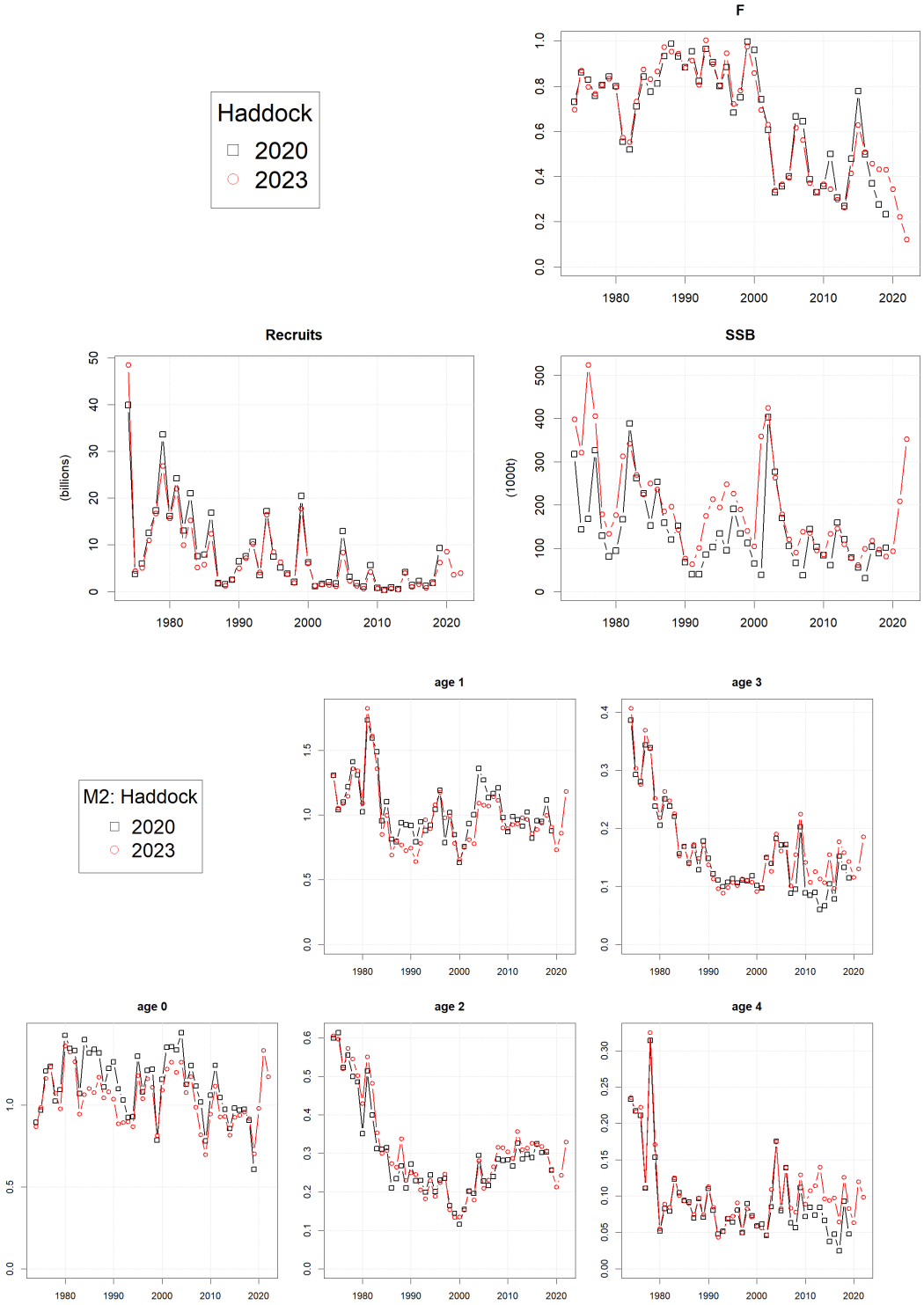

Figure 6.1-53. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of haddock from the 2020 and 2023 key runs.

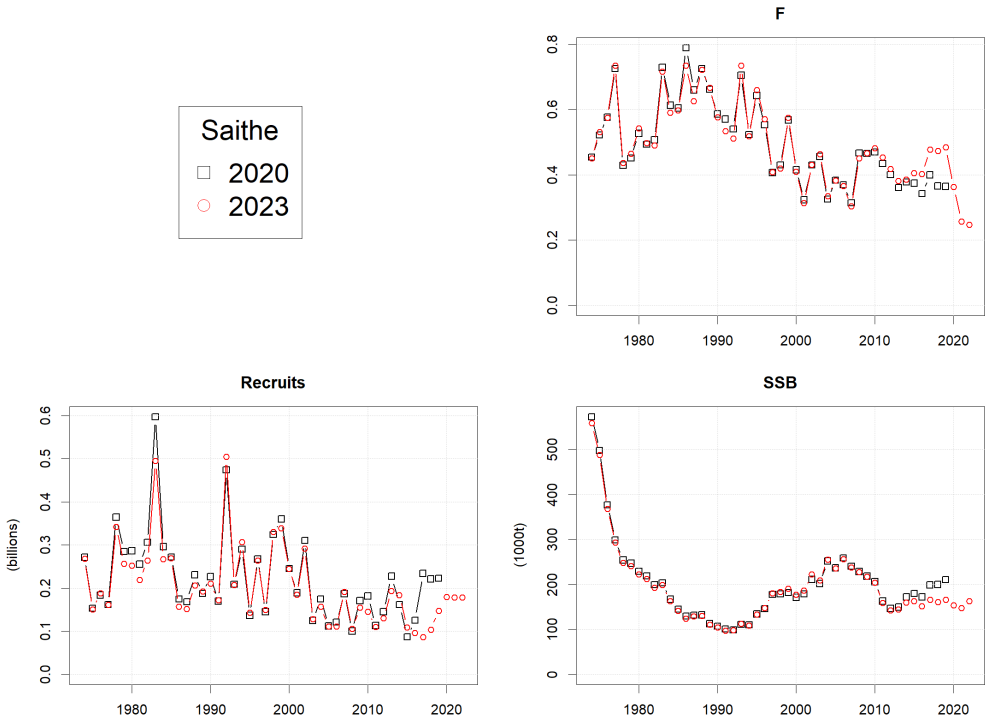

Figure 6.1-54. Comparison of estimated recruitment, mean F and SSB of Saithe from the 2020 and 2023 key runs.

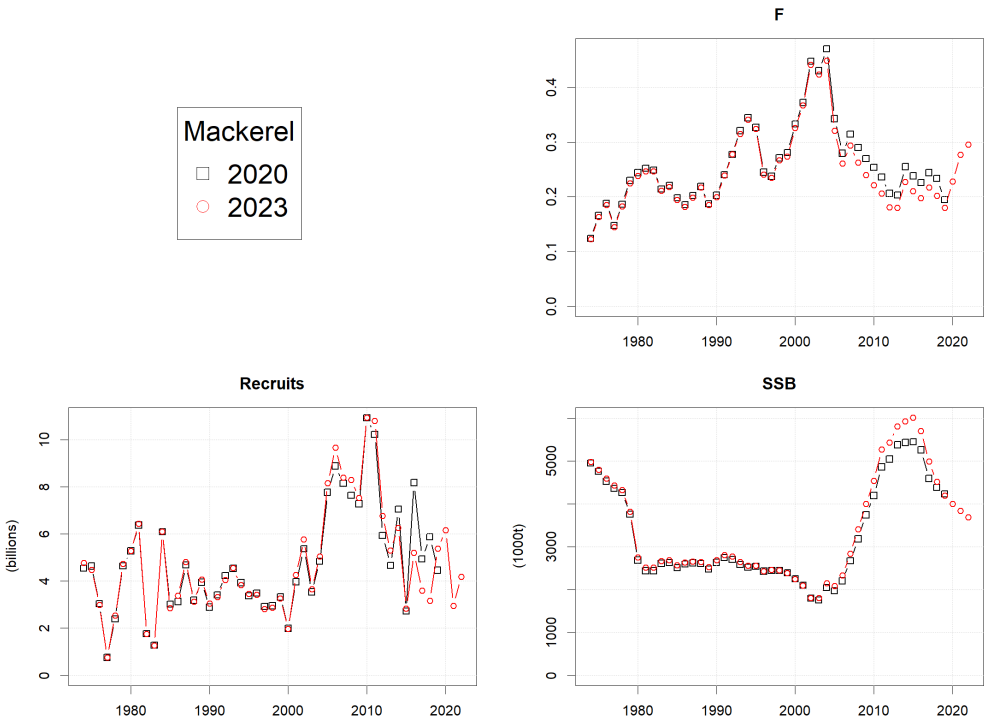

Figure 6.1-55. Comparison of estimated recruitment, mean F and SSB of Mackerel from the 2020 and 2023 key runs.

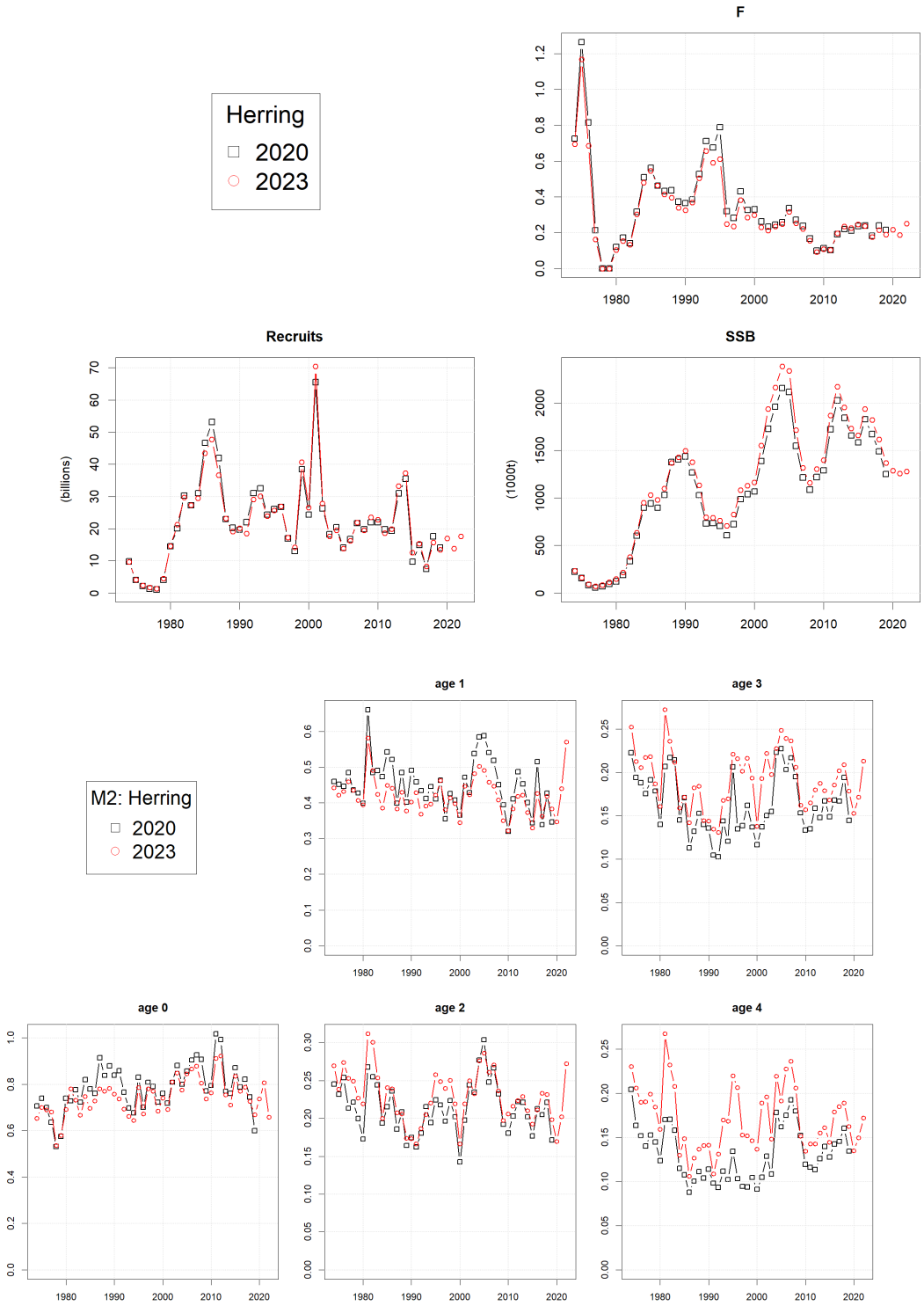

Figure 6.1-56. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of herring from the 2020 and 2023 key runs.

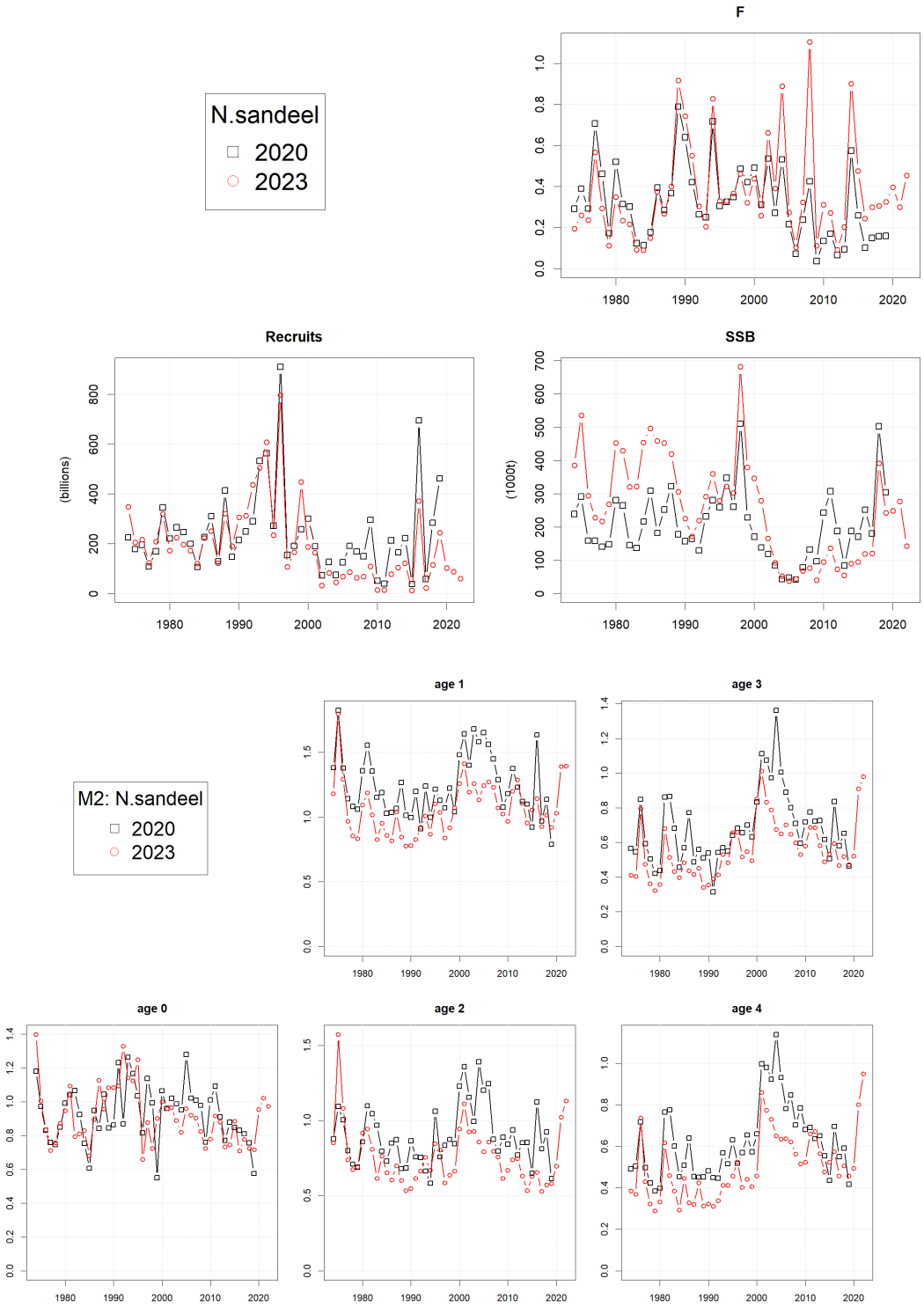

Figure 6.1-57. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of northern sandeel from the 2020 and 2023 key runs.

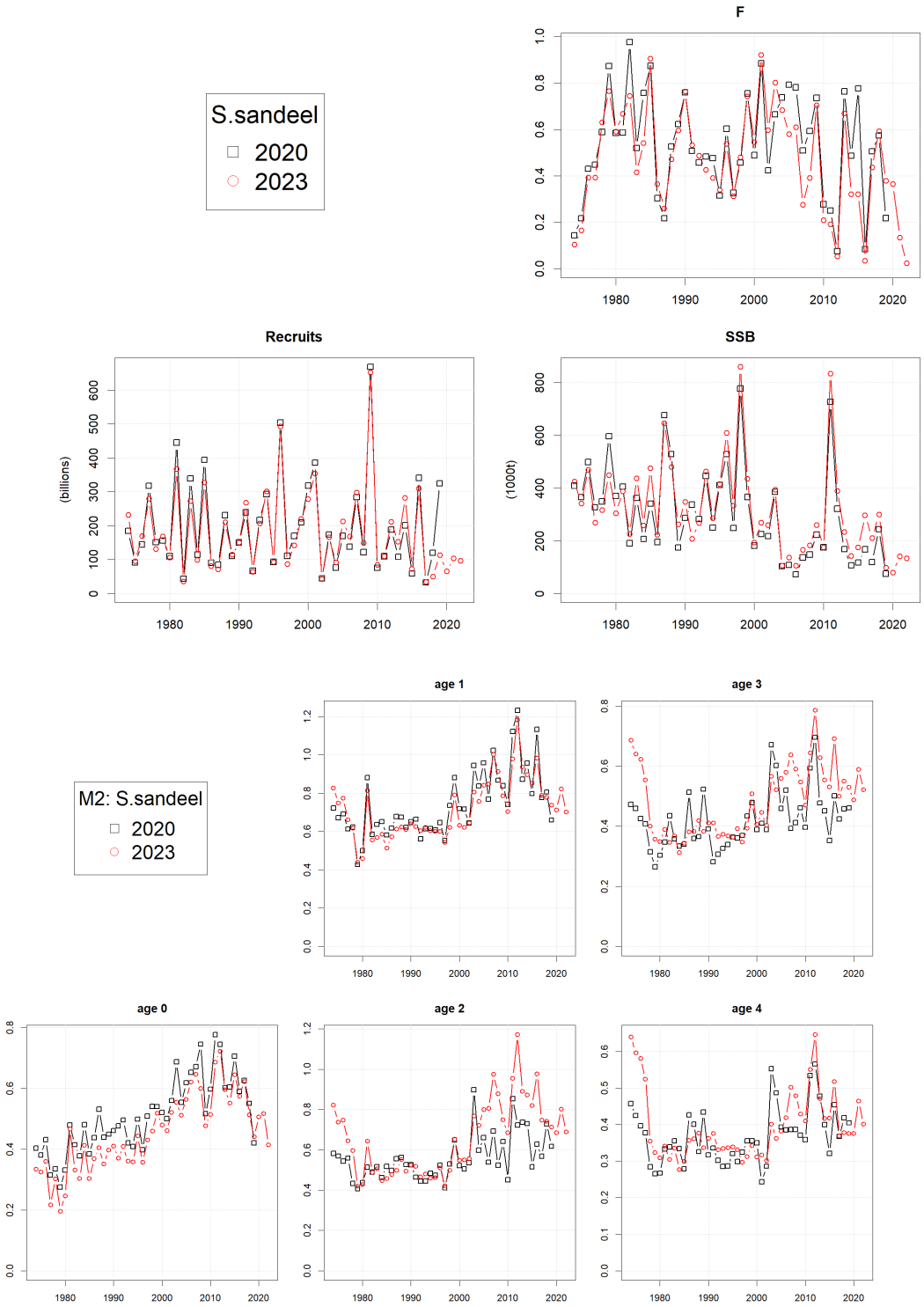

Figure 6.1-58. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of southern sandeel from the 2020 and 2023 key runs.

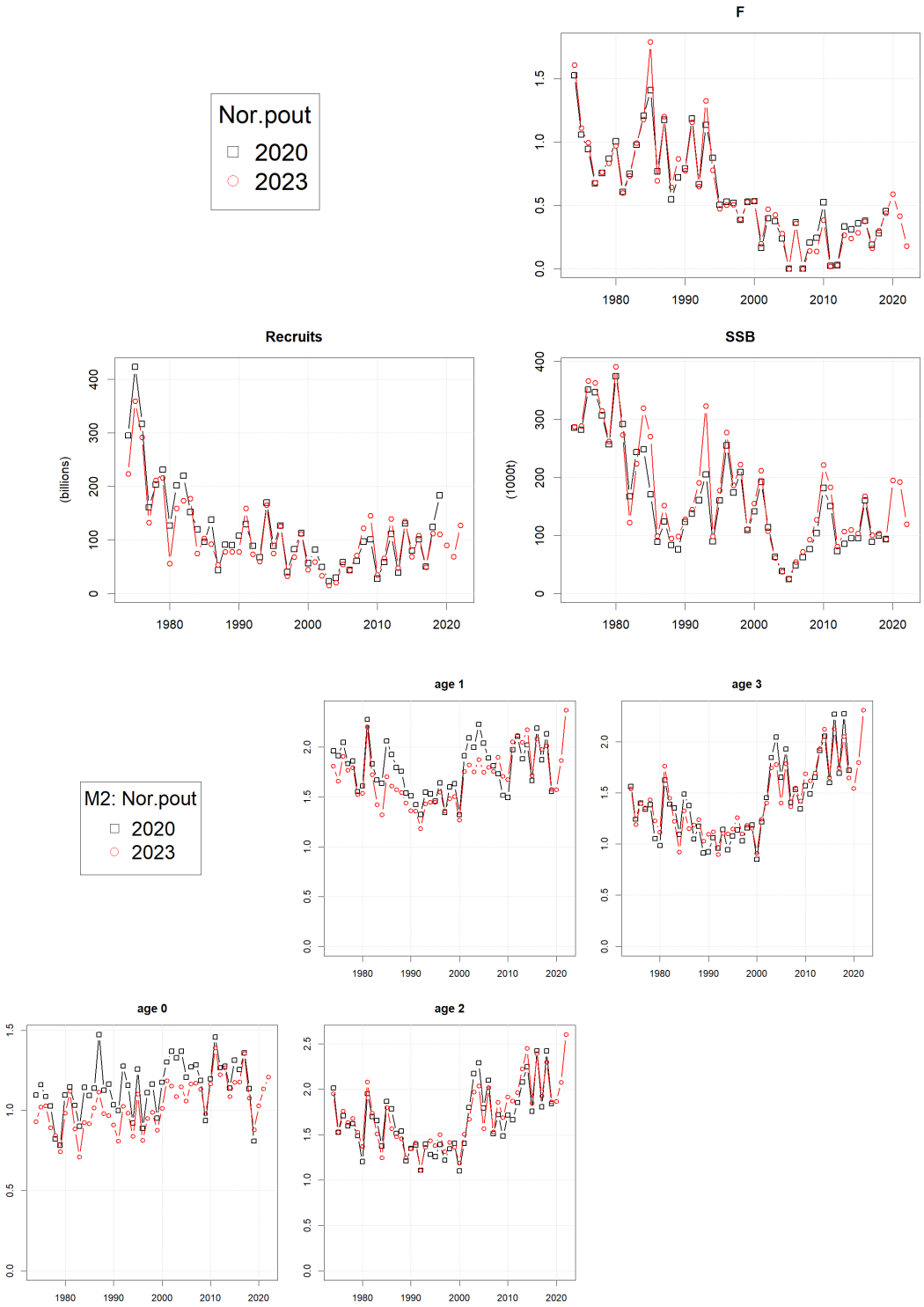

Figure 6.1-59. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of Norway pout from the 2020 and 2023 key runs.

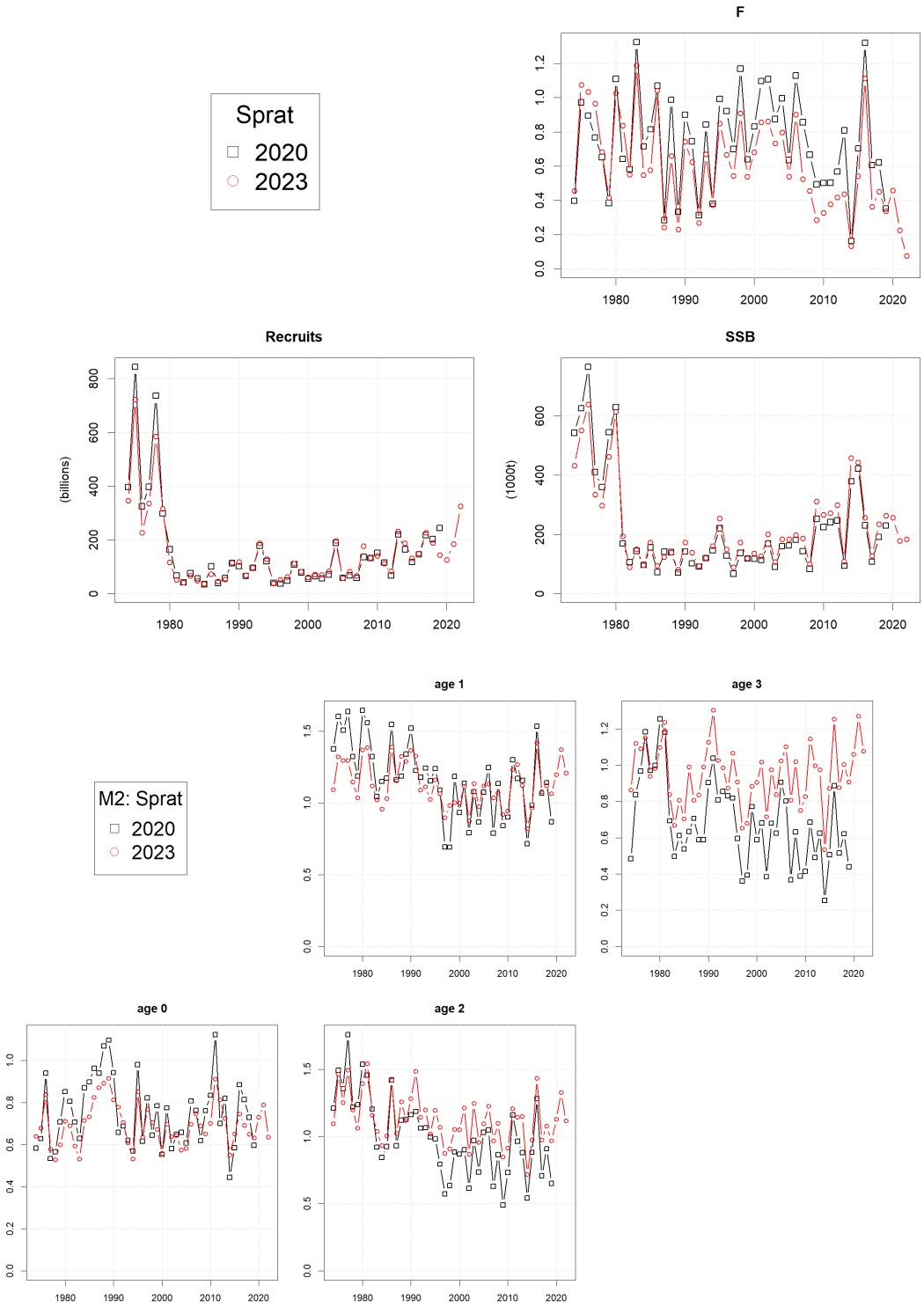

Figure 6.1-60. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of sprat from the 2020 and 2023 key runs.

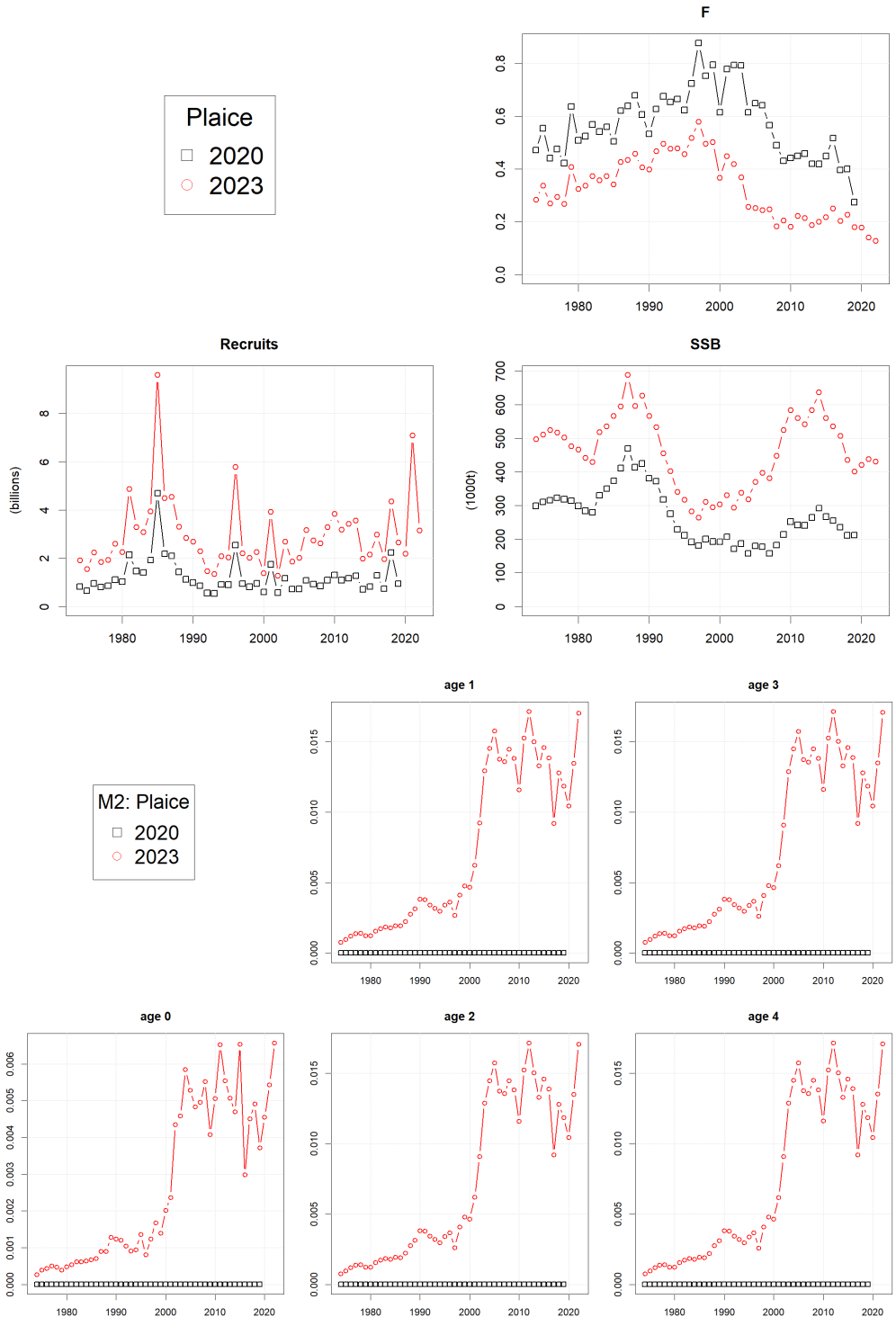

Figure 6.1-61. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of sprat from the 2020 and 2023 key runs.

Conclusion - 2023 key run

WGSAM 2023 discussed the changes in input data and the results in detail and concluded that:

- M2 seems consistently estimated between key runs and shows a limited retrospective pattern using the last key run an excluding 1–4 years of data
- Some ICES assessments make use of the estimated natural mortalities (M1+M2) from SMS and update those in benchmark. If used, WGSAM does not recommend updating existing data series of natural mortality by simply adding the latest three new years. The time-series as a whole shows patterns which would not be retained by this procedure. For example, herring shows an increased natural mortality over the past decade, but adding only the latest three years will give the impression that natural mortality has decreased over the last five years.

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WD01 Seal number update for the 2023 SMS North Sea key-run

WD02 Seal diet analysis

WD03 why the new fish stomach data from the North Sea were not included in the 2023 SMS key-run

WD04 Summary of bird inputs for the SMS North Sea key-run

WD05 Estimating uncertainties of diet data for use in Stochastic Multispecies Models (SMS).

Appendix 1: SMS, a stochastic age–length structured multispecies model applied to North Sea and Baltic Sea stocks

Working document to ICES WKMULTBAL, March 2012

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Overview

SMS (Stochastic Multi Species model) is a fish stock assessment model which includes the estimation of predation mortalities from observation of catches, survey indices and stomach contents. Estimation of predation mortality is based on the theory for predation mortality as defined by Andersen and Ursin (1977) and Gislason and Helgason (1985). SMS is a "forward running" model that operates with a chosen number of time steps (e.g. quarters of the year). The default SMS is a one-area model, but the model has options for spatial explicit predation mortality given a known stock distribution.

Model parameters are estimated using maximum likelihood (ML) technique. Uncertainties of the model parameters are estimated from the Hessian matrix and confidence limits of derived quantities like historical fishing mortalities and stock abundances are estimated from the parameter estimates and the delta-method. SMS can be used for forecast scenarios and Management Strategy Evaluations, where fishing mortalities are estimated dynamically from Harvest Control Rules.

This document describes the model structure and the statistical models used for parameter estimation.

Model Structure

Survival of the stocks

The survival of the stocks is described by the standard exponential decay equation of stock numbers (N).

$$N_{s,a,y,q+1} = N_{s,a,y,q}\, e^{-Z_{s,a,y,q}} \qquad \text{Eq. 1}$$

or

$$N_{s,a+1,y,+1,q=1} = N_{s,a,y,q=last\ season}\, e^{-Z_{s,a,y,q=last\ season}} \qquad \text{Eq. 2}$$

The instantaneous rate of total mortality, $Z_{s,a,y,q}$ by species s, age group a, year y and season q, is divided into three components; predation mortality (M2), fixed residual natural mortality (M1) and fishing mortality (F):

$$Z_{s,a,y,,q} = M1_{s,a,q} + M2_{s,a,y,q} + F_{s,a,y,q}$$

For non-assessment species which act as predators (e.g. grey seal and horse mackerel) stock numbers are assumed known and must be given as input.

Fishing mortality

Fishing mortality, $F_{s,a,y,q}$ is modelled from an extended separable model including age, year and season effects. However, as these effects may change over time a more flexible structure is assumed, allowing for such changes for specified periods. For convenience, the species index is left out in the following:

$$F_{a,y,q} = F^1_{Y,A1}\, F^2_y\, F^3_{Y,A2,q} \qquad \text{Eq. 3}$$

where indices $A1$ and $A2$ are a grouping of ages, (e.g. ages 1–3, 4–7 and 8–9) and Y is a grouping of years (e.g. 1975–1989, 1990–2011).

Eq. 3 defines that the years included in the model can be grouped into a number of period clusters (Y), in which the age selection (F^1) and seasonal selection (F^3) are assumed constant. $F^2$is the year effect, specifying the overall level of F for a particular year. The grouping of ages for age selection, $A1$, and season selection, $A2$, can be defined independently.

2.2.1 Options for year effect

Given a good relationship between F and effort, the fishing mortality can be calculated from the observed effort.

$$F_{a,y,q} = F^1_{Y,A1}\, EFFORT_y\, F^1_{Y,A2,q}$$

Natural Mortality

Natural mortality is divided into two components, predation mortality (M2) caused by the predators included in the model and a residual natural mortality (M1), which is assumed to be known and is given as input.

M2 of a prey species, $prey$, with size group l_{prey} due to a predator species, $pred$, with size group l_{pred} is calculated as suggested by Andersen and Ursin (1977) and Gislason and Helgason (1985).

$$M2_{prey,l_{prey},y,q} = \sum_{pred}\sum_{l_{pred}} \frac{\bar{N}_{pred,l_{pred},y,a}\;\; RA_{pred,l_{pred},y,q}\;\; S_{prey,pred,q}(l_{prey}, l_{pred})}{AB_{pred,l_{pred},y,a}} \qquad \text{Eq. 4}$$

where RA denotes the total food ration (weight) of one individual predator per time unit, where S denotes the food suitability defined in Eq. 8 and where AB is the total available (suitable) biomass. AB is defined as the sum of the biomass of preys weighted by their suitability. This total prey biomass includes also the so-called "other food" (OF) which includes all prey items not explicitly modelled, e.g. species of invertebrates and non-commercial fish species. Other food species are combined into one group, such that the total available prey biomass becomes:

$$AB_{pred,l_{pred},y,q} = \sum_{prey}\sum_{l_{prey}} \left(\bar{N}_{prey,l_{prey},y,q}\ W_{prey,l_{prey},y,q}\ S_{prey,pred,q}(l_{prey}, l_{pred})\right) + OF_{pred,}\ S_{OF,pred,q}(l_{pred}) \quad \text{Eq. 5}$$

M2 cannot directly be calculated from Eq. 4 because M2 also is included in the right-hand term in Eq. 6 to calculate $\bar{N}$.

$$\bar{N} = \frac{N\,(1 - e^{-(M1+M2+F)})}{M1 + M2 + F} \quad \text{Eq. 6}$$

As no analytical solution for $M2$ exists, $M2$ has to be found numerically. If the time step considered is sufficiently small, for instance, a quarter, $M2$ becomes small and can optionally be approximated by replacing the average number during the season, $\bar{N}$, on the right-hand side of Eq. 4 by the stock at the beginning of the season, N. As the right-hand side of the equation now is independent of M2 this quantity can be calculated directly from Eq. 4 where AB (Eq. 5) is modified correspondingly.

Use of size distribution by age

The equations outlined in the section above provide M2 at-size groups. However, predation mortality by age is needed as well because F and catches are age-structured. If just one size group per age group of predators and preys is assumed Eq. 4 can be used directly where the age index substitutes the size group index in stock numbers ($\bar{N}_{prey,a,y,q} = \bar{N}_{prey,l_{prey},y,q}$)

Given more size groups per age, the calculation of M2 at-age requires age–length-keys to split N at age to N at size group.

$$N_{s,l_s,y,q} = \sum_{a} N_{s,a,y,q}\ ALK_{s,a,l_s,y,q} \quad \text{Eq. 7}$$

where $ALK_{s,l_s,a,y,q}$ denotes the observed proportion of size group ls for a given species and age group, i.e. $\sum_{l_s} ALK_{s,l_s,a,y,q} = 1$

Assuming that F and M1 depend only on the age and that M2 only depends on the length, M2 at-age is estimated by: (leaving out the species, year and quarter indices).

$$M2_a = Z_a \frac{\sum_l \bar{N}_{a,l}\, M2_{a,l}}{D_a} = \log\left(\frac{N_a}{N_a - D_a}\right) \frac{\sum_l \bar{N}_{a,l}\ M2_l}{D_a}$$

where

$$\bar{N}_{a,l} = N_{a,l}\ \frac{1 - e^{-(F_{a,l}+M1_{a,l}+M2_{a,l})}}{F_{a,l} + M1_{a,l} + M2_{a,l}} = N_{a,l}\ \frac{1 - e^{-(F_a+M1_a+M2_l)}}{F_a + M1_a + M2_l}$$

and where

$$D_a = \sum_l \bar{N}_{a,l}\,(F_a + M1_a + M2_l)$$

denotes the number of individuals at-age who died within a season.

Food suitability

As suggested by Andersen and Ursin (1977) and Gislason and Helgason (1985) the size-dependent food suitability of prey entity j for predator entity i is defined as the product of a species dependent vulnerability coefficient, $\rho_{i,j}$, a size preference coefficient $\varrho_{i,j}(l_i, l_j)$, and an overlap index $o_{i,j,q}$. Suitability is then defined as:

$$S_{pred,prey,q}(l_{pred}, l_{prey}) = \rho_{pred,prey}\ \varrho_{pred,prey}(l_{pred}, l_{prey})\ o_{pred,prey,q} \qquad \text{Eq. 8}$$

For the "other food", suitability is defined as:

$$S_{OF,pred,q}(l_{pred}) = \rho_{OF,pred}\ \ o_{OF,pred,q} \exp\left(\upsilon_{pred}\ \log\left(W_{pred,l_{pred},q}/\overline{W}_{pred}\right)\right) \qquad \text{Eq. 9}$$

Where $\overline{W}_{pred}$ is the average size of the predator species. Eq. 9 extends the original equation, to allow size dependent suitability for other food, for values of υ_{pred} different from zero. The overlap index may change between seasons but is assumed independent of year and size.

Log-normal distributed size selection

Several functions can be used for size preference of a prey. Andersen and Ursin (1977) assumed that a predator has a preferred prey size ratio and that a prey twice as big as the preferred size is as attractive as another half the prey size. This was formulated as a log-normal distribution:

$$\varrho_{pred,prey}(l_{pred}, l_{prey}) = \exp\left(-\frac{\left(\log\left(\frac{W_{l_{pred}}}{W_{l_{prey}}}\right) - \eta_{PREF\ pred}\right)^2}{2\,\sigma^2_{PREF\ pred}}\right); 0 < \varrho \leq 1 \qquad \text{Eq. 10}$$

Where η_{PREF} is the natural logarithm of the preferred size ratio, $\sigma^2_{PREF}$is the "variance" of relative preferred size ratio, expressing how selective a predator is concerning the size of a prey and where $W_{l_s}$is the mean weight for a species size group.

The basic size selection equation (Eq. 10) has been extended by modifying the preferred size ratio parameter.

$$\varrho_{pred,prey}(l_{pred}, l_{prey}) = \exp\left(-\frac{\left(\log\left(\frac{W_{l_{pred}}}{W_{l_{prey}}}\right) - \left(\eta_{PREF\ pred} + \xi_{prey} + \varpi_{pred}\ \log\left(W_{l_{pred}}\right)\right)\right)^2}{2\,\sigma^2_{PREF\ pred}}\right) \qquad \text{Eq. 11}$$

Where ξ_{prey} specify a prey-specific adjustment term for the preferred size ratio, and where ϖ_{pred} specifies how the preferred size range can change by predator size.

Uniform size selection

Alternatively, a uniform size preference can be assumed within the range of the observed size ratio and zero size selection outside that ratio:

$$\varrho_{pred,prey}(l_{prep}, l_{prey}) = \left\{ \begin{array}{ll} 1 & \text{for } \eta_{MIN_{pred,prey}} \leq \dfrac{W_{l_{pred}}}{W_{l_{prey}}} \leq \eta_{MIN_{pred,prey}} \\ 0 & \text{for values outside observed range} \end{array} \right\} \quad \text{Eq. 12}$$

where η_{MIN} and η_{MAX} are the observed minimum and maximum predator/prey size ratios.

Constraint uniform size selection

The uniform size preference does not take into account that the preferred predator/prey size ratio might change by size, such that larger individuals select relatively smaller preys (Floeter and Temming, 2005; Sharft *et al.*, 2000). A way to account for that is to assume that the fixed minimum and maximum constants, η_{MIN} and η_{MAX}, depend on the predator size:

$$_{pred,prey}(l_{pred}, l_{prey}) = \left\{ \begin{array}{ll} 1 \text{ for } U1_{pred,prey} + U2_{pred,prey} \log(W_{l_{pred}}) \leq \log\left(\dfrac{W_{l_{pred}}}{W_{l_{prey}}}\right) \leq U3_{pred,prey} + U4_{pred,prey} \log(W_{l_{pred}}) \\ 0 \quad \text{for values outside regression range} \end{array} \right\} \quad \text{Eq. 13}$$

The regression parameters are estimated externally by quantile regression (e.g. Koenker and Bassett, 1978) using e.g. the 2.5% and 97.5% percentiles of stomach content data. Figure 7.1 shows an example of such regression.

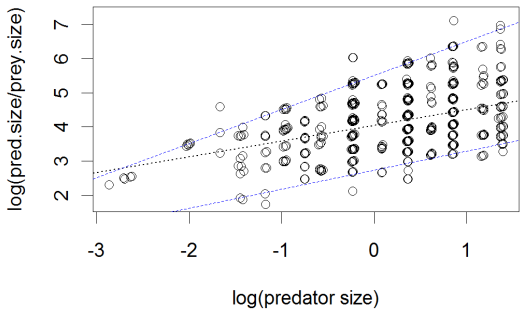

Figure 7.1. Quantile regression of stomach contents observations (Baltic cod eating cod), with 2.5%, 50% and 97.5% lines shown. Predator and prey size in weight.

Adjustment of age–size keys

For the North Sea configuration, age length keys were obtained from the IBTS surveys where the same gear (i.e. the GOV trawl) has been used in the period considered. This allows an adjustment of the observed ALK's to account for mesh size selection. Using a logistic length-dependent selection function, selection is defined as:

$$SL_s(l) = 1/\left(1 + e^{(S1_s - S2_s * l)}\right)$$

Where $S1_s$ and $S2_s$ are species-specific gear selection parameters.

The adjusted ALK can then be derived from the observed ALK by:

$$ALK_{s,l_s,a,y,a} = \text{ObservedALK}_{s,l_s,a,y,q} \; / \; SL_{s,l_s}$$

which finally has to be standardised to 1 for each age before used in Eq. 7.

Growth

Not implemented yet!

Food ration

Food ration, RA, pr. time step is given as input or estimated from mean weight by size group assuming an exponential relationship between ration and body weight W.

$$RA_{pred,l_{pred},q} = \gamma_{pred,q} \; W_{pred,l_{pred}}^{\varsigma pred} \qquad \text{Eq. 14}$$

where the coefficient γ and ς are assumed to be known.

Body weight at-size group lpred is estimated from mean length within the size group and a length–weight relationship.

Area-based SMS

SMS has three area explicit options:

Default one area model. Both F and M2 are calculated for the entire stock area;

M2 by area. M2 is calculated by subareas, but F is assumed global;

M2 and F by area. Both M2 and F are calculated by area (forecast only).

Stock distribution

For the area-based models, the stock is assumed redistributed between areas between each seasonal time step.

$$N_{s,a,y,q}^{area} = N_{s,a,y,q} \; DIST_{s,a,y,q,area}$$

Where

DIST is a stock distribution key that sums up to 1

$$\sum_{area} DIST_{s,a,y,q,area} = 1$$

The calculation of M2 for Option 1) is provided in the previous section.

The method for option 3) is very similar, but the calculations must be done by each subarea separately.

$$Z_a^{area} = F_a^{area} + M1_a^{area} + M2_a^{area}$$

where $M2^{area}$ is calculated as given in Eq. 4.

Option 2) is the hybrid, where F is global but M is calculated by area.

$$Z_a^{area} = F_a + M1_a^{area} + M2_a^{area}$$

$\bar{N}$ in an area is calculated in the usual way

$$\bar{N}_a^{area} = N_a^{area} \frac{1 - e^{-Z_a^{area}}}{Z_a^{area}}$$

The total number of individuals who died due to predation mortality (DM2) then becomes:

$$DM2_a = \sum_{area} M2_a^{area} \bar{N}_a^{area} \qquad \text{Eq. 15}$$

M2 for the whole stock can be estimated from:

$$M2_a = \log\left(\frac{N_a}{N_a - D_a}\right) \frac{DM2_a}{D_a}$$

where

$$D_a = \sum_{area} DF_a^{area} + DM1_a^{area} + DM2_a^{area}$$

and DF and DM1 are the number died due to fishery and residual mortality (M1) and are calculated in similar ways as specified for DM2 (Eq. 3).

Area based suitability parameters

For the "one area" SMS suitability is defined by Eq. 8.

The area-based version of suitability uses an area-specific vulnerability and overlap index, while the size preference (ϱ) is assumed independent of area.

$$S_{pred,prey,q}^{area}(l_{pred}, l_{prey}) = \rho_{pred,prey}^{area} \varrho_{pred,prey}(l_{pred}, l_{prey}) o_{pred,prey,q}^{area}$$

Statistical models

Three types of observations are considered: Total international catch-at-age; survey abundance indices and relative stomach content. For each type, a stochastic model is formulated and the likelihood function is calculated. As the three types of observations are independent, the total log-likelihood is the sum of the contributions from the three types of observations. A stock–recruitment (penalty) function is added as a fourth contribution.

Catch-at-age

Catch-at-age observations are considered stochastic variables subject to sampling and process variation. The probability model for these observations is modelled along the lines described by Lewy and Nielsen (2003):

Catch-at-age is assumed to be lognormal distributed with log mean equal to log of the standard catch equation The variance is assumed to depend on age and season and to be constant over years. To reduce the number of parameters, ages and seasons can be grouped, e.g. assuming the same variance for age 3 and age 4 in one or all seasons. Thus, the likelihood function, LCATCH, associated with the catches is:

$$L_{CATCH} = \prod_{s,a,y,q} \frac{1}{\sigma_{CATCH\ s,a,q}\sqrt{2\pi}} \; exp\left(-\frac{\left(\log\left(C_{s,a,y,q}\right) - E\left(\log\left(C_{s,a,y,q}\right)\right)\right)^2}{2\,\sigma^2_{CATCH\ s,a,q}}\right) \qquad \text{Eq. 16}$$

Where

$$E\left(\log\left(C_{s,a,y,q}\right)\right) = \log\left(F_{s,a,y,q}\,\bar{N}_{s,a,y,q}\right)$$

Leaving out the constant term, the negative log-likelihood of catches then becomes:

$$\begin{aligned} l_{CATCH} &= -\log(L_{CATCH}) \\ &\propto \text{NOY} \sum_{s,a,q} \log\left(\sigma_{CATCH\ s,a,q}\right) \\ &+ \sum_{s,a,y,q} \left(\log\left(C_{s,a,y,q}\right) - E\left(\log\left(C_{s,a,y,q}\right)\right)\right)^2 / 2\sigma^2_{CATCH\ s,a,q} \end{aligned} \qquad \text{Eq. 17}$$

Where NOY is the number of years in the time-series.

Annual catches

Catch-at-age numbers by quarter have not been available for some of the demersal North Sea stocks in recent years. For use in the default SMS configuration of the North Sea, where quarterly time step is used, it is assumed that the seasonal distribution (the F^3 parameter in Eq. 3) is known and given as input. The likelihood function is modified to make use of the observed annual catches.

$$E\left(\log\left(C_{s,a,y}\right)\right) = \log\left(\sum_{q} F_{s,a,y,q}\;\; \bar{N}_{s,a,y,q}\right)$$

$$L_{CATCH} = \prod_{s,a,y} \frac{1}{\sigma_{CATCH\ s,a}\sqrt{2\pi}} \; exp\left(-\frac{\left(\log\left(C_{s,a,y}\right) - E\left(\log\left(C_{s,a,y}\right)\right)\right)^2}{2\,\sigma^2_{CATCH\ s,a}}\right) \qquad \text{Eq. 18}$$

Survey indices

Similarly to the catch observations, survey indices, $CPUE_{survey,s,a,y,q}$ are assumed to be log-normally distributed with mean:

$$E\left(\log\left(CPUE_{survey,s,a,y,q}\right)\right) = \log\left(Q_{survey,a}\;\; \bar{N}_{SURVEY\ s,a,y,q}\right) \qquad \text{Eq. 19}$$

where Q denotes catchability by survey and $\bar{N}_{SURVEY}$ is mean stock number during the survey period. Catchability may depend on a single age or group of ages. Similarly, the variance of log cpue, σ^2_{SURVEY} may be estimated individually by age or by clusters of age groups. The negative log-likelihood is in the same form as Eq. 16.

$$
\begin{aligned}
& l_{SURVEY} \\
& = -\log(L_{SURVEY}) \\
& \propto NOY_{survey,s} \sum_{survey,s,a} \log\left(\sigma_{SURVEY\ survey,s,a}\right) \\
& + \sum_{survey,s,a,y} \left(\log\left(CPUE_{survey,s,a,y}\right) - E\left(\log\left(CPUE_{survey,s,a,y}\right)\right)\right)^2 / 2\sigma^2_{SURVEY\ s,a}
\end{aligned}
\qquad \text{Eq. 20}
$$

Stomach contents

The stomach contents observations, which are the basis for modelling predator food preference, consist of the average proportions by weight of the stomach content averaged over the stomach samples in the North Sea. The model observations, $STOM_{pred,l_{pred},prey,l_{prey},y,q}$, are given for combinations of prey and predator species and size classes. In the following, we use entity i for a combination of predator species and predator size class (e.g. saithe 50–60 cm) and entity j for the combination of prey species and prey size class eaten by entity$i$. Model observations therefore become $STOM_{i,j,y,q}$.

$STOM$ is assumed to be stochastic variables subject to sampling and process variations. For a given predator entity the observations across prey entities i are continuous variables which sum to one. Thus, the probability distribution of the stomach observations for a given predator including all prey/length groups needs to be a multivariate distribution defined on the simplex. As far as the authors know the Dirichlet distribution is the only distribution fulfilling this requirement. Leaving out the year and season index, the Dirichlet density function for a predator entity i with k observed diet proportions $STOM_{i,1}, \ldots STOM_{i,k-1} > 0$ and the parameters $p_1, \ldots, p_k > 0$ has the probability density given by S:

$$
f_i = f\left(STOM_{i,1}, \ldots, STOM_{i,k-1} \mid p_{i,1}, \ldots, p_{i,k}\right) = \frac{\Gamma(p_i)}{\prod_{j=1}^{k} \Gamma\left(p_{i,j}\right)} \prod_{j=1}^{k} STOM_{i,j}^{p_{i,j}-1} \qquad \text{Eq. 21}
$$

Where

$$
STOM_{i,k} = 1 - \sum_{j=1}^{k-1} STOM_{i,j}
$$

and

$$
p_i = \sum_{j=1}^{k} p_{i,j}
$$

The mean and variance of the observations in the Dirichlet distribution are:

$$
E\left(STOM_{i,j}\right) = \frac{p_{i,j}}{p_i}
$$

$$
Var\left(STOM_{i,j}\right) = \frac{E\left(STOM_{i,j}\right)\left(1 - E\left(STOM_{i,j}\right)\right)}{p_i + 1} \qquad \text{Eq. 22}
$$

The expected value of the stomach contents observations is modelled using the theory developed by Andersen and Ursin (1977):

$$
E\left(STOM_{i,j}\right) = \frac{\bar{N}_j\ W_j\ S_{i,j}(l_i, l_j)}{\sum_j \left(\bar{N}_j\ W_j\ S_{i,j}(l_i, l_j)\right) + OF_i\ S_{OF,i}(l_i)} = \frac{p_{i,j}}{p_i} \qquad \text{Eq. 23}
$$

where the food suitability function, S, is defined by Eq. 8 and Eq. 9. We make the same assumption as made for the calculation of M2 (Eq. 4) that the small time steps used in the model, allows a replacement of $\bar{N}_j$ by N_j in Eq. 23.

Regarding the variance of stomach contents observations unpublished analyses of the present authors of data from the North Sea stomach-sampling project 1991 (ICES, 1997) indicate that the relationship between the variance and the mean of the stomach contents may be formulated in the following way:

$$Var\left(STOM_{i,j,y,q}\right) = \frac{E\left(STOM_{i,j,y,q}\right)\ \left(1 - E\left(STOM_{i,j,y,q}\right)\right)}{V_{pred}\ U_{i,y,q}} \qquad \text{Eq. 24}$$

where $U_{i,y,q}$ is a known quantity reflecting the sampling level of a predator entity, e.g. the number of hauls containing stomach samples of a given predator and size class. V_{pred} is a predator species-dependent parameter linking the sampling level and variance. Equating Eq. 22 and Eq. 24 implies that:

$$P_{i,y,q} = V_{pred}\ U_{i,y,q} - 1 \qquad \text{Eq. 25}$$

Insertion of Eq. 25 into Eq. 23 results in that:

$$P_{i,j,y,q} = \left(V_{pred}\ U_{i,y,q} - 1\right) \frac{\bar{N}_j\ W_j\ S_{i,j}(l_i, l_j)}{\sum_j \left(\bar{N}_j\ W_j\ S_{i,j}(l_i, l_j)\right) + OF_i\ S_{OF,i}(l_i)}$$

The parameters, $p_{i,j,y,q}$ are uniquely determined through stock numbers, total mortality, suitability parameters and V_{pred}.

Assuming that the diet observations for the predator/length groups are independent the negative log-likelihood function including all predators/length groups are derived from Eq. 21:

$$l_{STOM} = -\log(L_{STOM}) = -\sum_{i,j,y,q} \log\left(f_{i,j,y,q}\right) \qquad \text{Eq. 26}$$

Modification of the stomach contents model

The stomach contents observations, $STOM_{prey,l_{prey},pred,l_{pred},y,q}$ are given for combinations of prey and predator species and size classes. For a diet consisting of a large proportion of "other food" and several species and prey size classes, the proportion of the individual combination of species and size becomes small (less than 0.1%) for several prey entities. Very small proportions, in combination with a modest sampling size per stratum, make the estimation of parameters impossible in some cases. To overcome the problem SMS has an option to let the likelihood use proportion summed overall size classes for a given prey species such that the prey entity equals the species.

The same grouping of all sizes from a prey is applied when the uniform size selection option (Eq. 12) is used. The likelihood function is the same as used for stomach observations that include prey size.

Stock–recruitment

To enable estimation of recruitment in the last year for cases where survey indices catch from the recruitment age are missing (e.g. saithe), and to estimate parameters for forecast use, a stock–recruitment relationship $R_{s,y} = R\left(SSB_{s,y} | \alpha_s, \beta_s\right)$ penalty function is included in the likelihood function.

Recruitment to the model takes place in the same season ($recq$) and at the same age (fa) for all species. It is estimated from the Spawning–Stock Biomass (SSB) in the first season (fq) of the year, and a stock–recruitment relation. SSB is calculated from stock numbers, proportion mature (PM) and mean weight in the sea.

$$SSB_{s,y} = \sum_{a} N_{s,y,a,q=recq}\ PM_{s,y,a,q=recq}\ W_{s,y,a,q=recq} \qquad \text{Eq. 27}$$

At present, the Ricker (Eq. 28), the Beverton and Holt (Eq. 29), segmented regression (Eq. 30) and geometric mean are implemented.

$$R_{s,y} = \alpha_s\ SSB_{s,y-fa,fq}\ e^{(\beta_s\ SSB_{s,y-fa,fq})} \qquad \text{Eq. 28}$$

$$R_{s,y} = \frac{\alpha_s\ SSB_{s,y-fa,fq}}{1 + \beta_s\ SSB_{s,y-fa,q}} \qquad \text{Eq. 29}$$

$$R_{s,y} = \begin{cases} \alpha_s\ SSB_{s,y-fa,fq} & \text{for } SSB_{s,y-fa,fq} < \beta_s \\ \alpha_s\ \beta_s & \text{for } SSB_{s,y-fa,fq} < \beta_s \end{cases} \qquad \text{Eq. 30}$$

Assuming that recruitment is lognormal distributed, the negative log-likelihood, l_{SR}, equals:

$$\begin{aligned} l_{SR} &= -\log(L_{SR}) \\ &\propto NOY \sum_{s} \log(\sigma_{SR\,a}) \\ &+ \sum_{s,a,y} \left(\log\left(N_{ss,a=fa,y,q=recq}\right) - E\left(\log\left(R_{s,y}\right)\right)\right)^2 / 2\sigma_{SR\,s}^2 \end{aligned} \qquad \text{Eq. 31}$$

Where NOY gives the number of years selected and where Eq. 31 gives the expected recruitment for the Ricker case.

$$E(\log(R_s)) = \log\left(\alpha_s\, SSB_{s,y-fa,fq}\, e^{(\beta_s\, SSB_{s,y-fa,fq})}\right) \qquad \text{Eq. 32}$$

Total likelihood function and parameterisation

The total negative log likelihood function, l_{TOTAL}, is found as the sum of the four terms:

$$l_{TOTAL} = l_{CATCH} + l_{SURVEY} + l_{STOM} + l_{SR}$$

To ensure uniquely determined parameters it is necessary to fix part of them. For the F at-age model (Eq. 3) the year selection at the beginning of each year range (Y) has been fixed to one ($F^2_{y=\text{first year in each group of years}} = 1$). The season effect in the last season of all years and ages is also fixed ($F^3_{y,a,q=last\ season} = 1/\text{number of seasons}$).

Eq. 4 and Eq. 8 indicate that it is only possible to determine relative vulnerability parameters, $\rho_{pred,prey}$. We have chosen to fix the vulnerability of other food for all predators to 1.0. Similarly, the biomass of other food OFpred has arbitrarily been set (e.g. at 1 million tonnes) for each predator. The actual value by predator was chosen to obtain estimates of vulnerability parameters for the fish prey at around 1. Other parameters than suitability are practically unaffected by the actual choice of biomass of other food.

In the food suitability function (Eq. 8 and Eq. 9) vulnerability and overlap effects cannot be distinguished. Hence the overlap parameters must be fixed for at least one season. In practice, several combinations of overlap have however to be fixed (at e.g. 1).

Initial stock size, i.e. the stock numbers in the first year and recruitment over the years are used as parameters in the model while the remaining stock sizes are considered as functions of the parameters determined by Eq. 1 and Eq. 2.

The year effect ($F^2_{y,s}$) in the separable model for fishery mortality (Eq. 3) takes one parameter per species for each year in the time-series which sums up to a considerable number of parameters. To reduce this high number of parameters, the year effect can optionally be modelled from a cubic spline function which requires fewer parameters. The number of knots must be specified if this option is used.

Another way to reduce the number of parameters is to substitute the parameters $\sigma_{CATCH}, \sigma_{SURVEY}$ and σ_{SR} used in the likelihood functions by their empirical estimates. This optional substitution has practically no effect on the model output and the associated uncertainty.

Appendix 1 gives an overview of parameters and variables in the model.

The parameters are estimated using maximum likelihood (ML) i.e. by minimizing the negative log-likelihood, l_{TOTAL}. The variance/covariance matrix is approximated by the inverse Hessian

matrix. Uncertainties of functions of the estimated parameters (such as biomass and mean fishing mortality) are calculated using the delta method.

SMS forecast

SMS is a forward-running model and can as such easily be used for forecast scenarios and Management Strategy Evaluation (MSE). SMS used the estimated parameters to calculate the initial stock numbers and exploitation patterns used in the forecast. Exploitation pattern is assumed constant in the forecast period but is scaled to a specified average F, derived dynamically from Harvest Control Rules (HCR). Recruits are produced from the stock–recruitment relation, input parameters and a noise term.

Recruitment

Recruitment is estimated from the available stock–recruitment relationships, f(SSB), and optionally a lognormal distributed noise term with standard deviation std.

$$R = f(SSB)\ e^{(std\ NORM(0,1))} \qquad \text{Eq. 33}$$

Where NORM(0,1) is a random number drawn from a normal distribution with mean=0 and standard deviation 1. A default value for std can be obtained from the estimated variance of stock–recruitment relationship, $\sigma^2_{SR_S}$ (Eq. 34)

Application of the noise function for the lognormal distributed recruitment gives on average median recruitment as specified by f(SSB). Optionally, recruitment can be adjusted with half of the variance, to obtain, on average, a mean recruitment given by f(SSB).

$$R = f(SSB)\ e^{(std\ NORM(0,1))}\ e^{\left(-(std^2/2)\right)} \qquad \text{Eq. 35}$$

Harvest Control Rules

Several HCR have been implemented, e.g. constant F and the ICES interpretation of management according to MSY for both short- and long-lived species. Selected, more complex management plans in force for the North Sea and Baltic Sea species have also been implemented.

Model validation

Model validation (in the years 2004–2009) was focused on the performance of the model using simulated data from an independent model and simulated data produced by the SMS model itself. The independent model was implemented using the R-package (R Development Core Team. 2011) and included a medium complex North Sea configuration (nine species, of which four are predators and eight species are preys). The simulation model follows the SMS model specification with an addition of von Bertalanffy growth curves to model mean length-at-age. Variance around mean length-at-age was assumed to increase by increasing age. This combined age–length approach made it possible to simulate all the data needed for model verification. Test dataset from the simulation model included 20 years of catch data, one survey time-series per species covering all years and ages, and four quarterly stomach samples in year ten including stomach observations for all predator length groups. Data from the independent simulation

model was used to verify that the SMS model works as intended and to investigate model sensitivity concerning observation errors on catch, survey cpue and stomach data.

To test if model parameters were identifiable when uncertainties estimated from real data were applied, the SMS model was modified to produce observations with the estimated observation noise of catch, survey and stomach data. The experiment consists of the following steps:

Estimate model parameters using the SMS model and available North Sea data.

Generate 100 sets of input data from SMS output (expected catch numbers, survey indices and stomach observations) and their associated variance of these values).

Let SMS estimate 100 sets of parameters from the 100 sets of input data.

This procedure results in one set of "true parameters", $\theta = (\theta_1, \dots, \theta_k)$ and 100 sets of estimated parameters, $\hat{\theta}_j = \left(\hat{\theta}_{1,j}, \dots, \hat{\theta}_{k,j}\right),\ j = 1, \dots, k$. Based on the 100 repetitions and for each of the k parameters the mean and the standard deviation of the mean $\bar{\hat{\theta}}_i$ and σ_i and hence the 95% confidence limits, was calculated. Finally, the proportion of the parameters was calculated for which θ_i lies in the 95% confidence interval of $\bar{\hat{\theta}}_i$.

The test showed that parameters are identifiable for most "real" North Sea configurations. For some species with relatively few diet observations, size selection parameters (Eq. 11) and the variance parameter (V) linking the stomach sampling level to the variance of Dirichlet distribution (Eq. 24 and Eq. 25), were outside the 95% confidence interval of $\bar{\hat{\theta}}_i$.

A more informal testing of the model has been done by simply using the model. SMS has been applied to produce the so-called key run for both the species rich North Sea system (ten species with stock number estimation including seven prey species, and 16 species of "other predators") (ICES, WGSAM 2011) and the species poor Baltic Sea (cod, herring and sprat, one predator and three prey species) (WGSAM 2008; WKMAMPEL 2009). In addition the model has been used in single-species mode for the ICES advice of blue whiting in the North East Atlantic (WGWIDE 2011) since 2005 and several sandeel stocks in the North Sea since 2009 (WGNSSK 2011). For MSE purposes, the model has been applied for sandeel and Norway pout in the North Sea (AGSANNOP 2007), blue whiting and pelagic stocks in the Baltic (WKMAMPEL 2009) in both single and multispecies mode.

SMS is essentially an extension of the statistical models normally used for single-species stock assessment. This allows the use of the long list of available diagnostics tools, e.g. residual plots, and retrospective analysis, developed for model testing of submodels for catch-at-age and survey indices. For stomach observations, however, fewer established methods are available. To apply reliable residual plots for stomach observations residuals need to be independent, which is not the case for the stomach contents model as the observations with respect to prey entity sum to one. Instead, we do the following: Let the predator entity, year and quarter be given and consider the stomach contents observations following the Dirichlet distribution:

$$STOM_r = \left(STOM_{r,1}, \dots, STOM_{r,k-1}\right) \sim Dir(p_{r,1}, \dots, p_{r,k})$$

Where r is the combined entity of predator entity, year and quarter and where $p_{r,j}, j = 1, \dots, k$ are the Dirichlet parameters estimated. Instead of considering the weight proportions, STOM, we consider absolute weight in the stomachs, $W_{r,j},\ j = 1, \dots, k$, where

$$STOM_{r,j} = \frac{W_{r,j}}{\sum_j W_{r,j}}$$

If we assume that $W_{r,j},\ j = 1, \ldots, k$ are independent and follow gamma distributions with the same scale parameter, θ_r, i.e.

$$W_{r,j} \sim \Gamma(p_{r,j}, \theta_r)\ \ j = 1, \ldots, k$$

it is well known that $STOM_r$ follows the Dirichlet distribution. We now assume that the opposite is the case (we have to prove that!) and hence assume that the absolute weights, $W_{r,j}$ are independent gamma distributed variables. We then transform these observations to obtain normal distributed residuals: Leaving out the indices, we get that $U = pgamma(W, p, \theta)$, where pgamma is the distribution function of the gamma distribution, is uniform distributed. To obtain normal distributed variables U is finally transformed to $V = qnorm(U)$, where qnorm is the inverse of the distribution function of the standardized normal distribution. This means that V is our new residuals for stomach contents observations.

To obtain the absolute weight of the prey entities from the relative stomach content, $STOM$, we have to know the total stomach weight of the predator entity. We have not extracted those from the basic observations but simply assumed that the total weight in the stomach is proportional to the number of stomachs sampled for a given predator entity.

Implementation

The SMS has been implemented using the AD Model Builder (Fournier *et al.*, 2011), which is freely available from ADMB Foundation (www.admb-project.org). ADMB is an efficient tool including automatic differentiation for Maximum likelihood estimation of many parameters in nonlinear models.

SMS configurations may contain more than 1000 parameters of which less than 5% are related to predation mortality. It is not possible to estimate all parameters simultaneously without sensible initial parameter values. Such values are obtained in three phases:

Estimate "single-species" stock numbers, fishing mortality and survey catchability parameters assuming that natural mortality (M1+M2) are fixed and known (i.e. as used by the ICES single-species assessments).

Fix all the "single-species" parameters estimated in step 1 and use the fixed stock numbers to estimate initial parameter values for the predation parameters.

Use the parameter values from step 1 and 2 as initial parameter values and re-estimate all parameters simultaneously in the full model including estimation of predation mortality M2.

Optimisation might potentially be dependent on the initial parameter values, however, the same final result was obtained using the three steps above or using a configuration where step two is omitted. Using step two however in general makes the estimation process more robust as extreme values and system crashes are avoided.

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Notation, parameters and variables

Indices

a	age
area	area with specific predation mortality
A1, A2	group of ages
Fa	first age group in the model
i	prey entity, combination of prey species and prey size group
j	predator entity, combination of predator group and predator size group
l	species size class
lpred	predator size class
lprey	prey size class
other	other food “species”
pred	predator species
prey	prey species
q	season of the year, e.g. quarter
recq	recruitment season
s	species
survey	survey identifier
y	year
Y	group of years

Parameters and variables

AB	available (suitable) prey biomass for a predator
ALK	proportion at-size for a given age group. Input
C	catch in numbers. Observations
Cpue	catch in numbers per unit of effort. Observations
D	number died
DM1	number died due to M1
DM2	number died due to M2
DF	number died due to F
F	instantaneous rate of fishing mortality
F^1	age effect in separable model for fishing mortality. Estimated parameter
F^2	year effect in separable model for fishing mortality. Estimated parameter
F^3	season effect in separable model for fishing mortality. Estimated parameter
M1	instantaneous rate of residual natural mortality. Input
M2	instantaneous rate of predation mortality estimated in the model
N	stock number
Ns,a,y=first year,q=1	Stock number in the first year of the model. Estimated parameters
Ns,a=fa,q=recq	Stock numbers at youngest age (recruitment). Estimated parameter
OF	Biomass of other food for a predator. Input
Q	catchability, proportion of the population caught by one effort unit. Estimated
Rs,y	recruitment calculated from stock–recruitment model
RA	food ration, biomass consumed by a predator. Input
S	suitability of a prey entity as food for a predator entity
S1, S2	mesh selection parameters. Estimated
SSB	spawning–stock biomass
STOM	weight proportion of prey i found in the stomach of predator j. Observations
U	sampling intensity of stomachs. Observation
V	variance of diet observations in relation to sampling intensity. Estimated Parameter
W	body weight. Input
Z	instantaneous rate of total mortality
α	stock–recruitment parameter. Estimated
β	stock–recruitment parameter. Estimated
ϱ	prey size preference of a predator. Estimated parameter
γ	food ration coefficients. Input
ς	food ration exponent. Input
υ	size dependent preference for other food. Estimated parameter
ηPREF	natural logarithm of the preferred predator prey size ratio. Estimated parameter
ηMIN	observed minimum relative prey size for a predator species. Input
ηMAX	observed maximum relative prey size for a predator species. Input
o	spatial overlap between predator and prey species. Estimated parameter
ρ	coefficient of species vulnerability. Estimated parameter
σCATCH	standard deviation of catch observations. Estimated parameter
σPREF	parameter expressing how particular a predator is about the size of its prey. Parameter
σSR	standard deviation of stock–recruitment estimate. Estimated parameter
σSTOM	standard deviation of stomach content observations (used with lognormal distribution)
σSURVEY	standard deviation of survey cpue observations. Estimated parameter

Appendix 2: Option file for SMS-key-runs

Key-run 2023

File SMS.dat

```
# sms.dat option file
# the character "#" is used as comment character, such that all text and numbers
# after # are skipped by the SMS program
#
########################################
# Produce test output (option test.output)
#  0 no test output
#  1 output file sms.dat and  file fleet.info.dat as read in
#  2 output all single species input files as read in
#  3 output all multi species input files as read in
#  4 output option overview
#
# 11 output between phases output
# 12 output iteration (obj function) output
# 13 output stomach parameters
# 19 Both 11, 12 and 13
#
# Forecast options
# 51 output hcr_option.dat file as read in
# 52 output prediction output summary
# 53 output prediction output detailed
0
########################################
# Produce output for SMS-OP program. 0=no, 1=yes
0
########################################
# Single/Multispecies mode (option VPA.mode)
# 0=single species mode
# 1=multi species mode, but Z=F+M (used for initial food suitability parm. est.)
# 2=multi species mode, Z=F+M1+M2
0
########################################
# Number of areas for multispecies run (default=1)
1
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
#
# single species parameters
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
#
## first year of input data (option first.year)
1974
########################################
## first year used in the model (option first.year.model)
```

```
1974
########################################
## last year of input data (option last.year)
2019
########################################
## last year used in the model (option last.year.model)
2019
########################################
##  number of seasons (option last.season). Use 1 for annual data
4
########################################
## last season last year (option last.season.last.year). Use 1 for annual data
4
########################################
## number of species (option no.species)
27
########################################
# Species names, for information only. See file species_names.in
#   Fulmar Guillemot Her. Gull Kittiwake GBB. Gull Gannet Puffin Razorbill R. radiata G. gurnards
W.horse mac N.horse mac Grey seal H. porpoise Hake Cod Whiting Haddock Saithe Mackerel Herring N.
sandeel S. sandeel Nor. pout Sprat Plaice Sole
########################################
## first age all species (option first.age)
0
########################################
## recruitment season (option rec.season). Use 1 for annual data
3
########################################
## maximum age for any species(max.age.all)
10
########################################
## various information by species
# 1. last age
# 2. first age where catch data are used (else F=0 assumed)
# 3. last age with age dependent fishing selection
# 4. Esimate F year effect from effort data. 0=no, 1=yes
# 5. Last age included in the catch at age likelihood (normally last age)
# 6. plus group, 0=no plus group, 1=plus group
# 7. predator species, 0=no, 1=VPA predator, 2=Other predator
# 8. prey species, 0=no, 1=yes
# 9. Stock Recruit relation
#      1=Ricker, 2=Beverton & Holt, 3=Geom mean,
#      4= Hockey stick, 5=hockey stick with smoother,
#      51=Ricker with estimated temp effect,
#      52=Ricker with known temp effect,
#      >100= hockey stick with known breakpoint (given as input)
# 10. Additional data for Stock Recruit relation
# 11. Additional data for Stock Recruit relation
##
1 0 0 0 0 0 2 0 0 0 0  # 1 Fulmar
1 0 0 0 0 0 2 0 0 0 0  # 2 Guillemot
1 0 0 0 0 0 2 0 0 0 0  # 3 Her. Gull
1 0 0 0 0 0 2 0 0 0 0  # 4 Kittiwake
```

```
1 0 0 0 0 0 2 0 0 0 0  # 5 GBB. Gull
1 0 0 0 0 0 2 0 0 0 0  # 6 Gannet
1 0 0 0 0 0 2 0 0 0 0  # 7 Puffin
1 0 0 0 0 0 2 0 0 0 0  # 8 Razorbill
3 0 0 0 0 0 2 0 0 0 0  # 9 R. radiata
4 0 0 0 0 0 2 0 0 0 0  # 10 G. gurnards
3 0 0 0 0 0 2 0 0 0 0  # 11 W.horse mac
6 0 0 0 0 0 2 0 0 0 0  # 12 N.horse mac
1 0 0 0 0 0 2 0 0 0 0  # 13 Grey seal
1 0 0 0 0 0 2 0 0 0 0  # 14 H. porpoise
9 0 0 0 0 0 2 0 0 0 0  # 15 Hake
10 1 9 0 10 1 1 1 107000 0 0  # 16 Cod
 8 0 6 0  8 1 1 1 119970 0 0  # 17 Whiting
10 0 7 0 10 1 1 1 94000 0 0  # 18 Haddock
10 3 8 0 10 1 1 0 1      0 0  # 19 Saithe
10 1 7 0 10 1 1 0 3      0 0  # 20 Mackerel
 8 0 5 0  8 1 0 1 1      0 0  # 21 Herring
 4 0 3 0  4 1 0 1 1      0 0  # 22 N. sandeel
 4 0 3 0  4 1 0 1 1      0 0  # 23 S. sandeel
 3 0 2 0  3 0 0 1 50000      0 0  # 24 Nor. pout
 3 1 2 0  3 1 0 1 94000 0 0  # 25 Sprat
10 1 7 0 10 1 0 0 1      0 0  # 26 Plaice
10 1 7 0 10 1 0 0 1      0 0  # 27 Sole
########################################
## use input recruitment estimate (option use.known.rec)
#   0=estimate all recruitments
#   1=yes use input recruitment from file known_recruitment.in
0
########################################
## adjustment factor to bring the beta parameter close to one (option beta.cor)
#           Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
         1e+06        1e+06        1e+05        1e+05        1e+06        1e+05        1e+05        1e+06
1e+06        1e+06        1e+06        1e+05
########################################
## year range for data included to fit the R-SSB relation (option SSB.R.year.range)
# first (option SSB.R.year.first) and last (option SSB.R.year.last) year to consider.
# the value -1 indicates the use of the first (and last) available year in time-series
# first year by species
#           Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
          1988         1982         1988           -1         1980           -1           -1           -1
1977         1981           -1           -1
# last year by species
#           Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
            -1           -1           -1           -1           -1           -1           -1           -1
-1           -1           -1           -1
########################################
## Objective function weighting by species (option objective.function.weight)
# first=catch observations,
# second=CPUE observations,
# third=SSB/R relations
```

```
# fourth=stomach observations, weight proportions
# fifth=stomach observations, number at length
##
0 0 0 0.1 1  # 1 Fulmar
0 0 0 0.1 1  # 2 Guillemot
0 0 0 0.1 1  # 3 Her. Gull
0 0 0 0.1 1  # 4 Kittiwake
0 0 0 0.1 1  # 5 GBB. Gull
0 0 0 0.1 1  # 6 Gannet
0 0 0 0.1 1  # 7 Puffin
0 0 0 0.1 1  # 8 Razorbill
0 0 0 1 1  # 9 R. radiata
0 0 0 1 1  # 10 G. gurnards
0 0 0 1 1  # 11 W.horse mac
0 0 0 1 1  # 12 N.horse mac
0 0 0 1 1  # 13 Grey seal
0 0 0 1 1  # 14 H. porpoise
0 0 0 1 1  # 15 Hake
1 1 0.1 1 0  # 16 Cod
1 1 0.1 1 0  # 17 Whiting
1 1 0.1 1 0  # 18 Haddock
1 1 1   1 0  # 19 Saithe
1 1 1   1 0  # 20 Mackerel
1 1 0.1 0 0  # 21 Herring
1 1 0.1 0 0  # 22 N. sandeel
1 1 0.1 0 0  # 23 S. sandeel
1 1 0.1 0 0  # 24 Nor. pout
1 1 0.1 0 0  # 25 Sprat
1 1 0.1 0 0  # 26 Plaice
1 1 0.1 0 0  # 27 Sole
########################################
## parameter estimation phases for single species parameters
# phase.rec (stock numbers, first age) (default=1)
1
# phase.rec.older (stock numbers, first year and all ages) (default=1)
1
# phase.F.y (year effect in F model) (default=1)
1
# phase.F.y.spline (year effect in F model, implemented as spline function)
-1
# phase.F.q (season effect in F model) (default=1)
1
# phase.F.a (age effect in F model) (default=1)
1
# phase.catchability (survey catchability) (default=1)
1
# phase.SSB.R.alfa (alfa parameter in SSB-recruitment relation) (default=1)
1
# phase.SSB.R.beta (beta parameter in SSB-recruitment relation) (default=1)
1
########################################
## minimum CV of catch observation used in ML-estimation (option min.catch.CV)
0.1
```

```
########################################
## minimum CV of catch SSB-recruitment relation used in ML-estimation (option min.SR.CV)
0.2
########################################
## Use proportion landed information in calculation of yield (option calc.discard)
#    0=all catches are included in yield
#    1=yield is calculated from proportion landed (file proportion_landed.in)
#           Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
              0            0            0            0            0            0            0            0
0           0           0           0
########################################
## use seasonal or annual catches in the objective function (option combined.catches)
# do not change this options from default=0, without looking in the manual
#    0=annual catches with annual time steps or seasonal catches with seasonal time steps
#      1=annual catches with seasonal time steps, read seasonal relative F from file F_q_ini.in
(default=0)
#           Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
              1            1            1            1            1            0            0            0
0           0           1           1
########################################
## use seasonal or common combined variances for catch observation
# seasonal=0, common=1 (use 1 for annual data)
#           Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
              1            1            1            1            1            0            0            0
0           0           1           1
########################################
##
# catch observations: number of separate catch variance groups by species
#          Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
            4            5            5            3            3            3            3            2
3           2           3           3
#  first age group in each catch variance group
1 2 7 9         #  Cod
0 1 2 5 7       #  Whiting
0 1 2 6 8       #  Haddock
3 5 8           #  Saithe
1 2 3           #  Mackerel
0 1 8           #  Herring
0 1 4           #  N. sandeel
0 1             #  S. sandeel
0 1 3           #  Nor. pout
1 3             #  Sprat
1 2 3           #  Plaice
1 2 3           #  Sole
########################################
##
# catch observations: number of separate catch seasonal component groups by species
#          Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
```

```
           4           4           3           2           3           2           3           3
3           3           2           1
#  first ages in each seasonal component group by species
1 2 3 5         #  Cod
0 1 2 3         #  Whiting
0 1 2           #  Haddock
3 4             #  Saithe
1 2 4           #  Mackerel
0 1             #  Herring
0 1 2           #  N. sandeel
0 1 2           #  S. sandeel
0 1 3           #  Nor. pout
1 2 3   #  Sprat
1 2             #  Plaice
1               #  Sole
########################################
## first and last age in calculation of average F by species (option avg.F.ages)
2 4  # Cod
2 6  # Whiting
2 4  # Haddock
4 7  # Saithe
4 8  # Mackerel
2 6  # Herring
1 2  # N. sandeel
1 2  # S. sandeel
1 2  # Nor. pout
1 2  # Sprat
2 6  # Plaice
2 6  # Sole
########################################
## minimum 'observed' catch, (option min.catch). You cannot log zero catch at age!
#
# 0 ignore observation in likelihood
#
# negative value gives percentage (e.g. -10 ~ 10%) of average catch in age-group for input catch=0
# negative value less than -100 substitute all catches by the option/100 /100 *average catch in the
age group for catches less than (average catch*-option/10000
#
# if option>0 then will zero catches be replaced by catch=option
#
# else if option<0 and option >-100 and catch=0 then catches will be replaced by catch=average(catch
at age)*(-option)/100
# else if option<-100  and catch < average(catch at age)*(-option)/10000 then catches will be replaced
by catch=average(catch at age)*(-option)/10000
#           Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
             0           0           0           0           0           0           0           0
0           0           0           0
########################################
##
# catch observations: number of year groups with the same age and seasonal selection
#           Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
```

```
           3           3           3           2           3           3           2           2
2           1           3           2
#  first year in each group (please note #1 will always be changed to first model year)
1974 1993 2007  #  Cod
1974 1991 2007  #  Whiting
1974 1985 2000  #  Haddock
1974 1992       #  Saithe
1974 1980 2004  #  Mackerel
1974  1983 1998 #  Herring
1974 2005       #  N. sandeel
1974 2005       #  S. sandeel
1974   2003 #  Nor. pout
1974            #  Sprat
1974 1990 2003  #  Plaice
1974 1990       #  Sole
########################################
##
# number of nodes for year effect Fishing mortality spline
# 1=no spline (use one Fy for each year), >1 number of nodes
#          Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
           1           1           1           1           1           1           1           1
1           1           1           1
#  first year in each group
1975            #  Cod
1975            #  Whiting
1975            #  Haddock
1975            #  Saithe
1975            #  Mackerel
1975            #  Herring
1975            #  N. sandeel
1975            #  S. sandeel
1975            #  Nor. pout
1975            #  Sprat
1975            #  Plaice
1975            #  Sole
########################################
## year season combinations with zero catch (F=0) (option zero.catch.year.season)
# 0=no, all year-seasons have catchs,
# 1=yes there are year-season combinations with no catch.
#   Read from file zero_catch_seasons_ages.in
# default=0
1
########################################
## season age combinations with zero catch (F=0) (option zero.catch.season.ages)
# 0=no, all seasons have catchs,
# 1=yes there are seasons with no catch. Read from file zero_catch_season_ages.in
# default=0
1
########################################
## Factor for fixing last season effect in F-model (default=1) (fix.F.factor))
#           Cod      Whiting      Haddock       Saithe     Mackerel      Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
```

```
             1           1           1           1           1           1           1           1
1           1           1           1
########################################
## Uncertanties for catch, CPUE and SSB-R observations (option calc.est.sigma)
#  values: 0=estimate sigma as a parameter (the right way of doing it)
#          1=Calculate sigma and truncate if lower limit is reached
#          2=Calculate sigma and use a penalty function to avoid lower limit
#  catch-observation, CPUE-obs, Stock/recruit
#           1           0           0
            0           0           0
########################################
# Read HCR_option file (option=read.HCR) default=0
#  0=no  1=yes
0
########################################
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
#
# multispecies parameters
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
#
# Exclude year,season and predator combinations where stomach data are not incl.(option incl.stom.all)
#   0=no, all stomach data are used in likelihood
#   1=yes there are combinations for which data are not included in the likelihood.
#      Read from file: incl_stom.in
#   default(0)
1
########################################
##  N in the beginning of the period or N bar for calculation of M2 (option use.Nbar)
#  0=use N in the beginning of the time step (default)
#  1=use N bar
0
########################################
## Maximum M2 iterations (option M2.iterations) in case of use.Nbar=1
3
########################################
## convergence criteria (option max.M2.sum2) in case of use.Nbar=1
#  use max.M2.sum2=0.0 and M2.iterations=7 (or another high number) to make Hessian
3
########################################
## likelihood model for stomach content observations (option stom.likelihood)
#  1 =likelihood from prey weight proportions only (see option below)
#  2 =likelihood from prey weight proportions and from prey numbers to estimate size selection
#  3 =Gamma distribution for prey absolute weight and size selection from prey numbers
1
########################################
# Variance used in likelihood model for stomach contents as prey weight proportion (option stom-
ach.variance)
#  0 =not relevant,
#  1 =log normal distribution,
#  2 =normal distribution,
#  3 =Dirichlet distribution
```

```
3
########################################
## Usage of age-length-keys for calc of M2 (option simple.ALK))
#  0=Use only one sizegroup per age (file lsea.in or west.in)
#  1=Use size distribution per age (file ALK_all.in)
0
########################################
## Usage of food-rations from input values or from size and regression parameters (option consum)
#  0=Use input values by age (file consum.in)
#  1=use weight at age (file west.in) and regression parameters (file consum_ab.in)
#  2=use length at age (file lsea.in), l-w relation and regression parameters (file consum_ab.in)
1
########################################
## Size selection model based on (option size.select.model)
#  1=length:
#      M2 calculation:
#         Size preference:
#           Predator length at age from file: lsea.in
#           Prey     length at age from file: lsea.in
#         Prey mean weight is weight in the sea from file: west.in
#      Likelihood:
#         Size preference:
#           Predator mean length per length group (file: stom_pred_length_at_sizecl.in)
#           Prey mean length per ength group (file stomlen_at_length.in
#         Prey mean weight from mean weight per prey length group (file: stomweight_at_length.in
#  2=weight:
#      M2 calculation:
#         Size preference:
#           Predator weight at age from file: west.in
#           Prey     weight at age from file: west.in
#         Prey mean weight is weight in the sea from file: west.in
#      Likelihood:
#         Size preference
#                Predator mean weight is based on mean length per predator length group (file:
stom_pred_length_at_sizecl.in)
#              and l-w relation (file: length_weight_relations.in),
#           Prey mean weight per prey length group (file: stomweight_at_length.in)
#         Prey mean weight from mean weight per prey length group (file: stomweight_at_length.in
#  3=weight:
#       M2 calculation: Same as option 2
#       Likelihood:
#         Size preference:
#                Predator mean weight is based on mean length per predator length group (file:
stom_pred_length_at_sizecl.in)
#              and l-w relation (file: length_weight_relations.in),
#             Prey mean weight per prey length group (file: stomlen_at_length.in) and l-w relation
(file:length_weight_relations.in)
#          Prey mean weight from prey mean length per prey length group (file: stomlen_at_length.in)
and l-w relation (file: length_weight_relations.in)
#  4=weight:
#       M2 calculation:
#         Size preference:
```

```
#              Predator mean weight from file lsea.in (length in the sea) and l-w relation (file:
length_weight_relations.in)
#               Prey mean weight from file lsea.in (length in the sea) and l-w relation (file:
length_weight_relations.in)
#       Likelihood:  Same as option 3
#  5=weight in combination with simple.ALK=1:
#       M2 calculation:
#         Size preference:
#           Predator weight based on length from file ALK_all.in (length distribution at age) and l-
w relation (file: length_weight_relations.in)
#           Prey     weight based on length from file ALK_all.in (length distribution at age) and l-
w relation (file: length_weight_relations.in)
#         Prey mean weight based on length from file ALK_all.in (length distribution at age) and l-w
relation (file: length_weight_relations.in)
#       Likelihood: Same as for option 2
#  6=weight in combination with simple.ALK=1:
#       M2 calculation: Same as option 5
#       Likelihood: Same as option 3
2
########################################
# Adjust Length at Age distribution by a mesh selection function (option L50.mesh)
#  Please note that options simple.ALK shoud be 1 and option size.select.model should be 5
# L50 (mm) is optional given as input. Selection Range is estimated by the model
# L50= -1 do not adjust
# L50=0, estimate L50 and selection range
# L50>0, input L50 (mm) and estimate selection range
# by VPA species
#           Cod     Whiting     Haddock      Saithe    Mackerel     Herring  N. sandeel  S. sandeel
Nor. pout       Sprat      Plaice        Sole
            -1          -1          -1          -1          -1          -1          -1          -1
-1          -1          -1          -1
########################################
## spread of size selection (option size.selection)
#   0=no size selection, predator/preys size range defined from observations
#   1=normal distribution size selection
#   3=Gamma distribution size distribution
#     4=no  size  selection,  but  range  defined  by  input  min  and  max  regression  parameters  (file
pred_prey_size_range_param.in)
#   5=Beta distributed size distribution, within observed size range
#   6=log-Beta size distributed, within observed size range
#
# by predator
#       Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull      Gannet      Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake           Cod
Whiting     Haddock      Saithe    Mackerel
             0           0           0           0           0           0           0           0
0            0           0           0           0           4           0           0           0
0           0           0
########################################
## sum stomach contents over prey size for use in likelihood for prey weight proportions (option
sum.stom.like)
#   0=no, use observations as they are; 1=yes, sum observed and predicted stomach contents before used
in likelihood for prey weight proportions
```

```
#
# by predator
#        Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull       Gannet       Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake            Cod
Whiting     Haddock      Saithe    Mackerel
             1            1            1            1            1            1            1            1
1            1            1            1            1            1            1            1            1
1            1            1
########################################
## # Use estimated scaling factor to link number of observation to variance for stomach observation
likelihood (option stom_obs_var)
#     0=no, do not estiamte factor (assumed=1);  1=yes, estimate the factor;  2=equal weight (1) for
all samples
#
# by predator
#        Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull       Gannet       Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake            Cod
Whiting     Haddock      Saithe    Mackerel
             1            1            1            1            1            1            1            1
1            1            1            1            1            1            1            1            1
1            1         1
########################################
## # Upper limit for Dirichlet sumP. A low value (e.g. 10) limits the risk of overfitting. A high
value (e.g. 100) allows a full fit. (option stom_max_sumP)
# by predator
#        Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull       Gannet       Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake            Cod
Whiting     Haddock      Saithe    Mackerel
           100          100          100          100          100          100          100          100
100          100          100          100          100          100          100          100          100
100          100           100
########################################
## Scaling factor (to bring parameters close to one) for relation between no of stomachs sampling and
variance
#  value=0: use default values i.e. 1.00 for no size selection and otherwise 0.1 (option var.scale.stom)
#        Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull       Gannet       Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake            Cod
Whiting     Haddock      Saithe    Mackerel
             1            1            1            1            1            1            1            1
1            1            1            1            1          1            1            1            1
1            1            1
########################################
## other food suitability size dependency  (option size.other.food.suit)
#  0=no size dependency
#  1=yes, other food suitability is different for different size classes
#        Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull       Gannet       Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake            Cod
Whiting     Haddock      Saithe    Mackerel
             0            0            0            0            0            0            0            0
1            0            0            0            0            0            0            0            1
0            1            1
########################################
```

```
## Minimum observed relative stomach contents weight for inclusion in ML estimation (option
min.stom.cont)
#        Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull       Gannet       Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake           Cod
Whiting      Haddock       Saithe     Mackerel
         9e-05        9e-05        9e-05        9e-05        9e-05        9e-05        9e-05        9e-05
9e-05        9e-05        9e-05        9e-05        9e-05        9e-05        9e-09        9e-09        9e-09
9e-09        9e-05        9e-05
########################################
## Upper limit for no of samples used for calculation of stomach observation variance (option
max.stom.sampl)
#        Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull       Gannet       Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake           Cod
Whiting      Haddock       Saithe     Mackerel
          1000         1000         1000         1000         1000         1000         1000         1000
1000         1000         1000         1000         1000         1000         1000         1000         1000
1000         1000         1000
########################################
## Max prey size/ pred size factor for inclusion in M2 calc (option max.prey.pred.size.fac)
#        Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull       Gannet       Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake           Cod
Whiting      Haddock       Saithe     Mackerel
              5            5            5            5            5            5            5            5
0.5          0.5          0.5          0.5           50           50          0.9          0.5          0.9
0.5          0.5          0.5
########################################
## inclusion of individual stomach contents observations in ML for weight proportions (option
stom.type.include)
# 1=Observed data
# 2= + (not observed) data within the observed size range (=fill in)
# 3= + (not observed) data outside an observed size range. One obs below and one above (=tails)
# 4= + (not observed) data for the full size range of a prey species irrespective of predator size
(=expansion)
#        Fulmar    Guillemot    Her. Gull    Kittiwake    GBB. Gull       Gannet       Puffin    Razorbill
R. radiata G. gurnards W.horse mac N.horse mac    Grey seal H. porpoise          Hake           Cod
Whiting      Haddock       Saithe     Mackerel
              2            2            2            2            2            2            2            2
2            2            2            2            2            2            2            2            2
2            2            2
########################################
## use overlap input values by year and season (use.overlap)
#   0: overlap assumed constant or estimated within the model
#   1: overlap index from file overlap.in (assessment only, use overlap from last year in forecast)
#   2: overlap index from file overlap.in (assessment and forecast)
0
########################################
## parameter estimation phases for predation parameters
#  the number gives the phase, -1 means no estimation
#
#  vulnerability (default=2) (phase phase.vulnera)
2
# other food suitability slope (default=-1) (option phase.other.suit.slope)
2
```

```
# preferred size ratio (default=2) (option phase.pref.size.ratio)
-1
# predator size ratio adjustment factor (default=-1) (option phase.pref.size.ratio.correction))
-1
# prey species size adjustment factor (default=-1) (option phase.prey.size.adjustment)
-1
# variance of prefered size ratio (default=2) (option phase.var.size.ratio)
-1
# season overlap (default=-1) (option phase.season.overlap)
2
# Stomach variance parameter (default=2) (option phase.Stom.var)
2
# Mesh size selection of stomach age length key (default=-1) (option phase.mesh.adjust)
-1
########################################
```

File file_info.dat (survey settings)

```
# minimum CV of CPUE observations
0.20
# number of fleets by species
# COD
2
# WHG
2
# HAD
2
# POK
1
# MAC
1
# HER
3
# NSA
5
# SSA
3
# NOP
4
# SPR
3
# Ple
6
# SOL
2
#########################################################################
# 1-2, First year last year,
# 3-4. Alpha and beta - the start and end of the fishing period for the fleet given as fractions of the season (or year if annual data
are used)
# 5-6   first and last age,
# 7.   last age with age dependent catchability,
# 8.   last age for stock size dependent catchability (power model), -1 indicated no ages uses power model
# 9.   season for survey,
# 10.  number of variance groups for estimated catchability
# by species and fleet
#########################################################################
# COD  ############################
1983 2022 0 1 1 7   4 -1 1 3  # Fleet01: IBTS_Q1_gam
1992 2022 0 1 0 7   4 -1 3 3  # Fleet02: IBTS_Q3_gam
#
# WHG  ############################
1983 2022 0 0 1 5   4 -1 1 2 # Fleet02: IBTS_Q1
1991 2022 0 1 0 5   4 -1 3 3 # Fleet03: IBTS_Q3
#
# HAD  ############################
1983 2022 0 1 1 8   4 -1 1 2 # Fleet01: IBTS_Q1
1991 2022 0 1 0 8   2 -1 3 3 # Fleet03: IBTS_Q3
#
# POK  ############################
#1992 2022 0 1 3 8   4 -1 3 2 # Fleet01: IBTS Q3
1974 2022 0 0 3 9   3 -1 1 1  # Fleet02: SAM output with noise
#
# MAC  ############################
#1998 2019 0 1   0  0  0 -1 3 1  # Fleet01: recruitment-idx
#2010 2022 0 1   3 10  5 -1 3 2  # Fleet02: Swept-idx
1980 2022 0 0.1 1  9  1 -1 1 1  # Fleet03: SAM output with noise
#
# HER  ############################
1989 2022 0.9 1 1 8   3 -1 2 3 # Fleet01: HERAS
1984 2023 0 0 1 1   1 -1 1 1 # Fleet03: IBTS Q1
1992 2023 0 0 0 0   0 -1 3 1 # Fleet02: MIK
#
# NSA, SAN north  ############################
2004 2022 0 1 0 1  1 -1 4 2 # Fleet01: Dregde survey
1983 2002 0 1 1 3  3 -1 2 1 # Fleet02: Commercial, first half year 1983-2002
2003 2022 0 1 1 3  3 -1 2 2 # Fleet03: Commercial, first half year 2003-2022
1976 2004 0 1 0 0  0 -1 3 1 # Fleet04: Commercial, second half year (old data)
2009 2022 0.5 0.7 1 4 3 -1 2 2 # Fleet05: acoustic
#
# SSA, SAN South  ############################
2004 2022 0 1 0 1  1 -1 4 2  # Fleet01: Dregde survey
1983 2002 0 1 1 3  3 -1 2 2  # Fleet02: Commercial, first half year 1983-2002
2003 2022 0 1 1 3  3 -1 2 1  # Fleet03: Commercial, first half year 2003-2022
#
# NOP  ############################
1992 2022 0 1 0 1  1 -1 3 2 # Fleet01: EGFS
1984 2023 0 0 1 3  3 -1 1 2 # Fleet03: IBTS Q1
1991 2022 0 1 2 3  3 -1 3 2 # Fleet03: IBTS Q3
1998 2022 0 1 0 1  1 -1 3 2 # Fleet04: SGFS
#
```

```
# SPR  ############################
2006 2022 0.9 1 1 3  3 -1 2 2 # Fleet01: HERAS Acoustic Q2
1983 2023 0 0   1 3  3 -1 1 2 # Fleet01: IBTS Q1
1992 2022 0 1   1 3  3 -1 3 2 # Fleet03: IBTS Q3
#
# PLE  ############################
1985 1995 0 1 1 9 4 -1 3 3 # Fleet01: BTS-Isis
1996 2022 0 1 1 10 4 -1 3 3 # Fleet02: BTS_IBTSQ3
2007 2022 0 1 1 8 5 -1 1 3 # Fleet06: IBTS_Q1
1974 1999 0 1 1 7 5 -1 3 3 # Fleet03: SNS1 1974-1999
2000 2022 0 1 1 7 4 -1 3 3 # Fleet04: SNS2 2000-
1990 2022 0 1 0 0 0 -1 3 1 # Fleet05:  DYFS
#
# SOL ############################
1985 2022 0 1 1 10  4 -1 3 4 # Fleet02: BTS
1974 2022 0 1 1 6  3 -1 3 3 # Fleet01: SNS
#
#########################################################################
# First age group in groups for estimates of variance of catchability at age
# COD  ############################
1 2 3 # Fleet01: IBTS_Q1_gam
0 1 2  # Fleet02: IBTS_Q3_gam
#
# WHG  ############################
1 2   # Fleet01: IBTS_Q1
0 1 2   # Fleet02: IBTS_Q3
#
# HAD  ############################
1 2    # Fleet01: IBTS_Q1
0 1 3  # Fleet03: IBTS_Q3
#
# POK  ############################
# 3 5    # Fleet01: IBTS Q3
3     # Fleet02: SAM output with noise
#
# MAC  ############################
#0    # fleet01: recruitment
#3 6  # Fleet02: Swept-idx
1    # Fleet03: SAM output
#
# HER  ############################
1 2 3 # Fleet01: HERAS
1    # Fleet02: IBTS Q1
0    # Fleet03: MIK
#
# NSA, SAN north  ############################
0 1 # Fleet01: Dregde survey
1  # Fleet02: Commercial, first half year 1982-1998
1 2 # Fleet03: Commercial, first half year 1999-
0  # Fleet04: Commercial, first half year (old data)
1 4  #  Fleet05: acoustic
# SSA, SAN South  ############################
0 1  # Fleet01: Dregde survey
1 2  # Fleet02: Commercial, first half year 1983-2002
1   # Fleet03: Commercial, first half year 2003-2022
#
# NOP  ############################
0 1    # Fleet01: EGFS
1 2   # Fleet02: EGFS
2 3   # Fleet03: IBTS Q1
0 1   # Fleet04: SGFS
#
# SPR  ############################
 1 2  # Fleet01:HERAS Acoustic Q2
 1 2  # Fleet02: IBTS_Q1
 1 2  # Fleet04: IBTS Q3
#
# PLE  ############################
1 3 5  # Fleet01: BTS-Isis-early
1 2 3  # Fleet02: BTS_IBTSQ3
1 3 5  # Fleet03: IBTS_Q1
1 3 5  # Fleet04: SNS1
1 3 5  # Fleet05: SNS2
0  # Fleet06:  DYFS
# SOL ############################
1 2 5 7  # Fleet02: BTS
1 2 4  # Fleet01: SNS
-999 # check
```

Annex 4: Working documents

WD01 Seal number update for the 2023 SMS North Sea key-run

WD02 Seal diet analysis

WD03 Why the new fish stomach data from the North Sea were not included in the 2023 SMS key-run

WD04 Summary of bird inputs for the SMS North Sea key-run

WD05 Estimating uncertainties of diet data for use in Stochastic Multispecies Models (SMS)

Seal number update for 2023 keyrun

Vanessa Trijoulet

1 Data used in the previous keyrun

Grey seal numbers have not been updated since the 2011 keyrun. According to the SMS stock annex, grey seal numbers from Thomas (2011) were used for 1984-2009 (North Sea and Orkney). The numbers for the period prior 1984 were estimated assuming exponential growth in 1984-1990, and the numbers after 2009 were assumed equal to the 2009 value as the population at that time seemed to be leveling off. Seal estimates from Thomas (2011) are given for the beginning of the breeding season, which corresponds more or less to quarter 4. The seal numbers in quarter 4 in the 2020 keyrun are given in Table 1.1. There is a decrease in seal numbers between Q4 in one year and Q1-3 in the next year (around 12-17%), probably to account for seal mortality after the breeding counts, however it was not possible to find a systematic method to reconstruct these values, and this was not mentioned in the stock annex.

Table 1.1: Seal numbers (thousands) in quarter 4 used in the 2020 keyrun

year	N
1974	16
1975	17
1976	18
1977	20
1978	21
1979	23
1980	25
1981	27
1982	29
1983	31
1984	33
1985	36
1986	39
1987	42
1988	45
1989	49
1990	52
1991	56

year	N
1992	60
1993	64
1994	68
1995	72
1996	76
1997	80
1998	84
1999	87
2000	91
2001	94
2002	97
2003	99
2004	101
2005	103
2006	104
2007	105
2008	106
2009	107
2010	107
2011	107
2012	107
2013	107
2014	107
2015	107
2016	107
2017	107
2018	107
2019	107

More importantly, it was not possible to reproduce the numbers from the 2020 keyrun. Indeed Thomas (2011) proposes two tables for seal numbers following two different estimation methods. None of the tables matches the seal numbers in the 2020 keyrun (Figure 1.1). Number in the 2020 keyrun are actually closer to the total estimates including seals in Div. 6a rather than the sum of the estimates for North Sea and Orkney.

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkney	Total
1984	5.3 (4 6.5)	5.7 (4.4 6.9)	26.5 (20.9 32.2)	21.1 (16.4 25.7)	58.5 (45.8 71.4)
1985	5.6 (4.3 6.9)	6 (4.7 7.2)	27.9 (22.1 33.8)	22.3 (17.5 26.9)	61.7 (48.7 74.8)
1986	6.1 (4.8 7.4)	6.3 (5 7.5)	29.2 (23.2 35.1)	23.7 (18.7 28.2)	65.2 (51.7 78.2)
1987	6.5 (5.1 7.9)	6.6 (5.3 7.9)	30.4 (24.3 36.7)	25.3 (20 30.2)	68.9 (54.7 82.6)
1988	7 (5.6 8.4)	7 (5.6 8.3)	31.6 (25 38.1)	27.1 (21.5 32.2)	72.7 (57.6 87)
1989	7.5 (6 9)	7.3 (5.8 8.8)	32.3 (25.5 39.1)	29 (23.1 34.5)	76.2 (60.4 91.3)
1990	8 (6.4 9.6)	7.7 (6.1 9.1)	33 (25.9 40)	31 (24.8 36.7)	79.6 (63.2 95.3)
1991	8.6 (6.9 10.2)	8 (6.3 9.5)	33.5 (26.2 40.5)	33 (26.5 39)	83 (65.9 99.2)
1992	9.2 (7.4 10.9)	8.2 (6.5 9.9)	33.8 (26.4 40.8)	35 (28.2 41.4)	86.2 (68.5 103.1)
1993	9.8 (8 11.6)	8.5 (6.7 10.2)	34 (26.5 41.1)	37.2 (29.9 44)	89.4 (71 107)
1994	10.5 (8.5 12.4)	8.7 (6.8 10.5)	34 (26.6 41.1)	39.3 (31.7 46.6)	92.5 (73.6 110.6)
1995	11.2 (9.1 13.2)	8.8 (6.9 10.8)	33.9 (26.6 41)	41.5 (33.4 49.3)	95.5 (76.1 114.3)
1996	12 (9.7 14.1)	9 (7 10.9)	33.8 (26.7 40.8)	43.7 (35.1 52)	98.4 (78.5 117.8)
1997	12.8 (10.3 15)	9 (7 11)	33.6 (26.6 40.5)	45.8 (36.7 54.7)	101.3 (80.7 121.3)
1998	13.6 (11 16)	9.1 (7.1 11.1)	33.4 (26.6 40.2)	47.9 (38.2 57.3)	104 (82.9 124.6)
1999	14.5 (11.7 17)	9.1 (7.1 11.1)	33.2 (26.5 39.9)	49.8 (39.5 59.8)	106.5 (84.8 127.8)
2000	15.3 (12.4 18.1)	9.1 (7.2 11.1)	33.1 (26.4 39.6)	51.5 (40.7 62.2)	109 (86.6 131)
2001	16.3 (13.1 19.2)	9.1 (7.2 11)	32.9 (26.4 39.4)	53 (41.6 64.4)	111.2 (88.2 134.1)
2002	17.2 (13.7 20.4)	9 (7.2 11)	32.8 (26.4 39.3)	54.3 (42.3 66.5)	113.3 (89.6 137.2)
2003	18.2 (14.4 21.7)	9 (7.2 11)	32.7 (26.3 39.2)	55.3 (42.8 68.7)	115.2 (90.7 140.5)
2004	19.2 (14.9 23)	9 (7.2 11)	32.7 (26.3 39.2)	56.1 (43.2 70.9)	116.9 (91.6 144)
2005	20.1 (15.4 24.4)	8.9 (7.1 10.9)	32.7 (26.3 39.2)	56.7 (43.4 73)	118.5 (92.2 147.4)
2006	21.1 (15.8 25.8)	8.9 (7.1 10.9)	32.7 (26.3 39.2)	57.1 (43.4 75)	119.8 (92.6 150.9)
2007	22 (16.1 27.4)	8.9 (7.1 10.9)	32.8 (26.3 39.2)	57.4 (43.4 76.8)	121 (92.8 154.3)
2008	22.9 (16.3 29)	8.9 (7.1 10.9)	32.8 (26.3 39.3)	57.5 (43.2 78.5)	122.1 (92.9 157.7)
2009	23.8 (16.5 30.7)	8.9 (7.1 10.9)	32.9 (26.3 39.4)	57.5 (42.9 80)	123.1 (92.8 161.1)
2010	24.6 (16.6 32.5)	8.9 (7.1 10.9	33 (26.3 39.5)	57.5 (42.6 81.3)	124 (92.6 164.2)

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkney	Total
1984	4.4 (3.7 5.4)	4.7 (4 5.8)	22.6 (18.7 27.5)	17.6 (15 21.5)	49.3 (41.4 60.2)
1985	4.7 (4.1 5.7)	5 (4.2 6.1)	23.8 (19.9 28.7)	18.8 (16 22.7)	52.3 (44.3 63.3)
1986	5.1 (4.4 6.2)	5.3 (4.5 6.4)	24.9 (20.9 30.1)	20.1 (17.4 24.1)	55.4 (47.3 66.8)
1987	5.5 (4.8 6.6)	5.6 (4.8 6.8)	25.9 (21.5 31.5)	21.6 (18.7 25.9)	58.7 (49.8 70.7)
1988	6 (5.1 7.1)	5.9 (5.1 7.2)	26.9 (22.4 32.8)	23.2 (20.2 27.7)	62 (52.8 74.8)
1989	6.4 (5.5 7.7)	6.2 (5.3 7.6)	27.5 (23 33.6)	24.8 (21.6 29.7)	65 (55.4 78.5)
1990	6.9 (5.9 8.2)	6.5 (5.5 7.9)	28 (23.3 34.4)	26.6 (23 31.7)	67.9 (57.7 82.2)
1991	7.4 (6.3 8.8)	6.8 (5.6 8.3)	28.3 (23.6 34.7)	28.3 (24.6 33.9)	70.8 (60.1 85.6)
1992	7.9 (6.7 9.4)	7 (5.8 8.5)	28.5 (23.7 35)	30.1 (26.2 35.9)	73.6 (62.5 88.8)
1993	8.5 (7.2 10.1)	7.2 (6 8.8)	28.6 (23.9 35)	31.9 (27.8 38)	76.2 (64.9 91.9)
1994	9.1 (7.7 10.8)	7.3 (6.1 9)	28.6 (24.1 34.9)	33.8 (29.5 40.1)	78.8 (67.3 94.8)
1995	9.7 (8.3 11.5)	7.4 (6.2 9.2)	28.5 (24.2 34.7)	35.5 (31 42.2)	81.3 (69.7 97.6)
1996	10.4 (8.9 12.3)	7.5 (6.2 9.3)	28.4 (24.2 34.4)	37.3 (32.5 44.2)	83.6 (71.8 100.2)
1997	11.1 (9.5 13.1)	7.6 (6.3 9.3)	28.3 (24.2 34)	38.9 (33.8 46.2)	85.8 (73.7 102.6)
1998	11.8 (10.1 13.9)	7.6 (6.3 9.3)	28.1 (24.1 33.6)	40.3 (34.9 48)	87.8 (75.5 104.9)
1999	12.5 (10.7 14.8)	7.6 (6.4 9.3)	28 (24.1 33.3)	41.6 (35.9 49.6)	89.7 (77.1 106.9)
2000	13.2 (11.3 15.6)	7.6 (6.4 9.2)	27.9 (23.9 33)	42.6 (36.8 50.9)	91.3 (78.4 108.7)
2001	13.9 (11.8 16.5)	7.6 (6.4 9.2)	27.7 (23.8 32.8)	43.5 (37.5 51.9)	92.8 (79.5 110.3)
2002	14.7 (12.2 17.5)	7.6 (6.4 9.1)	27.7 (23.7 32.6)	44.1 (38 52.6)	94 (80.4 111.8)
2003	15.4 (12.6 18.5)	7.5 (6.4 9.1)	27.6 (23.7 32.5)	44.6 (38.4 53.2)	95.1 (81.1 113.1)
2004	16 (13 19.5)	7.5 (6.4 9)	27.5 (23.6 32.4)	44.9 (38.4 53.5)	96 (81.4 114.4)
2005	16.7 (13.3 20.5)	7.5 (6.3 9)	27.5 (23.5 32.4)	45.1 (38.2 53.7)	96.8 (81.4 115.6)
2006	17.3 (13.5 21.6)	7.5 (6.3 9)	27.5 (23.5 32.4)	45.2 (37.9 53.8)	97.5 (81.1 116.8)
2007	17.8 (13.7 22.7)	7.5 (6.3 9)	27.5 (23.5 32.5)	45.2 (37.5 54)	98 (80.9 118.1)
2008	18.3 (13.8 23.9)	7.5 (6.2 9)	27.6 (23.4 32.6)	45.2 (37.1 54.2)	98.5 (80.6 119.6)
2009	18.7 (13.9 25.2)	7.5 (6.2 9)	27.6 (23.4 32.7)	45.1 (36.8 54.4)	98.9 (80.4 121.3)
2010	19.1 (14 26.5)	7.5 (6.2 9)	27.6 (23.4 32.8)	45.1 (36.5 54.7)	99.3 (80.2 122.9)

Figure 1.1: Seal estimates from Thomas (2011) obtained from pup production data only (top figure), or from pup production and 2008 total population estimate (bottom figure).

According to Thomas (2021), the grey seal number estimates relate to seals associated with the regularly monitored colonies. A multiplier is required to account for the seals that breed outside these colonies. This does not explain the large difference between the numbers in the 2020 keyrun and the numbers in Thomas (2011) given that most of the colonies are monitored.

In addition, after discussions with scientists at the Sea Mammal Research Unit (SMRU) of the University of St. Andrews, the population estimates from the SCOS reports are for the population that breed on the British side of the North Sea. There are estimates for grey seals elsewhere in the North Sea that are available in the OSPAR assessment report.

2 Most recent seal numbers data

2.1 Extrapolate data for 1984-2022

Most recent grey seal numbers come from Thomas (2021) and include estimates for the period 1984-2020. Contrary to the last keyrun, the seal population does not seem to level off after 2009. Seal numbers from 2021-2022 were obtained via personal communication (Phil Hammond (SMRU)).

Multipliers on the grey seal estimates to account for non-monitored colonies were made available for the years 1985, 2002, 2010, 2019, 2022 (pers. comm. Phil Hammond (SMRU)). Estimates for 1984-2022, were therefore extrapolated to the full British colonies following a linear regression between the scaled estimates (Figure 2.1).

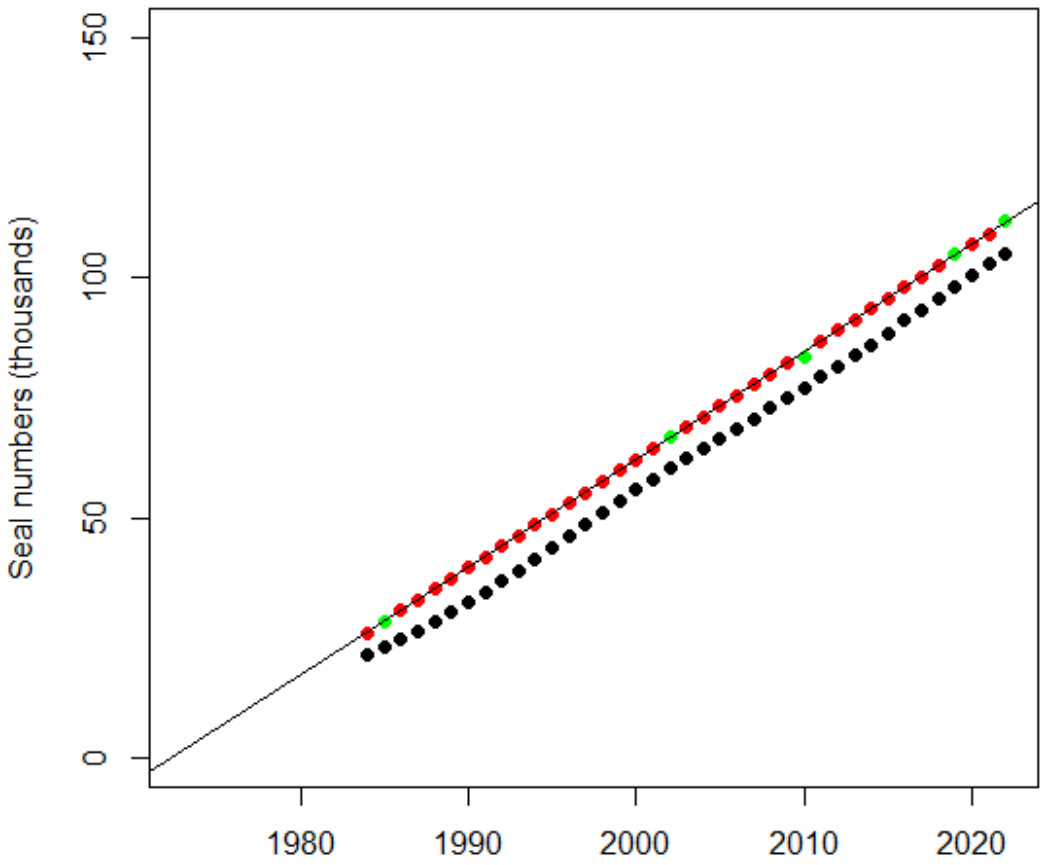

Figure 2.1: Seal estimates from Thomas (2021, 1984-2020) and provided by SMRU (2021-2022) in thousands in black. The green dots show the known estimates scaled to all British colonies. The red dots are the extrapolated numbers for the missing years. The line illustrate the linear regression used to extrapolate the estimates.

2.2 Extrapolate data for 1973-1983

Numbers prior to 1984 are predicted following a linear regression on the log scale so that the population is assumed to have an exponential growth in the period 1984-1990 (similar method as for the 2020 keyrun) (see Figure 2.2).

The corresponding seal numbers on the natural scale are given in Figure 2.3).

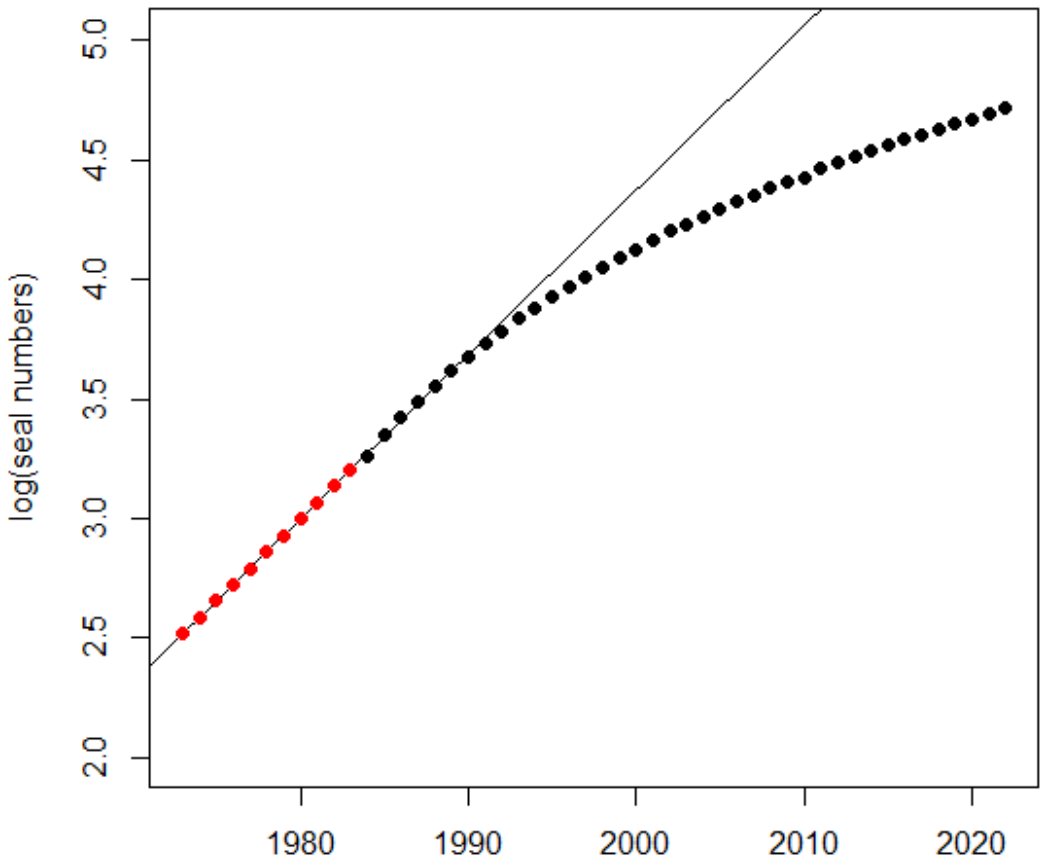

Figure 2.2: Seal extrapolated estimates for 1984-2022 in black. In red are the predictions for 1973-1983 following the linear regression highlighted by the line.

2.3 Seals outside of the UK

Time series of grey seals in the 2020 keyrun were based on the monitoring of colonies along the east coast of the UK. While these represent the majority of grey seal reproducing in the North Sea, colonies are also found along the European and Norwegian coasts of the North Sea.

Table 2.1: Pup counts in the North Sea taken from ICES 2022.

	pupCount
Norway south of 62N	35
Wadden Sea	1927

	pupCount
Dutch Delta Area	23
Scottish North Sea	32213
English North Sea	10725

ICES (2022) provide pup counts for different areas of the North Sea from recent surveys (2017, 2019, 2020, or 2021). The colonies in the North Sea were extracted (Table 2.1). Proportion of the pup counts outside the UK was estimated using these estimates and resulting in a proportion of around 0.044. While this is a strong assumption since based on only one survey point per area taken in different years, a multiplier of around 1.044 was applied to our British grey seal population estimates to extrapolate the numbers to the entire North Sea grey seal population. The final estimates are illustrated in orange in Figure 2.3.

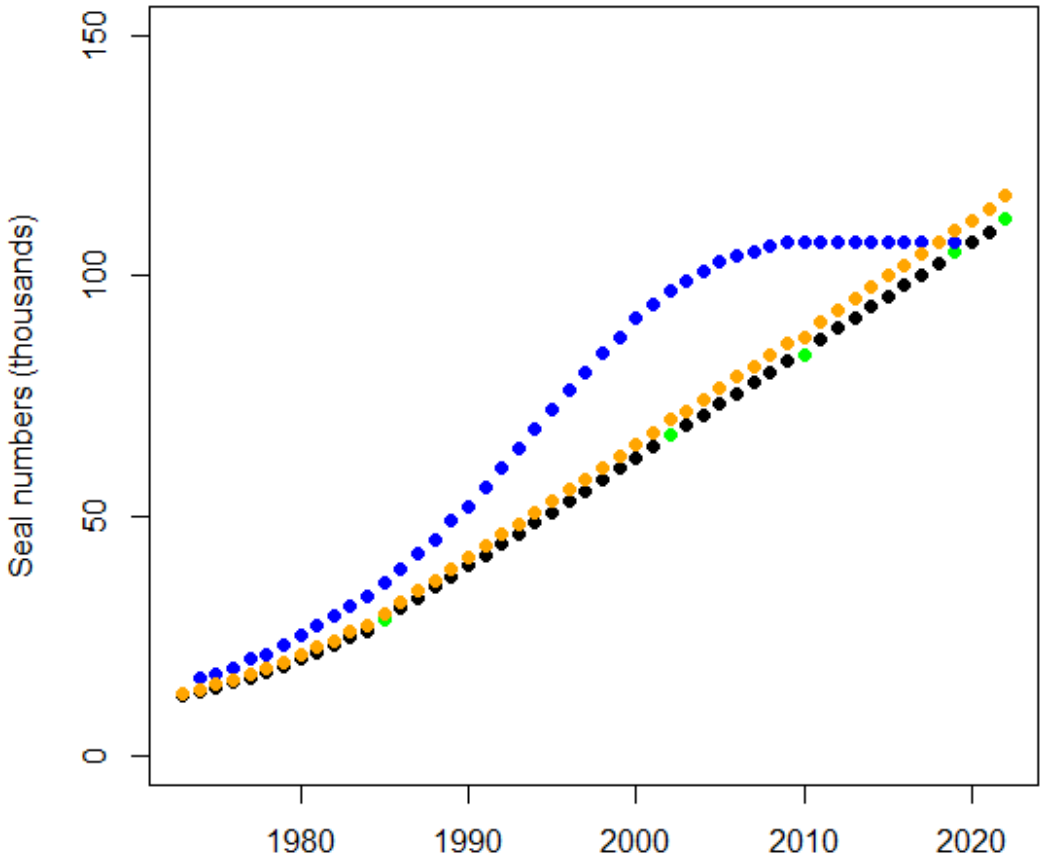

Figure 2.3: British grey seal estimates in thousands in black. The green dots illustrates the know non-extrapolated estimates. The blue dots show the number used in the 2020 keyrun (quarter 4). The orange dots represent the estimates where the British seal estimates were scaled up to account for the grey seals in the rest of the North Sea.

3 Conclusions

The working group decided to use the orange estimates as the final numbers for the 2023 North Sea keyrun in quarter 4. These are given in Table 3.1.

Table 3.1: Grey seal numbers (thousands) use for the 2023 North Sea keyrun.

Year	FinalAllNS
1973	12.930

Year	FinalAllNS
1974	13.853
1975	14.841
1976	15.901
1977	17.035
1978	18.251
1979	19.554
1980	20.949
1981	22.444
1982	24.046
1983	25.762
1984	27.206
1985	29.693
1986	31.898
1987	34.244
1988	36.590
1989	38.936
1990	41.282
1991	43.628
1992	45.974
1993	48.320
1994	50.666
1995	53.012
1996	55.358
1997	57.704
1998	60.050
1999	62.395
2000	64.741
2001	67.087
2002	69.900
2003	71.779
2004	74.125
2005	76.471
2006	78.817
2007	81.163
2008	83.509

Year	FinalAllNS
2009	85.855
2010	86.963
2011	90.547
2012	92.893
2013	95.239
2014	97.585
2015	99.931
2016	102.277
2017	104.623
2018	106.968
2019	109.420
2020	111.660
2021	114.006
2022	116.877

Estimates of seal numbers are from monitoring data collected at the beginning of the Autumn breeding season which approximates the quarter 4 of the year. For this reason, the population estimates in quarters 1-3 were assumed to be the same as in the quarter 4 the year before.

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Seal diet analysis

Vanessa Trijoulet

1 Data available

Grey seal diet was made available for the years 1985, 2002, and 2010-2011 by the SMRU (Phil Hammond pers. comm.) for use in SMS.The way the seal diet data was obtained is described in detail in Hammond and Wilson (2016). The data included seal consumption per fish stock that are considered in SMS (cod, whiting, haddock, herring, sandeel, norway pout, sprat, plaice) in tonnes per year, quarter (Q1-4), and regions of the North Sea (regions 1-4, Shetland, Orkney and northern North Sea, central North Sea, and southern North Sea respectively). The data also included outputs from otolith experiments as estimated fish length in the diet given otolith size (per year, region, and quarter).

These data allow us to allocate total consumption to length class of fish prey, the methods used are described below.

2 Method to allocate length distribution to grey seal consumption estimates

Each fish length sample is converted to weight using length-weight relationship parameters from Coull (1989) (as also used in the previous keyruns). The fish weights (weighted by the total consumption per region and quarter) are summed across regions such that the weight consumed is given per species, length bin, quarter, and year. Weights are then converted to proportion consumed per length bin, and these proportions are multiplied by the total grey seal consumption (in weight) per species and quarter to obtain the weight of prey consumed per length bin. The biomass of other food eaten by grey seals is derived from the total grey seal consumption per quarter and year. The output csv file ("adjusted_seal_diet.csv") contains the biomass of prey eaten by all grey seals (column "prey_w") per length bin, quarter, and year. The number of scat samples per quarter and year is used to give information on uncertainty in the diet data, those are added to the column "n_food" in the output diet file.

Few assumptions were made while handling grey seal diet, as follows:
- Sprat was added to other food because of the small total consumption in each year and the lack of length samples (was absent from the seal diet in the 2020 keyrun, so already considered other food).
- If there are less than 5 length bins for a prey in one quarter and year, the length distribution from the adjacent quarter is added to these samples. This "borrowing" is made between quarters 1-2 and quarters 3-4. The 5 samples threshold was chosen after realizing that in few instances only 1-3 samples were available despite fish being consumed. We

assume these are not representative of the real length distribution in the diet. The borrowing between quarters was chosen so that it might keep a distinction between spawning seasons, e.g., spring, autumn.
- The diet in 1985 and 2010-2011 is given for a set of years e.g., 1983, 1985, 1988, and 2010-2011. In SMS, we assume the diet is in the year where there is the largest number of samples, i.e., 1985, and 2010.

The code for the analysis is available on the WGSAM GitHub repository. The script creates figures of the length distribution before and after borrowing.

3 Method to split sandeel diet per area (northern or southern North Sea)

Sandeel in the North Sea area is managed as six individually assessed stocks. Given the lack of input data at the correct spatial scale, two sandeel stocks are considered in SMS and split into northern and southern North Sea stocks. In the previous SMS keyruns, the total grey seal predation was attributed entirely to the northern sandeel stock. In the 2023 keyrun, the proportion of sandeel consumed by grey seals was extracted from the diet data with the assumption that the northern areas correspond to Shetland, Orkney and northern North Sea, and the southern area to the central North Sea, and the southern North Sea. This resulted in the proportions in Table 3.1. These proportions are used to split the diet data between northern and southern sandeel. The code to extract the proportions is also available on the WGSAM repository.

Table 3.1: Proportion of sandeel consumed per area

	1985 North	1985 South	2002 North	2002 South	2010 North	2010 South
Quarter 1	0.879	0.121	0.795	0.205	0.598	0.402
Quarter 2	0.892	0.108	0.781	0.219	0.657	0.343
Quarter 3	0.844	0.156	0.776	0.224	0.669	0.331
Quarter 4	0.820	0.180	0.805	0.195	0.637	0.363

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Hammond, P. S., and L. J. Wilson. 2016. "Grey Seal Diet Composition and Prey Consumption." Scottish Marine and Freshwater Science Vol 7 No20. Marine Scotland Science. https://doi.org/10.7489/1799-1.

WD: why the new fish stomach data from the North Sea were not included in the 2023 SMS key-run

An updated stomach database has been made available for the ICES community (https://stomachdata.ices.dk/inventory), which, among other things, contains a range of newly analysed fish stomachs from the North Sea that could potentially be relevant for the SMS key-run. However, WGSAM decided against using the new data in the 2023 key-run based on several factors: 1) the data was not available until the week of WGSAM, and there was therefore not sufficient time to properly analyse and quality check the data. 2) The geographical distribution of the new stomach data was not comparable to the other data already used in SMS (see Figure 1 for an example of sample distribution of mackerel stomachs), and since SMS uses an average diet per year and season, there was concerns that without an intermediate standardisation the limited sampling distribution would not be representative of the predator-prey interactions in the entire spatial domain of the model. 3) Many of the newly analysed samples had substantial amounts of unidentified organic matter in their stomach. For consistency in the data one would expect that when the predators become larger, they would switch to a more piscivorous diet; however many of the new samples included only prey species in a small subset of length classes, with the remainder falling into the 'other food' category which results in an inconsistent treatment of the otherfood category if no correction in the data is applied.

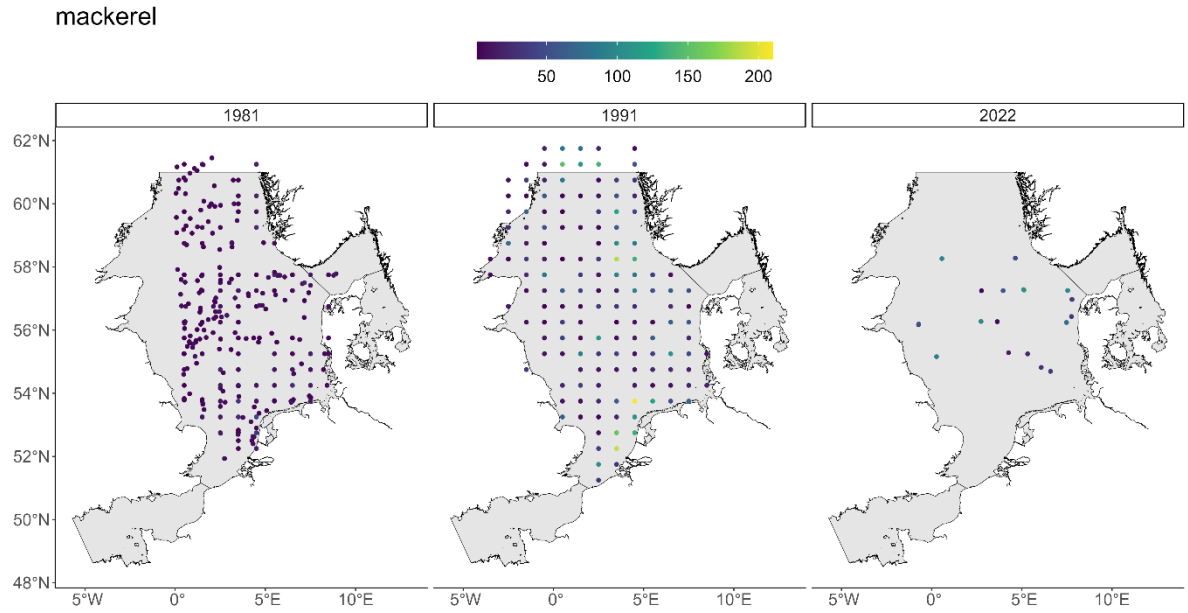

Figure 1: Distribution of mackerel stomachs in 1981, 1991, and the new data from 2022.

Summary of bird inputs for SMS

Michael A. Spence and Floor H. Soudijn

1 Background

The abundances of marine birds used in SMS were evaluated by the review panel. It was not clear how the bird numbers were calculated. According to the WGSAM 2011 report (ICES, 2011), bird abundances were calculated as the sum of at sea observations in the ESAS database and number of individuals in the colonies (source unknown) for the breeding season. How numbers were calculated outside the breeding season is not specified. Prior to 1990(?), abundance were estimated based on linear or logistic regression (ICES 2011). No data were available after 2011, and it seemed time for an update of the data.

At WGSAM 2023, we investigated the possibility of using bird numbers based on a study by Waggitt et al. (2020), which were also used in Spence et al. (2021). However, there were concerns about the reliability and repeatability of these numbers because they were not explicitly published in Waggitt et al. (2020). In the publication, monthly density maps were published that were averaged across years. For calculation of the annual bird abundances, a time varying version of the original models was used. It is known that the observational data has poor cover of the waters along the UK coast. It seems impossible to produce reliable density estimates based on these data per year. Indeed, Waggit himself advised against the use of the bird numbers (personal communication James Waggit).

An alternative source of marine bird abundance estimates is found in Dierschke et al. (2022). Dierschke et al. (2022) produced a report on annual abundance of breeding pairs for OSPAR. The report is based on counts of breeding pairs at breeding colonies in the Greater North Sea OSPAR region (II a, b, d, e and f, of which areas II a, b, d and f correspond to ICES area 4, Figure 1). These abundance estimates are based on counts of breeding pairs in the North Sea, which means there are no estimates of abundance available outside the breeding season. Second, not all breeding individuals necessarily feed in the North Sea. Below we describe how we can use these data in SMS and also give some more details on data quality.

Figures 2 to 9 compare the data from SMS in 2020, Waggitt et al. (2020) and Dierschke et al. (2022). The three time series are generally different but the trends in data in the SMS 2020 key run and report by Dierschke et al. (2022) seems to be roughly similar, but there are some deviations in absolute numbers, especially for the Northern Fulmar and Northern Gannet. The numbers produced by Dierschke et al. (2022) have the obvious advantage of including more years of actual data compared to the SMS data.

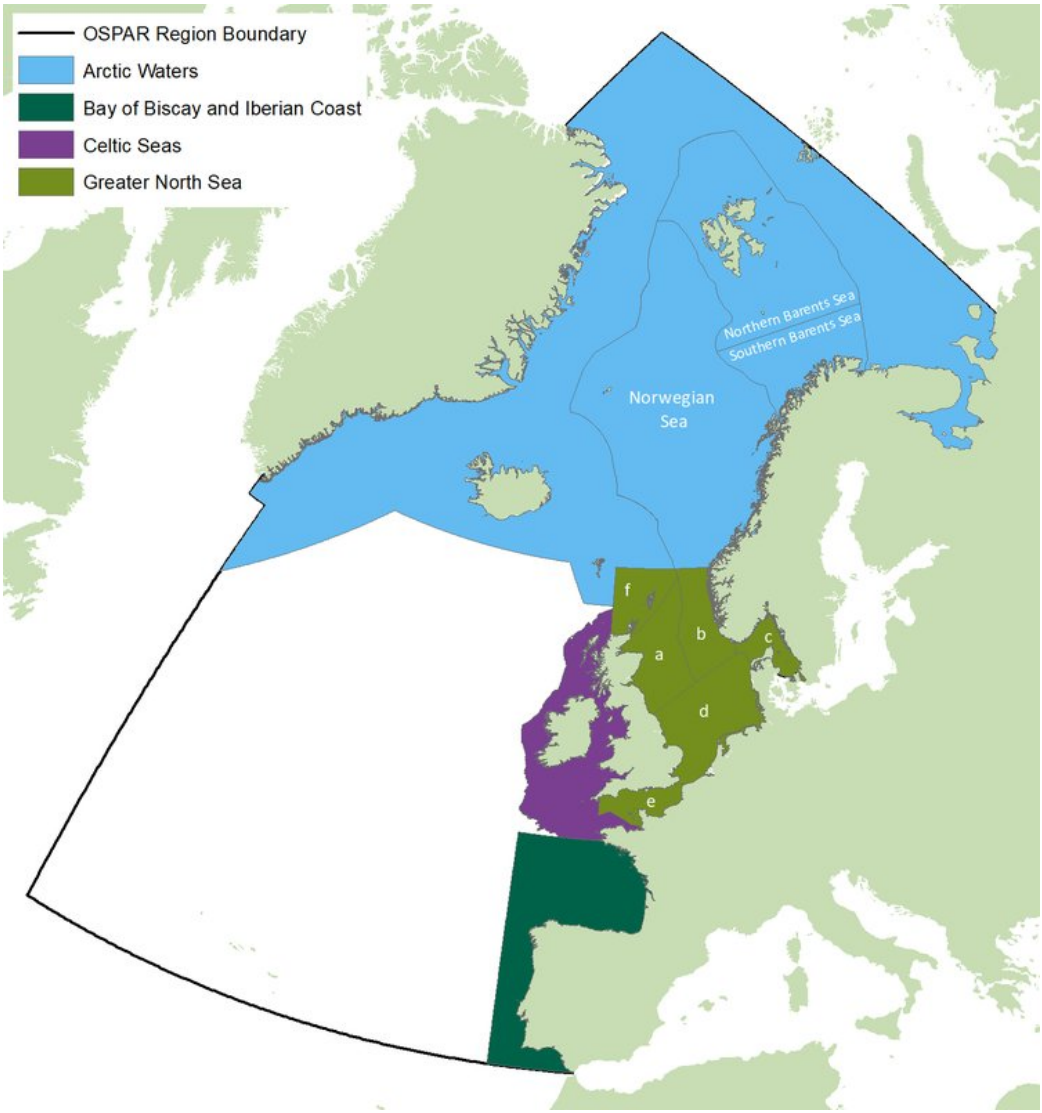

Figure 1: Marine bird assessment areas as used by Dierschke et al. (2022).

2 SMS numbers for 2023 key run

We have two proposals for the use of bird data for SMS key run. Let $N_{i,t,q}^{2023}$ be the numbers of the ith species in the tth year and the qth quarter in the 2023 key run. Similarly, let $D_{i,t}$ represent the abundance estimates by Dierchike et al. (2022).

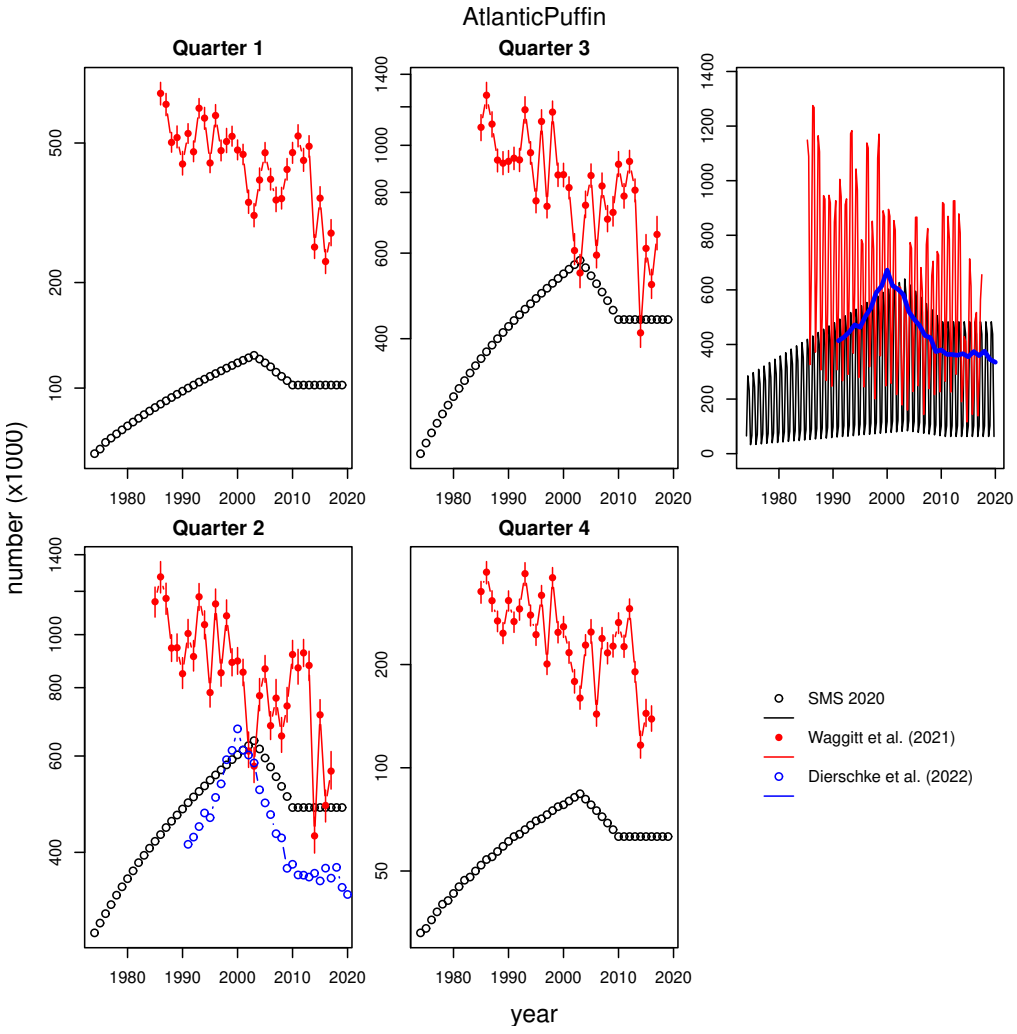

Figure 2: Comparison of studies for Atlantic puffin.

2.1 Proposition 1

We continue as the 2020 key run, with the additional three years of bird abundances needed (for 2020-2022) being the same as the bird abundances used in 2019. That is, the data for the WGSAM 2023 key run in the years $t = 1974, \ldots, 2019$: $N^{2023}_{i,t,q} = N^{2020}_{i,t,q}$ for all species i and quarters q. Then, for the years $t = 2020, 2021, 2022$, $N^{2023}_{i,t,q} = N^{2020}_{i,2019,q}$ for and all species i and quarters q.

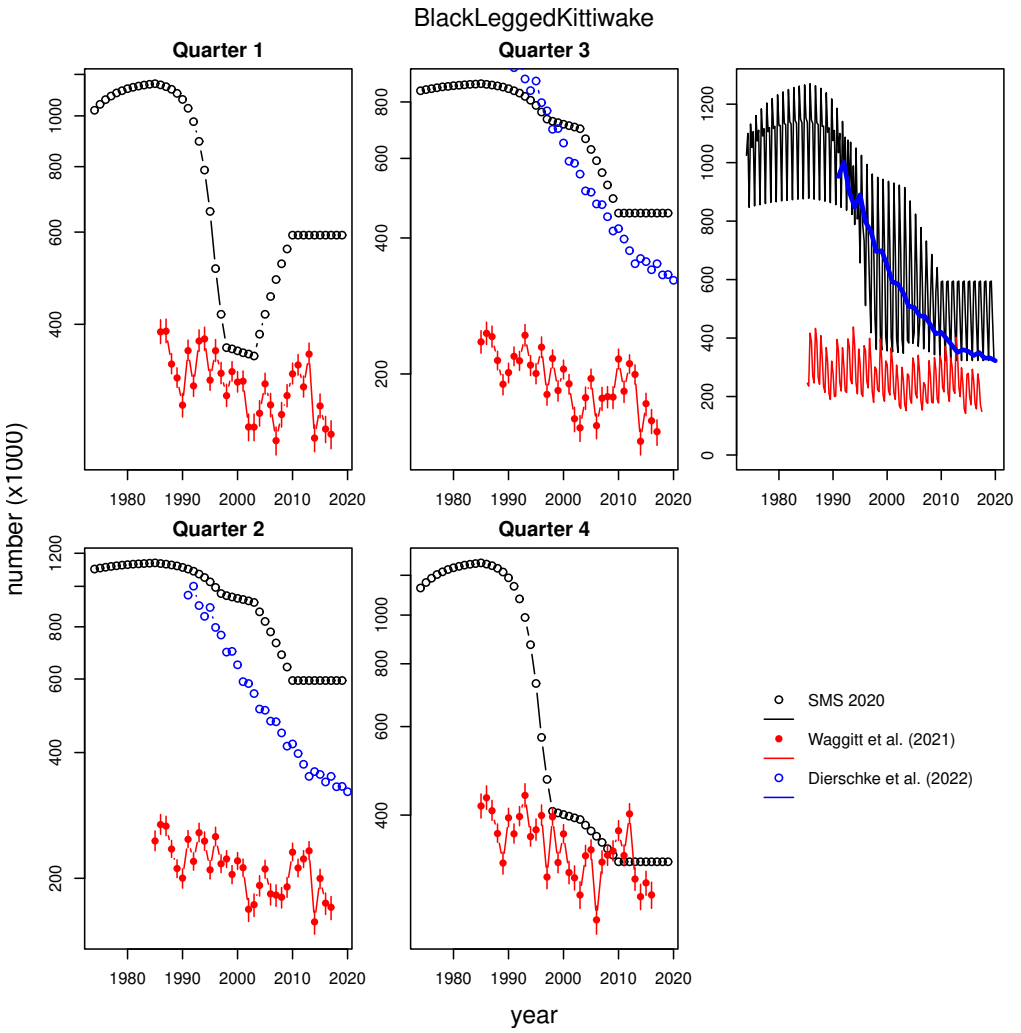

Figure 3: Comparison of studies for Black legged kittiwake.

2.2 Proposition 2

We use the numbers as reported by Dierschke et al., (2022), summed over OSPAR subregions IIa, IIb, IId and IIf for the quarters that fall inside the breeding seasons. These quarters differ per species as can be seen in Table 1. Since birds often arrive a bit before they initiate breeding and stay for some time after, we have taken the breeding numbers for all quarters that overlap with the breeding season even if it is only for one month Table 1).

From 1991-2020 we let the numbers be the same as Dierschke et al., (2022) in the breeding quarters. For the quarters that fall outside of the breeding season, we calculated bird abundances based on abundance ratios between

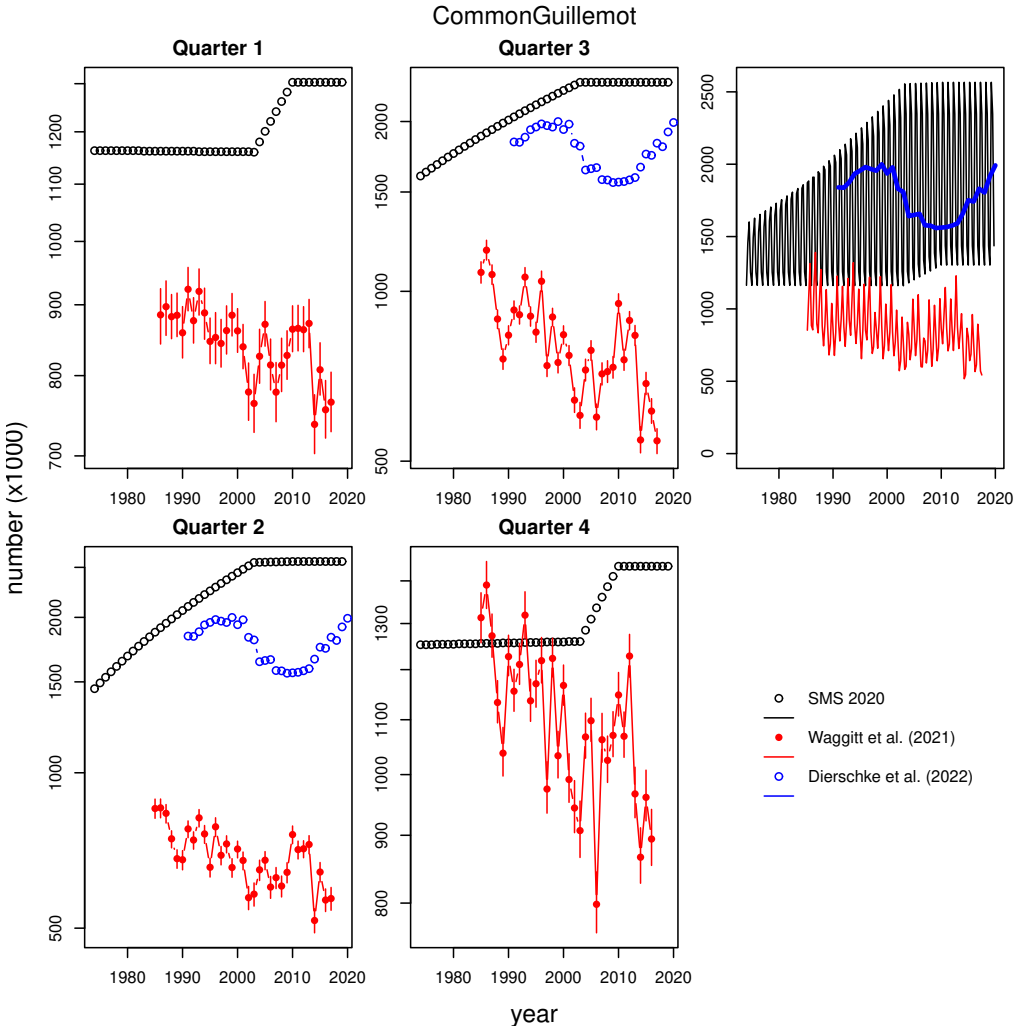

Figure 4: Comparison of studies for Common guillemot.

the abundance in the different quarters in the SMS 2020 key run compared to abundances in quarter 2 (as this is for all species the height of the breeding season). For the years between $t = 1991, \ldots 2020.$, this means

$$N^{2023}_{i,t,q} = \frac{N^{2020}_{i,t,q}}{N^{2020}_{i,t,2}} D_{i,t}, \tag{1}$$

the abundance for the 2023 key run in each quarter outside the breeding season q is equal to the abundance ratio in the 2020 key run between the abundance in q and $q = 2$ for all species i who's breeding season is solely quarter 2(see Table 1). For the species who's breeding season includes quarter

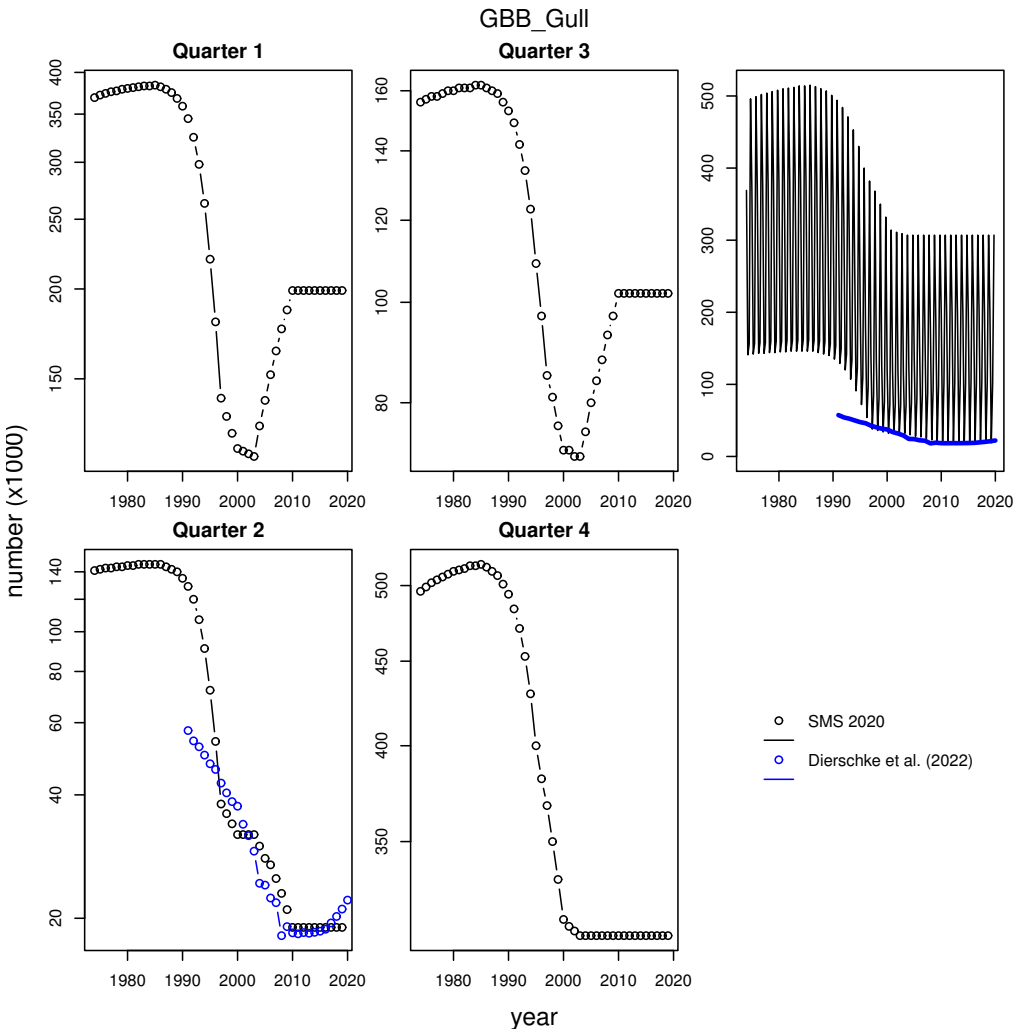

Figure 5: Comparison of studies for GBB gull.

3, then $N^{2023}_{i,t,3} = N^{2023}_{i,t,2}$ for all t and equation 1 holds for quarters 1 and 4.

From 2021-2022 we use the same abundances as for 2020, i.e. $N^{2023}_{i,t,q} = N^{2023}_{i,2020,q}$ for $t = 2021, 2022$ and all i and q. For the years prior to 1991, when there is no data available (in the 2019 SMS key run the values were based on linear or logistic regression back through time) we use the relative changes in abundance such as were used for the 2019 key run (ICES, 2011) between 1974 - 1990, as a ratio of the abundance in 1991, i.e.,

$$N^{2023}_{i,t,q} = \frac{N^{2020}_{i,t,q}}{N^{2020}_{i,1991,2}} D_{i,1991}, \mathbf{??} \tag{2}$$

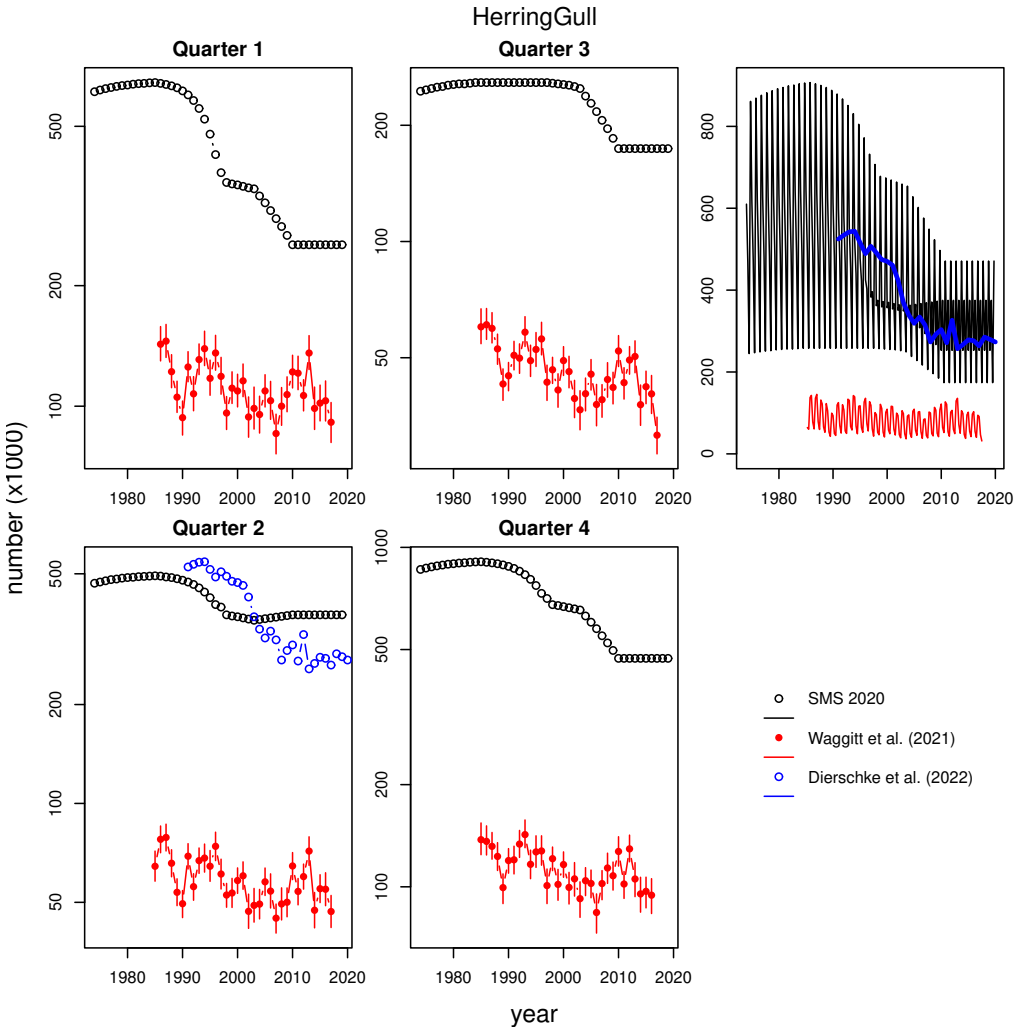

Figure 6: Comparison of studies for Herring gull.

all species i who's breeding season is solely quarter 2(see Table 1), q and $t = 1974, \ldots 1990$. For the species who's breeding season includes quarter 3, then $N^{2023}_{i,t,3} = N^{2023}_{i,t,2}$ for all t and equation **??** holds for quarters 1 and 4. Note that for the absolute values, we use the values reported by Dierschke et al. (2022) for 1991. Figures 10 to 17 compare the two propositions.

References

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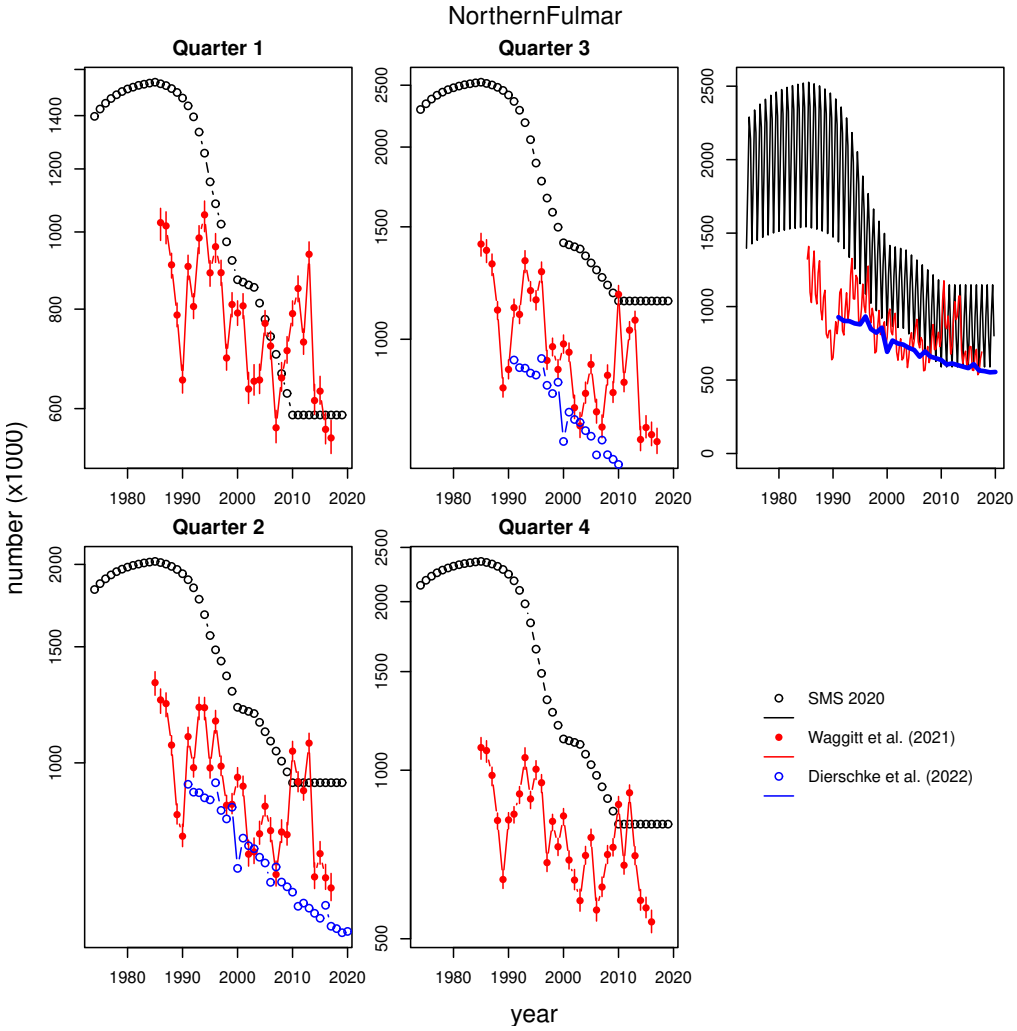

Figure 7: Comparison of studies for Northern fulmar.

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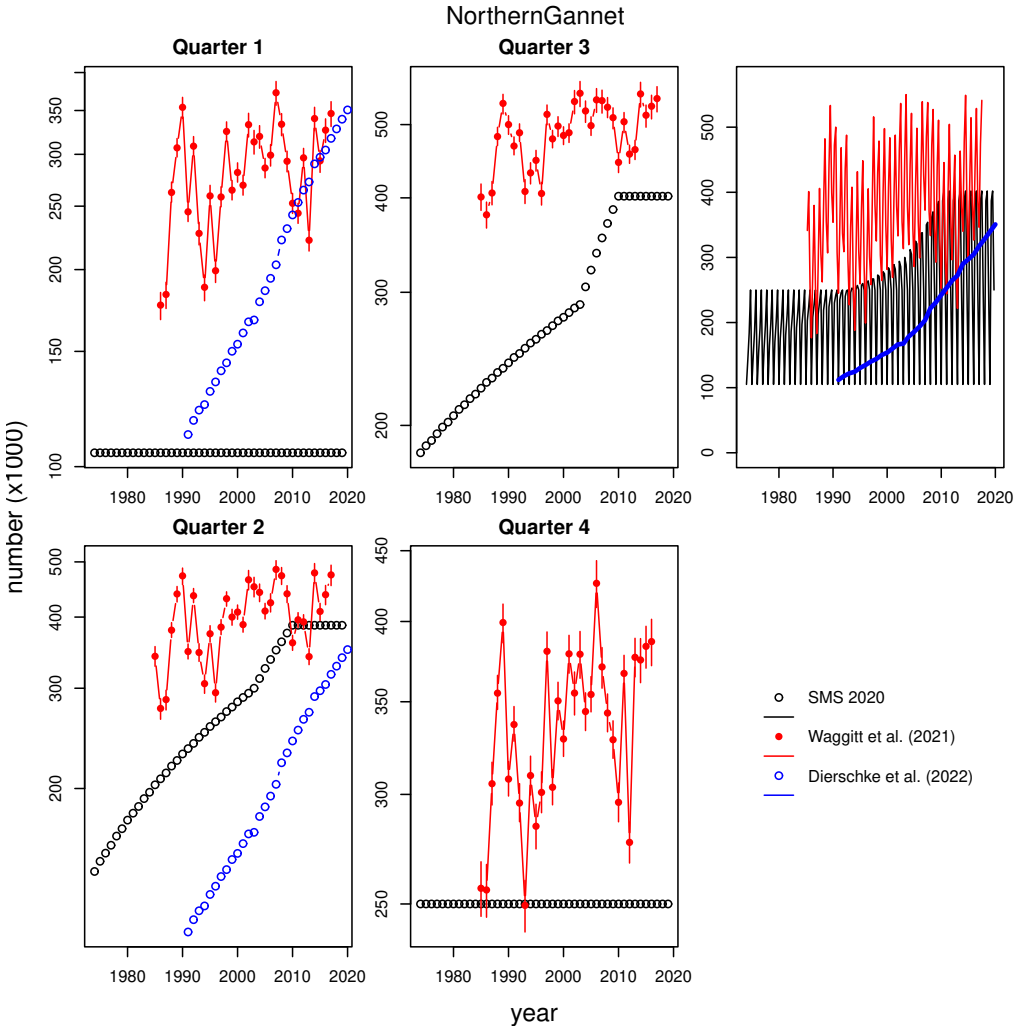

Figure 8: Comparison of studies for Northern gannet.

ICES (2011) WGSAM working group report. ICES, Copenhagen, Denmark. ICEM xxx

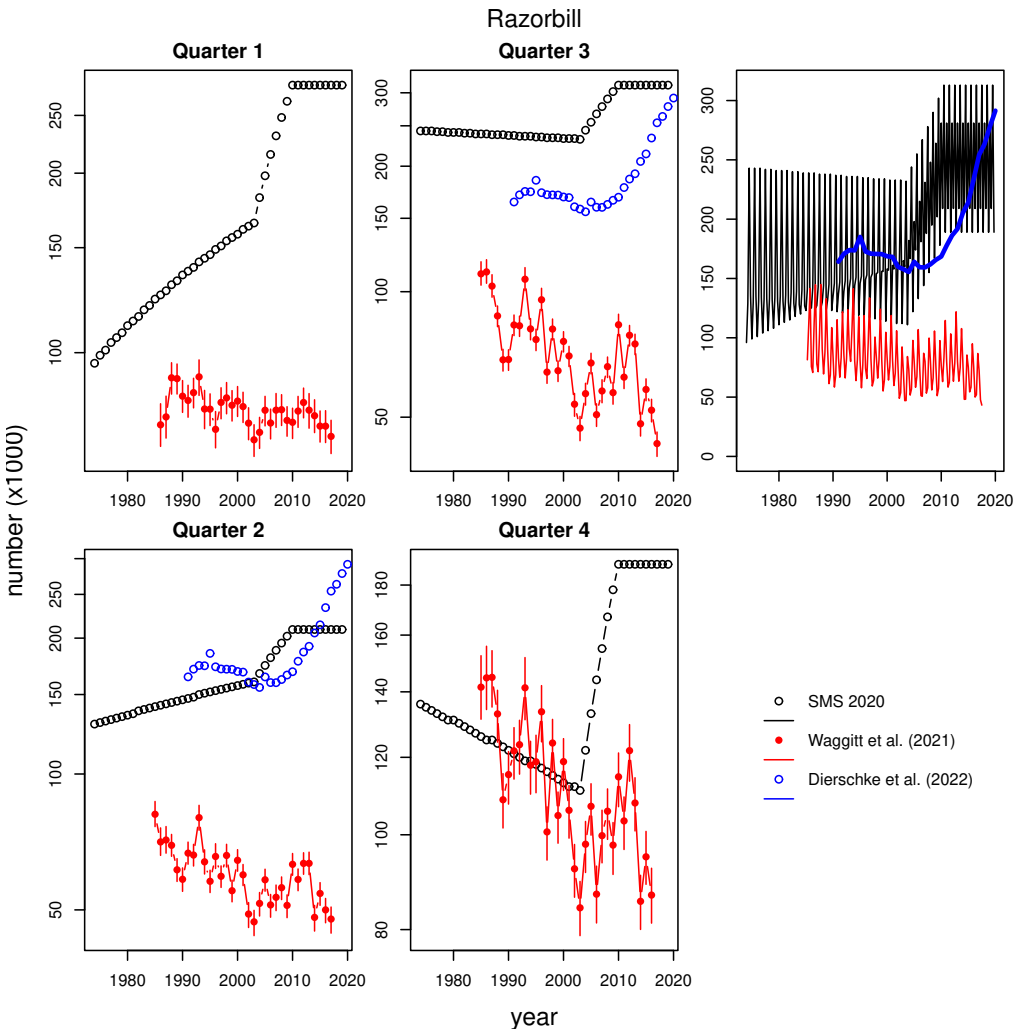

Figure 9: Comparison of studies for Razorbill.

Species	**breeding**	**quarters**	**source**
Atlantic puffin	April – June	Q2	
Black legged kittiwake	mid-June - August	Q2,Q3	
Common guillemot	May - July	Q2,Q3	
Greater black backed gull	April-June	Q2	
Herring gull	April- June	Q2	
Northern fulmar	May-July	Q2, Q3	
Northern gannet	April - July	Q2, Q3	
Razorbill	May - July	Q2, Q3	

Table 1: Breeding season per species and quarter(s) for which breeding season abundance are proposed to be used.

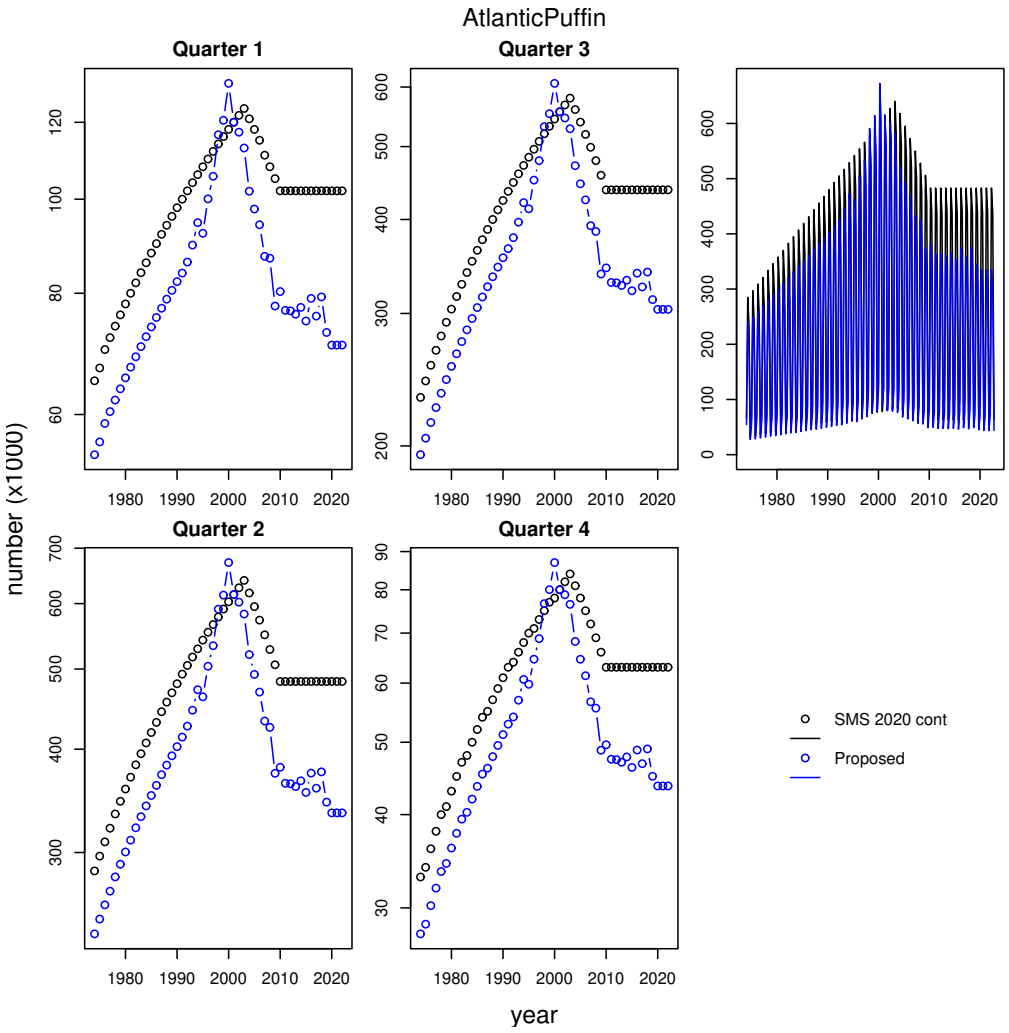

Figure 10: Comparison of proposals for Atlantic puffin.

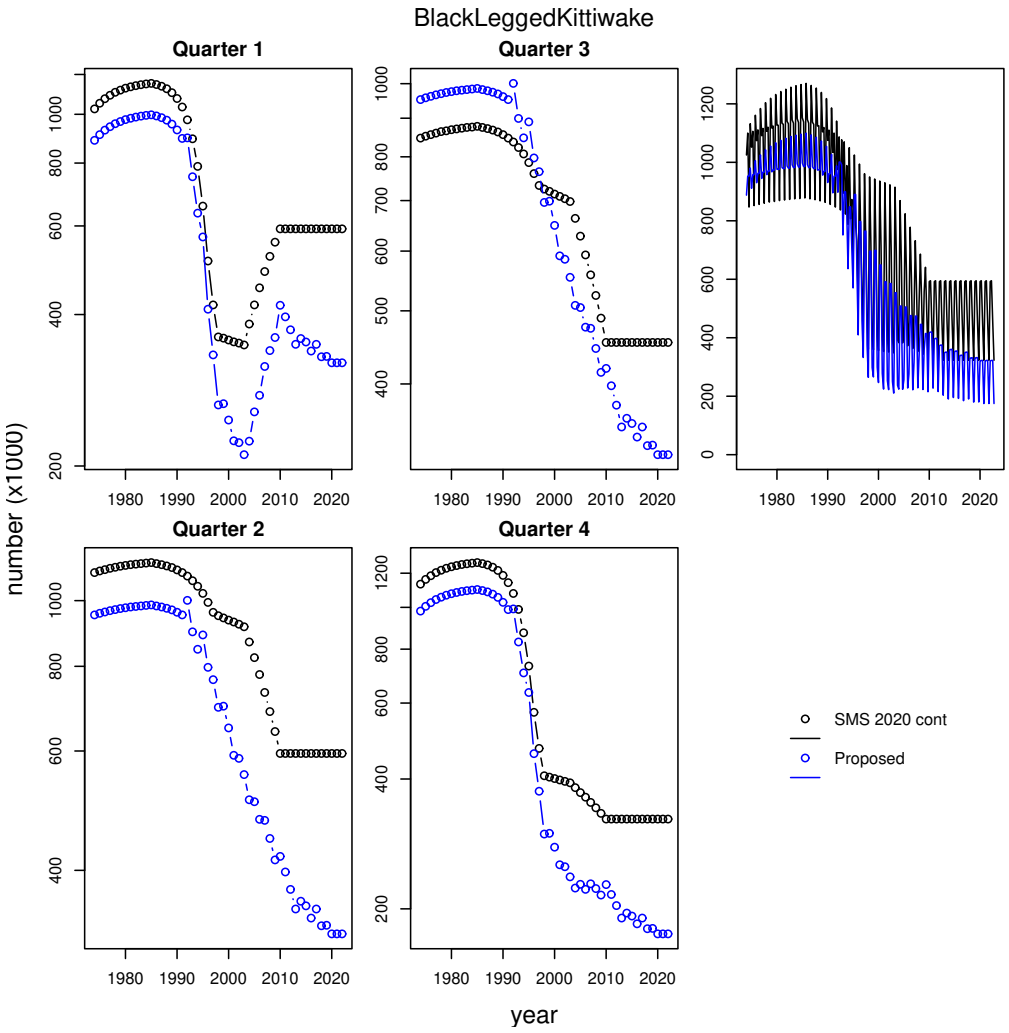

Figure 11: Comparison of proposals for Black legged kittiwake.

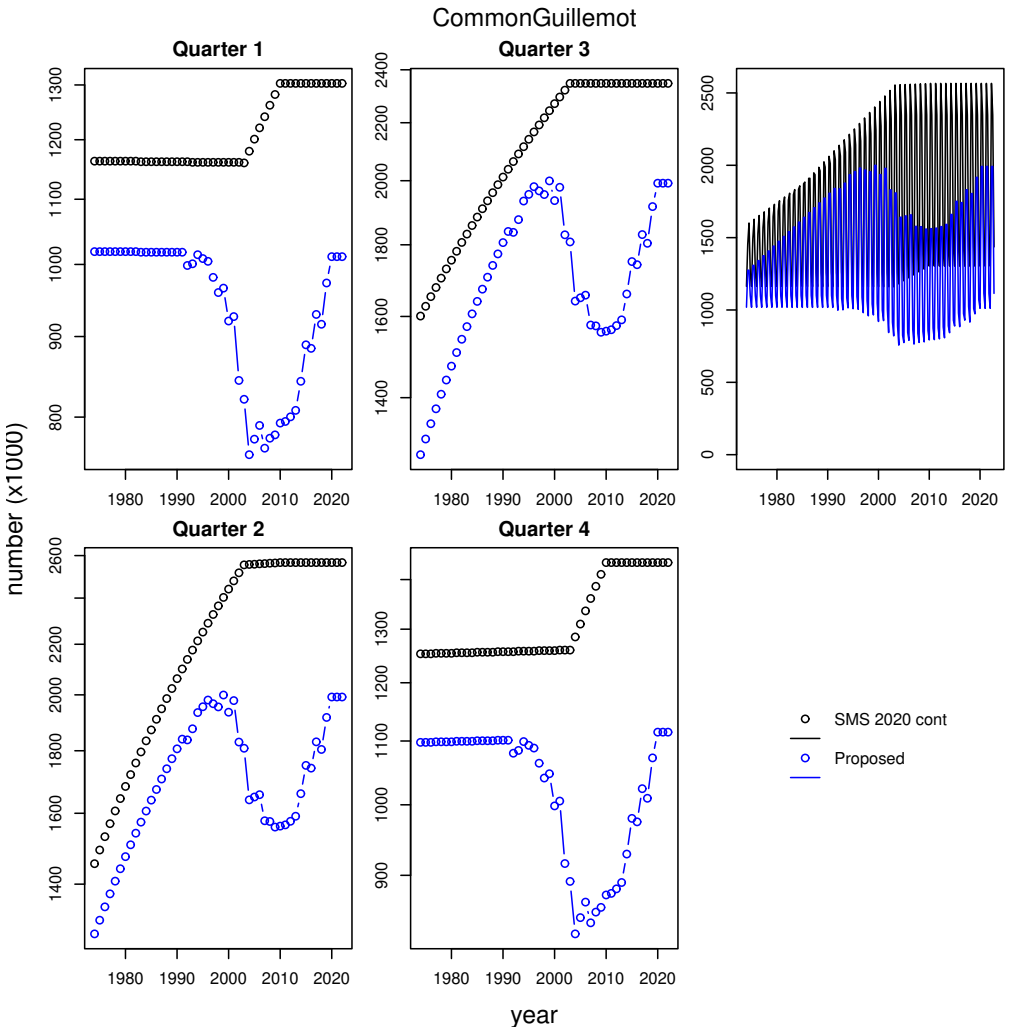

Figure 12: Comparison of proposals for Common guillemot.

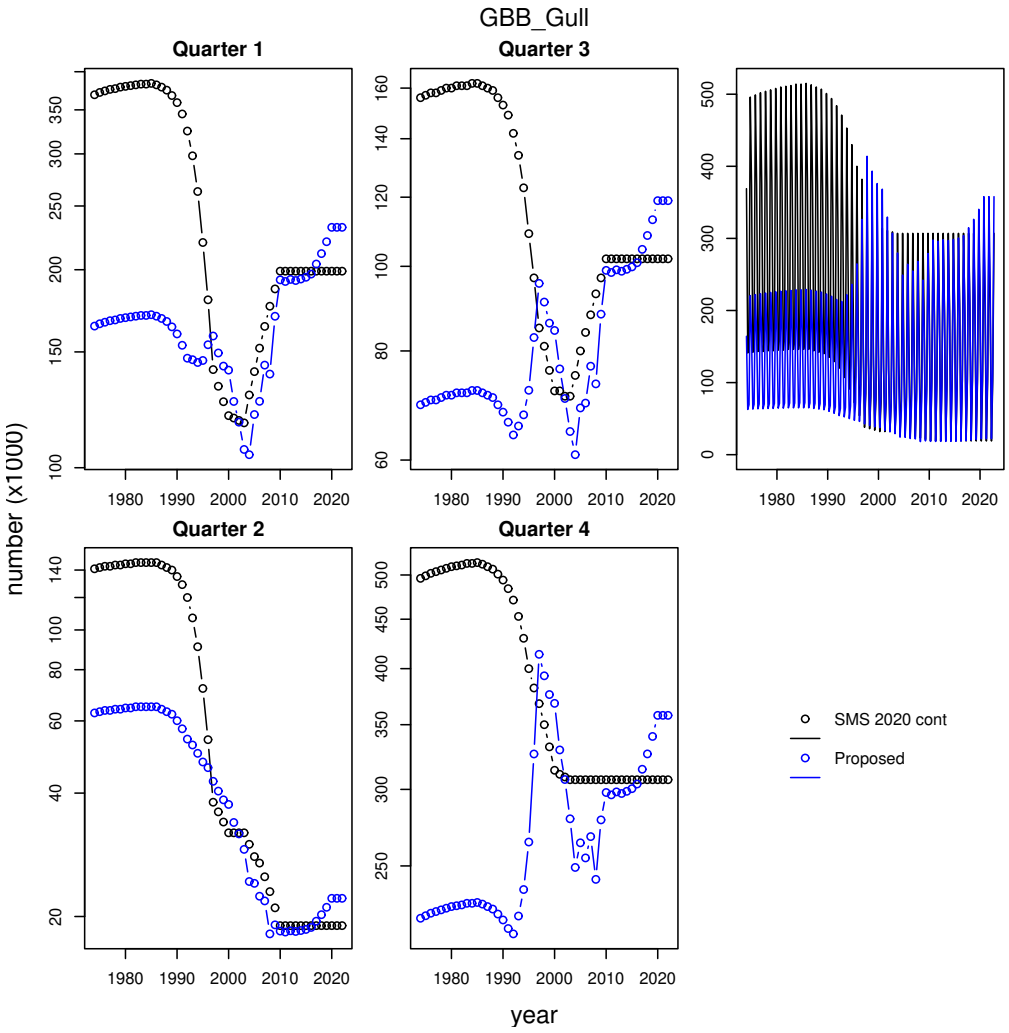

Figure 13: Comparison of proposals for GBB gull.

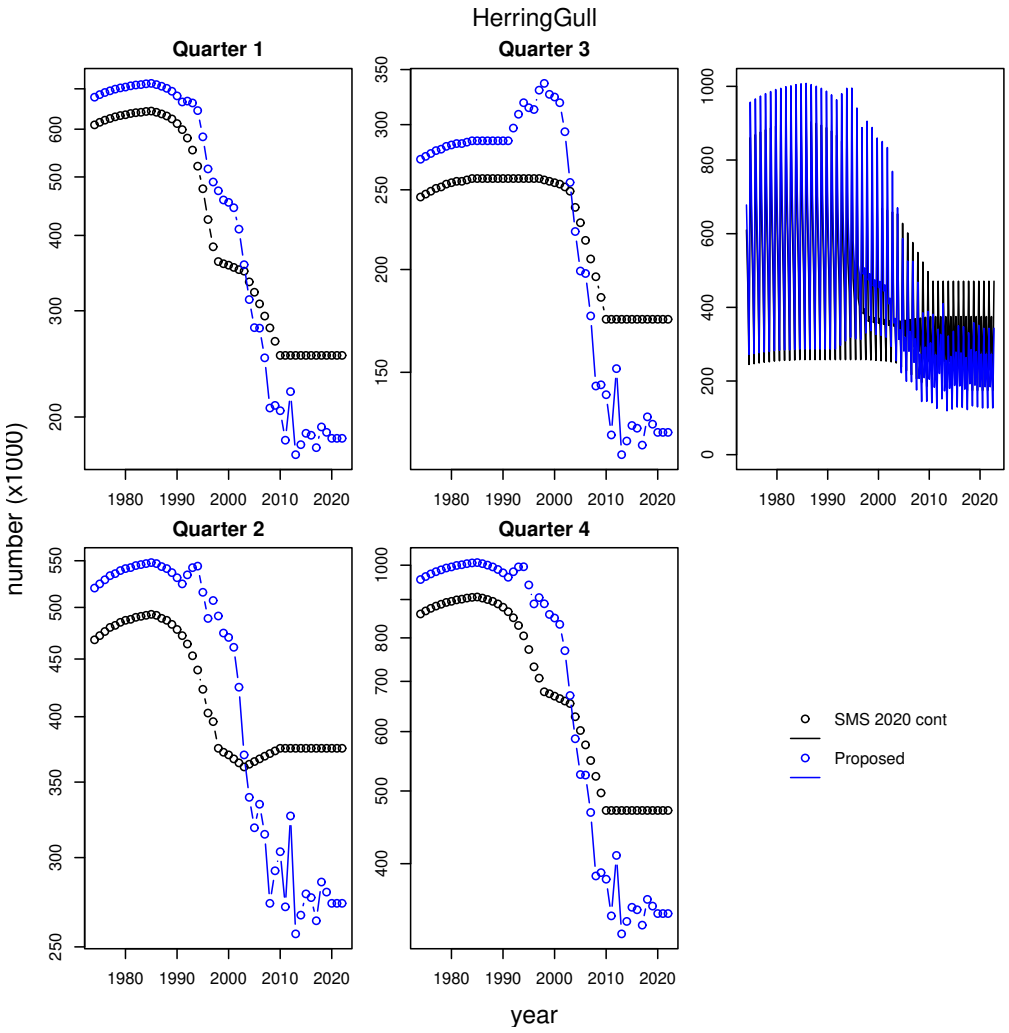

Figure 14: Comparison of proposals for Herring gull.

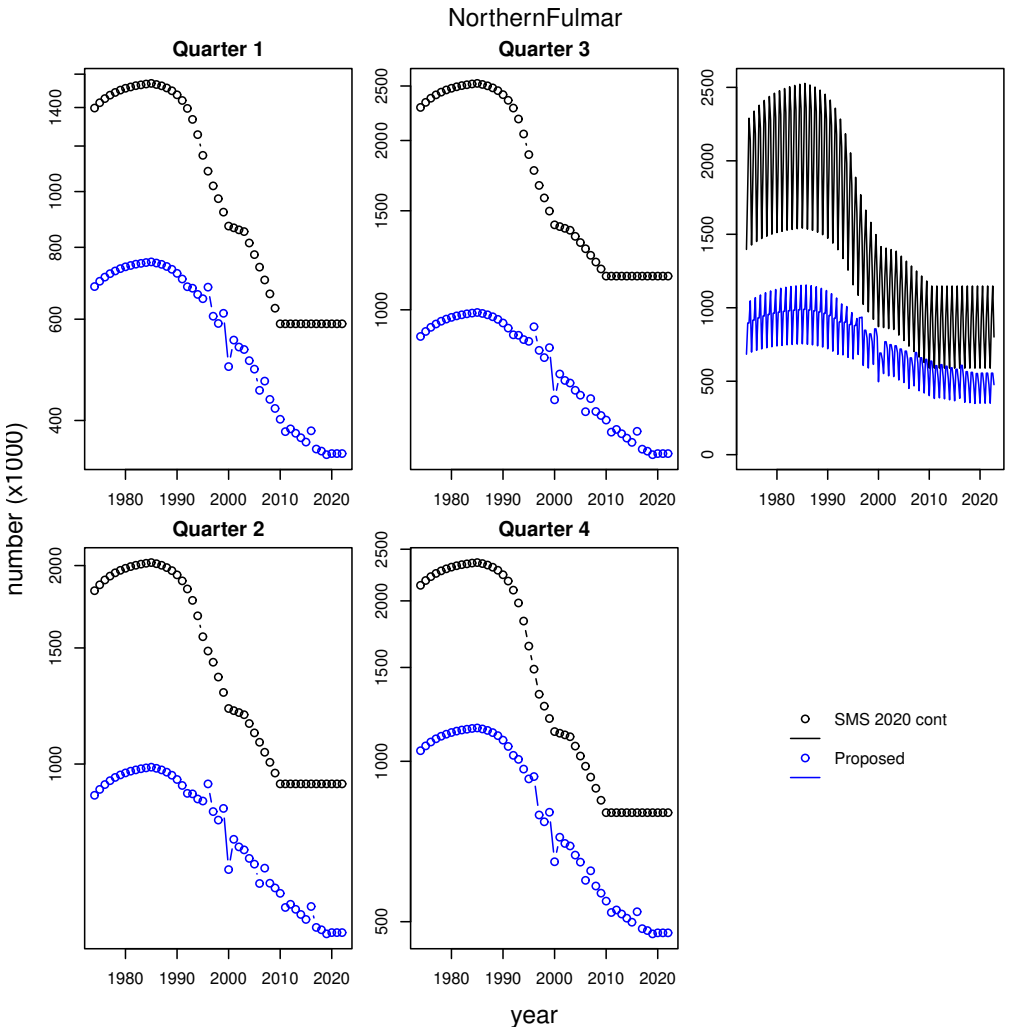

Figure 15: Comparison of proposals for Northern fulmar.

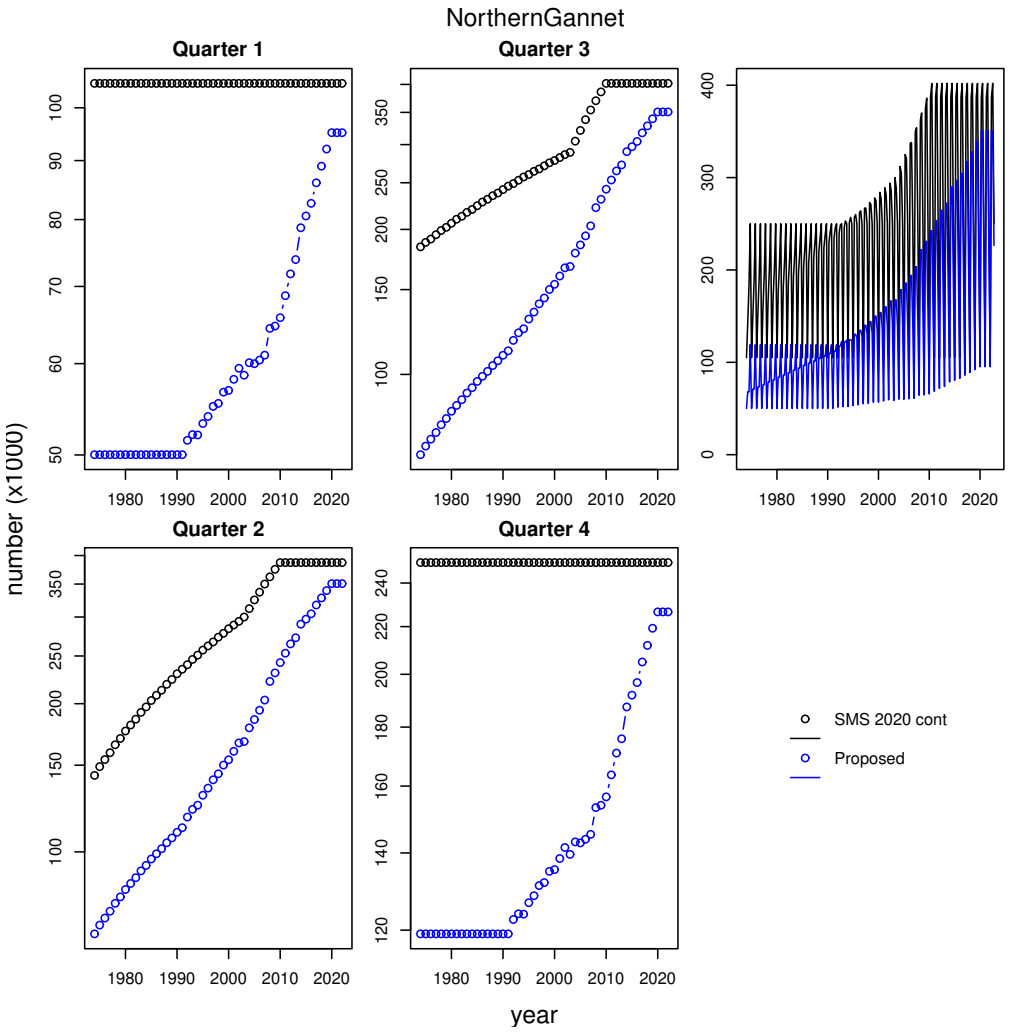

Figure 16: Comparison of proposals for Northern gannet.

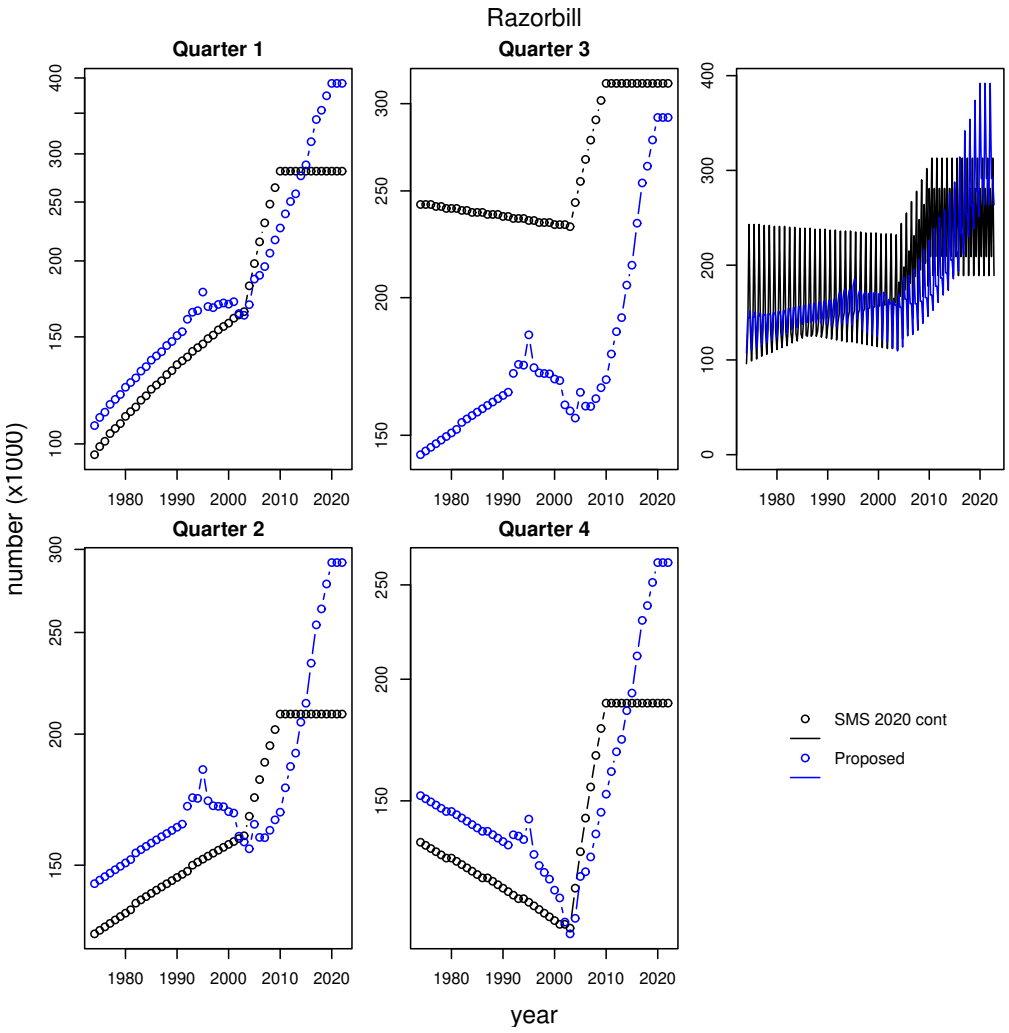

Figure 17: Comparison of proposals for Razorbill.

Estimating uncertainties of diet data for use in Stochastic Multispecies Models (SMS).

Working document to ICES WGSAM October 2023

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2023-11-10

Summary

Introduction

Diet data are important for estimating predation mortalities in multispecies models. Diet data may have been obtained from observations of stomach contents or from a qualitative estimate obtained from e.g. expert knowledge. For both types of data, it may be difficult to quantify the observation uncertainty of the diet data and the uncertainty of diet data is often ignored or estimated within the estimation model for estimating predation mortality.

SMS (Lewy and Vinther, 2004) is a stock assessment model including biological interaction estimated from a parametrised size-dependent food selection function. The model is formulated and fitted to observations of total catches, survey cpue and stomach contents (diet) for the North Sea. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix.

In the present SMS analysis, the following predator and prey stocks were available: predators and prey (cod, whiting, haddock), prey only (herring, sprat, northern and southern sandeel, Norway pout, plaice), predator only (saithe, mackerel), no predator–prey interactions (sole) and 'external predators' (eight species of seabirds, starry ray, grey gurnard, North Sea horse-mackerel, western horse-mackerel, hake, grey seals and harbour porpoise). The population dynamics of all species except 'external predators' were estimated within the model.

In this analysis diet data is estimated from the default method where the "population" diet is basically calculated from a stratified mean of the individual stomach content samples without an estimate of uncertainties. This diet data set is compared with diet from a new method where diet is estimated from bootstrapping of individual samples and where the uncertainties of the estimated diet are derived from fitting a Dirichlet distribution to the bootstrap replicates. The bootstrap method provides input parameters for the Dirichlet distribution applied for diet observation in the SMS, whereas the default SMS model estimates Dirichlet parameters within the SMS from an assumed relation between sampling level of stomachs and uncertainties. The results, e.g. estimated predation mortality, of the approaches are finally compared.

Data and method.

Input to the SMS includes diet data estimated from observations from around 200,000 fish stomachs primarily sampled in the period 1981-1991 (ICES XXX). Observations from each sample are available from ICES (XX). Diet data for grey seals are obtained from analysis of scats (with fish otoliths). For harbour porpoise, diet data are obtained from the stomach contents of stranded or by-caught animals. For both species of marine mammals, data are not available at sample level such that bootstrapping of samples was not possible. The

same is the case for diet data for seven individual species of sea birds, where diet data are based on expert knowledge, rather than a documented compilation of available observations into a diet composition. compiled diet data are just available for hake.

The likelihood function for diet compares the observed prey weight proportions (x_i) with the within SMS estimated values. x_i is assumed to be stochastic variables subject to sampling and process variations. For each predator entity (combinations of predator species j, predator length group l, year y and quarter q) the observations across prey entities i (e.g. sprat, herring and cod) are continuous variables which sum to one. Thus, the probability distribution of the stomach observations for a given predator including all prey groups needs to be a multivariate distribution defined on the simplex. The Dirichlet distribution is fulfilling this requirement. The probability density function for each predator entity , (e.g. cod, 35-40 cm, in quarter 4 of 1991) with K preys observed in the diet proportions becomes:

$$f(x_1, x_2, ..., x_K|\alpha_1, \alpha_2, ..., \alpha_K) = \frac{\Gamma(\alpha_0)}{\prod_{i=1}^{K} \Gamma(a_i)} \prod_{i=1}^{K} x_i^{(\alpha_i - 1)}$$

where K is the number of preys, x is the observed prey weight proportion and α is the model parameters such that

$$\sum_{(i=1)}^{K} x_i = 1$$

and

$$\alpha_0 = \sum_{i=1}^{K} \alpha_i$$

The mean and variance of the observations in the Dirichlet distribution are:

$$E[x_i] = \frac{\alpha_i}{\alpha_0}$$

and

$$Var[x_i] = \frac{E[x_i]\ (1 - E[x_i])}{\alpha_0 + 1}$$

Regarding the variance of stomach contents observations unpublished analyses of data from the North Sea stomach-sampling project 1991 (ICES, 1997) indicate that the relationship between variance and the mean of the stomach contents may be formulated in the following way:

$$Var[x_i] = \frac{E[x_i]\ (1 - E[x_i])}{V_j\ U_{j,l,y,q}}$$

where U_j is a known quantity reflecting the sampling level of stomachs for predator j, predator size class l, in year y, and quarter q and V_j is a predator specific parameter estimated within SMS. The two equations for variance imply that:

$$\alpha_{0\ j,l,y,q} = V_j\ U_{j,l,y,q} - 1$$

Estimating α parametres

The compilation of the individual stomach samples from e.g. trawl hauls into the average diet of the North Sea predators basically follows the technique given by ICES (1993). The average "population" diet or food ration is basically calculated from a stratified mean of the individual stomach content samples, weighted by the strata density of the predator and the area of the strata. This seems simple, but incomplete and patchy sampling makes it often necessary to use a series of *ad hoc* solutions. The compilation of stomach

contents for the 2023 keyrun was done using the Fish-Stomachs R-package (available from (https://github.com/MortenVinther/FishStomachs).

The FishStomachs package defines data structures suitable for stomach data and provides the necessary methods to compile observed stomach data into population diet and biomass eaten, used for multispecies models.

The stomach contents compilation followed the steps outlined below:

1. Read and check data from the agreed exchange format;
2. Bias correct to take into account variable evacuation rate;
3. Assign size classes for predators and preys;
4. Bias correct to take into account regurgitated stomachs within sample units;
5. Aggregate stomach contents within sample_id and size classes.
6. Allocate unidentified or partly identified prey items;
7. Calculate the population diet and food ration from a weighted average.

The FishStomachs package makes it possible to estimate uncertainties of the estimated diet from bootstrapping of individual samples. Bootstrapping is made between step 4 and 5 in the steps above. First, a set of 500 bootstrap replicates are made from random sampling with replacement of the individual stomach samples (*i.e.* trawl hauls). The diet is then estimated for each replicate (step 5-7 above), such that a set of 500 replicates of diets are produced. The distribution of diet replicates is finally fitted to a Dirichlet distribution (using function diri.est in R-package Compositional) for estimation of the α parameters. Figure 1 shows an example where the bootstrap replicates fit quite well with observations for Dirichlet distribution. Another example Figure 2 with much fewer stomach samples shows in some cases a two topped distribution of the bootstrap replicates and a poor fit to the estimated Dirichlet distribution with a low α_0 value.

Effect on SMS results

Three runs with the SMS model were done to explore the effect of using input values for uncertainty on diet data:

- **Default**, diet data are compiled without estimation of uncertainties and SMS estimates $\alpha_{0\,j,l,y,q}$ from an assumed relation between number of stomach samples and uncertainty.
- **alpha prey**, diet data are estimated from a Dirichlet fit to bootstrap replicates. $\alpha_{0\,j,l,y,q}$ and prey proportions derived from the Dirichlet fit to the bootstrap data (α_{prey}/α_0) are used as input to SMS.
- **alpha 0**, as above with the use of input $\alpha_{0\,j,l,y,q}$, but prey proportions are taken from the default configuration.

All the SMS configurations were configured with a maximum α_0 at 5 for the seven bird species to constrain the influence of the rather uncertain estimate of bird diets from expert knowledge. The uncertainties of diet data for grey seal and harbour porpoise were estimated within SMS from the assumed sampling level.

Output from SMS is substantial and this document only presents results for cod (predator and prey) and herring (prey only). The results for these two species reflect well the difference in results for the other not shown species.

Results

Effects on estimated diet

The estimated α_0 depends on the sampling level, the predator species and the number of preys for a given predator entity (Figure 3. The median value of α_0 and thereby the precision of the diet estimate is highest

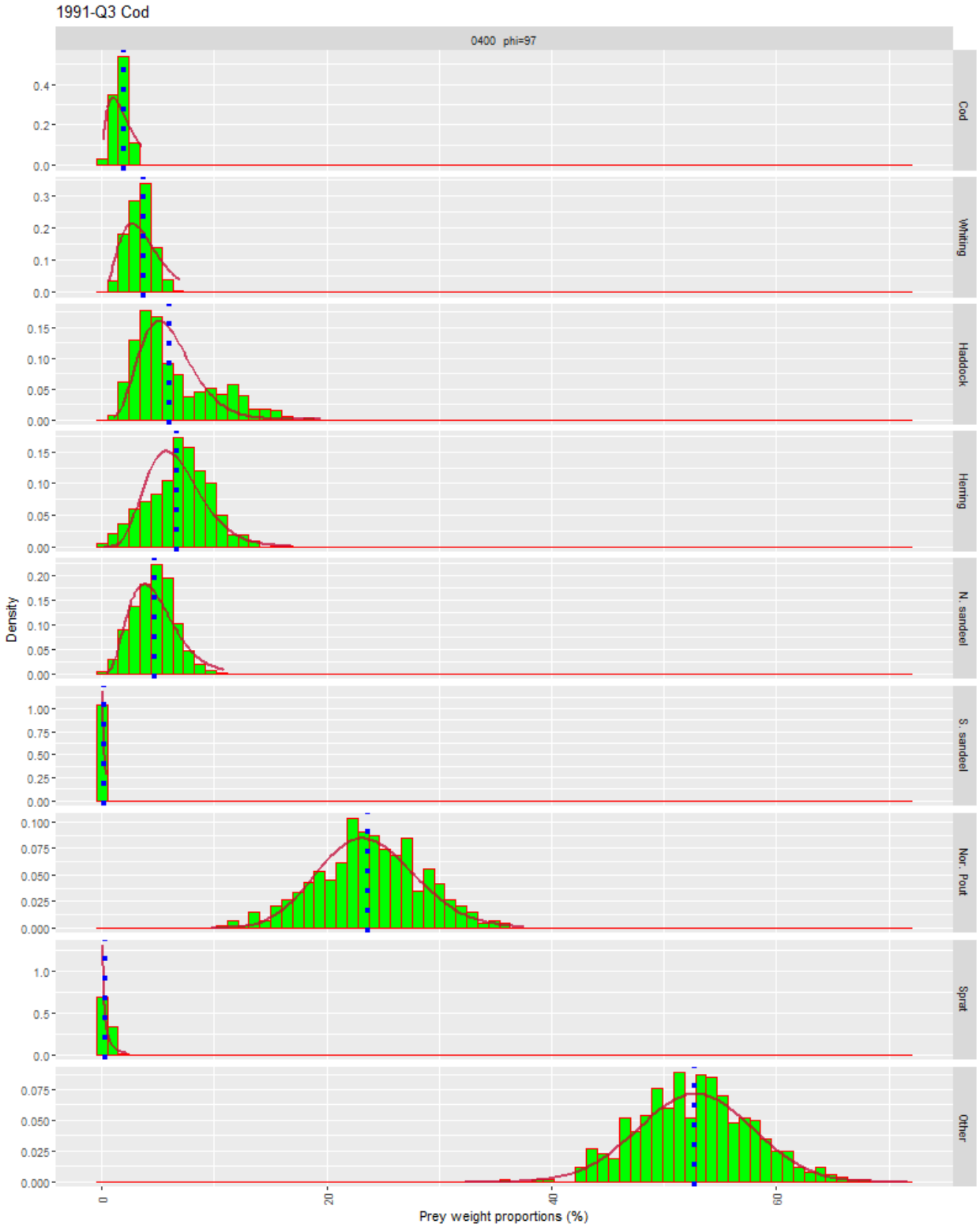

Figure 1: Bootstrap replicates of diet weight proportions for predator cod 40-50 cm in quarter 3 of 1991. The red curve shows the fitted Dirichlet distribution, the blue line shows the average weight proportion of the full (non-bootstrapped) dataset. The fitted concentration parameter (or α_0) is shown at the top panel as phi.

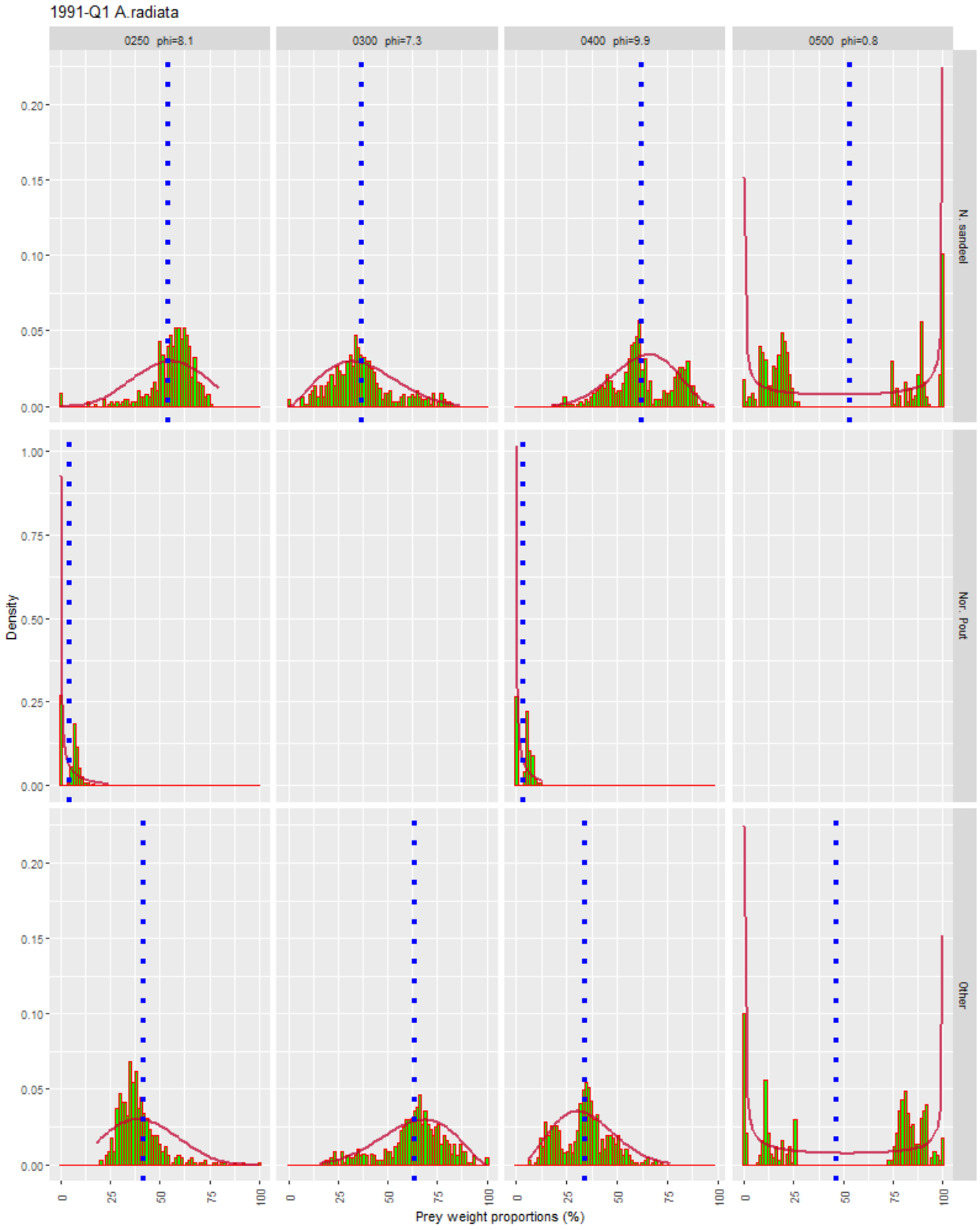

Figure 2: Bootstrap replicates of diet weight proportions for predator *Amblyraja radiata* in quarter 1 of 1991. The red curve shows the fitted Dirichlet distribution, the blue lines show the average weight proportion of the full (non-bootstrapped) dataset. The fitted concentration parameters (α_0) are shown at the top of the panel as value phi.

for cod and whiting followed by haddock and saithe. This corresponds well to the sampling level for these predators,

The bootstrap estimates of α_0 (Figure 3) are in general higher than the values estimated within the SMS model (Figure 4). A considerable increase in the median α_0 from bootstrap is seen for cod and whiting (Table 1), while the bootstrap method gives a smaller α_0 for saithe and mackerel.

The prey weight proportions estimated from the two methods are, highly correlated (Figure 5). There are however examples where the two estimates differ quite at lot. The "other food" prey constitutes a high diet proportion for most predators and there is a tendency that the proportions estimated from α_{prey} are higher than the simple approach (Figure 6). As the diet proportions sum up to one, the weight proportion from named preys become smaller when estimated from α_{prey}. This can also be seen for some predator-prey combinations in Figure 5, even though the bias is not large. A closer look at diet data from cod for diet data shows the difference in prey proportion seems to depend on the prey proportion. A small prey proportion (e.g. 1-2 %) estimated from α_{prey} is in general higher than the simple estimate (Figure 7).

Effects on SMS results

The overall effect of the choice of diet data and method seems limited based on the assessment output, recruitment, average fishing mortality (F) and spawning stock biomass (SSB). For both cod (Figure 8) and herring (Figure 9). the largest difference is for recruitment. For both cod and herring, and the other species not presented, there is a tendency that the "alpha prey" SMS configuration provides the lowest estimate of recruitment. Estimated recruitment is influenced by the predation mortality (M2) at age for all ages. A closer look at the M2 (Figure 10) and (Figure 11) reveals quite similar results for the three SMS configurations. It is also seen that the ratio of M2 at age between configurations is not the same for all ages, such that e.g. the "alpha prey" configuration for herring provides the lowest M2 at age 0, but the highest M2 for ages 2-4.

The SMS likelihood statistics (Table 2) for the three configurations show that the "default" configuration gives the best (lowest negative log likelihood value) followed by the "alpha 0" and "alpha prey" SMS. The largest differences in log-likelihood are for diet data, where the individual likelihood contributions by predator are best for the "default" configuration. The same pattern is seen for the likelihood values for catch and CPUE, even though there are few exceptions, e.g. the likelihood of cod CPUE is best when the uncertainties of diet data are given as input ("alpha prey" and "alpha_0").

Discussion

SMS is a model with likelihood contributions from both catch, cpue, stock-recruitment and diet observation. The stock-recruitment likelihoods are down-weighted (factor 0.1) within SMS as both recruitment and SSB are estimated within the model and as such not observations to the model. The remaining three likelihood components have no *a priori* weighting, such that the overall model fit and weighting of the data sources are done from the total likelihood of the model. A catch-at-age observation fits, in general, better than a CPUE observation. Diet observations have in general the poorest fit which might explain the rather stable estimates of F and SSB and to some extent also recruitment, even though diet data are changed considerably.

The initial testing of the SMS model with artificial input data with known variance and known model parameters showed that the model is able to estimate model parameters to the correct values, if the variance of input data was not too high. The were however problems in estimating the parameters that link α_0 to the sampling level of diet data (the V_j parameters in the relation between sampling level and variance). The same is seen in several SMS runs, where this parameter in some cases only can be estimated if the parameter reaches an input bound for one of the predators. The bound for cod and two bird species was e.g. reached in the 2020 Key run for the North Sea. This suggests that input values for α_0 are advantageous to fix the variance of diet data.

The prey proportions estimated from the Dirichlet α values differ in some cases quite a lot from the prey proportions estimated the default way. This difference seems largest for poorly sampled diets, however for

even a species like cod with large sample sizes, there seems to be a consistent difference , where e.g. small (around <2%) prey proportions become higher when the bootstrap method is applied. If this difference is due to the bootstrap itself or due to the estimation of the α parameters needs to be investigated. A way to circumvent this bias is to use the estimated α_0 to scale the default prey proportions (estimated without bootstrapping). Likelihood statistics from the "alpha prey" and "alpha 0" configurations are however quite the same, even though the estimated M2 values may vary slightly between the two configurations.

The bootstrap method provides higher α_0 and for e.g. cod and whiting than the default method (Table 1, and Figure 3 and 4). Likewise, the bootstrap method provides higher α_{prey} Figure 12), but the diet likelihoods (Figure 13) are not better. The default method estimates an α_0 (or actually a parameter, V_{pred}, to estimate α_0 from sampling level) that gives the best total likelihood for all diet observations from the given predator. To handle the in general rather poor fit between observed and estimated diet, it seems like the optimization ends up with a low V_{pred} and thereby a lower α_0 and α_{prey} for all diet data for the predator. The approach where α_0 is provided as input for each predator entity, will in some cases where bootstrapping estimates a low observation variance, resulting in a poorer likelihood either because the bootstrap estimate of variance is biased (too low) or due to process uncertainties (the model for diet is not adequate to model predation, and produces large residuals for diets observation). Providing α_0 estimated externally to SMS reduces the number of estimated parameters and is a first step in separating observation and process uncertainties.

Some diet entities are based on only a few samples which creates a two-topped distribution of the bootstrap replicates (see Figure 2). The α_0 value estimated becomes very low for these cases such the diet input gets a low weight in minimizing the total model likelihood. It could be argued that such diet based on only a few samples should not be used by SMS, however providing input values for the accuracy of the diet entity limits the risk of overfitting.

Table 1: Median α_0 estimated within SMS and from bootstrapping.

Predator	SMS	bootstrap
A. radiata	9.8	4.7
Grey gurnard	8.9	11.1
Western horse mackerel	3.1	2.4
North Sea horse mackerel	10.4	1.2
Cod	24.4	42.1
Whiting	14.8	30.4
Haddock	12.0	14.2
Saithe	16.0	13.7
Mackerel	15.8	11.1

Table 2: Negative log likelihood from catch, Cpue, stock-recruitment, diet observation and total from SMS where α_0 is estimated by bootstrapping (label bootstrap) or within SMS (label simple). The likelihood contributions from 8 bird species, hake, plaice, sole and marine mammals are not shown as α_0 is estimated within SMS and therefore almost identical between runs, but included in the totals.

SMS conf.	Species	Catch	CPUE	SSB Recruit	Diet	neg log likelihood
default	A.radiata	0.0	0.0	0.0	-44.5	-44.5
default	G.gurnards	0.0	0.0	0.0	-49.3	-49.3
default	W.horse.mac	0.0	0.0	0.0	1.8	1.8
default	N.horse.mac	0.0	0.0	0.0	-11.4	-11.4
default	Cod	-447.9	-137.1	-8.9	-1629.7	-2222.7
default	Whiting	-266.5	-171.4	-33.6	-735.1	-1176.3
default	Haddock	-134.2	-176.3	17.9	-77.5	-386.3
default	Saithe	-326.3	-74.3	-22.5	-84.8	-507.9
default	Mackerel	-457.6	-76.1	-8.2	-102.8	-644.7
default	Herring	266.2	-194.9	-11.1	0.0	70.2
default	N.sandeel	149.6	49.2	13.1	0.0	200.1
default	S.sandeel	100.3	-19.6	1.7	0.0	80.9
default	Nor.pout	269.8	-44.9	-8.9	0.0	224.0
default	Sprat	221.7	-53.4	-5.5	0.0	167.8
default	All	-1472.0	-1018.8	-100.0	-4485.0	-7020.5
alpha prey	A.radiata	0.0	0.0	0.0	-35.0	-35.0
alpha prey	G.gurnards	0.0	0.0	0.0	-15.8	-15.8
alpha prey	W.horse.mac	0.0	0.0	0.0	2.3	2.3
alpha prey	N.horse.mac	0.0	0.0	0.0	-11.3	-11.3
alpha prey	Cod	-443.8	-138.4	-8.5	-1477.2	-2067.1
alpha prey	Whiting	-259.9	-173.0	-31.9	-530.2	-966.4
alpha prey	Haddock	-124.4	-181.0	18.2	-58.8	-362.3
alpha prey	Saithe	-322.5	-73.4	-23.3	-14.1	-433.4
alpha prey	Mackerel	-457.9	-75.7	-8.1	-84.7	-626.4
alpha prey	Herring	266.0	-192.7	-12.1	0.0	72.1
alpha prey	N.sandeel	156.4	54.2	12.8	0.0	211.9
alpha prey	S.sandeel	107.2	-18.9	1.7	0.0	88.4
alpha prey	Nor.pout	283.7	-38.4	-7.8	0.0	244.5
alpha prey	Sprat	223.3	-53.2	-2.9	0.0	169.8
alpha prey	All	-1419.2	-1010.3	-96.0	-3981.9	-6456.1
alpha 0	A.radiata	0.0	0.0	0.0	-32.1	-32.1
alpha 0	G.gurnards	0.0	0.0	0.0	-23.3	-23.3
alpha 0	W.horse.mac	0.0	0.0	0.0	4.9	4.9
alpha 0	N.horse.mac	0.0	0.0	0.0	-5.4	-5.4
alpha 0	Cod	-444.2	-138.1	-8.7	-1399.6	-1989.7
alpha 0	Whiting	-260.3	-172.9	-31.5	-577.4	-1013.7
alpha 0	Haddock	-127.8	-177.6	17.6	-43.8	-347.4
alpha 0	Saithe	-323.0	-73.5	-23.1	3.6	-416.1
alpha 0	Mackerel	-457.8	-75.8	-8.1	-84.6	-626.3
alpha 0	Herring	265.0	-194.9	-11.6	0.0	68.9
alpha 0	N.sandeel	156.3	53.8	12.1	0.0	211.2
alpha 0	S.sandeel	108.2	-20.1	2.0	0.0	88.2
alpha 0	Nor.pout	279.0	-42.6	-8.5	0.0	235.6
alpha 0	Sprat	221.1	-52.6	-3.7	0.0	168.1
alpha 0	All	-1430.6	-1014.4	-97.4	-3910.8	-6400.6

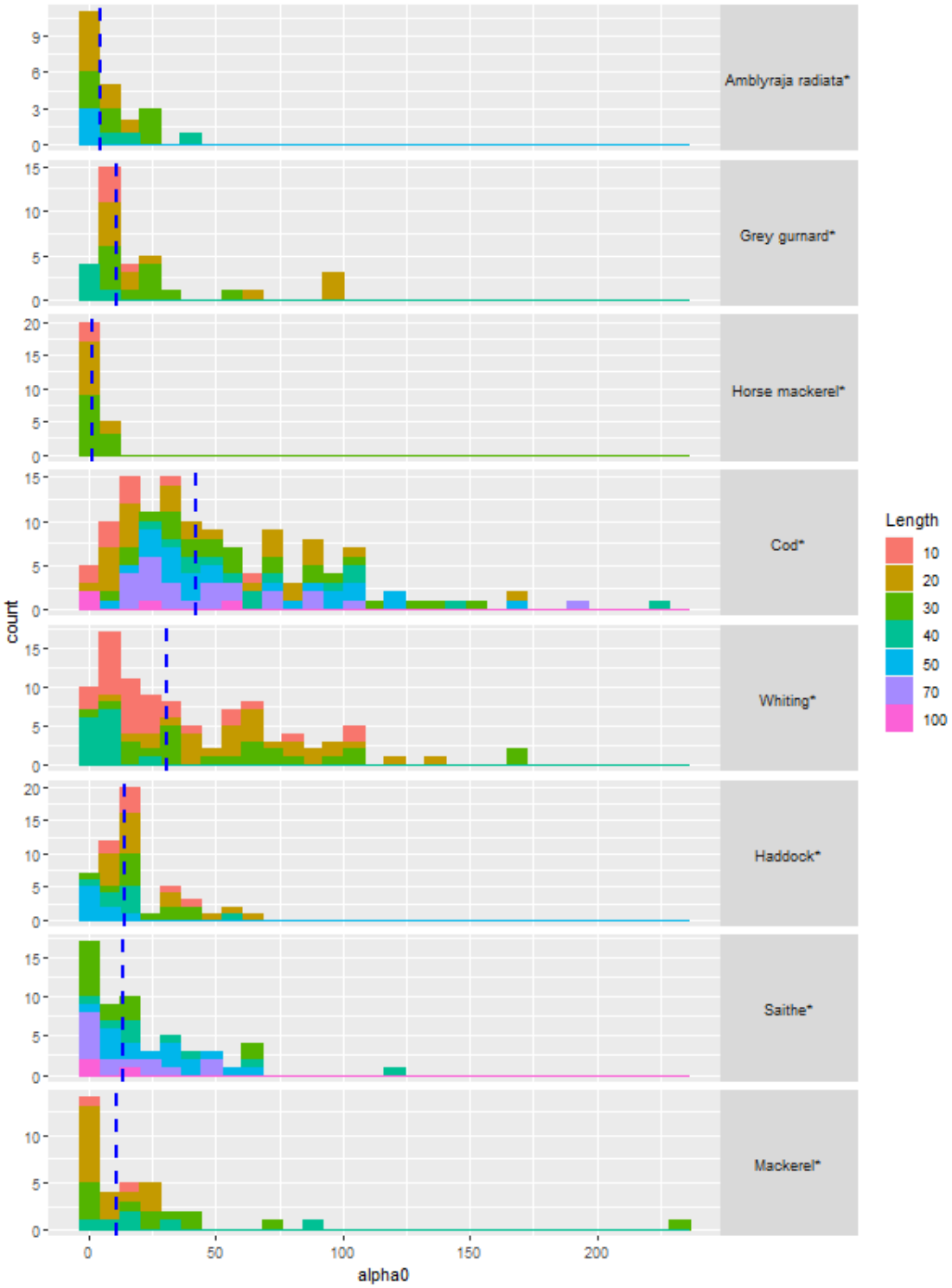

Figure 3: Histogram of estimated α_0 from bootstrapping by predator species and predator length classes. The blue lines show the median α_0.

Figure 4: Histogram of within SMS estimated α_0 by predator species and predator length classes. The blue line shows the median α_0.

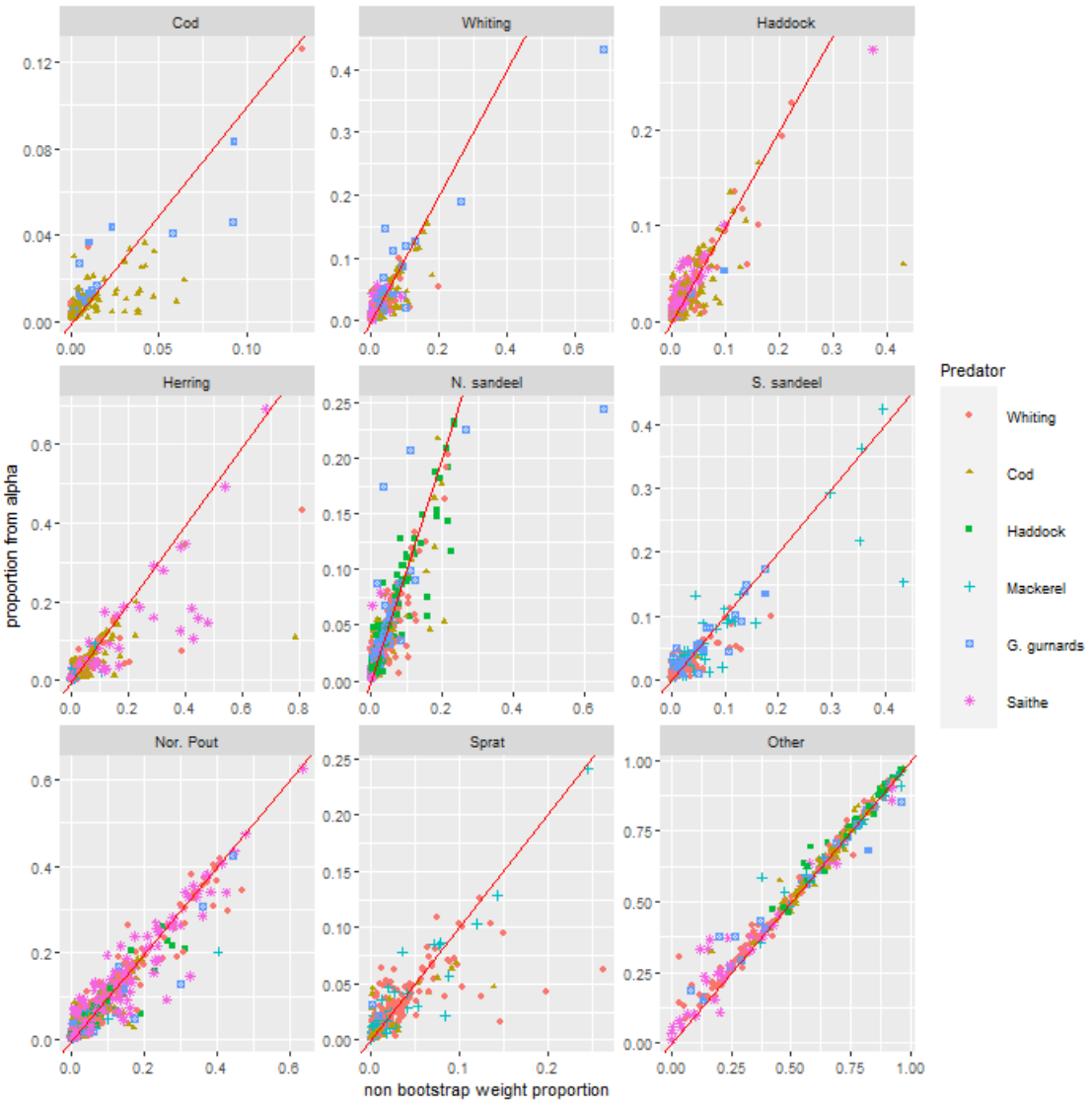

Figure 5: Weight proportion in the diet by prey species and predator estimated from non-bootstrapped data (x-axis) against prey proportion estimated from bootstrapping derived from Dirichlet α_{prey} values. The red lines have slope 1.

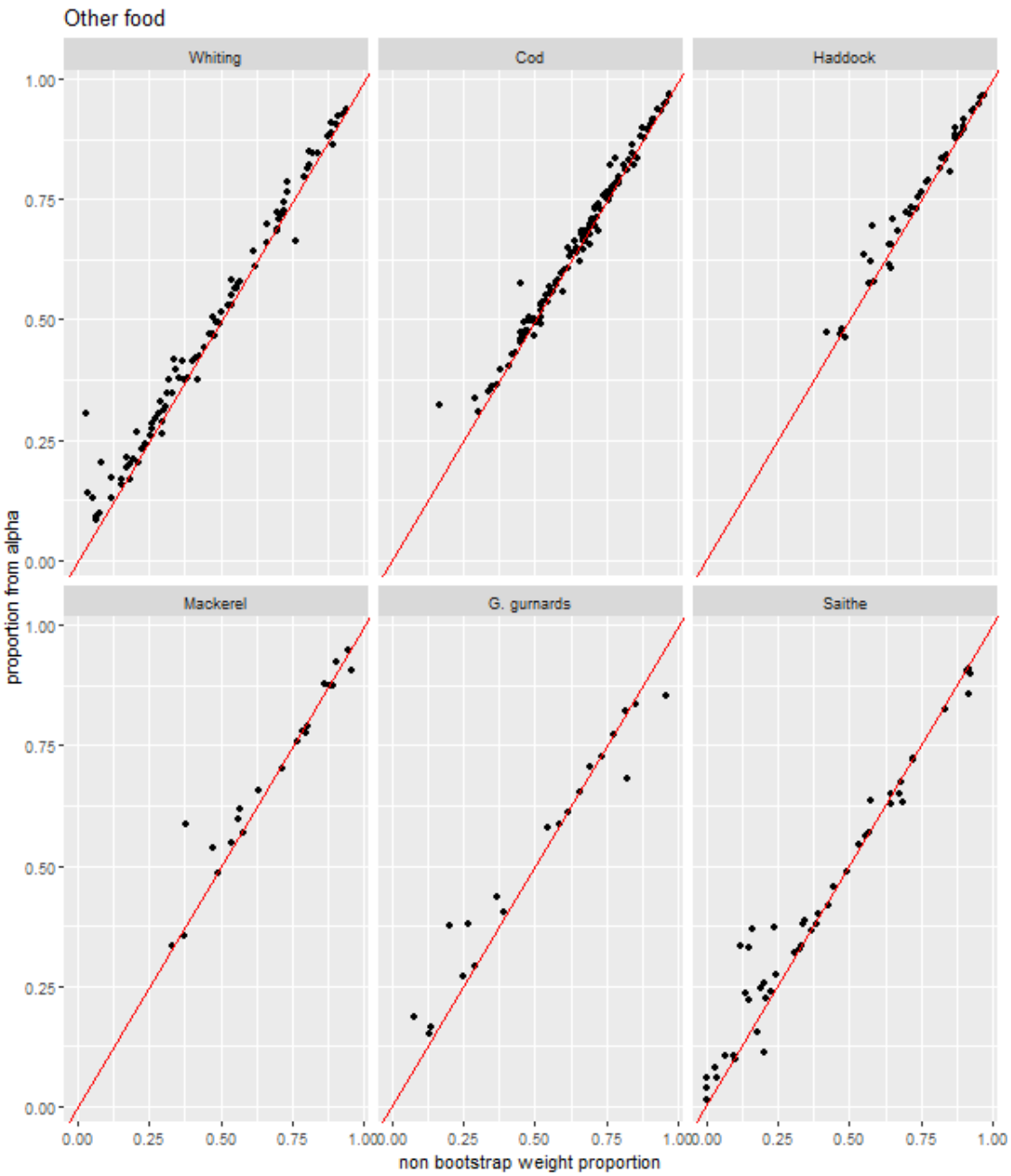

Figure 6: Weight proportion in the diet of 'other food' by predator estimated from non-bootstrapped data (x-axis) against prey proportion estimated from bootstrapping derived from Dirichlet α_{prey} values. The red lines have slope 1.

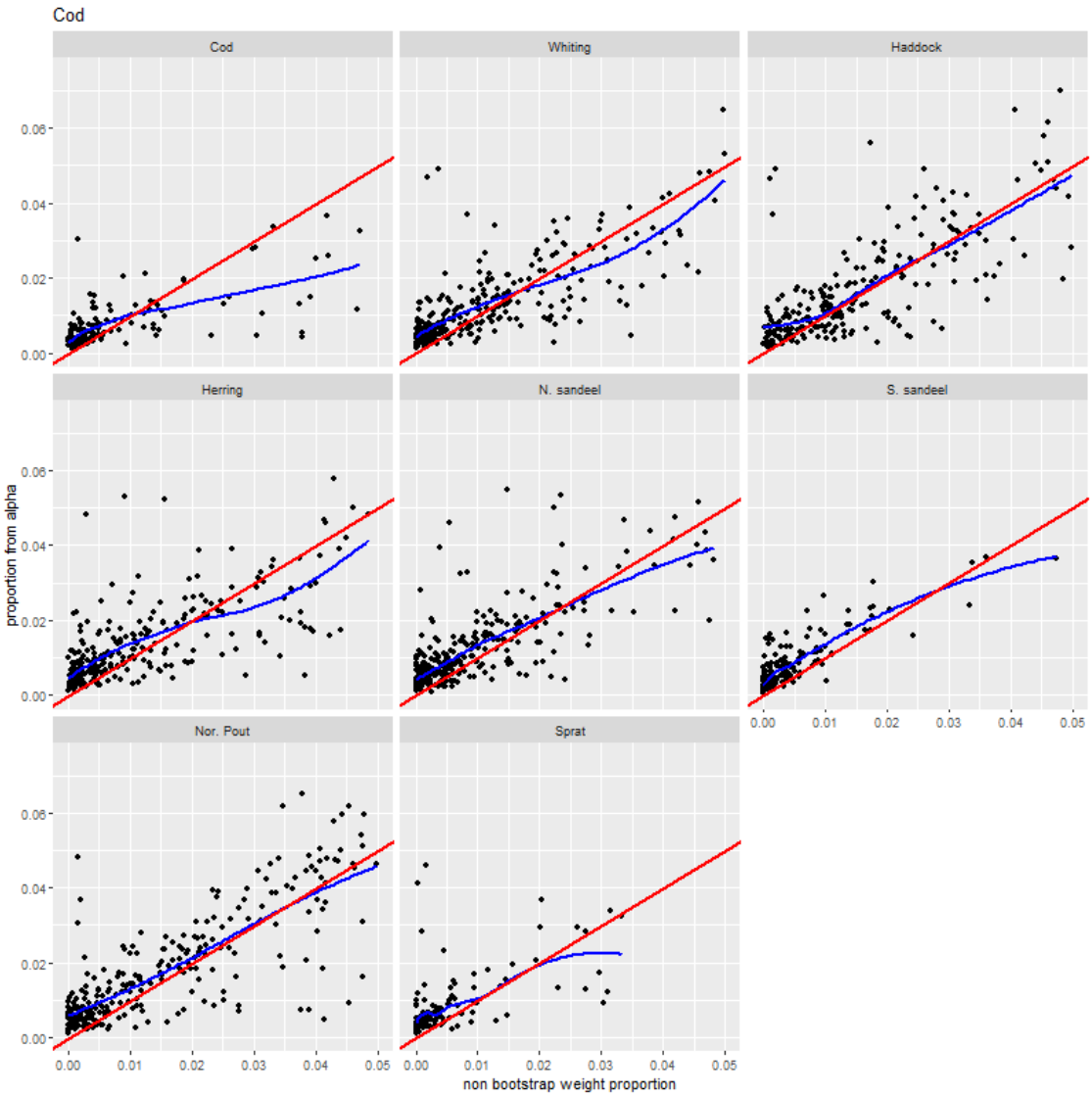

Figure 7: Weight proportion in the diet by prey species of cod estimated from non-bootstrapped data (x-axis) against prey proportion estimated from bootstrapping derived from Dirichlet α_{prey} values, for preys with less than 0.05 observed weight proportion in the diet. The red lines have slope 1.

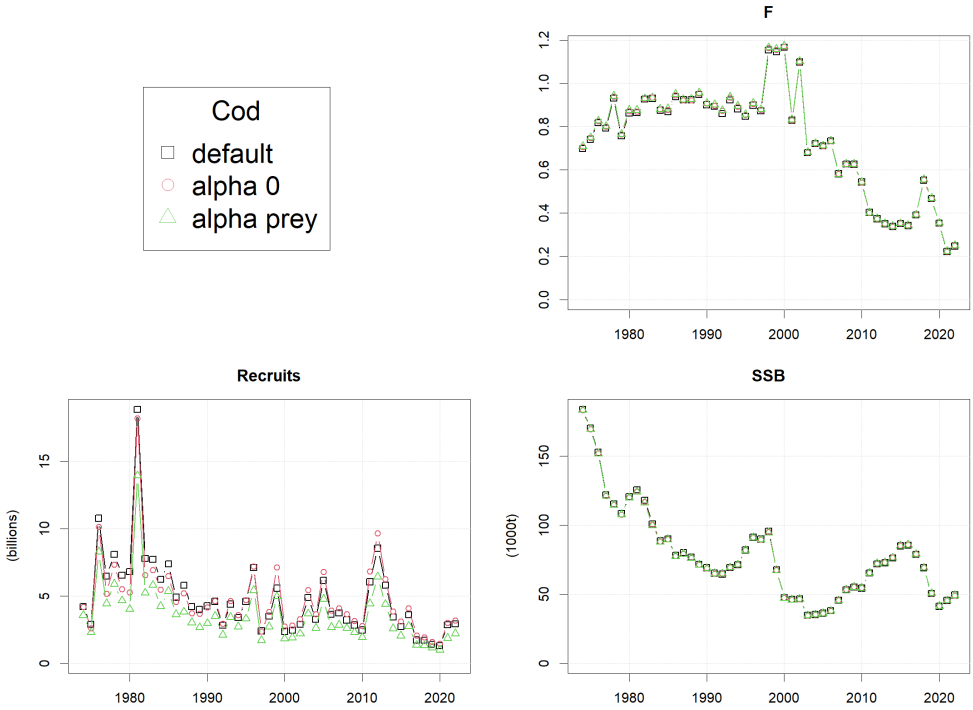

Figure 8: Main assessment results for cod from SMS configurations (see text for labels).

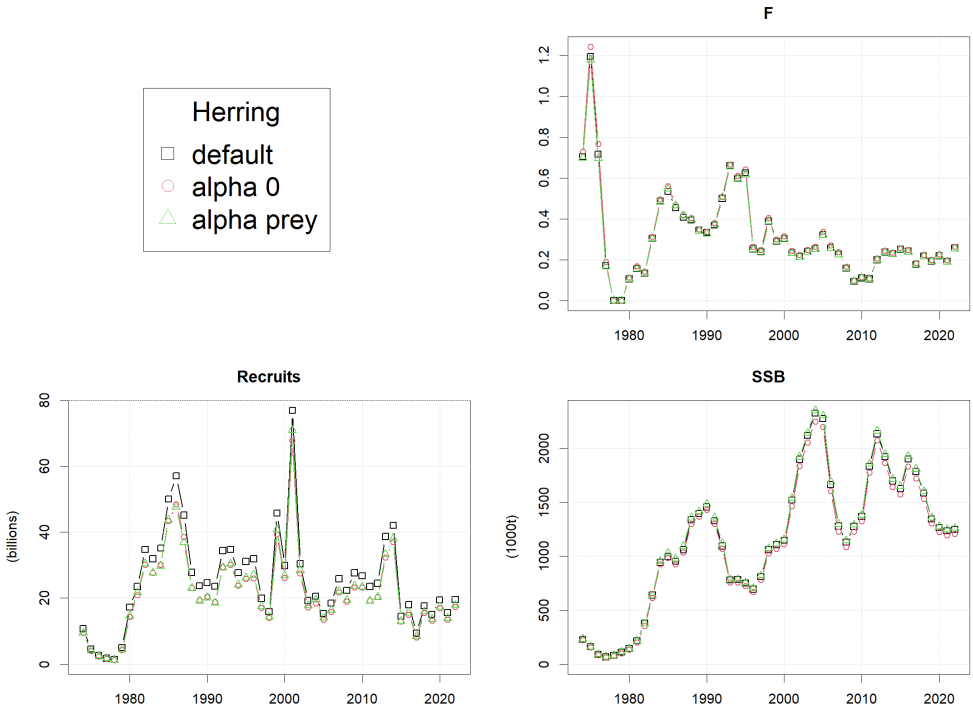

Figure 9: Main assessment results for herring from SMS configurations.

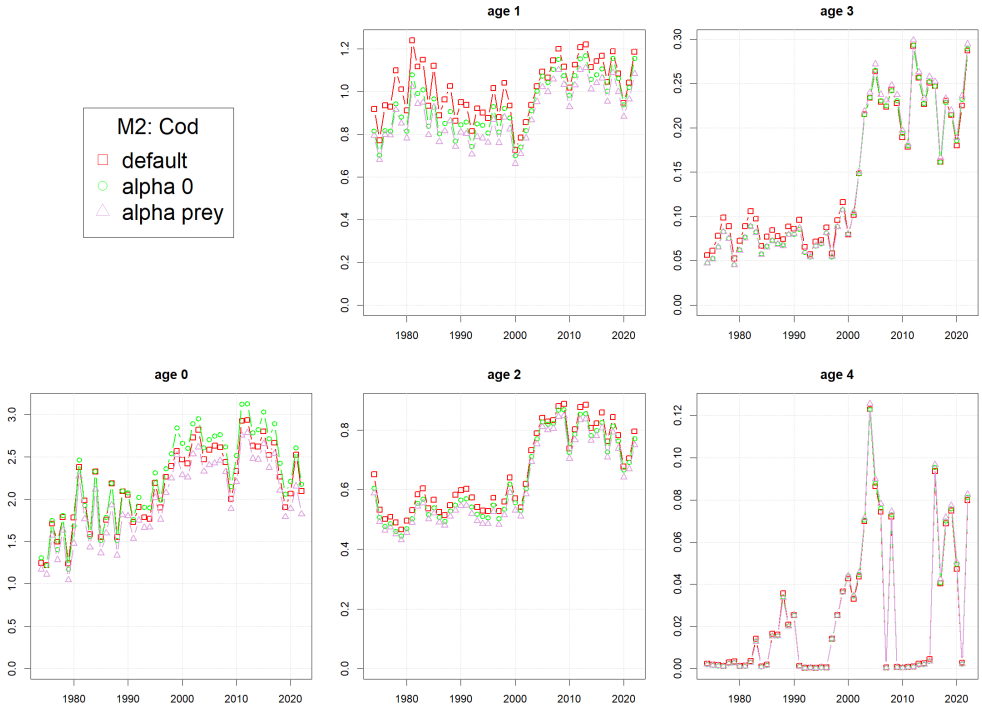

Figure 10: M2 by age for cod from SMS configurations.

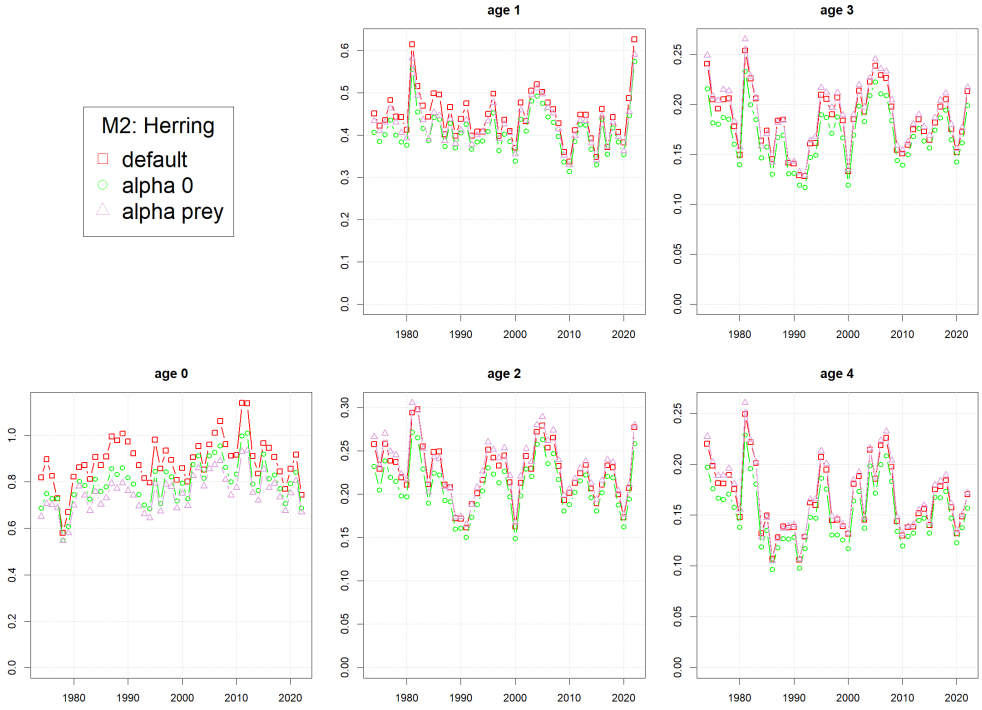

Figure 11: M2 by age for herring from SMS configurations.

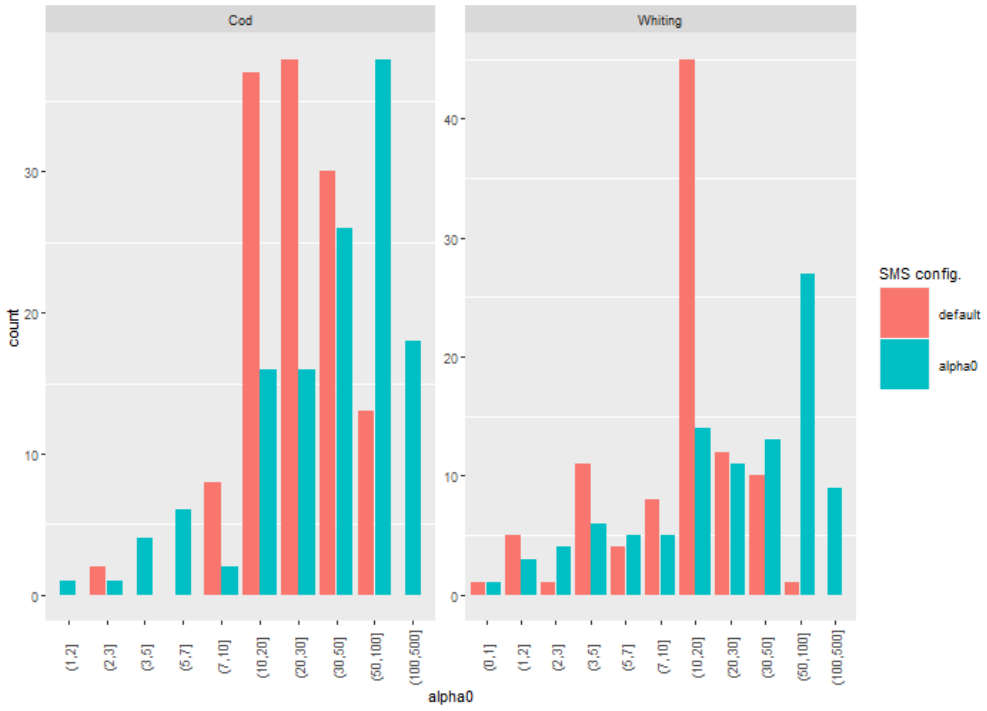

Figure 12: Histogram of the α_{prey} for diet observation used by SMS configurations.

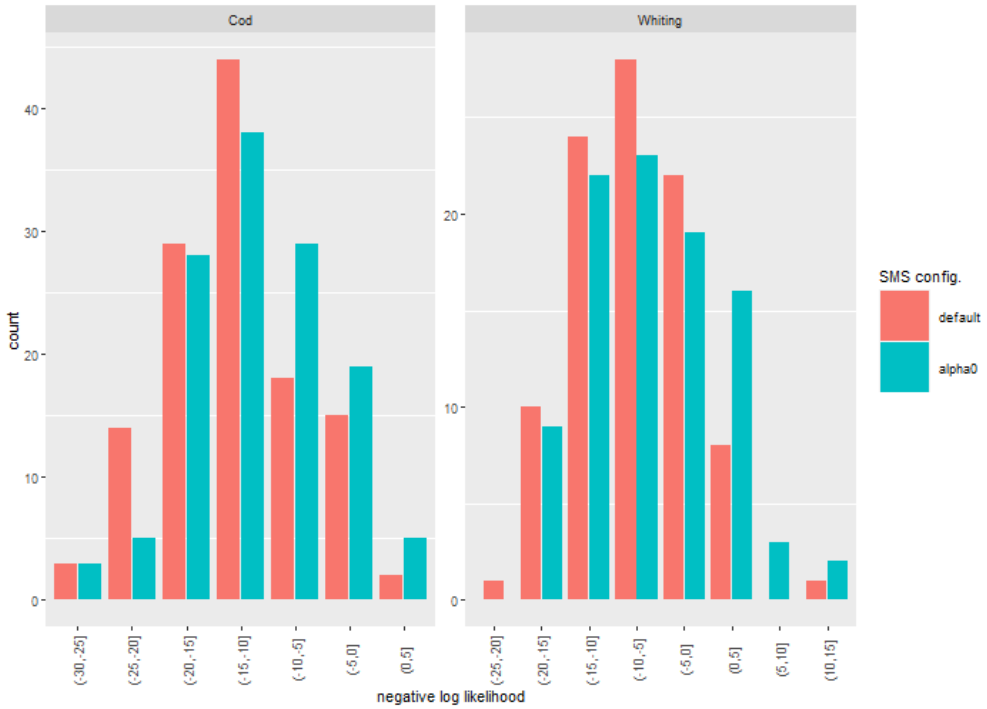

Figure 13: Histogram of negative log liklihood contibutions for diet observation estimated by SMS configurations.