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WORKING GROUP ON MULTISPECIES ASSESSMENT METHODS (WGSAM; outputs from 2020 meeting)

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Total number of authors:
25

Link to article, DOI:
10.17895/ices.pub.7695

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

WORKING GROUP ON MULTISPECIES ASSESSMENT METHODS (WGSAM; outputs from 2020 meeting)

VOLUME 3 | ISSUE 10

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

CIEM CONSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

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ISSN number: 2618-1371

ICES Scientific Reports

Volume 3 | Issue 10

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Recommended format for purpose of citation:

ICES. 2021. Working Group on Multispecies Assessment Methods (WGSAM; outputs from 2020 meeting). ICES Scientific Reports. 3:10. 231 pp. https://doi.org/10.17895/ices.pub.7695

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

Contents

i Executive summary

The Working Group on Multispecies Assessment Methods (WGSAM) aims at enabling research on predator-prey interactions for developing advice on the ecosystem approach to fisheries management.

This report details results related to WGSAM term of reference B: "Update of key-runs (standardized model runs updated with recent data) of multispecies and ecosystem models for different ICES regions". Multispecies model key-runs are used in ICES advice processes, and WGSAM provides critical expert review of these key-runs to recommend appropriate use of results.

Although key-run reviews have been conducted in the past, requests for reviews are increasing. Therefore, WGSAM first formalized a consistent set of review criteria to conduct key-run reviews. These are outlined in section 2 of this report and are posted online (https://ices-eg.github.io/wg_WGSAM/ReviewCriteria.html). WGSAM then applied these review criteria to one key-run for the North Sea ecosystem. The review is detailed in section 3 of this report. As the review criteria were applied, WGSAM also noted any difficulties with the review process in order to further refine the review criteria and to make future key-run reviews more efficient and effective.

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 cod, haddock, herring, Norway pout, southern North Sea sandeel, northern North Sea sandeel, sprat, and whiting.

ii Expert group information

Expert group name	Working Group on Multispecies Assessment Methods (WGSAM)
Expert group cycle	Multiannual
Year cycle started	2019
Reporting year in cycle	2/3
Chair(s)	Alexander Kempf, Germany
	Sarah Gaichas, USA
Meeting venue(s) and dates	14–18 October 2019, Rome, Italy (19 participants)
	12–16 October 2020, via WebEx/Correspondence (25 participants)

1 Key-run review criteria

One of the main tasks of WGSAM is the review of so called "key-runs" from multi species and ecosystem models. A 'key-run' refers to a model parameterization and output that is accepted as a standard by ICES WGSAM, and thus serves as a quality assured source for scientific input to ICES advice products (e.g., natural mortality estimates as input for single species assessments).

WGSAM members used the same criteria developed in 2019 for the 2020 key-run review, detailed below and posted at: https://ices-eg.github.io/wg_WGSAM/ReviewCriteria.html. The review carried out during the 2020 WGSAM meeting for the North Sea SMS key-run is documented in Section 3.

WGSAM Key-run Review Criteria

1.1 Background

This document provides criteria for consistent review of models by the multispecies assessment working group of the International Council for the Exploration of the Sea (ICES WGSAM). For nearly a decade, WGSAM has reviewed model "key-runs" as part of its Terms of Reference. Recently, WGSAM reviewed key-runs for the North Sea SMS model in 2014 and 2017, the North Sea EwE model in 2015, and the Baltic EwE model in 2016. Key-run reviews are scheduled for Baltic Sea Gadget and SMS models and the Irish Sea EwE model in 2019.

WGSAM Term of Reference b for 2019–2021 reads: "Update of key-runs (standardized model runs updated with recent data, producing agreed output and agreed upon by WGSAM participants) of multispecies and ecosystem models for different ICES regions. The key-runs provide information on natural mortality for inclusion in various single species assessments. Deliverables: Report on output of multispecies models including stock biomass and numbers and natural mortalities for use by single species assessment groups and external users".

Because WGSAM is increasingly asked to provide model framework reviews as well as key-run reviews, we have drafted this document to provide consistent guidelines and review criteria for both reviewers and groups submitting models for review. Guidelines are based on experience from past reviews (see WGSAM reports from 2013–2018 as well as, e.g.: https://www.st.nmfs.noaa.gov/science-quality-assurance/cie-peer-reviews/peer-review-reports) as well as best practices outlined in the literature (NRC, 2007; Kaplan and Marshall, 2016).

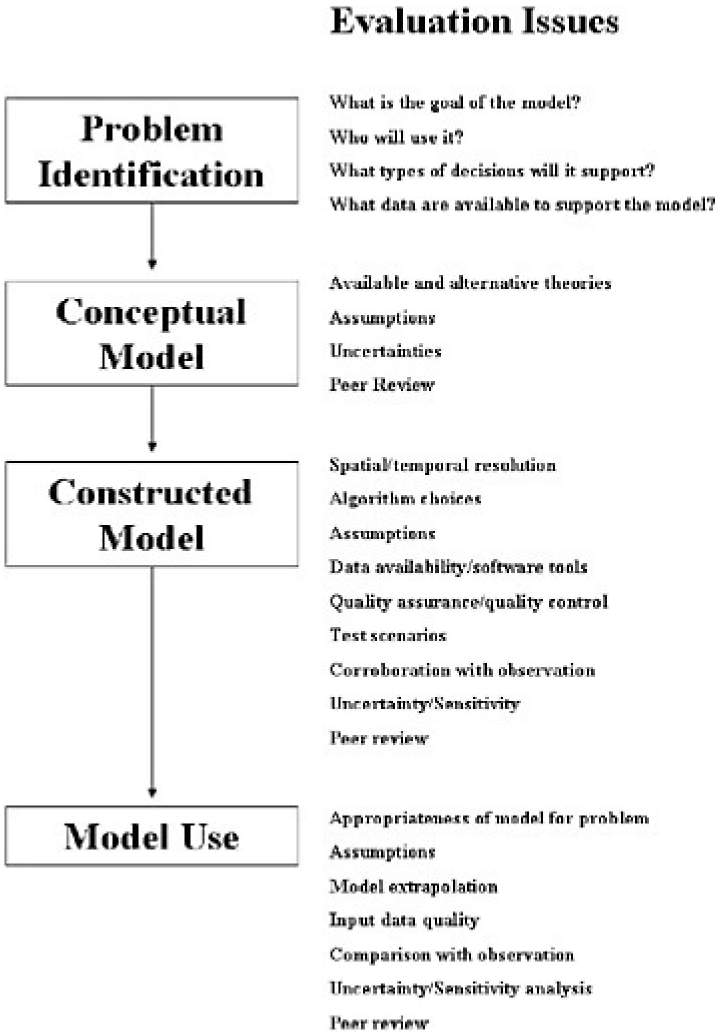
1.2 Model Life Cycle and Objectives for Evaluation

The US National Research Council has summarized the general objectives for model evaluation and tailored them to different stages of the model life cycle with reference to models used in environmental regulation processes (NRC, 2007). The application of multispecies and ecosystem models within fishery management processes is similar enough that this summary provides a useful framework for our criteria.

The general objectives of model review are threefold: (NRC, 2007 p 108)

> *Is the model based on generally accepted science and computational methods?*
> *Does it work, that is, does it fulfill its designated task or serve its intended purpose?*
> *Does its behavior approximate that observed in the system being modelled?*

The model life cycle further specifies review priorities.



Model Life Cycle, NRC 2007

WGSAM receives most requests for model review after the problem identification and conceptual model stage. However, it is important to provide documentation of these processes to reviewers so that the completed model can be evaluated.

In addition, models involved in a management process may face the tradeoff between complexity and transparency, where the need to account for many interactions and processes may render the model harder to explain, and perhaps accept, by decision-makers (NRC, 2007). Because the audience for WGSAM key-runs tends to be other scientists, evaluating the extent to which models are transparent to a scientific, stock assessment oriented audience is appropriate here.

We consider WGSAM reviews to be "peer review".

> *Peer review attempts to ensure that the model is technically adequate, competently performed, properly documented, and satisfies established quality requirements through the review of assumptions, calculations, extrapolations, alternate interpretations, methodology, acceptance criteria, and/or conclusions pertaining from a model or its application. (NRC, 2007)*

2 Key-run Reviews

As described above, model key-runs are currently used to provide inputs to other assessment models; specifically, natural mortality (M) time-series. This places key-runs clearly within the "Model Use" phase of the life cycle. This means that reviews should evaluate (from the figure above):

1. Appropriateness of the model for the problem (problem identification)
2. Assumptions (scientific basis, computational infrastructure; adequacy of conceptual model)
3. Input data quality
4. Comparison with observations
5. Uncertainty/sensitivity analysis
6. Peer review (WGSAM's role, but consider previous reviews from model construction)

Reviewers will rely on submitted documentation to address these issues. At each point, if documentation is inadequate to address the problem that will be noted. Review criteria for each point are outlined below, and presentations should include this information.

2.1 Is the model appropriate for the problem?

Define the problem, and why this model is (or reviewers to explain why it is not) appropriate.

Define the focal species, spatial, and temporal resolution needed to address the problem.

Current uses:

For example, we are asked to provide M-at-age time-series for North Sea and Baltic herring, cod, whiting, haddock, sprat, sandeel, and possibly other species. Spatial scale is at the stock level and temporal resolution is annual, starting at a stock-specific year and going to 2018.

Therefore, the multispecies model(s) must provide this output and sensitivity in this particular output is most important. However, there are other potential uses for these models that have yet to be defined.

A new use for WKIRISH:

> *The aim with the Irish Sea Ecopath is to use the model to "fine tune" the quota advice within the predefined EU Fmsy ranges. In "good" conditions you could fish at the top of the range, in "poor" conditions you should fish lower in the range. The range has already been evaluated as giving good yield while still being precautionary, so this should be fine for ICES to use in advice, so any reviewers should have this in mind.*

For the Irish Sea EwE model, key outputs will be used to determine where the reference point should be within the MSY range for each species. Therefore, outputs defining Ecosystem conditions and both ecosystem and species productivity under the prevailing conditions are most important.

2.2 Is the scientific basis of the model sound?

Is the modelling framework and methodology well established, and has it been previously reviewed and applied? Unless it is not, then WGSAM would use methods outlined for "Constructed Model" review in the flowchart above, or a model framework review.

WGSAM has provided model framework reviews for the LeMans ensemble (2016), FLBEIA (2017), and a multispecies state-space model (2017). Here we outline more general model framework review guidelines for future meetings.

Model frameworks may be at different stages of the model life cycle than the key runs described above, although to date WGSAM has received requests for review closest to the "Constructed Model" phase. This means that reviews should evaluate (from the figure above):

1. Spatial and temporal resolution
2. Algorithm choices
3. Assumptions (scientific basis, computational infrastructure; adequacy of conceptual model)
4. Data availability/software tools
5. Quality assurance/quality control (code testing)
6. Test scenarios
7. Corroboration with observations
8. Uncertainty/sensitivity analysis
9. Peer review (WGSAM's role, but consider previous reviews from prior steps)

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

See above defining the problem. Which datasets are adequate, which could be improved, and which are missing?

Show the input data as a simple chart: beginning and end of time-series, gaps, different length of time-series, spatial resolution of data.

Give information on input data pedigree/quality, reference for where it comes from, whether it is survey data or comes from other model output, whether confidence intervals or other uncertainty measures are available and used in the model.

Categorize the assumptions behind modelled ecological or biological processes. Emphasize those related to species interactions (predation, competition), environmental pressures, and also fleet dynamics if needed to address the problem. If the model is spatial, how do these processes happen in space?

Is the parameterization consistent with scientific knowledge (e.g. (PREBAL) diagnostics Link (2010) for general relationships across trophic levels, sizes, etc.).

2.4 Does model output compare well with observations?

Here we refer to the more detailed performance criteria developed in Kaplan and Marshall, 2016. We have modified them for our purposes.

Characterize the reference dataset used for comparisons. Has the data been used to construct this model? Is the reference dataset from another model? Describe reference data source(s).

1. (if important to use–projection) All functional groups persist in an unfished unperturbed run.
2. (if important to use–projection) Model stabilizes for the last ~20 years of an unfished, unperturbed 80–100 year run.
3. The key-run should define the hindcast time period where agreement with other data sources or assessments is needed. Review will determine if the model fits adequately within that time period. Error ranges are needed for comparison or reference datasets.
4. Focal species should match biomass and catch trends over the hindcast time period. For full system models, species comprising a majority of biomass should also match general hindcast trends. Suggested tests include modelling efficiency, RMSE, etc. (Sterman 1984; Stow *et al.*, 2009; Joliff *et al.*, 2009; Allen and Somerfield 2009; Lehuta *et al.* 2013 and 2016; and Olsen *et al.* 2016).
5. Patterns of temporal variability captured (emergent or forced with e.g. recruitment time-series).
6. Productivity for focal species (or groups totaling ~80% of system biomass in full system models) should qualitatively match life history expectations (prebal diagnostics). *WGSAM noted that productivity is difficult to evaluate for multispecies models when the quantity being estimated (M, Fmsy) is expected to differ from single species estimates due to the structure of the model. An independent estimate of productivity was difficult to establish during this meeting. For future reviews, modellers could consider comparisons based on individual level survival and longevity, while the portion of productivity related to recruitment levels requires further thought.*
7. Natural mortality decreases with age for majority of groups.
8. Age and length structure qualitatively matches expectations for majority of groups.
9. Diet predicted qualitatively matches empirical diet comp for majority of groups.
10. Spatial distribution of outputs match reference datasets for spatial models (most important if output required at spatial resolution of model, comment if a match in aggregate but not at higher resolution).
11. Ecosystem indicators (relationship between abundance and body size, pelagic to demersal, Large Fish Indicator) match reference data if needed for problem.

2.5 Uncertainty

Has uncertainty been assessed in the output of interest? Has sensitivity analysis been performed and how does it affect those outputs?

The key-run should show estimates of uncertainty in the output quantity of interest. Uncertainty analysis is best if possible to estimate confidence intervals. If not possible list key sources of uncertainty, expected bounds on outputs based on those (possibly from sensitivity analysis)–i.e. design sensitivity analysis to approximate uncertainty analysis.

Specific analyses, sensitivity of key output in:

1. Retrospective analysis (5 year peel of all input data)
2. Forecast uncertainty: remove last 3–5 years of survey index only to see how well the model works in forecast mode, given the catch that actually happened.
3. Sensitivity to stomach data and other key or low-confidence data sources
4. Sensitivity to key parameters: consumption rates, residual mortality (M1, M0)
5. Sensitivity to initial conditions

For complex models with long runtimes, simpler ways to address uncertainty may be appropriate (Kaplan and Marshall, 2016).

Best practice is to retain multiple parameterizations that meet the above criteria to allow scenario testing across a range of parameterizations. Parameter uncertainty can be addressed even in complex models. A simple method uses bounding (e.g. base, low bound, and high bound productivity scenarios; Saltelli and Annoni 2010).

2.6 Previous peer review

What did they point out and have issues been addressed?

Review of constructed models should have evaluated spatial and temporal resolution, algorithm choices, data availability and software tools, quality assurance/quality control of code, and test scenarios.

2.7 Review recommendations

WGSAM key-run review reports will address the sections above, and then make a recommendation for the appropriate uses of model outputs. WGSAM key-run review reports will also end with a list of recommendations for items to be addressed in future key-runs.

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3 North Sea SMS key-run review

3.1 Is the model appropriate for the problem?

The SMS model will be used to provide natural mortality estimates by age and year as input to single species assessments of cod, 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 model. However, an assumption is needed for residual mortalities M1 while the predation mortalities M2 are estimated (M = M1+M2). The model is able to provide estimates for the years 1974 to 2019.

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, and 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 North Sea cod, haddock, herring, Norway pout, southern North Sea sandeel, northern North Sea sandeel, sprat, and whiting. The 2020 North Sea SMS keyrun is primarily an update of the 2017 keyrun by extension of the input data and their update when the single species stock assessment input data were revised through benchmarks or inter-benchmarks. Overall, the model structure and main assumptions are consistent with the previous keyrun. The model remains appropriate in relation to the purpose of providing predation mortality estimates.

3.2 Is the scientific basis of the model sound?

The SMS model is an established and reviewed modelling framework (ICES WGSAM 2014, 2017) 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), 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 North Sea (i.e., sandeel, sprat).

3.3 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 2017 SMS North Sea key-run include:

- 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 a lower mean weight at ages for the youngest ages and a higher mean weights 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.

While some of the single species assessments start with age 1 as recruits, SMS starts with age 0. Given that predation mortalities are important for age 0, this is understandable. But e.g., the mean weight at age remains highly uncertain for the 0 group. The use of same or distinct weight-at-age for the catches and the stocks align to what is used by the single species stock assessments.

Additional data needed to parameterize SMS are stomach data. Compilation of stomach data for the 2020 keyrun is consistent with the methodology used for the previous keyrun. No new fish stomach data are added to the model. Main bulk of stomach data continue to be from 1981 and 1991. A test run (not keyrun) was performed by compiling stomach data with the R-package FishStomachs (beta version not published yet). Predation is implemented as in the previous keyrun.

Consumption rates are calculated based on the weight and not the length of the predators. The cylinder gastric evacuation rate model from Andersen and Beyer (2005a, b) is applied.

Overall, the data quality 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

In addition to M2 values, SMS estimates many (1870 in total) other parameter values related to e.g. diet choice, fishing mortality and recruitment. A summary table of the estimated parameters and their uncertainty ranges can be found in the Stock Annex (Annex 3, section 5.1.1, table 5.1.1.1).

Assumptions regarding stock distributions are as follows:

- ICES has stated that about 7% of the combined western and North Sea horse 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. WGSAM 2020 considered this to be a strong assumption not supported by any data and advice to assume instead a constant stock size (average of the previously proposed trajectory). The major differences compared to previous assumption are in quarter 1 and that anyway present the lowest feeding.
- Hake is a widely distributed species assessed as a unique stock and monitored through a set of scientific surveys depending on the region. SMS requires to inform

on the part of the stock present in the North Sea. Survey characteristics are inconsistent among the different areas and do not allow a straightforward computation of the percentage presence of hake in each region (i.e., pattern of increase is unrealistically too abrupt and steep when survey data are directly applied). The alternative adopted and validated by the group is the use of proportion of landings in the Noth Sea. Despite such calculation is recognised to be proned to bias due to heterogeneous effort and catchabilities, comparison with recent survey based modelling estimates (Staby *et al.* 2018) reassure on the level and steepeness of estimated increase.

- Since the last benchmark (ICES 2018), sprat in area IV and 3a is assessed as a single stock. The 2020 keyrun required evaluation of the proportion of sprat in the North Sea. Sprat is monitored in area IV and 3a by the HERAS acoustic survey and indices of abundance are available for the stock area since 2006. No information is available before that time and time-series of catch proportion was proposed as an alternative to provide sprat stock proportion in the North Sea prior 2006. While both series match for the last years, they are very noisy and the values based on catch are unrealistically low in the mid-1980s likely due to quotas restrictions. It was decided to smooth the HERAS series from 2006 on and to use a constant value for the period before corresponding to the HERAS 2006 value.
- Mackerel distribution remains an issue as the proportion of the Northeast Atlantic stock which occurs in the North Sea is relatively small and variable in relation to the whole stock. No new information is available and same assumptions as in the 2017 keyrun are adopted.
- Major assumptions on stock distribution, overlap and vulnerability remain the same as in the 2017 key run. In the suitability function, the effect of overlap and vulnerability is not entirely separable. The predator-prey overlap is allowed to vary quarterly (although it is estimated only for a limited number of combinations or fixed to better mirror observations from the stomachs) in the model but it is assumed constant among years. The vulnerability parameter is constant and also estimated in the model.

The parameterization of the diet selection sub-model is based on several assumptions. First there is only one vulnerability parameter per interaction for the full model time-series. The assumption of constant vulnerability may be violated if e.g. the spatial predator-prey overlap changes. Given an assumed constant overlap, the implied Holling type II functional feeding response as used in SMS is well known to lead to instability when prey items become low in abundance and makes them vulnerable to extinction in the model. However, this is mainly an issue for forecasts when trying to make predictions outside the range of observations.

Another important assumption is a constant biomass pool of “Other Food” in time. If the availability of important Other Food prey items changes over time, this can lead to biased predictions of relative stomach contents and therefore predation mortalities. As shown under section 3.4, this could be an issue for this key-run.

There are several options in SMS how the size selection of the predators is modelled (see Annex 3, appendix 1). Without additional new information the diet data remain insufficient to estimate the size preference parameters and a uniform size preference is maintained in the 2020 keyrun as in the past.

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

3.4 Does model output compare well with observations?

In this review report we reproduce only a few diagnostic plots; please see the Annex 3 for all comparisons with observations and other North Sea SMS key-run results. Diagnostic plots are also posted online for download at:
https://ices-eg.github.io/wg_WGSAM/NS_2020_key_run.html

Catch data

The SMS key-run is generally able to reproduce the overall annual catches for all the modelled species (Figure 1). Some more pronounced difference 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 peakes in the annual catches are also somehow underestimated for some stocks (i.e., cod in 1980, herring in 1987–1989, mackerel in 2014) but the model is able to reproduce both the long term pattern as well as the interannual variability of fisheries yields.

Figure 1. SMS North Sea model fits (Yield.hat) to catch data (Yield).

Survey data

The model fits age specific time-series from multiple surveys carried out throughout the North Sea. 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 keyrun. Among the most visible patterns it is worth to mention those for plaice which shows strong year effects across several surveys (i.e. BTS Combined, IBTSQ3; Figure 2), and for the oldest ages of sole (Figure 3). More effort on tuning the assessment for plaice and sole might have improved the fit, however plaic and sole are neither predator nor prey in the model, and the assessment results for those species do not affect e.g. predation mortality for other stocks.

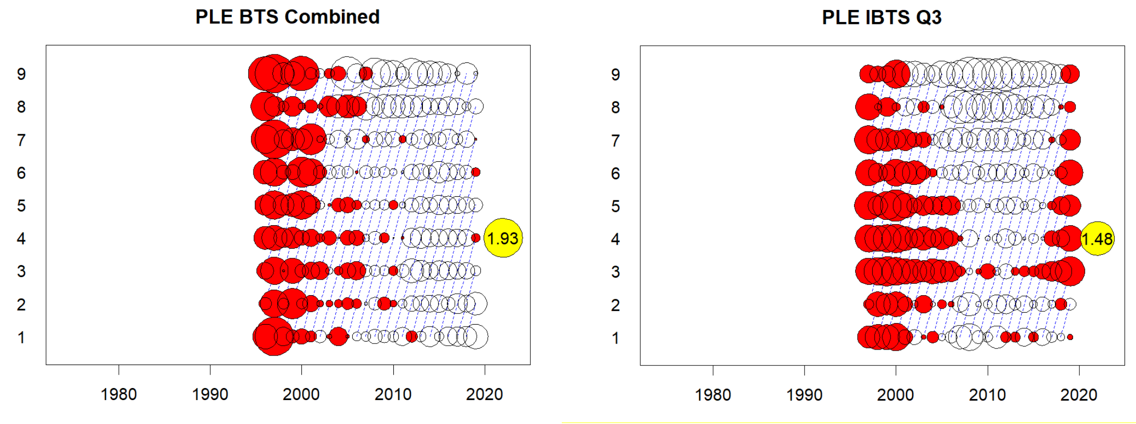

Figure 2. Plaice survey number at age residual plots.

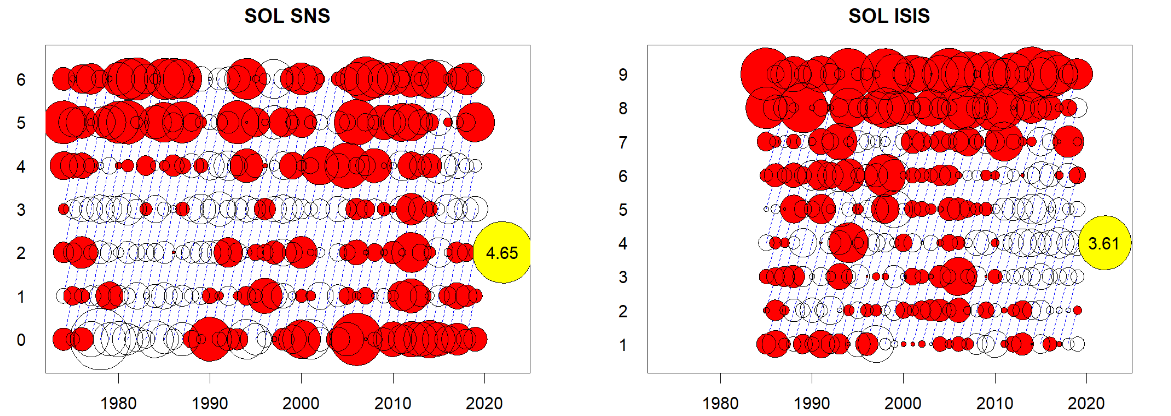

Figure 3. Sole survey number at age residual plots.

Stomach data

The SMS model is run with a quarterly time step and input data (incl. stomach data) are fitted on a quarterly basis. 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.

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. On an annual basis, the species composition in the stomachs appears well represented in the model. For many of the main predators, other food represents a considerable proportion of the total diet. For instance, approx. 3/4 or more of the cod diet is consistently composed of other food (Figure 4). 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. other food is approx. 60% in 1981 but around 30% in 1991 because of the increasing contribution of herring, Figure 5), grey gurnards or harbour porpoise (Figure 6). In those cases, when stomach data are available from a single year 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, or simply observation variability coming from the data (Figure 7).

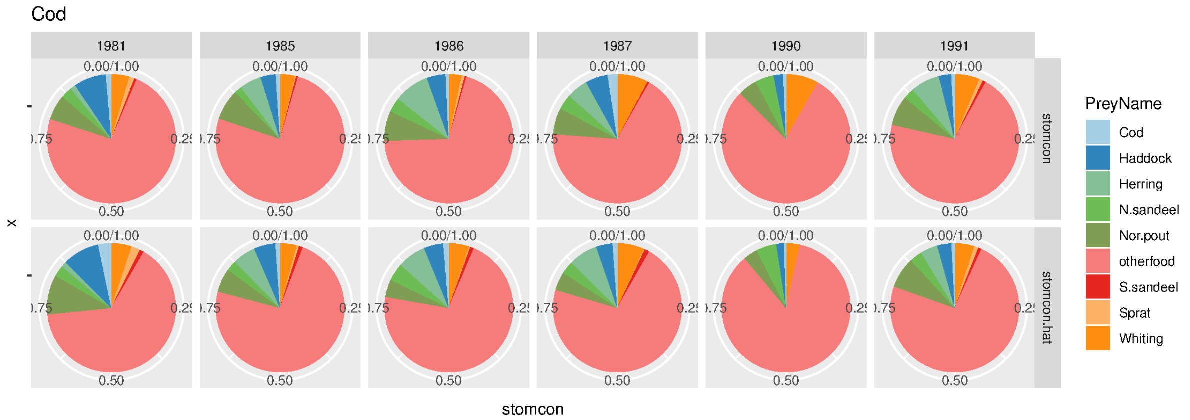

Figure 4. Input (top) and estimated (bottom) diet composition for cod.

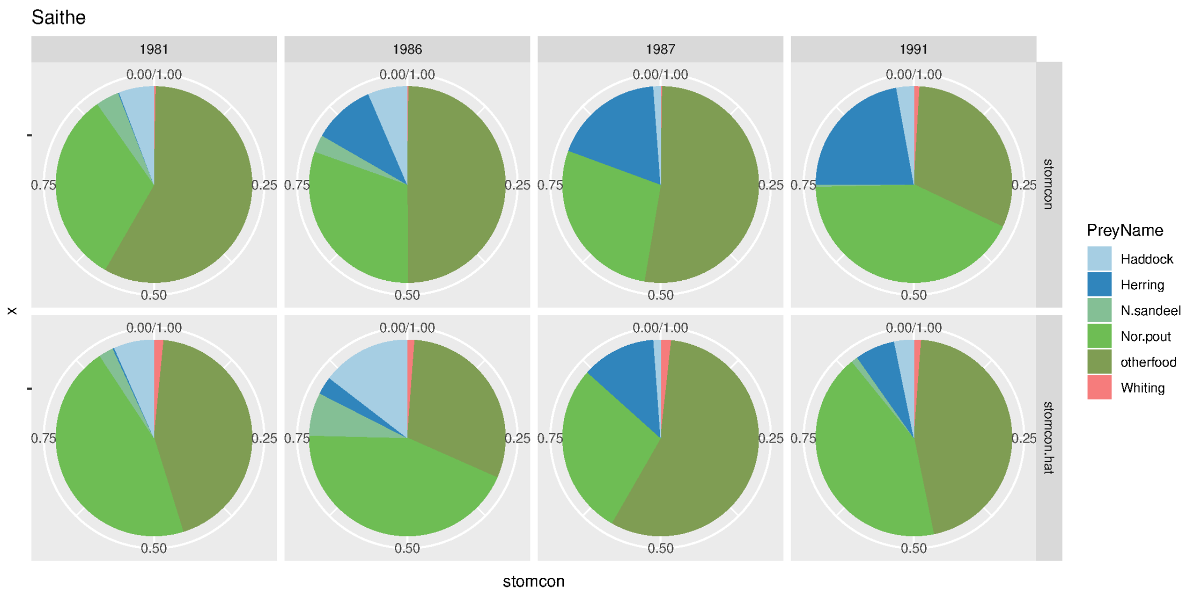

Figure 5. Input (top) and estimated (bottom) diet composition for saithe.

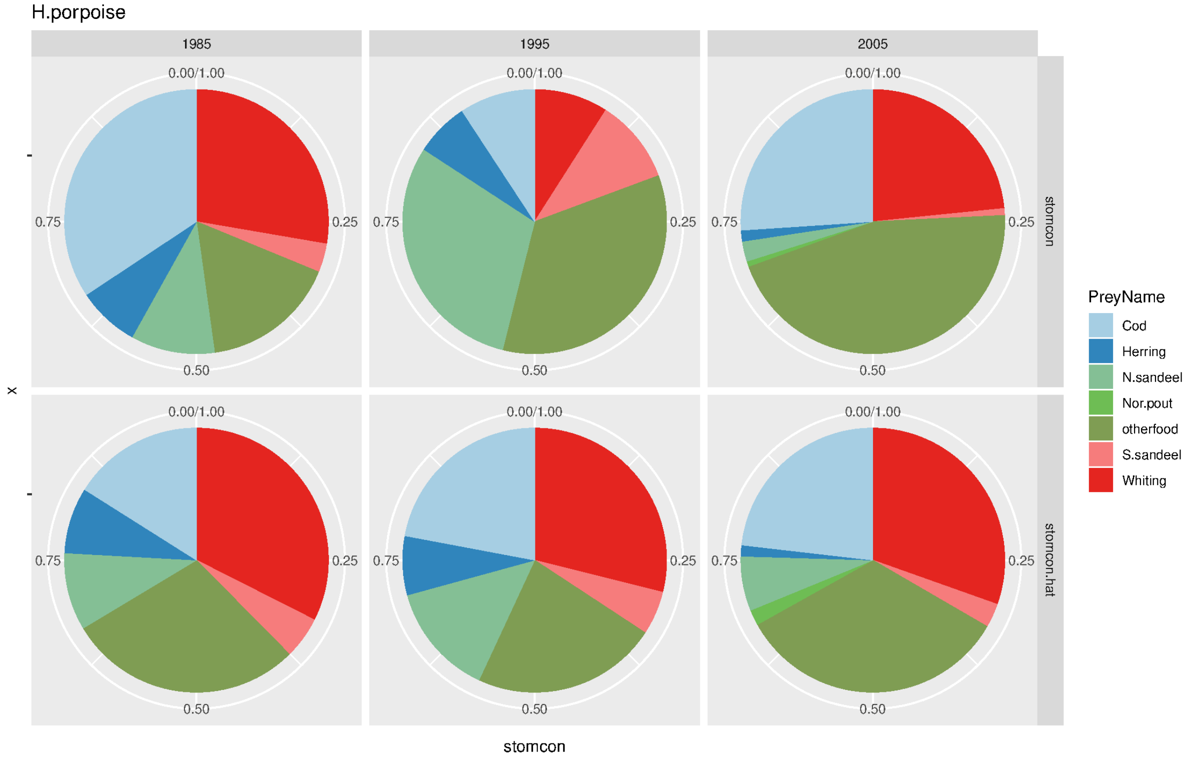

Figure 6. Input (top) and estimated (bottom) diet composition for harbor porpoise.

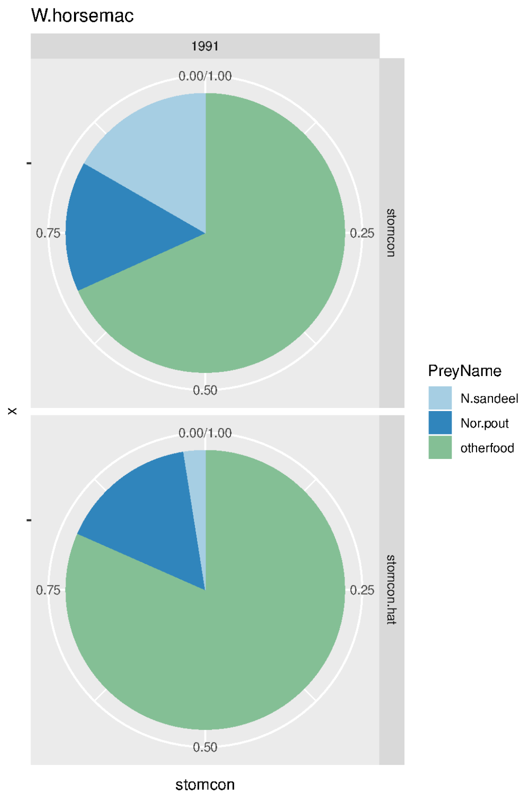

Figure 7. Input (top) and estimated (bottom) diet composition for western horse mackerel.

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 (i.e., N. sandeel, S. sandeel, Norway pout, Sprat), where predation mortality for age 0 in quarter 3 is larger than the predation mortality in quarter 4. This is probably linked to the uncertainties of estimating mean size of 0-groups.

When M2 is evaluated on a quarterly basis, it is noticed that in some years birds appear as sporadic important contributors to M2 for some ages. This is for instance the case of both N. & S. sandeel age 3–4 and whiting age 2 (Figures 8–9).

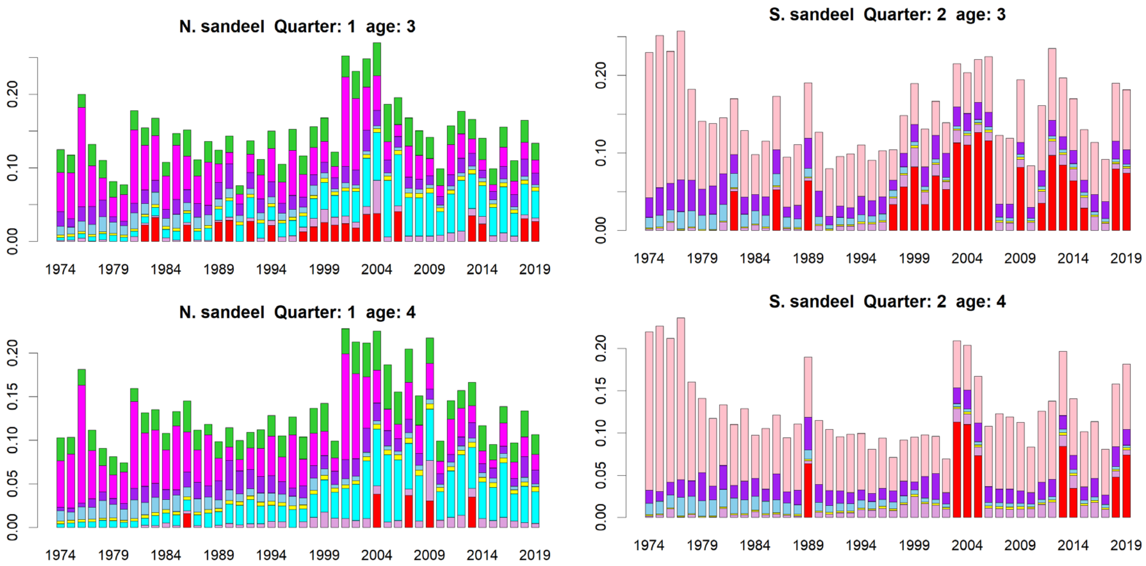

Figure 8. Predation mortality by predator on Northern (left) and Southern (right) sandeel in certain ages and quarters.

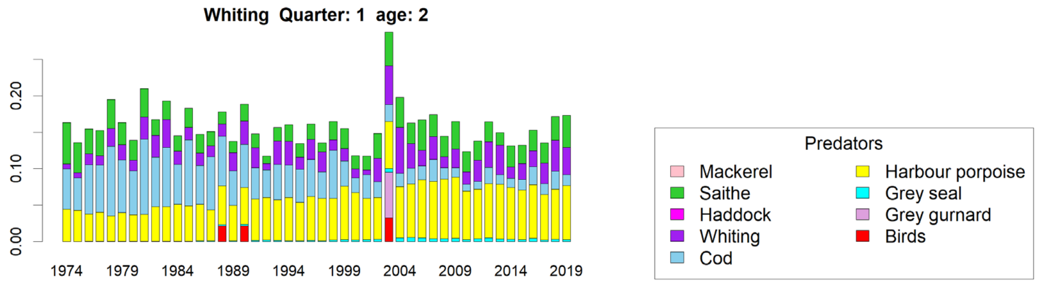

Figure 9. Predation mortality by predator on age 2 Whiting in quarter 1.

3.5 Uncertainty

Some uncertainty in the North Sea SMS key-run M2 outputs is related to model structure regarding the predator diets For example, the prey suitability of different predators is estimated in the models as the product of:

vulnerability x overlap x size preference

As no size preference is implemented in the present key-run (except for the other food component, and that the predator-prey size ratio must be within the observed range), the suitability is determined by the estimation of overlap and vulnerability. The associated parameters have in some cases rather high CV (i.e., other food parameter suitability of whiting has a CV of 174) and it is difficult to assess if the model is always able to properly partition the contribution of overlap and vulnerability.

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. This parameter is estimated around a similar scale for all the species aside from hake. It is difficult to have a perception of how the estimated parameters of the Dirichlet distributions affect the model, but we cannot exclude that in some cases implications could be vast.

To get a better idea on true uncertainties several sensitivity runs were carried out:

1. Retrospective analysis (5 year peel of all input data)
   i. SSB, F, Recruitment
   ii. M2 by age
2. Sensitivity to stomach data (old vs. new stomach data compilation method for the same data)
   i. Initial test only, not recommending to use new method yet
   ii. Suggested stepwise look at each change
3. Uncertainty of the estimates (CV)

Retrospective pattern in M2

Retrospective patterns in M2 are overall small and in general less pronounced than retrospectives in SSB, F or R likely due to predator-prey buffering. The only exception is the retrospective pattern of M2 in S. sandeel (Figure 10), which is possibly related to the retro pattern in F when 2019 data are considered.

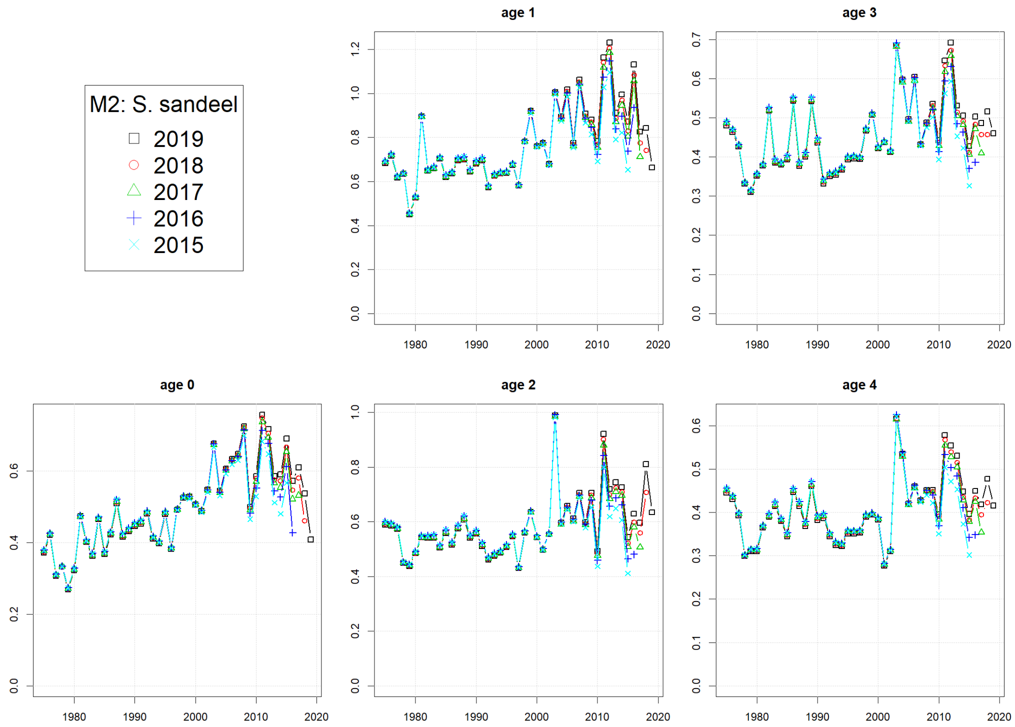

Figure 10. Retrospective pattern in M2 for S. sandeel.

Sensitivity to stomach data compilation methods (new R package approach)

A new R-package, FishStomachs, is at present under development for improving the preparation of stomach data and compiling stomach input files for SMS. Preliminary tests have shown consistent (but not identical) results between the new R procedure and the old calculations based on SAS. The new procedure improves the compilation of the stomach input files for the multispecies model in several aspects (i.e., bias correction for variable evacuation rates, improved allocation of unidentified or partly identified preys, and more), it will be easier to be maintained in the future and it will enhance further improvements. The 2020 keyrun uses the old procedure and compilation of stomach data with the new R-package has only been done for testing purposes.

Uncertainty in SSB, Recruitment, and M2

As expected, uncertainty in SSB and Recruitment tend to be higher for short lived species in the North Sea SMS key-run. Recruitment CVs are also expected to increase in the most recent modelled years. The pattern is generally observed but a more steady increase of CV is observed over time for cod. Several assumptions are proposed to explain the pattern (introduction of a new survey in 1991, change in distribution of the species ignored in SMS, lower recruitment since 1996). It is noted that the single species assessment of cod also encounters fitting problems and a benchmark is planned.

The CVs for M2 values are generally low for all modelled species. However early ages (0, 1, 2) of cod, herring and haddock present increasing CV over time. It is questioned whether having a majority of the observed stomach data early in the time-series could create such pattern. It is also noteworthy that the age 0–1 of herring have a M2 CV higher compared to the other species. Also in this case the reasons remain unexplained but may be related to uncertainty in recruitment.

3.6 Previous peer review

The SMS methodology has been reviewed in ICES WKMULTBAL (2012) and WGSAM (2015, 2019).

Comparison with the previously reviewed and approved 2017 key-run was part of the 2020 WGSAM review and is summarized here. Most results were comparable between key-runs and differences in results were mainly attributable to changes in SMS inputs.

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 2017 key run. Mackerel and Norway Pout show small deviations compared to 2017, which are consistent with changes in F, SSB and Recruitment in the single species assessments.

Cod presents relatively big changes compared to the previous keyrun (lower SSB and higher F between 2014 and 2016). Given that these are consistent with the retro bias observed in the single species assessment, this was considered to pertain to the input data.

Changes in whiting SSB and F are also significant and are probably attributed to modifications of mean weight at age of whiting. A slight change is also noted in the assessment following the 2018 benchmark. Due to the problematic whiting single-species assessment, the IBTS Q1 was split into two periods (1978–1988 and 1989–2020), just as was done in 2017.

Saithe SSB is tuned to the assessment numbers. However, the F values through time are higher than in the previous key run time-series. Here as well, it is assumed that the retrospective bias in the assessment is responsible for the changes.

Herring presents a higher SSB and lower F than in the 2017 keyrun which is also consistent with the historical retrospective bias from the single species assessment following the 2018 benchmark.

For Southern sandeel, the F values are lower and the SSB and recruitment are a bit higher. This could be because survey data is used here for SSB instead of assessment data.

For sprat, F is systematically higher throughout the time-series which is similarly visible when the key run is compared to the single species assessment. A dedicated test has been run to explain the difference which is related to the fact that the single species assessment has shifted by 6 months (from 1 July to 30 June) to match the in-year advice for this stock, while this is not the case for the SMS model. In addition to that, in the single species assessment model, catches were moved from the last time-step of the model and forced to be zero in all the years except the initial year of the assessment. After these two aspects are accounted for, the 2020 keyrun returns F values of sprat highly consistent with the single species assessment.

Changes in M2 since last keyrun

Whiting M2 is relatively different compared to the previous keyrun for age 1, age 2 and to a lesser extend for ages 3 and 4 at the beginning of the time-series. This probably has to do with updated weights at age (lower weights, higher predation rates). Potentially due to changes in cannibalism rates (see stock annex for diet plots).

There are some changes in herring M2 compared to the 2017 key run. Predation mortality of herring follows the same trend in the two key runs. The most striking difference is a M2 in the most recent years for age 2+. This is mainly due to a lower stock of the predators cod and saithe estimated in the 2020 run. Despite the visible change in absolute values of M2 between the two key runs, it is noted that the temporal pattern remains highly similar. M1 is estimated within the single species North Sea herring assessment and works as a scaling parameter, hence it is expected that the present changes in the absolute value of M2 will have a limited impact on the assessment.

M2 for southern sandeel and sprat are also quite different, both could be due to changes in the diet of whiting related to the new weight at age data of whiting. For southern sandeel, this could also be due to changes in the survey data input. For sprat, it could also be due to the new input data from the single species assessment that was used.

3.7 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	2020
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	1974–2019
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/NorthSeaKeyRun_2020.zip and https://github.com/ices-eg/wg_WGSAM
Further details in	Report of the Working Group on Multispecies Assessment Methods 2020

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 2017.

For further work WGSAM recommends the following:

1. There is a need for updated stomach sampling to understand how diets have changed with changes in species ranges. There are large proportions of other food in the diets of several species. Ideally, these need to be refined and it needs to be assessed whether this has changed.
2. Need for better knowledge of the proportion of several stocks (hake, mackerel, N horse mackerel) that habituate the North Sea.
3. A future run with age 1 as recruits could be tried because the input for the 0 group is highly uncertain for many species.
4. Need of further investigations related to the following issues:

- No size preference in predation is implemented in the model at the moment. With more stomach data it would be possible to test the impact of such an assumption
- Unclear why the M2 CV increases for a number of prey stocks
- Impact of the Dirichlet estimated parameter on the resulting predation mortality in general, and reason behind the need of a scaling factor for the hake Dirichlet parameter

3.8 References

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Annex 1: List of participants

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Annex 2: Resolutions

The **Working Group on Multispecies Assessment Methods** (WGSAM), chaired by Sarah Gaichas, USA, and Alexander Kempf, Germany, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2019	14–18 October	Rome, Italy		
Year 2020	12–16 October	online meeting/ by corresp.		physical meeting cancelled - remote work
Year 2021			Final report by DATE	**Change in Chair** Incoming co-chair: Valerio Bartolino Outgoin co-chair: Alexander Kempf

ToR descriptors

ToR	Description	Background	Science Plan codes	Duration	Expected Deliverables
a	Review further progress and deliver key updates on multispecies modelling and ecosystem data analysis contributing to modelling 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.
b	Update of key-runs (standardized model runs updated with recent data) of multispecies and eco-system models for different ICES regions	The key runs provide information on natural mortality for inclusion in various single species assessments	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	Establish and apply methods to assess the skill of multispecies models intended for operational advice	This work is aimed at assessing the performance of models intended for strategic or tactical management advice.	5.1; 6.1; 6.3	Establish methods 2019, apply 2020-2021	Manuscript for methods, report on success of methods for different examples.
d	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, as applied for example management questions	5.1; 6.1; 6.3	3 years	Report on methods for comparing models and for constructing model ensembles.
e	Management Strategy Evaluation (MSE) methods	Adapting existing multispecies/ecosystem	5.3; 6.1; 6.3	3 years	Review of MSE modelling approaches.

	and applications for mutispecies and ecosystem advice, including evaluating management procedures and estimating biological reference points	models for MSE (operating models, assessment models), visualizing tradeoffs and uncertainty for managers and stakeholders		Review of visualization methods. Review of applications throughought the ICES area with lessons learned.

Summary of the Work Plan

Year 1	All ToRs, Key run Baltic, multiple models
Year 2	All ToRs, Key Run North Sea SMS (maybe others)
Year 3	All ToRs, Key Run US Northeast Shelf, multiple models

Supporting information

Priority	The current activities of this Group will lead ICES into issues related to the ecosystem effects of fisheries, especially with regard to the application of the MSY Approach. The activities will provide information (e.g., natural mortality estimates, performance of indicators) and tools (e.g., multi-model ensembles, keyrun models) valuable for the implementation of an integrated advice in several North Atlantic ecosystems. Consequently, these activities are considered to have a very 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	Approx 20. Expertise in ecosystem, modelling and fish stock assessment from across the whole ICES region.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	ACOM, most assessment Expert Groups
Linkages to other committees or groups	WGMIXFISH, WGDIM, WGBIFS, IBTSWG, WGECO, WGINOSE, WGIAB, WGNARS, WGIPEM.
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	November 2020 (after the WGSAM 2020 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.

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 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 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 prey and the resulting consumption showed a larger contribution from sandeel and herring while whiting was less important than previously estimated.

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 key 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.

1 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.

2 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.

2.1 Analytical assessment stocks

This group of stocks includes:

1) Cod;
2) Haddock;
3) Whiting;
4) Saithe;
5) Mackerel;
6) Herring;
7) Northern sandeel;
8) Southern sandeel;
9) Sprat;
10) Norway pout;
11) Plaice;
12) 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	8+	North Sea and eastern English Channel	1978	0-8	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 Katte-gat	1967	3–10	year
Herring	HER	9+	North Sea, Skagerrak and Kat-tegat, 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 Kat-tegat	1974	0–3	quarter
Norway pout	NOP	3	North Sea, Skagerrak, and Kat-tegat	1984	0–3	quarter
Plaice	PLE	10+	North Sea, Skagerrak	1957	1–15	year
Sole	SOL	10+	North Sea	1957	1–10	year

2.1.1 Quarterly catch data

Quarterly catch-at-age number 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 stocks 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 both stock areas and the addition of discards 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 (kindly provided by Henrik Kjems at ICES, in 2017). 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 including quarterly catch data, but the data series includes only 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	2005–2019*
Northern sandeel	1982–2019*
Southern sandeel	1982–2019*
Sprat	1974–2019
Norway pout	1982–2019

Unfortunately, the quarterly catches provided did not appear to be updated back in time in response to e.g. benchmark decisions on changes in 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 in landings and discards, and in some cases 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 number-at-age. This proportion is assumed the same for all quarters.

2.1.2 Cod

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 (see ICES, WGNSSK 2020). For cod, annual scaling factors of observed catches, 1993–2005, are estimated by the ICES SAM assessments. The input catch numbers are raised by this factor before used in SMS.

Survey data

Survey data are copied from the single-species assessment (see table below where alfa and beta is the timing of the survey, given as proportion of the year).

	NAME	YEARS	AGES	ALFA AND BETA	SOURCE
1	IBTS Q1, Gam	1983–2020	1–5	0–0.25	WGNSSK 2020
2	IBTS Q3, Gam	1992–2019	1–4	0.5–0.75	WGNSSK 2020

Biological data

Proportion mature and single-species natural mortality (M) data are copied from the assessment.

The single-species assessment assumes that mean weight-at-age in the stock is equal to mean weight-at-age in the catch. This overestimates the mean weight of the youngest age classes, as the larger individuals within an age class are more likely to be retained in the fishing gear.

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 give weight 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 is maintained, but raised to the annual mean weight used in single-species assessment. Raising is done from the simple mean of quarterly mean weights and the annual single-species mean weight in the particular year. The mean weight for quarter 1 will thereby be lower than the single-species stock weights, which lead to a smaller SSB (quarter 1) in SMS, compared to the single-species SSB. This was changed from previous practice in 2017 to ensure that a consistent method was used in all years. Figure 2.1.1 compares the two sets of mean weights. As the pre 2017 weight at age data have remained virtually unchanged since the large key run, the two sets appears identical.

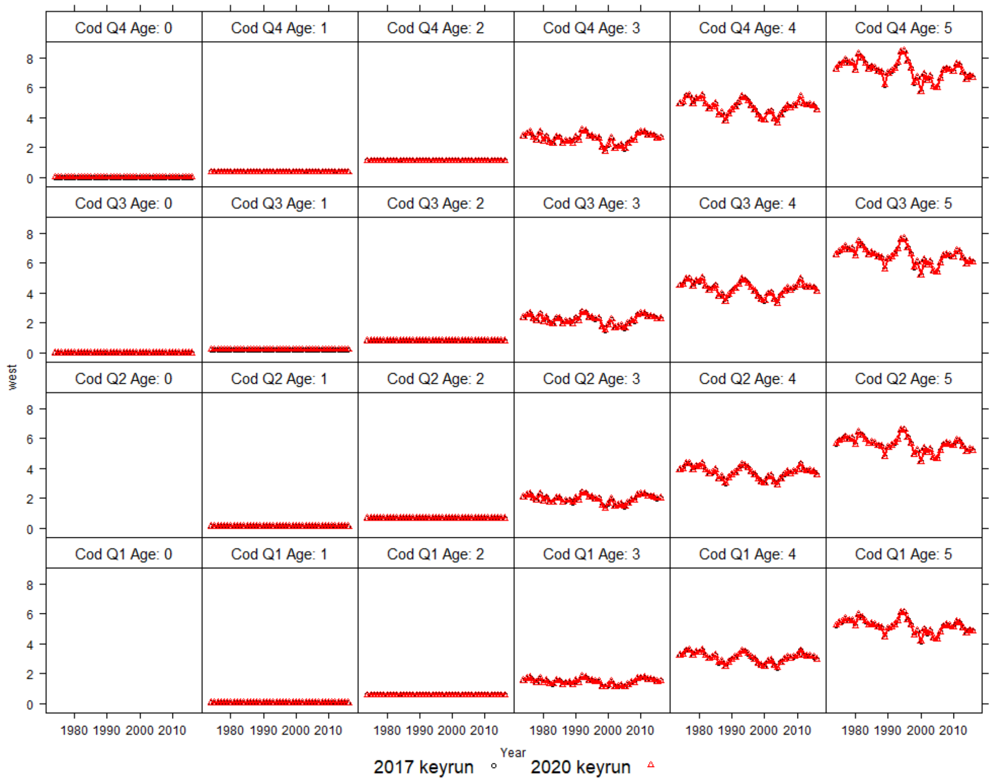

Figure 2.1.1. Mean weight-at-age in the sea of cod by quarter as used in the 2017 and 2020 key runs.

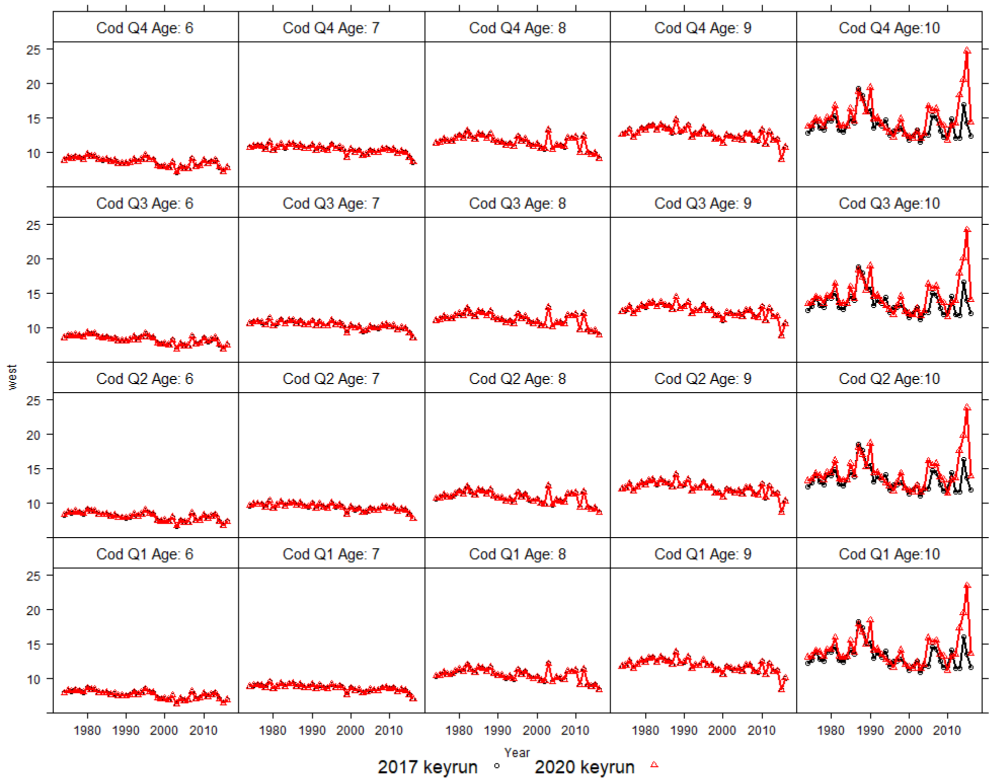

Figure 2.1.1. Continued. Mean weight-at-age in the sea of cod by quarter as used in the 2017 and 2019 key runs.

Stock distribution

The ICES "North Sea cod" includes the stock areas, North Sea, Skagerrak and the eastern Channel (see Table 2.1.1). SMS calculates predation mortalities for the fish within the North Sea, so data on the proportion of the fish stock within the North Sea is needed, ideally by year, quarter and age.

The NS-IBTS covers the North Sea, Kattegat, Skagerrak and the English Channel (just Quarter 1 since 2007), **and provides data to assess the distribution of cod, whiting and Norway pout** but less relevant data for haddock and saithe, where IBTS only partly covers the stock area. Herring is not included because 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 plaice population is not divided between areas, as plaice is not a predator or prey in the SMS model, such that a population split does not affect the other species.

The distribution 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 ICES DATRAS database (data type "cpue per age per subarea", survey NS-IBTS, quarter 1 and 3).

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

1) 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).

2) An index for stock abundance per area (North Sea, Skagerrak, Kattegat and English Channel) is calculate as the sum of average roundfish area cpue, weighted by the area (km^2) of the roundfish areas.

3) 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 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.

Results for cod

The observed proportion of the stock within and outside the North Sea is shown for Quarter 1 (Figure 2.1.3) and quarter 3 (Figure 2.1.4) and Figure 2.1.5 show the observed proportion within the North Sea (excluding the English Channel data, as those exist only for the last ten 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 statistical 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 (**Figure 2.1.6**)

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 age 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 2.1.6), 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. These methods result in the proportion of the stock within the North Sea presented in Table 2.1.4. The proportions are assumed to be the same for all quarters.

Table 2.1.4. Proportion of the cod stock within the North Sea (ICES Subarea 4) by year and age as used in SMS.

	Age				
Year	0&1	2	3	4	5+
1974	0.94	0.91	0.88	0.94	0.96
1975	0.93	0.91	0.88	0.93	0.96
1976	0.93	0.90	0.88	0.93	0.96
1977	0.92	0.90	0.88	0.93	0.96
1978	0.91	0.90	0.88	0.93	0.95
1979	0.90	0.89	0.88	0.93	0.95
1980	0.89	0.89	0.88	0.93	0.95
1981	0.88	0.89	0.88	0.93	0.95
1982	0.87	0.88	0.88	0.93	0.95
1983	0.85	0.88	0.88	0.92	0.95
1984	0.84	0.88	0.88	0.92	0.95
1985	0.83	0.87	0.88	0.92	0.95
1986	0.81	0.87	0.87	0.92	0.95
1987	0.80	0.86	0.87	0.92	0.95
1988	0.78	0.86	0.87	0.92	0.95
1989	0.76	0.86	0.87	0.92	0.95
1990	0.74	0.85	0.87	0.92	0.94
1991	0.73	0.85	0.87	0.92	0.94
1992	0.71	0.84	0.87	0.91	0.94
1993	0.69	0.84	0.87	0.91	0.94
1994	0.67	0.83	0.87	0.91	0.94
1995	0.66	0.83	0.87	0.91	0.94
1996	0.64	0.82	0.87	0.91	0.94
1997	0.62	0.82	0.86	0.91	0.94
1998	0.61	0.81	0.86	0.91	0.94
1999	0.60	0.81	0.86	0.91	0.94
2000	0.59	0.80	0.86	0.91	0.94
2001	0.58	0.80	0.86	0.90	0.94
2002	0.57	0.79	0.86	0.90	0.94
2003	0.56	0.79	0.86	0.90	0.94
2004	0.56	0.78	0.86	0.90	0.94
2005	0.56	0.78	0.86	0.90	0.94
2006	0.55	0.77	0.86	0.90	0.94
2007	0.56	0.76	0.85	0.90	0.94
2008	0.56	0.76	0.85	0.90	0.94
2009	0.56	0.75	0.85	0.90	0.94
2010	0.57	0.75	0.85	0.90	0.94
2011	0.57	0.74	0.85	0.90	0.94
2012	0.58	0.73	0.85	0.89	0.94
2013	0.59	0.73	0.85	0.89	0.94

2014	0.60	0.72	0.85	0.89	0.94
2015	0.61	0.71	0.85	0.89	0.94
2016	0.62	0.70	0.85	0.89	0.94
2017	0.63	0.70	0.84	0.89	0.94
2018	0.64	0.69	0.84	0.89	0.94
2019	0.65	0.68	0.84	0.89	0.94

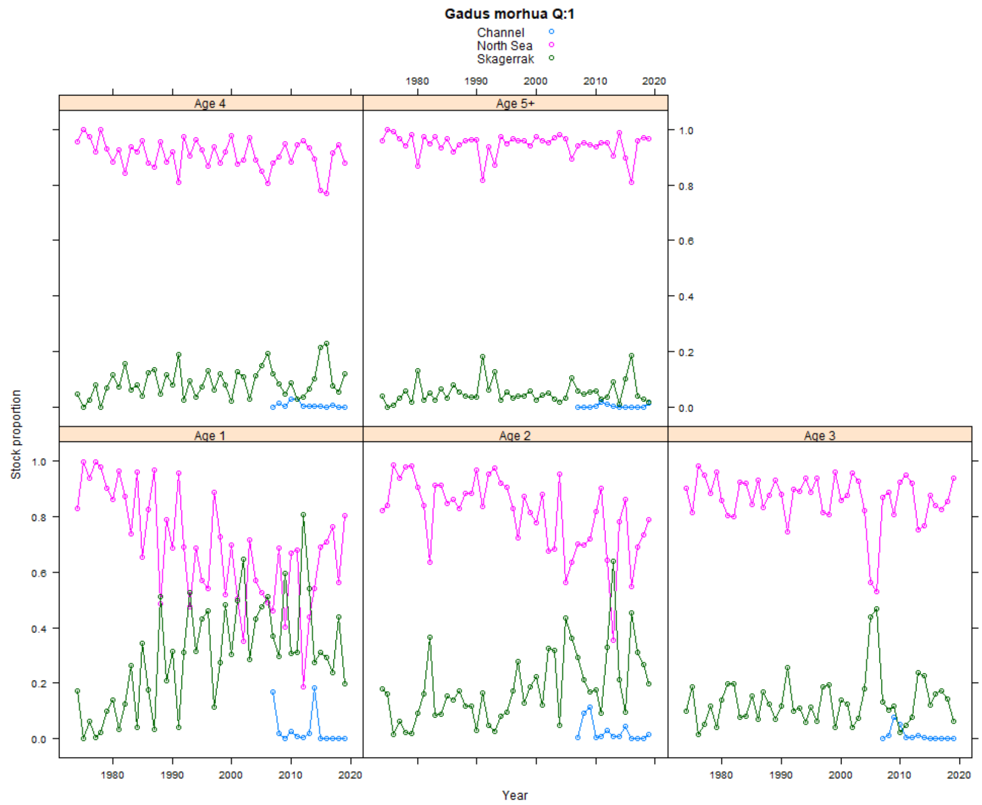

Figure 2.1.2. Stock distribution, Cod quarter 1. Please note that data for the English Channel were available since 2007.

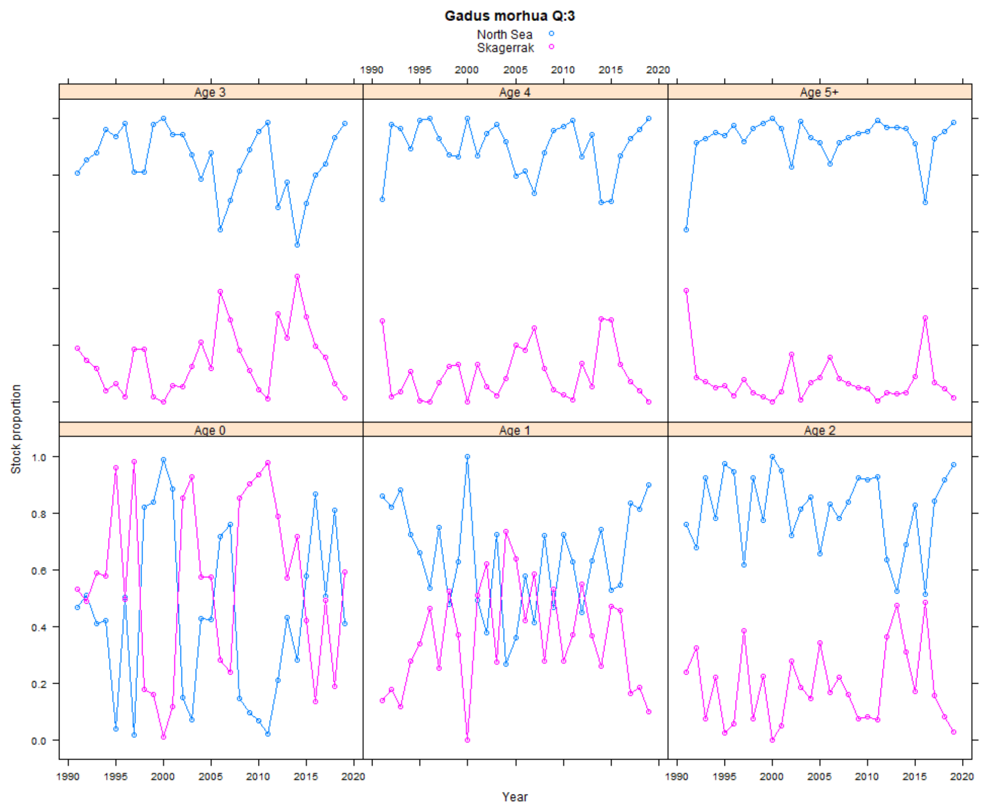

Figure 2.1.3. Stock distribution, Cod quarter 3.

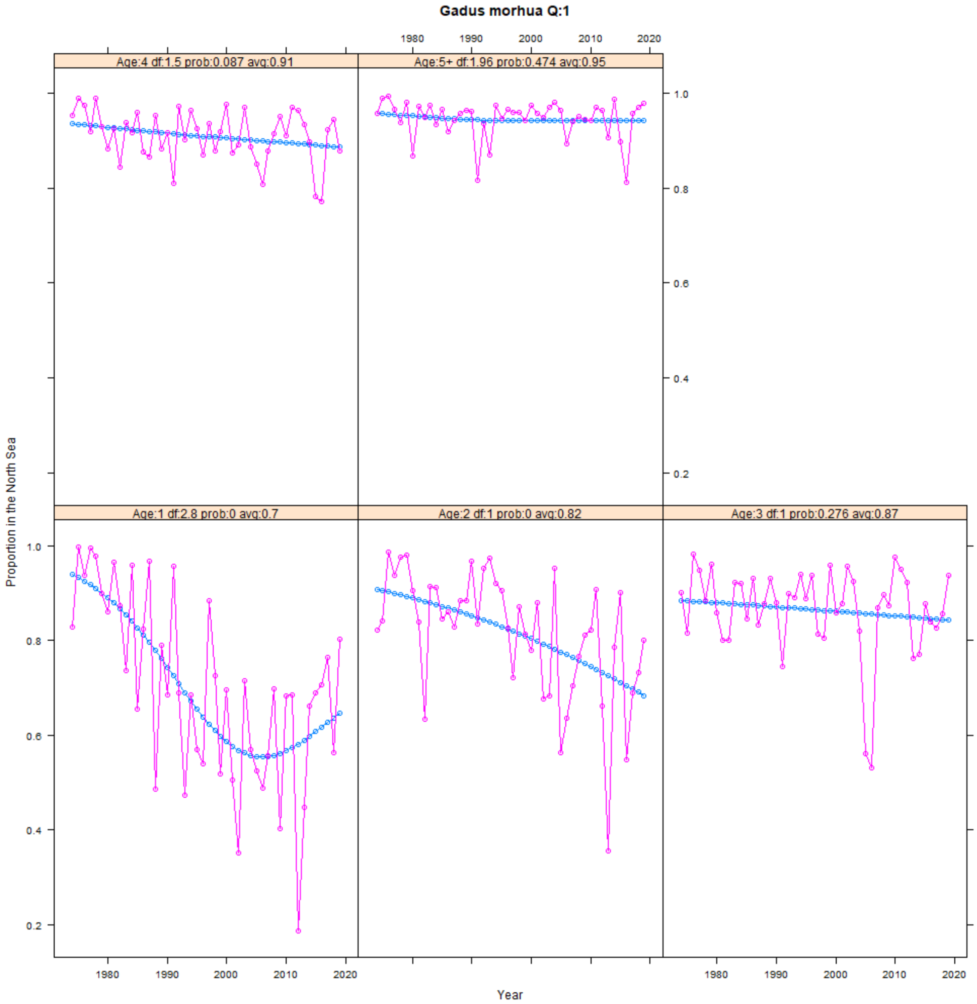

Figure 2.1.4. Observed and fitted proportion of the cod stock (North Sea & Skagerrak data) within the North Sea. For each age the degree of freedom for the fit, the significance of the fit and the average proportion is shown.

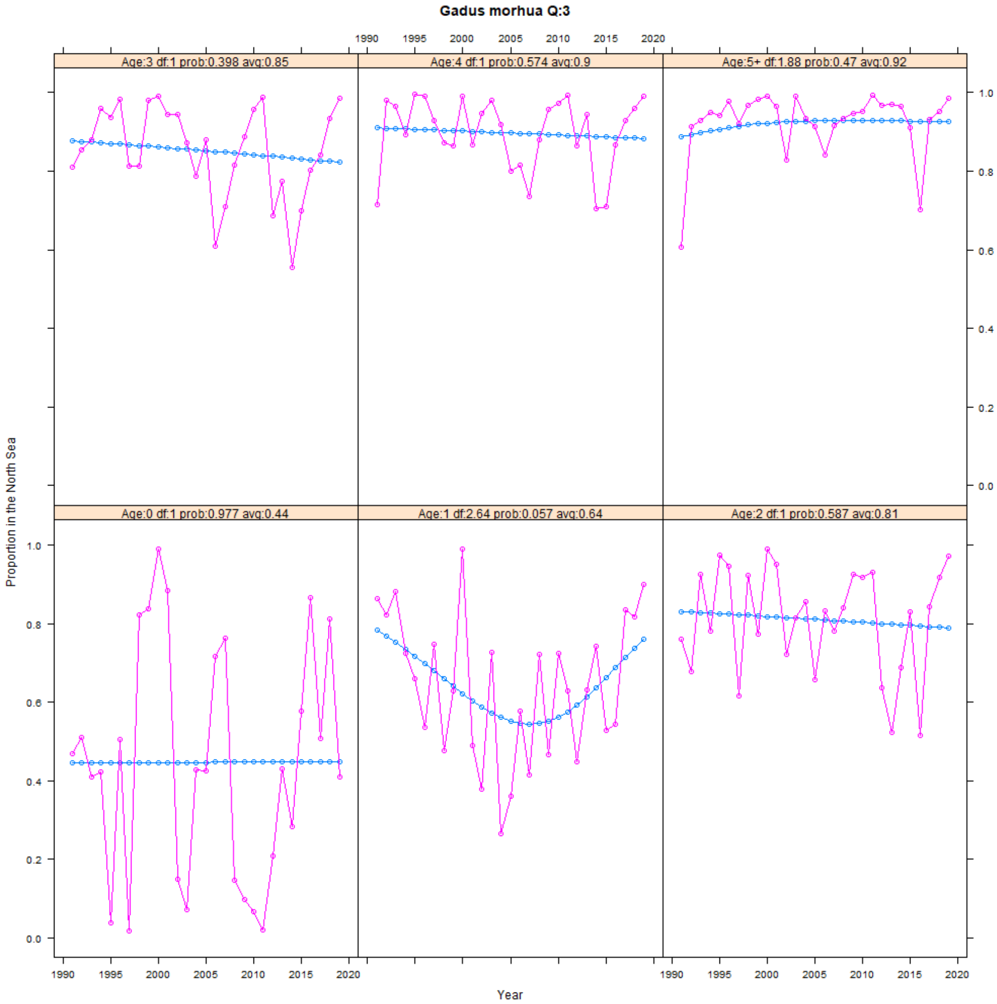

Figure 2.1.5. Observed and fitted proportion of the cod stock (North Sea & Skagerrak data) within the North Sea. For each age the degree of freedom for the fit, the significance of the fit and the average proportion is shown.

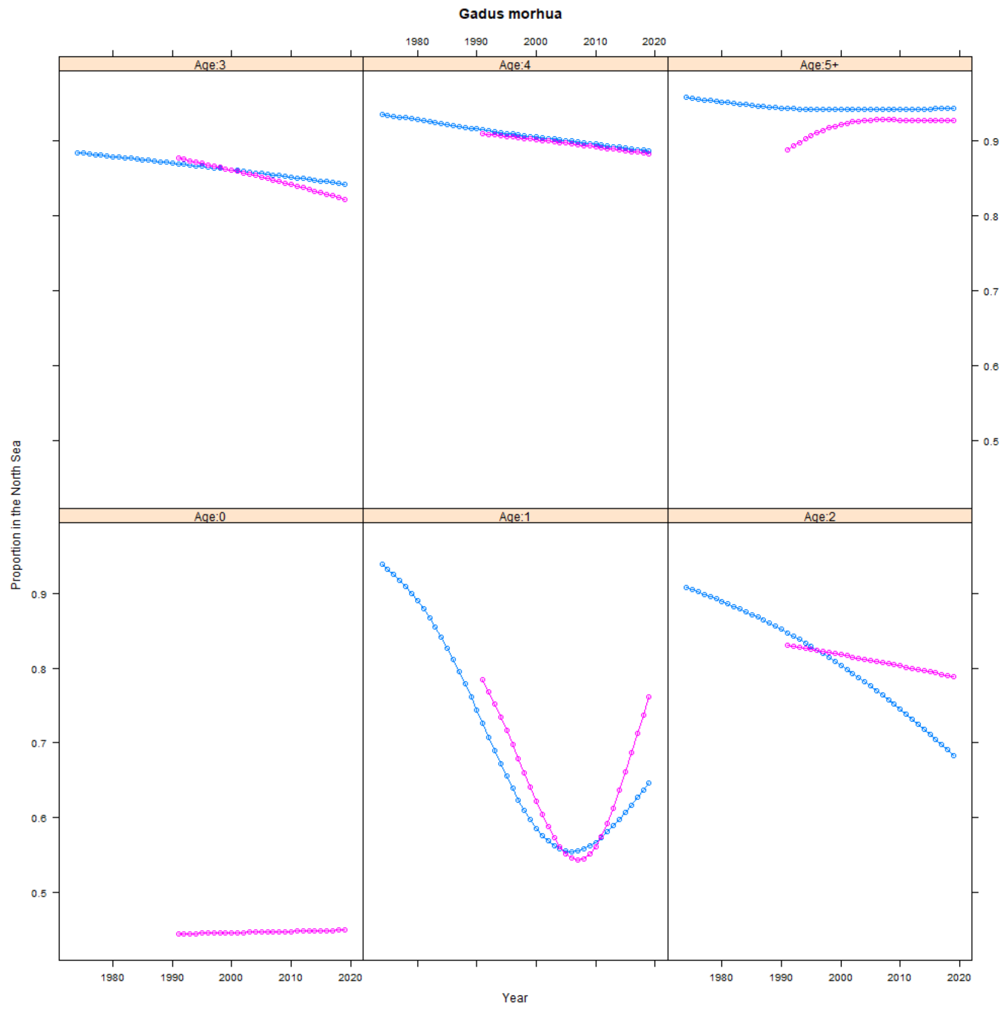

Figure 2.1.6. Fitted proportion of the cod stock (North Sea & Skagerrak data) within the North Sea for quarter 1 (1974–2019) and quarter 3 (1991–2019).

2.1.3 Whiting

Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2020) 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.

Survey data

Survey data are copied from the single-species assessment.

	Name	Years	Ages	alfa and beta	Source
1	IBTS Q1	1978–2020	1–5	0–0.25	WGNSSK 2020
2	IBTS Q3	1991–2019	0–5	0.5–0.75	WGNSSK 2020

IBTS Q1 data were in SMS split in two time series, 1978-1988 and 1989-2020 for a better model fit.

Biological data

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

The single-species assessment has gone through a benchmark since last key run and now provides estimates of 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 1 and older were assumed equal to mean weight in the stock but applying a quarter specific correction for other quarters (Figure 2.1.1). The new set of mean weights are lower for ages 0-4, almost the same for ages 5-6, and higher for ages 7-8+.

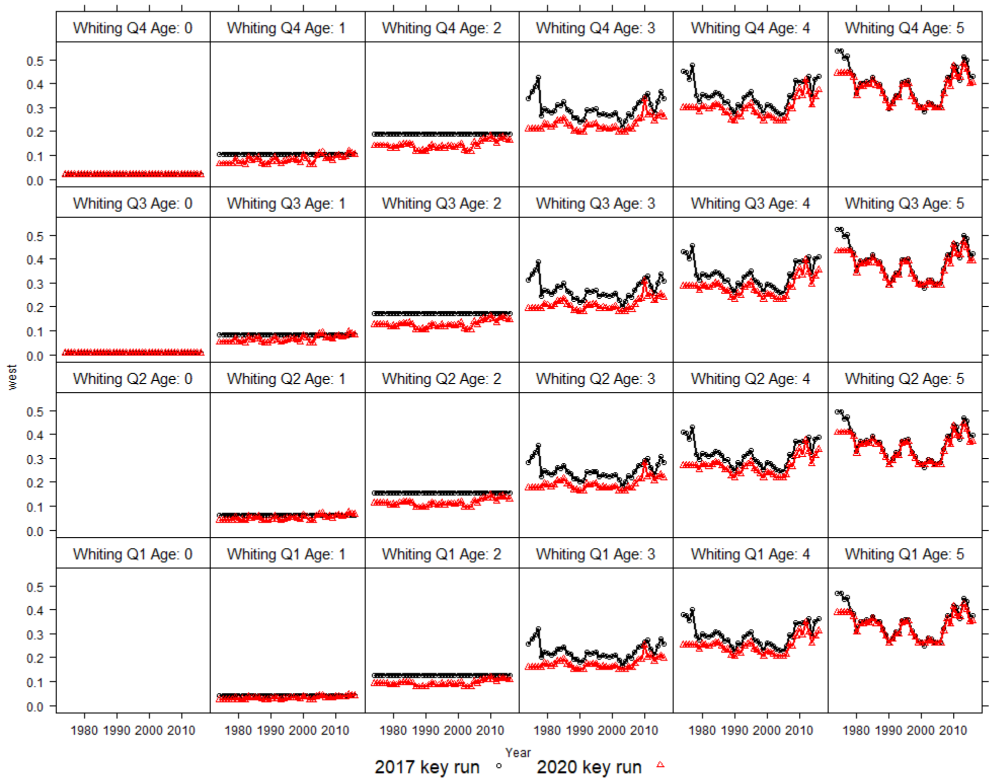

Figure 2.1.1 Mean weight-at-age in the sea of whiting by quarter as used in the 2017 and 2019 key runs.

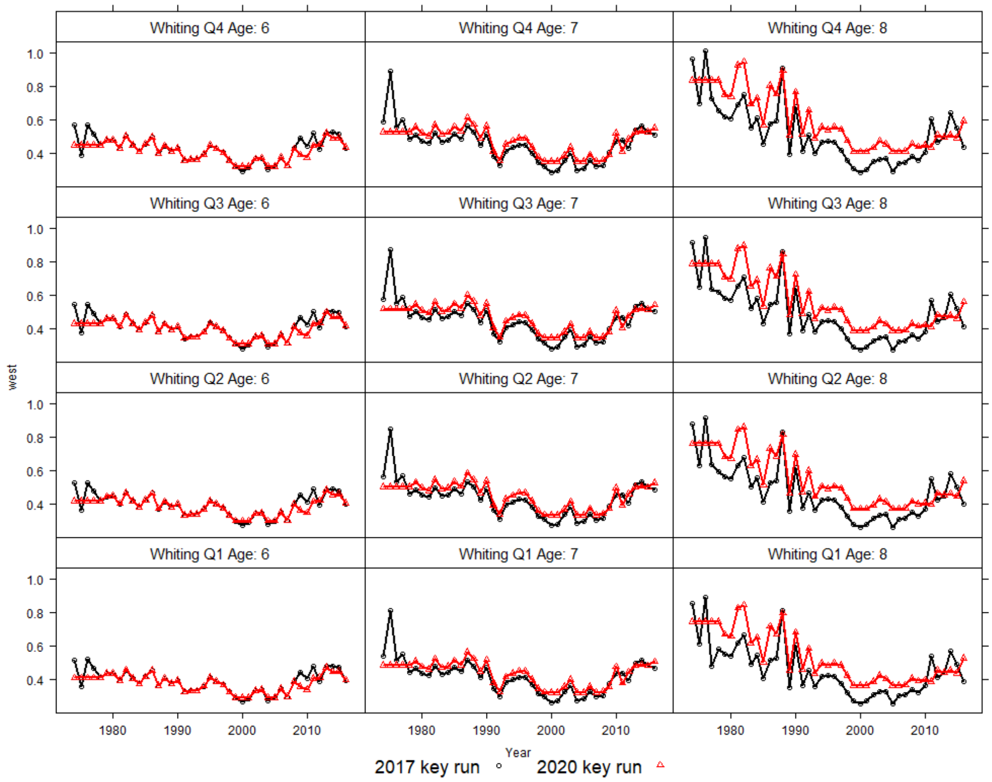

Figure 2.1.1 Continued. Mean weight-at-age in the sea of whiting by quarter as used in the 2017 and 2019 key runs.

Stock distribution

Survey data for the English Channel are only available for Quarter 1 since 2007 (Figure 2.1.7) but show that the proportion within the Channel is variable but low, and decreasing by 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, quarter and ages in SMS.

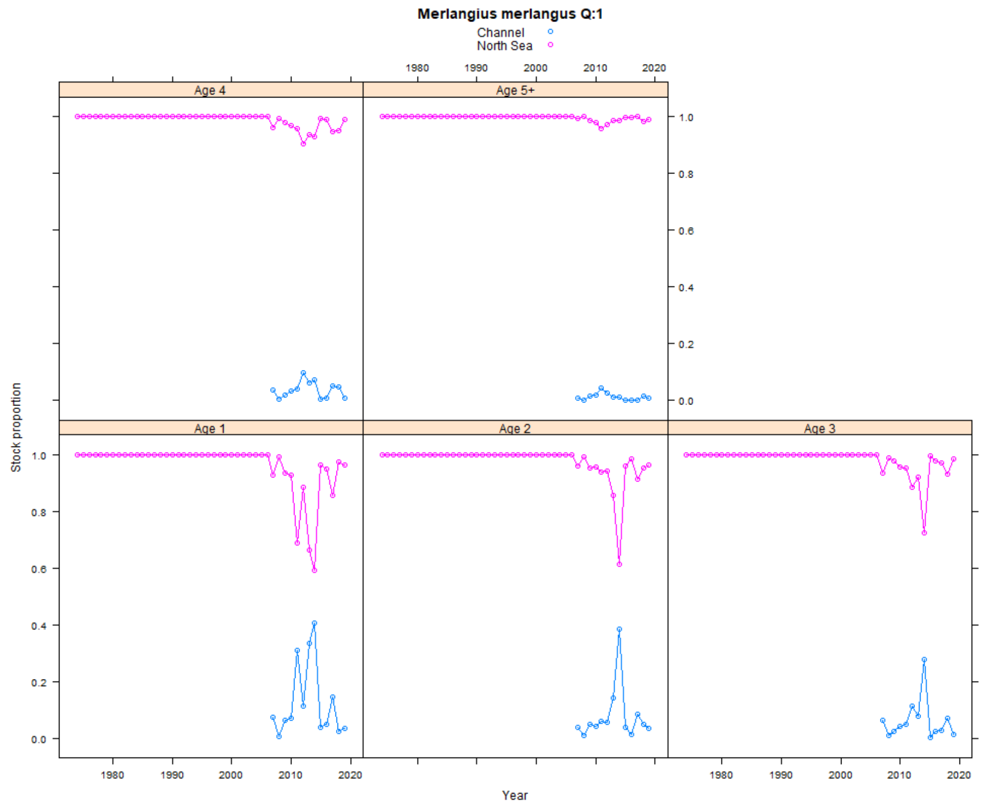

Figure 2.1.7. Stock distribution, Whiting quarter 1. Please note that data for the English Channel were available since 2007.

2.1.4 Haddock

Catch data

Annual catch-at-age data are available from the assessment (WGNSSK, 2020) since 1965, and were used in SMS.

Survey data

Survey data are copied from the single-species assessment (survey 1 and 2).

	Name	Years	Ages	Alfa and beta	Source
1	IBTS Q1	1967–2020	1–5	0–0.25	WGNSSK 2020
2	IBTS Q3	1991–2019	0–5	0.5–0.75	WGNSSK 2020

IBTS Q1 data were in SMS split in 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 2020).

The single-species assessment assumes that mean weight-at-age in the stock is equal to 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. Applied mean weight-at-age in the sea can be found in Appendix 2.

Stock distribution

Survey data for Area 6 are not analysed here. Catch data (WGNSSK 2020) 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.

2.1.5 Saithe

Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2020) 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 make 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 the single-species assessment were used a survey data (fleet 2). Saithe in SMS acts as 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
2	Stock assessment N	1974–2016	3–9	0–0	WGNSSK 2020

Biological data

Proportion mature and M are copied from the single-species input (WGNSSK 2020).

The single-species assessment assumes that mean weight-at-age in the stock is equal to 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. Applied mean weight-at-age in the sea can be found in Appendix 2.

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.

2.1.6 Mackerel

The ICES assessment of this Northeast Atlantic mackerel is conducted with data from 1980 for age 0–12+ (WGWIDE 2020). 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 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).

Catch data

Annual catch numbers and mean weight-at-age in the catch are copied from the ICES assessment (WGWIDE 2020).

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, which 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
1	Swept area	2010–2019	3–10	0.58–0.75	WGWIDE 2017
2	Stock assessment N	1980–2019	0–9	0–0	WGWIDE 2017

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 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 (1980–2019) from the assessment (WGWIDE 2020), these were used to scale the year independent MSVPA data in a similar way as for cod (Figure 2.1.8).

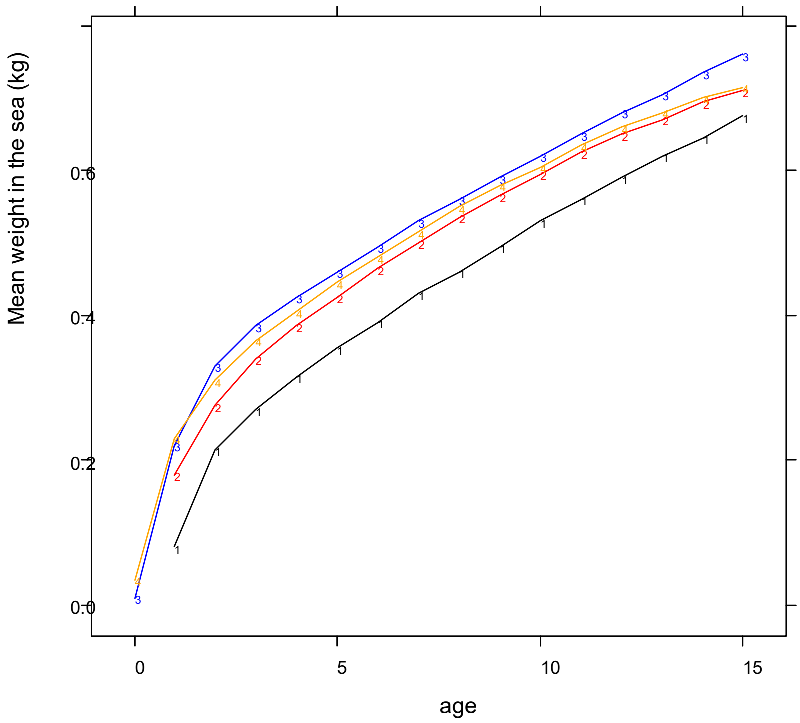

Figure 2.1.8. Mean weight-at-age in the sea by quarter as used in MSVPA (ICES CM 1997/Assess:16) and used as basis for SMS input.

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 2.1.5 and Table 2.1.6 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 2.1.7) and an additional assumption on the relative size of the North Sea component, which not has been surveyed at the same time (Table 2.1.8).

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 2.1.8). The proportion of the catch within the North Sea has however increased in 2018 and 2019.

Table 2.1.5. 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 2.1.6. 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 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	70	70	30	70	70	90	80	80	80	85	85	55
1974												
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 2.1.7 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 2.1.8. 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

YEAR	NORTH SEA	WESTERN	SOUTHERN
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
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*	0.038	0.856	0.105
2018*	0.038	0.856	0.105
2019*	0.038	0.856	0.105

*Assumed equal to 2016.

Using the available proportion of the stock by component (Table 2.1.7) and the proportion of each component within the North Sea (Table 2.1.5 and Table 2.1.6), it is possible to calculate the proportion of Northeast Atlantic mackerel within the North Sea (Figure 2.1.9).

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.

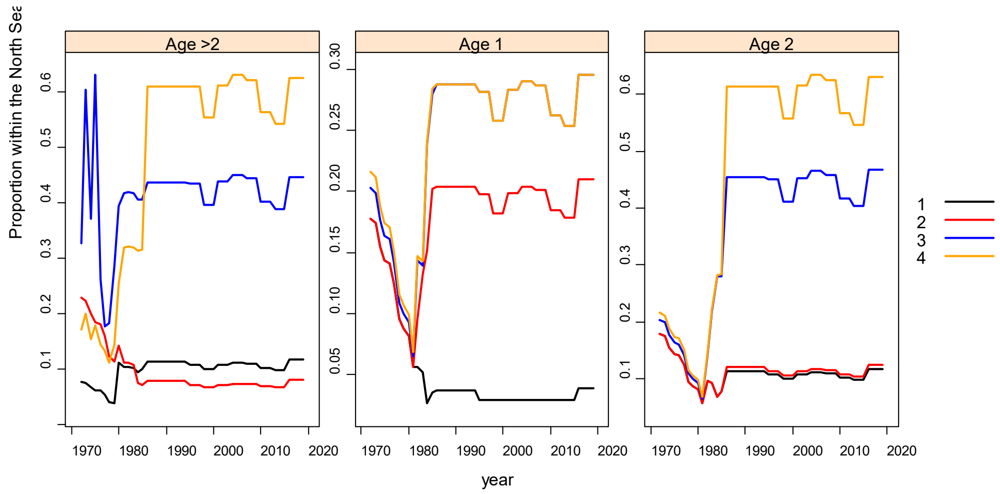

Figure 2.1.9. Preliminary estimate of proportion of the Northeast Atlantic Mackerel stock by age group and quarter (1–4) within the North Sea calculated from stock distributions presented in Table 2.1.4–Table 2.1.6.

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 show a northerly and easterly expansion of the catch areas (WGWIDE 2020) which is also reflected in the catch proportion from the North Sea (Figure 2.1.10). 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 2.1.9) becomes smaller for the period since 2000 (Figure 2.1.11), however increased in the most recent years.

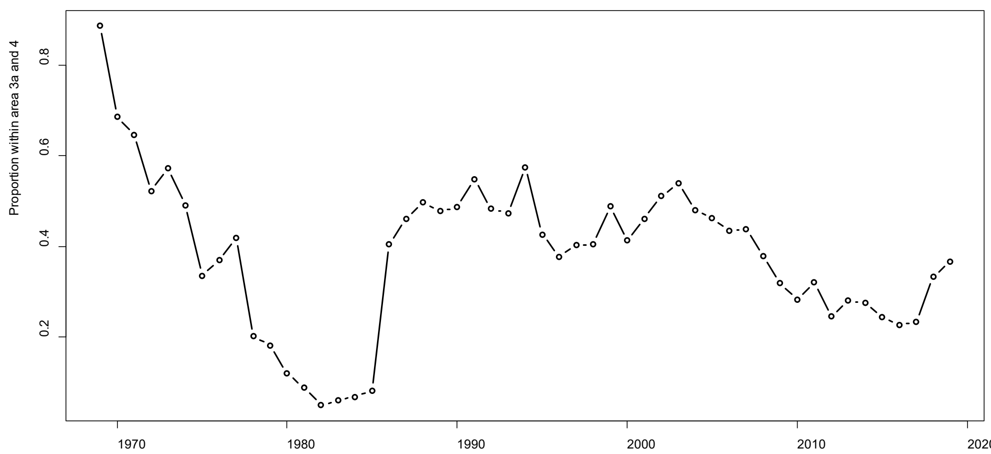

Figure 2.1.10. Proportion of mackerel catches in the North Sea. Data from WGWIDE 2020.

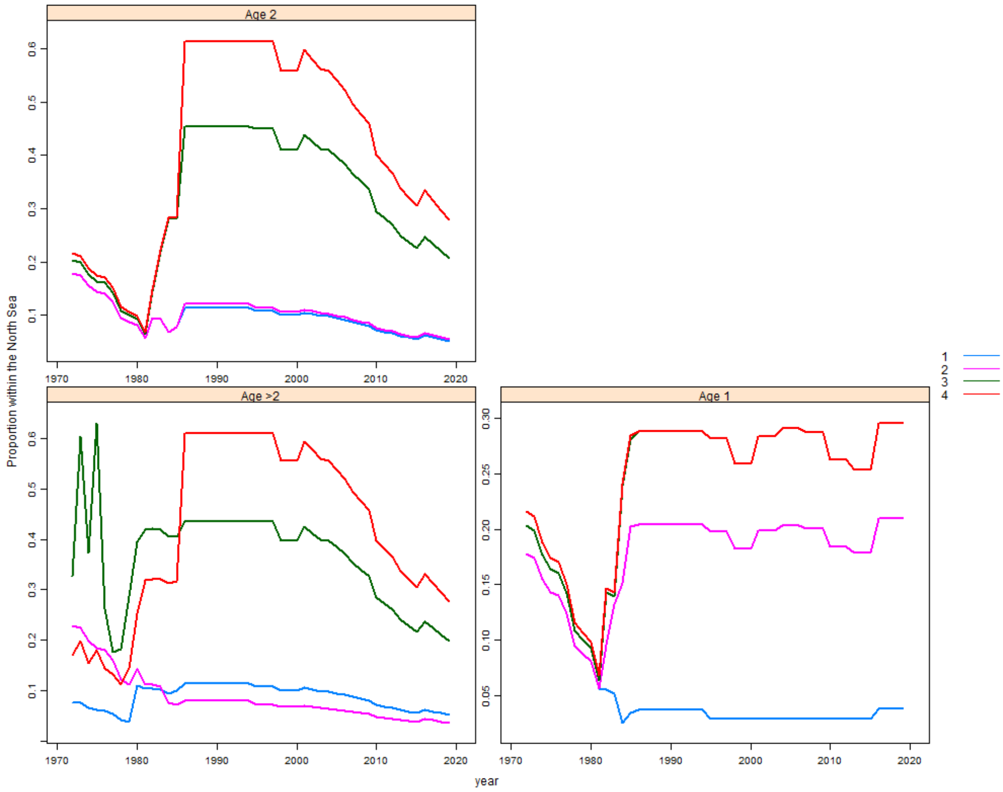

Figure 2.1.11. Estimate of proportion of the Northeast Atlantic Mackerel stock by age group and quarter (1–4) within the North Sea calculated from stock distributions presented in Table 4–Table 6 and the proportions caught within the North Sea since 2000 (Figure 2.1.10).

WGSAM, 2120 concluded to use the proportion of the stock within the North Sea as presented by Figure 2.1.11. It was recognised that this estimate is based on a series of assumptions, however the estimate seems the best available.

2.1.7 Herring

In 2020, the age range was changed from 0–9+ to 0–8+ to follow the single-species configuration.

Catch data

Annual catch exist for the period since 1947 (HAWG 2020). Quarterly data, 2005–2016 are available from the stock coordinator (Norbert Rohlf) and from the 2007 key run (1974–2004). The quarterly data, 2017-2019 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). The MIK survey is a SSB index and cannot be used by SMS.

	Name	Years	Ages	Alfa and beta	Source
1	HERAS Q2	1989–2019	1–8	0.54–0.56	HAWG 2020
2	IBTS Q1	1984–2020	1–1	0.10-0.10	HAWG 2020
4	MIK	1992–2020	0–0	0–0	HAWG 2020

2.1.8 Sandeel

The ICES sandeel assessments (2020) 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, sandeel in SMS are divided using the previously used Northern and Southern sandeel areas (Figure 2.1.12).

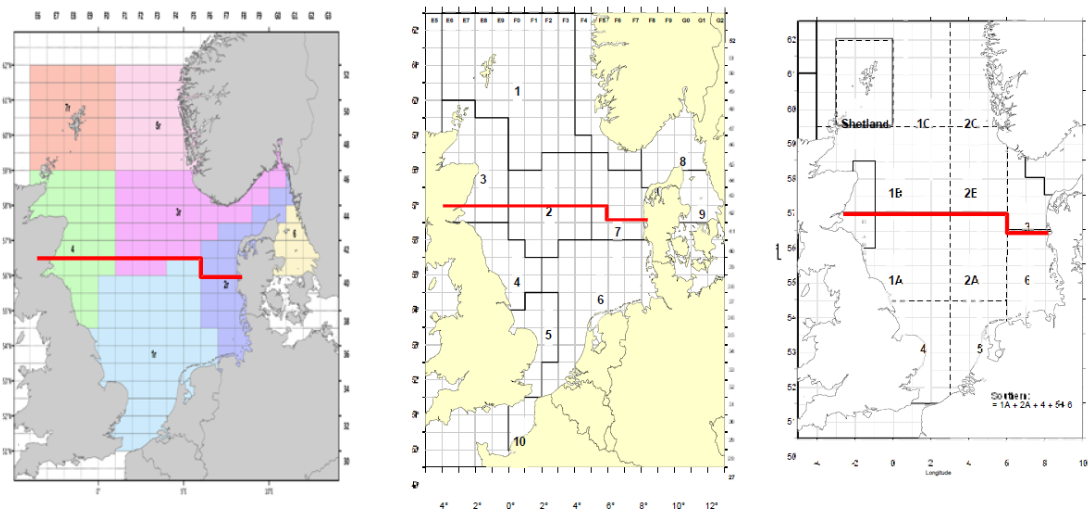

Figure 2.1.12. Sandeel stock and data compilation areas: The left plot shows the stock areas as applied by ICES in 2017. The red line shows the division between the previously used "Northern" and "Southern" sandeel areas. The plot in the middle show the ICES roundish areas, which are used as strata in the compilation of stomach content data. The right plot shows the northern and southern areas with samplings areas.

Catch data since 1983 are available by ICES rectangle (HAWG 2020, Anna Rindorf pers. comm.) and were aggregated into the two stocks. Data 1974–1982 are available from the 1999 ICES assessment, where assessment data are aggregated into a Northern and Southern 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 area 4, 5 and 6. This split aligns fairly well with the two stock areas (Figure 2.1.12).

Estimating mean weight in the stock is a special concern for sandeel, as 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). Moreover, weight in the catch of 0-group is highly variable as the 0-group fishery only occurs in part of the time-series and the exact timing of it varies. The stock mean weight of sandeel age 1+

in quarter 2 and 3 were estimated from the long-term (1982–2019) 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 0-group in quarter 3 is assumed to be the 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 same observations used in the single-species assessments in areas 1–3 using the same model but deriving sandeel surveys indices for the northern and southern North Sea (Mikael van Deurs, 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	2004–2019	0–1	0.75–1	M. van Deurs
2	Commercial 1 half year	1982–1989	1–3	0.25–0.5	HAWG 2020
3	Commercial 1 half year	1999–2019	1–3	0.25–0.5	HAWG 2020
4	Commercial 2 half year	1976–2004	1–3	0.25–0.5	Sandeel assessment 2005

Southern Sandeel surveys:

	Name	Years	Ages	alfa and beta	Source
1	Dredge survey	2004–2019	0–1	0.75–1	M. van Deurs
2	Commercial 1 half year	1982–1989	1–3	0.25–0.5	HAWG 2020
3	Commercial 1 half year	1999–2004	1–3	0.25–0.5	HAWG 2020
4	Commercial 1 half year	2005–2009	1–3	0.25–0.5	HAWG 2020
5	Commercial 1 half year	2010–2019	1–3	0.25–0.5	HAWG 2020

2.1.9 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 2020) 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 to 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 2020), using the above mentioned data transformation of year, quarter and ages.

Survey data

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

	Name	Years	Ages	Source
1	IBTS Q1	1983–2020	0–3+	HAWG 2020
2	HERAS Q2	2006–2019	1–3+	HAWG 2020
3	IBTS Q3	1992–2019	1–3+	HAWG 2020

Biological data

Proportion mature and stock mean weight data are copied from single-species data. Applied mean weight-at-age in the sea can be found in Appendix 2.

Stock distribution

The proportions of the sprat stock observed within the North Sea was 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 2.1.2). The landings distribution are 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 prior to 2004. The data were smoothed and used to predict distribution of the stock prior to 2004 (Figure 2.1.3). The same distribution was used for all ages and quarters (Figure 2.1.4).

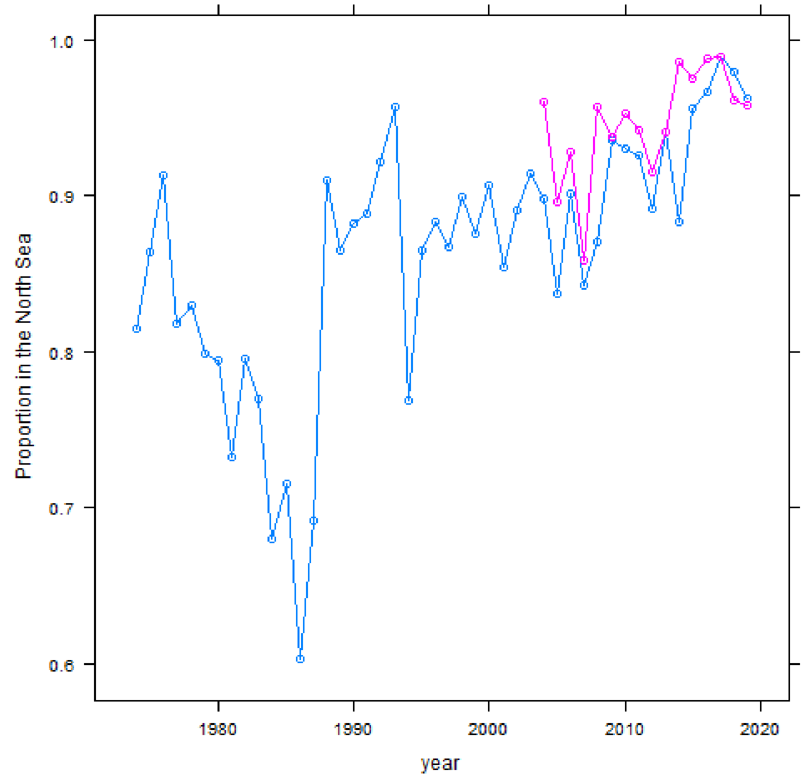

Figure 2.1.2. Proportion of the sprat stock (North Sea, Kattegat and Skagerrak data) within the North Sea estimated from landings statistics (1974-2019) and the HERAS survey (2004-2019

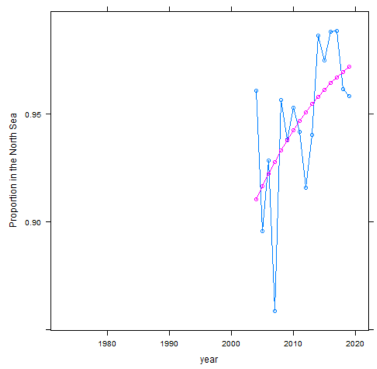

Figure 2.1.3. Observed and fitted proportion of the sprat stock (North Sea, Kattegat and Skagerrak data) within the North Sea with data from the HERAS survey.

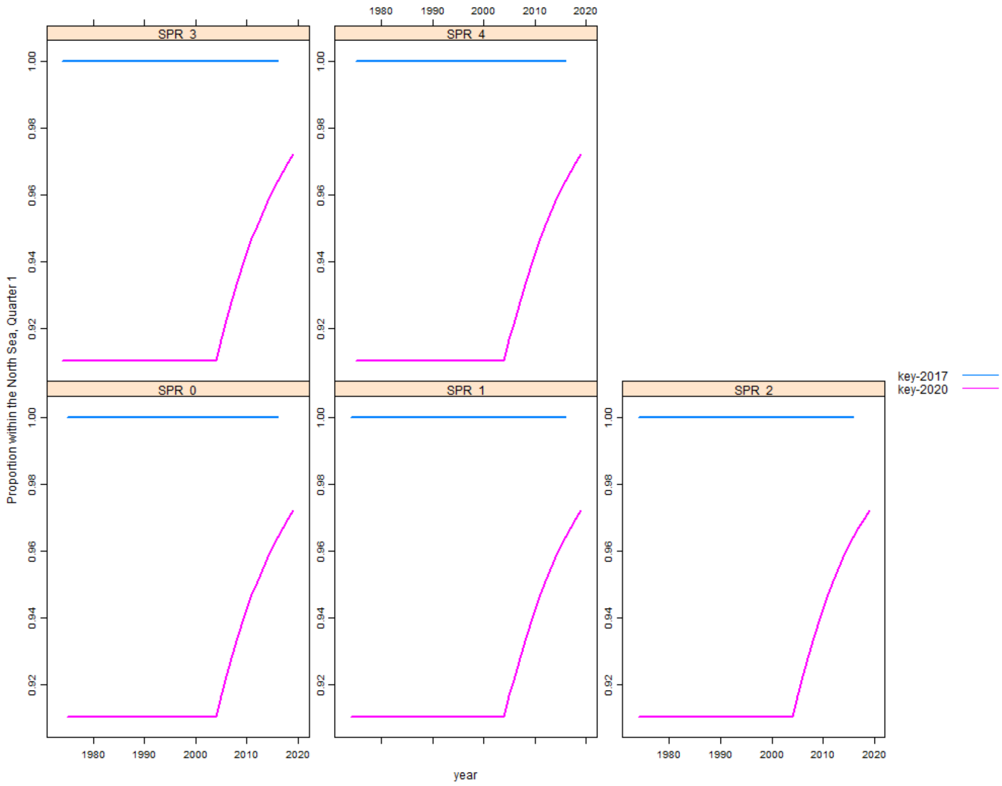

Figure 2.1.4. Proportion of the sprat stock (North Sea, Kattegat and Skagerrak data) within the North Sea as applied in SMS.

2.1.10 Norway pout

The single-species sprat assessment (WGNSSK 2020) 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, stock NPMar20)

Survey data

Survey data are copied from the single-species assessment.

	Name	Years	Ages	alfa and beta	Source
1	EGFS	1982–2019	0–1	0.5–0.75	WGNSSK 2020
2	SGFS	1992–2019	0–1	0.5–0.75	WGNSSK 2020
3	IBTS Q1	1984–2020	1–3	0.0–0.0	WGNSSK 2020
4	IBTS Q3	1991–2019	2–3	0.5–0.75	WGNSSK 2020

Biological data

Proportion mature, stock mean weight and M data are copied from single-species data. Applied mean weight-at-age in the sea can be found in Appendix 2.

2.1.11 Plaice

Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2020) 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-Isis-early	1985–1995	1–8	0.66–0.75	WGNSSK 2020
2	BTS-Combined	1996–2019	1–9	0.66–0.75	WGNSSK 2020
3	SNS1	1974–1999	1–6	0.66–0.75	WGNSSK 2020
4	SNS2	2000–2019	1–6	0.66–0.75	WGNSSK 2020
5	IBTS Q3	1997–2019	1–9	0.63–0.63	WGNSSK 2020
6	IBTS Q1	2007–2019	1–7	0.10–0.10	WGNSSK 2020

Biological data

Proportion mature data are copied from the single-species input (WGNSSK 2020).

The single-species assessment assumes that mean weight-at-age in the stock is equal to 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.

2.1.12 Sole

Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2020) 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	1985–2019	1–10	0.66–0.75	WGNSSK 2020
2	SNS	1974–2019	1–6	0.66–0.75	WGNSSK 2020
3	ISIS	1985–2019	1–9	0.66–0.75	WGNSSK 2020

Biological data

Proportion mature data are copied from the single-species input (WGNSSK 2020).

The single-species assessment assumes that mean weight-at-age in the stock is equal to 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.

2.2 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 are given in Figure 2.2.1.

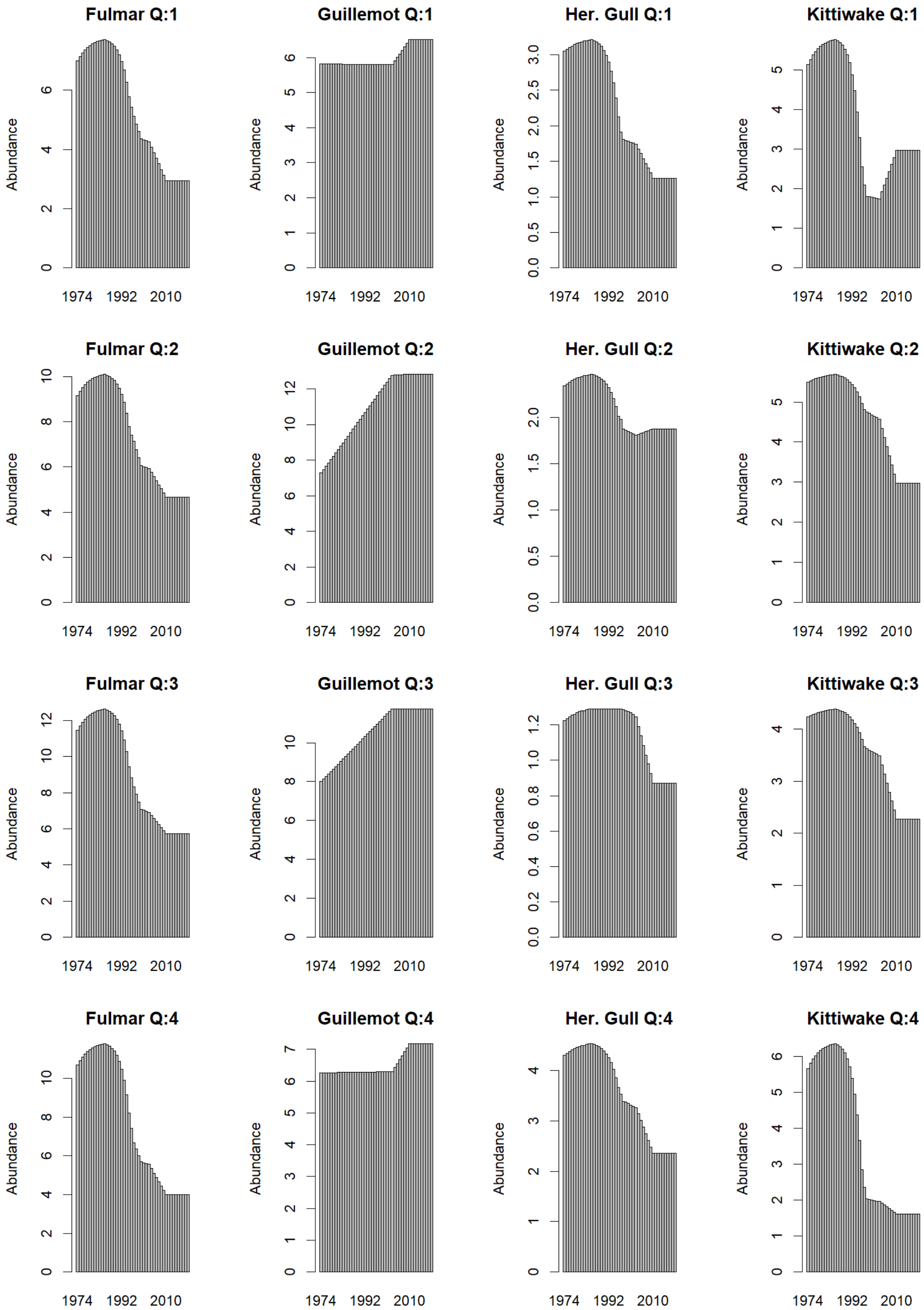

Figure 2.2.1. Estimates as used by SMS of the abundance of "external predators" present in the North Sea. (Abundance of birds and marine mammals are given as numbers (1000), and as population biomass (1000 t) for fish species.

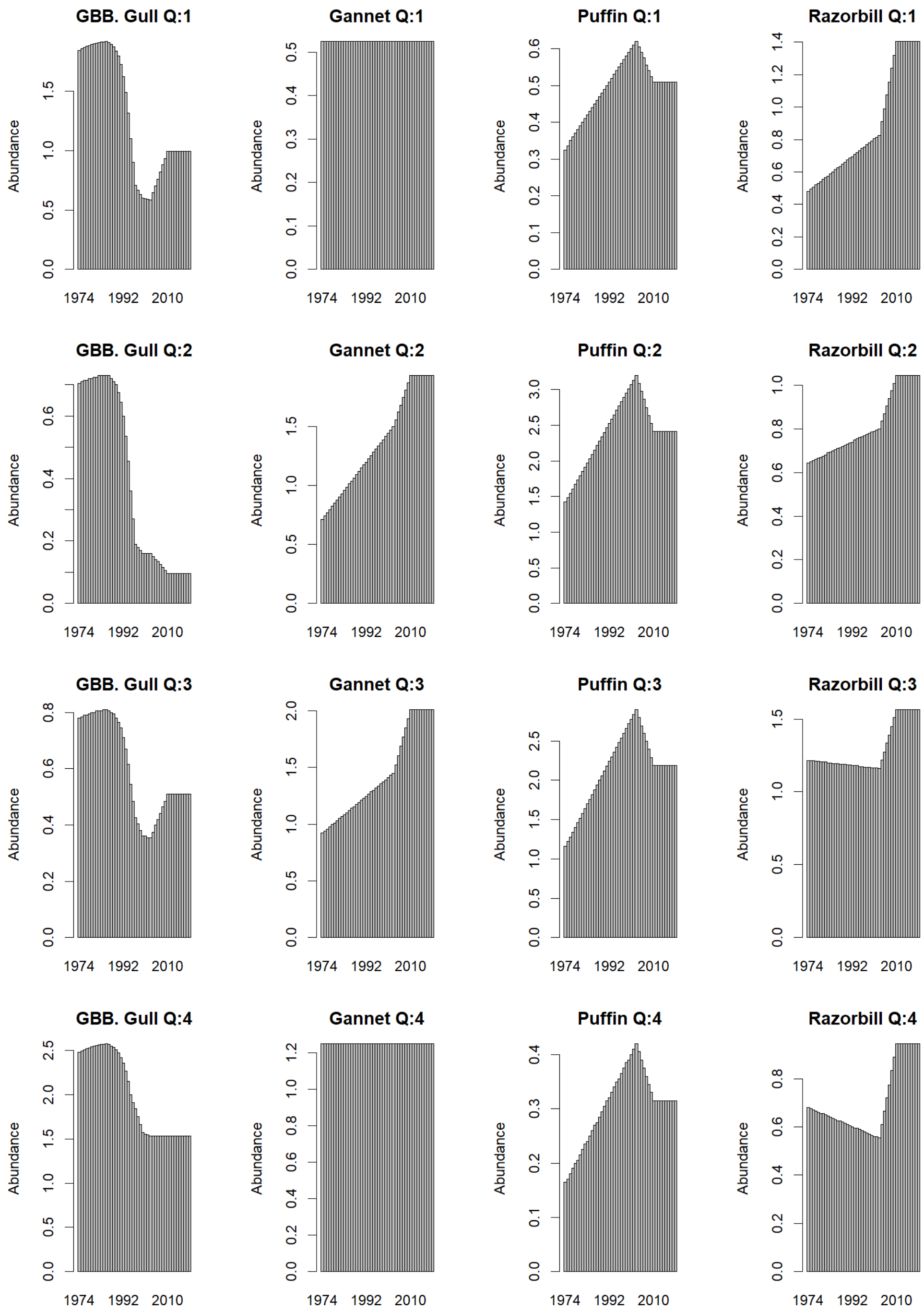

Figure 2.2.1. (Continued.) Estimates as used by SMS of the abundance of "external predators" present in the North Sea. (Abundance of birds and marine mammals are given as numbers (1000), and as population biomass (1000 t) for fish species.

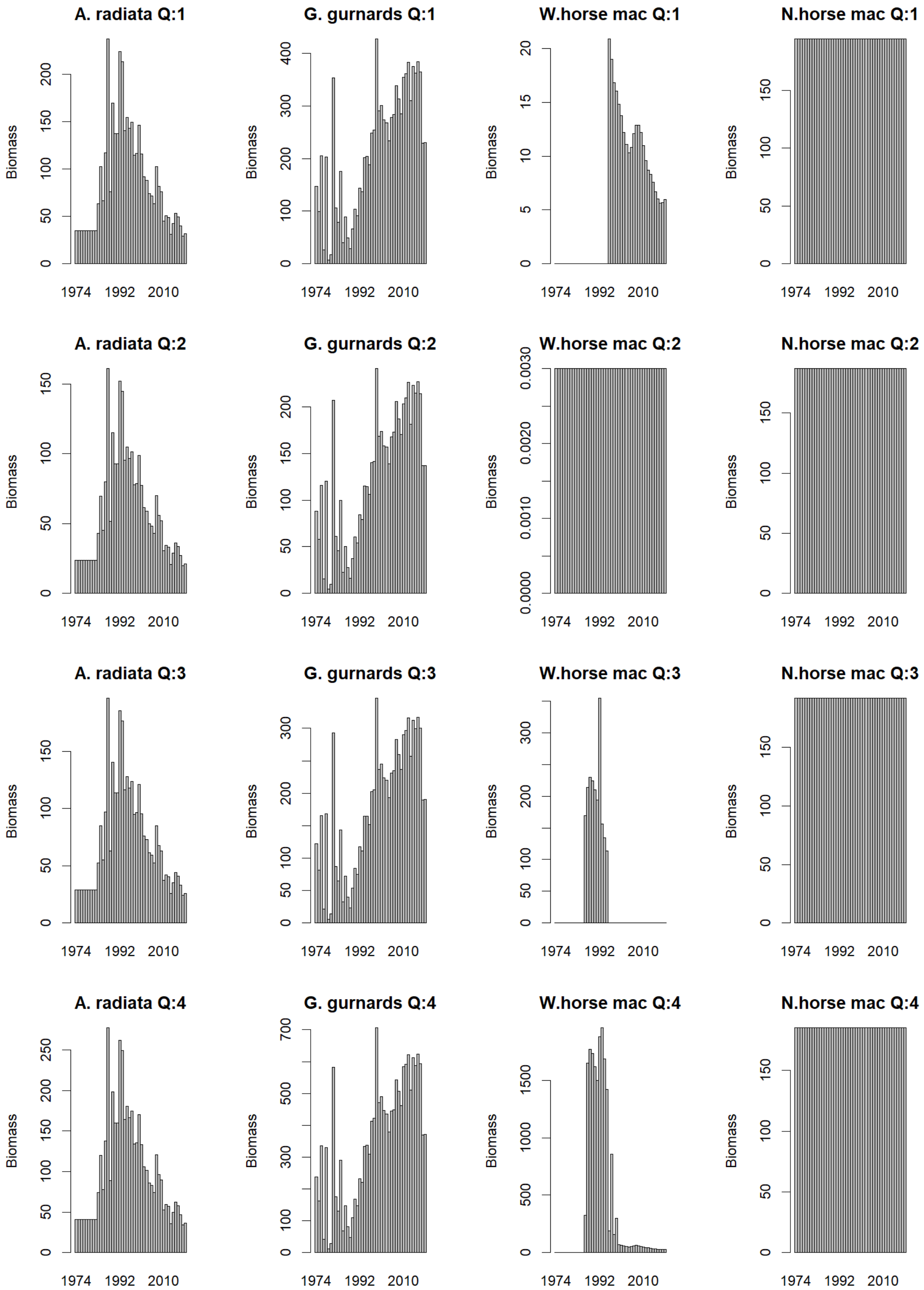

Figure 2.2.1. (Continued.) Estimates as used by SMS of the abundance of "external predators" present in the North Sea. (Abundance of birds and marine mammals are given as numbers (1000), and as population biomass (1000 t) for fish species.

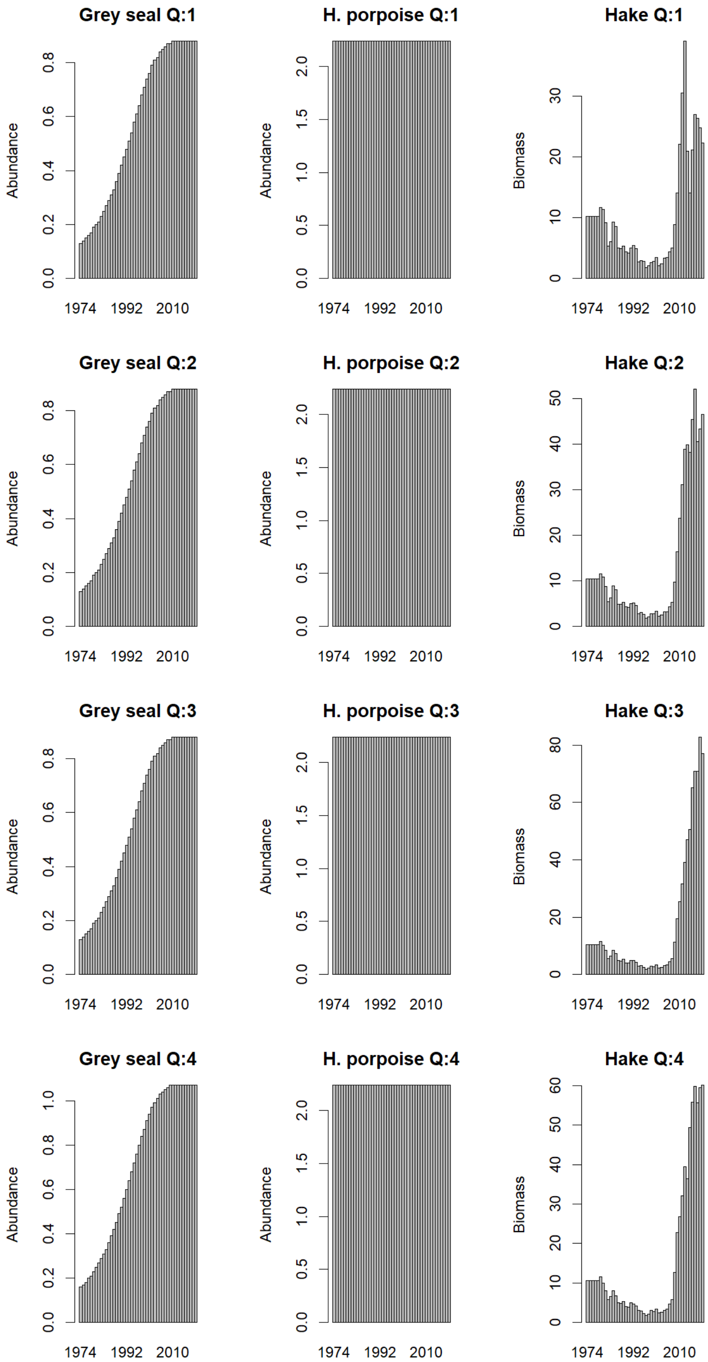

Figure 2.2.1. (Continued.) Estimates as used by SMS of the abundance of "external predators" present in the North Sea. (Abundance of birds and marine mammals are given as numbers (1000), and as population biomass (1000 t) for fish species.

2.2.1 Birds

Numbers of seabirds in the North Sea were calculated using two sources: counts of seabirds at sea and counts of seabirds staying in the colony while breeding or attending nest sites. Seabirds at sea have systematically been recorded in the North Sea since 1979, with a joint database, the European Seabirds at Sea Database (ESAS), existing since 1991. The ESAS database version 4.1 (as of September 2004) contained data from seabirds at sea counts over the period 1979 to 2004. Coverage of the North Sea over years and seasons was unequal. Yearly distance travelled ranged between 4407 and 301 293 km. As seabirds are partly on land while breeding and also at other times of the year, conversion factors based on breeding population numbers were used to derive population numbers from number recorded at sea. Data from breeding population numbers were taken from published accounts, from national databases and from ICES Working Group on Seabird Ecology reports. Energy requirements for chicks were also estimated and expressed as numbers of adults as these are not covered by the energy budgets for adults. All these numbers derived from land/colonies were then added to the numbers calculated for the sea areas from the ESAS database.

Because of the rather limited temporal coverage of the data, at-sea numbers for each quarter of a year were estimated for two time periods only, 1979–1991 and 1992–2004. Data were calculated separately for six sub-regions. The data obtained by this procedure were treated differently afterwards depending on bird species. From known trends in breeding population numbers over the last decades and from trends in small subsets of the North Sea, different models were applied to calculate numbers at sea for all years and quarters from 1963 to 2004. For four species (northern gannet, common guillemot, Atlantic puffin, razorbill), a linear trend was assigned to the population trend as this has more or less been the case for the overall breeding bird numbers (counts of breeding birds are not available on an annual or biannual basis for the whole North Sea). This is certainly a simplification of the real situation but should reflect the overall trends. For the other four species (northern fulmar, herring gull, great black-backed gull and black-legged kittiwake), a logistic model was applied as all four species showed substantial increases from the 1960s to the 1980s/1990s and declines afterwards. The derivation of seabird data was updated with more recent years and trends in ICES, WGSAM 2011, and has not been updated since. Therefore, populations from 2011 onwards were assumed constant.

2.2.2 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 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 (SAS procedure Genmod) 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 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 tonnes by size classes are 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 prior to 1981 and these data were finally allocated to one year, "pre-1981". The year effect for "pre-1981" was used for 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 and average biomass of 205 kt is assumed for the years 1977–2013, where the year range is chosen mainly for stability reasons.

2.2.3 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, 2020).

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 2.2.1).

Table 2.2.1. 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 (Figure 2.2.2). 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.

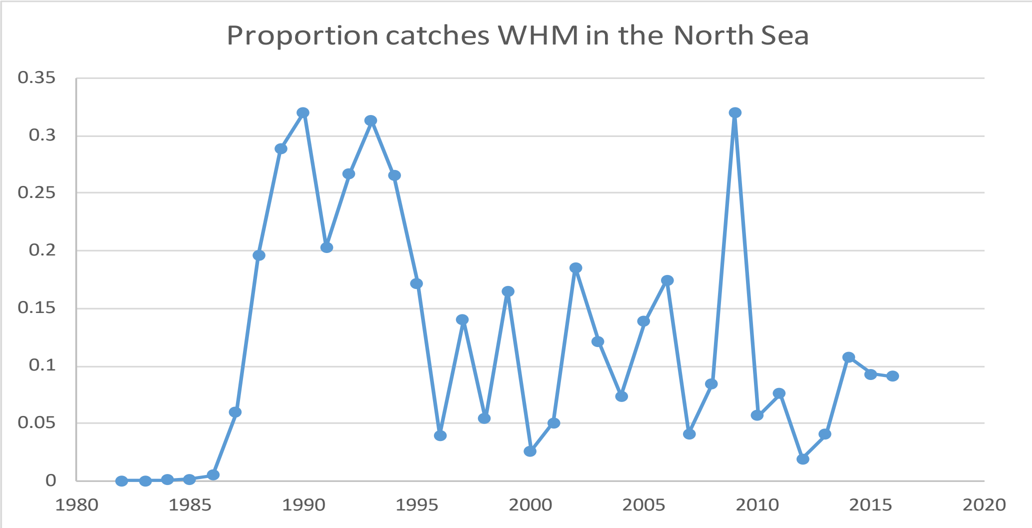

Figure 2.2.1. Proportion of western horse mackerel catches in the North Sea (data from WGWIDE 2017)

2.2.4 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 were 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 2.2.4.1) show a steep increase of landings from the North Sea since 2002.

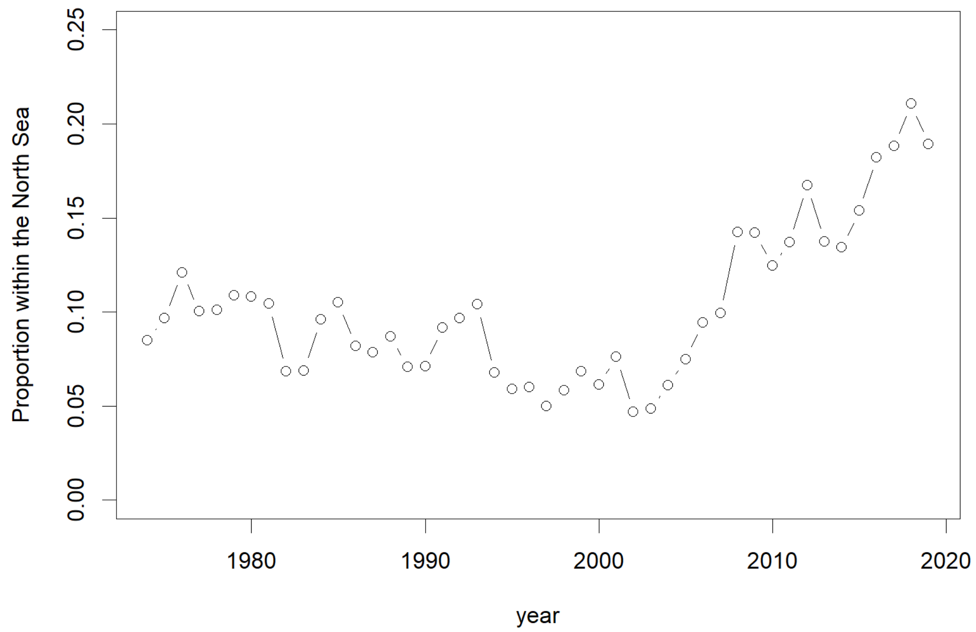

Figure 2.2.4.1 Proportion of landings within the North Sea from the stock of "northern hake" estimated from landings weights derived from Table 9.1 in ICES WGBIE, 2020.

Quarterly landings data for the "northern hake" are available from ICES TAF since 2013. The proportions of total seasonal landings from the North Sea (Table 2.2.4) show an increasing trend in North Sea landings in quarters 3 and 4.

Table 2.2.4 Percentage of quarterly "northern hake" landings taken in the North Sea. Data from ICES TAF (InterCatch) 2020.

YEAR	Q1	Q2	Q3	Q4
2013	8.8%	16.4%	18.7%	14.0%
2014	5.2%	13.7%	17.6%	16.7%
2015	7.1%	14.9%	21.1%	18.0%
2016	8.7%	17.1%	23.9%	20.8%
2017	9.4%	14.8%	26.6%	21.1%
2018	9.5%	16.6%	31.4%	22.1%
2019	8.1%	16.4%	26.3%	19.8%
Average	8.1%	15.7%	23.7%	18.9%
rescaled average	49%	95%	143%	114%

The ICES assessment for "northern hake" is an ss3 assessment and provides quarterly abundance 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 2013-2019 (Table 2.2.4.). 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 2.2.4) and the "rescaled average" from Table 2.2.4. The number of hake in the North Sea in the years 1974-1977 is assumed 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 quite 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 (ICES, 2017), 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.

The biomass (sum of stock numbers and mean weight) as used in SMS is shown in Figure 2.2.4.2

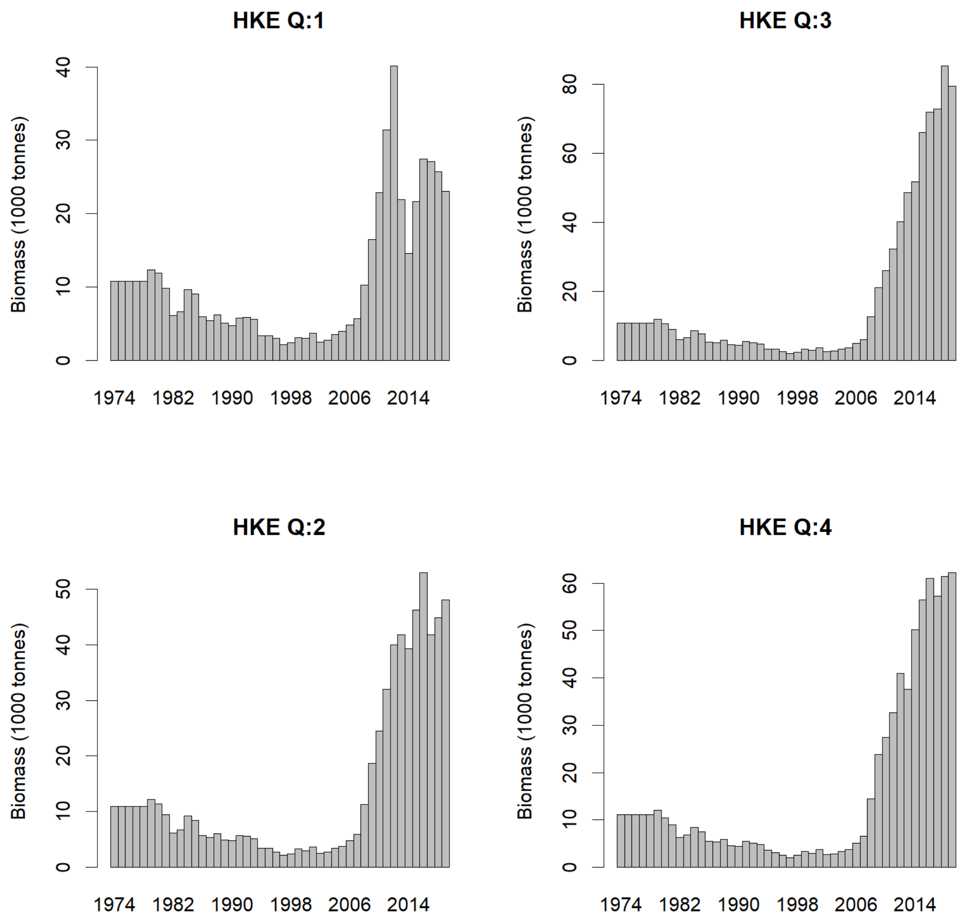

Figure 2.2.4.2. Biomass of hake in the North Sea as used by SMS.

A swept area estimate of Hake in the North Sea (Staby, 2018) estimated from IBTS Q1 and IBTS Q3 data (Figure 2.2.2) show a similar biomass in the North Sea since 1997, as the biomass used in SMS.

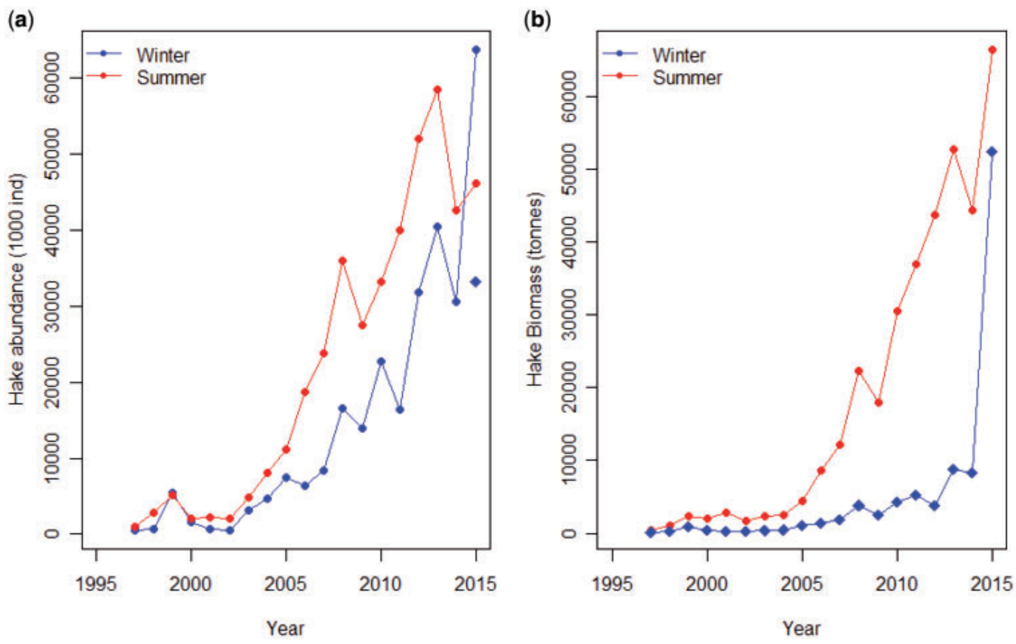

Figure 2.2.2. Swept area estimate of Hake in the North Sea from IBTS Q1 and Q3 data (copied from Staby, 2018).

References

ICES. 2017. Report of the Working Group on Fish Distribution Shifts (WKFISHDISH), 22–25 November 2016, ICES HQ, Copenhagen, Denmark. ICES CM 2016/ACOM: 55. 197 pp.

Staby, A., Skjæraasen, J. E., Geffen, A. J., and Howell, 2018. D. Spatial and temporal dynamics of European hake (*Merluccius merluccius*) in the North Sea. – ICES Journal of Marine Science, 75: 2033–2044.

2.2.5 Grey seal

The abundance of grey seals was estimated using a demographic model fitted to pup production estimates, and estimates of adult numbers based on haul-out counts in the North Sea and Orkney for the period 1984 to 2009 (Buckland *et al.*, 2004; Thomas, 2011). Populations prior to 1984 are estimated assuming exponential growth in the period up to 1990 (using 1984–1990 to estimate parameters). For 2010 onwards, the value in 2009 is used as populations are assumed to be levelling off.

2.2.6 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).

2.3 Diet and ration data

2.3.1 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.

References

BECAUSE (Critical Interactions BEtween Species and their Implications for a PreCAUtionary FISheries Management in a variable Environment- a Modelling Approach)

https://cordis.europa.eu/project/id/502482/reporting/fr

2.3.2 Mammals

Data on grey seals

Seal diet data derived from scats were sampled in 1985 and 2002 at haul-out sites around the UK coast. Recently, data from 2010/2011 were also presented by Hammond and Wilis (2016), but these data were not available to WGSAM. However, they confirm the previous estimates of high gadoid consumption, with very large cod and ling recorded in the scats.

An aggregated estimate of grey seal diet composition based on the 1985 and 2002 collections was calculated for each of these years weighted according to the number of seals using each haul-out site. The sizes of fish consumed by the seals were inferred from otolith measurements which are corrected for the effects of digestion. 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 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, sandeel 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 where 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, at 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 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 correction for differences in evacuation times between prey were applied. In 2017, the data were corrected to account for the fact that 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 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 were used, which is also a change from previously. The correction compared to previously resulted in a 50% increase in herring, 267% increase in sandeel, a 54% decrease for whiting and smaller changes for other species (Figure 2.3.1).

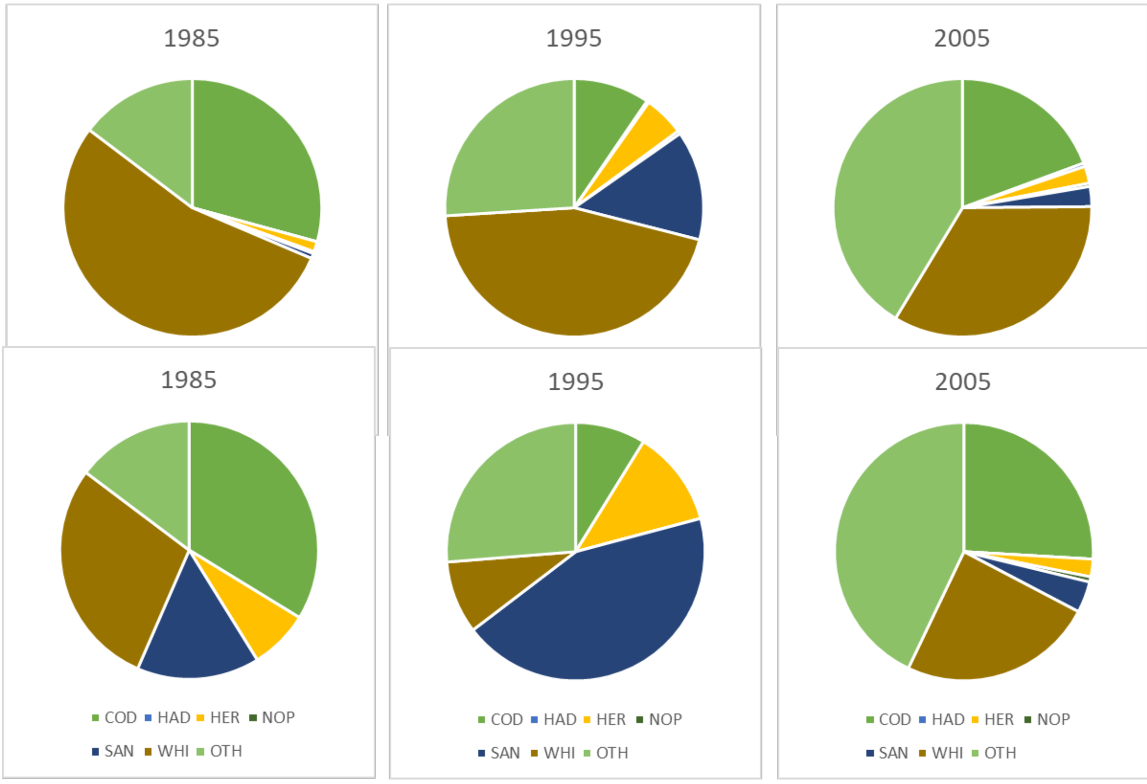

Figure 2.3.1. Harbour porpoise stomach content recorded (top) and consumption rates after correcting for differences in residence times (bottom).

2.3.3 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 to collect 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 inclusion of more fish species. The highest sampling intensity was in in 1981 and 1991. Further information on the background for the ICES stomach sampling project are given in Daan (1989); ICES, 1989 and ICES, 1997.

Stomach contents data on exchange format are available from ICES (http://ices.dk/marine-data/data-portals/Pages/Fish-stomach.aspx)

Compilation of stomach contents data

Stomach contents data are given by year, quarter, predator, predator length/age, prey and prey length/age. The compilation of the individual stomach samples from a trawl haul into average diet of the North Sea follows the technique given by ICES 1997 and is briefly described below. Most stomachs have been pooled within a haul for each of the predator length groups considered.

For each haul the stomach samples for a given species and length class include the information on the number of a) empty stomachs; b) stomach with skeleton remains only; c) stomach with food and d) stomach with food, but regurgitated. In most cases stomachs within a haul are pooled at the time of sampling for each predator size class. Only stomach contents from the feeding, non-regurgitated stomachs were recorded and later bulked to save time. In the calculation of the average stomach content, it was assumed that the regurgitated stomachs had similar stomach content as the (valid) feeding fish.

First the average stomach content per ICES roundfish area is calculated using stomach data from the ICES rectangles available. If more than one sample is taken from a rectangle, the average stomach content for a predator length class is calculated as a weighted mean, using the number of stomachs sampled as weights. The average stomach content of a given predator and length class in a roundfish area are calculated as a weighted mean of the average stomach content per ICES square weighted by the square root of the arithmetic mean of the observed cpues within a rectangle.

Partly digested prey items are in some cases not fully identified to species level or size class. In such cases a species or size redistribution of unidentified items was made accordingly to the observed diet (see ICES, 1997 for details).

The length based observations were optionally transformed into age groups using an age–length-key (ALK) given by quarter and roundfish area. The ALKs were derived from quarterly surveys or alternatively from commercial catches. Stomach contents data by ages are however not used by SMS.

For a given predator the average North Sea stomach contents by quarter were finally calculated as a weighted mean of the average stomach contents by roundfish area. The quarterly proportions of the stock in the roundfish areas of the total North Sea stock of a given predator were used as weighting factors. The spatial distribution of the predators and age–length keys by roundfish area were derived from quarterly surveys or commercial catches.

References

ICES. 1989. Database report of the Stomach Sampling Project 1981. Coop. Res. Rep. 164: 1–145.

ICES. 1997. Database report of the Stomach Sampling Project 1991. Coop. Res. Rep. 219: 1–442.

2.3.4 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).

Ration (R) (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 2.3.2. 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 dependent on quarter (Table 2.3.3).

Table 2.3.3. Parameters for estimating quarterly ration per individual from its mean weight (ration= 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 2.3.2) generally decreased with 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 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 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.

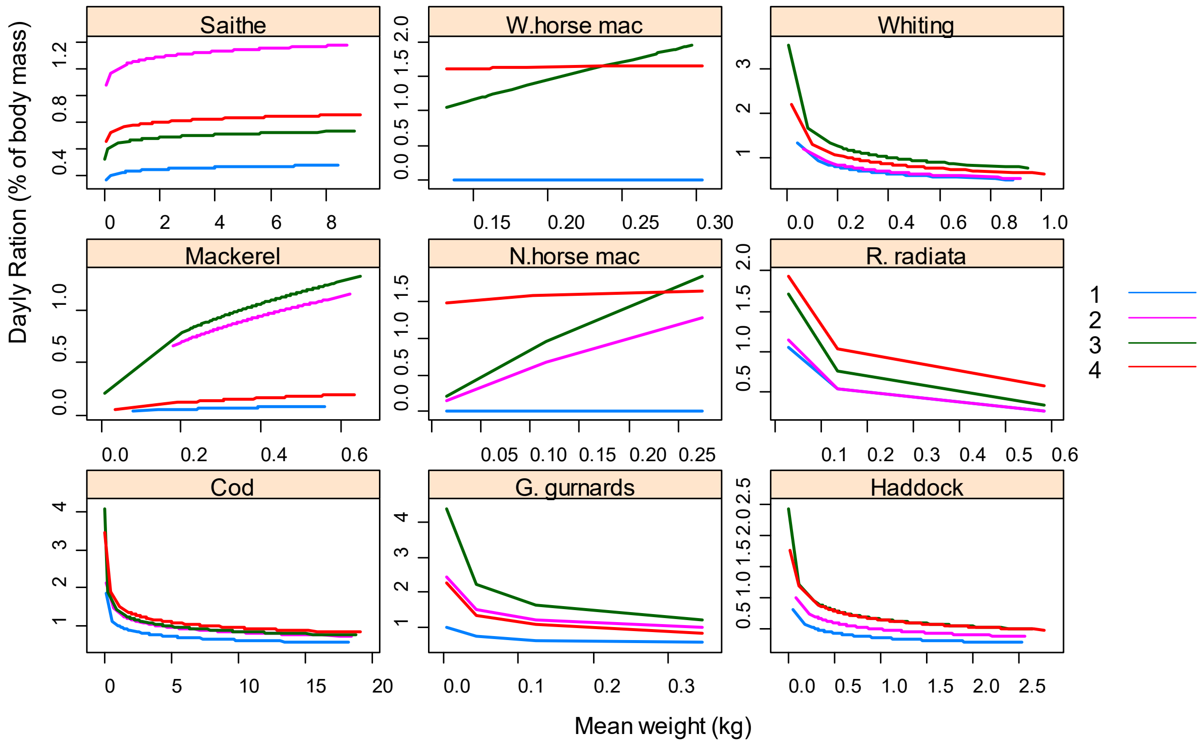

Figure 2.3.2. Daily consumption rates as used in SMS calculated from the method of Andersen. Colours show quarter of the year.

2.3.5 Estimation of diet from stomach contents

The diet of fish species was estimated from the observed stomach contents, taking the prey and temperature dependence into account as done for the calculation of food ration. Stomachs were firstly pooled into one sample including stomachs from a predator, predator size class, year, quarter and roundfish area, from which the diet was derived. Average temperate for this stratum was derived from temperature by ICES rectangle weighted by the number of stomachs sampled in the rectangles. The outline of the method to derive diet at population levels is described in 2.3.3.1.

Compared to the observed stomach content the estimate of diet shows a relative larger proportion of “other food” and thereby a lower proportion of fish prey (mainly because the energy contents in most fish is higher compared to invertebrates). An example is show in Table 2.3.4, where the ratio between the new and old estimate is shown for the predators cod and whiting.

Table 2.3.4. Ratio between observed stomach content and the estimated diet data used in SMS for cod in 1991, quarter 2 and 3.

		Predator size class (lower length in mm)												
		100	**120**	**150**	**200**	**250**	**300**	**350**	**400**	**500**	**600**	**700**	**800**	**1000**
Quarter	prey	.	.	.	.	.	0.52	.	0.6	0.77	.	0.73	0.6	.
2	COD													
	HAD	.	.	.	0.55	.	.	0.6	0.59	0.8	0.82	0.72	0.68	0.72
	HER	.	.	.	.	.	0.47	0.64	0.54	0.73	0.75	0.75	0.63	0.68
	NOP	.	.	.	.	.	0.52	0.61	0.59	0.79	0.78	0.82	0.69	0.72
	NSA	.	.	0.48	0.52	0.53	0.55	0.65	0.63	0.81	0.82	0.89	0.69	0.72
	OTH	.	1	1.04	1.05	1.12	1.29	1.39	1.32	1.25	1.22	1.26	1.34	1.48
	SPR	.	.	.	.	0.41	0.47	.	0.47	0.76	0.64	0.61	0.62	0.8
	SSA	.	.	0.47	0.46	0.44	0.50	0.68	0.61	0.7	0.66	0.65	0.59	0.87
	WHG	.	.	.	0.46	.	.	0.59	0.61	0.77	0.8	0.79	0.61	0.71
3	COD	.	0.82	.	0.52	0.67	0.67	0.71	0.65	0.71	0.79	0.86	0.76	0.86
	HAD	.	.	.	0.49	0.63	0.64	0.7	0.7	0.75	0.75	.	0.75	0.86
	HER	.	.	.	.	.	0.37	.	0.75	0.71	0.71	0.77	0.69	0.8
	NOP	0.96	0.82	.	0.49	0.65	0.66	0.68	0.69	0.68	0.74	0.78	0.75	0.86
	NSA	.	.	.	0.5	0.63	0.60	0.69	0.7	0.68	0.78	0.83	0.74	.
	OTH	1	1.01	1	1.26	1.55	1.36	1.19	1.51	1.35	1.57	1.6	1.33	1.04
	PLE	.	.	.	.	.	0.61	.	.	.	.	.	.	.
	SOL	.	.	.	.	.	.	.	.	0.78	.	.	.	.
	SPR	.	.	.	.	.	0.42	.	0.64	.	0.38	0.42	.	.
	SSA	.	.	.	.	0.62	0.40	0.34	0.37	.	.	0.27	.	.
	WHG	.	.	.	.	0.64	0.43	0.53	0.69	0.69	0.75	0.53	0.67	.

Table 2.3.5. Ratio between observed stomach content and the estimated diet data used in SMS for whiting in 1991, quarter 2 and 3.

		PREDATOR SIZE CLASS (LOWER LENGTH IN MM)							
		100	120	150	200	250	300	350	400
Quarter	prey	.	0.91	0.84	0.95	0.98	.	.	.
2	COD								
	HAD	.	.	0.87	0.86	0.92	.	.	.
	HER	.	.	0.9	.	0.87	0.92	0.86	0.87
	NOP	.	.	0.97	0.89	0.93	0.9	0.93	0.91
	NSA	.	0.99	0.97	0.88	0.92	0.86	0.93	0.91
	OTH	1	1.01	1.04	1.17	1.14	1.23	1.22	1.23
	SPR	.	.	0.85	0.88	0.92	0.95	0.92	0.92
	SSA	0.98	0.86	0.9	0.92	0.99	1.03	1.02	0.99
	WHG	.	0.88	0.82	0.97	0.99	0.98	0.95	0.92
3	COD	.	.	.	0.7	0.95	0.88	.	.
	HAD	1.06	1	0.63	0.77	0.94	1.04	1.08	1.15
	HER	.	.	0.46	0.74	0.87	0.93	0.96	0.85
	NOP	1.05	1.02	0.56	0.79	0.93	1.04	1.08	1.02
	NSA	1.03	1.01	0.62	0.79	0.92	1.02	1.05	1.03
	OTH	0.98	0.97	1.07	1.35	1.5	1.27	1.29	2.33
	SPR	.	.	0.59	0.57	0.75	0.78	0.65	.
	SSA	.	.	0.57	0.79	0.9	0.84	0.72	.
	WHG	1.05	0.88	0.4	0.73	0.92	0.95	1.05	0.93

Appendix 3 provides an overview of diet data as used by SMS by the individual predators and size class. Number of stomachs sampled is also presented in Appendix 3.

Size distribution of predator and prey size classes used for stomach observations

Most of the sampled stomachs have been pooled into size classes, e.g. saithe 300–400 mm in the 1981 sampling, such that information on the individual fish does not exist. Similarly, size of prey item was pooled within size classes, e.g. herring 150–200 mm, in the compilation of stomach contents data. The size distribution and mean length of the individual size classes (and they differs 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. Sandeel are not caught during IBTS and data from the Danish commercial fishery 1987–2003 were used instead for this prey species. For both data sources, data from several years were combined into one average quarterly size distribution.

This size distribution was then used to split total biomass eaten on age groups using a length–weight relation, and length–age keys from the quarterly IBTS data 1991–1997.

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 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.

2.3.6 New stomach data

New data were collected in 2013 on mackerel diet composition. Unfortunately, the length of the prey items was not recorded, and therefore, the data cannot be used without assigning the prey types to specific length groups.

References

Andersen N.G. 2012. Influences of potential predictor variables on gastric evacuation in Atlantic cod *Gadus morhua* feeding on fish prey: parameterization of a generic model. J Fish Biol 80:595–612.

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Lambert T. 1985. Gastric emptying time and assimilation efficiency in Atlantic mackerel (*Scomber scombrus*). Can J Zool 63:817–820.

Temming A, Bøhle B, Skagen DW, Knudsen FR. 2002. Gastric evacuation in mackerel: the effects of meal size, prey type and temperature. J Fish Biol 61:50–70.

2.4 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)

2.4.1 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.

2.4.2 Length–weight relations

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

Table 2.4.1. 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

References

Coull K. A., Jermyn A. S., Newton A. W., Henderson G.I. and Hall W.B. 1989. Length–weight Relationships for 88 Species of Fish Encountered in the North East Atlantic. Scottish Fisheries Research Report Number 43: 81pp.

Silva J. F., Ellis J. R. and Ayers R. A. 2013. Length–weight relationships of marine fish collected from around the British Isles. Sci. Ser. Tech. Rep., Cefas Lowestoft, 150: 109pp.

2.4.3 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.

Table 2.4.2. 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

2.4.4 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 on 4 quarters.

3 Model configuration

The configuration of the SMS model aims firstly to mimic the results from ICES single-species assessment models when SMS is run in single-species mode (no estimation of predation mortality) using the same annual M values as the single-species assessment, and secondly to configure options for predation mortality as concluded at the last key run (if not changed).

Appendix 4 presents the SMS configuration (option files) used for the 2020 key run.

3.1 Fishing mortality

SMS uses a separable F model while some of the ICES single-species models use a more flexible model for F (e.g. SAM using random walk F, Further, 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, but the results should be quite close.

In Appendix 5, the stock summaries from ICES single-species assessment are compared with the summaries from the SMS runs using fixed M. The differences are commented below.

3.1.1 Cod

The 2020 SMS model run for cod in single-species mode mirrors the ICES assessment in the development of F (Appendix 5, Figure A5.1). SSB is somewhat lower due to the use of quarter 1 mean weight in the stock in SMS whereas the ICES assessments use annual average weight-at-age when estimating SSB. SMS uses the ICES mean weights as an annual mean weight, but uses a fixed quarterly growth increment factor, which means that mean weight in quarter 1, as used in the calculation of SSB, becomes smaller in SMS than in the ICES assessment. Recruitment in SMS is always at age zero in quarter 3, while the ICES assessment uses age 1 at the beginning of the year. This difference in recruitment timing makes it difficult to compare the two recruitment estimates.

3.1.2 Whiting

The 2020 SMS run mirrors the development in F and SSB from the ICES assessment quite well (Appendix 5, Figure A5.2). Recruitment from the two models follows the same trend, but higher in the ICES version as recruitment at age 0 takes place in the beginning of quarter 1 in the ICES model and in quarter 3 in SMS.

3.1.3 Haddock

The 2020 SMS assessment of haddock followed the trend of F and SSB from the ICES assessment quite well, but F is larger and SSB is lower in the SMS run (Appendix 5, Figure A5.3).

3.1.4 Saithe

F and SSB are quite similar between the two runs (Appendix 5, Figure A5.4), but recruitment seems different due to recruitment at age 0 in SMS and at age 3 in ICES assessment. The SMS uses the stock numbers (with noise) estimated by the ICES assessment as "survey" cpue. The two assessment should therefore be quite close, however F in the most recent years differ, probably due to process noise in the ICES (SAM) assessment.

3.1.5 Mackerel

SMS uses the stock numbers (with noise) estimated by the ICES assessment as "survey" cpue. The two assessment should therefore be quite close. F and recruitment are however more variable in the SMS, probably due to process noise in the ICES (SAM) assessment.

3.1.6 Herring

The 2020 SMS assessment of herring follows the ICES assessment reasonably well. Catches are set to zero in 1978-1979 and SMS gives a zero F for those years, while ICES (SAM) estimates an F (Appendix 5, Figure A5.6).

3.1.7 Norway pout

The ICES assessment estimates SSB on November 1st, whereas the SMS uses SSB by January 1st, and since natural mortality is larger than growth in the period between the two, the ICES values are substantially lower than the SMS ones. The 2020 SMS run shows similar developments in F but F is much more variable between years than in the ICES (seasonal SAM) assessment (Appendix 5, Figure A5.7).

3.1.8 Sandeel

Sandeel are assessed by ICES in sub-stocks that are not identical to those in the multi-species SMS implementation. Therefore, the results are not compared.

3.1.9 Sprat

In the ICES assessment, Sprat is recruited in quarter 3 at age 0 and the model year goes from 1 July to 30 June such that calendar quarter 3 becomes model quarter 1. In the WGSAM sprat assessment the model year follows the calendar year, and sprat is, as all other species recruited to the model in quarter 3. The time-shift means that the ICES assessment has two more observations per cohort (age 3 in model quarter 3 and 4) than in the WGSAM version where they becomes part of the plus-group.

Recruitment and SSB are quite similar between the two assessments, but F is consistenly lower in SMS. This difference is due to the different timing of the assessment and because the figure shows "annual F". "annual F" is based on the annual Z (equal to the sum of quarterly F and M) and the sum of number died by quarter due to fishing (catch) and due to M (deadM) such that annual F = Z*catch/(catch+deadM). Annual F is different from the sum of quarterly F.

The sprat assessment has a high M (around 0.4 per quarter) which means that timing of the fishing matters:

For the full time period since 1974, 51% of the catch weight are caught in calendar quarter 3, 36 % in quarter 4, 12 % in quarter and ~0 % in quarter 2 (as catches are moved to quarter 1)

Using timing from the ICES (model year: calendar Q3, Q4, Q1 and Q2) means that an age-group has not been depleted very much from natural causes (M) before the main catches are taken.

Using WGSAM timing gives two quarters (calendar Q1 and Q2) with low catches and strong depletion of the stock due to M, before the large catches in Q3 and Q4 are taken.

Said in another way; the average catch numbers within a 12 months period (either Q3-4-1-2 in the ICES version or Q1-2-3-4 in the WGSAM version) is the same. The number died from natural caused is however larger in in the WGSAM version, which mean that the annual F becomes smaller in that version as it is calculated from the proportion died due to fishing. We would therefor expect a higher "annual F" in the WGSAM version, and that is what we get! (Appendix 5, Figure A5.8).

3.1.10 Plaice and sole

Plaice and sole are not a predators or preys in SMS, so the final SMS assessment is equal to the single-species SMS presented (Appendix 5, Figure A5.8 and A5.9). The stock dynamics are estimated very different for plaice but similar for sole.

3.2 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 indicted as statistical 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 2017 and 2020 key run, 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.

4 Other issues

The SMS model, and input and input can be found at 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 the period 1974–2016.
- NortSeaKeyRun_2020: The SMS North Sea key run made at the 2020 WGSAM, including data for the period 1974–2019.
- input_output: Detailed presentation of input and output file for the 2020 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 a SMS run

5 Results of the 2020 North Sea SMS key run

Changes of input data to the new key run and ICES benchmarks for some of the stocks since the 2017 key run have produced stock summaries (recruitment, mean F and SSB) from the 2020 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 and 2017 can be found on https://github.com/ices-eg/wg_WGSAM

Key run summary sheet

AREA	NORTH SEA
Model name	SMS
Type of model	Age–length structured statistical estimation model
Run year	2020
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	1974–2019.
Time step	Quarterly
Area structure	North Sea
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 multi-species dynamic
Model changes since last key run	All time-series updated. Mackerel included as a modelled stock. Proportion of the stock within the North Sea given as input and used for estimating M2. Daily food ration of changed for the main fish species. Bias correction of diet composition of harbour porpoise and the main predatory fish.
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 2017

5.1 Results of the 2020 key run

The input and output from the model are comprehensive and cannot all be presented in this report. This report presents only the key-output.

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 .

The structure of data in the "input_output" directory to be downloaded is:

Input

c.obs

plots of observed catch numbers-at-age from the 2017- and 2020 key runs

OtherPredators

plots of stock size of external predators from the 2017- and 2020 key runs

West

plots of mean weight-at-age in the sea from the 2017- and 2020 key runs

PropMat

plots of proportion mature-at-age in the sea from the 2017- and 2020 key runs

Ration

plots of consumption (food ration) at age from the 2017- and 2020 key runs

StomachContents

plots of relative stomach contents weight

Tables

Tables with most of the variables listed above

Output

Comparisons

- **ICES** Comparison of ICES single-species assessment and SMS in single-species mode
- **Summary** Comparison of stock summaries from the 2017 and 2020 key runs.
- **M2** Comparison of M2 values from the 2017 and 2020 key runs.

StockSummary

Stock summary plots

Uncertainties

Coefficient of variations of estimated recruitment, mean F, SSB and M2

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

WhoEatsWhom

Plots of biomass eaten by various combinations of predator and preys.

CSV files with the same information (on three aggregation levels).

Tables

Stock summary tables

F at age tables

Tables with M2 and M=M1+M2 values

Diagnostics

Residuals plots

- **Catch** observation residuals
- **Survey** observation residuals

Retrospective

- **Summary** Plots of stock summaries, retrospective analysis 2015 to 2019
- **M2** Plots of M2 at age, retrospective analysis 2015 to 2019

Text **in bold** shows directory names.

The key-run including executable and source file for SMS can be found in the directory **SMS-key-run-2020**

The main input and outputs are also shown in the HTML document NS_key_run_2020.html, which present the same data in a more user-friendly way.

5.1.1 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 and key output variables were obtained from the inverse Hessian matrix.

Parameter overview

The SMS estimates a large number of parameters (see Appendix 1 of section 8 for an overview of input, parameters and estimated variables). Out the total number of parameters (1870) only 144 relates to predation (Table 5.1.1.1). The rest (1736) 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" in Table 5.1.1.1) 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 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 5.1.1.1) 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 540 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 (43) is low, as a constant value is assumed for the species with annual catch data.

The sub-model for survey indices requires 125 parameters for the age based catchability and 86 parameters for the estimate of the variance of survey observations (Table 5.1.1.1).

114 parameters out of a total of 144 parameters related to predation are used to parameterize predator - prey vulnerabilities (Table 5.1.1.1). 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 5.1.1.2).

Table 5.1.1.1. Number of parameters estimated by group of data.

Parameter	1.recruit-ment	2.catch and F	3.survey index	4.predation	all
age effect in separable model for F	0	182	0	0	182
catchability survey	0	0	125	0	125
predator prey vulnerability	0	0	0	114	114
recruitment, stock N at youngest age	552	0	0	0	552
season effect in separable model for F	0	43	0	0	43
size dependent preference for other food	0	0	0	4	4
spatial overlap between predator and prey	0	0	0	6	6
stock–recruitment parameter (alfa)	12	0	0	0	12
stock–recruitment parameter (beta)	6	0	0	0	6
stock number in the first year	90	0	0	0	90
variance of catch observations	0	78	0	0	78
variance of diet obs.in relation to sampling	0	0	0	20	20
variance of stock–recruitment estimate	12	0	0	0	12
variance of survey cpue observations	0	0	86	0	86
year effect in separable model for F	0	540	0	0	540
All	672	843	211	144	1870

Table 5.1.1.2 Parameter overview. CV (percentage) of predator - prey vulnerability parameters

Predator	Cod	Whiting	Haddock	Herring	N. sandeel	S. sandeel	Nor. pout	Sprat
1_Fulmar	55	54	86	57	25	25	51	56
2_Guillemot		81	127	84	87	79		79
3_Her. Gull	78	39	56	51	115	114	43	56
4_Kittiwake	83	82	84	66	34	33		57
5_GBB. Gull	51	47	48	49	35	35	44	49
6_Gannet	56			24	30	29		51
7_Puffin				54	38	38		56
8_Razorbill		82		54	76	77	82	49
9_A. radiata	69	69			42	55	48	
10_G. gurnards	27	17	41	61	17	18	20	40
11_W.horse mac					48		54	
12_N.horse mac		35		34	71			64
13_Grey seal	16	24	20	38	14		36	
14_H. porpoise	25	26		41	39	47	96	
15_Hake		113		69			32	
16_Cod	10	8	8	8	12	14	8	13
17_Whiting	32	22	22	22	22	22	19	20
18_Haddock					16		19	
19_Saithe		30	26	28	28		22	
20_Mackerel				60	60	57	57	57

Key diagnostics

Key diagnostics (Table 5.1.1.3) 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.

Table 5.1.1.3 SMS model diagnostics.

October 29, 2020 13:51:58 run time:356 seconds

objective function (negative log likelihood): -5455.65
Number of parameters: 1870
Number of observations used in likelihood: 16254
Maximum gradient: 0.000544612
Akaike information criterion (AIC): -7171.31
Number of observations used in the likelihood:

	Catch	CPUE	S/R	Stomach	Sum
Species: 1, Fulmar	0	0	0	144	144
Species: 2, Guillemot	0	0	0	144	144
Species: 3, Her. Gull	0	0	0	168	168
Species: 4, Kittiwake	0	0	0	132	132
Species: 5, GBB. Gull	0	0	0	204	204
Species: 6, Gannet	0	0	0	96	96
Species: 7, Puffin	0	0	0	96	96
Species: 8, Razorbill	0	0	0	132	132
Species: 9, A. radiata	0	0	0	64	64
Species:10, G. gurnards	0	0	0	149	149
Species:11, W.horse mac	0	0	0	14	14
Species:12, N.horse mac	0	0	0	34	34
Species:13, Grey seal	0	0	0	54	54
Species:14, H. porpoise	0	0	0	19	19
Species:15, Hake	0	0	0	33	33
Species:16, Cod	460	302	46	881	1689
Species:17, Whiting	368	389	46	586	1389
Species:18, Haddock	460	409	46	131	1046
Species:19, Saithe	368	322	46	188	924
Species:20, Mackerel	460	432	46	105	1043
Species:21, Herring	1564	275	46	0	1885
Species:22, N. sandeel	828	231	46	0	1105
Species:23, S. sandeel	828	159	46	0	1033
Species:24, Nor. pout	644	269	46	0	959
Species:25, Sprat	552	240	46	0	838
Species:26, Plaice	460	872	44	0	1376
Species:27, Sole	460	980	44	0	1484
Sum	7452	4880	548	3374	16254

objective function weight:

	Catch	CPUE	S/R	Stom.	Stom N.
Species: 1, Fulmar	0.00	0.00	0.00	0.10	1.00
Species: 2, Guillemot	0.00	0.00	0.00	0.10	1.00
Species: 3, Her. Gull	0.00	0.00	0.00	0.10	1.00
Species: 4, Kittiwake	0.00	0.00	0.00	0.10	1.00
Species: 5, GBB. Gull	0.00	0.00	0.00	0.10	1.00
Species: 6, Gannet	0.00	0.00	0.00	0.10	1.00
Species: 7, Puffin	0.00	0.00	0.00	0.10	1.00
Species: 8, Razorbill	0.00	0.00	0.00	0.10	1.00
Species: 9, A. radiata	0.00	0.00	0.00	1.00	1.00
Species:10, G. gurnards	0.00	0.00	0.00	1.00	1.00
Species:11, W.horse mac	0.00	0.00	0.00	1.00	1.00
Species:12, N.horse mac	0.00	0.00	0.00	1.00	1.00
Species:13, Grey seal	0.00	0.00	0.00	1.00	1.00
Species:14, H. porpoise	0.00	0.00	0.00	1.00	1.00
Species:15, Hake	0.00	0.00	0.00	1.00	1.00
Species:16, Cod	1.00	1.00	0.10	1.00	0.00
Species:17, Whiting	1.00	1.00	0.10	1.00	0.00
Species:18, Haddock	1.00	1.00	0.10	1.00	0.00
Species:19, Saithe	1.00	1.00	1.00	1.00	0.00
Species:20, Mackerel	1.00	1.00	1.00	1.00	0.00
Species:21, Herring	1.00	1.00	0.10	0.00	0.00
Species:22, N. sandeel	1.00	1.00	0.10	0.00	0.00
Species:23, S. sandeel	1.00	1.00	0.10	0.00	0.00
Species:24, Nor. pout	1.00	1.00	0.10	0.00	0.00
Species:25, Sprat	1.00	1.00	0.10	0.00	0.00
Species:26, Plaice	1.00	1.00	0.10	0.00	0.00
Species:27, Sole	1.00	1.00	0.10	0.00	0.00

unweighted objective function contributions (total):

	Catch	CPUE	S/R	Stom.	Stom N.	Penalty	Sum
Fulmar	0.0	0.0	0.0	-326.1	0.0	0.00	-326
Guillemot	0.0	0.0	0.0	-208.5	0.0	0.00	-208
Her. Gull	0.0	0.0	0.0	-388.0	0.0	0.00	-388
Kittiwake	0.0	0.0	0.0	-237.9	0.0	0.00	-238
GBB. Gull	0.0	0.0	0.0	-503.0	0.0	0.00	-503
Gannet	0.0	0.0	0.0	-134.2	0.0	0.00	-134
Puffin	0.0	0.0	0.0	-104.8	0.0	0.00	-105
Razorbill	0.0	0.0	0.0	-152.8	0.0	0.00	-153
A. radiata	0.0	0.0	0.0	-35.7	0.0	0.00	-36
G. gurnards	0.0	0.0	0.0	-76.6	0.0	0.00	-77
W.horse mac	0.0	0.0	0.0	2.8	0.0	0.00	3
N.horse mac	0.0	0.0	0.0	-9.4	0.0	0.00	-9
Grey seal	0.0	0.0	0.0	-126.6	0.0	0.00	-127

H. porpoise	0.0	0.0	0.0	-25.7	0.0	0.00	-26
Hake	0.0	0.0	0.0	-17.1	0.0	0.00	-17
Cod	-442.7	-159.9	-4.3	-1454.0	0.0	0.00	-2061
Whiting	-279.9	-173.0	-30.3	-663.8	0.0	0.00	-1147
Haddock	-193.7	-158.2	17.4	-86.7	0.0	0.00	-421
Saithe	-308.8	-62.0	-16.0	-108.2	0.0	0.00	-495
Mackerel	-446.7	-49.5	-10.1	-80.6	0.0	0.00	-587
Herring	233.9	-182.5	-8.2	0.0	0.0	0.00	43
N. sandeel	138.4	35.1	4.0	0.0	0.0	0.00	177
S. sandeel	92.3	-51.6	4.5	0.0	0.0	0.00	45
Nor. pout	252.2	-44.1	-3.4	0.0	0.0	0.00	205
Sprat	190.7	-66.6	-3.5	0.0	0.0	0.00	121
Plaice	-513.9	-57.8	-24.1	0.0	0.0	0.00	-596
Sole	-424.2	134.8	1.6	0.0	0.0	0.00	-288
Sum	-1702.4	-835.3	-72.5	-4737.0	0.0	0.00	-7347

unweighted objective function contributions (per observation):

	Catch	CPUE	S/R	Stomachs
Fulmar	0.00	0.00	0.00	-2.26
Guillemot	0.00	0.00	0.00	-1.45
Her. Gull	0.00	0.00	0.00	-2.31
Kittiwake	0.00	0.00	0.00	-1.80
GBB. Gull	0.00	0.00	0.00	-2.47
Gannet	0.00	0.00	0.00	-1.40
Puffin	0.00	0.00	0.00	-1.09
Razorbill	0.00	0.00	0.00	-1.16
A. radiata	0.00	0.00	0.00	-0.56
G. gurnards	0.00	0.00	0.00	-0.51
W.horse mac	0.00	0.00	0.00	0.20
N.horse mac	0.00	0.00	0.00	-0.28
Grey seal	0.00	0.00	0.00	-2.34
H. porpoise	0.00	0.00	0.00	-1.35
Hake	0.00	0.00	0.00	-0.52
Cod	-0.96	-0.53	-0.09	-1.65
Whiting	-0.76	-0.44	-0.66	-1.13
Haddock	-0.42	-0.39	0.38	-0.66
Saithe	-0.84	-0.19	-0.35	-0.58
Mackerel	-0.97	-0.11	-0.22	-0.77
Herring	0.15	-0.66	-0.18	0.00
N. sandeel	0.17	0.15	0.09	0.00
S. sandeel	0.11	-0.32	0.10	0.00
Nor. pout	0.39	-0.16	-0.07	0.00
Sprat	0.35	-0.28	-0.08	0.00
Plaice	-1.12	-0.07	-0.55	0.00
Sole	-0.92	0.14	0.04	0.00

```
contribution by fleet:
----------------------
Species:16, Cod
COD IBTS Q1 gam            total:-101.913   mean:  -0.551
COD IBTS Q3 gam            total: -57.961   mean:  -0.518

Species:17, Whiting
WHG IBTS-Q1 1974-1988      total: -15.416   mean:  -0.280
WHG IBTS-Q1 1989-          total: -76.865   mean:  -0.480
WHG IBTS-Q3                total: -80.670   mean:  -0.464

Species:18, Haddock
HAD IBTS Q1 1974-1988      total: -30.346   mean:  -0.405
HAD IBTS Q1 1988-          total: -52.847   mean:  -0.341
HAD IBTS Q3                total: -75.020   mean:  -0.431

Species:19, Saithe
POK N with noise           total: -62.000   mean:  -0.193

Species:20, Mackerel
MAC Swept area             total: -19.821   mean:  -0.275
MAC N with noise           total: -29.702   mean:  -0.083

Species:21, Herring
HER HERAS                  total:-146.703   mean:  -0.702
HER IBTS-Q1                total: -22.842   mean:  -0.617
HER IBTS0                  total: -12.917   mean:  -0.461

Species:22, N. sandeel
NSA dredge                 total:   1.329   mean:   0.028
NSA Commercial 1982-1998   total:   0.840   mean:   0.016
NSA Commercial 1999-2019   total:  -0.014   mean:  -0.000
NSA Commercial 1976-2004 2 total:  19.623   mean:   0.677
NSA  acoustic SA 1R        total:  13.287   mean:   0.302

Species:23, S. sandeel
SSA SSA dredge             total:   3.818   mean:   0.080
SSA Commercial 1982-1998   total: -12.154   mean:  -0.238
SSA Commercial 1999-2004   total: -21.750   mean:  -1.208
SSA Commercial 1994-2009   total: -17.221   mean:  -1.148
SSA Commercial 2010-2019   total:  -4.296   mean:  -0.159
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Species:24, Nor. pout
NOP EGFSQ3                  total:   1.760   mean:   0.031
NOP IBTSQ1                  total: -43.405   mean:  -0.391
NOP IBTSQ3                  total:   4.854   mean:   0.084
NOP SGFSQ3                  total:  -7.276   mean:  -0.165

Species:25, Sprat
SPR Acoustic                total:  -7.359   mean:  -0.175
SPR IBTS Q1                 total:   2.558   mean:   0.022
SPR IBTS Q3                 total: -61.820   mean:  -0.736

Species:26, Plaice
PLE BTS Isis                total:  -0.726   mean:  -0.008
PLE BTS Combined            total: -20.617   mean:  -0.095
PLE SNS1                    total:  37.191   mean:   0.238
PLE SNS2                    total:   5.701   mean:   0.050
PLE IBTS Q3                 total: -20.674   mean:  -0.100
PLE IBTS Q1                 total: -58.713   mean:  -0.645

Species:27, Sole
SOL SNS                     total: 125.274   mean:   0.398
SOL BTS                     total: -59.820   mean:  -0.171
SOL ISIS                    total:  69.342   mean:   0.220
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F, Year effect:
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	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:	1.046	1.028	1.176	1.150	1.337	1.723	1.354	1.496	0.662	2.411	1.175	1.016
1976:	1.138	1.103	1.118	1.270	1.518	1.111	1.002	2.972	0.621	2.144	0.935	0.949
1977:	1.118	0.823	1.021	1.598	1.189	0.291	2.452	3.237	0.442	2.101	1.009	0.860
1978:	1.293	0.735	1.098	0.946	1.505	5.007	1.576	4.164	0.505	1.573	0.895	1.056
1979:	1.048	0.798	1.134	0.994	1.853	5.007	0.568	6.060	0.543	0.943	1.351	1.040
1980:	1.213	0.844	1.055	1.160	1.000	0.162	1.661	3.925	0.566	2.628	1.079	1.050
1981:	1.199	0.734	0.741	1.087	1.033	0.237	1.139	4.182	0.448	1.661	1.112	1.047
1982:	1.306	0.589	0.693	1.115	1.018	0.193	0.921	6.578	0.488	1.361	1.206	1.181
1983:	1.316	0.789	0.947	1.602	0.877	1.000	0.411	3.529	0.620	2.723	1.149	1.110
1984:	1.226	0.936	1.115	1.349	0.905	1.590	0.351	5.093	0.699	1.491	1.187	1.275
1985:	1.234	0.703	1.000	1.332	0.811	1.754	0.587	6.075	0.898	1.744	1.069	1.199
1986:	1.351	0.929	1.038	1.740	0.760	1.444	1.351	2.007	0.522	2.528	1.318	1.326
1987:	1.331	1.049	1.193	1.452	0.828	1.339	0.926	1.392	0.700	0.610	1.355	1.084
1988:	1.310	0.828	1.261	1.595	0.896	1.359	1.197	3.574	0.365	2.161	1.441	1.085
1989:	1.357	0.829	1.194	1.455	0.766	1.155	2.546	4.315	0.424	0.767	1.285	0.889
1990:	1.261	0.854	1.133	1.290	0.831	1.133	2.096	5.274	0.477	2.045	1.000	1.000
1991:	1.263	1.000	1.218	1.256	0.984	1.193	1.319	3.316	0.691	2.068	1.177	1.101
1992:	1.225	0.977	1.049	1.000	1.137	1.629	0.921	3.121	0.383	0.879	1.266	1.065
1993:	1.000	1.184	1.229	1.306	1.314	2.207	0.783	3.310	0.675	1.891	1.228	1.188
1994:	1.021	1.120	1.159	0.969	1.411	2.098	2.347	3.304	0.524	0.871	1.248	1.280
1995:	1.131	0.951	1.020	1.191	1.339	2.451	0.928	2.007	0.294	2.126	1.170	1.175
1996:	1.205	0.881	1.131	1.024	1.004	0.993	1.030	4.140	0.334	1.901	1.358	1.697
1997:	1.089	0.775	0.870	0.752	0.973	0.875	0.995	2.097	0.297	1.317	1.646	1.439
1998:	1.178	0.633	0.955	0.796	1.111	1.000	1.543	2.999	0.239	2.210	1.413	1.523
1999:	1.342	0.872	1.278	1.050	1.151	0.765	1.501	5.419	0.350	1.408	1.492	1.357
2000:	1.281	0.954	1.000	0.767	1.364	0.764	1.616	3.265	0.299	1.735	1.153	1.508
2001:	1.208	0.568	0.774	0.598	1.525	0.609	1.053	6.188	0.107	2.284	1.461	1.257
2002:	1.096	0.498	0.639	0.795	1.835	0.545	1.843	2.822	0.276	2.101	1.490	1.249
2003:	1.127	0.538	0.348	0.844	1.764	0.571	0.855	4.526	1.000	1.883	1.000	1.231
2004:	1.027	0.431	0.379	0.603	1.000	0.608	1.769	5.204	0.694	1.970	0.776	1.215
2005:	0.925	0.411	0.422	0.709	0.728	0.798	1.000	1.000	5.007	1.430	0.820	1.297
2006:	0.996	0.511	0.707	0.683	0.594	0.642	0.381	0.960	0.955	2.457	0.809	1.105
2007:	1.000	1.000	0.676	0.582	0.668	0.562	1.168	0.668	5.007	1.660	0.714	1.115
2008:	1.119	0.979	0.408	0.864	0.616	0.397	2.047	0.739	0.523	1.436	0.618	0.954
2009:	1.185	0.924	0.352	0.861	0.573	0.234	0.189	0.898	0.557	0.952	0.544	1.100
2010:	1.137	1.003	0.376	0.869	0.539	0.265	0.557	0.311	1.125	1.029	0.557	1.233
2011:	0.943	0.913	0.525	0.803	0.502	0.238	0.791	0.295	0.059	1.178	0.568	1.074
2012:	0.921	0.759	0.325	0.740	0.438	0.451	0.320	0.091	0.086	1.272	0.578	1.210
2013:	0.862	0.746	0.282	0.667	0.432	0.517	0.462	0.985	0.871	1.742	0.531	1.090
2014:	0.789	0.870	0.501	0.698	0.542	0.501	2.907	0.620	0.934	0.316	0.529	1.033
2015:	0.779	1.047	0.818	0.691	0.506	0.557	1.193	1.009	0.822	1.487	0.567	0.938
2016:	0.750	1.037	0.524	0.633	0.480	0.566	0.496	0.106	1.128	3.027	0.653	1.057
2017:	0.811	0.819	0.389	0.738	0.519	0.428	0.660	0.602	0.461	1.251	0.500	0.952
2018:	1.092	0.761	0.292	0.674	0.497	0.566	0.757	0.697	0.891	1.367	0.505	0.819
2019:	0.923	0.871	0.245	0.671	0.415	0.511	0.802	0.264	1.096	0.727	0.347	0.698

```
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
    2007-2019:   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
    2007-2019:   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
    2007-2019:   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
    2007-2019:   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
    2007-2019:   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
    2007-2019:   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
    2007-2019:   0.250 0.250 0.250 0.250
age: 3 - 8
    1974-1990:   0.250 0.250 0.250 0.250
    1991-2006:   0.250 0.250 0.250 0.250
    2007-2019:   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
    2000-2019:   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
    2000-2019:   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
    2000-2019:   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
    1992-2019:   0.250 0.250 0.250 0.250
age: 4 - 10
    1974-1991:   0.250 0.250 0.250 0.250
    1992-2019:   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
    2004-2019:   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
    2004-2019:   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
    2004-2019:   0.250 0.250 0.250 0.250

Herring
age: 0
    1974-1982:   0.000 0.000 0.903 0.500
    1983-1997:   0.000 0.000 1.175 0.500
    1998-2019:   0.000 0.000 0.583 0.500
age: 1 - 8
    1974-1982:   0.080 0.053 0.139 0.250
    1983-1997:   0.083 0.092 0.246 0.250
    1998-2019:   0.072 0.133 0.348 0.250

N. sandeel
age: 0
    1974-2004:   0.000 0.000 1.000 0.000
    2005-2019:   0.000 0.000 1.000 0.000
age: 1
    1974-2004:   0.000 3.522 0.500 0.000
    2005-2019:   0.000 22.055 0.500 0.000
age: 2 - 4
    1974-2004:   0.000 4.618 0.500 0.000
    2005-2019:   0.000 26.369 0.500 0.000
```

```
S. sandeel
age: 0
    1974-2004:   0.000 0.000 1.000 0.000
    2005-2019:   0.000 0.000 1.000 0.000
age: 1
    1974-2004:   0.000 3.295 0.500 0.000
    2005-2019:   0.000 5.316 0.500 0.000
age: 2 - 4
    1974-2004:   0.000 3.271 0.500 0.000
    2005-2019:   0.000 8.498 0.500 0.000

Nor. pout
age: 0
    1974-2002:   0.000 0.000 0.024 0.500
    2003-2019:   0.000 0.000 0.040 0.500
age: 1
    1974-2002:   0.057 0.050 0.171 0.250
    2003-2019:   0.002 0.020 0.119 0.250
age: 3
    1974-2002:   0.098 0.134 0.143 0.250
    2003-2019:   0.004 0.033 0.146 0.250

Sprat
age: 1
    1974-2019:   0.018 0.000 0.253 0.250
age: 2
    1974-2019:   0.045 0.000 0.129 0.250
age: 3
    1974-2019:   0.078 0.000 0.110 0.250

Plaice
Please note: Season effects are copied from input file
age: 1
    1974-1989:   0.250 0.250 0.250 0.250
    1990-2002:   0.250 0.250 0.250 0.250
    2003-2019:   0.250 0.250 0.250 0.250
age: 2 - 10
    1974-1989:   0.250 0.250 0.250 0.250
    1990-2002:   0.250 0.250 0.250 0.250
    2003-2019:   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
    1990-2019:   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  0.307  0.775  0.796  0.669  0.605  0.610  0.636  0.607  0.665  0.665
1993-2006:  0.000  0.145  0.696  0.941  0.890  0.859  0.826  0.841  0.862  0.891  0.891
2007-2019:  0.000  0.082  0.406  0.767  0.750  0.867  0.883  0.854  0.821  0.682  0.682
Whiting
1974-1990:  0.026  0.149  0.432  0.767  0.952  1.023  1.371  1.371  1.371
1991-2006:  0.016  0.131  0.337  0.511  0.633  0.774  0.843  0.843  0.843
2007-2019:  0.001  0.061  0.146  0.242  0.303  0.343  0.386  0.386  0.386
Haddock
1974-1984:  0.034  0.169  0.546  0.910  0.880  0.808  0.802  0.763  0.763  0.763  0.763
1985-1999:  0.017  0.162  0.616  0.882  0.902  0.819  0.634  0.744  0.744  0.744  0.744
2000-2019:  0.008  0.138  0.558  1.049  1.317  1.364  1.315  1.677  1.677  1.677  1.677
Saithe
1974-1991:  0.000  0.000  0.000  0.401  0.540  0.475  0.418  0.384  0.347  0.347  0.347
1992-2019:  0.000  0.000  0.000  0.183  0.487  0.588  0.568  0.516  0.475  0.475  0.475
Mackerel
1974-1979:  0.000  0.024  0.041  0.068  0.118  0.120  0.125  0.129  0.129  0.129  0.129
1980-2003:  0.000  0.034  0.079  0.132  0.189  0.221  0.239  0.286  0.286  0.286  0.286
2004-2019:  0.000  0.019  0.064  0.164  0.263  0.369  0.472  0.625  0.625  0.625  0.625
Herring
1974-1982:  0.355  1.155  1.635  1.662  1.391  1.372  1.372  1.372  1.372
1983-1997:  0.082  0.291  0.419  0.463  0.517  0.548  0.548  0.548  0.548
1998-2019:  0.097  0.118  0.262  0.423  0.585  0.749  0.749  0.749  0.749
N. sandeel
1974-2004:  0.027  0.070  0.079  0.076  0.076
2005-2019:  0.000  0.006  0.011  0.014  0.014
S. sandeel
1974-2004:  0.002  0.029  0.052  0.062  0.062
2005-2019:  0.001  0.091  0.135  0.155  0.155
Nor. pout
1974-2002:  0.129  2.499  6.922  6.922
2003-2019:  0.010  0.802  3.732  3.732
Sprat
1974-2019:  0.000  0.760  2.224  2.224
Plaice
1974-1989:  0.000  0.225  0.431  0.475  0.506  0.500  0.445  0.354  0.354  0.354  0.354
1990-2002:  0.000  0.112  0.406  0.480  0.551  0.608  0.619  0.474  0.474  0.474  0.474
2003-2019:  0.000  0.242  0.673  0.734  0.823  0.878  0.852  0.728  0.728  0.728  0.728
```

Sole

1974-1989:	0.000	0.002	0.201	0.566	0.591	0.485	0.452	0.357	0.357	0.357	0.357
1990-2019:	0.000	0.015	0.187	0.426	0.517	0.529	0.486	0.434	0.434	0.434	0.434

Exploitation pattern (scaled to mean F=1)

		0	1	2	3	4	5	6	7	8	9+
Cod											
1974-1992	season 1:	0	0.103	0.260	0.266	0.224	0.203	0.204	0.213	0.203	0.223
	season 2:	0	0.103	0.260	0.266	0.224	0.203	0.204	0.213	0.203	0.223
	season 3:	0.000	0.103	0.260	0.266	0.224	0.203	0.204	0.213	0.203	0.223
	season 4:	0.000	0.103	0.260	0.266	0.224	0.203	0.204	0.213	0.203	0.223
1993-2006	season 1:	0	0.043	0.207	0.279	0.264	0.255	0.245	0.250	0.256	0.264
	season 2:	0	0.043	0.207	0.279	0.264	0.255	0.245	0.250	0.256	0.264
	season 3:	0.000	0.043	0.207	0.279	0.264	0.255	0.245	0.250	0.256	0.264
	season 4:	0.000	0.043	0.207	0.279	0.264	0.255	0.245	0.250	0.256	0.264
2007-2019	season 1:	0	0.032	0.158	0.299	0.293	0.338	0.344	0.333	0.320	0.266
	season 2:	0	0.032	0.158	0.299	0.293	0.338	0.344	0.333	0.320	0.266
	season 3:	0.000	0.032	0.158	0.299	0.293	0.338	0.344	0.333	0.320	0.266
	season 4:	0.000	0.032	0.158	0.299	0.293	0.338	0.344	0.333	0.320	0.266
Whiting											
1974-1990	season 1:	0	0.041	0.119	0.211	0.262	0.282	0.377	0.377	0.377	
	season 2:	0	0.041	0.119	0.211	0.262	0.282	0.377	0.377	0.377	
	season 3:	0.014	0.041	0.119	0.211	0.262	0.282	0.377	0.377	0.377	
	season 4:	0.014	0.041	0.119	0.211	0.262	0.282	0.377	0.377	0.377	
1991-2006	season 1:	0	0.053	0.136	0.206	0.255	0.312	0.340	0.340	0.340	
	season 2:	0	0.053	0.136	0.206	0.255	0.312	0.340	0.340	0.340	
	season 3:	0.013	0.053	0.136	0.206	0.255	0.312	0.340	0.340	0.340	
	season 4:	0.013	0.053	0.136	0.206	0.255	0.312	0.340	0.340	0.340	
2007-2019	season 1:	0	0.054	0.128	0.213	0.267	0.302	0.340	0.340	0.340	
	season 2:	0	0.054	0.128	0.213	0.267	0.302	0.340	0.340	0.340	
	season 3:	0.003	0.054	0.128	0.213	0.267	0.302	0.340	0.340	0.340	
	season 4:	0.003	0.054	0.128	0.213	0.267	0.302	0.340	0.340	0.340	
Haddock											
1974-1984	season 1:	0	0.054	0.175	0.292	0.282	0.260	0.257	0.245	0.245	0.245
	season 2:	0	0.054	0.175	0.292	0.282	0.260	0.257	0.245	0.245	0.245
	season 3:	0.022	0.054	0.175	0.292	0.282	0.260	0.257	0.245	0.245	0.245
	season 4:	0.022	0.054	0.175	0.292	0.282	0.260	0.257	0.245	0.245	0.245
1985-1999	season 1:	0	0.051	0.192	0.276	0.282	0.256	0.198	0.232	0.232	0.232
	season 2:	0	0.051	0.192	0.276	0.282	0.256	0.198	0.232	0.232	0.232
	season 3:	0.010	0.051	0.192	0.276	0.282	0.256	0.198	0.232	0.232	0.232
	season 4:	0.010	0.051	0.192	0.276	0.282	0.256	0.198	0.232	0.232	0.232
2000-2019	season 1:	0	0.035	0.143	0.269	0.338	0.350	0.337	0.430	0.430	0.430
	season 2:	0	0.035	0.143	0.269	0.338	0.350	0.337	0.430	0.430	0.430
	season 3:	0.004	0.035	0.143	0.269	0.338	0.350	0.337	0.430	0.430	0.430
	season 4:	0.004	0.035	0.143	0.269	0.338	0.350	0.337	0.430	0.430	0.430
Saithe											
1974-1991	season 1:	0	0.000	0.000	0.221	0.297	0.262	0.230	0.211	0.191	0.191
	season 2:	0	0.000	0.000	0.221	0.297	0.262	0.230	0.211	0.191	0.191
	season 3:	0.000	0.000	0.000	0.221	0.297	0.262	0.230	0.211	0.191	0.191
	season 4:	0.000	0.000	0.000	0.221	0.297	0.262	0.230	0.211	0.191	0.191
1992-2019	season 1:	0	0.000	0.000	0.085	0.226	0.272	0.263	0.239	0.220	0.220
	season 2:	0	0.000	0.000	0.085	0.226	0.272	0.263	0.239	0.220	0.220
	season 3:	0.000	0.000	0.000	0.085	0.226	0.272	0.263	0.239	0.220	0.220
	season 4:	0.000	0.000	0.000	0.085	0.226	0.272	0.263	0.239	0.220	0.220
Mackerel											
1974-1979	season 1:	0	0.048	0.082	0.137	0.237	0.241	0.252	0.260	0.260	0.260
	season 2:	0	0.048	0.082	0.137	0.237	0.241	0.252	0.260	0.260	0.260
	season 3:	0.000	0.048	0.082	0.137	0.237	0.241	0.252	0.260	0.260	0.260
	season 4:	0.000	0.048	0.082	0.137	0.237	0.241	0.252	0.260	0.260	0.260
1980-2003	season 1:	0	0.035	0.081	0.135	0.193	0.226	0.244	0.293	0.293	0.293
	season 2:	0	0.035	0.081	0.135	0.193	0.226	0.244	0.293	0.293	0.293
	season 3:	0.000	0.035	0.081	0.135	0.193	0.226	0.244	0.293	0.293	0.293
	season 4:	0.000	0.035	0.081	0.135	0.193	0.226	0.244	0.293	0.293	0.293
2004-2019	season 1:	0	0.010	0.034	0.087	0.140	0.196	0.251	0.332	0.332	0.332
	season 2:	0	0.010	0.034	0.087	0.140	0.196	0.251	0.332	0.332	0.332
	season 3:	0.000	0.010	0.034	0.087	0.140	0.196	0.251	0.332	0.332	0.332
	season 4:	0.000	0.010	0.034	0.087	0.140	0.196	0.251	0.332	0.332	0.332
Herring											
1974-1982	season 1:	0	0.120	0.169	0.172	0.144	0.142	0.142	0.142	0.142	
	season 2:	0	0.079	0.112	0.114	0.096	0.094	0.094	0.094	0.094	
	season 3:	0.413	0.206	0.292	0.297	0.248	0.245	0.245	0.245	0.245	
	season 4:	0.229	0.372	0.527	0.535	0.448	0.442	0.442	0.442	0.442	

```
1983-1997 season 1:      0  0.072  0.104  0.115  0.128  0.136  0.136  0.136  0.136
          season 2:      0  0.080  0.116  0.128  0.142  0.151  0.151  0.151  0.151
          season 3:  0.286  0.214  0.308  0.340  0.380  0.403  0.403  0.403  0.403
          season 4:  0.122  0.217  0.313  0.345  0.385  0.409  0.409  0.409  0.409

1998-2019 season 1:      0  0.019  0.043  0.069  0.095  0.122  0.122  0.122  0.122
          season 2:      0  0.035  0.078  0.127  0.175  0.224  0.224  0.224  0.224
          season 3:  0.127  0.093  0.205  0.331  0.458  0.586  0.586  0.586  0.586
          season 4:  0.109  0.066  0.147  0.238  0.329  0.421  0.421  0.421  0.421

N. sandeel
1974-2004 season 1:      0  0.000  0.000  0.000  0.000
          season 2:      0  0.718  1.064  1.028  1.028
          season 3:  0.078  0.102  0.115  0.111  0.111
          season 4:  0.000  0.000  0.000  0.000  0.000

2005-2019 season 1:      0  0.000  0.000  0.000  0.000
          season 2:      0  0.584  1.377  1.757  1.757
          season 3:  0.001  0.013  0.026  0.033  0.033
          season 4:  0.000  0.000  0.000  0.000  0.000

S. sandeel
1974-2004 season 1:      0  0.000  0.000  0.000  0.000
          season 2:      0  0.633  1.103  1.314  1.314
          season 3:  0.012  0.096  0.169  0.201  0.201
          season 4:  0.000  0.000  0.000  0.000  0.000

2005-2019 season 1:      0  0.000  0.000  0.000  0.000
          season 2:      0  0.556  1.315  1.518  1.518
          season 3:  0.001  0.052  0.077  0.089  0.089
          season 4:  0.000  0.000  0.000  0.000  0.000

Nor. pout
1974-2002 season 1:      0  0.058  0.160  0.274
          season 2:      0  0.050  0.138  0.373
          season 3:  0.001  0.172  0.475  0.397
          season 4:  0.026  0.251  0.696  0.696

2003-2019 season 1:      0  0.002  0.009  0.017
          season 2:      0  0.018  0.084  0.137
          season 3:  0.000  0.108  0.502  0.615
          season 4:  0.006  0.226  1.052  1.052

Sprat
1974-2019 season 1:      0  0.021  0.148  0.259
          season 2:      0  0.000  0.000  0.000
          season 3:  0.000  0.288  0.428  0.364
          season 4:  0.000  0.284  0.831  0.831

Plaice
1974-1989 season 1:      0  0.119  0.229  0.252  0.268  0.265  0.236  0.188  0.188  0.188
          season 2:      0  0.119  0.229  0.252  0.268  0.265  0.236  0.188  0.188  0.188
          season 3:  0.000  0.119  0.229  0.252  0.268  0.265  0.236  0.188  0.188  0.188
          season 4:  0.000  0.119  0.229  0.252  0.268  0.265  0.236  0.188  0.188  0.188

1990-2002 season 1:      0  0.053  0.191  0.225  0.258  0.285  0.291  0.222  0.222  0.222
          season 2:      0  0.053  0.191  0.225  0.258  0.285  0.291  0.222  0.222  0.222
          season 3:  0.000  0.053  0.191  0.225  0.258  0.285  0.291  0.222  0.222  0.222
          season 4:  0.000  0.053  0.191  0.225  0.258  0.285  0.291  0.222  0.222  0.222

2003-2019 season 1:      0  0.076  0.213  0.232  0.260  0.277  0.269  0.230  0.230  0.230
          season 2:      0  0.076  0.213  0.232  0.260  0.277  0.269  0.230  0.230  0.230
          season 3:  0.000  0.076  0.213  0.232  0.260  0.277  0.269  0.230  0.230  0.230
          season 4:  0.000  0.076  0.213  0.232  0.260  0.277  0.269  0.230  0.230  0.230

Sole
1974-1989 season 1:      0  0.001  0.109  0.308  0.322  0.264  0.246  0.194  0.194  0.194
          season 2:      0  0.001  0.109  0.308  0.322  0.264  0.246  0.194  0.194  0.194
          season 4:  0.000  0.001  0.109  0.308  0.322  0.264  0.246  0.194  0.194  0.194

1990-2019 season 1:      0  0.009  0.109  0.248  0.301  0.308  0.283  0.253  0.253  0.253
          season 2:      0  0.009  0.109  0.248  0.301  0.308  0.283  0.253  0.253  0.253
          season 3:  0.000  0.009  0.109  0.248  0.301  0.308  0.283  0.253  0.253  0.253
          season 4:  0.000  0.009  0.109  0.248  0.301  0.308  0.283  0.253  0.253  0.253


sqrt(catch variance) ~ CV:
--------------------------

Cod
 1       0.611
 2       0.146
 3       0.146
 4       0.146
 5       0.146
 6       0.146
 7       0.233
```

8	0.233
9	0.450
10	0.450

Whiting

0	1.125
1	0.447
2	0.139
3	0.139
4	0.139
5	0.279
6	0.279
7	0.492
8	0.492

Haddock

0	0.824
1	0.512
2	0.244
3	0.244
4	0.244
5	0.244
6	0.397
7	0.397
8	0.637
9	0.637
10	0.637

Saithe

3	0.464
4	0.464
5	0.189
6	0.189
7	0.189
8	0.249
9	0.249
10	0.249

Mackerel

1	0.408
2	0.420
3	0.198
4	0.198
5	0.198
6	0.198
7	0.198
8	0.198
9	0.198
10	0.198

Herring

	season			
age	1	2	3	4
0			0.897	0.922
1	0.852	0.682	0.690	0.611
2	0.852	0.682	0.690	0.611
3	0.852	0.682	0.690	0.611
4	0.852	0.682	0.690	0.611
5	0.852	0.682	0.690	0.611
6	0.852	0.682	0.690	0.611
7	0.852	0.682	0.690	0.611
8	0.961	0.743	0.310	0.929

N. sandeel

	season			
age	1	2	3	4
0			1.352	
1		0.557	1.290	
2		0.557	1.290	
3		0.557	1.290	
4		1.142	1.297	

S. sandeel

	season			
age	1	2	3	4
0			1.414	
1		0.453	1.086	
2		0.453	1.086	
3		0.453	1.086	
4		0.453	1.086	

Nor. pout

```
             season
-------------------------------------
age        1       2       3       4

 0                       1.414   1.247
 1       0.911   0.701   0.558   0.729
 2       0.911   0.701   0.558   0.729
 3       1.414   1.149   1.170   1.414

Sprat
             season
-------------------------------------
age        1       2       3       4

 1       1.122           0.868   0.709
 2       1.122           0.868   0.709
 3       1.221           1.020   1.287

Plaice
 1       0.386
 2       0.170
 3       0.186
 4       0.186
 5       0.186
 6       0.186
 7       0.186
 8       0.186
 9       0.186
10       0.186

Sole
 1       1.414
 2       0.411
 3       0.180
 4       0.180
 5       0.180
 6       0.180
 7       0.180
 8       0.180
 9       0.180
10       0.180


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 IBTS Q1 gam                    0.806  4.617  9.725 10.702 10.702
 COD IBTS Q3 gam                    2.998  5.780  7.947  9.229
Whiting
 WHG IBTS-Q1 1974-1988              0.826  2.640  3.291  2.843  2.843
 WHG IBTS-Q1 1989-                  1.847  5.879  6.352  5.427  5.427
 WHG IBTS-Q3                 0.718  5.543  6.222  5.026  5.131  5.131
Haddock
 HAD IBTS Q1 1974-1988              0.155  0.428  0.421  0.421  0.421
 HAD IBTS Q1 1988-                  0.306  0.853  0.801  0.801  0.801
 HAD IBTS Q3                 0.137  0.536  0.606  0.606  0.606  0.606
Saithe
 POK N with noise                                 0.985  0.985  0.985  0.985  0.985  0.985
Mackerel
 MAC Swept area                                   0.634  0.954  1.520  1.520  1.520  1.520
 MAC N with noise                   1.013  1.013  1.013  1.013  1.013  1.013  1.013  1.013
Herring
 HER HERAS                          1.359  1.199  1.381  1.381  1.381  1.381  1.381
 HER IBTS-Q1                       13.991
 HER IBTS0                   0.422
N. sandeel
 NSA dredge                  0.510  0.443  0.809
 NSA Commercial 1982-1998           0.671  0.942  0.770
 NSA Commercial 1999-2019           0.896  1.821  2.590
 NSA Commercial 1976-2004 2  1.813
 NSA  acoustic SA 1R                1.246  2.829  3.768  3.768
S. sandeel
 SSA SSA dredge             18.896 10.180  8.111
 SSA Commercial 1982-1998           0.402  0.926  1.078
 SSA Commercial 1999-2004           0.830  0.755  0.928
 SSA Commercial 1994-2009           1.574  2.346  2.987
 SSA Commercial 2010-2019           0.648  1.812  2.722
Nor. pout
 NOP EGFSQ3                  0.376  3.270
 NOP IBTSQ1                         1.021  3.323  8.567
 NOP IBTSQ3                                5.552  8.360
 NOP SGFSQ3                  0.761  3.196
Sprat
 SPR Acoustic                      11.504 24.264 42.674
 SPR IBTS Q1                        4.522 12.884 18.536
 SPR IBTS Q3                        8.646 10.405  7.077
Plaice
```

```
 PLE BTS Isis                    2.875  2.659  1.228  0.282  0.282  0.282  0.282  0.282
 PLE BTS Combined                6.940  6.313  5.153  5.417  5.417  5.417  5.417  5.417
5.417
 PLE SNS1                        3.278  1.747  0.527  0.141  0.032  0.032
 PLE SNS2                       17.552  4.522  2.062  0.904  0.904  0.904
 PLE IBTS Q3                     3.212  9.416 14.455 17.222 28.733 28.733 28.733 28.733
 PLE IBTS Q1                     1.819  9.700 19.644 23.498 27.737 27.737 27.737
Sole
 SOL SNS                  6.657 18.612  7.284  2.346  2.346  2.346  2.346
 SOL BTS                         2.906  2.411  1.859  1.546  1.546  1.546  1.546  1.546
 SOL ISIS                        1.381  1.395  0.869  0.499  0.499  0.499  0.499  0.499

sqrt(Survey variance) ~ CV:
---------------------------
Cod                        age 0  age 1  age 2  age 3  age 4  age 5  age 6  age 7  age 8+
 COD IBTS Q1 gam                   0.60   0.31   0.31   0.31   0.31
 COD IBTS Q3 gam                   0.48   0.33   0.33   0.33
Whiting
 WHG IBTS-Q1 1974-1988             0.42   0.47   0.47   0.47   0.47
 WHG IBTS-Q1 1989-                 0.42   0.36   0.36   0.36   0.36
 WHG IBTS-Q3                0.74   0.37   0.33   0.33   0.33   0.33
Haddock
 HAD IBTS Q1 1974-1988             0.43   0.40   0.40   0.40   0.40
 HAD IBTS Q1 1988-                 0.45   0.43   0.43   0.43   0.43
 HAD IBTS Q3                0.52   0.28   0.28   0.46   0.46   0.46
Saithe
 POK N with noise                                0.50   0.50   0.50   0.50   0.50   0.50
Mackerel
 MAC Swept area                                  0.39   0.39   0.39   0.51   0.51   0.51
 MAC N with noise                  0.56   0.56   0.56   0.56   0.56   0.56   0.56   0.56
Herring
 HER HERAS                         0.51   0.23   0.29   0.29   0.29   0.29   0.29
 HER IBTS-Q1                       0.33
 HER IBTS0                  0.38
N. sandeel
 NSA dredge                 0.66   0.61   0.61
 NSA Commercial 1982-1998          0.62   0.62   0.62
 NSA Commercial 1999-2019          0.79   0.53   0.53
 NSA Commercial 1976-2004 2 1.19
 NSA  acoustic SA 1R               0.81   0.81   0.81   0.86
S. sandeel
 SSA SSA dredge             0.43   0.81   0.81
 SSA Commercial 1982-1998          0.59   0.43   0.43
 SSA Commercial 1999-2004          0.20   0.20   0.20
 SSA Commercial 1994-2009          0.20   0.20   0.20
 SSA Commercial 2010-2019          0.52   0.52   0.52
Nor. pout
 NOP EGFSQ3                 0.87   0.45
 NOP IBTSQ1                        0.51   0.37   0.37
 NOP IBTSQ3                               0.50   0.87
 NOP SGFSQ3                 0.74   0.36
Sprat
 SPR Acoustic                      0.51   0.51   0.51
 SPR IBTS Q1                       0.73   0.57   0.57
 SPR IBTS Q3                       0.43   0.24   0.24
Plaice
 PLE BTS Isis                      0.49   0.49   0.65   0.65   0.64   0.64   0.64   0.64
 PLE BTS Combined                  0.54   0.42   0.57   0.57   0.57   0.57   0.57   0.57
 PLE SNS1                          0.42   0.42   0.91   0.91   1.18   1.18
 PLE SNS2                          0.31   0.31   0.71   0.71   1.16   1.16
 PLE IBTS Q3                       0.48   0.38   0.59   0.59   0.59   0.59   0.59   0.59
 PLE IBTS Q1                       0.34   0.34   0.29   0.29   0.33   0.33   0.33
Sole
 SOL SNS                    1.41   0.60   0.66   0.66   1.09   1.09   1.09
 SOL BTS                           0.49   0.38   0.38   0.38   0.42   0.42   0.71   0.71
 SOL ISIS                          0.50   0.52   0.52   0.52   0.69   0.69   1.33   1.33


Recruit-SSB                                alfa      beta        var       sd
Cod          Hockey stick -break.:      126.893   1.070e+05   0.281     0.530
Whiting      Hockey stick -break.:      136.683   1.200e+05   0.075     0.273
Haddock      Hockey stick -break.:       37.544   9.400e+04   1.093     1.045
Saithe       Ricker:                      2.539   4.161e-06   0.183     0.428
Mackerel     Geometric mean:             15.309               0.221     0.471
Herring      Ricker:                     57.069   9.052e-07   0.258     0.508
N. sandeel   Ricker:                   2105.675   3.292e-06   0.437     0.661
S. sandeel   Ricker:                   1367.855   2.758e-06   0.447     0.669
Nor. pout    Hockey stick -break.:     1777.103   5.000e+04   0.314     0.560
Sprat        Hockey stick -break.:      901.554   9.400e+04   0.308     0.555
Plaice       Ricker:                      6.844   2.004e-06   0.123     0.351
Sole         Ricker:                      7.300   2.542e-05   0.396     0.629
```

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). As for all other retrospective assessment analysis, this analysis also shows that values (M2) in the terminal year of the time-series have larger uncertainties; however this uncertainty is not huge. The uncertainties in M2 seem mainly related to the retrospective patterns in stock numbers and not to the estimations of predation related parameters. Besides the last decade of M2 the time series of M2 are estimated consistently and independent of the terminal year in the analysis.

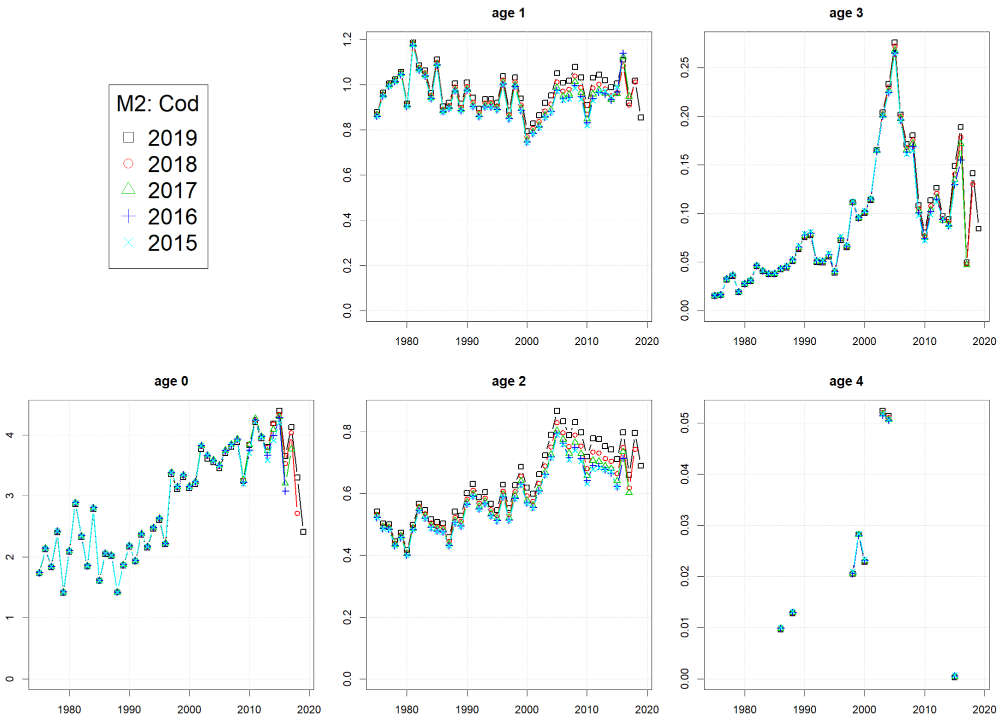

Figure 5.1.1 Retrospective analysis of M2 for cod.

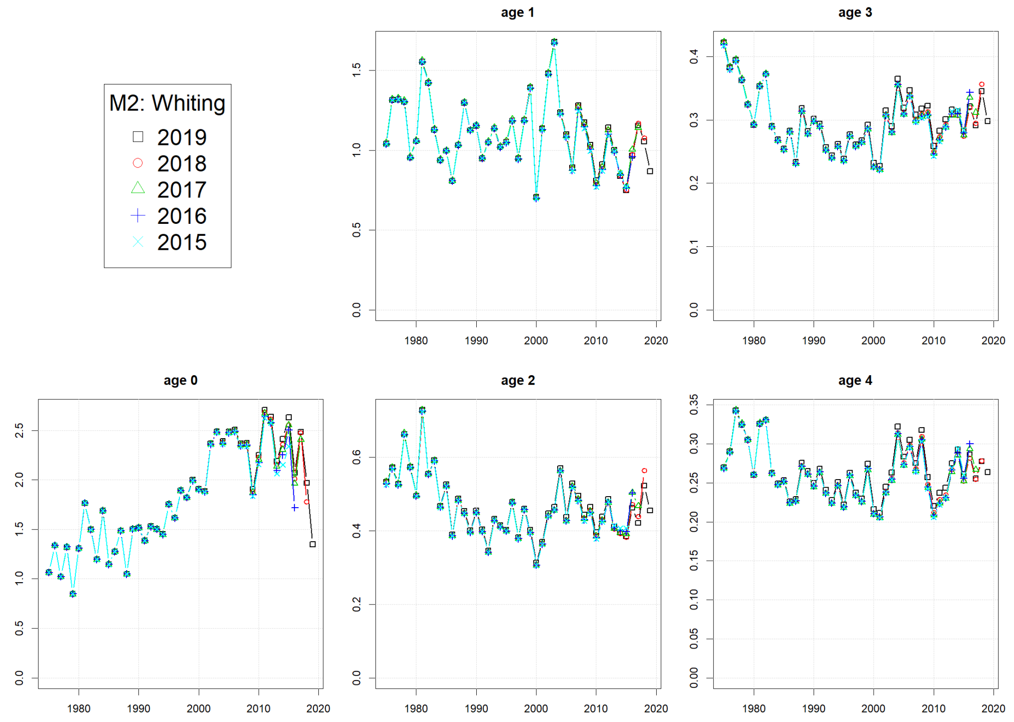

Figure 5.1.2. Retrospective analysis of M2 for whiting.

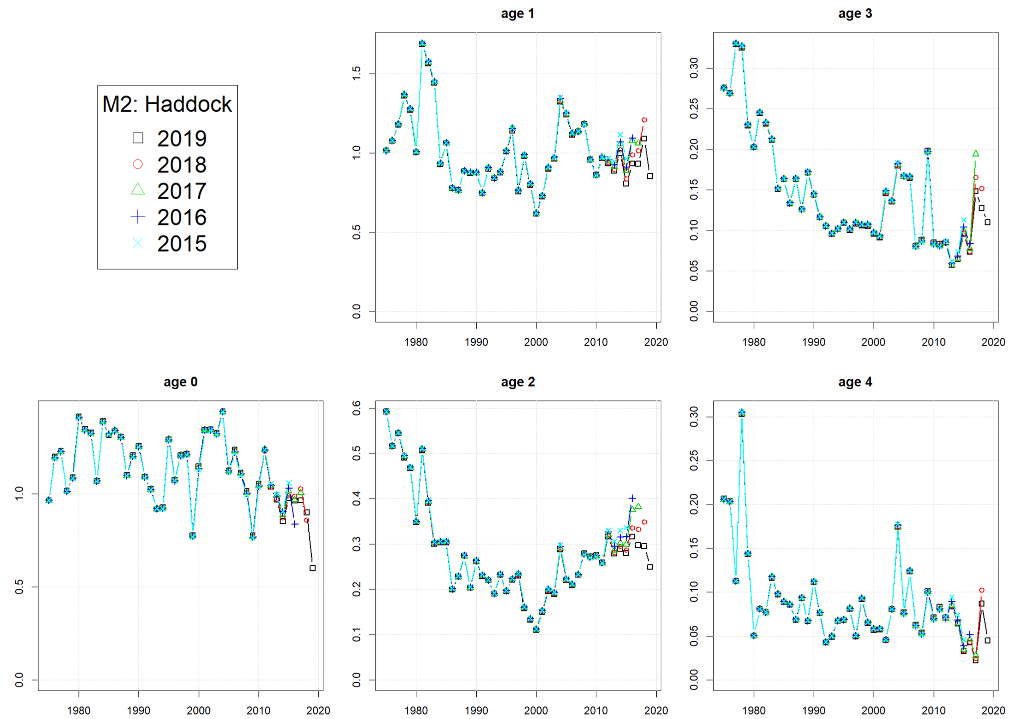

Figure 5.1.3. Retrospective analysis of M2 for haddock.

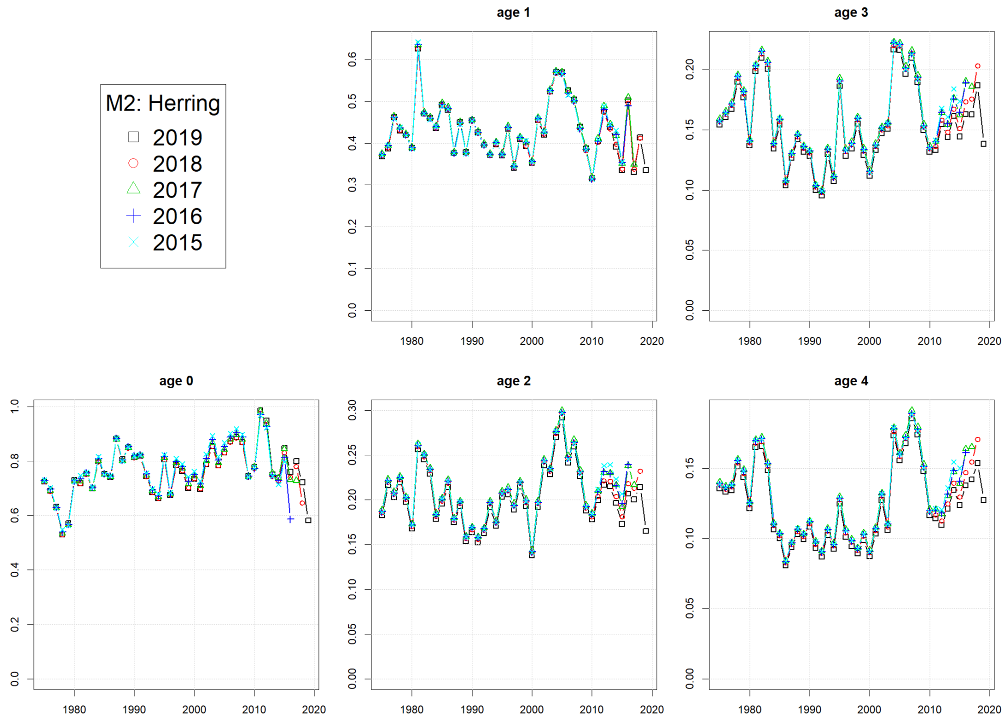

Figure 5.1.4. Retrospective analysis of M2 for herring.

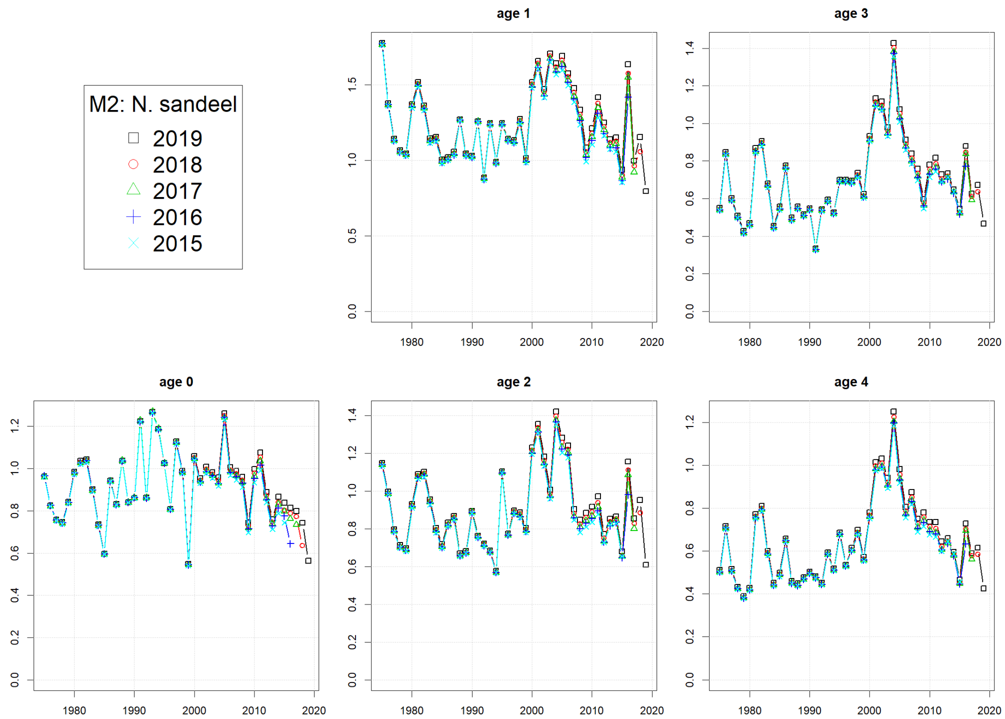

Figure 5.1.5. Retrospective analysis of M2 for northern sandeel

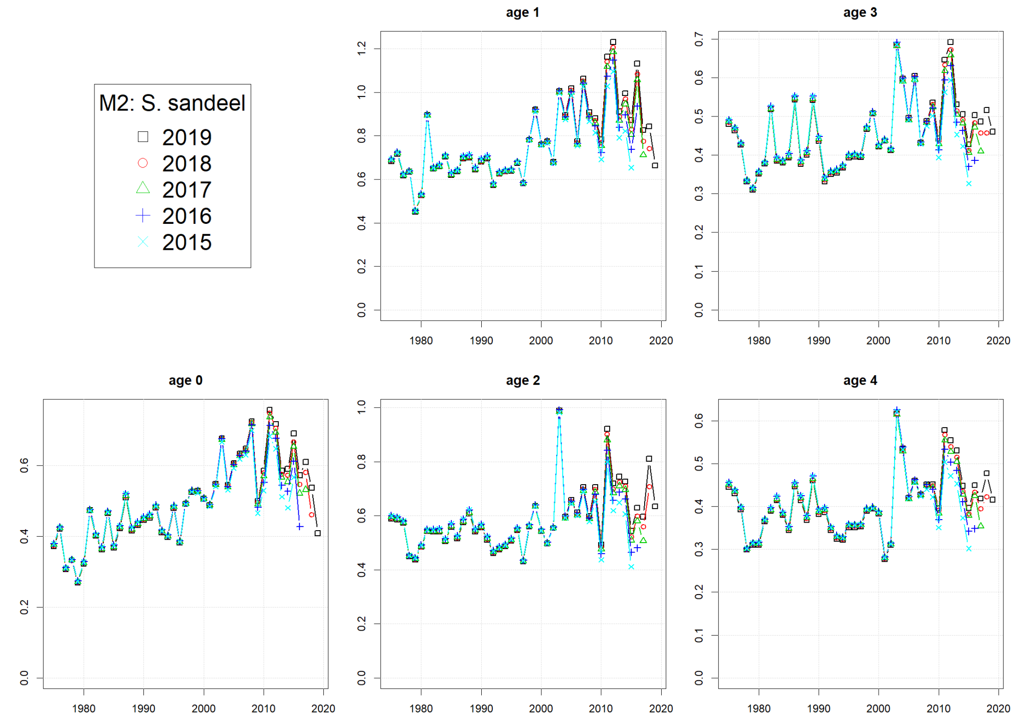

Figure 5.1.6. Retrospective analysis of M2 for southern sandeel.

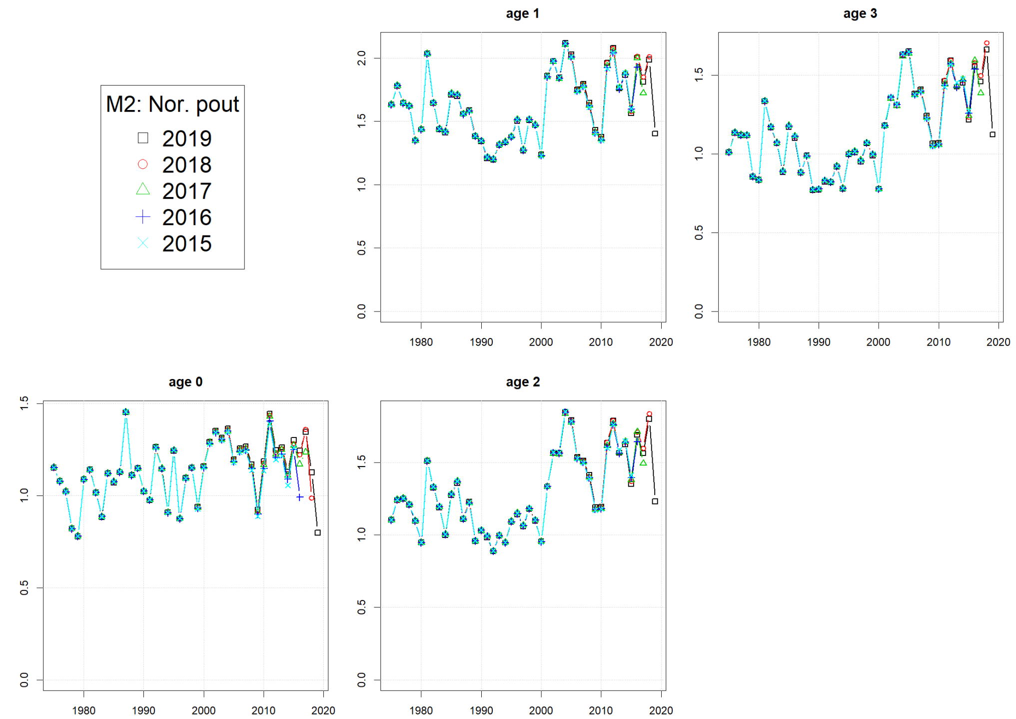

Figure 5.1.7. Retrospective analysis of M2 for Norway pout.

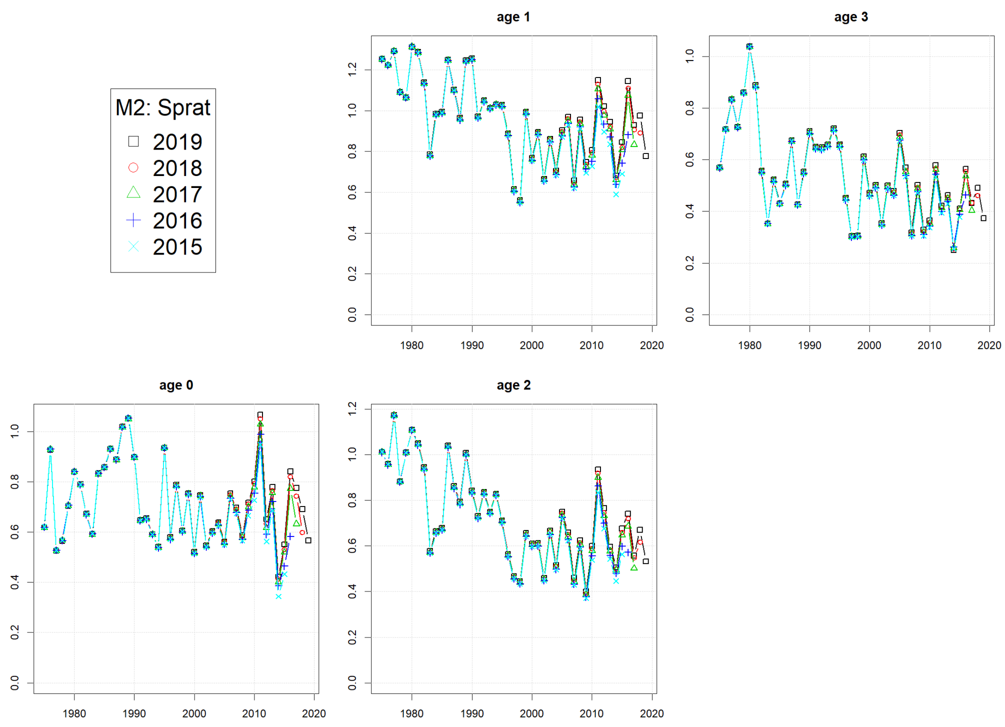

Figure 5.1.8. Retrospective analysis of M2 for sprat.

5.1.2 Stock summary results

The stock summaries are presented in Figure 5.1.9 to Figure 2.1.13.

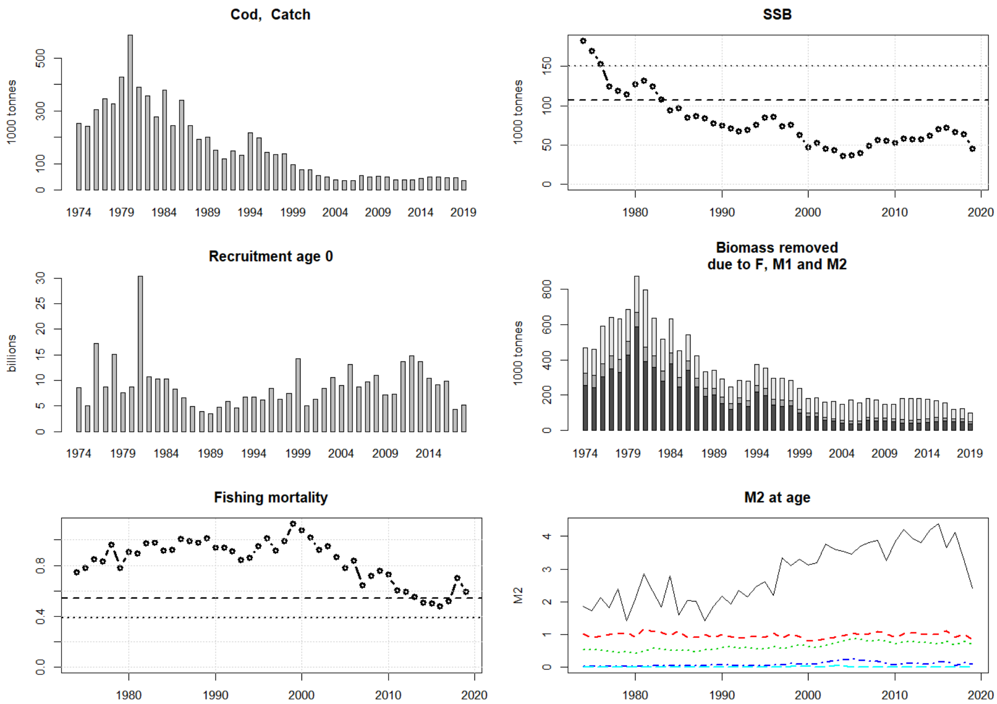

Figure 5.1.9. SMS output for cod. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

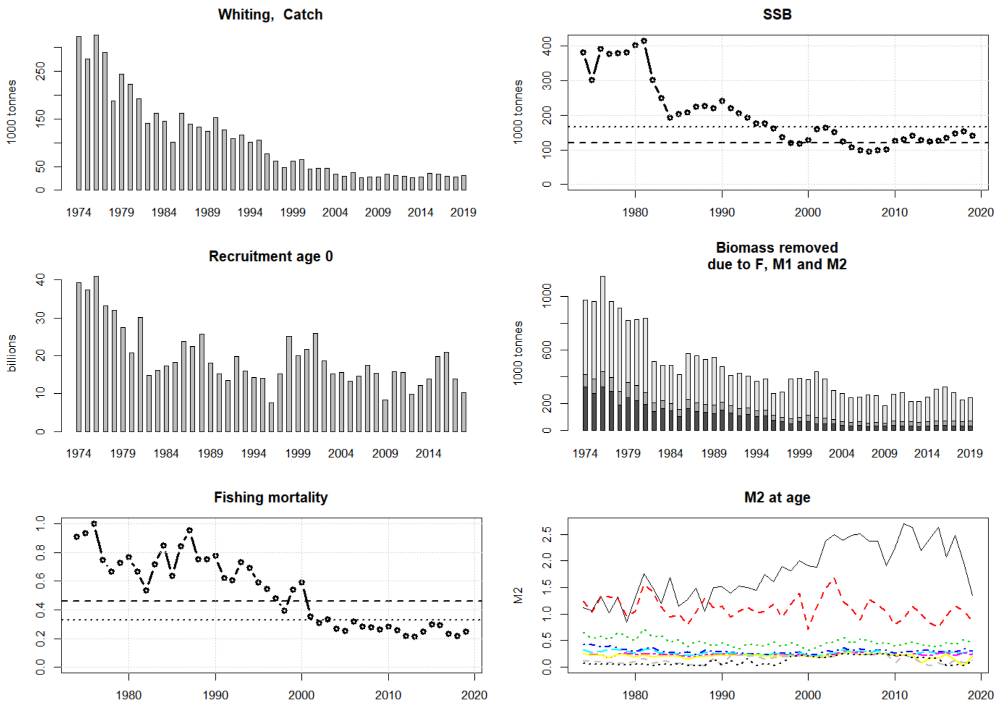

Figure 5.1.10. SMS output for whiting. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

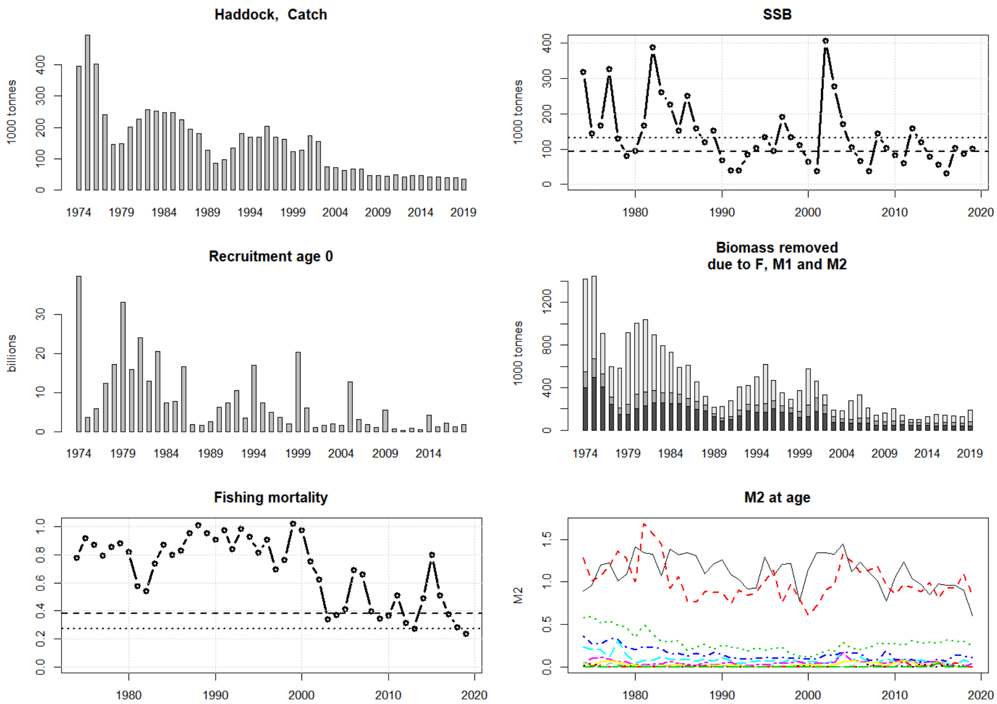

Figure 5.1.11. SMS output for haddock. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

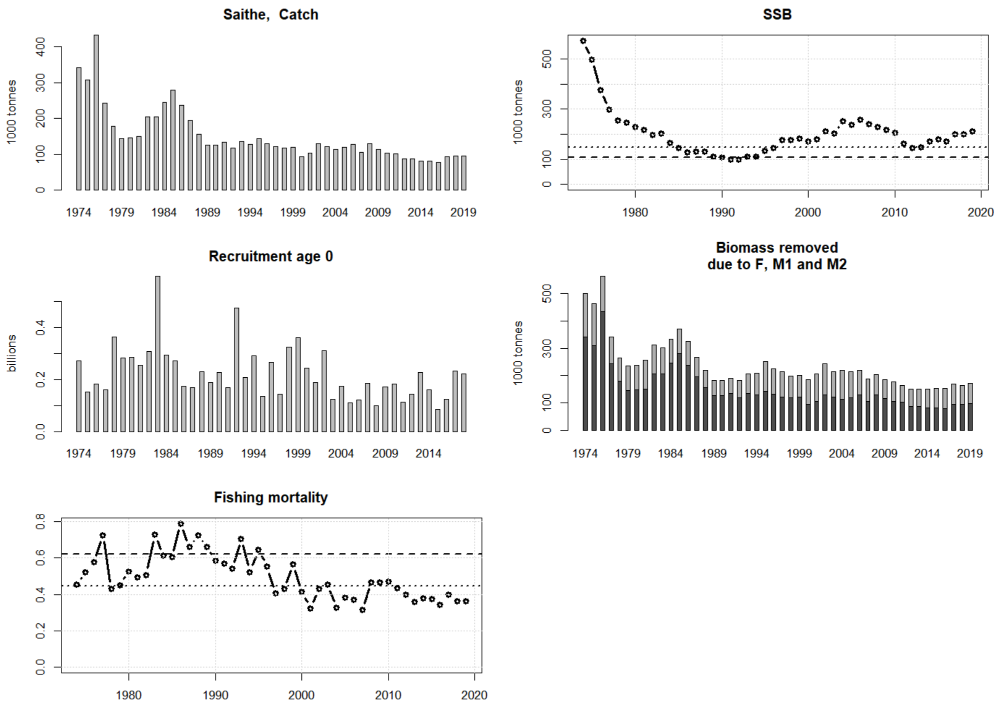

Figure 5.1.12. SMS output for saithe. Catch weight, Recruitment, F, SSB and Biomass removed due to fishery (F).

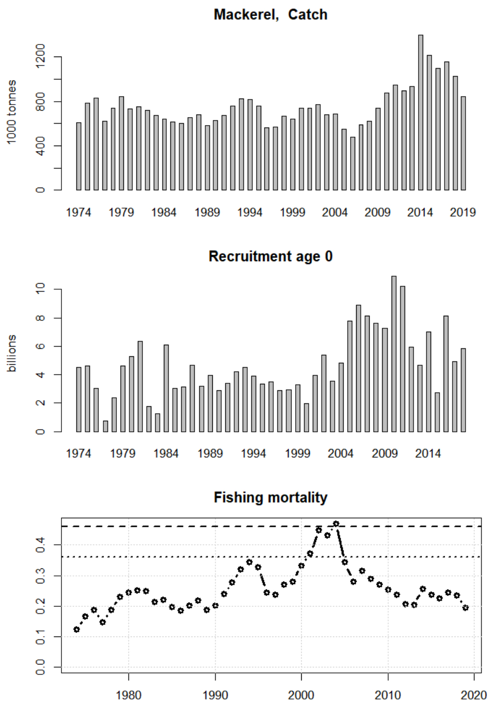

Figure 5.1.13. SMS output for Mackerel. Catch weight, Recruitment, F, SSB and Biomass removed due to fishery (F).

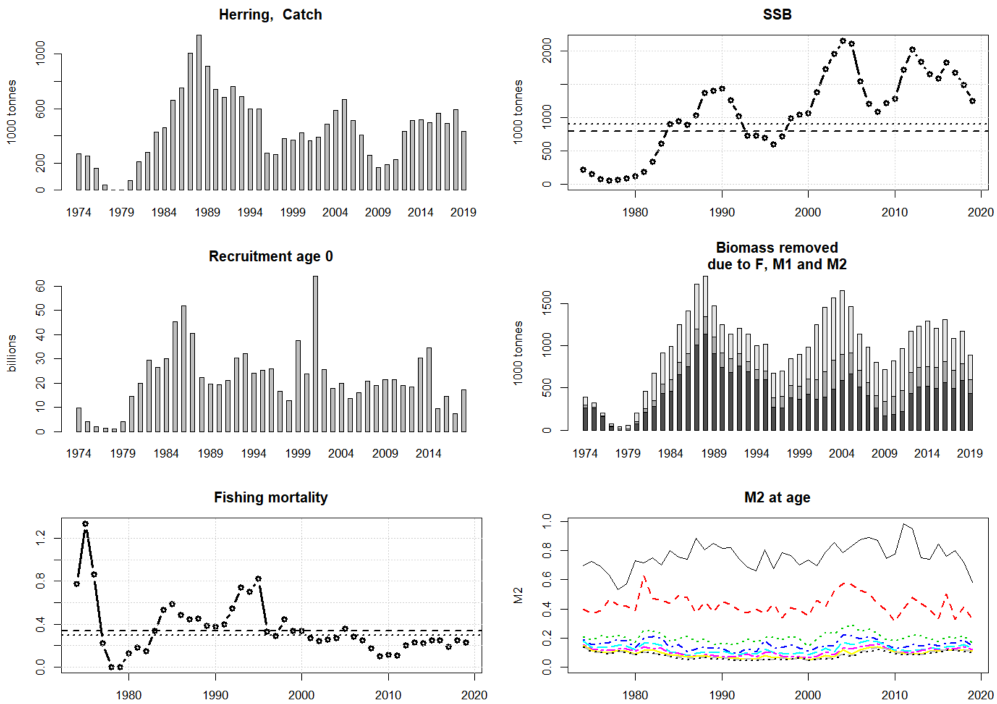

Figure 5.1.14. SMS output for Herring. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

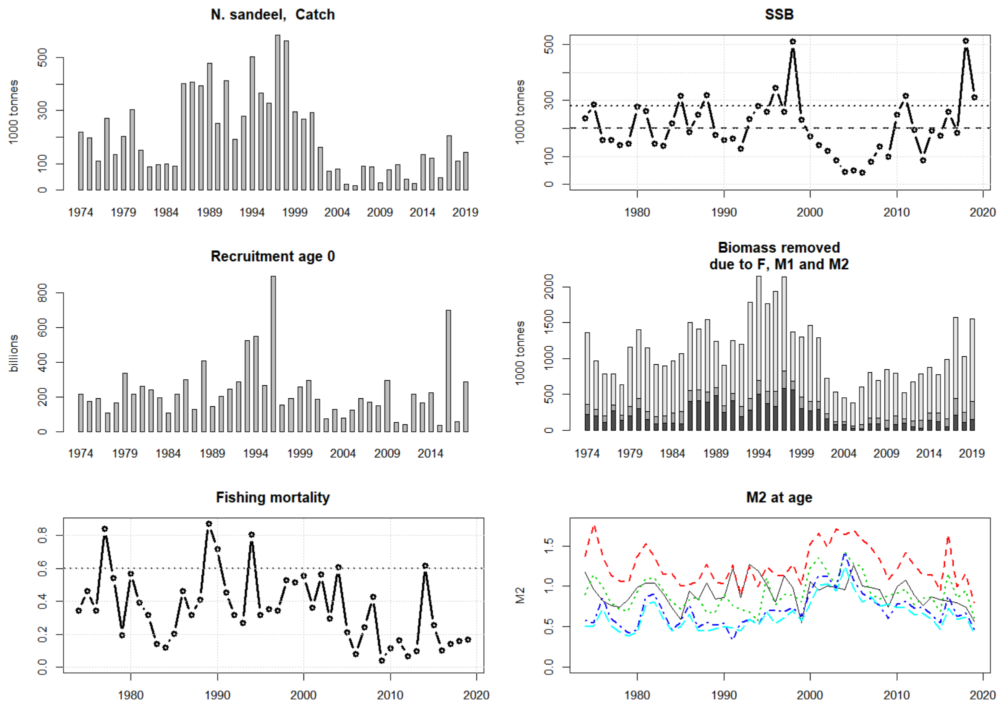

Figure 5.1.15. SMS output for Northern Sandeel. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

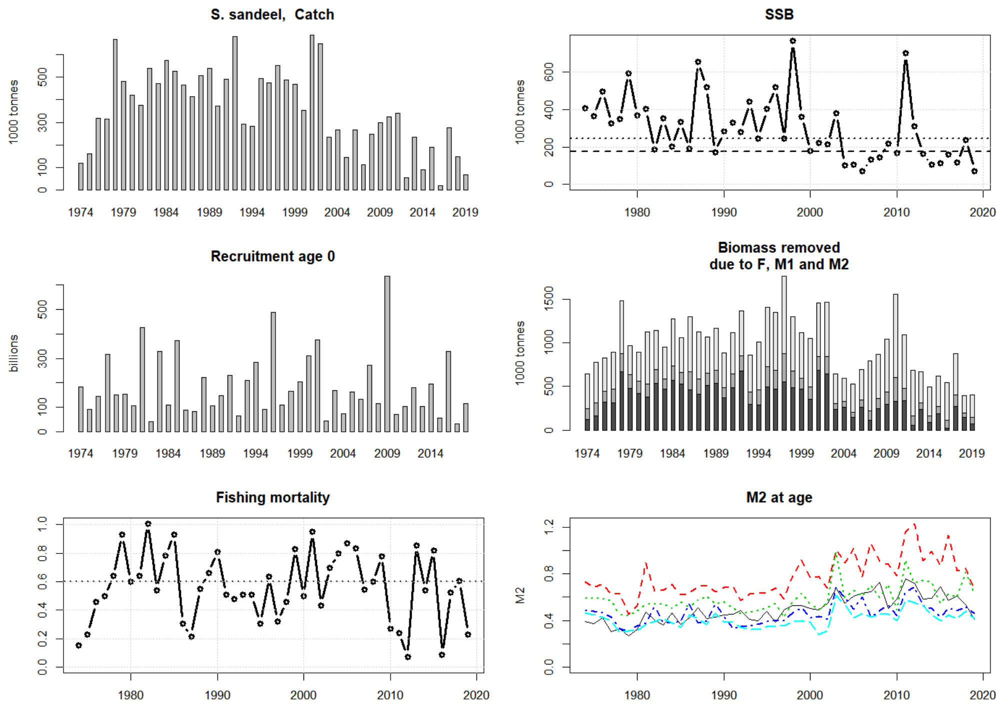

Figure 5.1.16. SMS output for Southern Sandeel. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

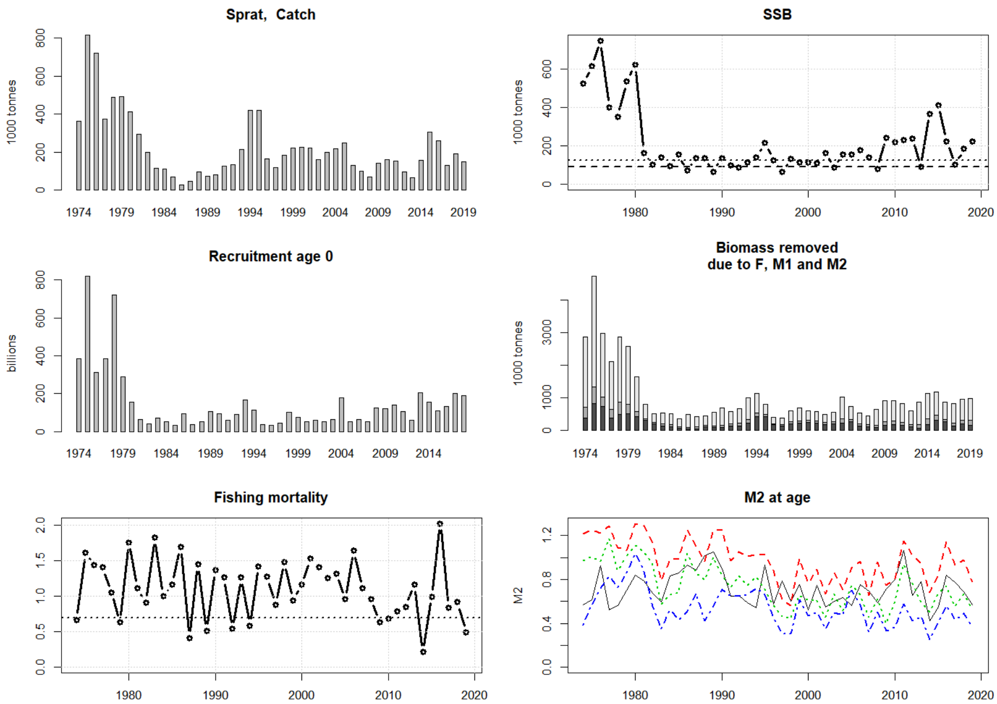

Figure 5.1.17. SMS output for Sprat. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

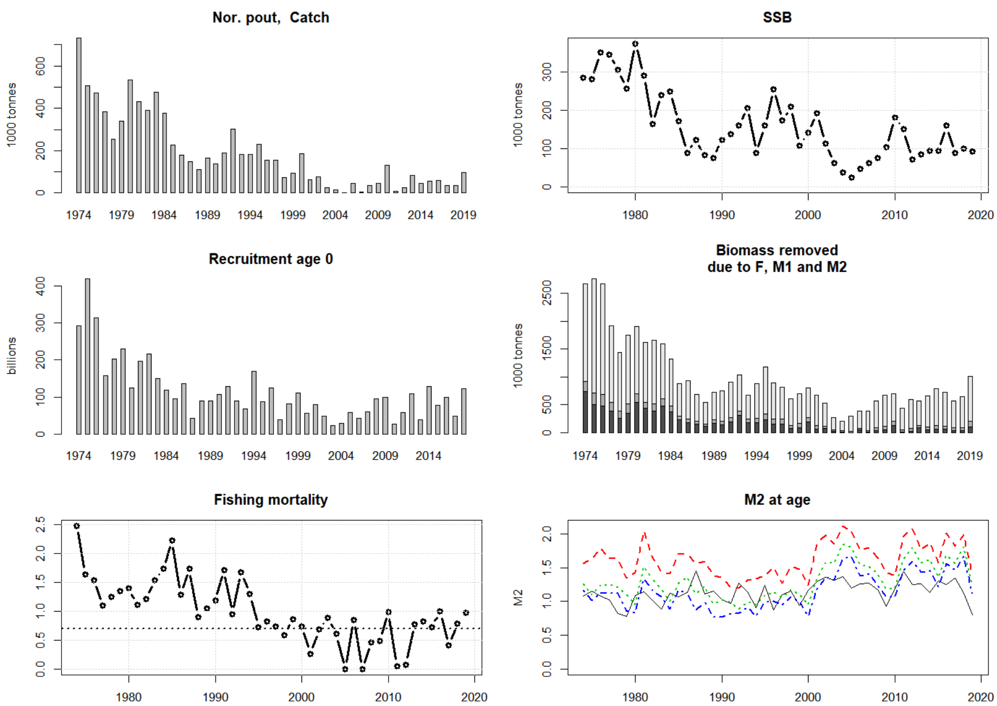

Figure 5.1.18. SMS output for Norway pout. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

5.1.3 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 5.1.19).

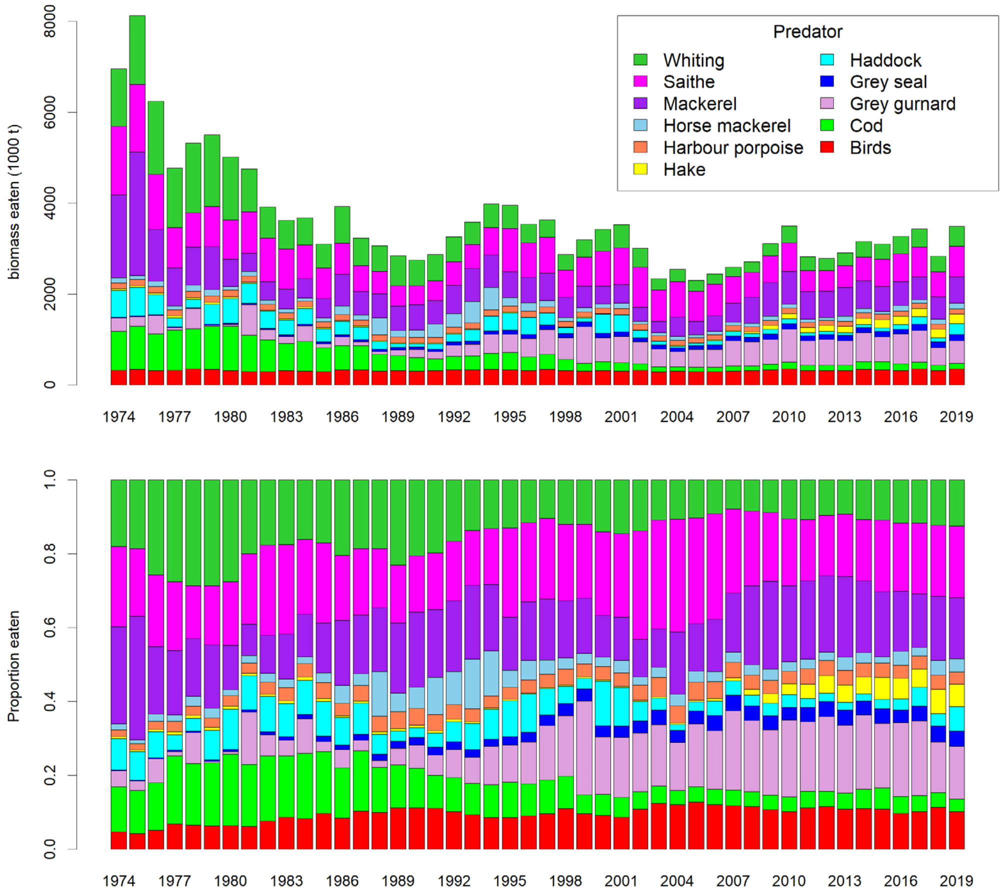

Figure 5.1.19. Eaten total biomass of all prey species by individual predator (groups). Upper figure shows the absolute weight eaten and the lower figure shows relative weight eaten.

Eaten biomass by prey

The eaten biomass of the individual SMS prey species (Figure 5.1.20) follows in general the prey stock sizes.

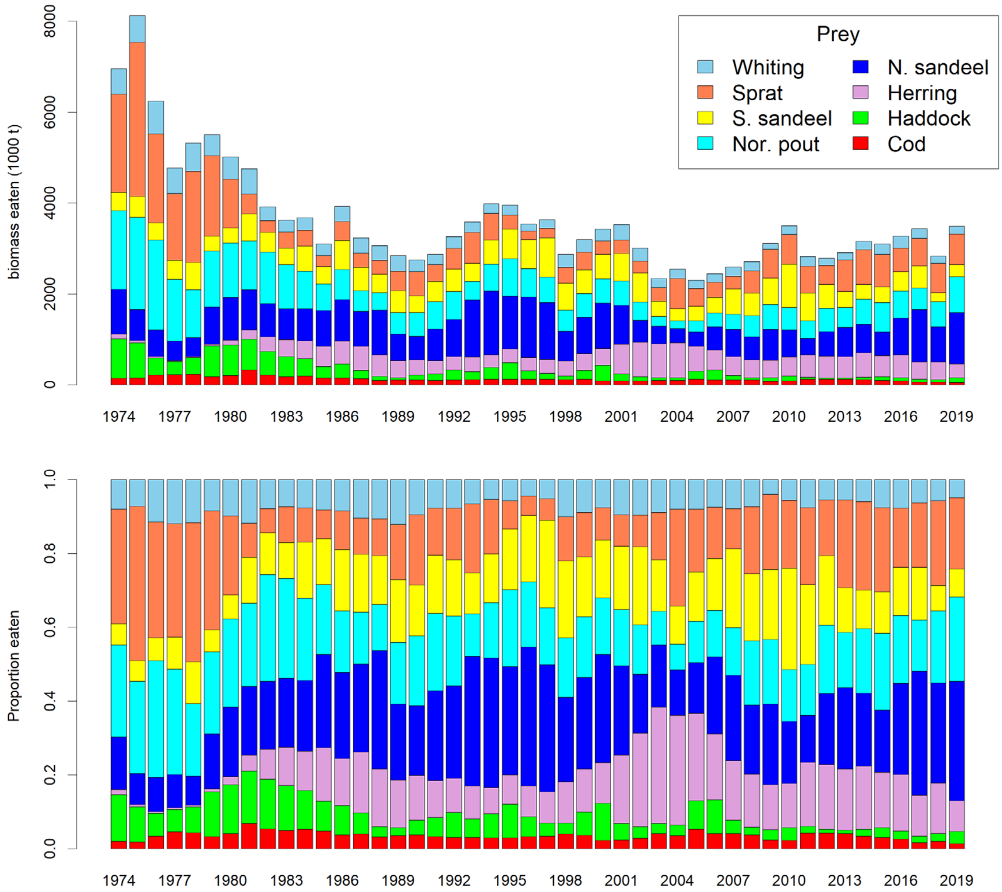

Figure 5.1.20. Eaten biomass of the individual prey species. Upper figure shows the absolute weight eaten and the lower figure shows relative weight eaten.

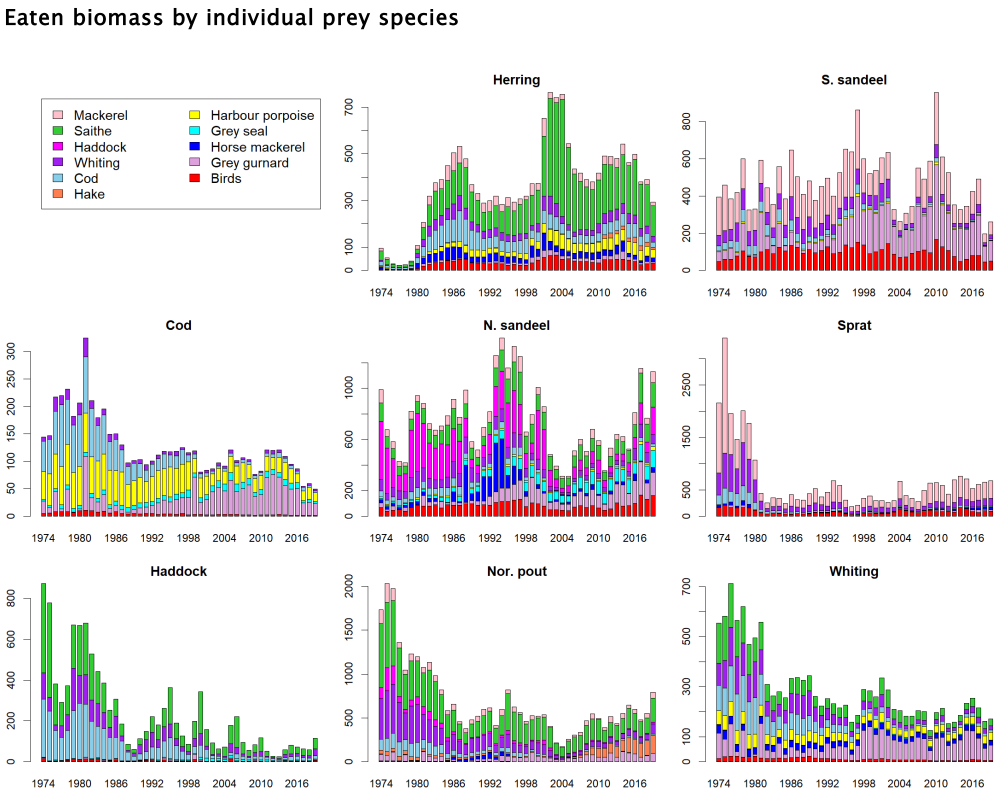

Figure 5.1.21. Eaten biomass (1000 tonnes) of the individual prey species by predator (groups).

5.1.4 Predation mortalities (M2)

The overall picture of M2 at-age (sum of quarterly M2 values) is highly variable between species (Figure 5.1.22). For cod and whiting, the steep increase in abundance of the predator grey gurnard has led to increase in M2 of 0-group fish in recent years. Further, mortality of 3-year old cod has increased substantially as a result of the recent increase in grey seal abundance. Haddock natural mortality particularly of age 2 fish has decreased over time with the decreased in the biomass of large cod and saithe. Herring M2 has been not clear temporal trend, but the contributions from the various predators changes over the years.

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 decrease in abundance of cod and whiting results in a small decrease in sprat M2.

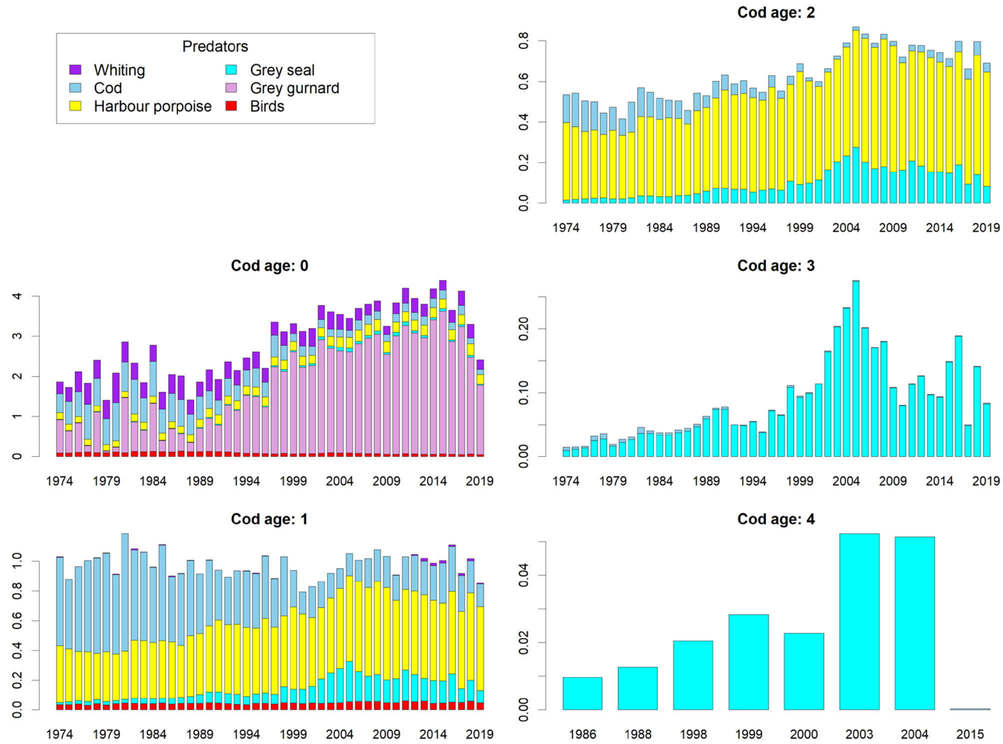

Figure 5.1.22 Predation mortality (M2) by prey species and age inflicted by predator species.

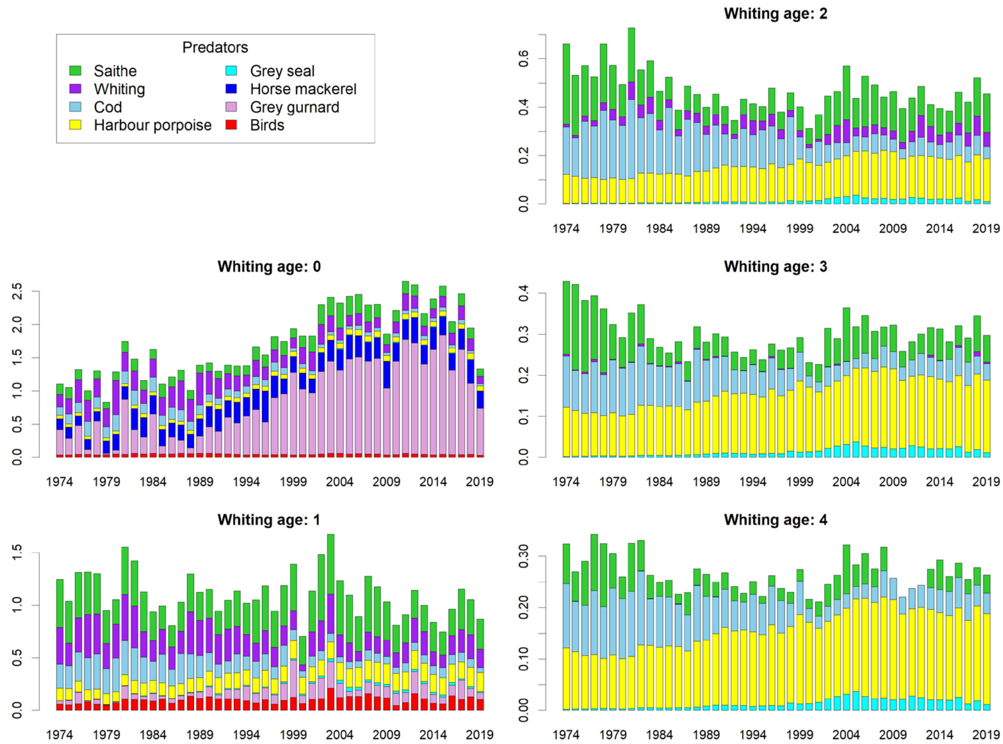

Figure 5.1.22. (Continued). Predation mortality (M2) by prey species and age inflicted by predator species.

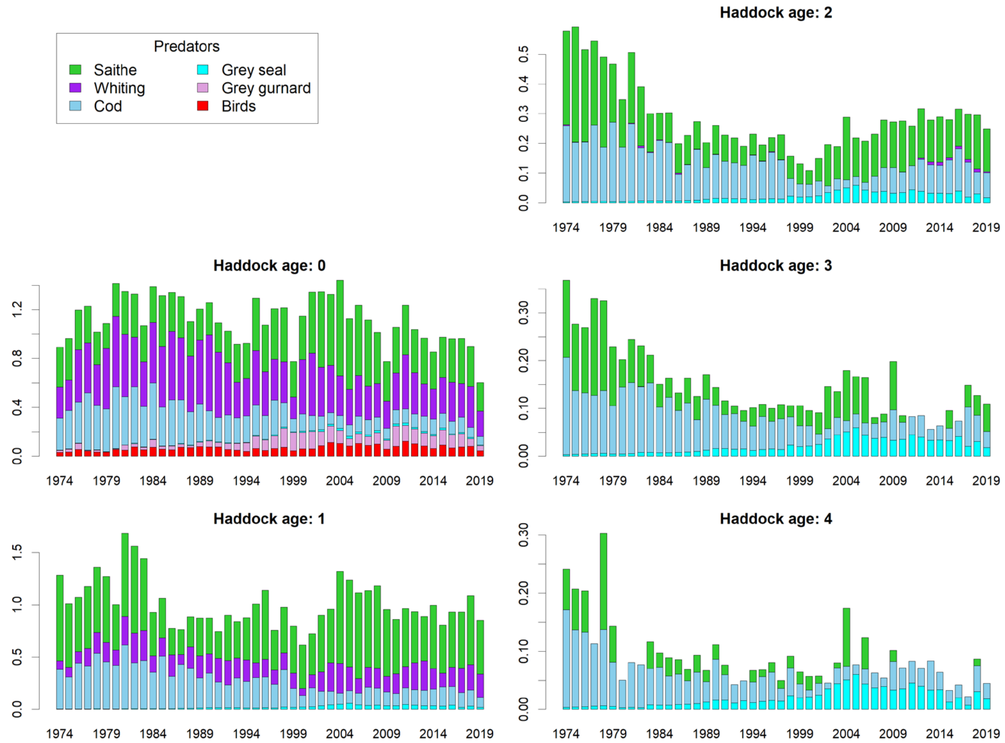

Figure 5.1.22. (Continued). Predation mortality (M2) by prey species and age inflicted by predator species.

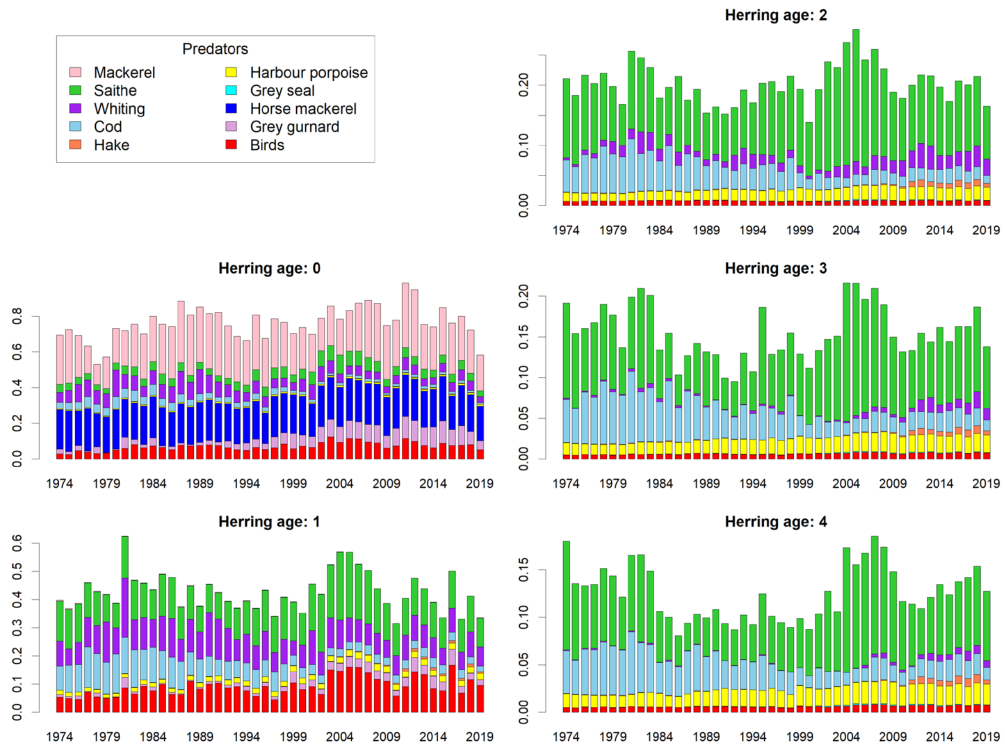

Figure 5.1.22. (Continued). Predation mortality (M2) by prey species and age inflicted by predator species.

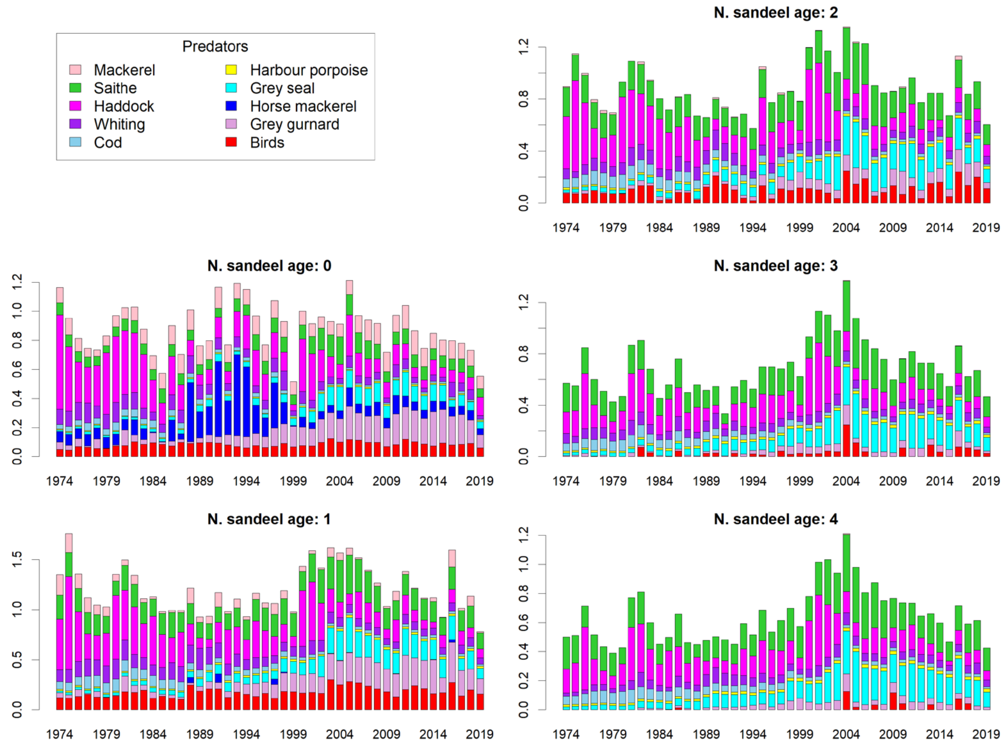

Figure 5.1.22. (Continued). Predation mortality (M2) by prey species and age inflicted by predator species.

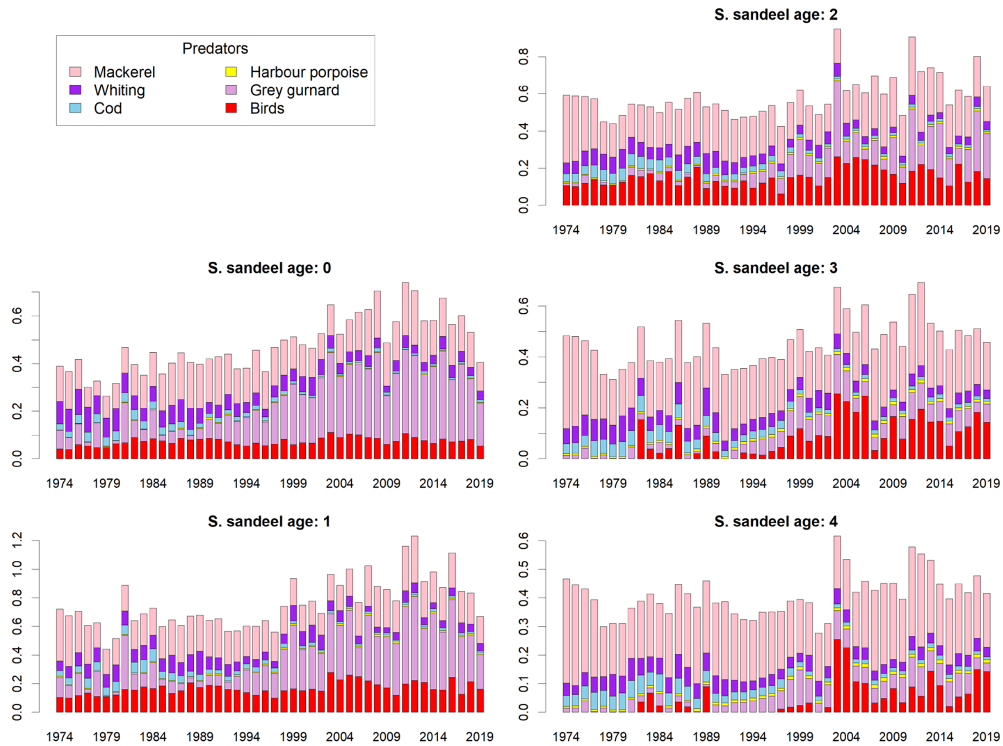

Figure 5.1.22. (Continued). Predation mortality (M2) by prey species and age inflicted by predator species.

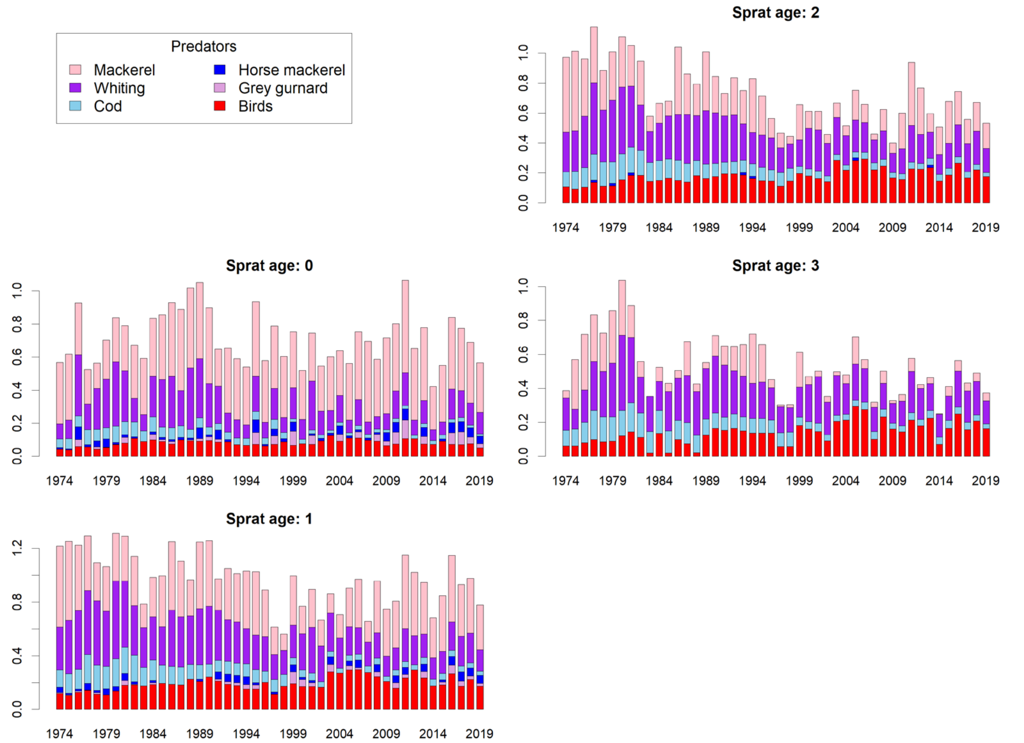

Figure 5.1.22. (Continued). Predation mortality (M2) by prey species and age inflicted by predator species.

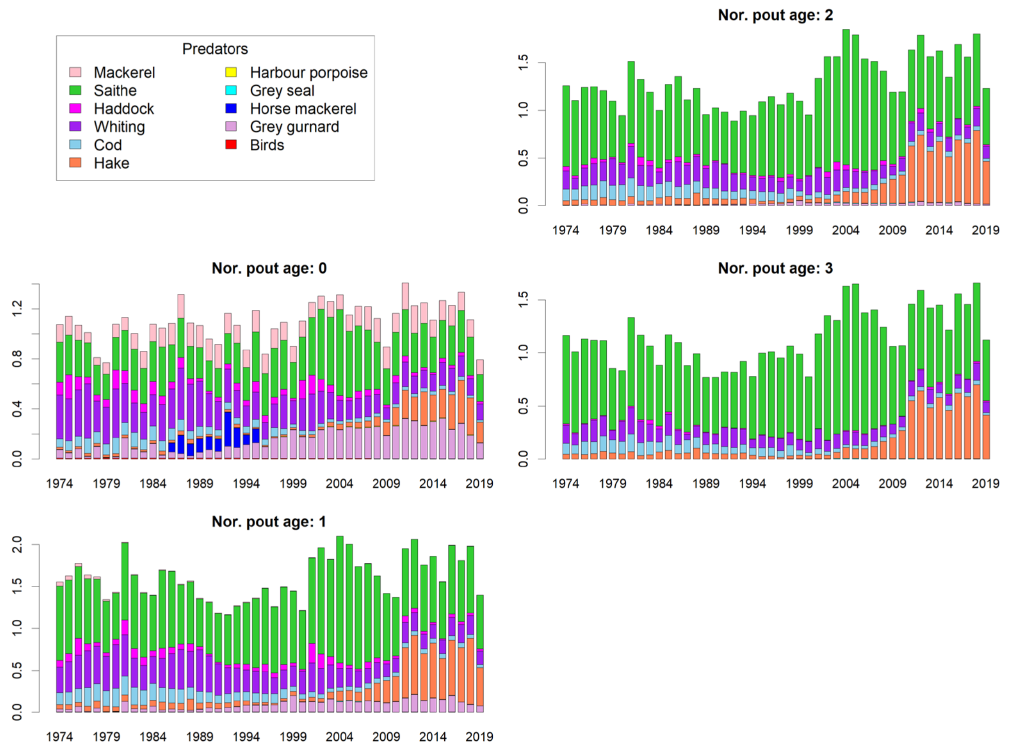

Figure 5.1.22. (Continued). Predation mortality (M2) by prey species and age inflicted by predator species.

5.1.5 Uncertainties of key output

SMS estimate the uncertainties of selected output variables using the Hessian delta-method approximation. Most variables like stock number and F for dynamic species are estimated within the model, while other variables like the stock numbers of "external predators" are assumed known without errors. This combination of estimated and assumed "known" variables will probably lead to an underestimate of the uncertainties of e.g. predation mortality. This section presents the uncertainties as estimated by SMS of SSB, mean F, recruitment and M2.

Uncertainties of SSB

The uncertainties presented as a Coefficient of Variation (standard deviation of the estimated value divided by the value itself) of SSB (Figure 5.1.23) show the highest uncertainties for the short lived and prey species Southern sandeel, Northern sandeel, sprat and slightly lower for Norway pout. The uncertainties for mackerel and for saithe seem too low, probably because of the use of stock numbers from the ICES assessment as artificial survey indices in SMS (see Section 2.1.6.2). A higher CV on the artificial cpue indices should probably have been used to better reflect the uncertainties in the SMS assessment!

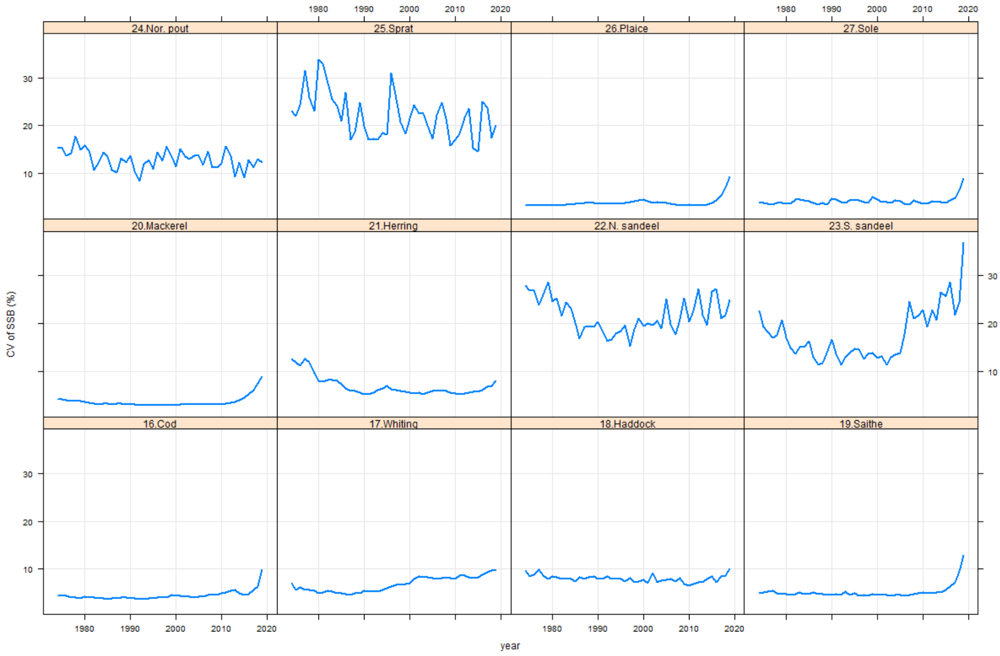

Figure 5.1.23. Uncertainties (1 sd / value) of estimated SSB as estimated by SMS.

Uncertainties of mean F

The uncertainties of mean F (mean of annual F for the most important ages classes in the catch) are in general high for the short lived species, sprat, sandeel and Norway pout, with few ages (i.e. age 1 and 2) in the calculation of mean F (Figure 5.1.24). The CV of mean F for the remaining long-lived species is typically in the range 5-10%.

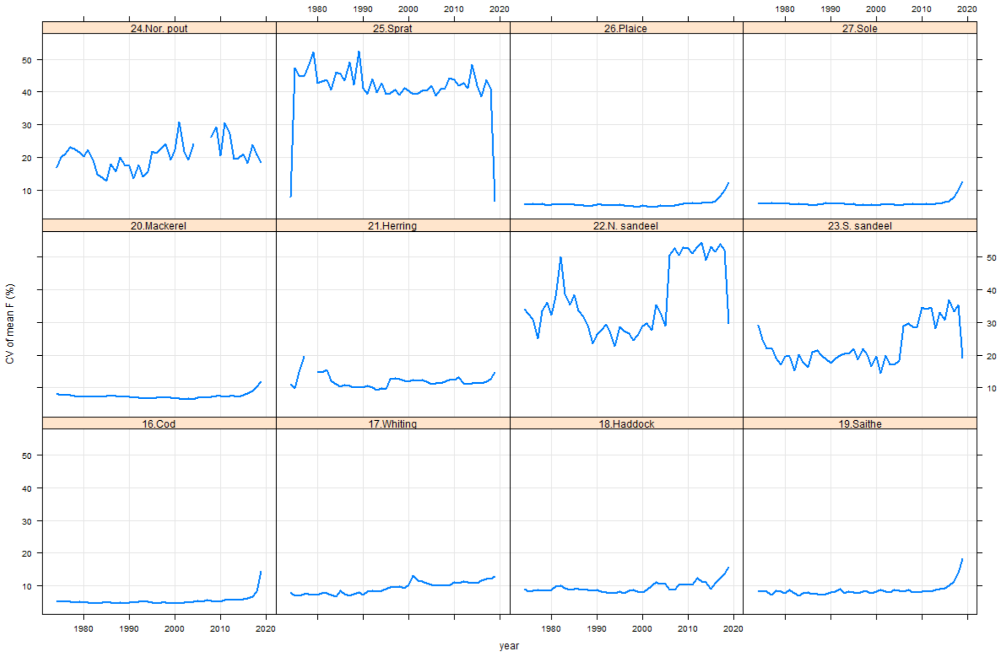

Figure 5.1.24. Uncertainties (1 sd / value) of estimated mean F as estimated by SMS.

Uncertainties of recruitment

The uncertainties of recruitment are very high (>50%) for the terminal year and high for the most recent years (Figure 5.1.25). Further back in time, the CV is highest for cod, the two sandeel stocks, sprat and whiting. For mackerel and saithe the CV seems too low as for SSB.

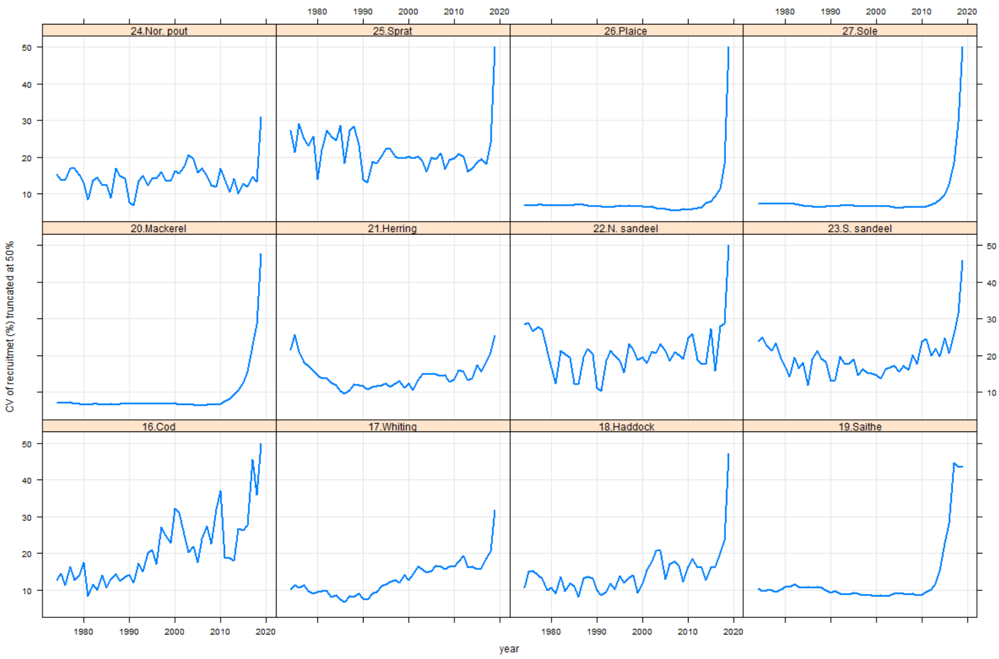

Figure 5.1.25. Uncertainties (1 sd / value) of estimated recruitment as estimated by SMS.

Uncertainties of Predation mortality (M2)

Ignoring the terminal year, the CVs of M2 are typically in the range 5–10% (Figure 5.1.26- 28), which is in the same range as CV of mean F for the predator species and CV of M2 at age is below the CV of mean F for prey species. For age 0 the CV of M2 increases significantly in the terminal years, due to the uncertainty on. CV is lowest for all ages for the prey species Norway pout and northern sandeel, which might be due to the (too) low uncertainty on abundance of their main predators, saithe and mackerel. Saithe is also a main predator on herring, but the CV on herring M2 is higher for all ages. CV of M2 is relatively high for cod ages 1 and 2. It is mainly cod itself, with a low uncertainty on stock abundance of older cod (SSB, Figure 5.1.23) and marine mammals, with stock abundance given as input, that predate on cod ages 1–2. The CV on M2 seems therefore mainly to arise from high uncertainties on the model parameters for predation from marine mammals and older cod.

Uncertainties presented as CV may give a biased impression for low values (of the “mean”). Figure 5.1.29 to Figure 5.1.31 show the estimated M2 vales for ages 0–2, with added lines for plus–minus 2 times the standard deviation. The overall picture is that the annual M2 at age values are statistically different between years for both examples of M2 without no temporal trend (e.g. ages 0–1 for Norway pout) and examples with a trend (e.g. cod age 0 and age 2).

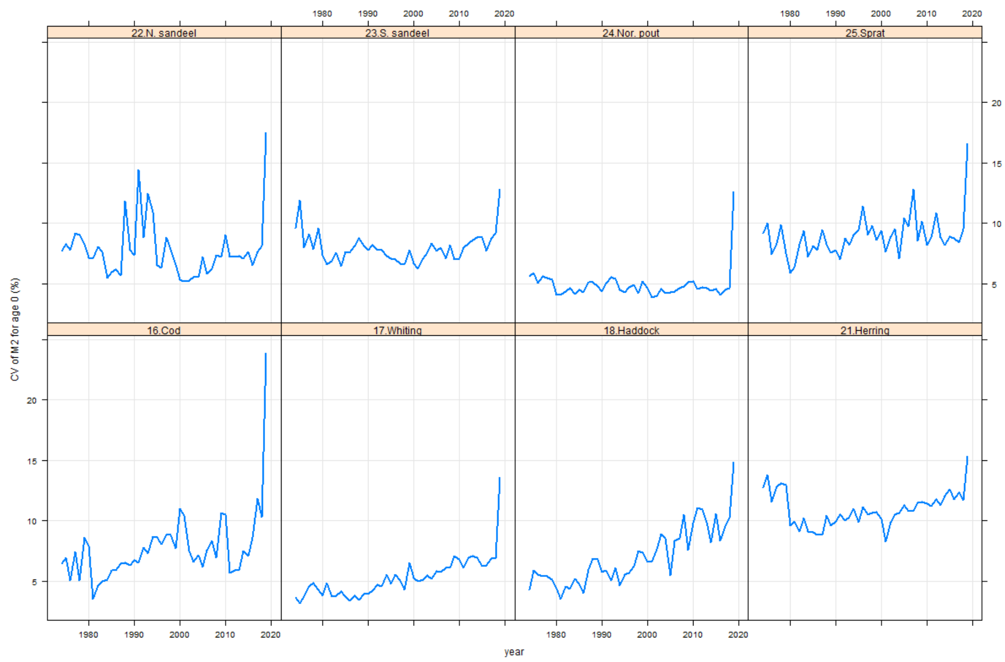

Figure 5.1.26. Age 0: M2 Uncertainties (1 sd / value) of estimated predation mortality (sum of quarterly M2) as estimated by SMS.

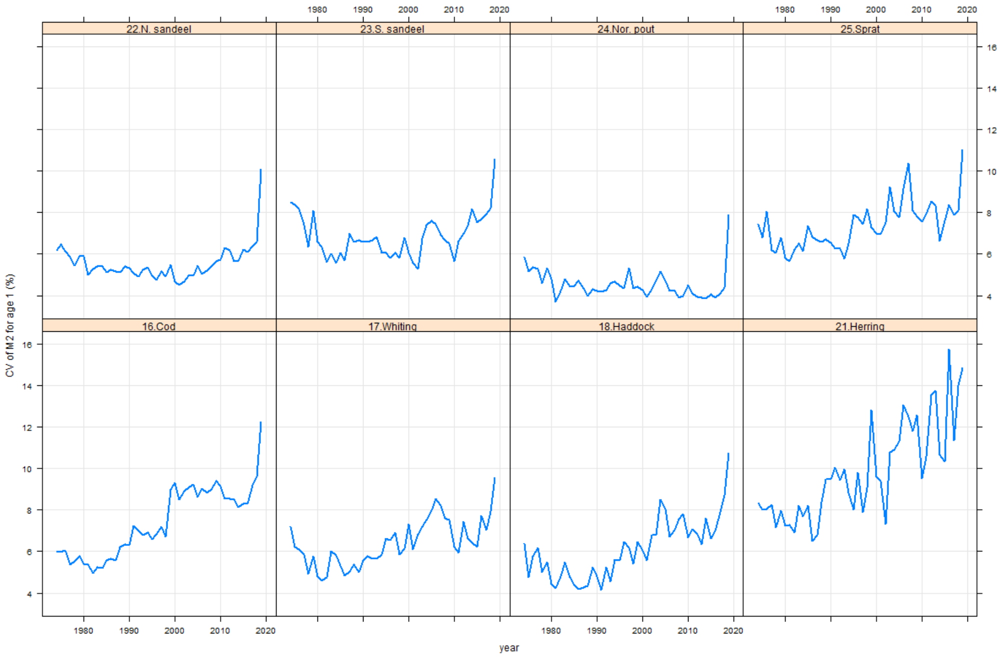

Figure 5.1.27. Age 1: M2 Uncertainties (1 sd / value) of estimated predation mortality (sum of quarterly M2) as estimated by SMS.

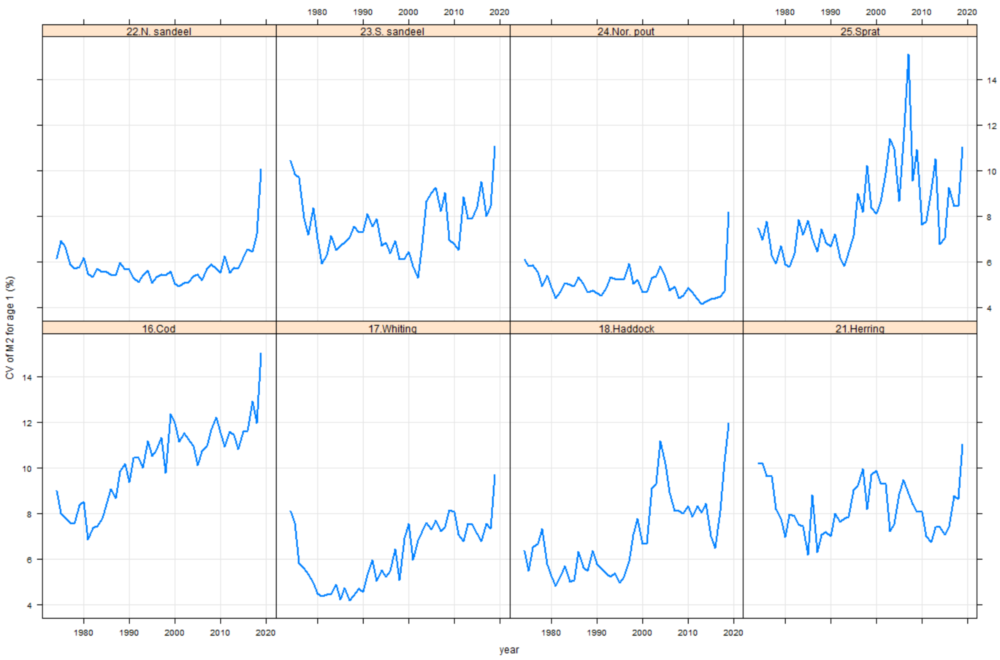

Figure 5.1.28. Age 2: M2 Uncertainties (1 sd / value) of estimated predation mortality (sum of quarterly M2) as estimated by SMS.

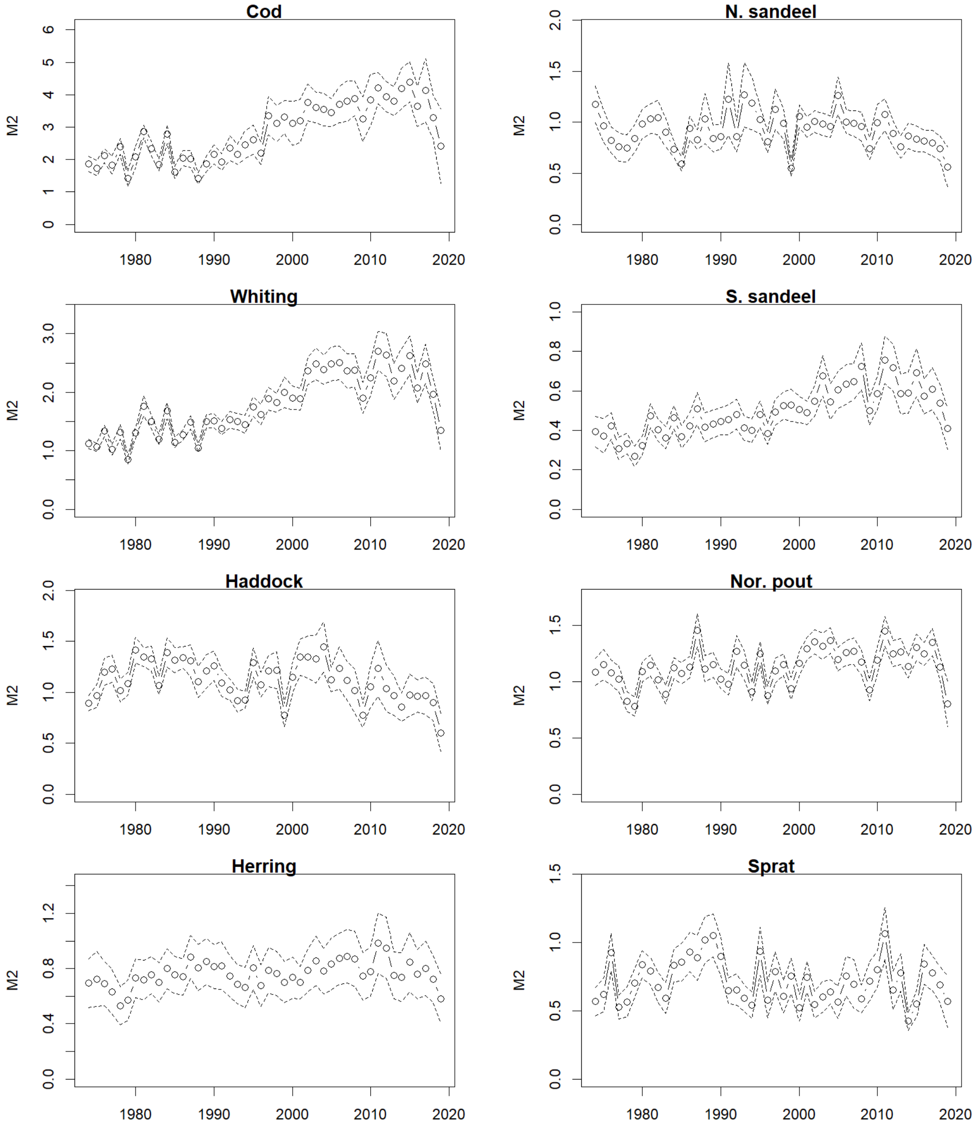

Figure 5.1.29. Age 0, M2 value with plus–minus 2 times the standard deviation as estimated by SMS.

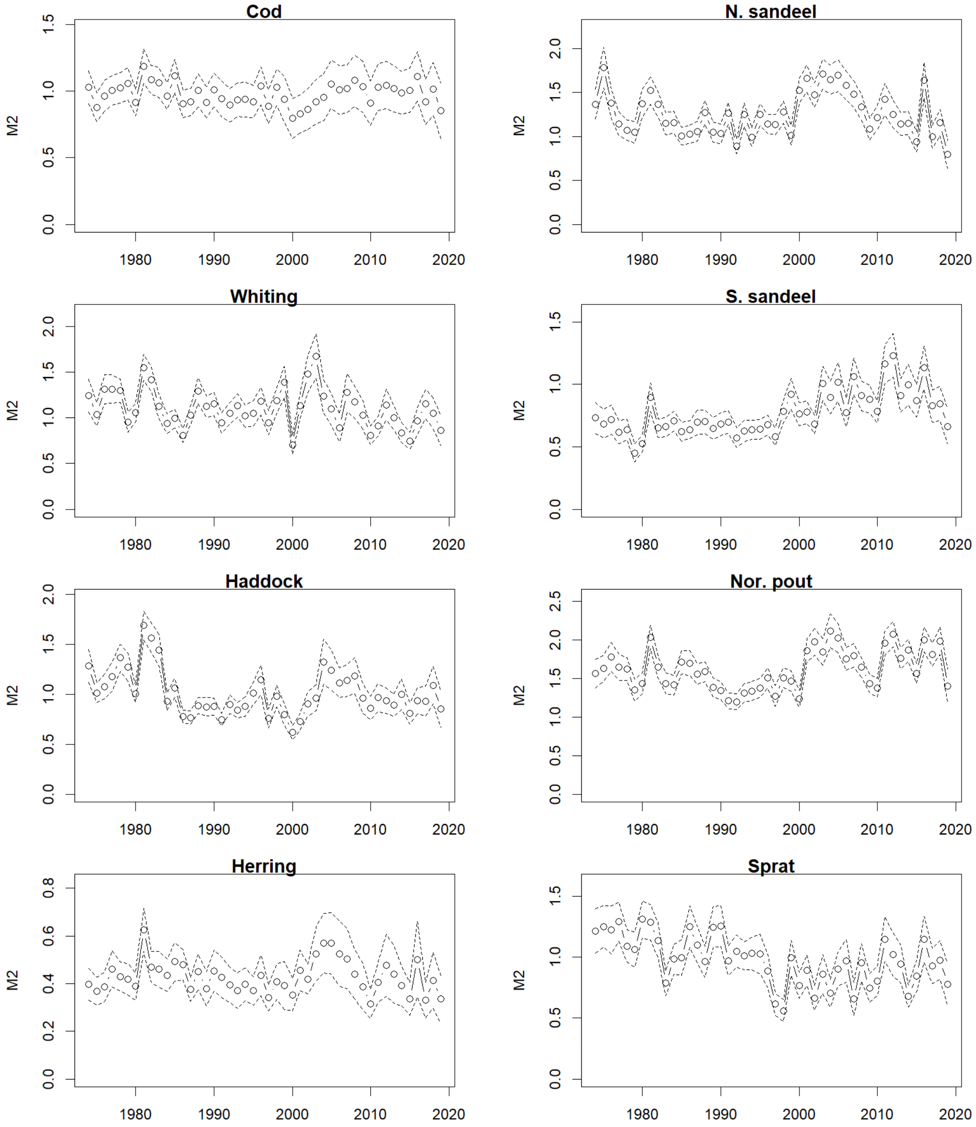

Figure 5.1.30. Age 1, M2 value with plus–minus 2 times the standard deviation as estimated by SMS.

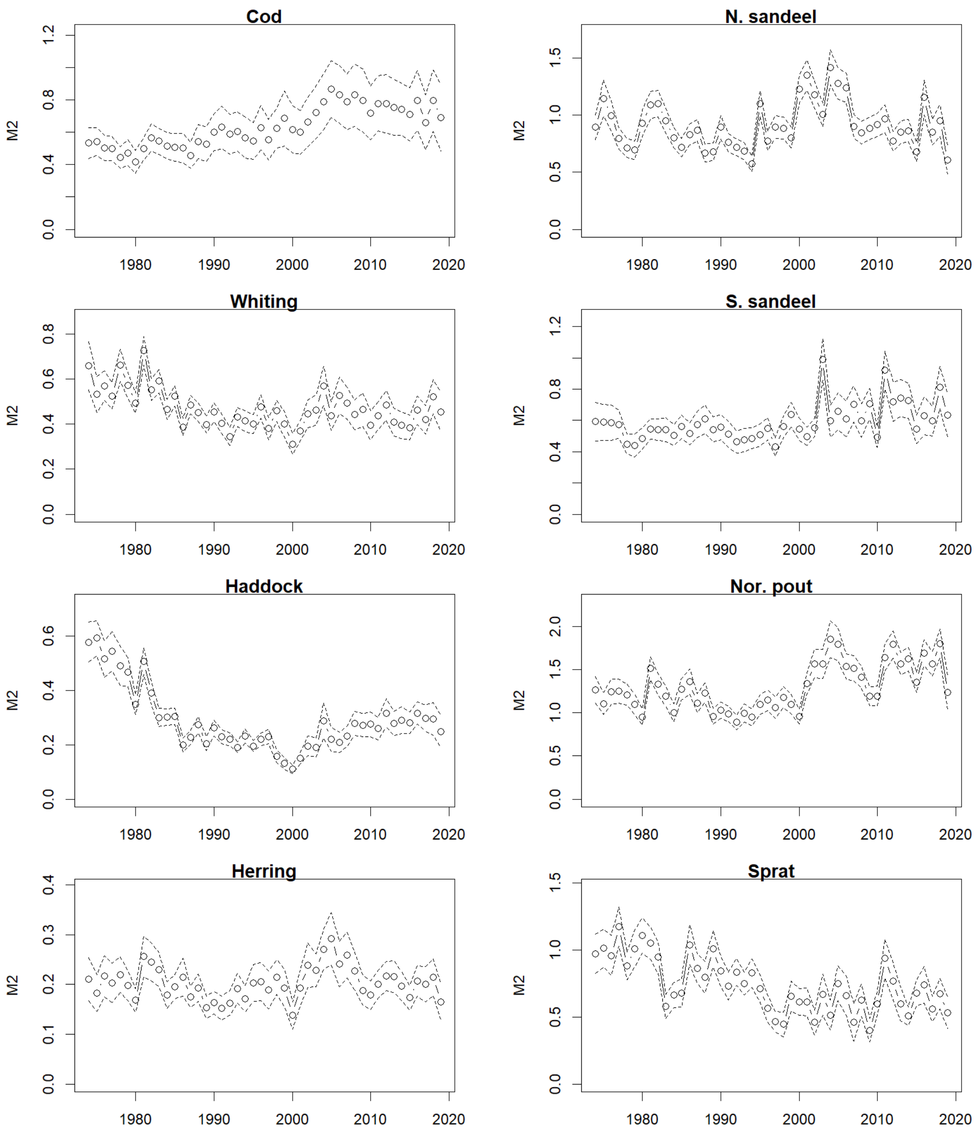

Figure 5.1.31. Age 2, M2 value with plus–minus 2 times the standard deviation as estimated by SMS.

5.1.6 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 new years.

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

Year/Age	0	1	2	3	4	5	6	7	8	9	10
1974	1.961	1.230	0.734	0.215	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1975	1.825	1.079	0.742	0.215	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1976	2.221	1.165	0.704	0.216	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1977	1.927	1.205	0.700	0.232	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1978	2.498	1.223	0.644	0.236	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1979	1.511	1.257	0.673	0.219	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1980	2.185	1.116	0.616	0.227	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1981	2.963	1.387	0.698	0.230	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1982	2.428	1.285	0.768	0.246	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1983	1.941	1.263	0.746	0.240	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1984	2.882	1.163	0.717	0.237	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1985	1.707	1.312	0.707	0.238	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1986	2.145	1.103	0.704	0.242	0.210	0.200	0.200	0.200	0.200	0.200	0.200
1987	2.114	1.119	0.658	0.244	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1988	1.517	1.206	0.741	0.251	0.213	0.200	0.200	0.200	0.200	0.200	0.200
1989	1.960	1.116	0.729	0.263	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1990	2.264	1.208	0.801	0.276	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1991	2.024	1.141	0.831	0.277	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1992	2.459	1.094	0.788	0.250	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1993	2.252	1.136	0.804	0.249	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1994	2.559	1.137	0.767	0.255	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1995	2.704	1.120	0.746	0.239	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1996	2.302	1.237	0.829	0.273	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1997	3.448	1.085	0.753	0.265	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1998	3.209	1.231	0.826	0.311	0.220	0.200	0.200	0.200	0.200	0.200	0.200
1999	3.407	1.139	0.887	0.295	0.228	0.200	0.200	0.200	0.200	0.200	0.200
2000	3.221	0.994	0.819	0.301	0.223	0.200	0.200	0.200	0.200	0.200	0.200
2001	3.295	1.029	0.800	0.314	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2002	3.868	1.064	0.863	0.365	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2003	3.708	1.119	0.924	0.404	0.252	0.200	0.200	0.200	0.200	0.200	0.200
2004	3.644	1.152	0.990	0.433	0.251	0.200	0.200	0.200	0.200	0.200	0.200
2005	3.551	1.251	1.068	0.476	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2006	3.795	1.208	1.034	0.402	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2007	3.900	1.217	0.988	0.371	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2008	3.980	1.279	1.031	0.380	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2009	3.349	1.231	0.997	0.308	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2010	3.932	1.109	0.920	0.280	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2011	4.304	1.230	0.978	0.314	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2012	4.039	1.244	0.976	0.326	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2013	3.901	1.219	0.953	0.297	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2014	4.285	1.188	0.942	0.294	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2015	4.495	1.205	0.912	0.349	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2016	3.749	1.310	0.998	0.389	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2017	4.225	1.120	0.861	0.250	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2018	3.398	1.217	0.996	0.341	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2019	2.507	1.054	0.890	0.284	0.200	0.200	0.200	0.200	0.200	0.200	0.200

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

Year/Age	0	1	2	3	4	5	6	7	8
1974	1.218	1.447	0.861	0.630	0.524	0.464	0.464	0.331	0.265
1975	1.164	1.240	0.732	0.622	0.470	0.431	0.421	0.304	0.256
1976	1.437	1.513	0.772	0.583	0.490	0.436	0.436	0.300	0.256
1977	1.121	1.517	0.726	0.594	0.543	0.382	0.382	0.289	0.252
1978	1.421	1.501	0.862	0.563	0.524	0.451	0.451	0.289	0.241
1979	0.947	1.153	0.772	0.524	0.505	0.461	0.437	0.267	0.243
1980	1.408	1.256	0.695	0.492	0.460	0.436	0.396	0.310	0.255
1981	1.864	1.754	0.927	0.553	0.526	0.455	0.439	0.370	0.252
1982	1.597	1.621	0.754	0.572	0.531	0.450	0.387	0.267	0.236
1983	1.297	1.327	0.791	0.490	0.463	0.431	0.424	0.330	0.258
1984	1.789	1.137	0.666	0.469	0.449	0.431	0.411	0.300	0.242
1985	1.246	1.196	0.725	0.455	0.453	0.416	0.409	0.274	0.274
1986	1.374	1.007	0.589	0.482	0.426	0.395	0.353	0.243	0.225
1987	1.586	1.232	0.686	0.434	0.429	0.393	0.387	0.241	0.233
1988	1.149	1.498	0.653	0.518	0.476	0.439	0.402	0.232	0.226
1989	1.604	1.325	0.600	0.482	0.465	0.436	0.415	0.365	0.365
1990	1.616	1.353	0.654	0.501	0.449	0.449	0.416	0.244	0.234
1991	1.486	1.147	0.603	0.494	0.468	0.438	0.438	0.415	0.328
1992	1.630	1.250	0.546	0.456	0.441	0.431	0.421	0.421	0.236
1993	1.601	1.336	0.632	0.444	0.428	0.422	0.414	0.403	0.359
1994	1.550	1.221	0.615	0.462	0.451	0.428	0.428	0.400	0.230
1995	1.852	1.252	0.602	0.438	0.422	0.407	0.400	0.356	0.271
1996	1.715	1.384	0.678	0.477	0.463	0.436	0.421	0.375	0.231
1997	1.991	1.148	0.581	0.461	0.437	0.416	0.402	0.396	0.278
1998	1.920	1.388	0.659	0.467	0.430	0.419	0.408	0.408	0.400
1999	2.099	1.593	0.601	0.492	0.474	0.438	0.427	0.419	0.419
2000	2.006	0.905	0.512	0.432	0.416	0.414	0.407	0.406	0.403
2001	1.985	1.336	0.569	0.427	0.411	0.393	0.389	0.389	0.380
2002	2.465	1.682	0.646	0.514	0.445	0.421	0.416	0.384	0.384
2003	2.589	1.877	0.664	0.490	0.463	0.437	0.406	0.403	0.403
2004	2.489	1.436	0.770	0.565	0.522	0.485	0.470	0.467	0.461
2005	2.586	1.297	0.637	0.519	0.483	0.473	0.471	0.471	0.431
2006	2.605	1.091	0.728	0.547	0.505	0.484	0.435	0.435	0.435
2007	2.468	1.479	0.694	0.508	0.475	0.435	0.457	0.435	0.432
2008	2.473	1.375	0.643	0.518	0.518	0.446	0.446	0.460	0.446
2009	2.006	1.233	0.665	0.522	0.457	0.451	0.451	0.451	0.451
2010	2.348	1.010	0.595	0.458	0.420	0.412	0.416	0.269	0.416
2011	2.806	1.111	0.638	0.482	0.437	0.431	0.431	0.431	0.431
2012	2.736	1.343	0.685	0.501	0.443	0.443	0.436	0.380	0.380
2013	2.289	1.202	0.611	0.516	0.475	0.432	0.289	0.285	0.382
2014	2.514	1.039	0.595	0.513	0.493	0.424	0.371	0.225	0.371
2015	2.729	0.948	0.585	0.482	0.461	0.461	0.361	0.277	0.369
2016	2.171	1.165	0.662	0.521	0.486	0.475	0.451	0.236	0.236
2017	2.584	1.354	0.621	0.491	0.455	0.423	0.333	0.333	0.240
2018	2.069	1.254	0.722	0.545	0.478	0.473	0.233	0.286	0.229
2019	1.447	1.067	0.655	0.498	0.464	0.432	0.412	0.325	0.325

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

Year/Age	0	1	2	3	4	5	6	7	8	9	10
1974	0.991	1.484	0.777	0.569	0.441	0.247	0.257	0.247	0.215	0.204	0.200
1975	1.065	1.214	0.792	0.476	0.407	0.307	0.215	0.240	0.240	0.206	0.200
1976	1.298	1.275	0.716	0.469	0.404	0.320	0.264	0.202	0.204	0.221	0.200
1977	1.328	1.378	0.744	0.530	0.313	0.299	0.275	0.240	0.202	0.200	0.203
1978	1.115	1.563	0.690	0.525	0.503	0.259	0.258	0.237	0.212	0.200	0.211
1979	1.187	1.472	0.667	0.429	0.343	0.265	0.232	0.213	0.213	0.210	0.202
1980	1.515	1.204	0.548	0.402	0.250	0.228	0.228	0.209	0.205	0.205	0.200
1981	1.447	1.887	0.707	0.445	0.281	0.224	0.213	0.216	0.204	0.202	0.202
1982	1.427	1.765	0.590	0.431	0.277	0.238	0.207	0.206	0.206	0.200	0.200
1983	1.168	1.642	0.500	0.411	0.316	0.239	0.215	0.215	0.202	0.204	0.202
1984	1.490	1.129	0.503	0.351	0.297	0.270	0.227	0.213	0.201	0.200	0.201
1985	1.414	1.263	0.504	0.363	0.289	0.243	0.233	0.211	0.204	0.200	0.200
1986	1.439	0.977	0.399	0.333	0.285	0.237	0.214	0.216	0.205	0.209	0.200
1987	1.406	0.965	0.428	0.363	0.269	0.222	0.209	0.208	0.209	0.207	0.201
1988	1.200	1.087	0.474	0.326	0.293	0.260	0.210	0.204	0.208	0.220	0.201
1989	1.306	1.073	0.403	0.371	0.267	0.230	0.225	0.207	0.201	0.201	0.208
1990	1.357	1.075	0.461	0.344	0.312	0.241	0.216	0.211	0.202	0.201	0.201
1991	1.191	0.946	0.429	0.316	0.276	0.263	0.225	0.207	0.205	0.201	0.200
1992	1.125	1.100	0.420	0.305	0.243	0.219	0.222	0.204	0.201	0.200	0.200
1993	1.018	1.041	0.390	0.296	0.249	0.222	0.213	0.212	0.201	0.201	0.200
1994	1.026	1.077	0.432	0.302	0.267	0.228	0.204	0.203	0.203	0.201	0.200
1995	1.392	1.209	0.395	0.309	0.268	0.227	0.209	0.202	0.205	0.204	0.200
1996	1.173	1.341	0.420	0.300	0.281	0.241	0.217	0.226	0.200	0.201	0.200
1997	1.307	0.958	0.430	0.308	0.250	0.246	0.211	0.211	0.202	0.200	0.200
1998	1.315	1.179	0.357	0.306	0.292	0.251	0.222	0.204	0.204	0.202	0.200
1999	0.875	0.998	0.332	0.305	0.265	0.260	0.230	0.225	0.219	0.201	0.200
2000	1.247	0.816	0.310	0.296	0.257	0.233	0.230	0.203	0.206	0.200	0.200
2001	1.443	0.926	0.350	0.291	0.257	0.241	0.225	0.204	0.200	0.202	0.200
2002	1.445	1.100	0.396	0.346	0.245	0.244	0.214	0.214	0.201	0.200	0.200
2003	1.425	1.162	0.389	0.335	0.280	0.255	0.229	0.203	0.201	0.200	0.200
2004	1.542	1.523	0.488	0.380	0.374	0.370	0.261	0.204	0.201	0.200	0.200
2005	1.225	1.441	0.420	0.367	0.277	0.280	0.277	0.208	0.202	0.201	0.200
2006	1.337	1.315	0.409	0.365	0.324	0.263	0.263	0.261	0.203	0.201	0.200
2007	1.213	1.336	0.432	0.281	0.263	0.258	0.250	0.250	0.234	0.208	0.200
2008	1.114	1.383	0.479	0.288	0.254	0.254	0.254	0.205	0.205	0.207	0.200
2009	0.876	1.158	0.472	0.398	0.301	0.247	0.218	0.208	0.201	0.201	0.202
2010	1.154	1.061	0.475	0.285	0.271	0.271	0.255	0.204	0.201	0.201	0.201
2011	1.335	1.166	0.459	0.283	0.283	0.283	0.277	0.269	0.212	0.277	0.200
2012	1.136	1.135	0.517	0.285	0.271	0.259	0.259	0.259	0.201	0.211	0.200
2013	1.068	1.088	0.479	0.257	0.284	0.245	0.213	0.231	0.231	0.208	0.200
2014	0.952	1.198	0.489	0.264	0.264	0.273	0.230	0.217	0.210	0.223	0.200
2015	1.075	1.006	0.480	0.296	0.233	0.259	0.259	0.259	0.205	0.252	0.255
2016	1.063	1.132	0.516	0.273	0.242	0.214	0.209	0.255	0.229	0.204	0.201
2017	1.065	1.131	0.497	0.348	0.222	0.206	0.201	0.206	0.206	0.252	0.201
2018	0.999	1.290	0.495	0.328	0.287	0.203	0.203	0.202	0.201	0.218	0.201
2019	0.701	1.052	0.449	0.310	0.245	0.245	0.205	0.206	0.201	0.200	0.201

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

Year/Age	0	1	2	3	4	5	6	7	8
1974	0.743	0.498	0.311	0.292	0.280	0.255	0.249	0.241	0.240
1975	0.774	0.468	0.283	0.254	0.236	0.226	0.214	0.208	0.207
1976	0.741	0.487	0.316	0.261	0.233	0.214	0.205	0.200	0.200
1977	0.683	0.562	0.303	0.267	0.234	0.215	0.199	0.194	0.193
1978	0.580	0.529	0.320	0.290	0.251	0.225	0.216	0.211	0.211
1979	0.621	0.518	0.298	0.277	0.244	0.226	0.211	0.200	0.200
1980	0.781	0.488	0.268	0.237	0.221	0.209	0.192	0.185	0.185
1981	0.768	0.726	0.356	0.299	0.265	0.241	0.215	0.207	0.207
1982	0.803	0.570	0.345	0.310	0.266	0.224	0.218	0.197	0.197
1983	0.750	0.560	0.329	0.301	0.249	0.228	0.198	0.192	0.187
1984	0.849	0.535	0.279	0.234	0.206	0.194	0.185	0.176	0.168
1985	0.803	0.591	0.296	0.255	0.200	0.195	0.179	0.171	0.153
1986	0.791	0.579	0.314	0.204	0.181	0.175	0.168	0.161	0.150
1987	0.932	0.476	0.275	0.227	0.194	0.178	0.174	0.164	0.157
1988	0.856	0.549	0.293	0.242	0.203	0.186	0.180	0.171	0.165
1989	0.901	0.478	0.254	0.232	0.199	0.180	0.165	0.164	0.157
1990	0.864	0.554	0.264	0.228	0.208	0.172	0.164	0.164	0.155
1991	0.870	0.526	0.252	0.200	0.193	0.171	0.160	0.159	0.152
1992	0.794	0.495	0.263	0.195	0.187	0.177	0.160	0.151	0.143
1993	0.736	0.471	0.292	0.230	0.203	0.188	0.156	0.156	0.147
1994	0.713	0.497	0.271	0.207	0.192	0.172	0.157	0.153	0.147
1995	0.856	0.470	0.303	0.286	0.225	0.202	0.178	0.151	0.149
1996	0.726	0.534	0.306	0.228	0.201	0.200	0.165	0.156	0.156
1997	0.836	0.441	0.289	0.234	0.194	0.176	0.167	0.161	0.148
1998	0.814	0.509	0.315	0.255	0.189	0.169	0.157	0.157	0.155
1999	0.752	0.493	0.293	0.229	0.199	0.172	0.164	0.163	0.163
2000	0.786	0.453	0.238	0.212	0.187	0.164	0.152	0.146	0.146
2001	0.748	0.555	0.292	0.233	0.203	0.174	0.160	0.155	0.155
2002	0.839	0.519	0.338	0.247	0.228	0.207	0.180	0.168	0.157
2003	0.905	0.623	0.329	0.251	0.206	0.184	0.173	0.160	0.154
2004	0.833	0.670	0.370	0.317	0.273	0.230	0.222	0.196	0.188
2005	0.881	0.669	0.392	0.316	0.256	0.225	0.191	0.179	0.169
2006	0.922	0.626	0.342	0.296	0.268	0.240	0.222	0.203	0.201
2007	0.938	0.604	0.360	0.310	0.286	0.250	0.233	0.220	0.206
2008	0.920	0.539	0.327	0.290	0.274	0.260	0.240	0.235	0.221
2009	0.795	0.487	0.288	0.250	0.248	0.229	0.226	0.224	0.205
2010	0.828	0.415	0.278	0.232	0.217	0.206	0.205	0.201	0.189
2011	1.036	0.505	0.300	0.233	0.214	0.202	0.194	0.190	0.187
2012	0.999	0.577	0.317	0.255	0.210	0.202	0.191	0.193	0.187
2013	0.801	0.539	0.315	0.244	0.221	0.213	0.191	0.185	0.187
2014	0.788	0.491	0.297	0.262	0.235	0.229	0.210	0.204	0.195
2015	0.897	0.435	0.273	0.244	0.224	0.216	0.211	0.209	0.201
2016	0.811	0.602	0.307	0.263	0.238	0.224	0.222	0.222	0.217
2017	0.850	0.431	0.301	0.263	0.242	0.223	0.214	0.214	0.214
2018	0.772	0.513	0.315	0.287	0.254	0.242	0.219	0.218	0.207
2019	0.632	0.435	0.265	0.238	0.227	0.221	0.211	0.207	0.201

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

Year/Age	**0**	**1**	**2**	**3**	**4**
1974	1.275	1.566	1.094	0.770	0.701
1975	1.063	1.978	1.347	0.750	0.712
1976	0.925	1.577	1.197	1.047	0.915
1977	0.858	1.342	0.996	0.801	0.716
1978	0.846	1.268	0.913	0.709	0.633
1979	0.942	1.247	0.895	0.626	0.589
1980	1.084	1.573	1.131	0.670	0.628
1981	1.136	1.719	1.289	1.068	0.972
1982	1.144	1.563	1.301	1.105	1.010
1983	1.002	1.345	1.155	0.881	0.800
1984	0.836	1.356	1.003	0.655	0.651
1985	0.696	1.205	0.917	0.758	0.698
1986	1.043	1.222	1.031	0.976	0.859
1987	0.931	1.257	1.068	0.698	0.661
1988	1.136	1.473	0.869	0.758	0.648
1989	0.940	1.246	0.880	0.717	0.677
1990	0.960	1.230	1.094	0.747	0.704
1991	1.325	1.460	0.961	0.534	0.681
1992	0.962	1.086	0.920	0.744	0.652
1993	1.369	1.446	0.884	0.793	0.793
1994	1.288	1.191	0.775	0.726	0.717
1995	1.125	1.446	1.303	0.899	0.886
1996	0.908	1.342	0.974	0.899	0.736
1997	1.229	1.333	1.096	0.895	0.814
1998	1.088	1.474	1.086	0.936	0.899
1999	0.648	1.214	1.004	0.824	0.773
2000	1.159	1.719	1.429	1.134	0.979
2001	1.054	1.860	1.554	1.333	1.215
2002	1.108	1.674	1.381	1.316	1.231
2003	1.082	1.907	1.206	1.180	1.141
2004	1.059	1.843	1.620	1.628	1.450
2005	1.361	1.892	1.481	1.276	1.181
2006	1.105	1.776	1.439	1.112	1.006
2007	1.089	1.679	1.104	1.038	1.074
2008	1.059	1.535	1.047	0.958	0.950
2009	0.844	1.285	1.084	0.798	0.980
2010	1.098	1.414	1.116	0.981	0.936
2011	1.176	1.619	1.171	1.017	0.934
2012	0.988	1.451	0.973	0.929	0.845
2013	0.860	1.340	1.052	0.934	0.860
2014	0.966	1.351	1.065	0.848	0.796
2015	0.937	1.139	0.879	0.745	0.667
2016	0.914	1.837	1.355	1.079	0.929
2017	0.898	1.197	1.053	0.825	0.789
2018	0.843	1.355	1.151	0.872	0.815
2019	0.663	0.996	0.809	0.667	0.626

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

Year/Age	**0**	**1**	**2**	**3**	**4**
1974	0.493	0.932	0.793	0.683	0.667
1975	0.472	0.883	0.789	0.681	0.646
1976	0.522	0.917	0.785	0.664	0.631
1977	0.407	0.818	0.774	0.626	0.594
1978	0.433	0.835	0.649	0.532	0.499
1979	0.369	0.651	0.638	0.511	0.511
1980	0.423	0.726	0.684	0.552	0.510
1981	0.574	1.096	0.743	0.578	0.566
1982	0.502	0.850	0.742	0.718	0.590
1983	0.463	0.860	0.742	0.585	0.614
1984	0.566	0.905	0.706	0.580	0.580
1985	0.468	0.820	0.759	0.594	0.545
1986	0.522	0.836	0.716	0.743	0.647
1987	0.610	0.895	0.775	0.577	0.615
1988	0.517	0.900	0.808	0.600	0.568
1989	0.532	0.844	0.742	0.742	0.660
1990	0.546	0.882	0.756	0.637	0.583
1991	0.553	0.897	0.711	0.532	0.587
1992	0.582	0.773	0.662	0.551	0.544
1993	0.511	0.825	0.675	0.555	0.524
1994	0.498	0.836	0.686	0.567	0.522
1995	0.581	0.839	0.707	0.594	0.551
1996	0.483	0.875	0.747	0.596	0.551
1997	0.592	0.783	0.630	0.595	0.554
1998	0.626	0.982	0.760	0.668	0.590
1999	0.628	1.122	0.836	0.708	0.595
2000	0.606	0.961	0.744	0.622	0.584
2001	0.588	0.976	0.698	0.637	0.477
2002	0.647	0.879	0.755	0.612	0.511
2003	0.776	1.206	1.190	0.884	0.817
2004	0.645	1.096	0.797	0.797	0.735
2005	0.706	1.218	0.858	0.697	0.621
2006	0.734	0.975	0.811	0.805	0.660
2007	0.749	1.263	0.905	0.631	0.627
2008	0.825	1.108	0.798	0.687	0.652
2009	0.600	1.081	0.905	0.736	0.651
2010	0.686	0.982	0.693	0.642	0.596
2011	0.858	1.363	1.121	0.846	0.779
2012	0.818	1.432	0.919	0.892	0.755
2013	0.686	1.112	0.944	0.731	0.731
2014	0.691	1.196	0.926	0.705	0.648
2015	0.791	1.071	0.744	0.628	0.597
2016	0.672	1.333	0.829	0.703	0.650
2017	0.710	1.027	0.796	0.686	0.619
2018	0.637	1.043	1.010	0.716	0.678
2019	0.509	0.864	0.834	0.660	0.616

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

Year/Age	**0**	**1**	**2**	**3**
1974	1.184	1.761	1.461	1.365
1975	1.252	1.833	1.303	1.211
1976	1.179	1.979	1.442	1.334
1977	1.123	1.844	1.451	1.319
1978	0.921	1.822	1.409	1.317
1979	0.878	1.549	1.297	1.055
1980	1.189	1.636	1.148	1.035
1981	1.242	2.235	1.711	1.535
1982	1.117	1.846	1.527	1.368
1983	0.983	1.637	1.391	1.267
1984	1.221	1.614	1.200	1.085
1985	1.171	1.911	1.474	1.372
1986	1.228	1.899	1.558	1.300
1987	1.554	1.760	1.311	1.081
1988	1.212	1.787	1.429	1.191
1989	1.249	1.584	1.158	0.971
1990	1.123	1.543	1.229	0.972
1991	1.075	1.409	1.184	1.022
1992	1.366	1.399	1.087	1.019
1993	1.245	1.514	1.196	1.120
1994	1.011	1.534	1.147	0.980
1995	1.344	1.578	1.292	1.198
1996	0.975	1.705	1.343	1.210
1997	1.196	1.472	1.260	1.153
1998	1.252	1.711	1.379	1.267
1999	1.038	1.669	1.297	1.191
2000	1.261	1.437	1.156	0.977
2001	1.392	2.059	1.535	1.379
2002	1.452	2.178	1.765	1.554
2003	1.415	2.047	1.766	1.510
2004	1.464	2.319	2.050	1.830
2005	1.298	2.226	1.991	1.851
2006	1.356	1.953	1.738	1.582
2007	1.368	1.997	1.713	1.607
2008	1.270	1.845	1.613	1.442
2009	1.025	1.632	1.391	1.265
2010	1.289	1.577	1.394	1.269
2011	1.546	2.163	1.836	1.663
2012	1.348	2.277	1.989	1.792
2013	1.364	1.962	1.767	1.627
2014	1.231	2.066	1.824	1.652
2015	1.402	1.766	1.551	1.416
2016	1.346	2.204	1.891	1.758
2017	1.448	2.014	1.763	1.660
2018	1.227	2.187	2.000	1.863
2019	0.900	1.604	1.432	1.322

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

Year/Age	0	1	2	3
1974	0.667	1.416	1.171	0.587
1975	0.718	1.453	1.212	0.769
1976	1.028	1.423	1.159	0.918
1977	0.626	1.492	1.373	1.034
1978	0.665	1.291	1.083	0.927
1979	0.803	1.264	1.209	1.059
1980	0.939	1.512	1.308	1.239
1981	0.890	1.489	1.250	1.089
1982	0.772	1.339	1.146	0.758
1983	0.692	0.986	0.778	0.553
1984	0.934	1.184	0.864	0.724
1985	0.958	1.195	0.879	0.631
1986	1.031	1.449	1.239	0.707
1987	0.989	1.303	1.061	0.875
1988	1.120	1.165	0.994	0.626
1989	1.152	1.447	1.208	0.754
1990	0.998	1.456	1.043	0.911
1991	0.747	1.171	0.931	0.851
1992	0.754	1.250	1.036	0.847
1993	0.691	1.212	0.949	0.859
1994	0.641	1.231	1.028	0.921
1995	1.035	1.227	0.912	0.859
1996	0.679	1.089	0.763	0.653
1997	0.888	0.815	0.666	0.503
1998	0.704	0.761	0.645	0.506
1999	0.854	1.194	0.856	0.812
2000	0.621	0.968	0.811	0.671
2001	0.846	1.094	0.812	0.702
2002	0.646	0.865	0.658	0.553
2003	0.702	1.062	0.866	0.699
2004	0.738	0.906	0.715	0.679
2005	0.662	1.104	0.950	0.903
2006	0.853	1.169	0.859	0.769
2007	0.796	0.857	0.660	0.519
2008	0.687	1.156	0.824	0.702
2009	0.817	0.948	0.600	0.529
2010	0.902	1.006	0.799	0.565
2011	1.167	1.349	1.136	0.778
2012	0.752	1.222	0.965	0.622
2013	0.879	1.145	0.795	0.663
2014	0.523	0.881	0.706	0.450
2015	0.651	1.046	0.877	0.612
2016	0.941	1.345	0.941	0.764
2017	0.875	1.130	0.758	0.632
2018	0.791	1.176	0.871	0.690
2019	0.667	0.978	0.732	0.573

6 Comparison with the 2017 key run

Since the last key run in 2017, there have 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:
  - 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 a lower mean weight at ages for the youngest ages and a higher mean weights 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 2017 key run and the new 2020 key run.

6.1.1 Cod

The main differences for cod between the two key runs are F and SSB in the terminal years with a higher F and lower SSB in the 2020 key run (Figure 5.2.1, upper panel).. This result is mainly from the changes in the ICES assessment.

Predation mortality of age 1 and 2 cod is slightly higher in the 2020 key (Figure 5.2.1, upper panel). Closer inspection of the M2 from the individual predators show an increase from harbour porpoise, possible linked to a lower M2 on whiting from harbour porpoise.

6.1.2 Whiting

The ICES benchmark of the whiting assessment gave a slightly higher recruitment, and lower SSB (Figure 5.2.1, upper panel).

Mean weights at age in the sea were also changed with lower mean weight for the youngest ages and a higher for the oldest ages in the 2020 key. This influence the predation mortality for whiting (Figure 5.2.1, lower panel). The 2020 key run estimates higher M2 for age 1-3 and lower M2 for the oldest ages.

6.1.3 Haddock

Recruitment, F, SSB and predation at age of haddock are largely the same between the two key runs (Figure 5.2.3).

6.1.4 Saithe

The two saithe assessments are quite similar (Figure 5.2.4).

6.1.5 Herring

The two herring assessments are quiet similar (Figure 5.2.5), except for the most recent years due to changes in the input for the ICES assessments. Changes in setting in the 2020 key run gave small changes in the first part of the assessment time series (exploitation pattern is now assumed the same in the period 1974-1983 where as the 2017 key run had two periods, 1974-1978 and 1978-1983 with different exploitation pattern, which is an over parametrisation of the model, that creates problems with the Hessian matrix.)

Predation mortality of herring follows the same trend in the two key runs. The most striking difference is a M2 in the most recent years for age 2+. This is mainly due to a lower stock of the predators cod and saithe estimated in the 2020 run..

6.1.6 Northern sandeel

The two assessments are quite similar (Figure 5.2.6) both with respect to “single species output” and predation mortality.

6.1.7 Southern sandeel

The 2020 key run estimate a higher F and a lower SSB in the recent years (Figure 5.2.7) which is also reflected in a slightly higher M2 in recent years.

6.1.8 Norway pout

Norway pout has been benchmarked but the differences in recruitment, F and SSB estimated from the SMS key runs in 2017 and 2020, are much smaller than for the ICES assessments. Despite a lower recruitment and SSB in the 2020 key run, predation mortalities remains large the same between the two key runs (Figure 5.2.8).

6.1.9 Sprat

The sprat assessment has changed (benchmark) which is also reflected in the stock summary (Figure 5.2.9) for the two key-runs with a higher F and a lower SSB in the 2020 key run. The presented M2 and mean F are annul values (annual F is e.g. calculated from the number caught within the year relative to the total number of died within the year, multiplied with the annual Z (sum of quarterly F, M1 and M2)). For a species like sprat with both a high M and F the timing of the fishery within the year will significantly affect the estimated annual F or M2. In the ICES assessment and 2020 key run the calendar quarter 2 catches are transferred to quarter 1 which in itself will give a higher annual F. This transfer of catches was first introduced by the latest key run and therefore not used in the 2017 key run. Because of this transfer of catches, the extension of the stock area and other changes made during the benchmark, the two set of result from the two key runs are not directly comparable.

M2 for age 1+ is estimated lower in the 2020 key run. This I mainly an effect of the used of annual M2. A comparison, using the sum of quarterly M2 shows actually a lower (sum of quarterly) M2 at age for the 2020 key run.

Figure 5.2.1. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of cod from the 2017 and 2020 key runs.

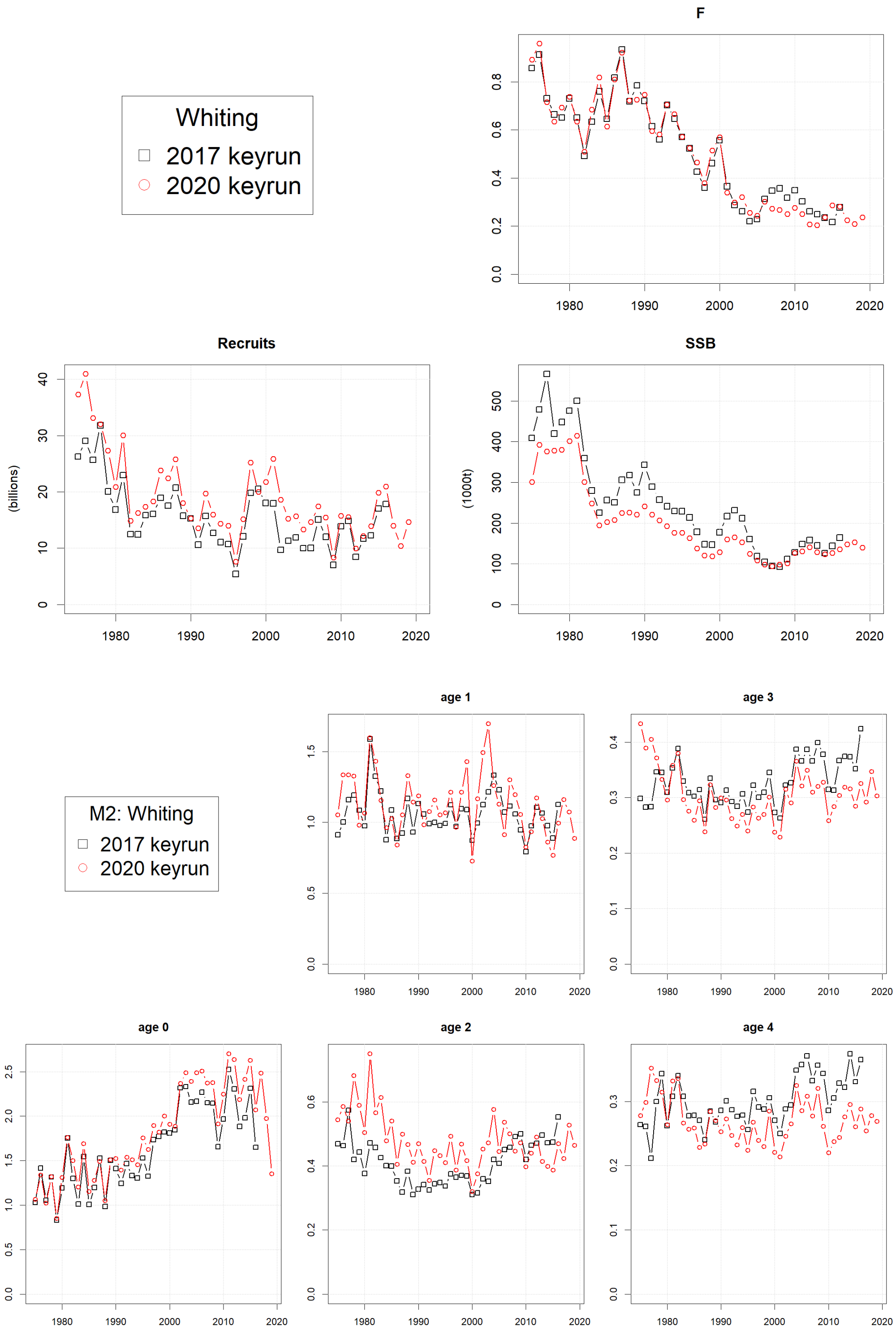

Figure 5.2.2. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of whiting from the 2017 and 2020 key runs.

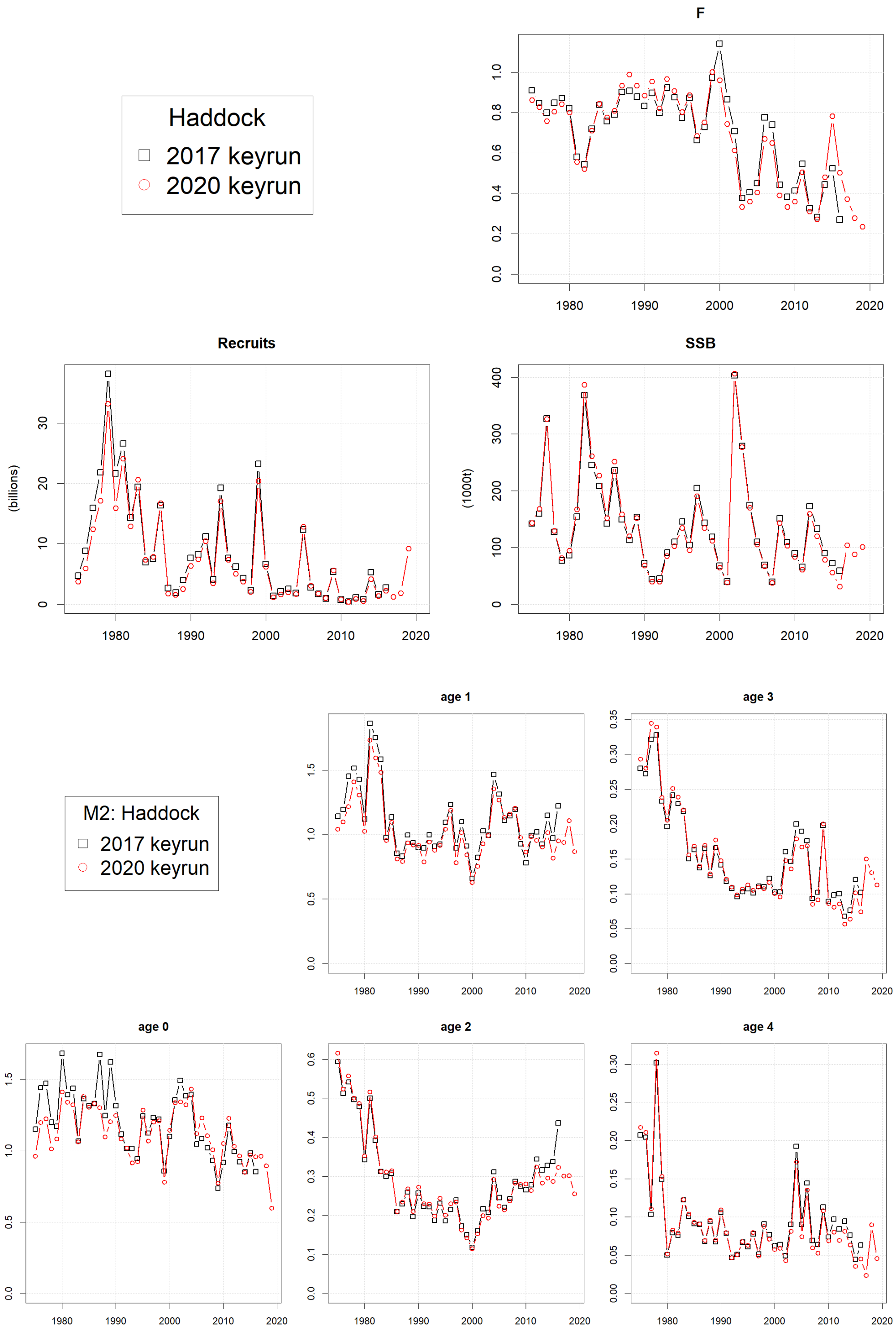

Figure 5.2.3. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of haddock from the 2017 and 2020 key runs.

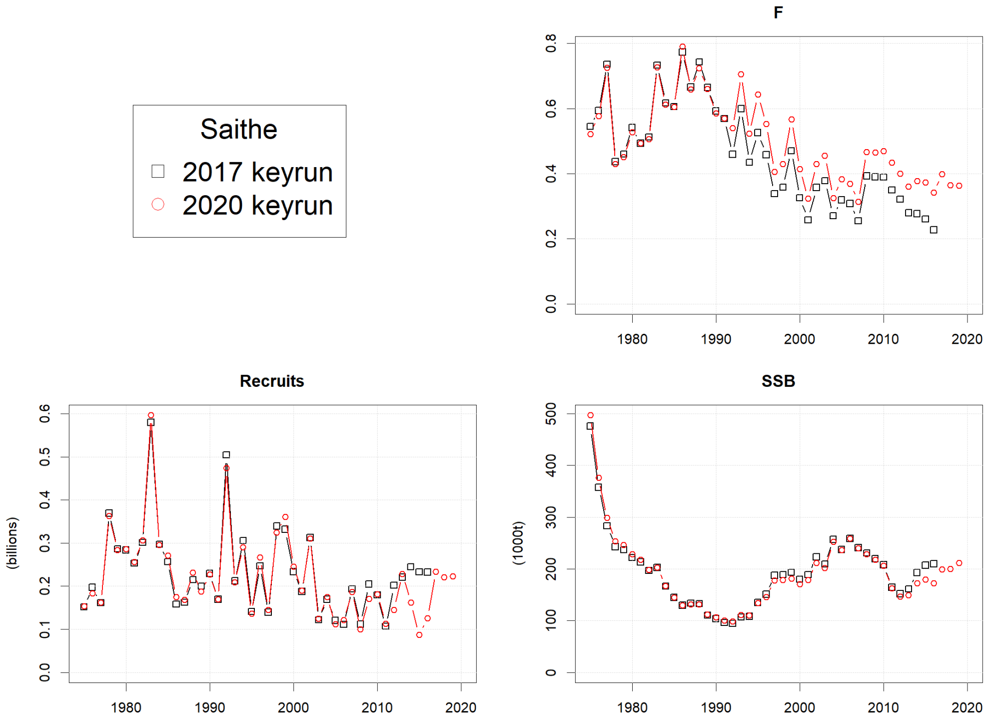

Figure 5.2.4. Comparison of estimated recruitment, mean F and SSB of Saithe from the 2017 and 2020 key runs.

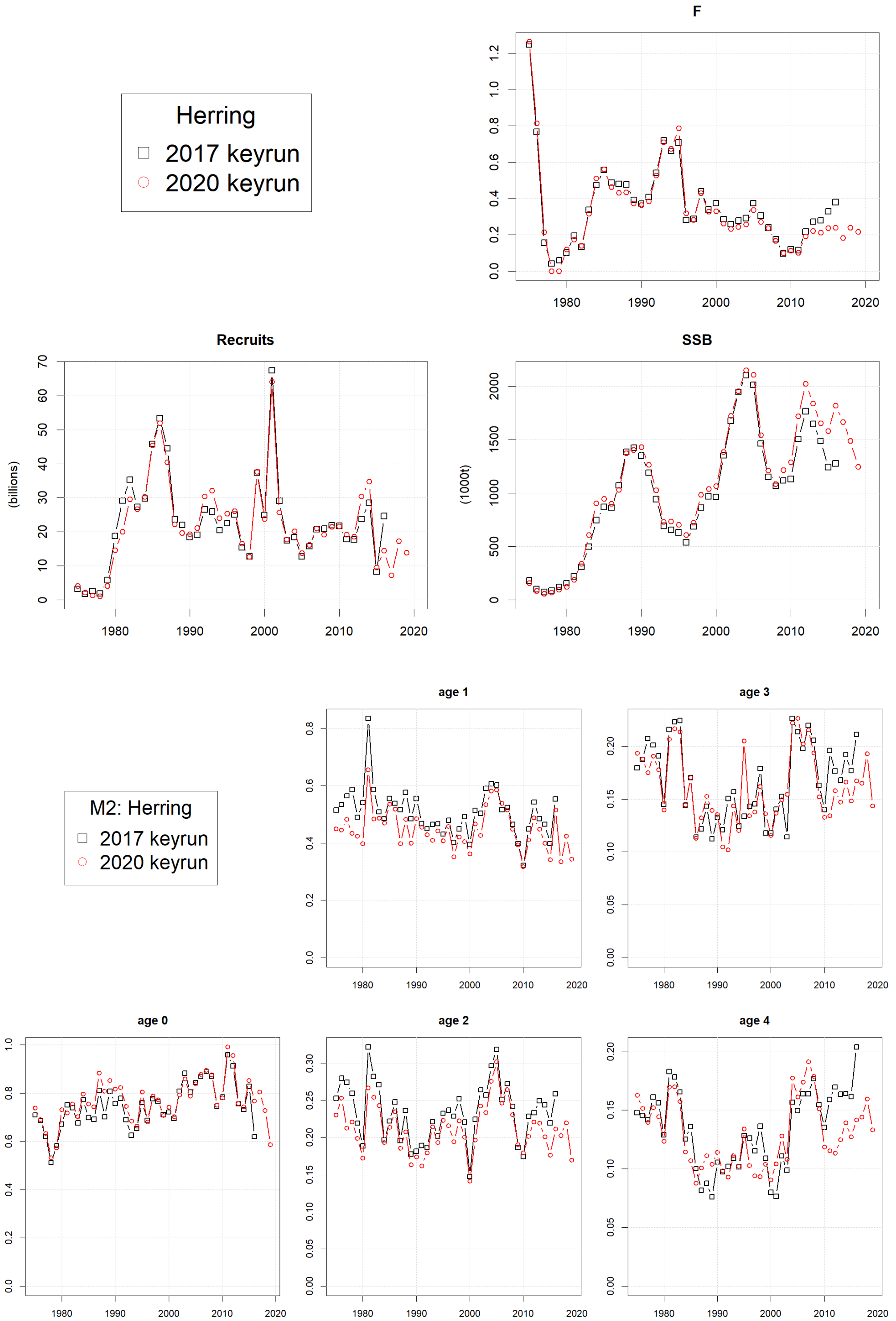

Figure 5.2.5. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of herring from the 2017 and 2020 key runs.

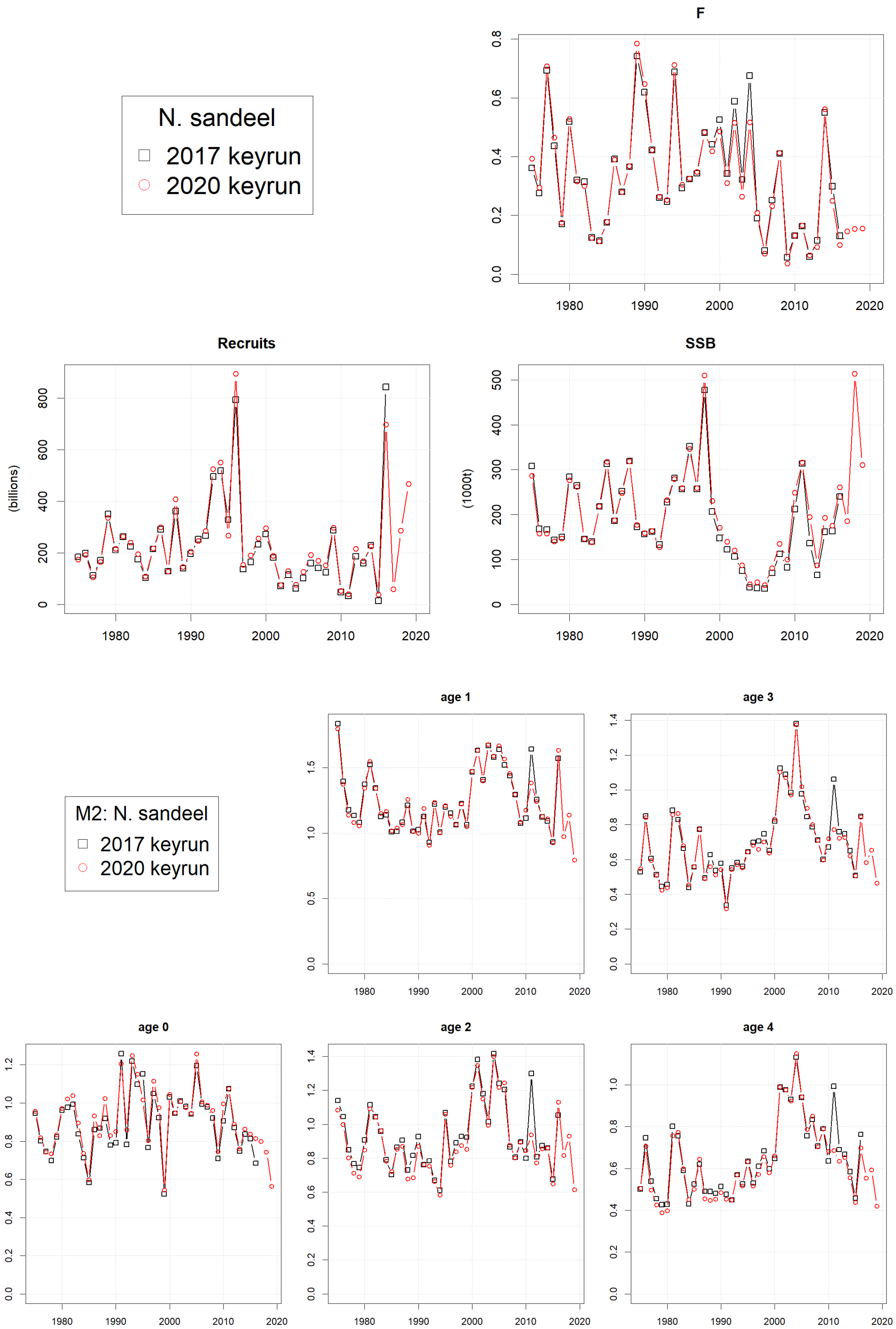

Figure 5.2.6. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of northern sandeel from the 2017 and 2020 key runs.

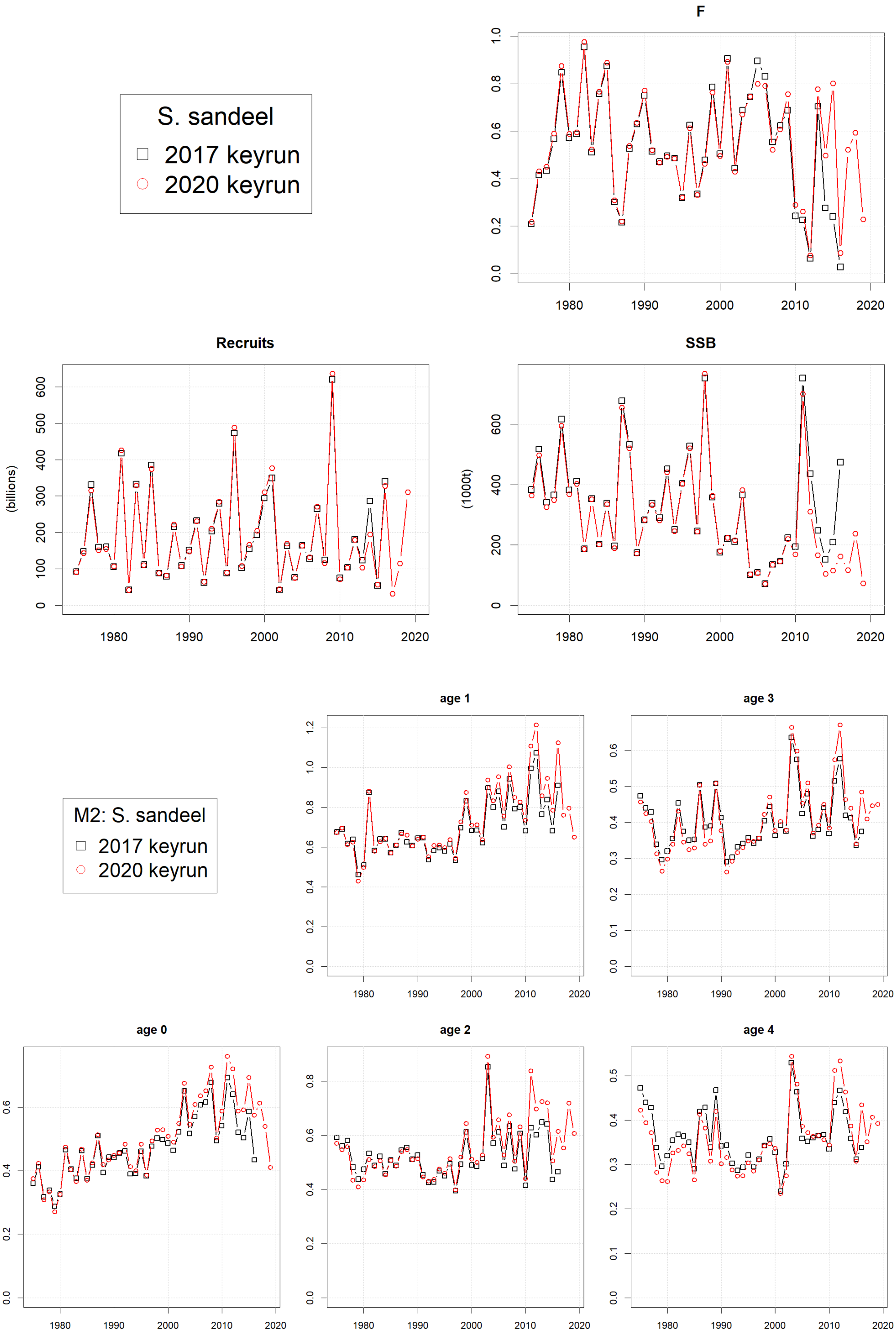

Figure 5.2.7. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of southern sandeel from the 2017 and 2020 key runs.

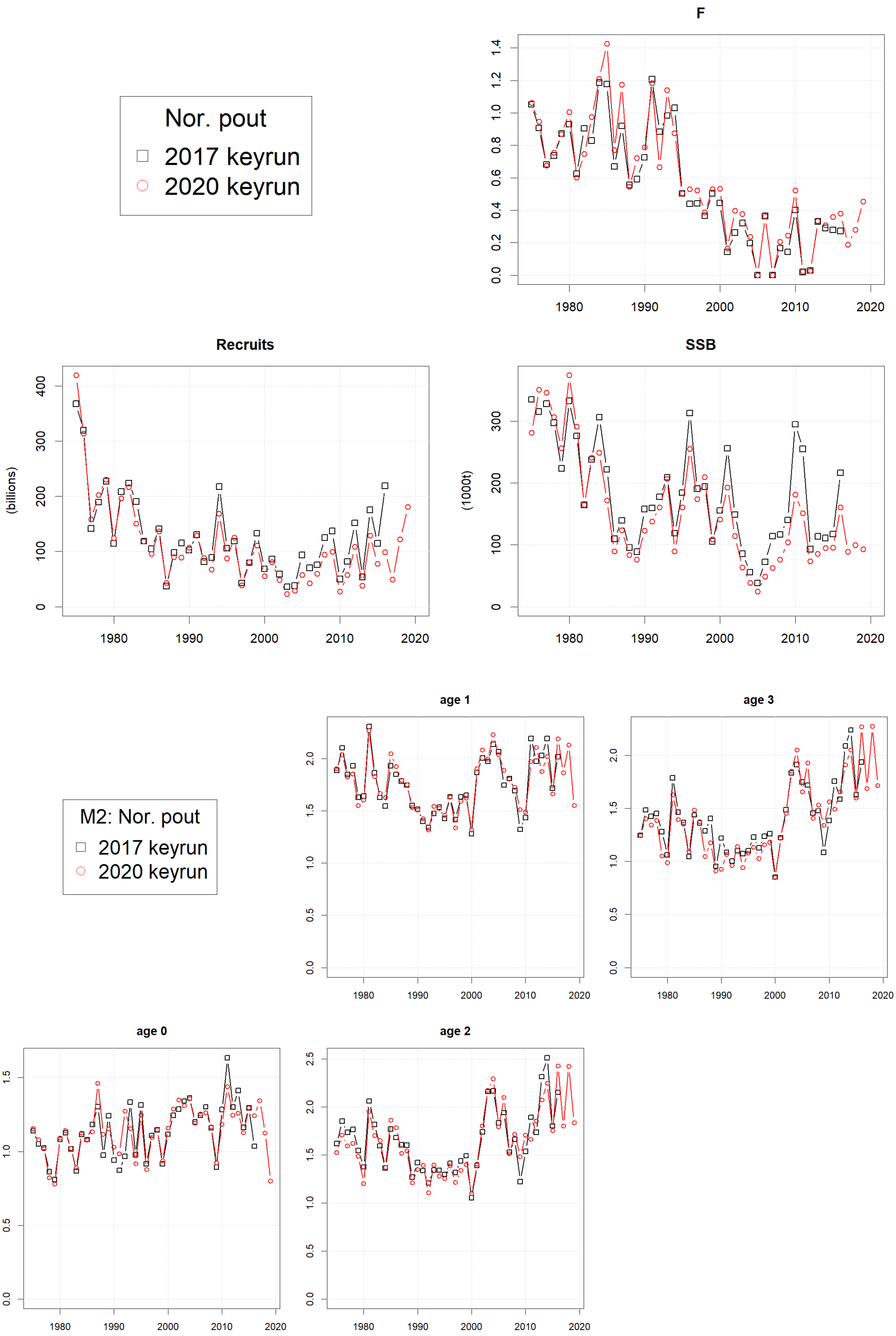

Figure 5.2.8. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of Norway pout from the 2017 and 2020 key runs.

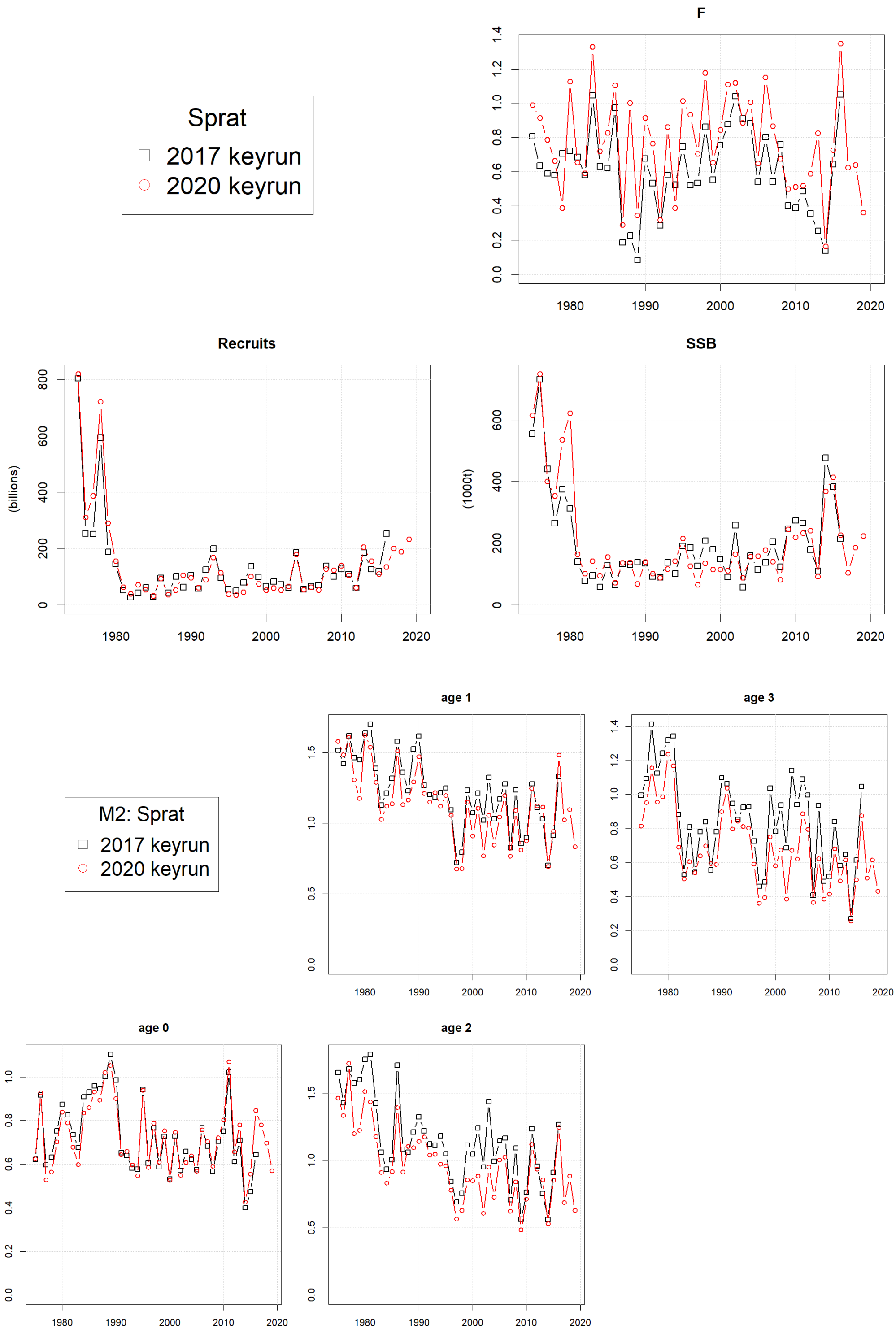

Figure 5.2.9. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of sprat from the 2017 and 2020 key runs.

6.2 Conclusion, 2020 key run

WGSAM 20120 discussed the changes in input data and the results in detail and concluded that:

- M2 seems consistently estimated between key runs and shows a very 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 are not 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.

7 References

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8 APPENDIX 1: SMS, a stochastic age-length structured multi-species model applied to North Sea and Baltic Sea stocks

Working document to ICES WKMULTBAL, March 2012

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8.1 Overview

SMS (Stochastic Multi Species model) is a fish stock assessment model in which includes 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 to 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.

8.2 Model Structure

8.2.1 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.

8.2.2 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 grouping of ages, (e.g. ages 1–3, 4–7 and 8–9) and Y is 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.

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

8.2.3 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 section 0 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:

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

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

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

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 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.

$$N_{s,l_s,y,q} = \sum_a N_{s,a,y,q} \; ALK_{s,a,l_s,y,q} \qquad \text{Eq. 7}$$

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 depends only of the age and that M2 only depends of 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 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" part 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 sizes.

8.2.3.1.1 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 ration, expressing how selective a predator is with respect to 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.

8.2.3.1.2 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:

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

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

7.2.3.2.2.1. 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:

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

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.

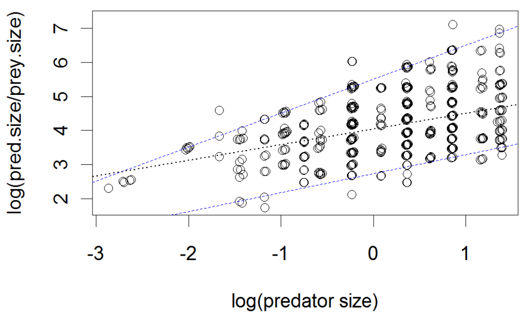

Figure 7.1. Quantile regression of stomach contents observations (Baltic cod eating cod), with 2.5%, 50% and 97.5% lines shown. Predator and prey size in weight.

8.2.4 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.

8.2.5 Growth

Not implemented yet!

8.2.6 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.

$$RA_{pred,l_{pred},q} = \gamma_{pred,q} \; W_{pred,l_{pred}}^{\varsigma_{pred}} \qquad \text{Eq. 2}$$

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.

8.2.7 Area-based SMS

SMS has three area explicit options:

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

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

3) 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 calculate 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 died due to predation mortality (DM2) then becomes:

$$DM2_a = \sum_{area} M2_a^{area} \bar{N}_a^{area} \qquad \text{Eq. 3}$$

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.

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

8.3 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 three types of observations. A stock–recruitment (penalty) function is added as a fourth contribution.

8.3.1 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:

$$L_{CATCH} = \prod_{s,a,y,q} \frac{1}{\sigma_{CATCH\ s,a,q}\sqrt{2\pi}}\ exp\left(-\frac{\left(\log(C_{s,a,y,q}) - E\left(\log(C_{s,a,y,q})\right)\right)^2}{2\ \sigma^2_{CATCH\ s,a,q}}\right) \qquad \text{Eq. 4}$$

Where

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

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

$$l_{CATCH} = -\log(L_{CATCH}) \propto \text{NOY} \sum_{s,a,q} \log\left(\sigma_{CATCH\ s,a,q}\right) + \sum_{s,a,y,q} \left(\log(C_{s,a,y,q}) - E\left(\log(C_{s,a,y,q})\right)\right)^2 / 2\sigma^2_{CATCH\ s,a,q} \qquad \text{Eq. 5}$$

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.

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

$$L_{CATCH} = \prod_{s,a,y} \frac{1}{\sigma_{CATCH\ s,a}\sqrt{2\pi}}\ exp\left(-\frac{\left(\log(C_{s,a,y}) - E\left(\log(C_{s,a,y})\right)\right)^2}{2\ \sigma^2_{CATCH\ s,a}}\right) \qquad \text{Eq. 6}$$

8.3.2 Survey indices

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

$$E(\log(CPUE_{survey,s,a,y,q})) = \log(Q_{survey,a} \ \bar{N}_{SURVEY\ s,a,y,q}) \qquad \text{Eq. 7}$$

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 groups 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 on the same form as Eq. 4.

$$l_{SURVEY} = -\log(L_{SURVEY}) \propto NOY_{survey,s} \sum_{survey,s,a} \log(\sigma_{SURVEY\ survey,s,a}) + \sum_{survey,s,a,y} \left(\log(CPUE_{survey,s,a,y}) - E(\log(CPUE_{survey,s,a,y}))\right)^2 / 2\sigma^2_{SURVEY\ s,a} \qquad \text{Eq. 8}$$

8.3.3 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 becomes $STOM_{i,j,y,q}$.

$STOM$ 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 $STOM_{i,1}, \dots STOM_{i,k-1} > 0$ and the parameters $p_1, \dots, p_k > 0$ has the probability density given byS:

$$f_i = f(STOM_{i,1}, \dots, STOM_{i,k-1} \mid p_{i,1}, \dots, p_{i,k}) = \frac{\Gamma(p_i)}{\prod_{j=1}^{k} \Gamma(p_{i,j})} \prod_{j=1}^{k} STOM_{i,j}^{p_{i,j}-1} \qquad \text{Eq. 9}$$

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:

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

$$Var(STOM_{i,j}) = \frac{E(STOM_{i,j})\ \left(1 - E(STOM_{i,j})\right)}{p_i + 1} \qquad \text{Eq. 10}$$

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

$$E(STOM_{i,j}) = \frac{\bar{N}_j\ W_j\ S_{i,j}(l_i, l_j)}{\sum_j \left(\bar{N}_j\ W_j\ S_{i,j}(l_i, l_j)\right) + OF_i\, S_{OF,i}(l_i)} = \frac{p_{i,j}}{p_i} \qquad \text{Eq. 11}$$

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. 11.

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:

$$Var(STOM_{i,j,y,q}) = \frac{E(STOM_{i,j,y,q})\ \left(1 - E(STOM_{i,j,y,q})\right)}{V_{pred}\ U_{i,y,q}} \qquad \text{Eq. 12}$$

where $U_{i,y,q}$ is a known quantity reflecting the sampling level of a predator entity, e.g. the number of hauls containing with 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. 10 and Eq. 12 implies that:

$$P_{i,y,q} = V_{pred}\, U_{i,y,q} - 1 \qquad \text{Eq. 13}$$

Insertion of Eq. 13 into Eq. 11 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. 9:

$$l_{STOM} = -\log(L_{STOM}) = -\sum_{i,j,y,q} \log(f_{i,j,y,q}) \qquad \text{Eq. 14}$$

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 "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 and Eq. 1) is used. The likelihood function is the same as used for stomach observations that include prey size.

8.3.4 Stock–recruitment

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

$$SSB_{s,y} = \sum_a N_{s,y,a,q=recq}\ PM_{s,y,a,q=recq}\ W_{s,y,a,q=recq} \qquad \text{Eq. 15}$$

At present the Ricker (Eq. 16), the Beverton and Holt (Eq. 17), segmented regression (Eq. 18) and geometric mean are implemented.

$$R_{s,y} = \alpha_s\ SSB_{s,y-fa,fq}\ e^{(\beta_s\ SSB_{s,y-fa,fq})} \qquad \text{Eq. 16}$$

$$R_{s,y} = \frac{\alpha_s\ SSB_{s,y-fa,fq}}{1 + \beta_s\ SSB_{s,y-fa,q}} \qquad \text{Eq. 17}$$

$$R_{s,y} = \begin{cases} \alpha_s\ SSB_{s,y-fa,fq} & \text{for } SSB_{s,y-fa,fq} < \beta_s \\ \alpha_s\ \beta_s & \text{for } SSB_{s,y-fa,fq} < \beta_s \end{cases} \qquad \text{Eq. 18}$$

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

$$l_{SR} = -\log(L_{SR}) \propto NOY \sum_{s} \log(\sigma_{SR\,a}) + \sum_{s,a,y} \left(\log\left(N_{ss,a=fa,y,q=recq}\right) - E\left(\log\left(R_{s,y}\right)\right)\right)^2 / 2\sigma_{SR\,s}^2 \quad \text{Eq. 19}$$

Where NOY gives the number of years selected and where Eq. 20 gives the expected recruitment for the Ricker case.

$$E(\log(R_s)) = \log\left(\alpha_s \, SSB_{s,y-fa,fq} \, e^{(\beta_s \, SSB_{s,y-fa,fq})}\right) \quad \text{Eq. 20}$$

8.4 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 in 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 predators. 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 of 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 were 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 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 sum up to a considerable number of parameters. To reduce this high number of parameters, the year effect can optionally be model 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 σ_{CATCH}, σ_{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.

8.5 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 pattern used in the forecast. Exploitation pattern are 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.

8.5.1 Recruitment

Recruitment is estimated from the available stock–recruitment relationships, f(SSB), (see Section 8.3.4) and optionally a lognormal distributed noise term with standard deviation std.

$$R = f(SSB)\ e^{(std\ NORM(0,1))} \qquad \text{Eq. 21}$$

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, σ^2_{SRs} (Eq. 19)

Application of the noise function for the lognormal distributed recruitment gives on average a 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).

$$R = f(SSB)\ e^{(std\ NORM(0,1))}\ e^{\left(-(std^2/2)\right)} \qquad \text{Eq. 22}$$

8.5.2 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.

8.6 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 include a medium complex North Sea configuration (nine species, of which four are predators and eight species 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 actually works as intended and to investigate model sensitivity with respect to 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:

1) Estimate model parameters using the SMS model and available North Sea data.
2) Generate 100 set of input data from SMS output (expected catch numbers, survey indices and stomach observations) and their associated variance of these values).
3) 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, $\hat{\theta}_j = (\hat{\theta}_{1,j}, \dots, \hat{\theta}_{k,j}),\ j = 1, \dots, k$. 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. 12 and Eq. 13), 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 the long list of available diagnostics tools, e.g. residuals 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 are 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:

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

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

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

it is well known that $STOM_r$ follows the Dirichlet distribution. We now assume that 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 mean that V is our new residuals for stomach contents observations.

To obtain the absolute weight of the prey entities form the relative stomach content, $STOM$, we have to know the total stomach weight for 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.

8.7 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:

1) 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).

2) 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.

3) 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 crash are avoided.

8.8 References

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Appendix 1. Notation, parameters and variables

Indices

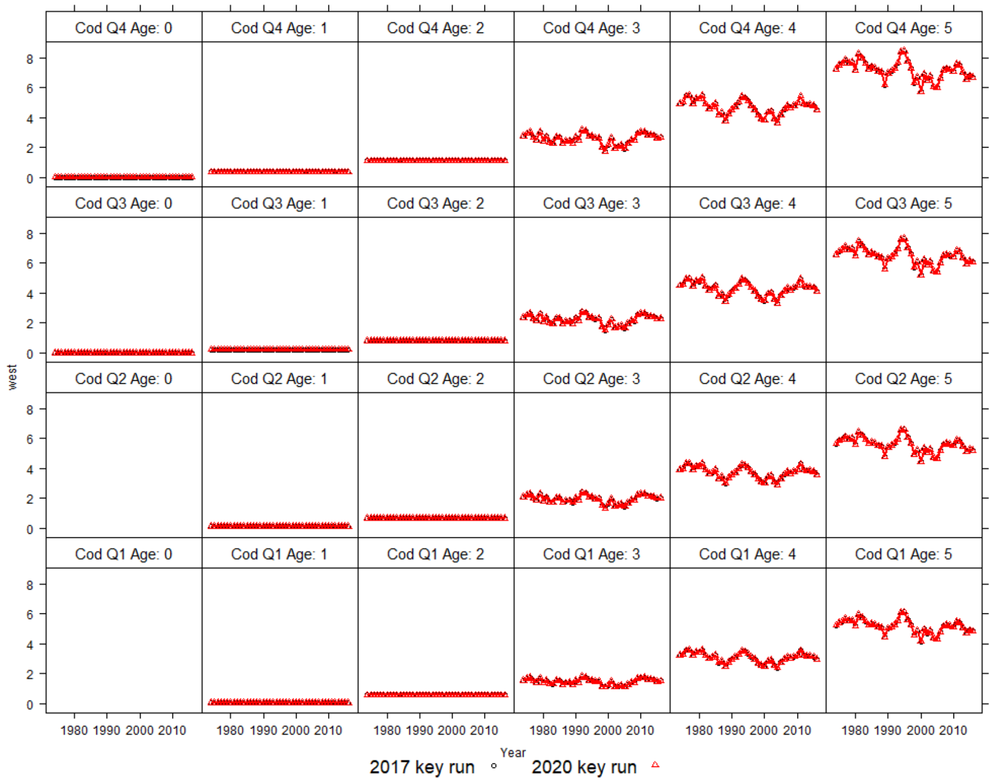
a	age
area	area with specific predation mortality
A1, A2	group of ages
Fa	first age group in the model
i	prey entity, combination of prey species and prey size group
j	predator entity, combination of predator group and predator size group
l	species size class
lpred	predator size class
lprey	prey size 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 identifer
y	year
Y	group of years

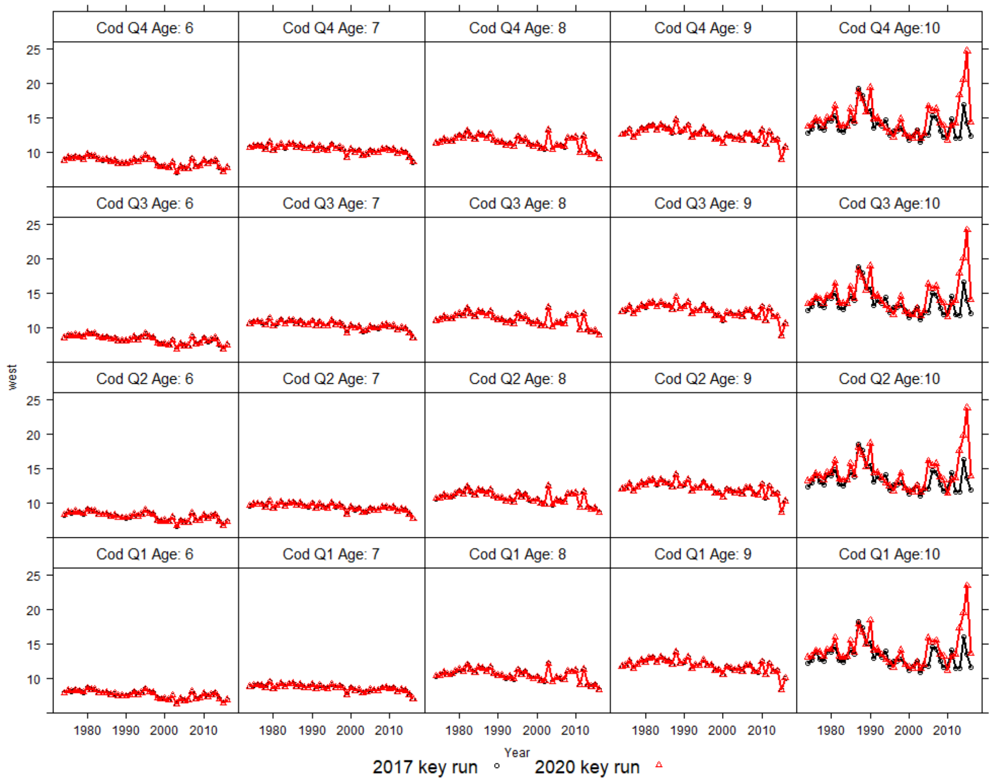
Parameters and variables

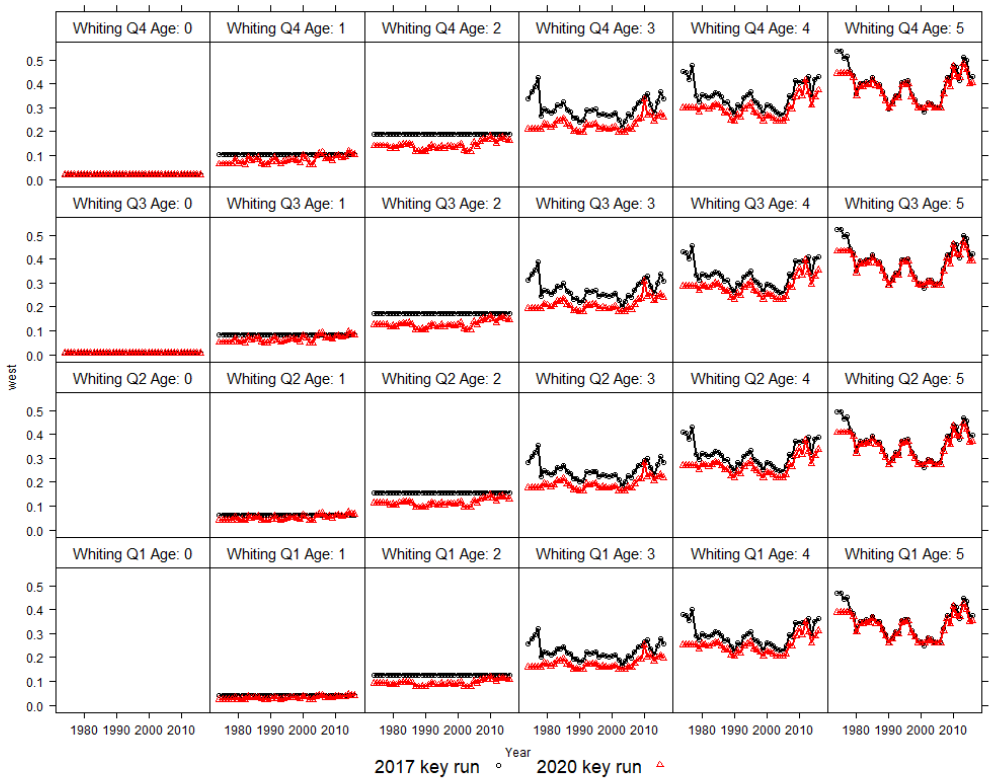
AB	available (suitable) prey biomass for a predator
ALK	proportion at-size for a given age group. Input
C	catch in numbers. Observations
Cpue	catch in numbers per unit of effort. Observations
D	number died
DM1	number died due to M1
DM2	number died due to M2
DF	number died due to F
F	instantaneous rate 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
$\eta PREF$	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
$\sigma CATCH$	standard deviation of catch observations. Estimated parameter
$\sigma PREF$	parameter expressing how particular a predator is about the size of its prey. Parameter
σSR	standard deviation of stock–recruitment estimate. Estimated parameter
$\sigma STOM$	standard deviation of stomach content observations (used with lognormal distribution)
$\sigma SURVEY$	standard deviation of survey cpue observations. Estimated parameter

9 APPENDIX 2: Mean weight-at-age in the sea



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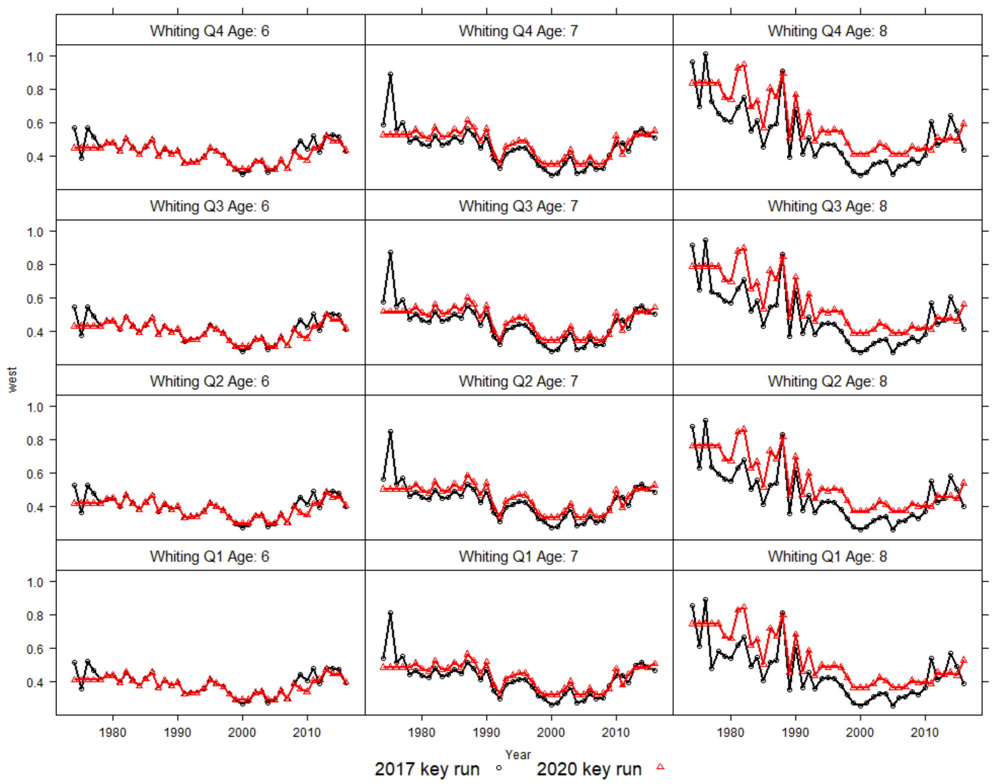
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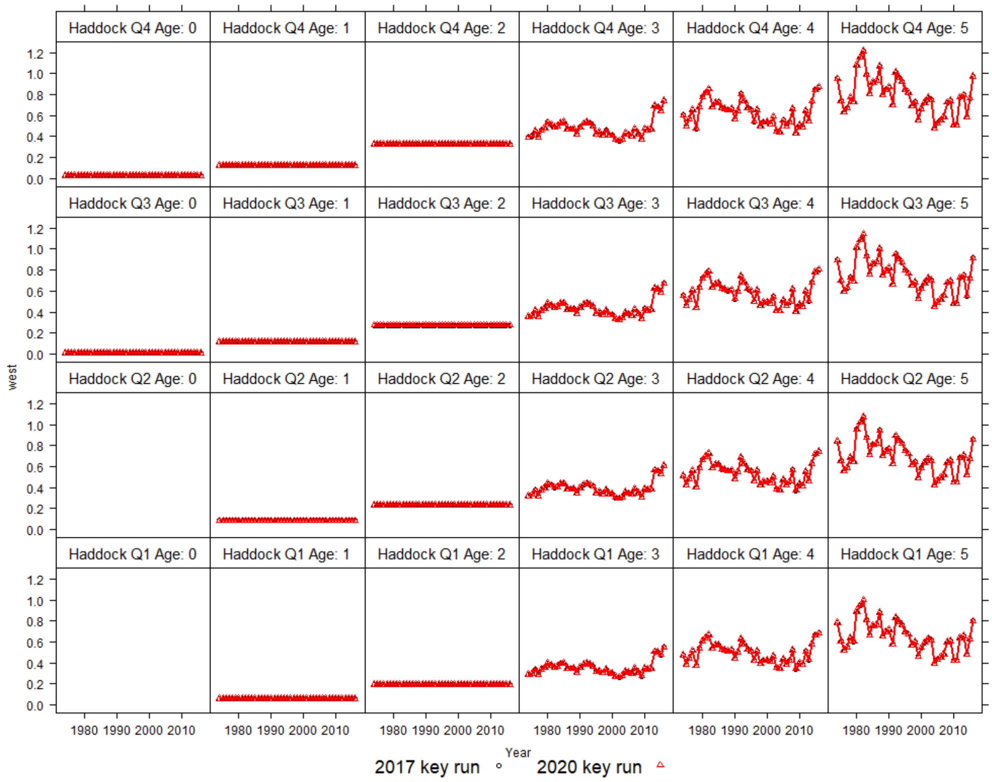
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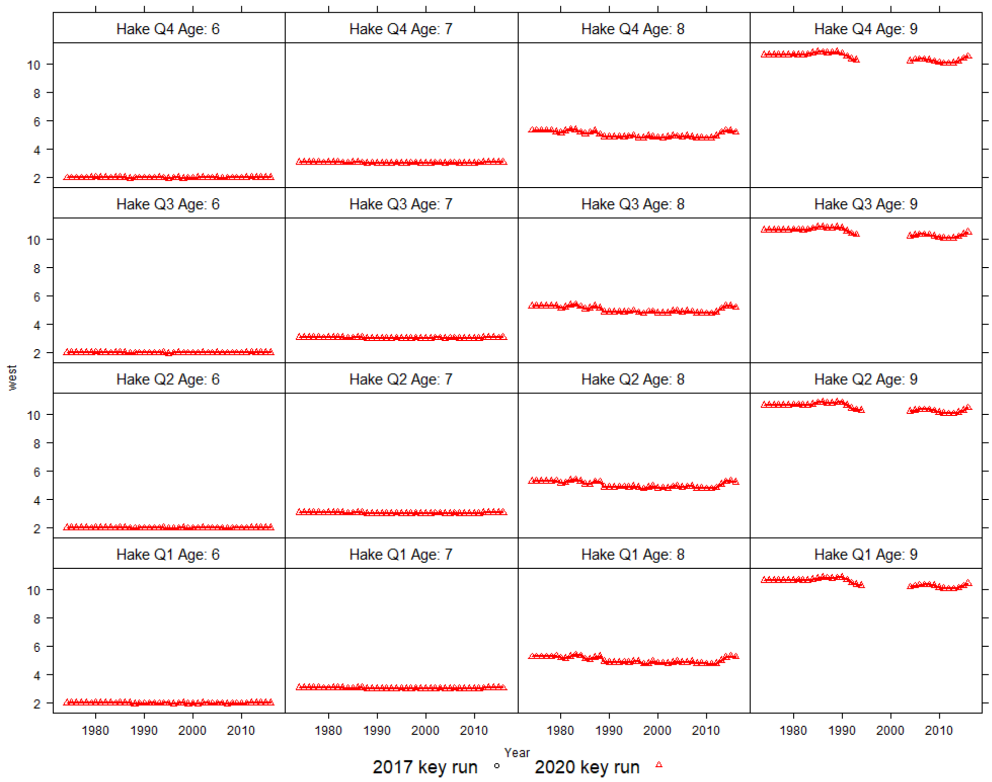
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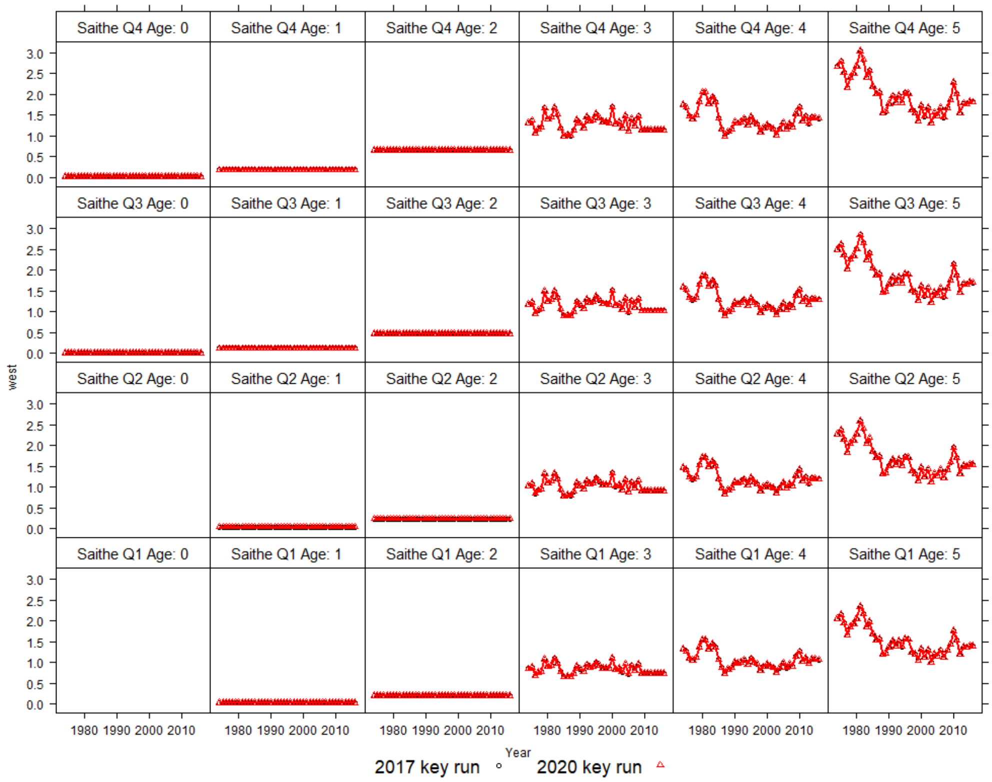
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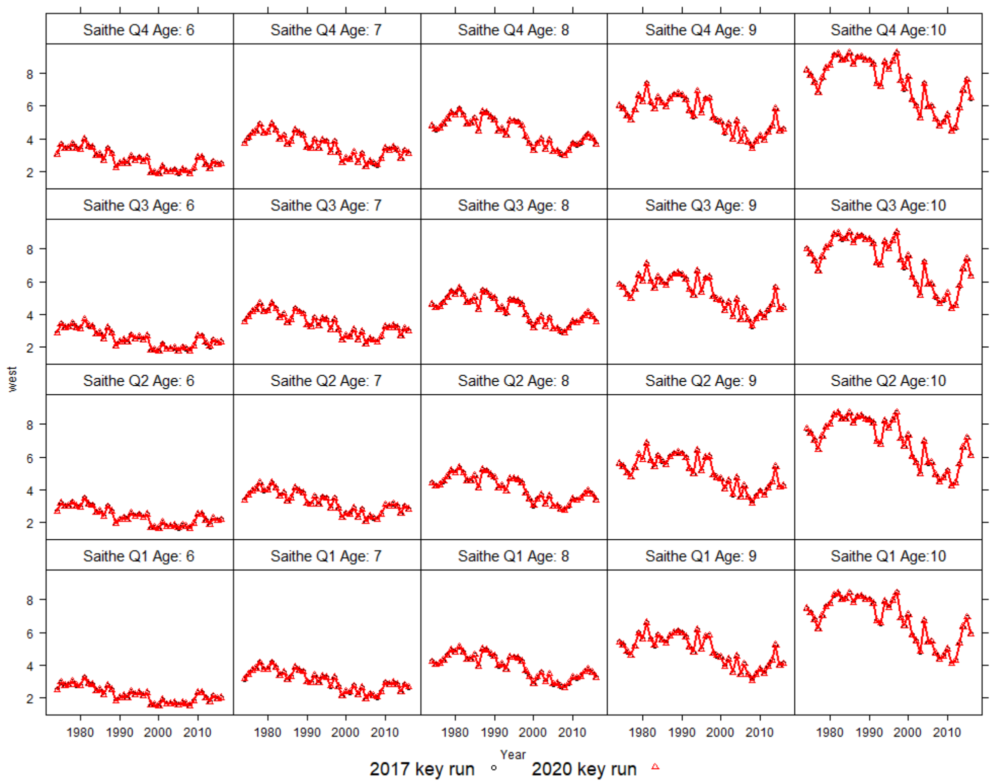
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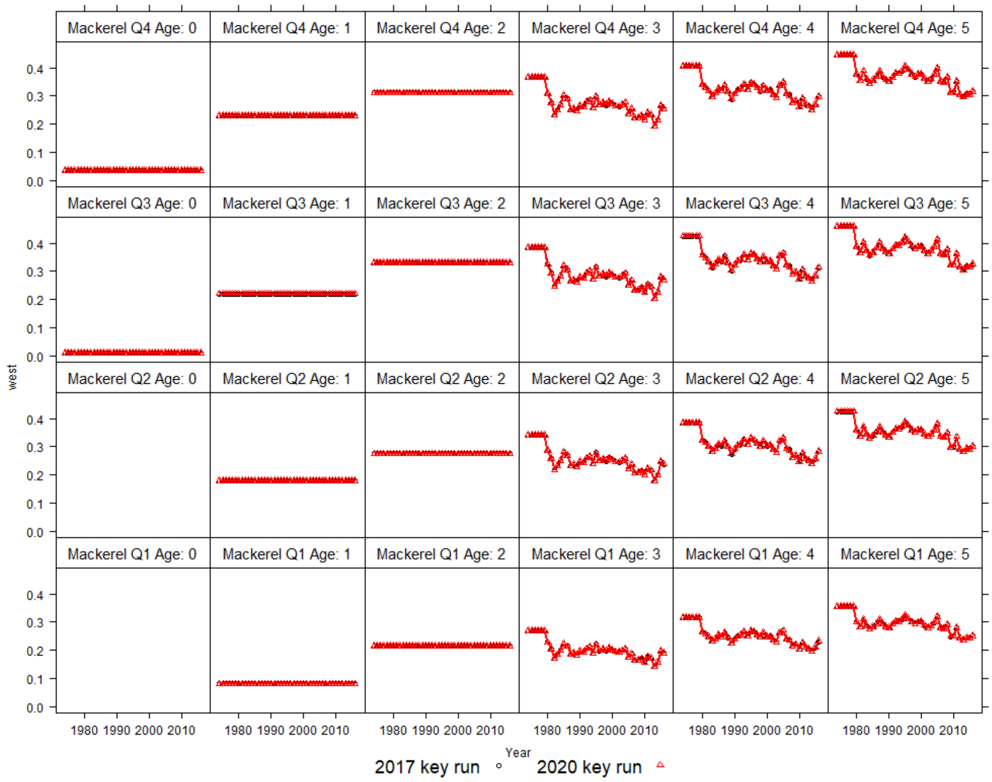

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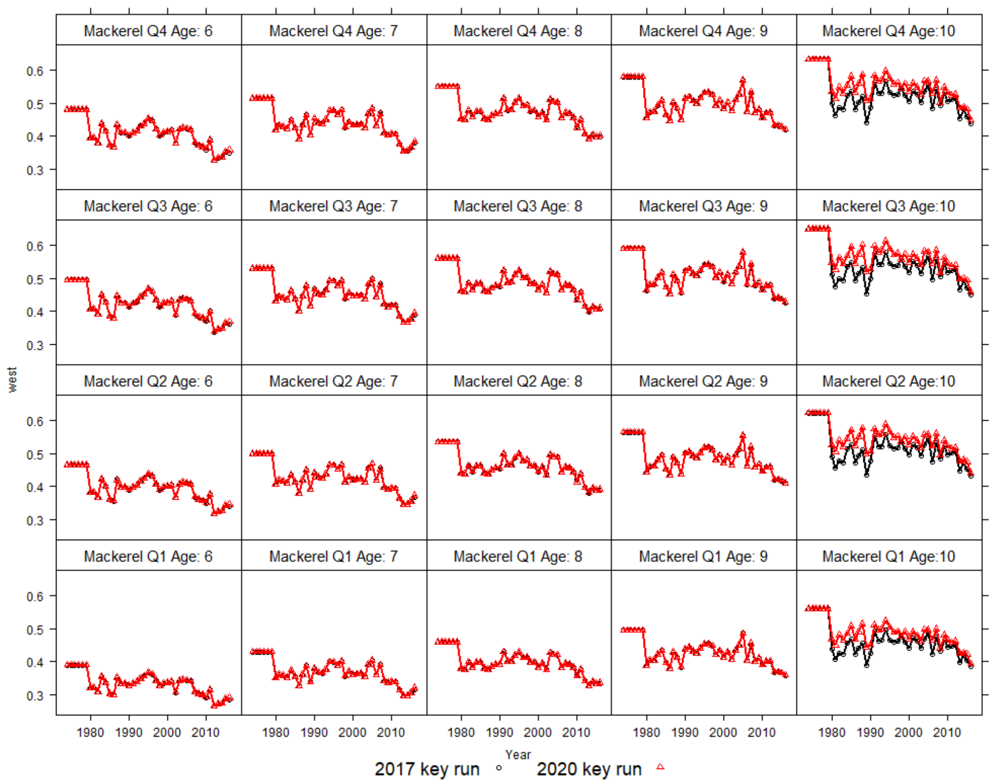

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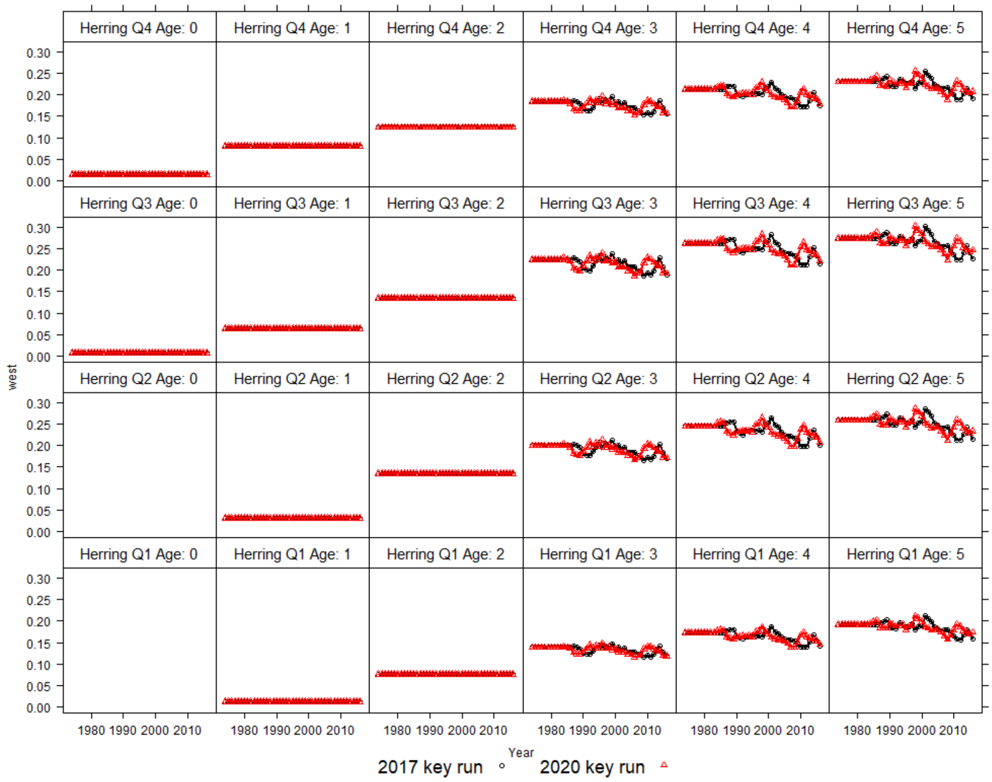
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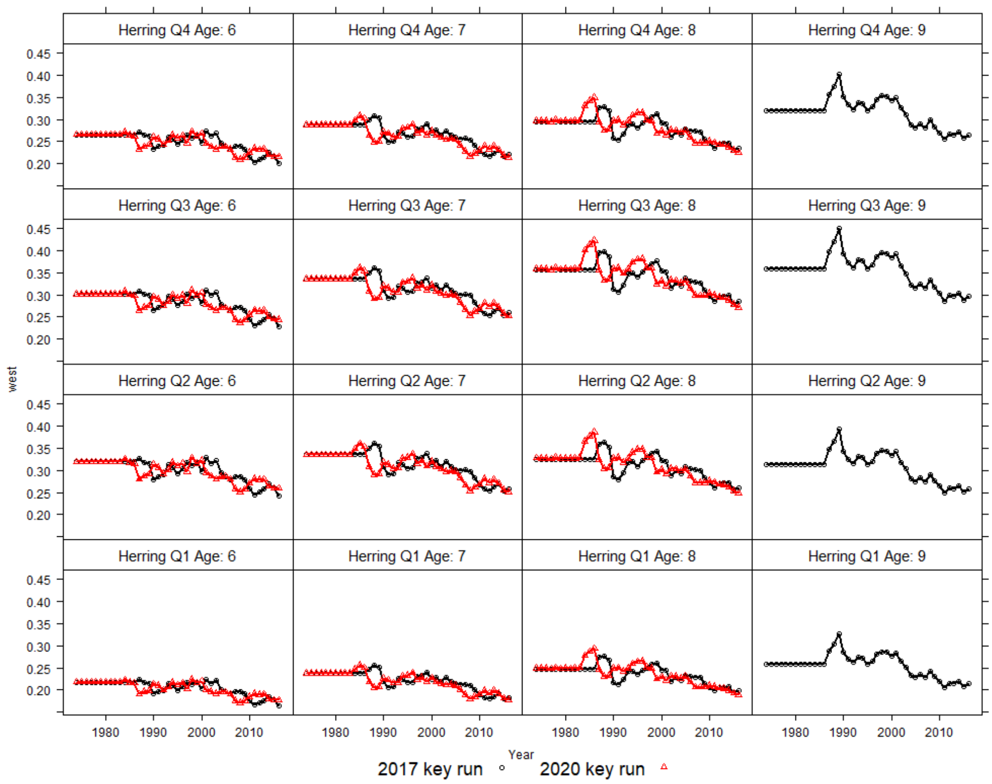
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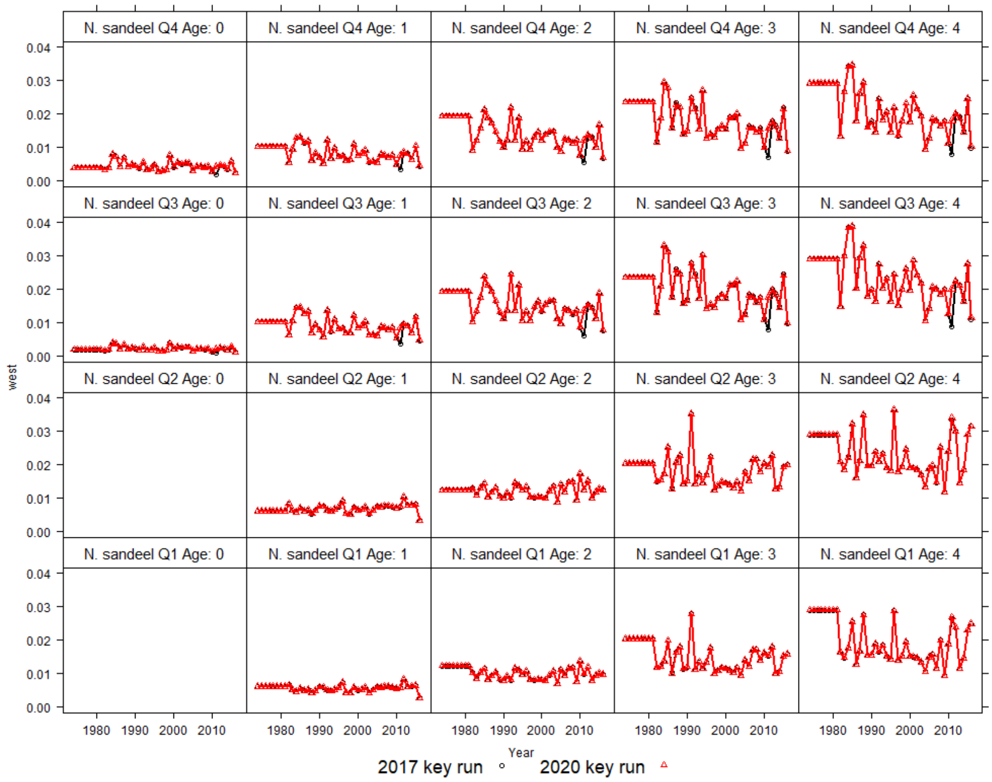
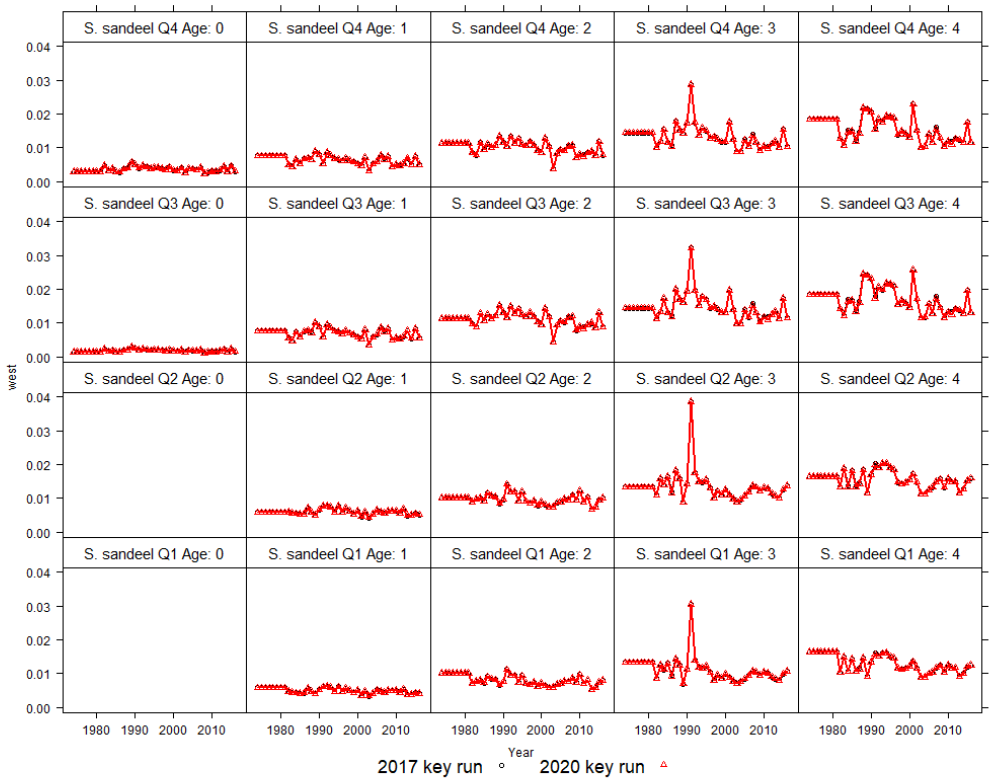
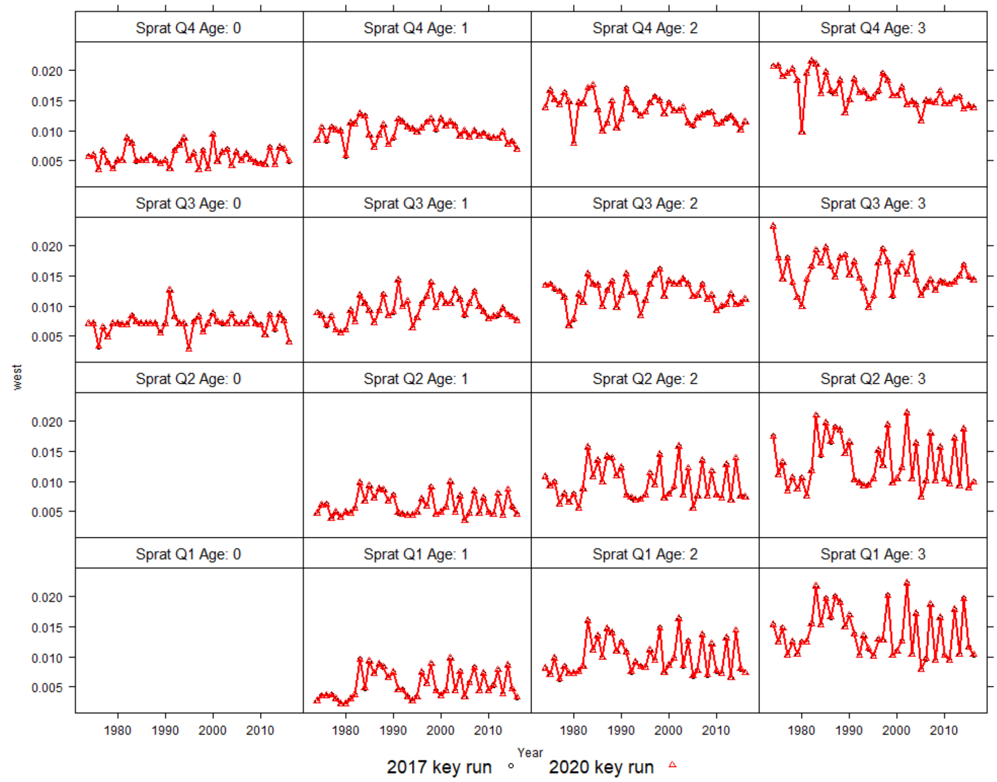
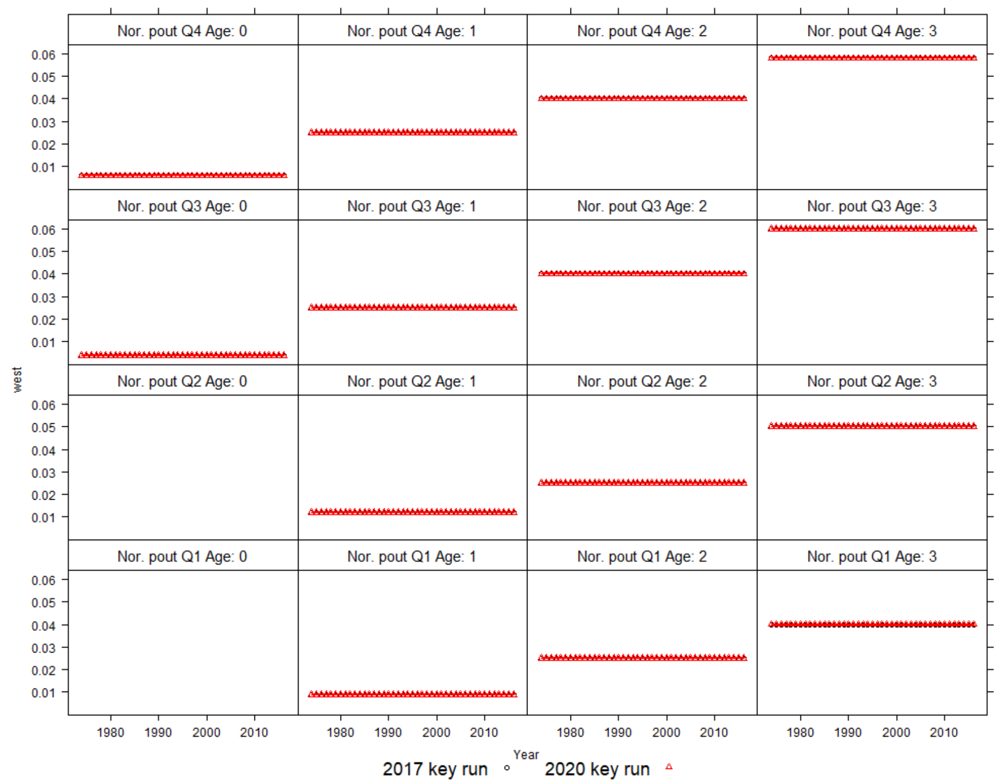
2017 key run
2020 key run


N. sandeel Q4 Age: 0
N. sandeel Q4 Age: 1
N. sandeel Q4 Age: 2
N. sandeel Q4 Age: 3
N. sandeel Q4 Age: 4
N. sandeel Q3 Age: 0
N. sandeel Q3 Age: 1
N. sandeel Q3 Age: 2
N. sandeel Q3 Age: 3
N. sandeel Q3 Age: 4
N. sandeel Q2 Age: 0
N. sandeel Q2 Age: 1
N. sandeel Q2 Age: 2
N. sandeel Q2 Age: 3
N. sandeel Q2 Age: 4
N. sandeel Q1 Age: 0
N. sandeel Q1 Age: 1
N. sandeel Q1 Age: 2
N. sandeel Q1 Age: 3
N. sandeel Q1 Age: 4
west
0.00
0.01
0.02
0.03
0.04
1980 1990 2000 2010
Year
2017 key run
2020 key run

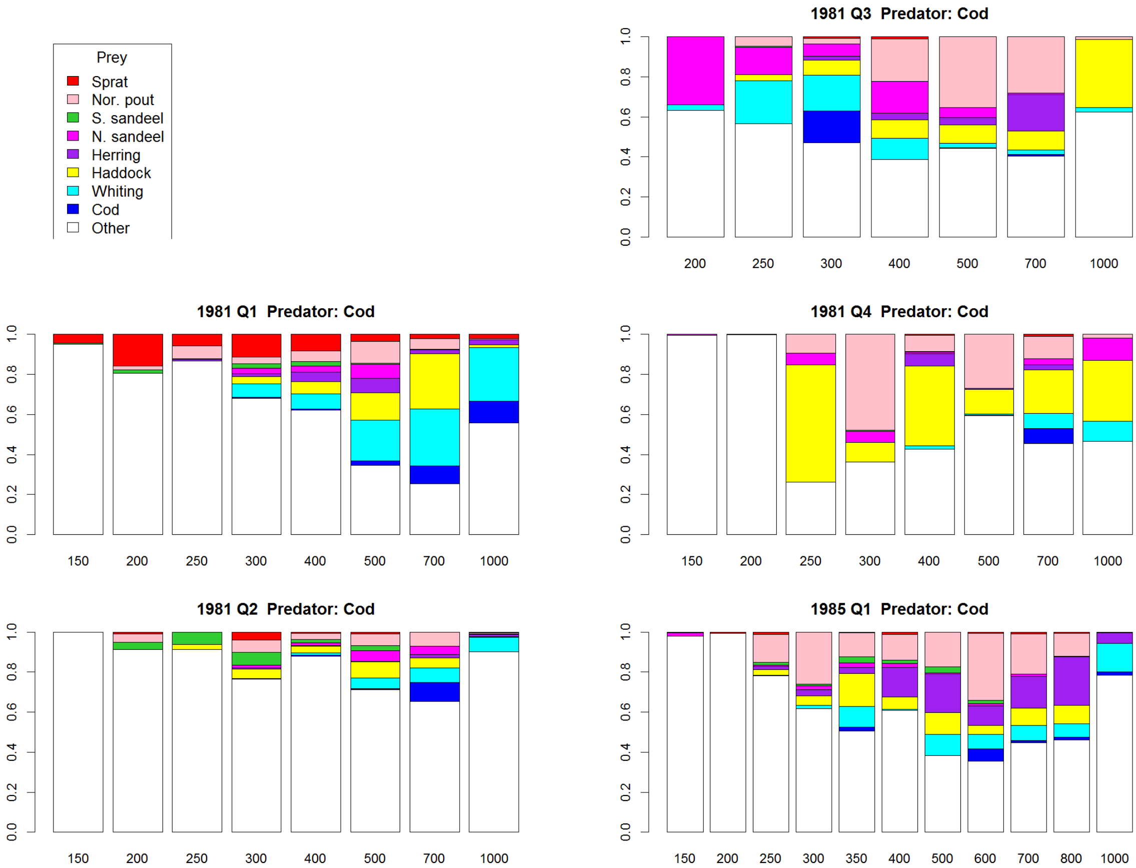

S. sandeel Q4 Age: 0
S. sandeel Q4 Age: 1
S. sandeel Q4 Age: 2
S. sandeel Q4 Age: 3
S. sandeel Q4 Age: 4
S. sandeel Q3 Age: 0
S. sandeel Q3 Age: 1
S. sandeel Q3 Age: 2
S. sandeel Q3 Age: 3
S. sandeel Q3 Age: 4
S. sandeel Q2 Age: 0
S. sandeel Q2 Age: 1
S. sandeel Q2 Age: 2
S. sandeel Q2 Age: 3
S. sandeel Q2 Age: 4
S. sandeel Q1 Age: 0
S. sandeel Q1 Age: 1
S. sandeel Q1 Age: 2
S. sandeel Q1 Age: 3
S. sandeel Q1 Age: 4
west
0.00
0.01
0.02
0.03
0.04
1980 1990 2000 2010
Year
2017 key run
2020 key run


Sprat Q4 Age: 0
Sprat Q4 Age: 1
Sprat Q4 Age: 2
Sprat Q4 Age: 3
Sprat Q3 Age: 0
Sprat Q3 Age: 1
Sprat Q3 Age: 2
Sprat Q3 Age: 3
Sprat Q2 Age: 0
Sprat Q2 Age: 1
Sprat Q2 Age: 2
Sprat Q2 Age: 3
Sprat Q1 Age: 0
Sprat Q1 Age: 1
Sprat Q1 Age: 2
Sprat Q1 Age: 3
west
0.020
0.015
0.010
0.005
1980
1990
2000
2010
Year
2017 key run
2020 key run

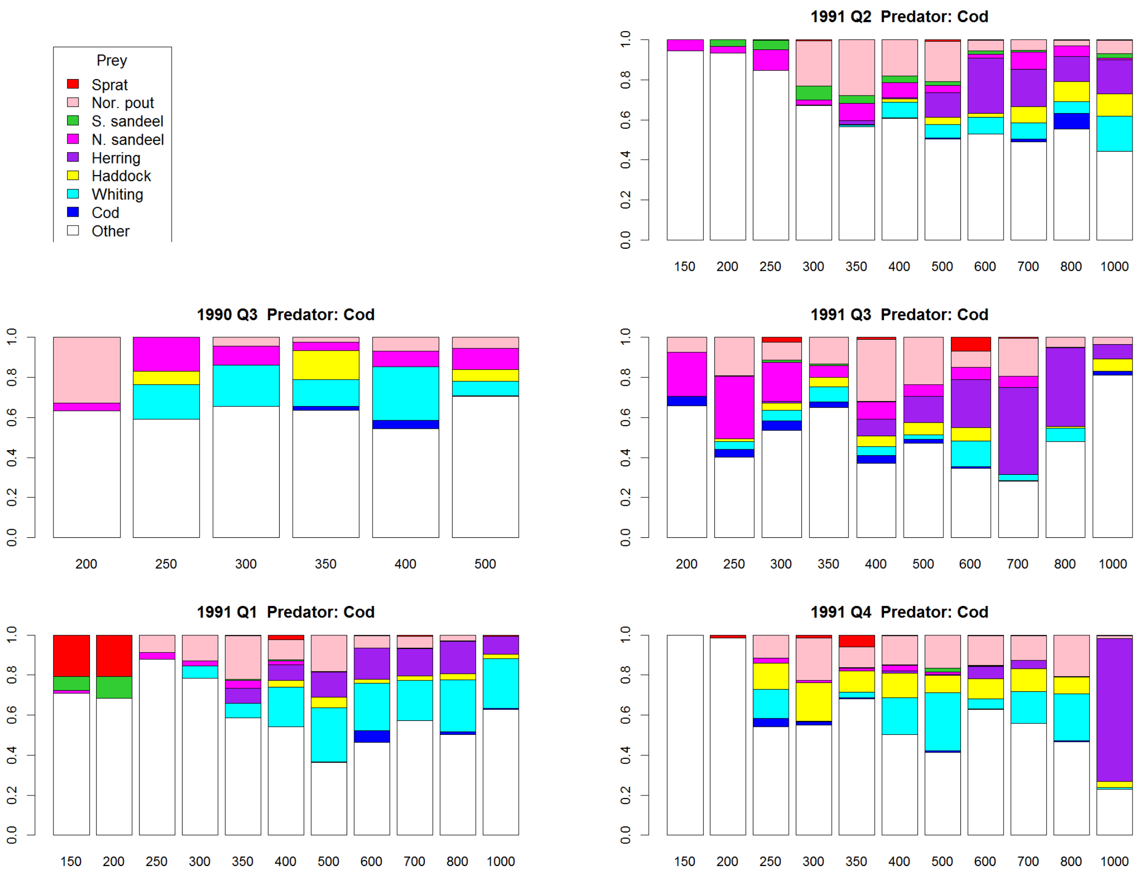

Nor. pout Q4 Age: 0
Nor. pout Q4 Age: 1
Nor. pout Q4 Age: 2
Nor. pout Q4 Age: 3
Nor. pout Q3 Age: 0
Nor. pout Q3 Age: 1
Nor. pout Q3 Age: 2
Nor. pout Q3 Age: 3
Nor. pout Q2 Age: 0
Nor. pout Q2 Age: 1
Nor. pout Q2 Age: 2
Nor. pout Q2 Age: 3
Nor. pout Q1 Age: 0
Nor. pout Q1 Age: 1
Nor. pout Q1 Age: 2
Nor. pout Q1 Age: 3
west
0.06
0.05
0.04
0.03
0.02
0.01
1980
1990
2000
2010
Year
2017 key run
2020 key run

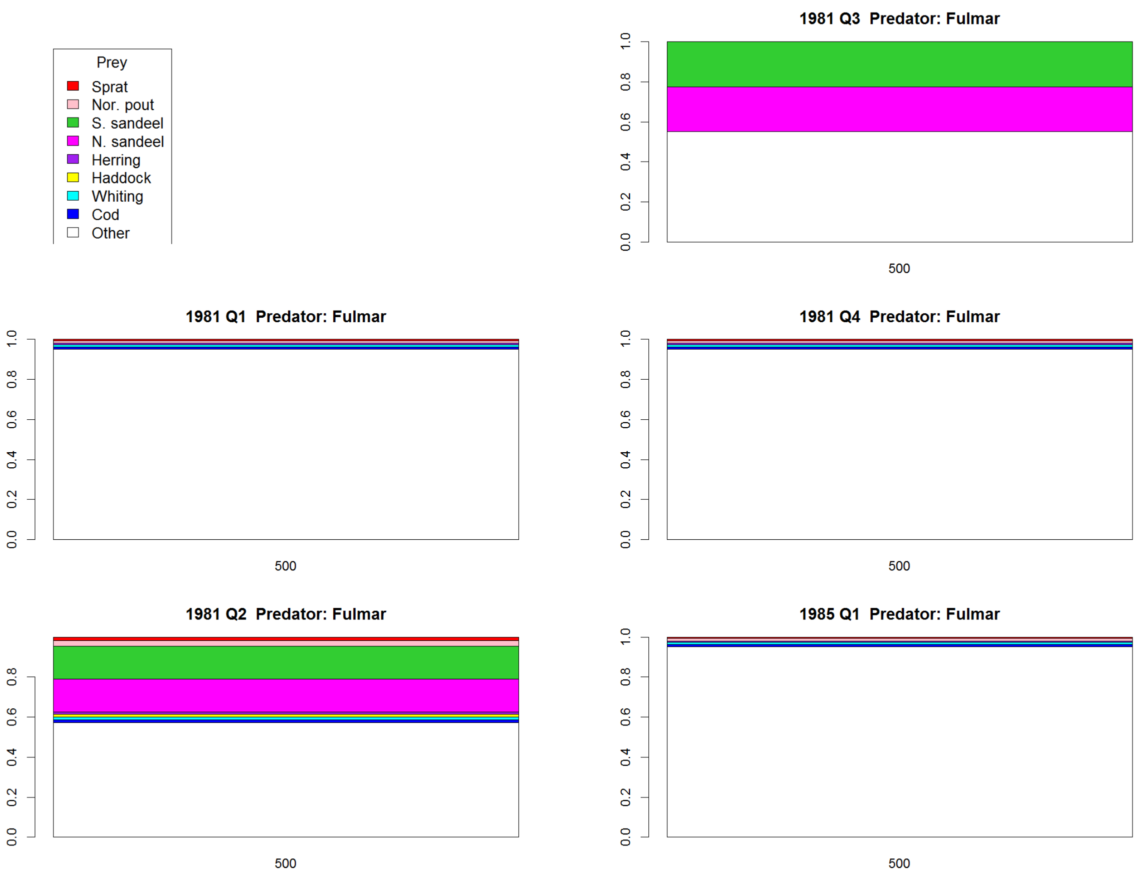
10 APPENDIX 3: Diet composition used in the model

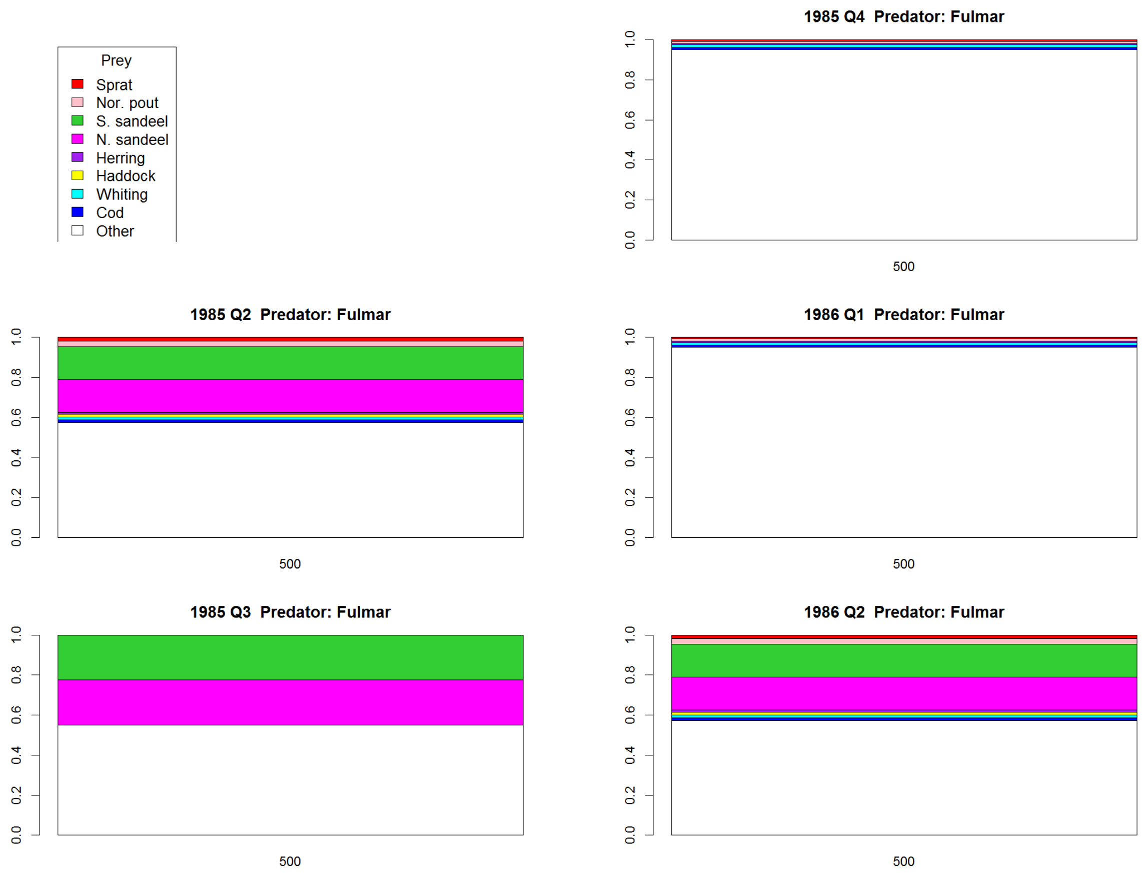
The following figures show the stomach content composition of fish and the diet composition (after correction of stomach contents for evacuation rate differences) for mammals. For each predator the stomach content is shown by observed predator size classes (showing the lower length in mm for the size class) or by dummy size class (birds and marine mammals). On the figures, all length classes of preys are merged. An example of stomach content, including prey size classes, are shown in the table at the end of this appendix.

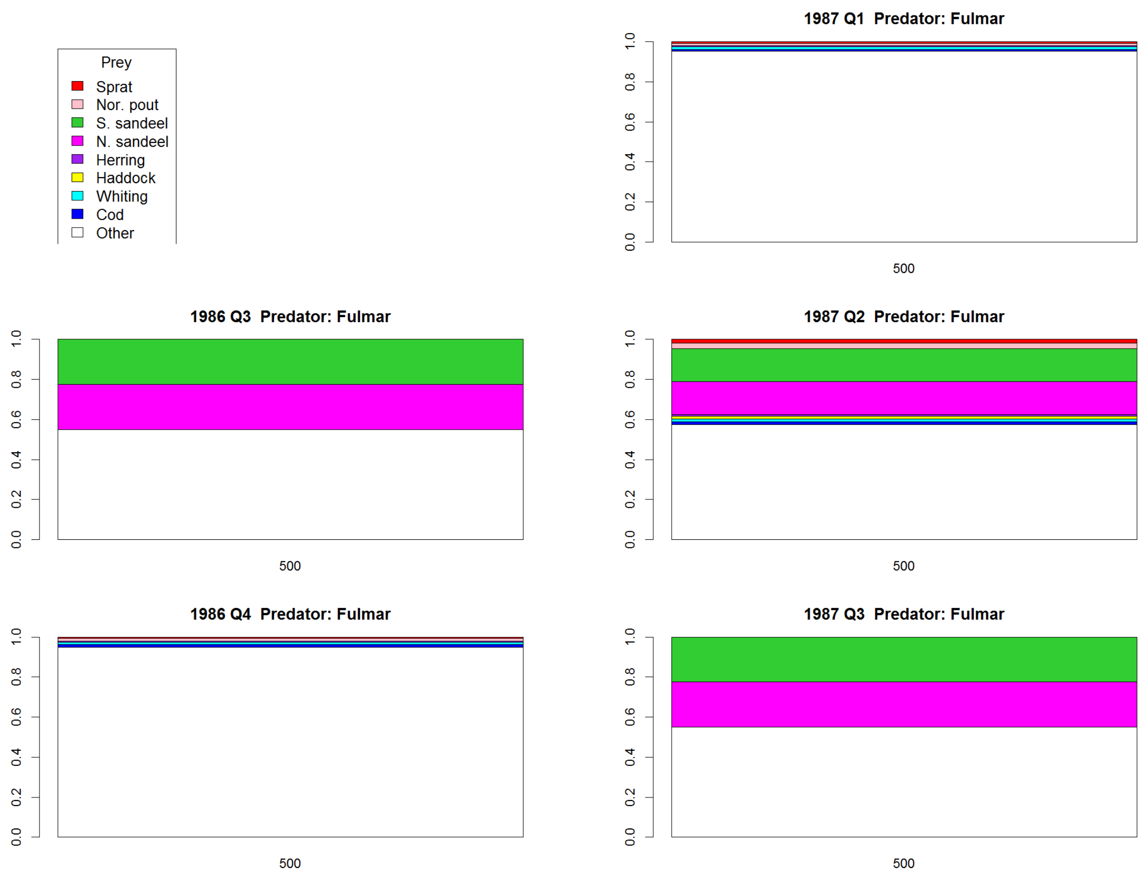

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
200 250 300 400 500 700 1000
1981 Q1 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 400 500 700 1000
1981 Q4 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 400 500 700 1000
1981 Q2 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 400 500 700 1000
1985 Q1 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 350 400 500 600 700 800 1000

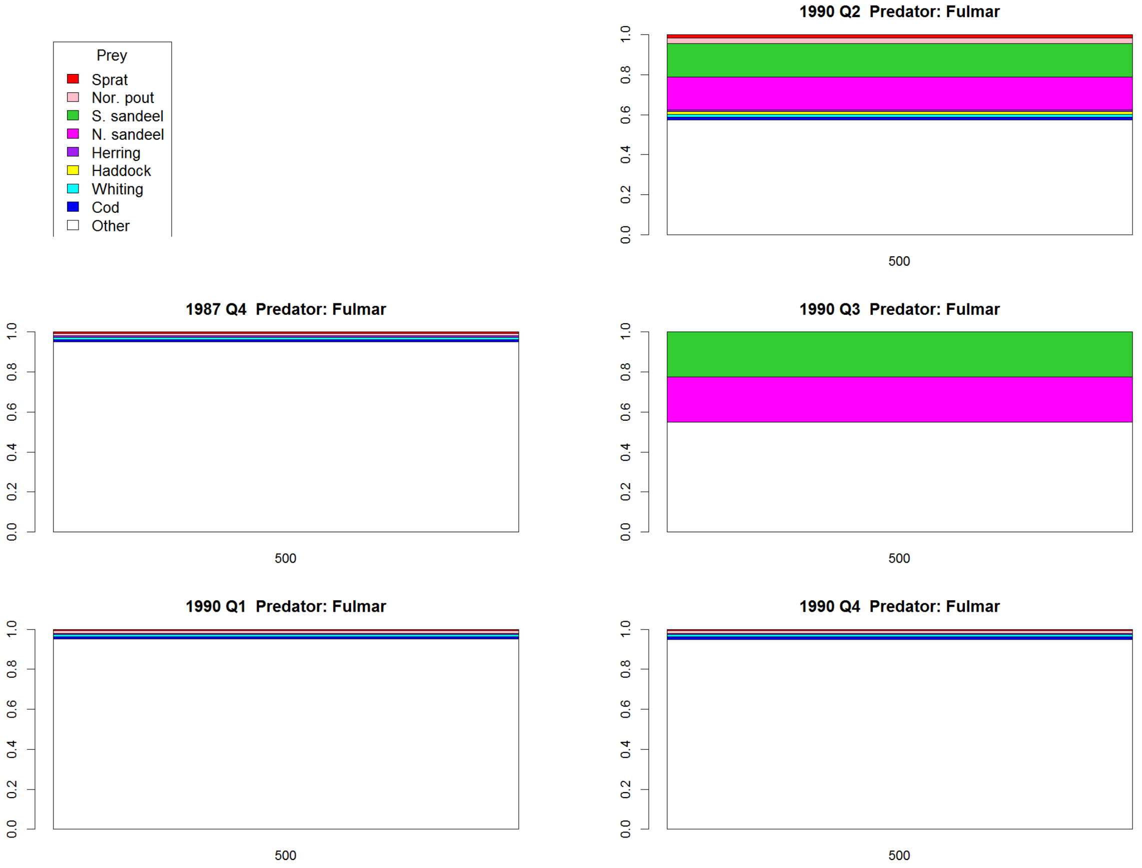

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1986 Q3 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 350 400 500 600 700 800 1000
1985 Q3 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 350 400 500 600 700 800 1000
1987 Q1 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 350 400 500 600 700 800 1000
1986 Q1 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 350 400 500 600 700 800 1000
1987 Q3 Predator: Cod
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 350 400 500 600 700 800 1000

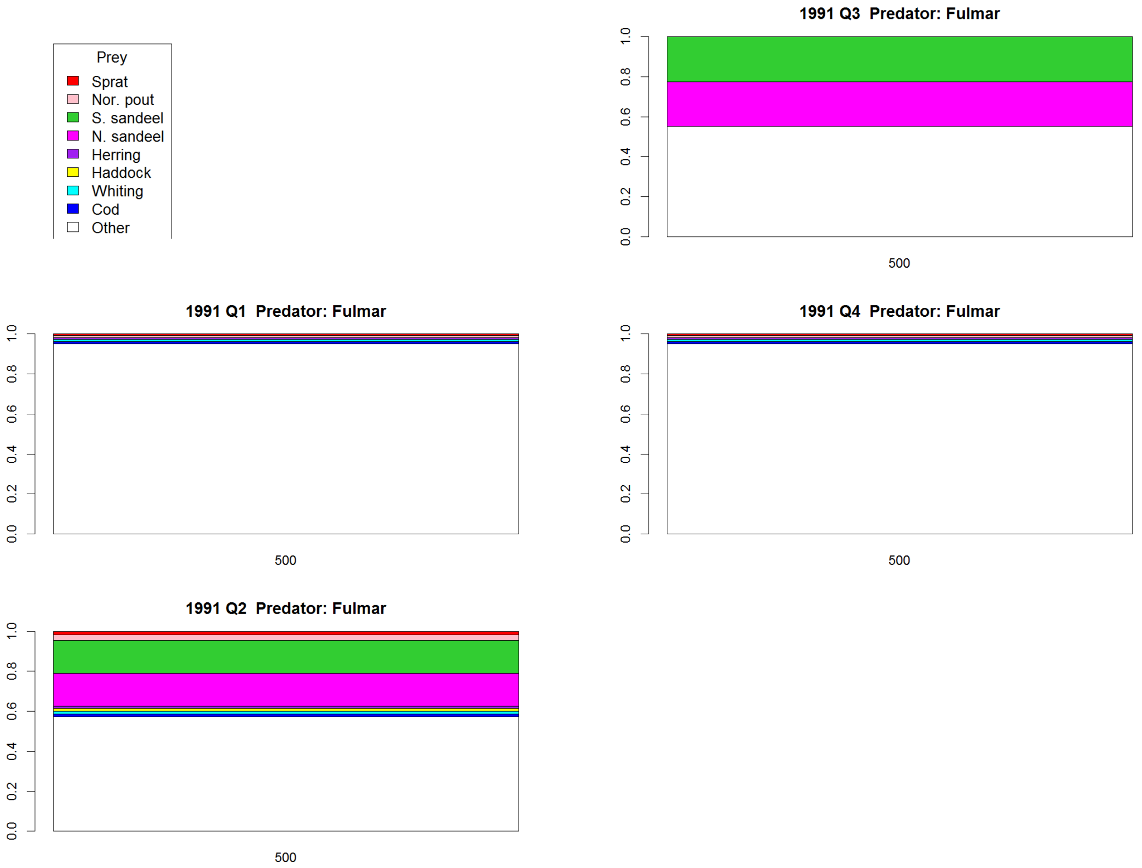

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q2 Predator: Cod
1990 Q3 Predator: Cod
1991 Q3 Predator: Cod
1991 Q1 Predator: Cod
1991 Q4 Predator: Cod
0.0
0.2
0.4
0.6
0.8
1.0
150 200 250 300 350 400 500 600 700 800 1000

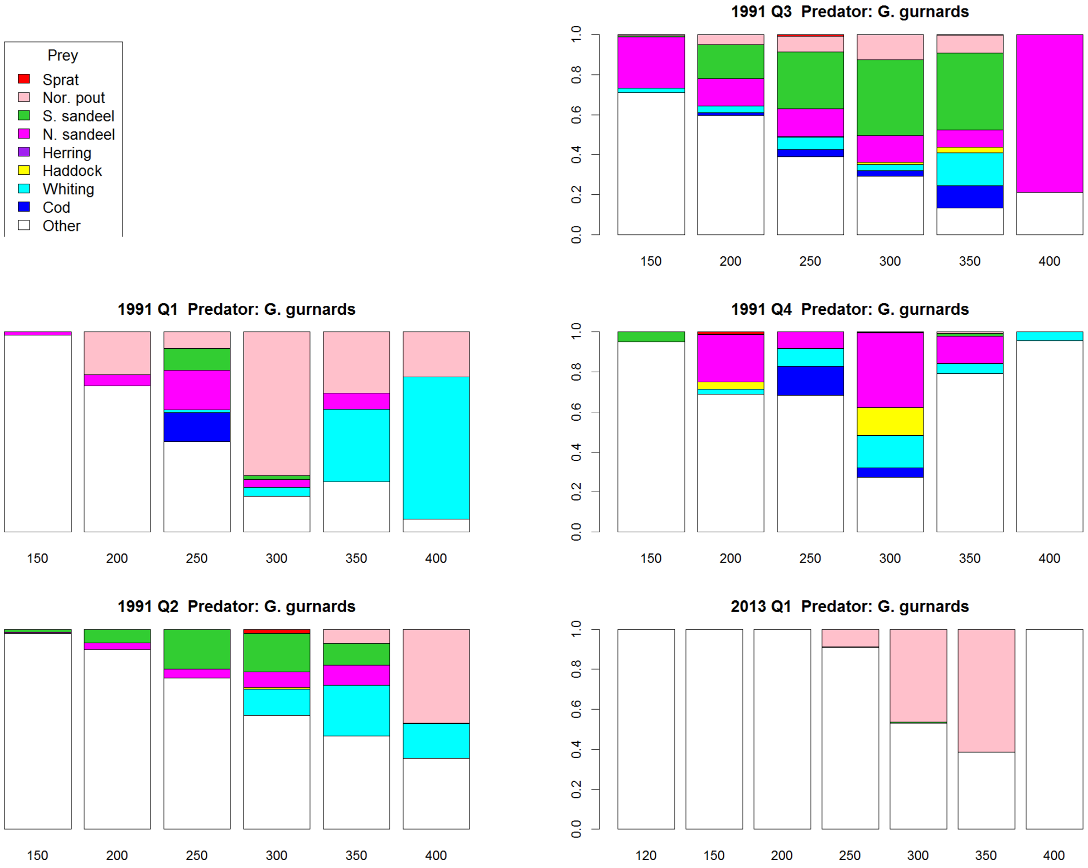

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Fulmar
1981 Q1 Predator: Fulmar
1981 Q4 Predator: Fulmar
1981 Q2 Predator: Fulmar
1985 Q1 Predator: Fulmar
0.0
0.2
0.4
0.6
0.8
1.0
500

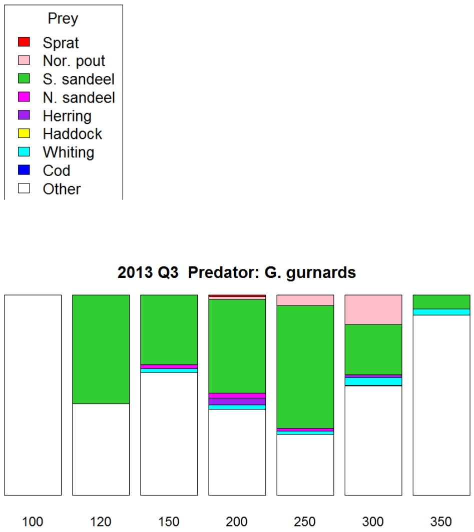

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Fulmar
1985 Q2 Predator: Fulmar
1986 Q1 Predator: Fulmar
1985 Q3 Predator: Fulmar
1986 Q2 Predator: Fulmar
0.0
0.2
0.4
0.6
0.8
1.0
500

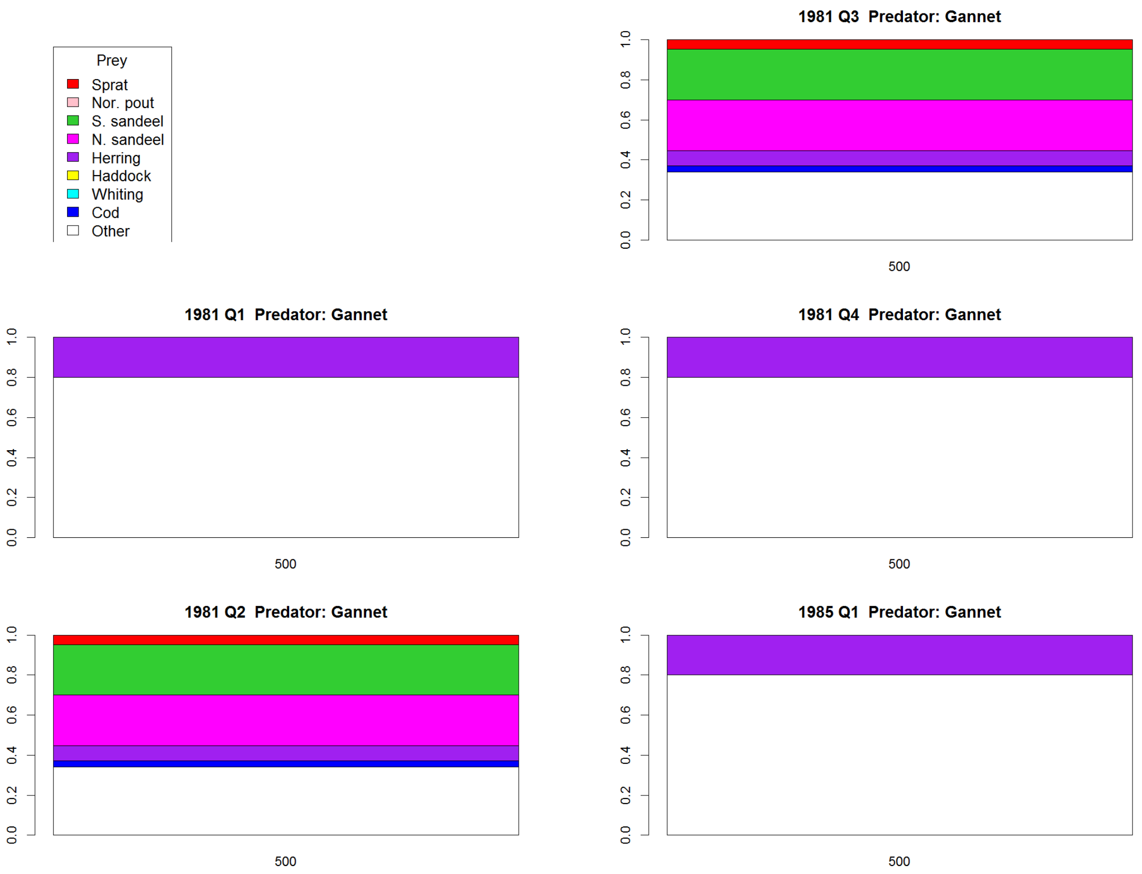

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Fulmar
1986 Q3 Predator: Fulmar
1987 Q2 Predator: Fulmar
1986 Q4 Predator: Fulmar
1987 Q3 Predator: Fulmar
0.0
0.2
0.4
0.6
0.8
1.0
500

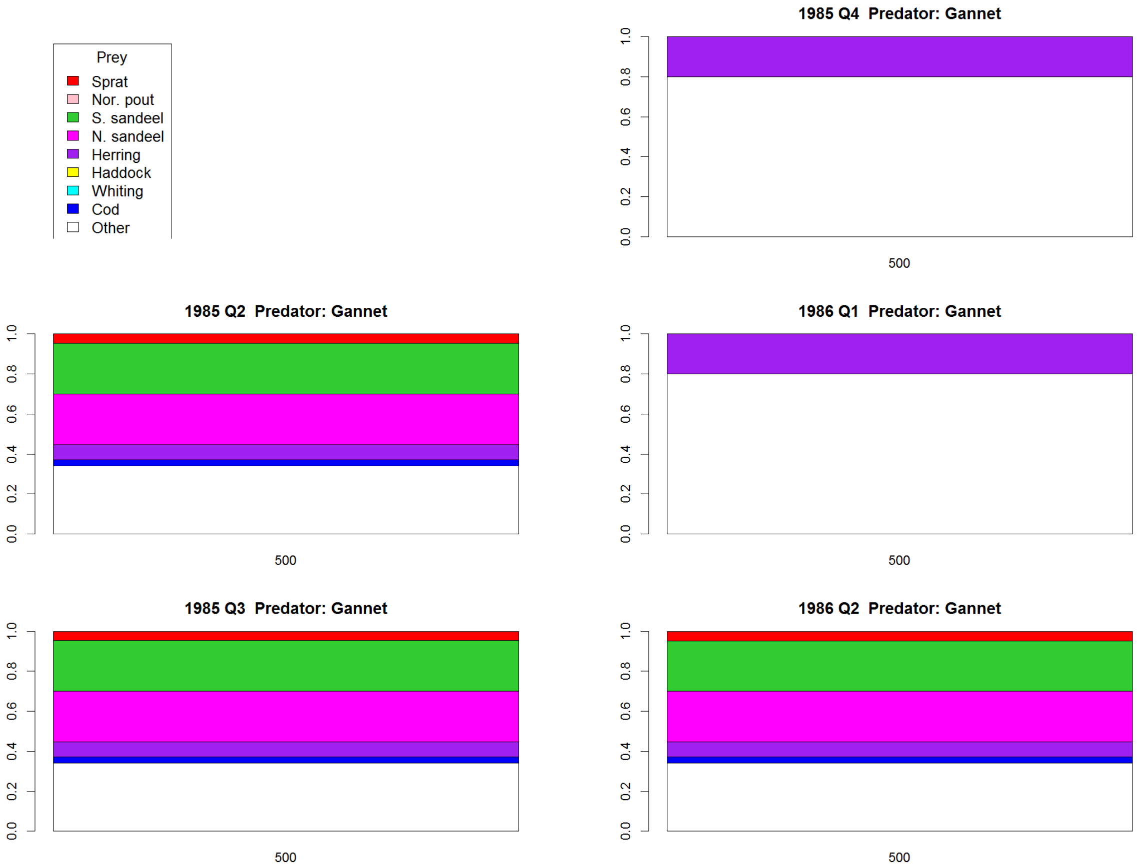

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Fulmar
1987 Q4 Predator: Fulmar
1990 Q3 Predator: Fulmar
1990 Q1 Predator: Fulmar
1990 Q4 Predator: Fulmar
0.0
0.2
0.4
0.6
0.8
1.0
500

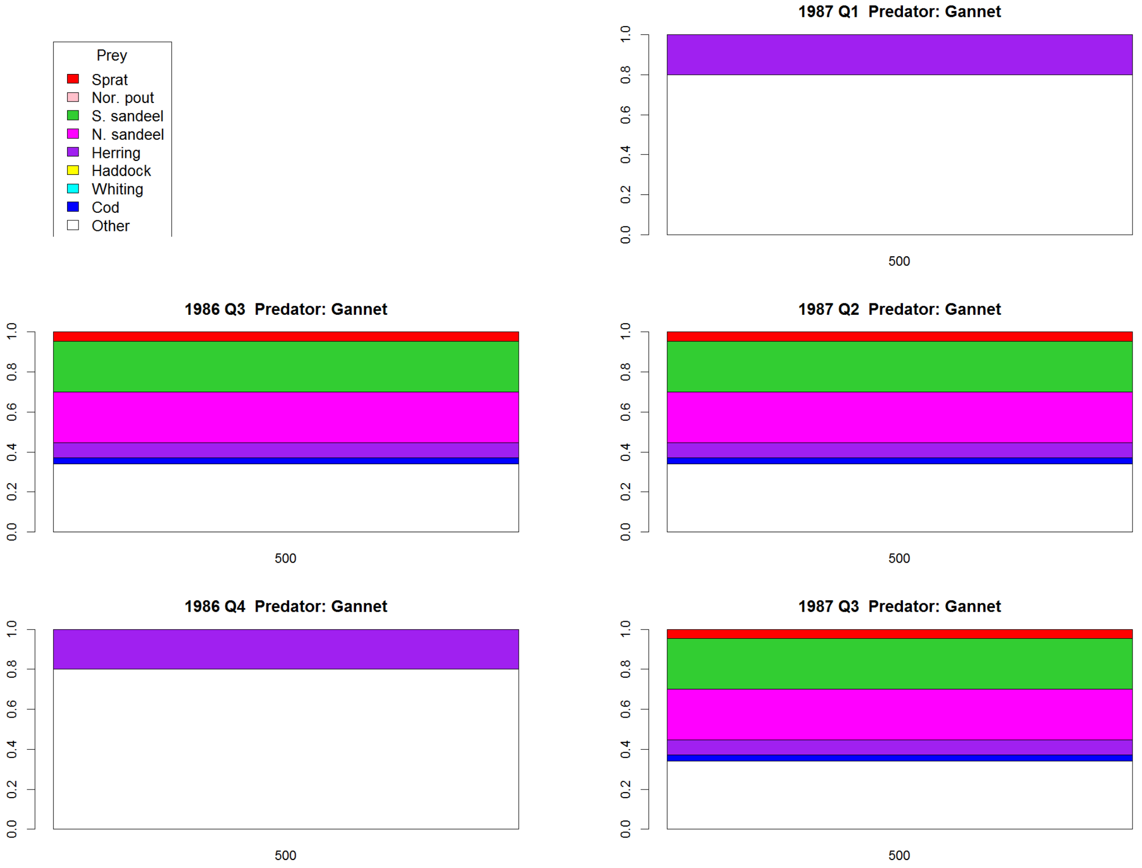

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Fulmar
1991 Q1 Predator: Fulmar
1991 Q4 Predator: Fulmar
1991 Q2 Predator: Fulmar
0.0
0.2
0.4
0.6
0.8
1.0
500

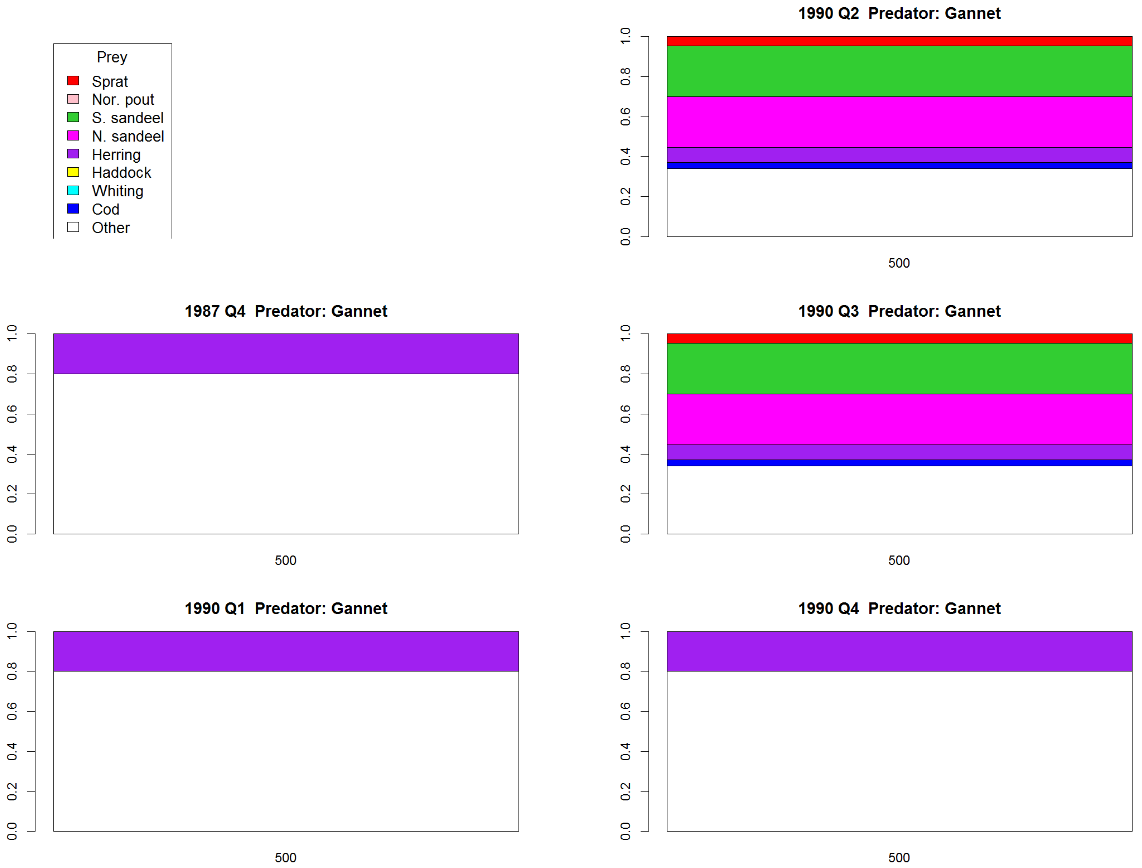

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: G. gurnards
1991 Q1 Predator: G. gurnards
1991 Q4 Predator: G. gurnards
1991 Q2 Predator: G. gurnards
2013 Q1 Predator: G. gurnards
0.0
0.2
0.4
0.6
0.8
1.0
120
150
200
250
300
350
400

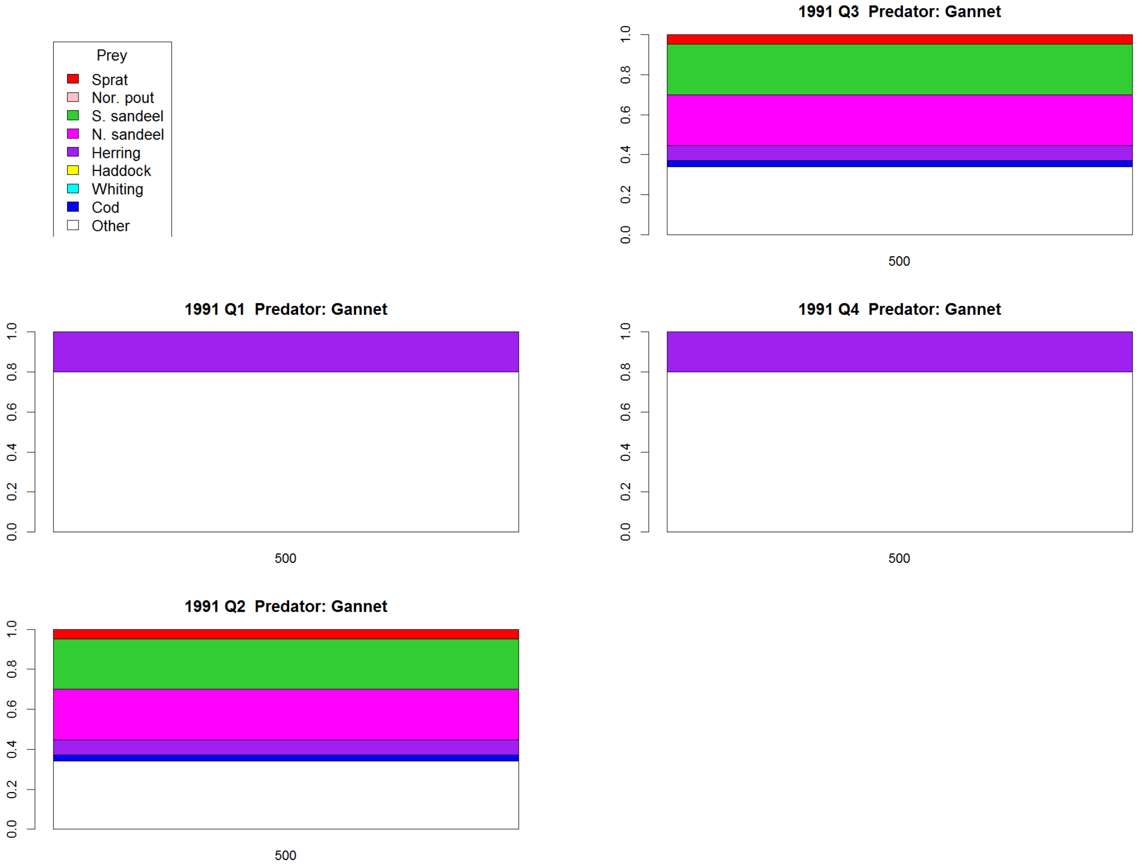

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
2013 Q3 Predator: G. gurnards
0.0
0.2
0.4
0.6
0.8
1.0
100
120
150
200
250
300
350

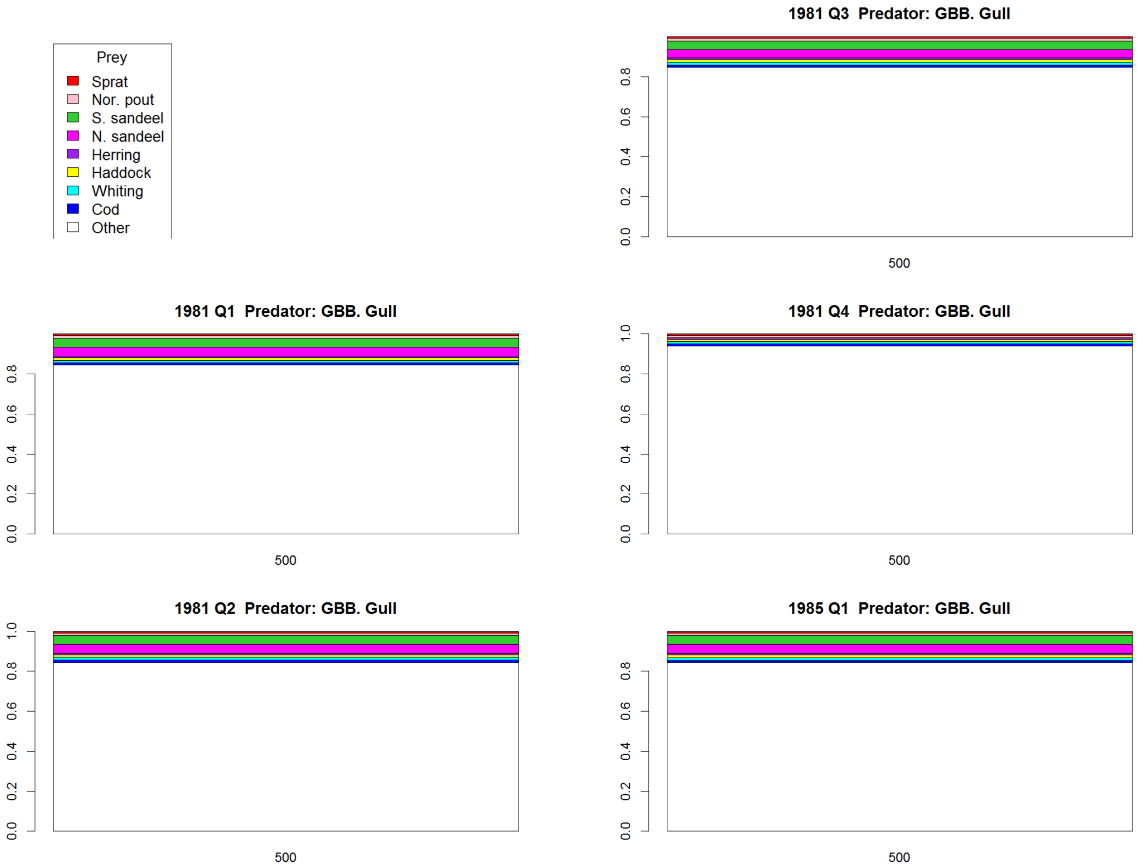

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Gannet
1981 Q1 Predator: Gannet
1981 Q4 Predator: Gannet
1981 Q2 Predator: Gannet
1985 Q1 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

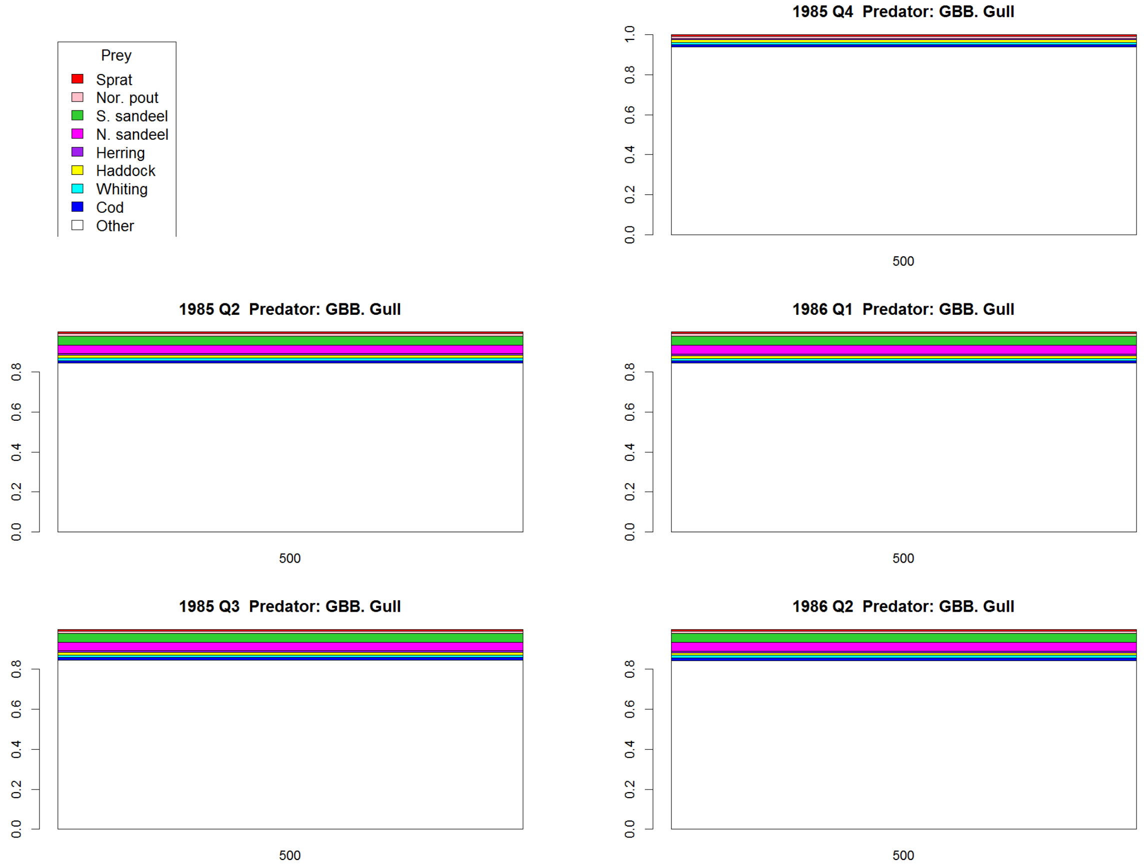

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Gannet
1985 Q2 Predator: Gannet
1986 Q1 Predator: Gannet
1985 Q3 Predator: Gannet
1986 Q2 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

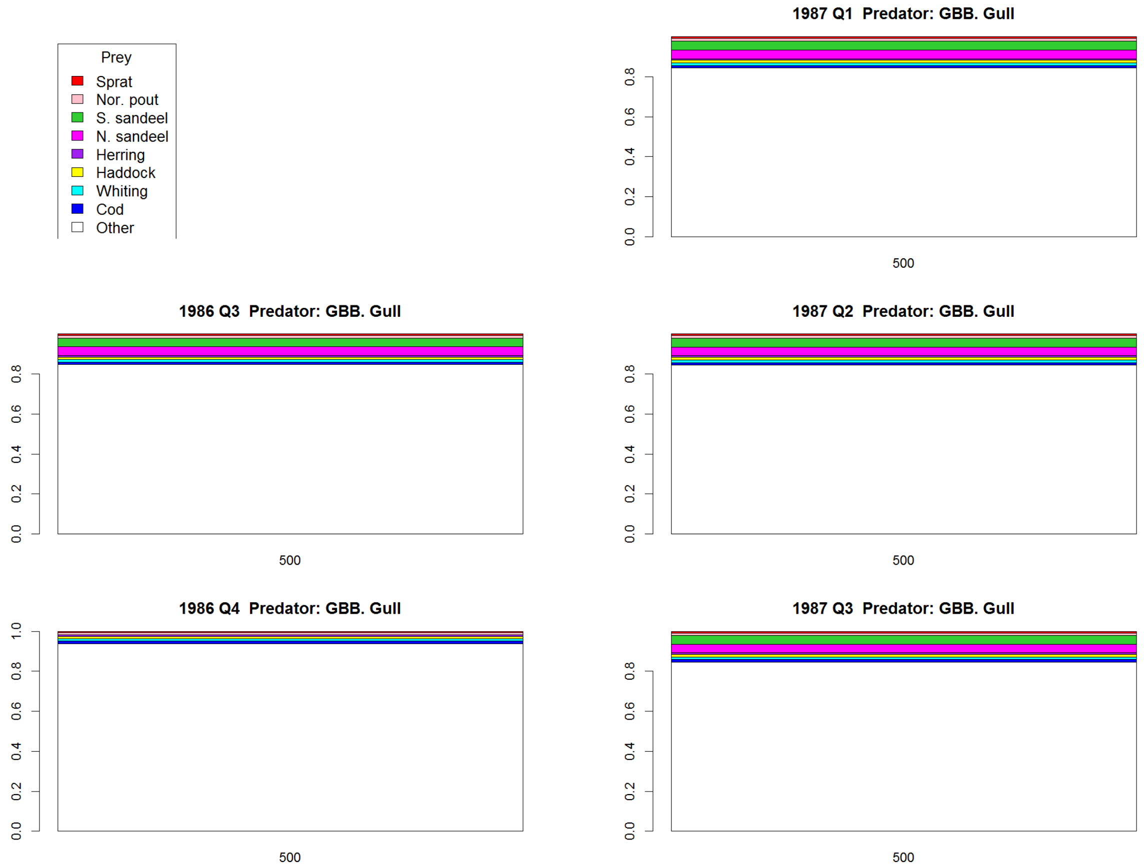

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Gannet
1986 Q3 Predator: Gannet
1987 Q2 Predator: Gannet
1986 Q4 Predator: Gannet
1987 Q3 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

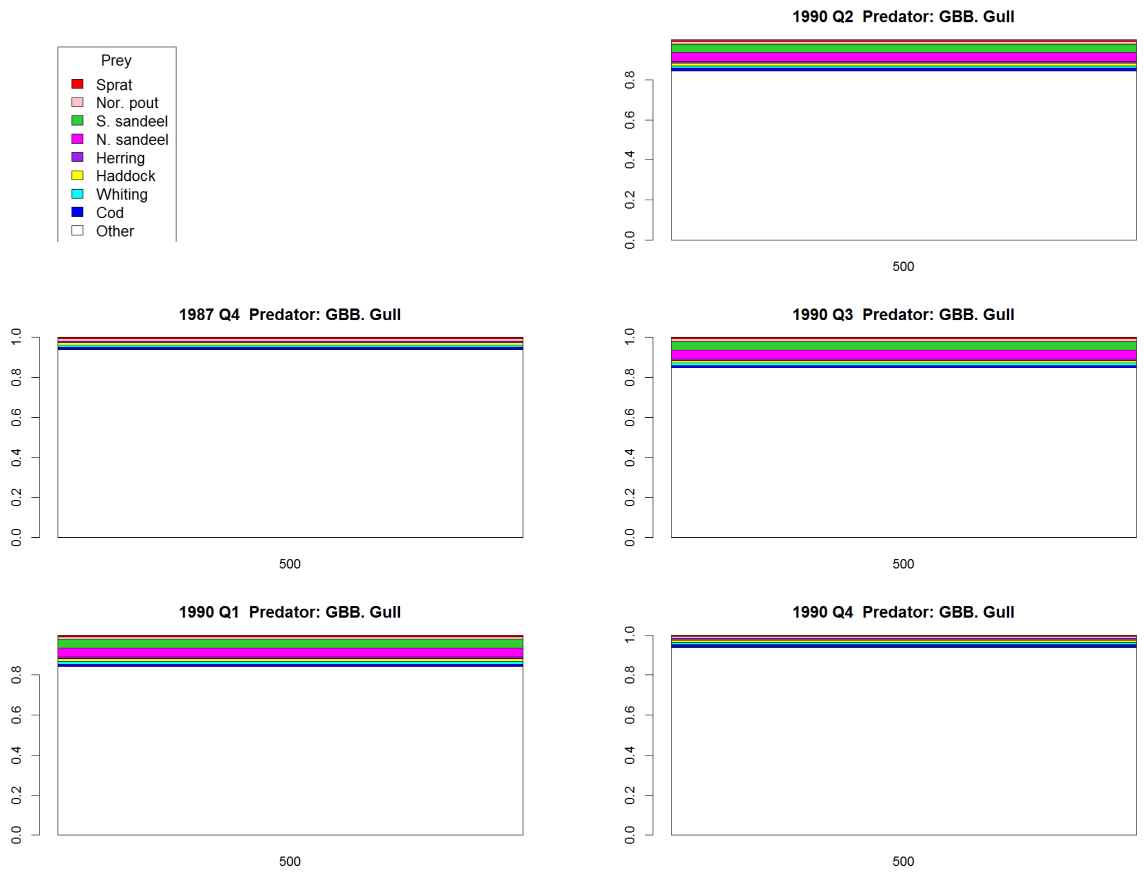

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Gannet
1987 Q4 Predator: Gannet
1990 Q3 Predator: Gannet
1990 Q1 Predator: Gannet
1990 Q4 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

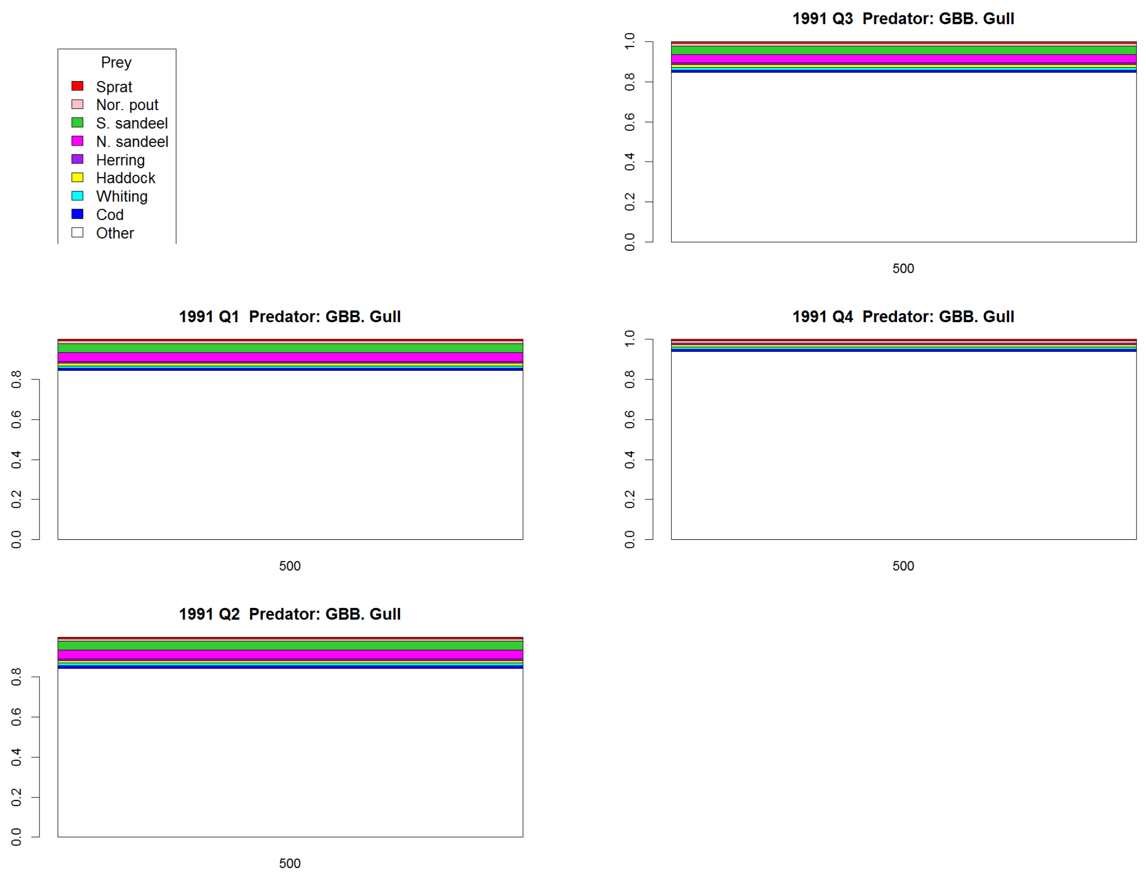

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Gannet
1991 Q1 Predator: Gannet
1991 Q4 Predator: Gannet
1991 Q2 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

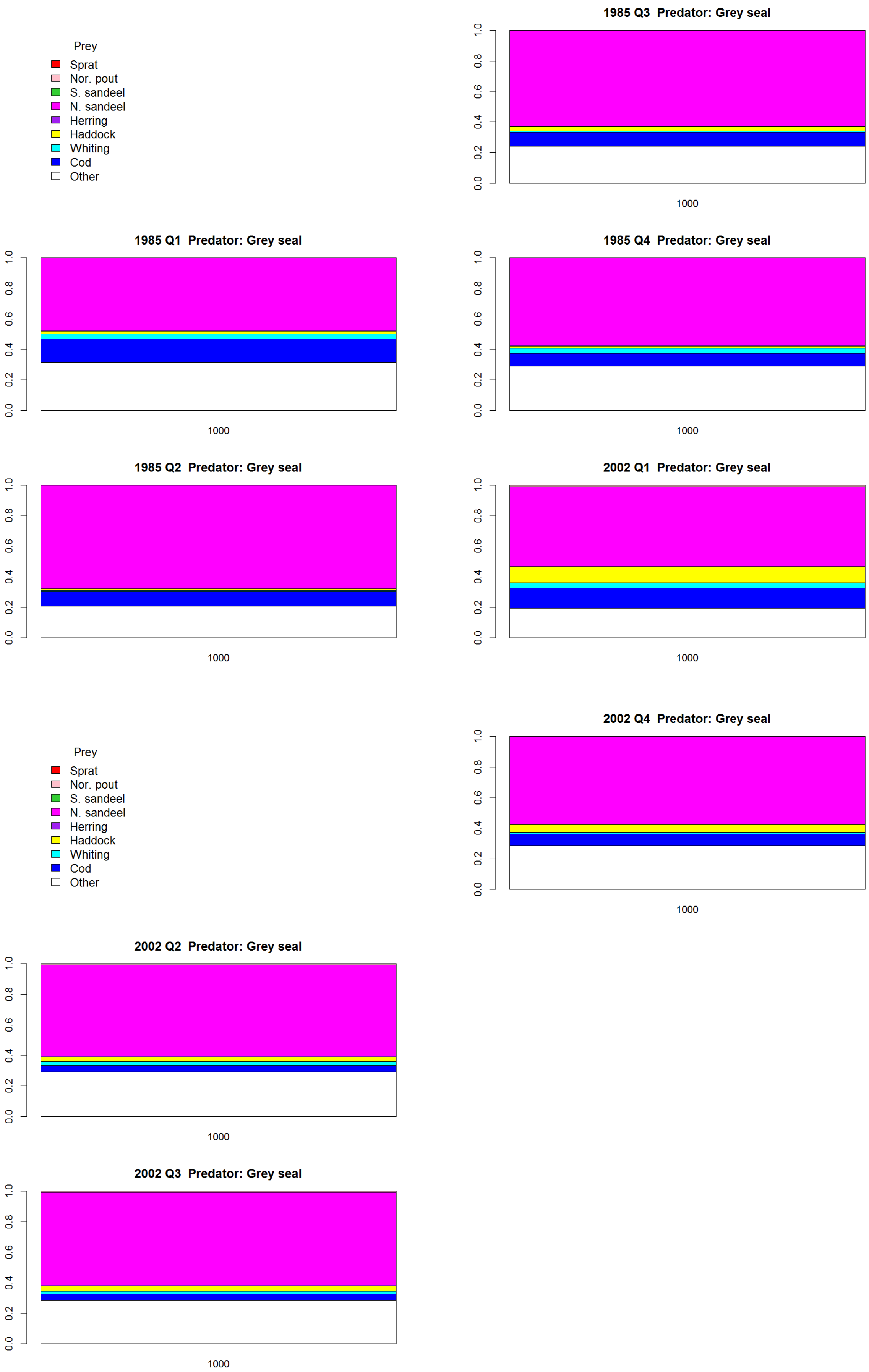

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: GBB. Gull
1981 Q1 Predator: GBB. Gull
1981 Q4 Predator: GBB. Gull
1981 Q2 Predator: GBB. Gull
1985 Q1 Predator: GBB. Gull
0.0
0.2
0.4
0.6
0.8
1.0
500

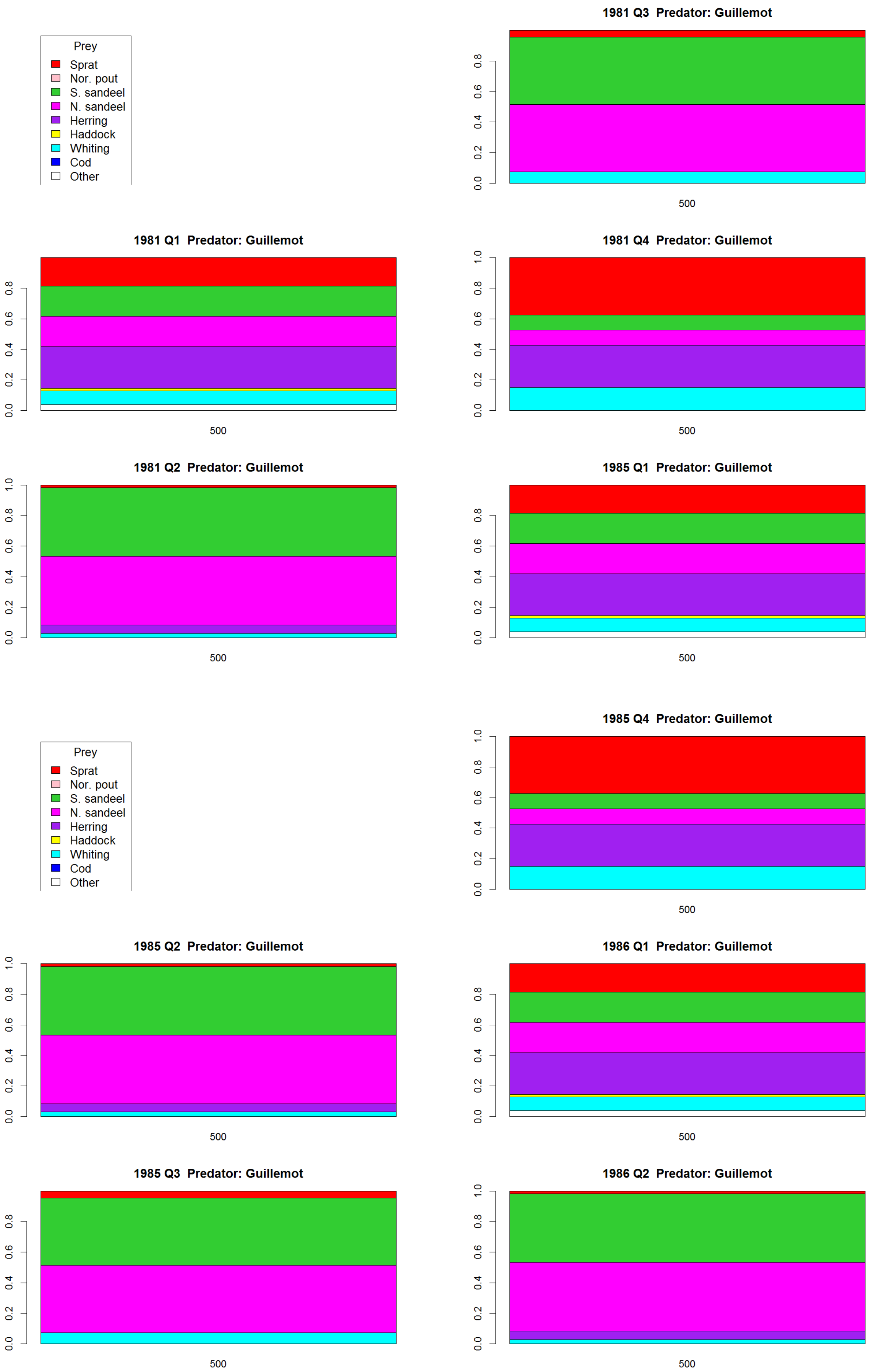

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: GBB. Gull
1985 Q2 Predator: GBB. Gull
1986 Q1 Predator: GBB. Gull
1985 Q3 Predator: GBB. Gull
1986 Q2 Predator: GBB. Gull
0.0
0.2
0.4
0.6
0.8
1.0
500

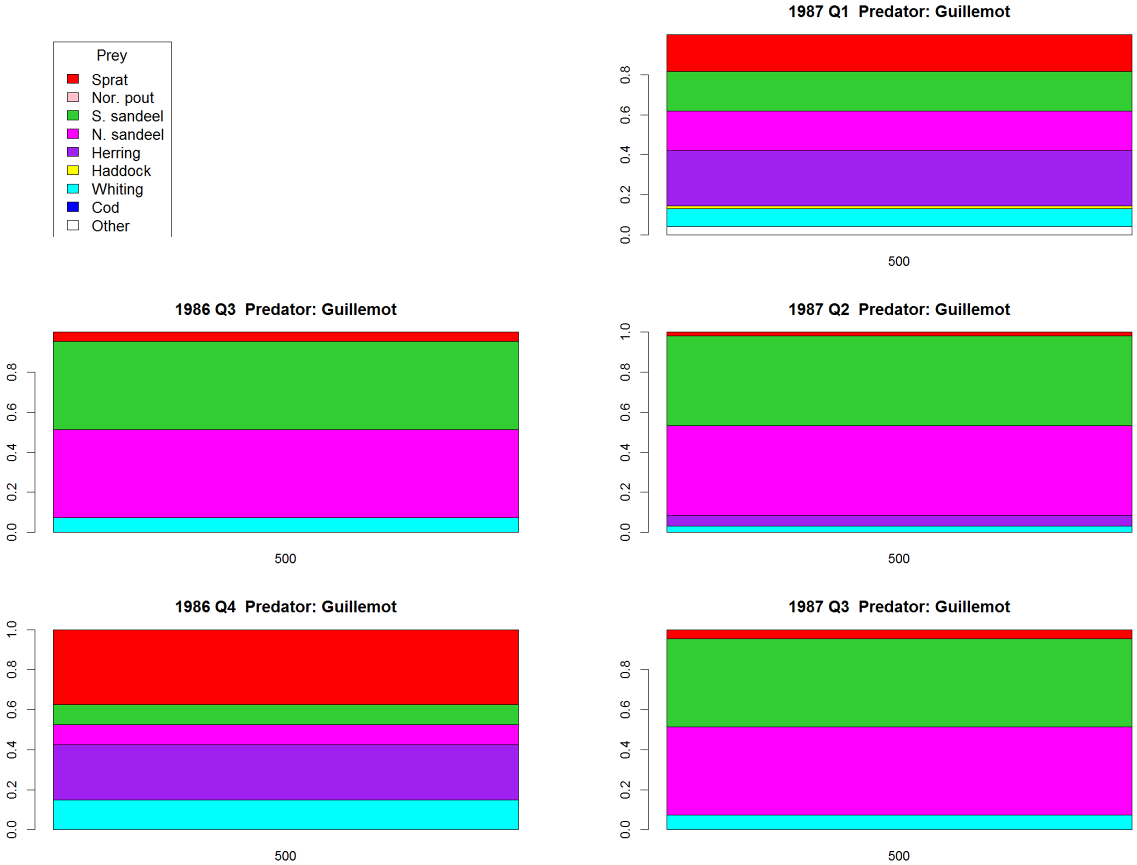

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: GBB. Gull
1986 Q3 Predator: GBB. Gull
1987 Q2 Predator: GBB. Gull
1986 Q4 Predator: GBB. Gull
1987 Q3 Predator: GBB. Gull
0.0
0.2
0.4
0.6
0.8
1.0
500

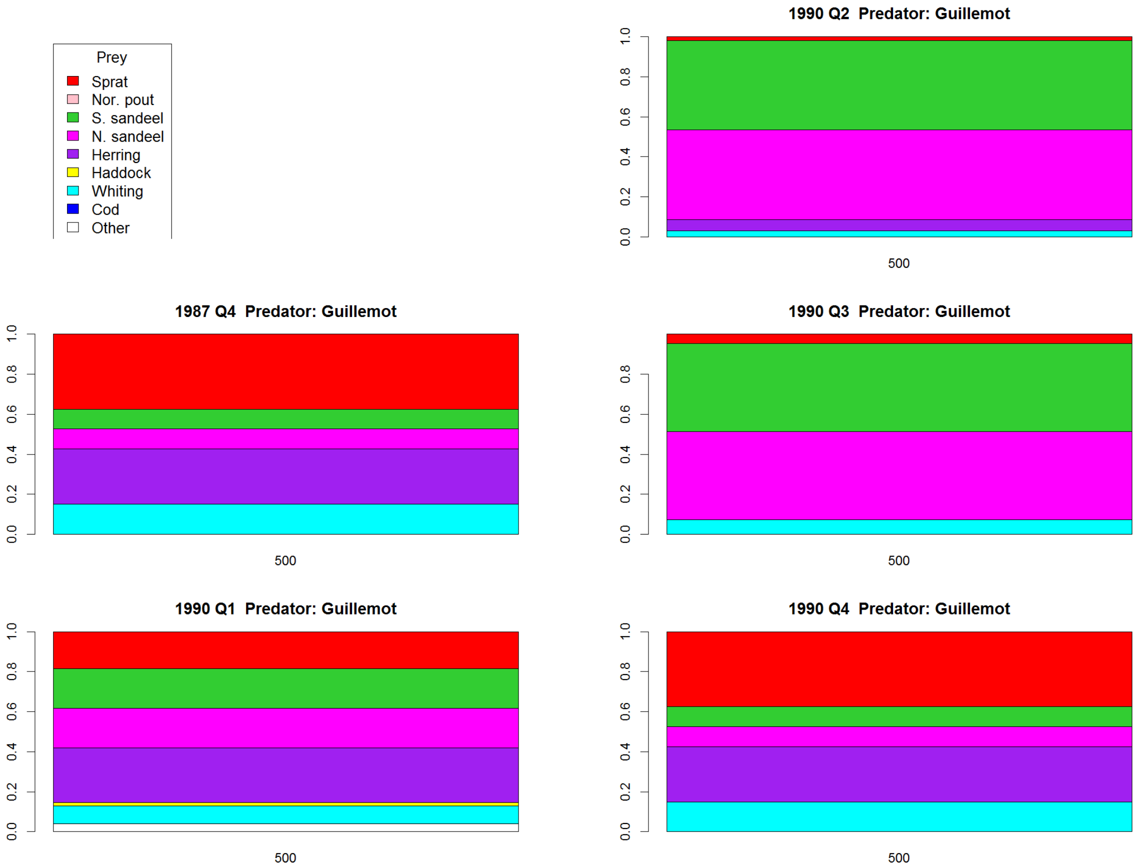

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: GBB. Gull
1987 Q4 Predator: GBB. Gull
1990 Q3 Predator: GBB. Gull
1990 Q1 Predator: GBB. Gull
1990 Q4 Predator: GBB. Gull
0.0
0.2
0.4
0.6
0.8
1.0
500

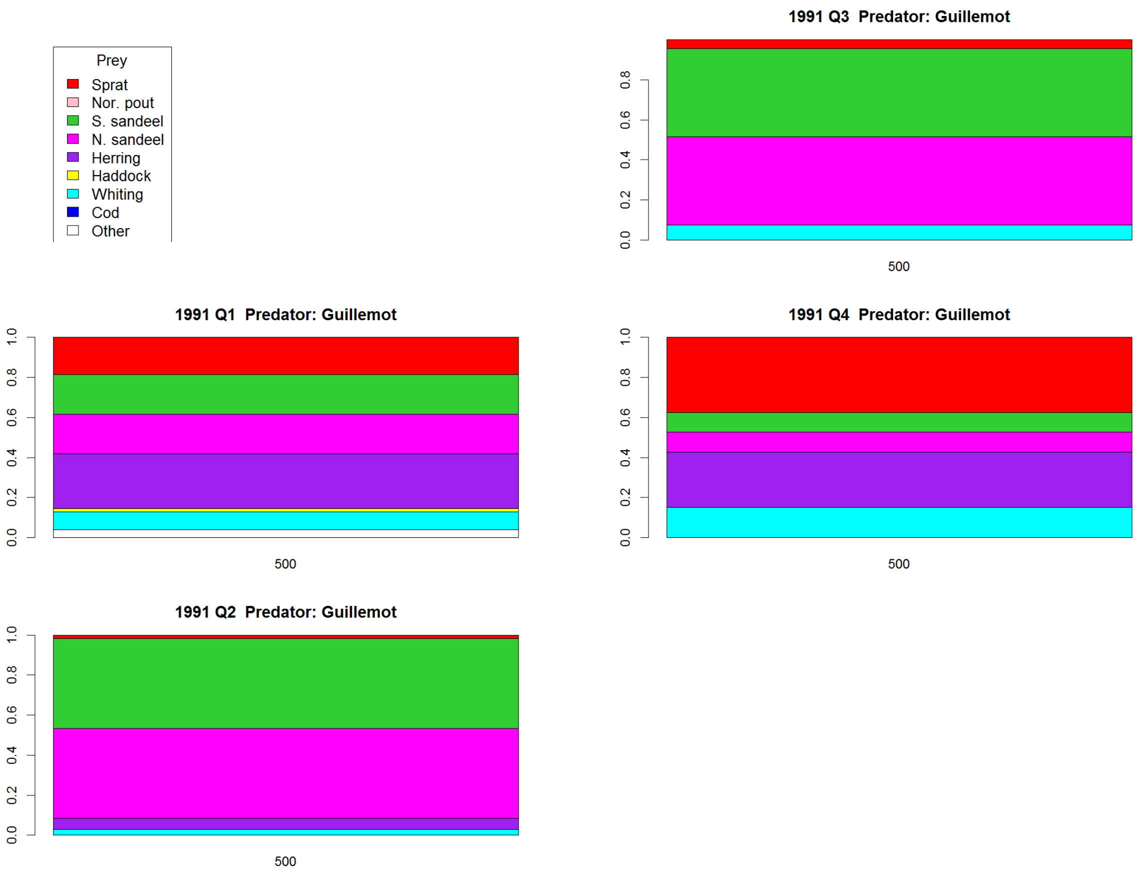

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: GBB. Gull
1991 Q1 Predator: GBB. Gull
1991 Q4 Predator: GBB. Gull
1991 Q2 Predator: GBB. Gull
0.0
0.2
0.4
0.6
0.8
1.0
500

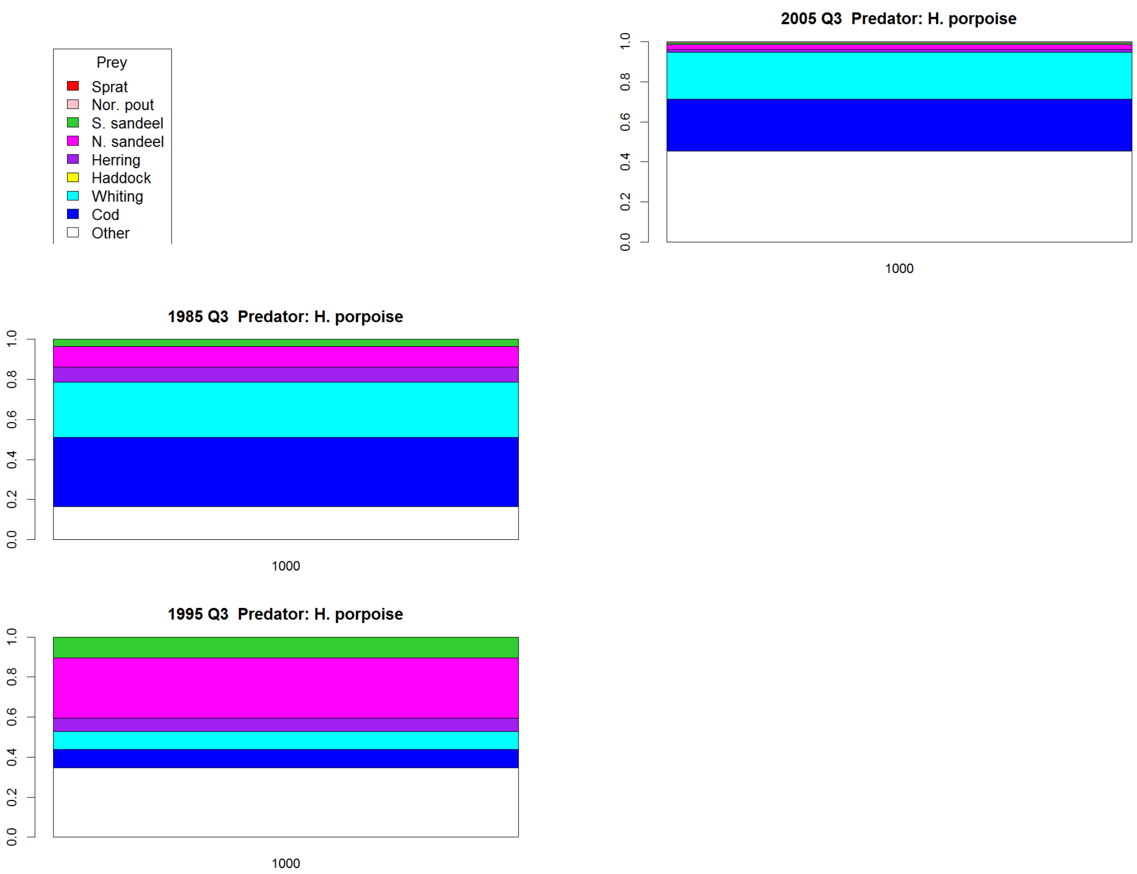

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q3 Predator: Grey seal
1985 Q1 Predator: Grey seal
1985 Q4 Predator: Grey seal
1985 Q2 Predator: Grey seal
2002 Q1 Predator: Grey seal
2002 Q4 Predator: Grey seal
2002 Q2 Predator: Grey seal
2002 Q3 Predator: Grey seal
0.0
0.2
0.4
0.6
0.8
1.0
1000

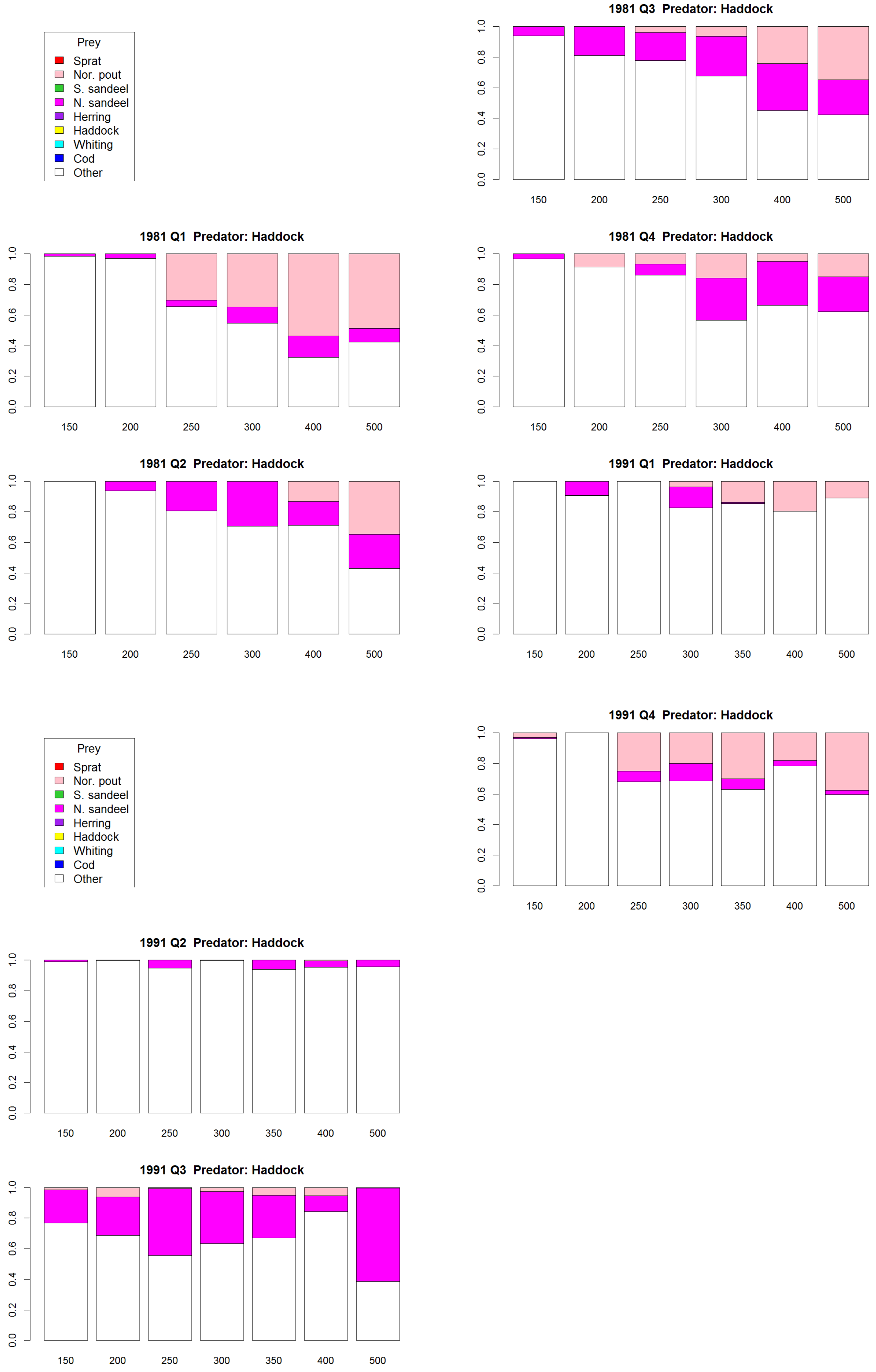

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Guillemot
1981 Q1 Predator: Guillemot
1981 Q4 Predator: Guillemot
1981 Q2 Predator: Guillemot
1985 Q1 Predator: Guillemot
Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Guillemot
1985 Q2 Predator: Guillemot
1986 Q1 Predator: Guillemot
1985 Q3 Predator: Guillemot
1986 Q2 Predator: Guillemot
500

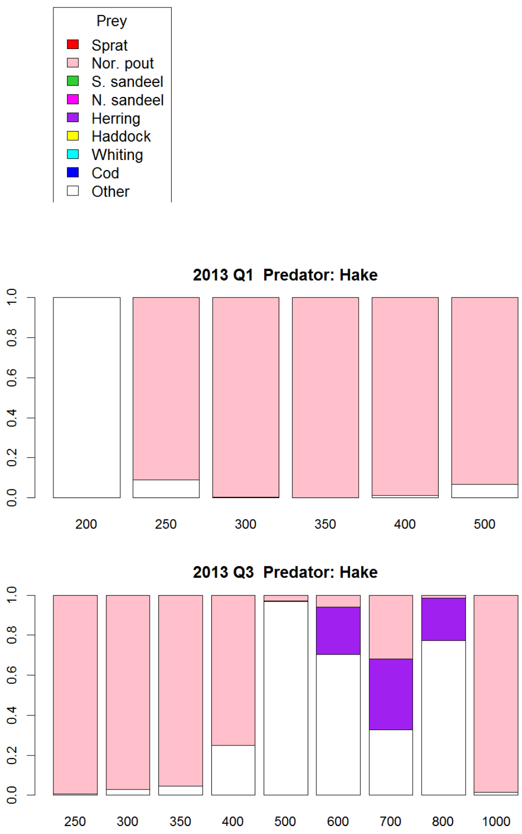

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Guillemot
1986 Q3 Predator: Guillemot
1987 Q2 Predator: Guillemot
1986 Q4 Predator: Guillemot
1987 Q3 Predator: Guillemot
500

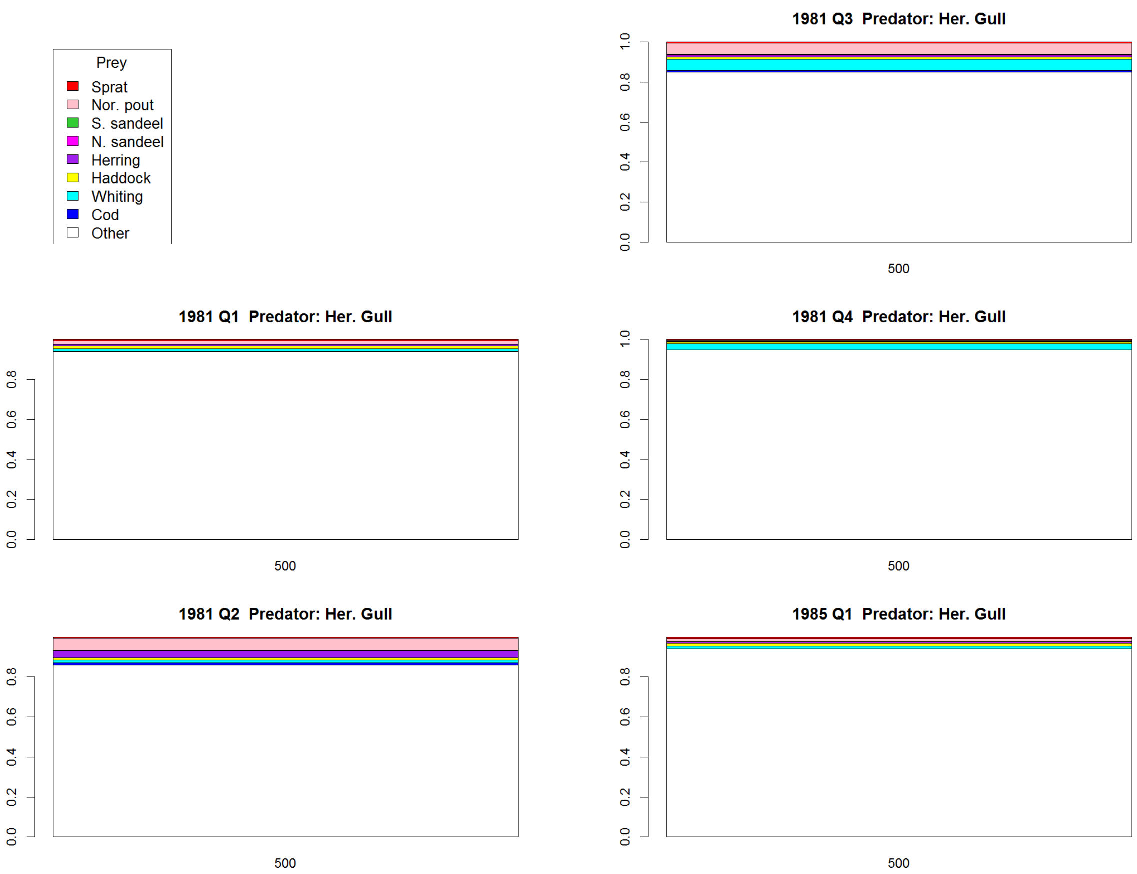

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Guillemot
1987 Q4 Predator: Guillemot
1990 Q3 Predator: Guillemot
1990 Q1 Predator: Guillemot
1990 Q4 Predator: Guillemot
500

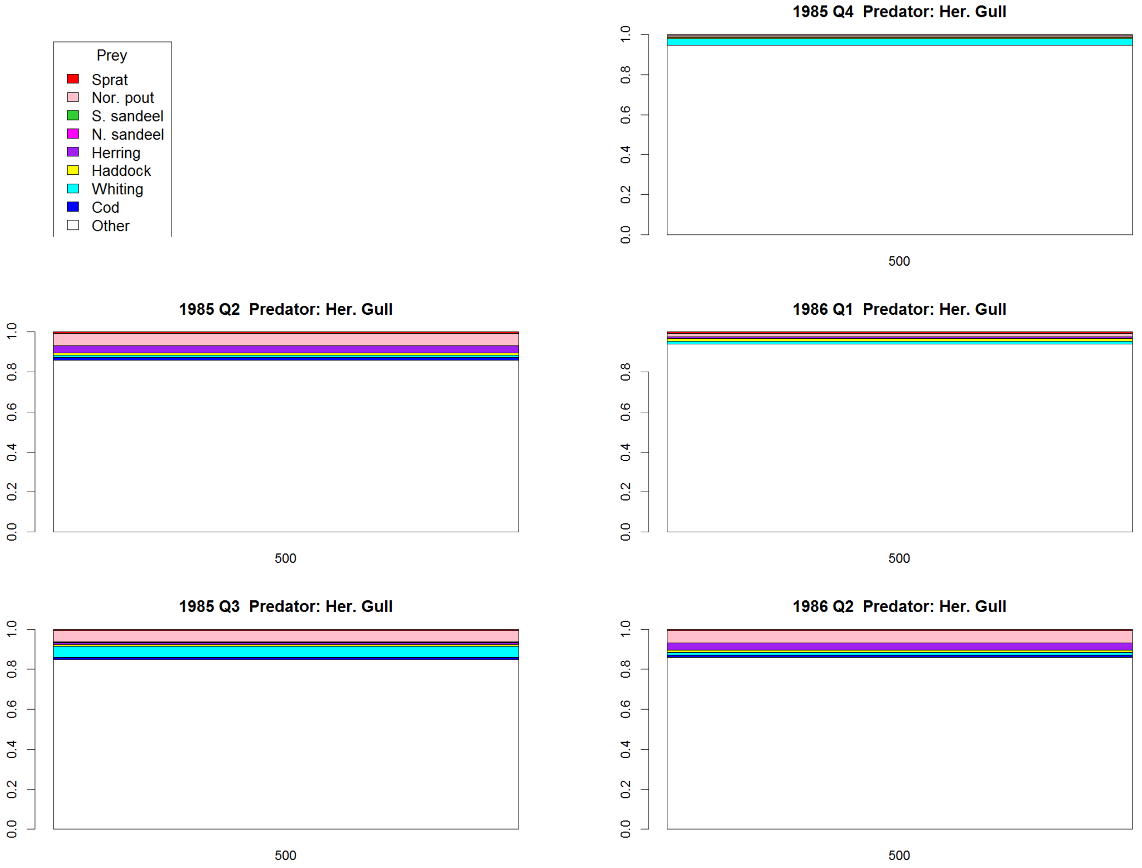

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Guillemot
0.0
0.2
0.4
0.6
0.8
500
1991 Q1 Predator: Guillemot
0.0
0.2
0.4
0.6
0.8
1.0
500
1991 Q4 Predator: Guillemot
0.0
0.2
0.4
0.6
0.8
1.0
500
1991 Q2 Predator: Guillemot
0.0
0.2
0.4
0.6
0.8
1.0
500

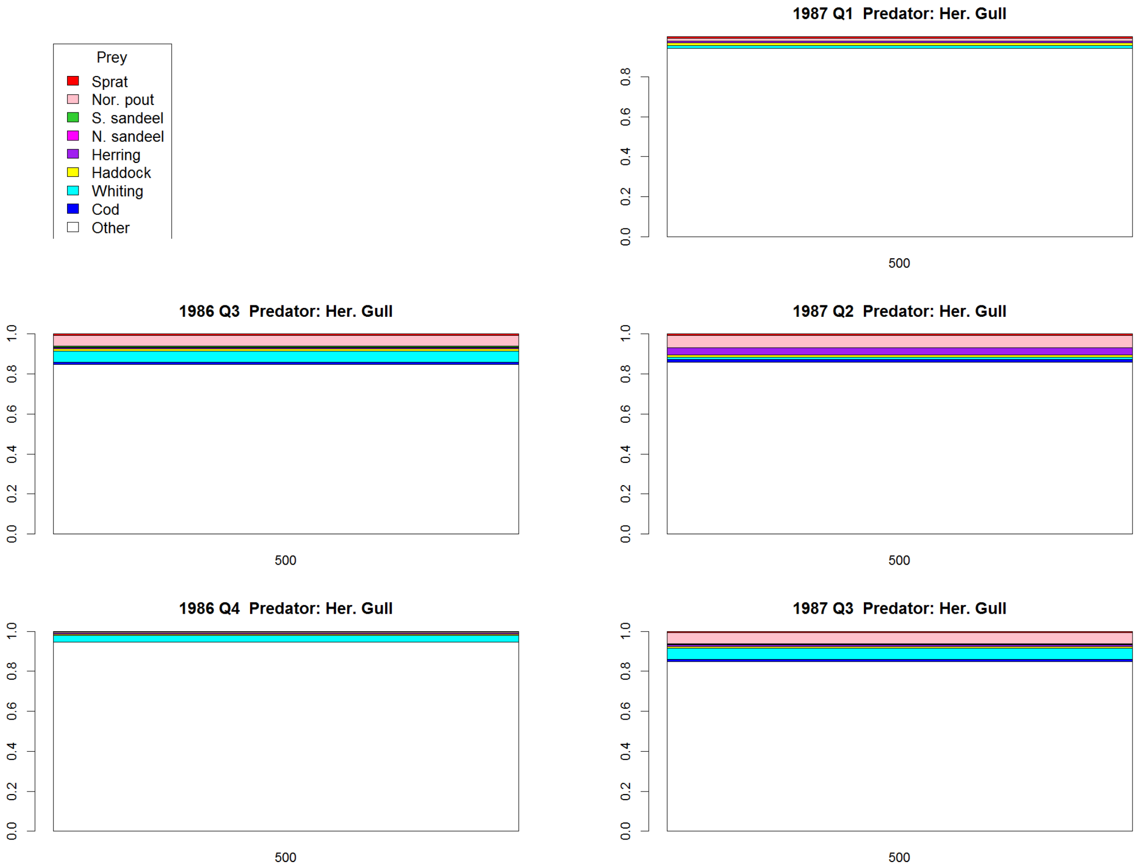

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
2005 Q3 Predator: H. porpoise
0.0
0.2
0.4
0.6
0.8
1.0
1000
1985 Q3 Predator: H. porpoise
0.0
0.2
0.4
0.6
0.8
1.0
1000
1995 Q3 Predator: H. porpoise
0.0
0.2
0.4
0.6
0.8
1.0
1000

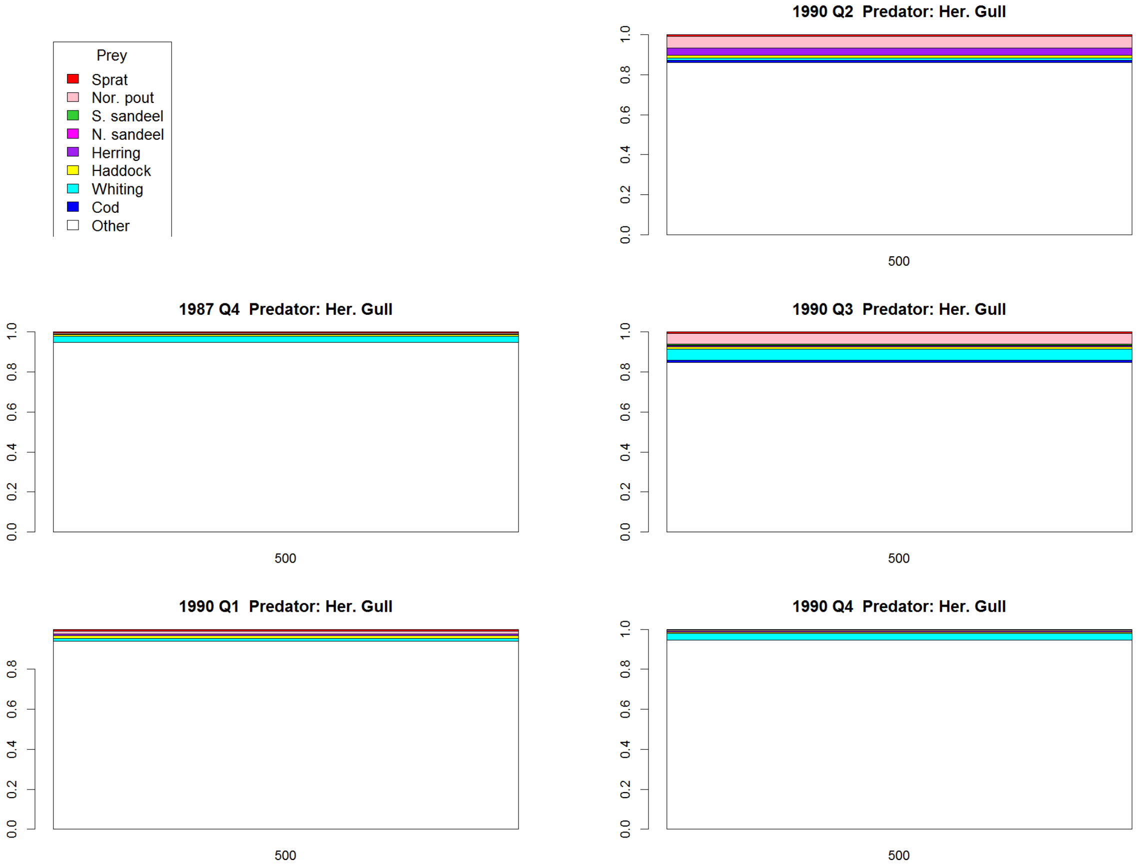

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Haddock
1981 Q1 Predator: Haddock
1981 Q4 Predator: Haddock
1981 Q2 Predator: Haddock
1991 Q1 Predator: Haddock
1991 Q4 Predator: Haddock
Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q2 Predator: Haddock
1991 Q3 Predator: Haddock
150
200
250
300
350
400
500

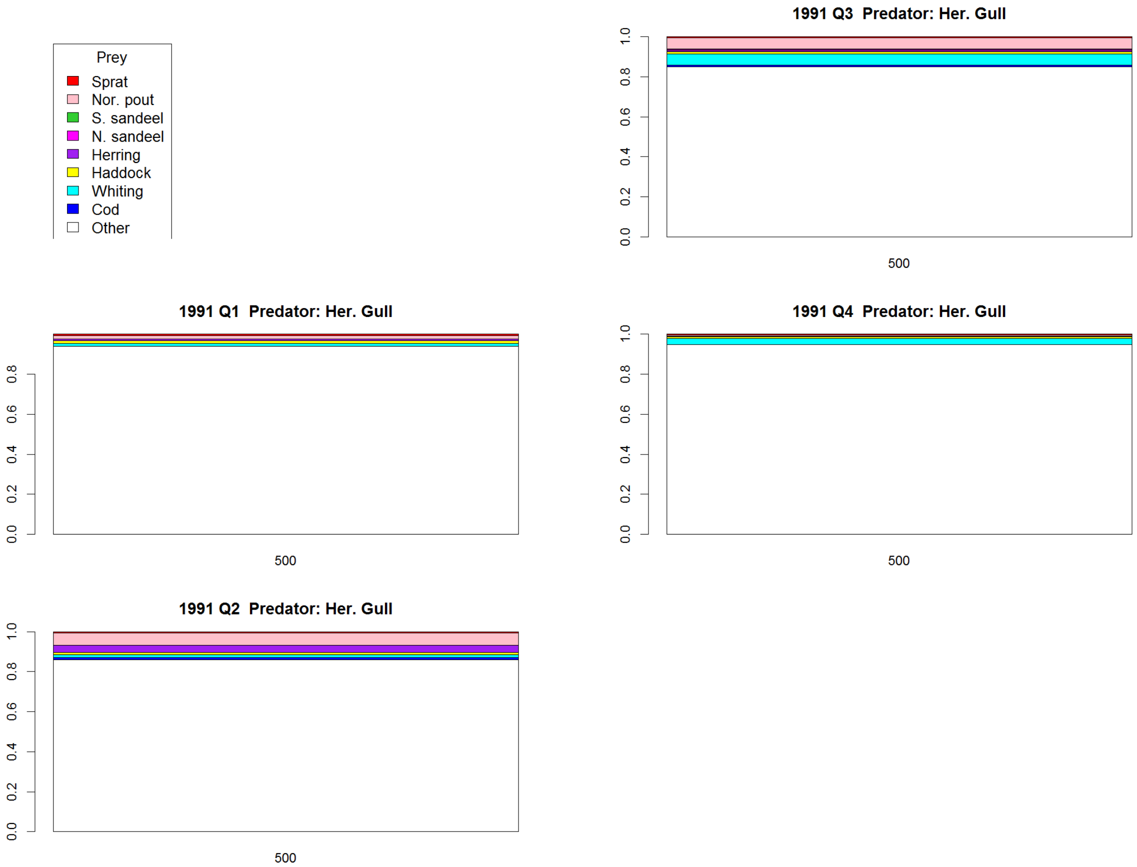

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
2013 Q1 Predator: Hake
0.0 0.2 0.4 0.6 0.8 1.0
200 250 300 350 400 500
2013 Q3 Predator: Hake
0.0 0.2 0.4 0.6 0.8 1.0
250 300 350 400 500 600 700 800 1000

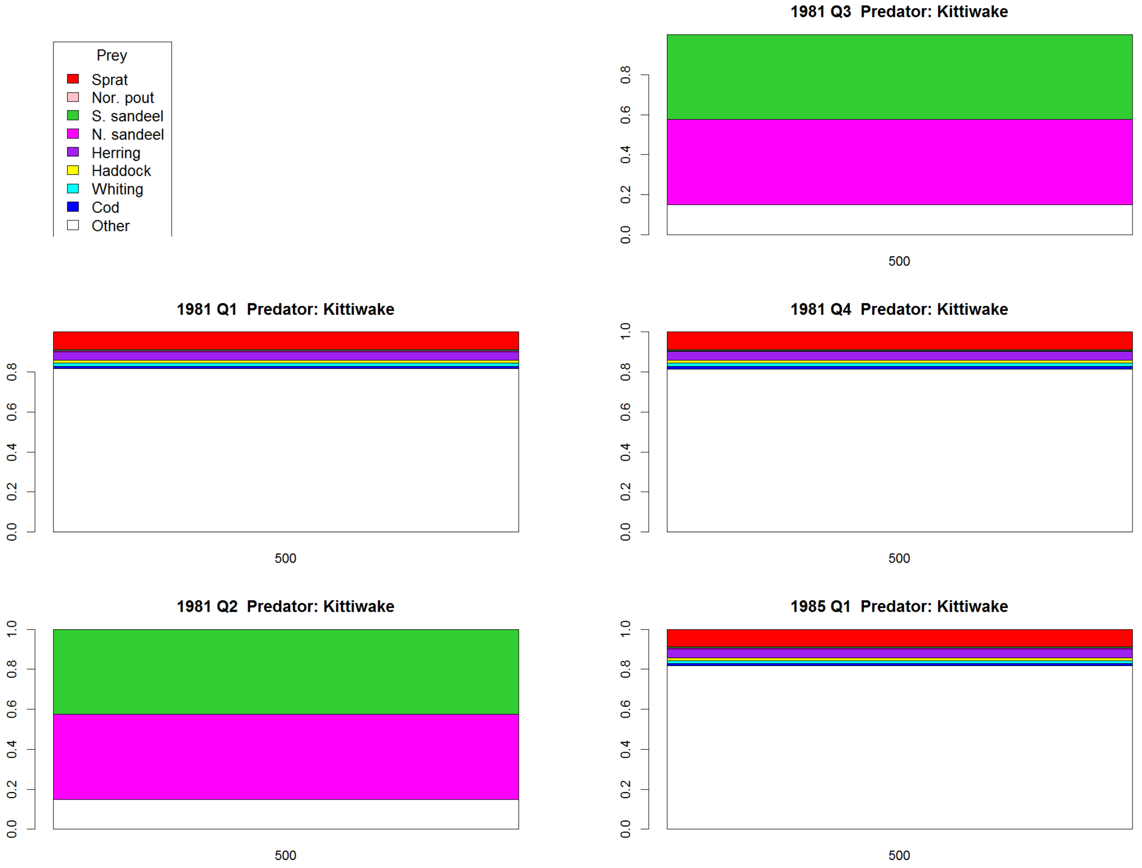

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Her. Gull
500
1981 Q1 Predator: Her. Gull
500
1981 Q4 Predator: Her. Gull
500
1981 Q2 Predator: Her. Gull
500
1985 Q1 Predator: Her. Gull
500

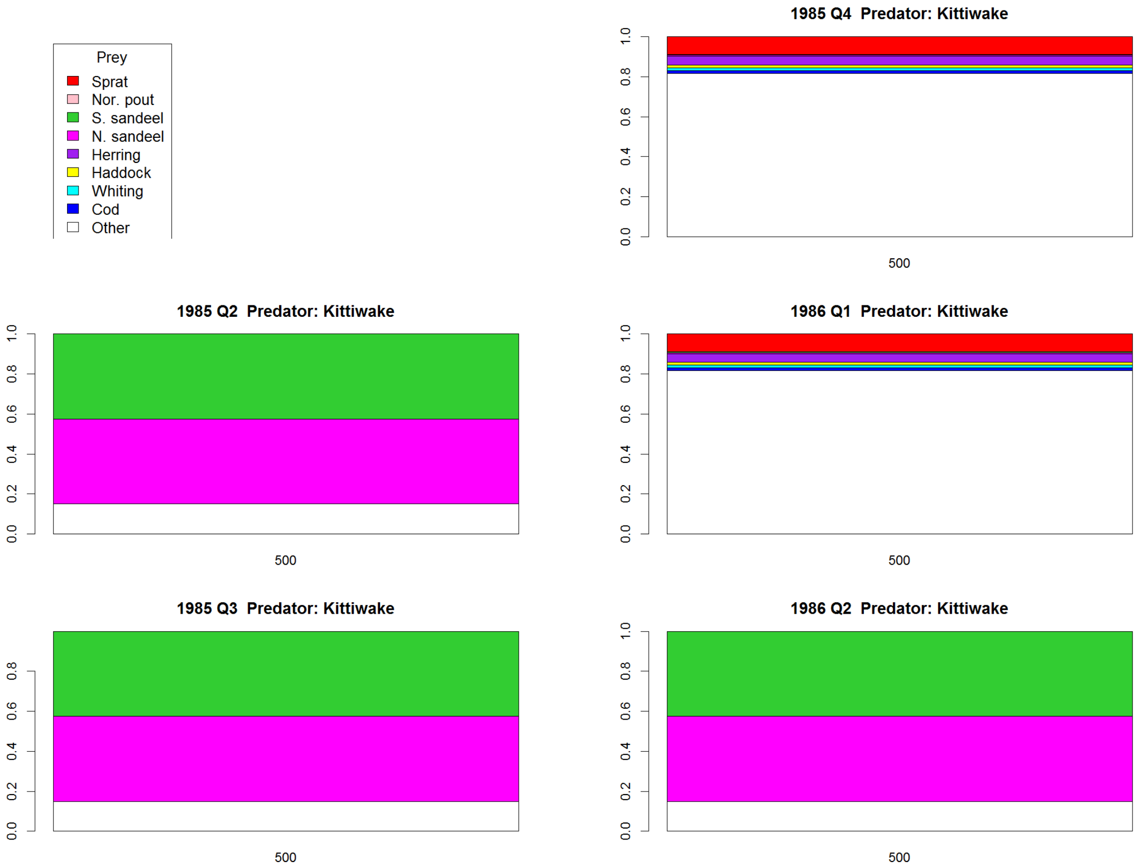

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Her. Gull
1985 Q2 Predator: Her. Gull
1986 Q1 Predator: Her. Gull
1985 Q3 Predator: Her. Gull
1986 Q2 Predator: Her. Gull
500

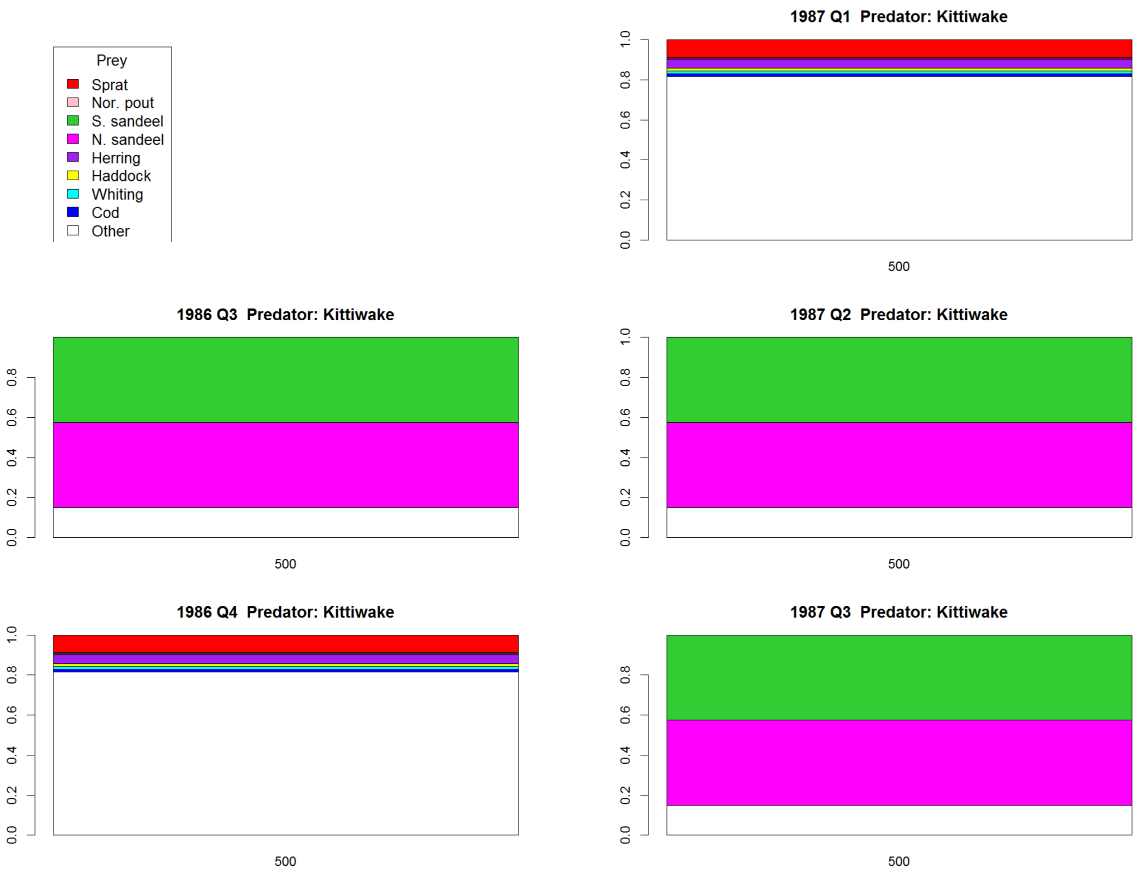

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Her. Gull
1986 Q3 Predator: Her. Gull
1987 Q2 Predator: Her. Gull
1986 Q4 Predator: Her. Gull
1987 Q3 Predator: Her. Gull
500

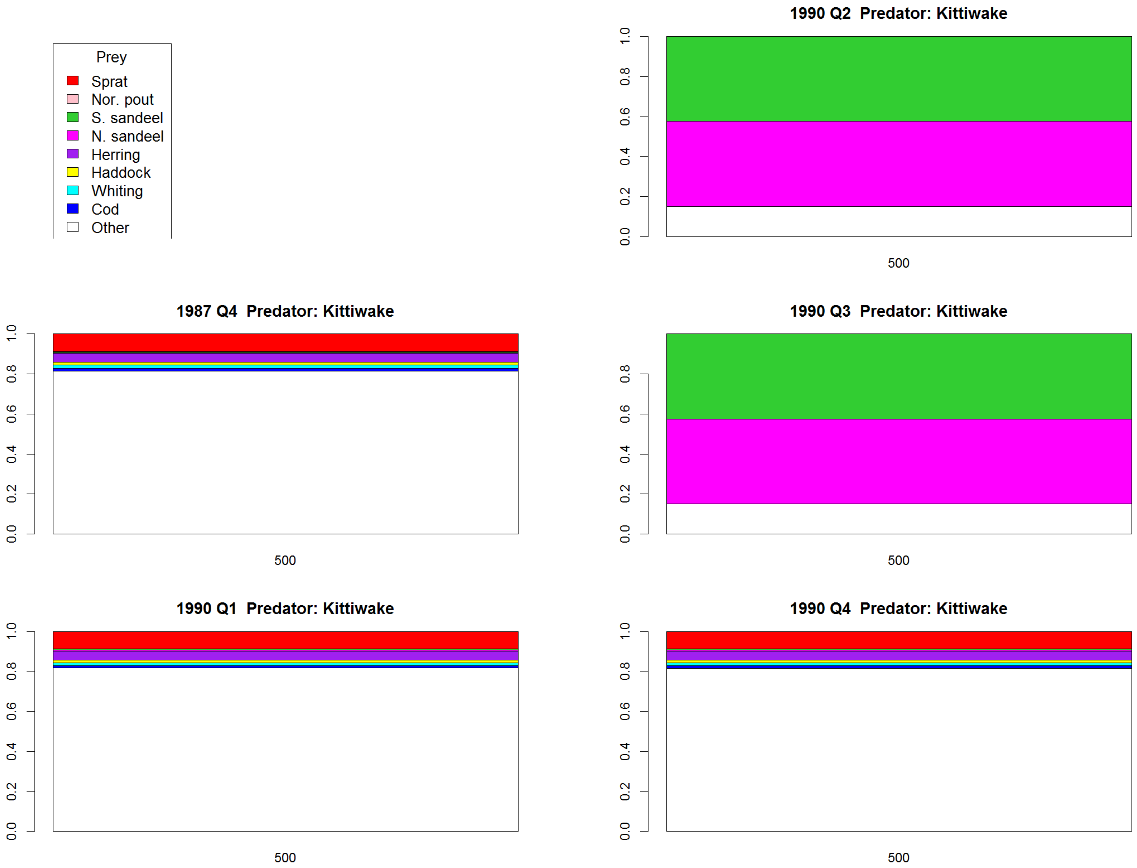

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Her. Gull
1987 Q4 Predator: Her. Gull
1990 Q3 Predator: Her. Gull
1990 Q1 Predator: Her. Gull
1990 Q4 Predator: Her. Gull
0.0
0.2
0.4
0.6
0.8
1.0
500

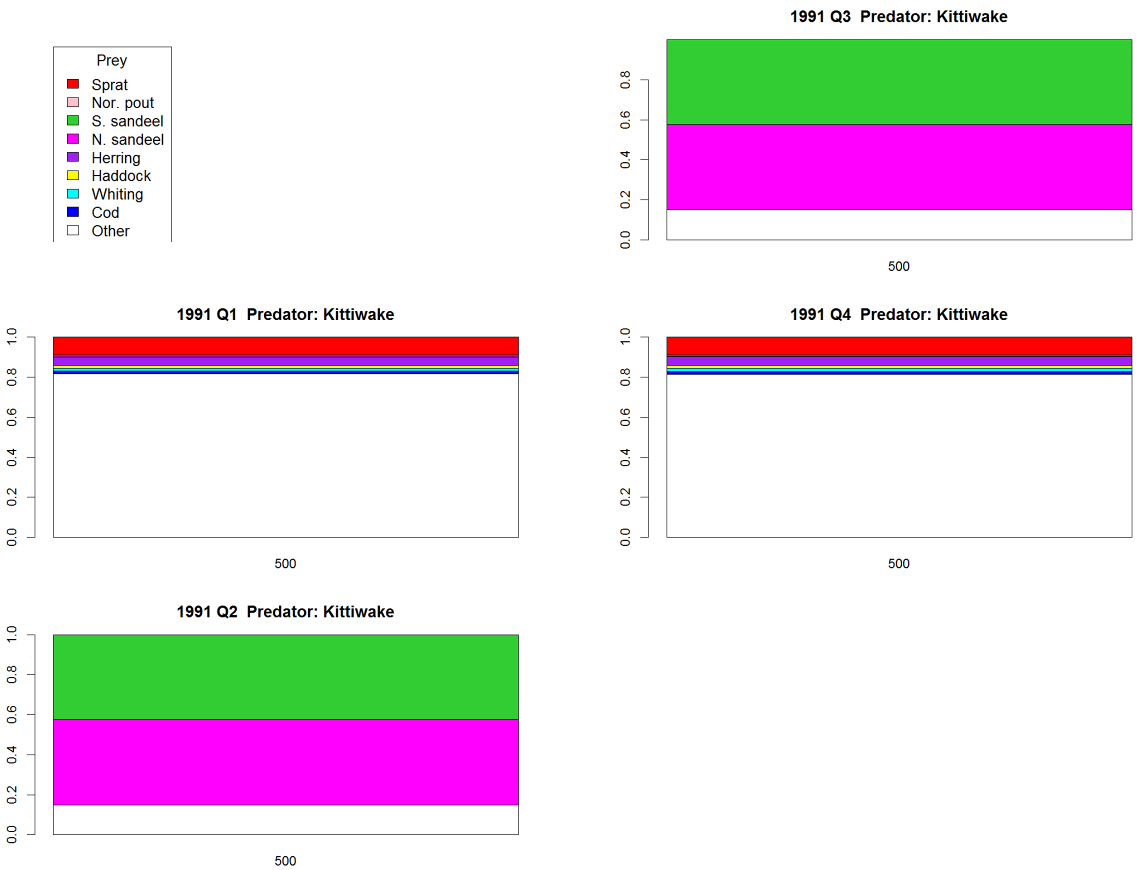

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Her. Gull
1991 Q1 Predator: Her. Gull
1991 Q4 Predator: Her. Gull
1991 Q2 Predator: Her. Gull
0.0
0.2
0.4
0.6
0.8
1.0
500

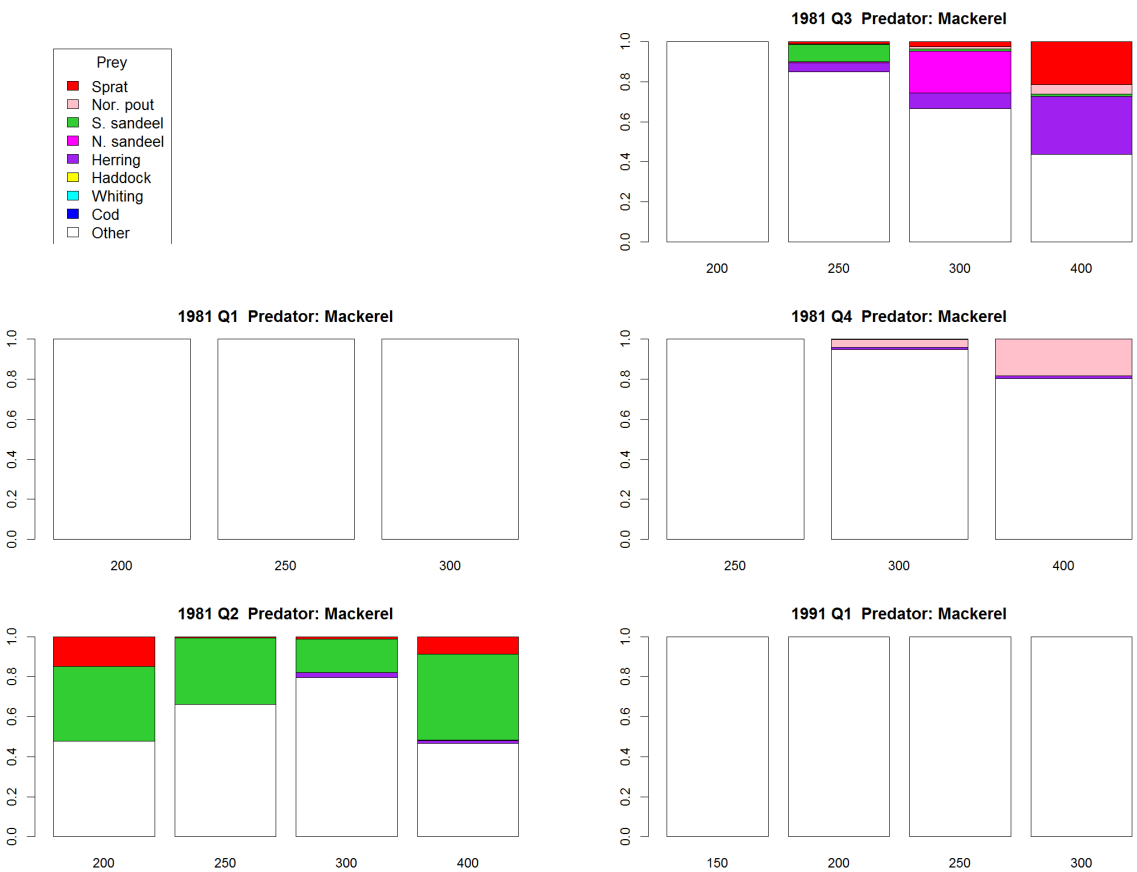

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Kittiwake
1981 Q1 Predator: Kittiwake
1981 Q4 Predator: Kittiwake
1981 Q2 Predator: Kittiwake
1985 Q1 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500

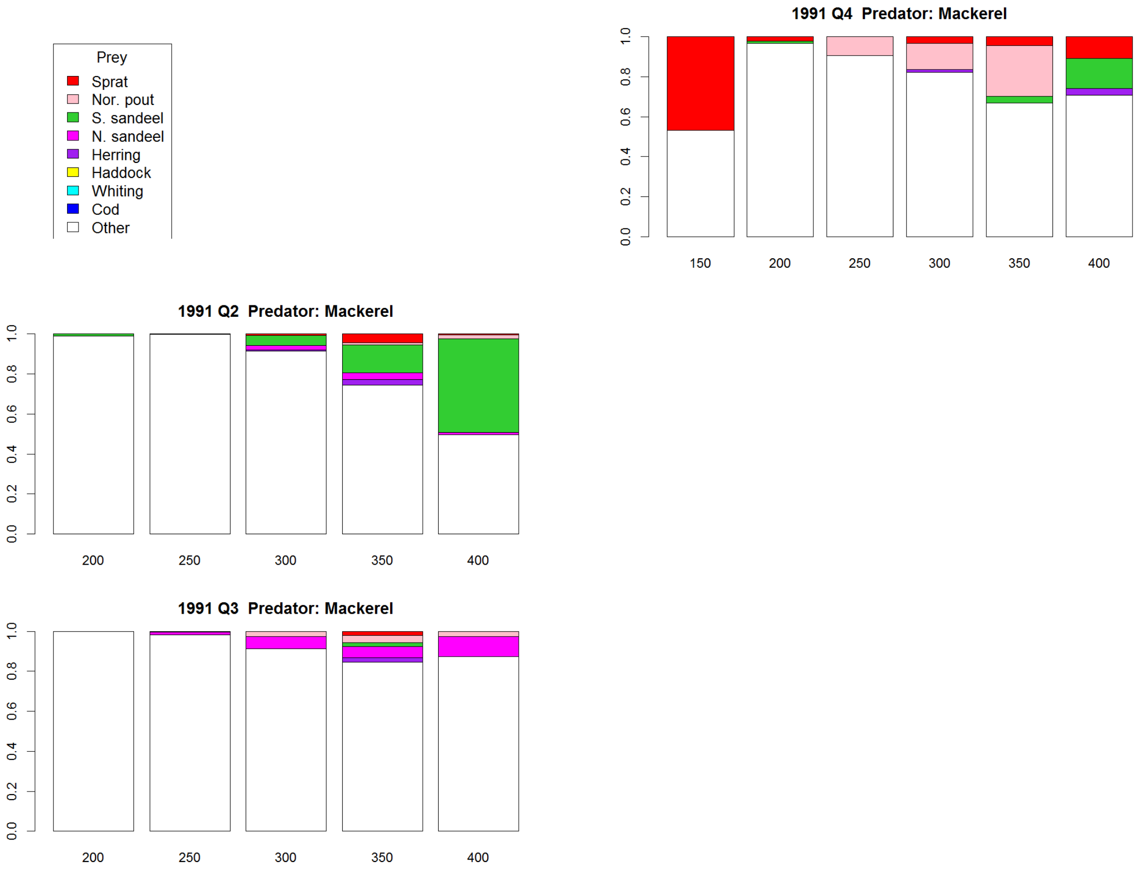

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Kittiwake
1985 Q2 Predator: Kittiwake
1986 Q1 Predator: Kittiwake
1985 Q3 Predator: Kittiwake
1986 Q2 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500

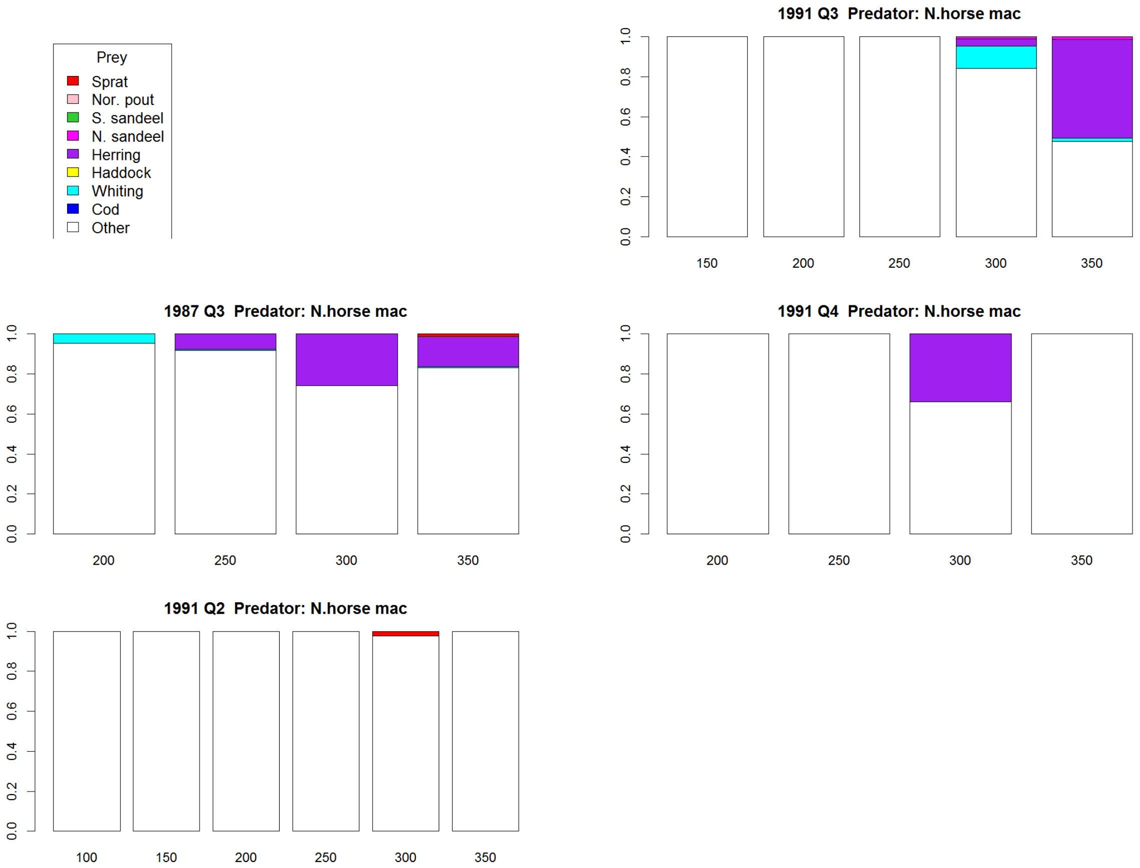

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Kittiwake
1986 Q3 Predator: Kittiwake
1987 Q2 Predator: Kittiwake
1986 Q4 Predator: Kittiwake
1987 Q3 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500

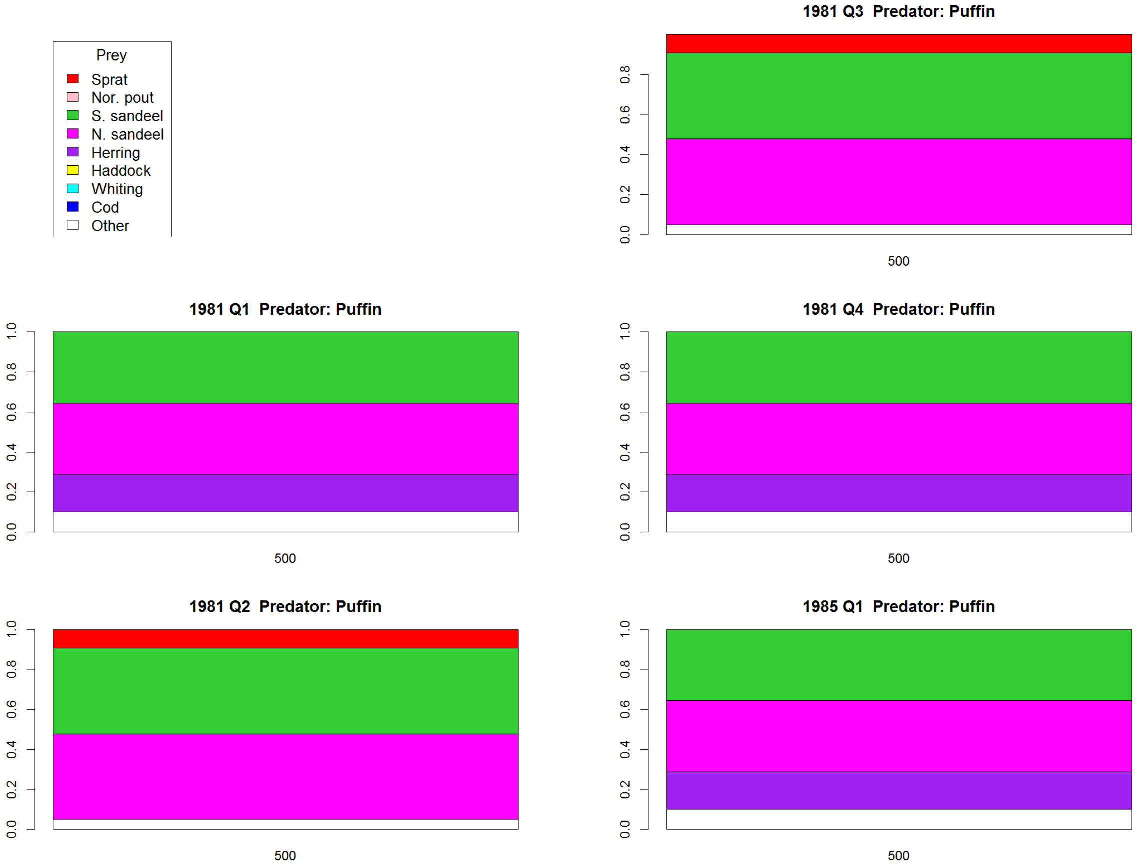

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Kittiwake
1987 Q4 Predator: Kittiwake
1990 Q3 Predator: Kittiwake
1990 Q1 Predator: Kittiwake
1990 Q4 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500

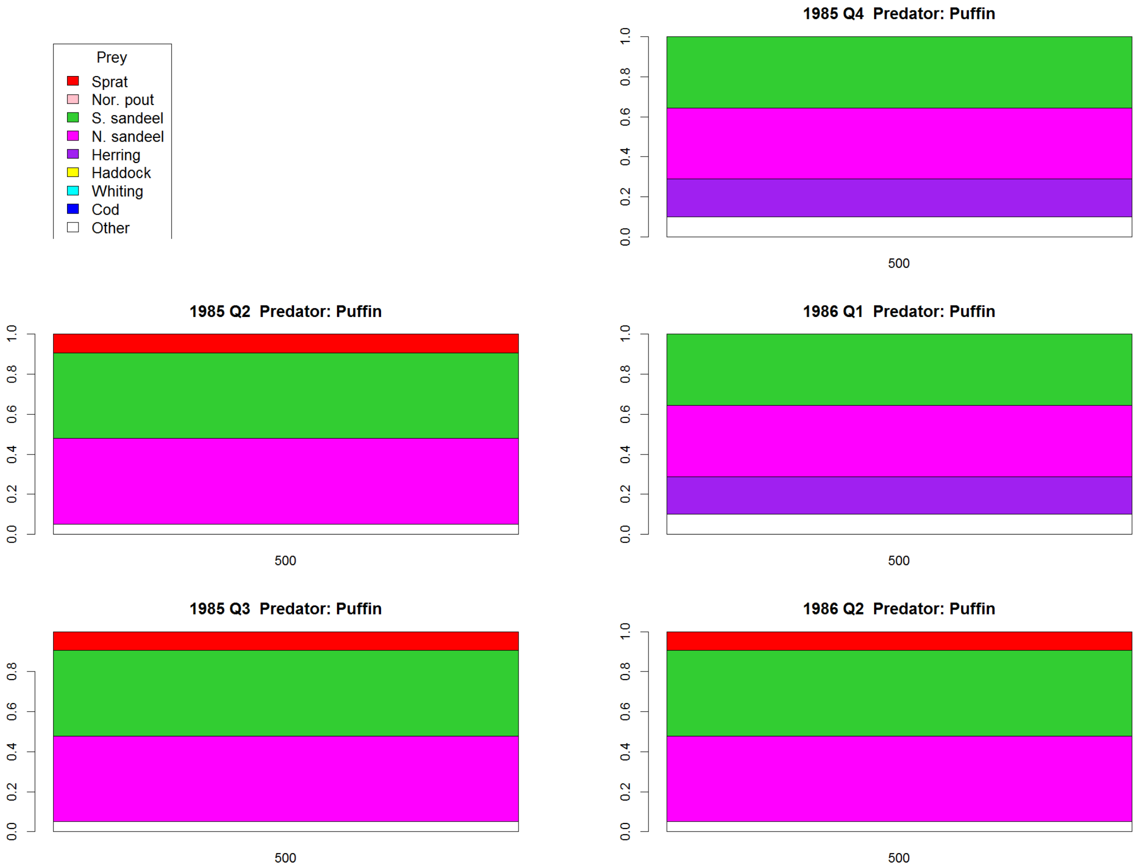

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
500
1991 Q1 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500
1991 Q4 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500
1991 Q2 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500

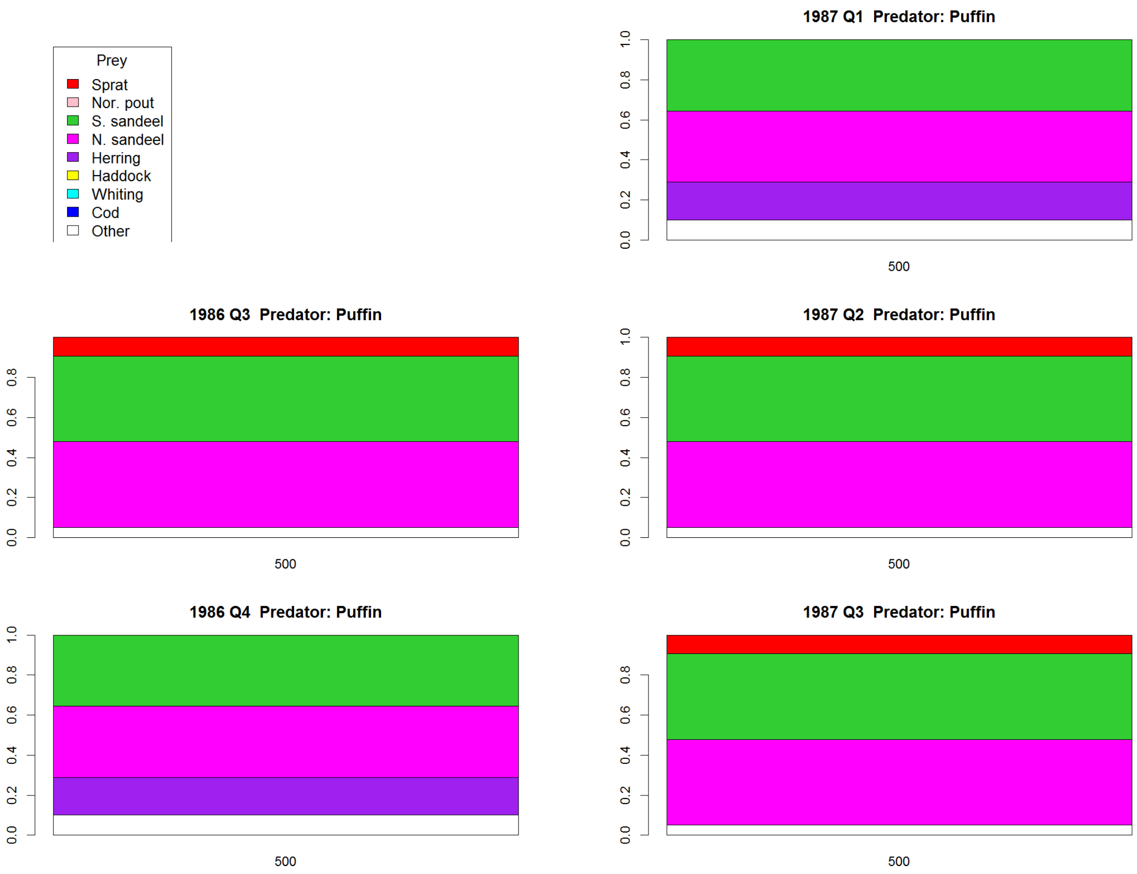

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Mackerel
0.0
0.2
0.4
0.6
0.8
1.0
200
250
300
400
1981 Q1 Predator: Mackerel
0.0
0.2
0.4
0.6
0.8
1.0
200
250
300
1981 Q4 Predator: Mackerel
0.0
0.2
0.4
0.6
0.8
1.0
250
300
400
1981 Q2 Predator: Mackerel
0.0
0.2
0.4
0.6
0.8
1.0
200
250
300
400
1991 Q1 Predator: Mackerel
0.0
0.2
0.4
0.6
0.8
1.0
150
200
250
300

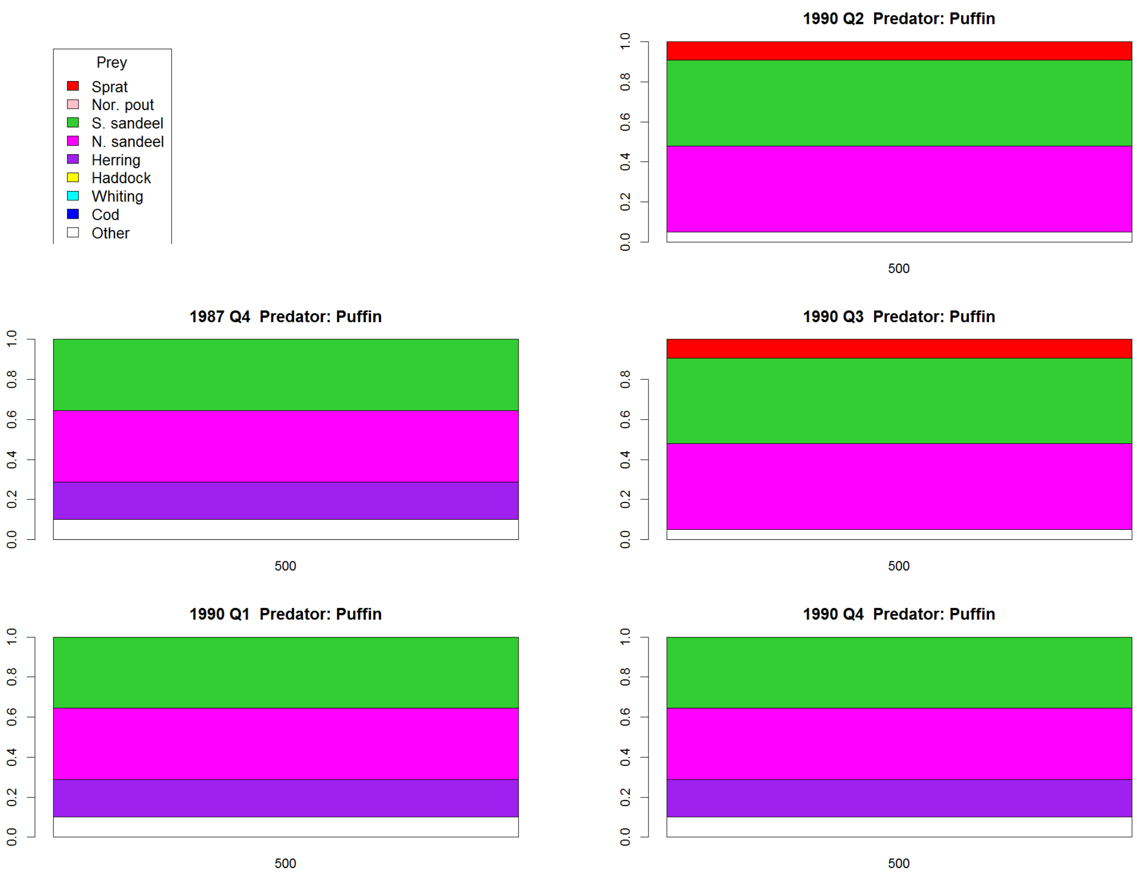

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q4 Predator: Mackerel
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 350 400
1991 Q2 Predator: Mackerel
0.0 0.2 0.4 0.6 0.8 1.0
200 250 300 350 400
1991 Q3 Predator: Mackerel
0.0 0.2 0.4 0.6 0.8 1.0
200 250 300 350 400

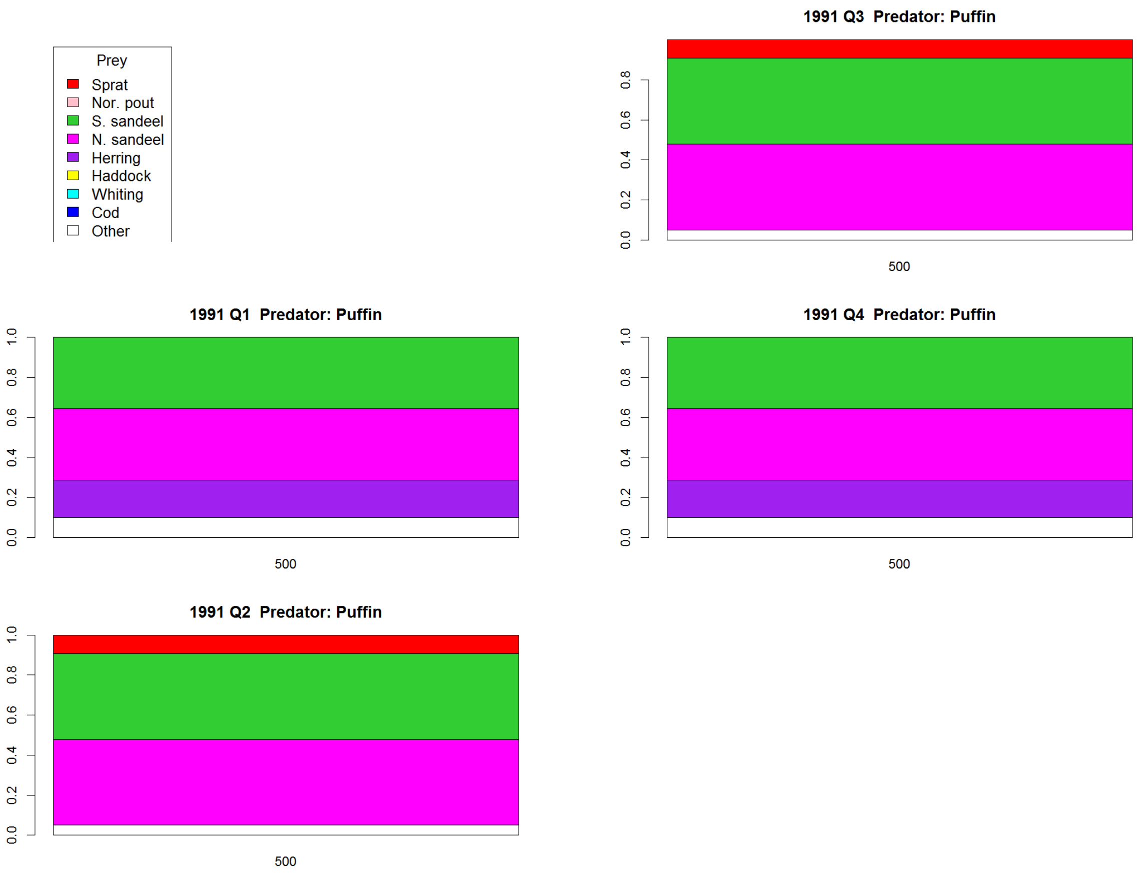

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: N.horse mac
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 350
1987 Q3 Predator: N.horse mac
0.0 0.2 0.4 0.6 0.8 1.0
200 250 300 350
1991 Q4 Predator: N.horse mac
0.0 0.2 0.4 0.6 0.8 1.0
200 250 300 350
1991 Q2 Predator: N.horse mac
0.0 0.2 0.4 0.6 0.8 1.0
100 150 200 250 300 350

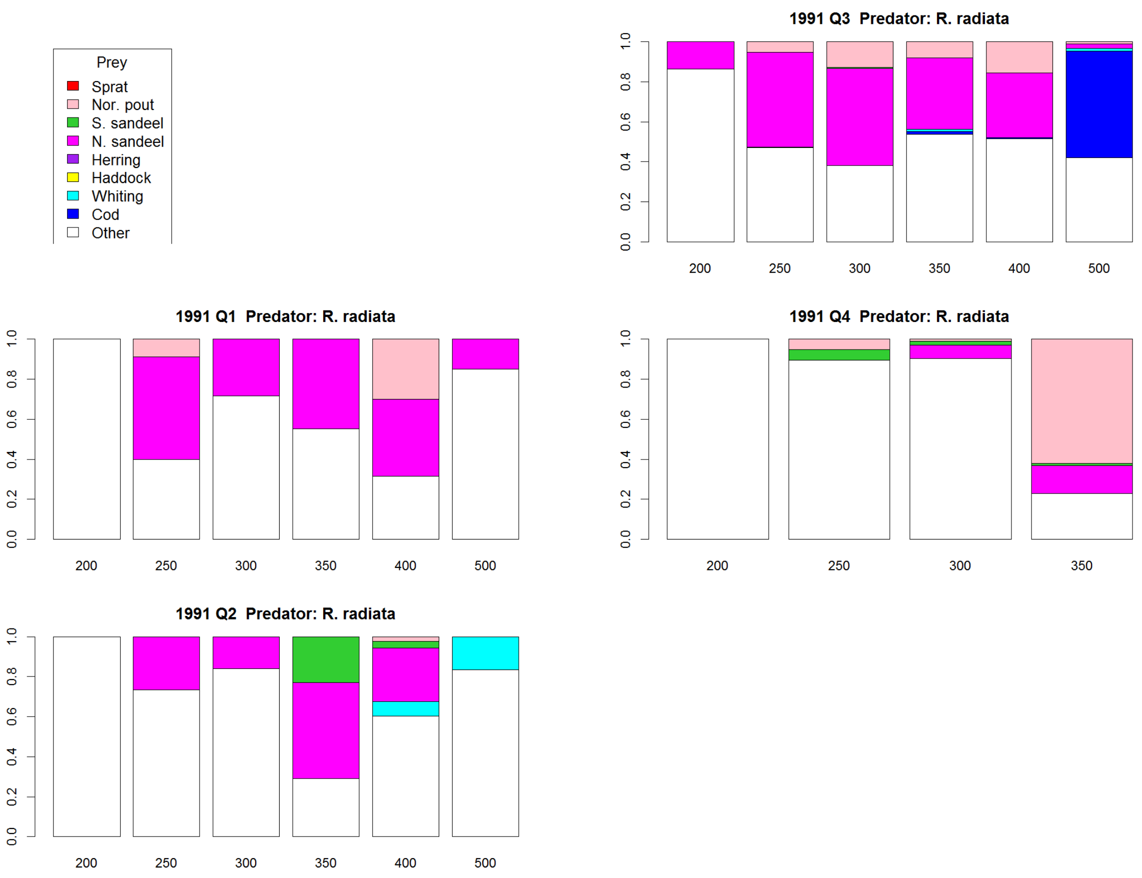

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Puffin
1981 Q1 Predator: Puffin
1981 Q4 Predator: Puffin
1981 Q2 Predator: Puffin
1985 Q1 Predator: Puffin
0.0
0.2
0.4
0.6
0.8
1.0
500

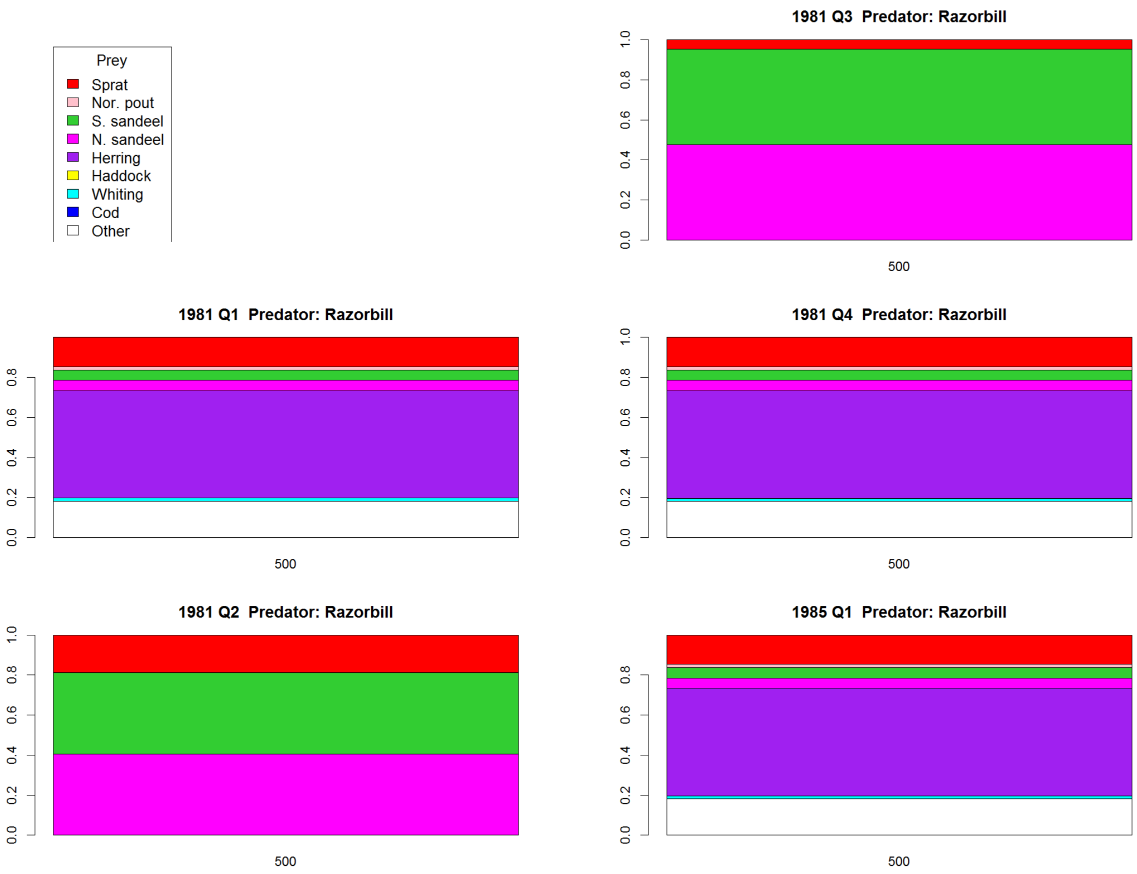

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Puffin
1985 Q2 Predator: Puffin
1986 Q1 Predator: Puffin
1985 Q3 Predator: Puffin
1986 Q2 Predator: Puffin
0.0
0.2
0.4
0.6
0.8
1.0
500


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Puffin
1986 Q3 Predator: Puffin
1987 Q2 Predator: Puffin
1986 Q4 Predator: Puffin
1987 Q3 Predator: Puffin
0.0
0.2
0.4
0.6
0.8
1.0
500

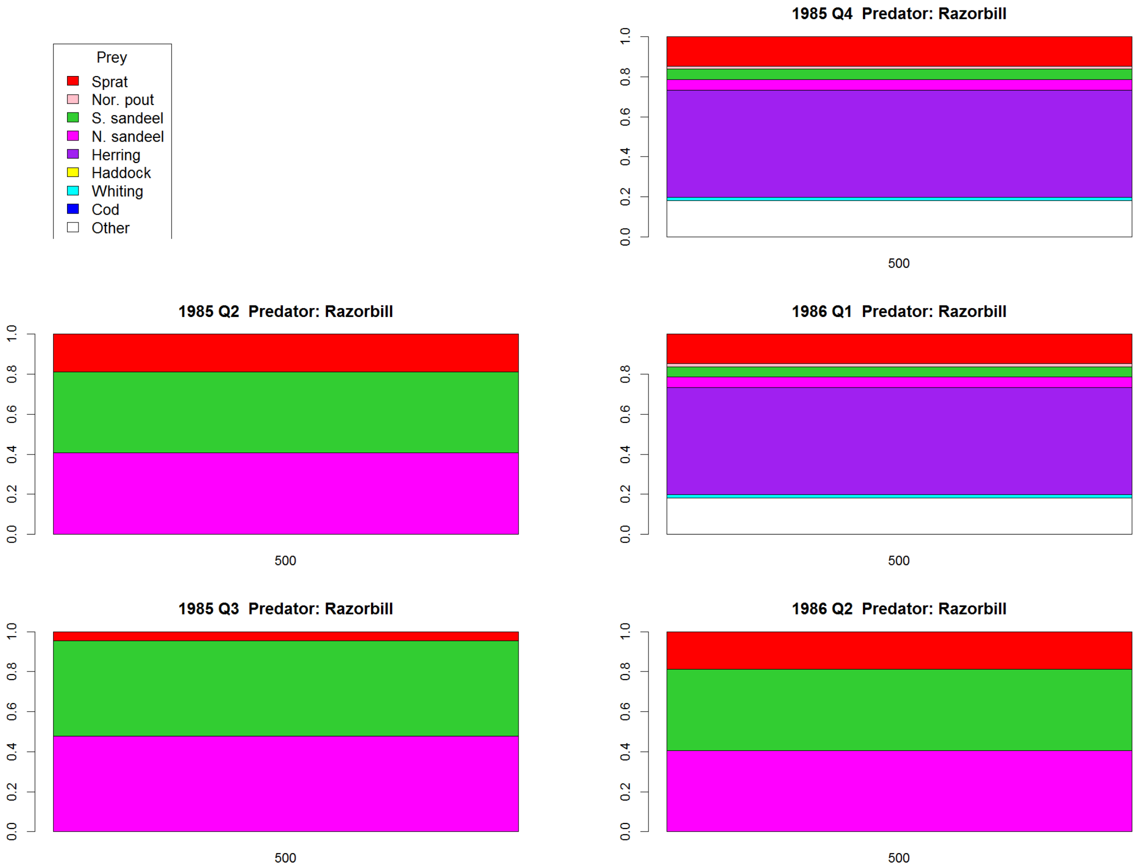

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Puffin
1987 Q4 Predator: Puffin
1990 Q3 Predator: Puffin
1990 Q1 Predator: Puffin
1990 Q4 Predator: Puffin
0.0
0.2
0.4
0.6
0.8
1.0
500


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Puffin
1991 Q1 Predator: Puffin
1991 Q4 Predator: Puffin
1991 Q2 Predator: Puffin
0.0
0.2
0.4
0.6
0.8
1.0
500

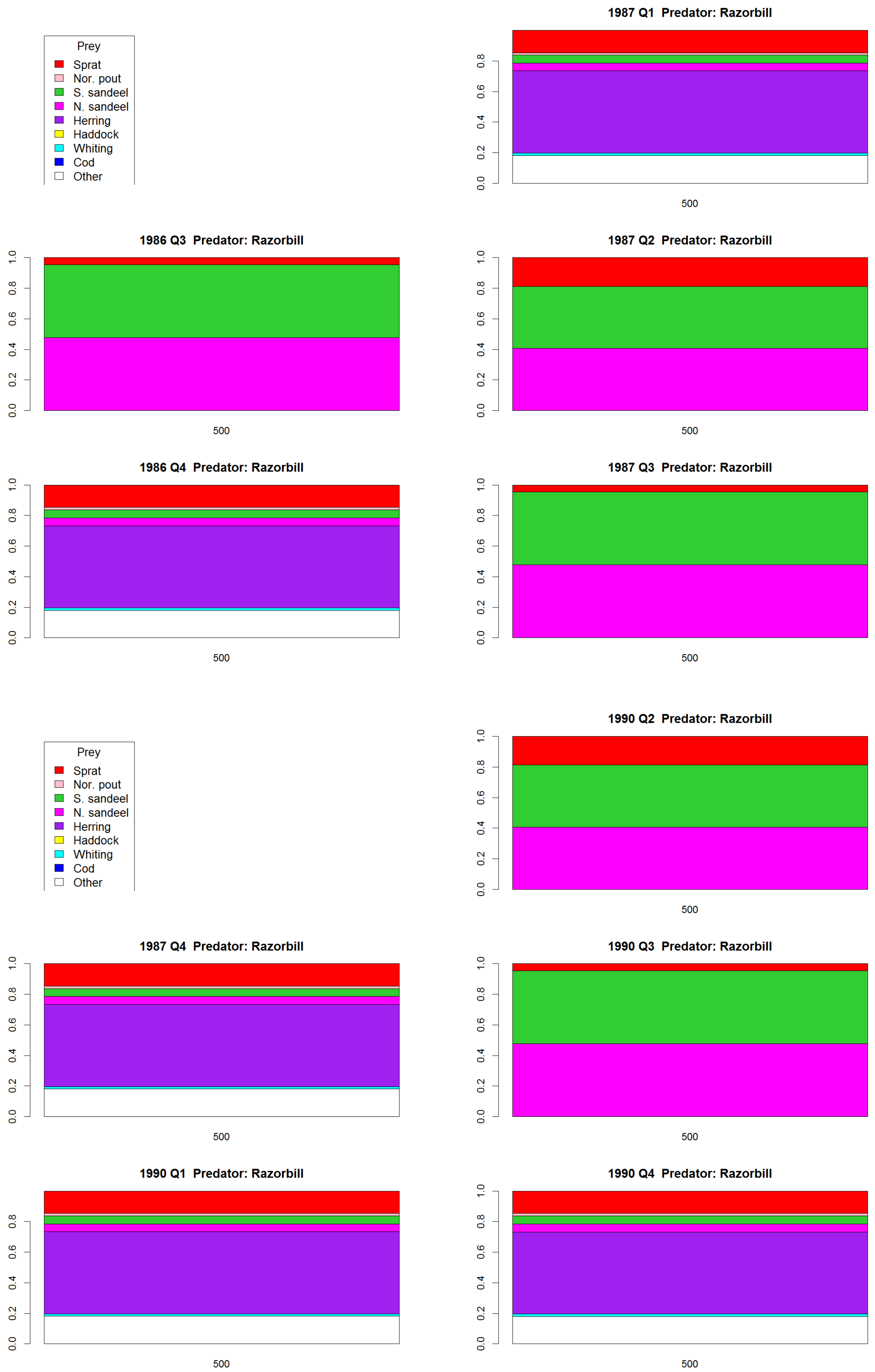

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: R. radiata
1991 Q1 Predator: R. radiata
1991 Q4 Predator: R. radiata
1991 Q2 Predator: R. radiata
0.0
0.2
0.4
0.6
0.8
1.0
200
250
300
350
400
500

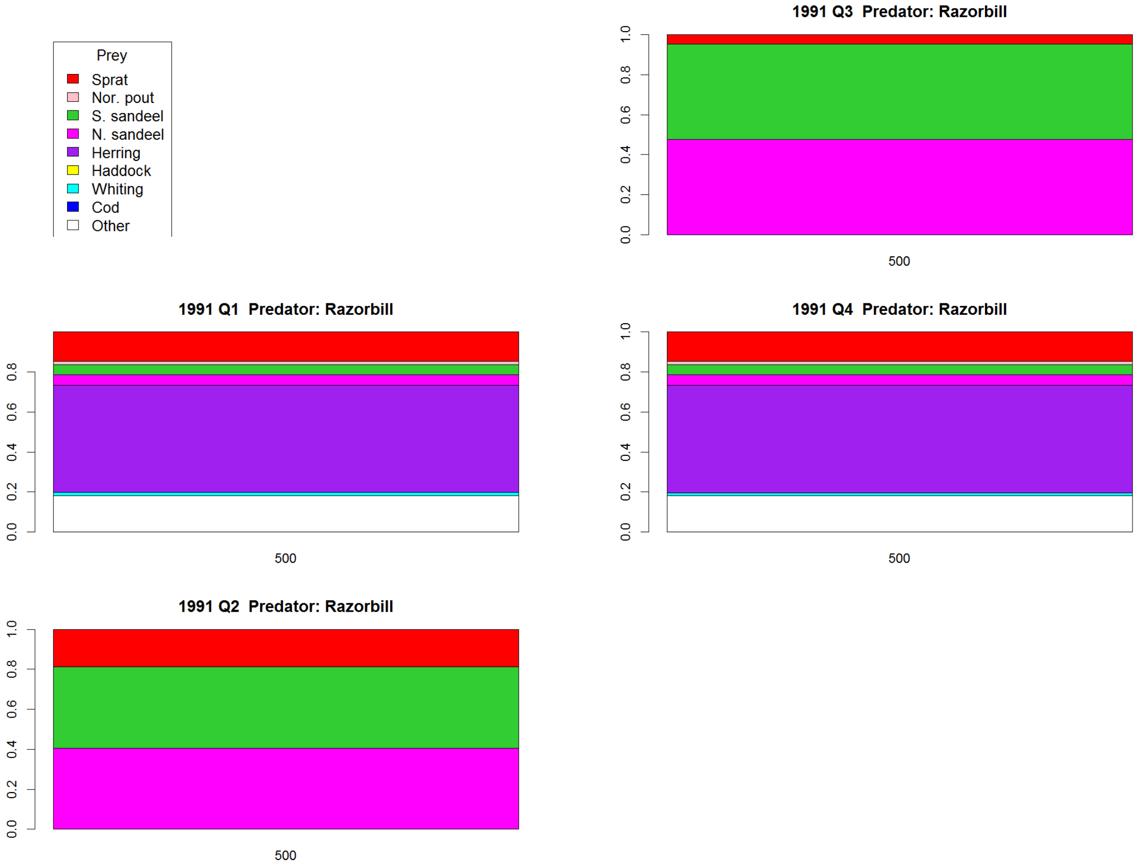


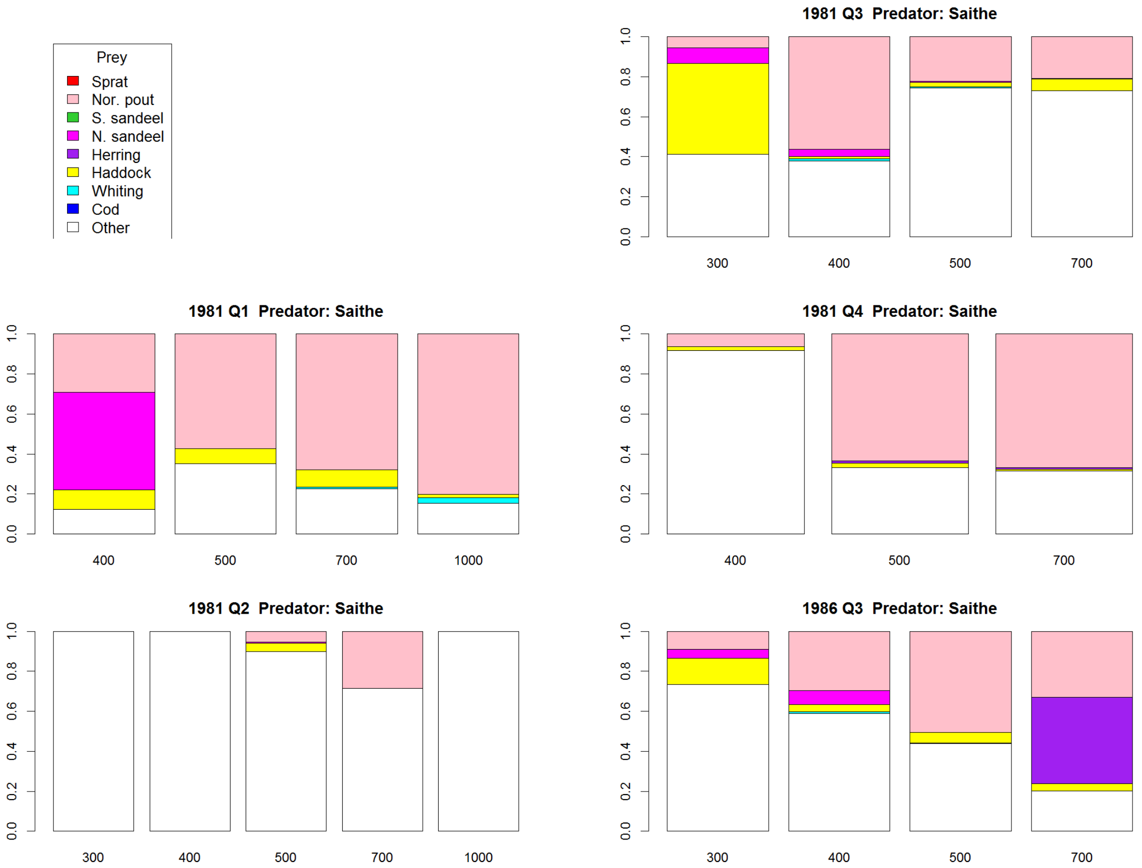
Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Razorbill
1981 Q1 Predator: Razorbill
1981 Q4 Predator: Razorbill
1981 Q2 Predator: Razorbill
1985 Q1 Predator: Razorbill
0.0
0.2
0.4
0.6
0.8
1.0
500



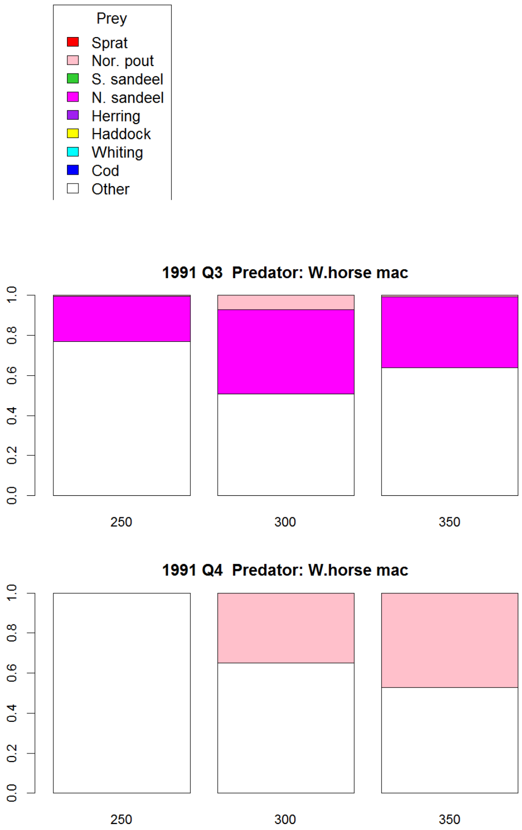
Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Razorbill
1985 Q2 Predator: Razorbill
1986 Q1 Predator: Razorbill
1985 Q3 Predator: Razorbill
1986 Q2 Predator: Razorbill
0.0
0.2
0.4
0.6
0.8
1.0
500

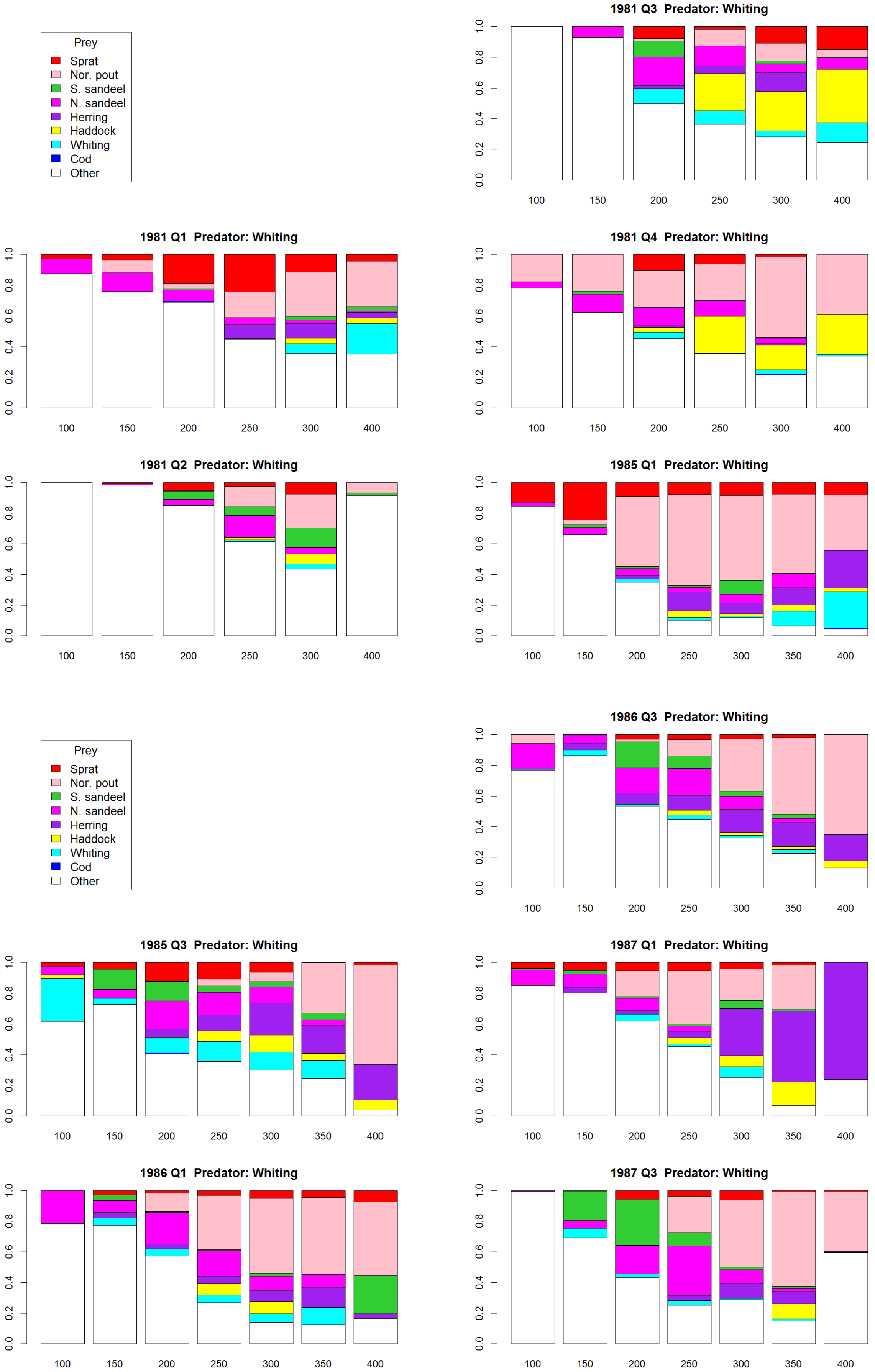

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Razorbill
1986 Q3 Predator: Razorbill
1987 Q2 Predator: Razorbill
1986 Q4 Predator: Razorbill
1987 Q3 Predator: Razorbill
1990 Q2 Predator: Razorbill
1987 Q4 Predator: Razorbill
1990 Q3 Predator: Razorbill
1990 Q1 Predator: Razorbill
1990 Q4 Predator: Razorbill
0.0
0.2
0.4
0.6
0.8
1.0
500


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Razorbill
1991 Q1 Predator: Razorbill
1991 Q4 Predator: Razorbill
1991 Q2 Predator: Razorbill
0.0
0.2
0.4
0.6
0.8
1.0
500


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Saithe
1981 Q1 Predator: Saithe
1981 Q4 Predator: Saithe
1981 Q2 Predator: Saithe
1986 Q3 Predator: Saithe
0.0
0.2
0.4
0.6
0.8
1.0
300
400
500
700
1000


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q2 Predator: Saithe
300 350 400 500 600 700 800 1000
1987 Q3 Predator: Saithe
300 400 500 700
1991 Q3 Predator: Saithe
400 500 600 700 800
1991 Q1 Predator: Saithe
300 350 400 500 600 700 800
1991 Q4 Predator: Saithe
350 400 500 600 700 800 1000


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: W.horse mac
250 300 350
1991 Q4 Predator: W.horse mac
250 300 350


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Whiting
1981 Q1 Predator: Whiting
1981 Q4 Predator: Whiting
1981 Q2 Predator: Whiting
1985 Q1 Predator: Whiting
1986 Q3 Predator: Whiting
1985 Q3 Predator: Whiting
1987 Q1 Predator: Whiting
1986 Q1 Predator: Whiting
1987 Q3 Predator: Whiting

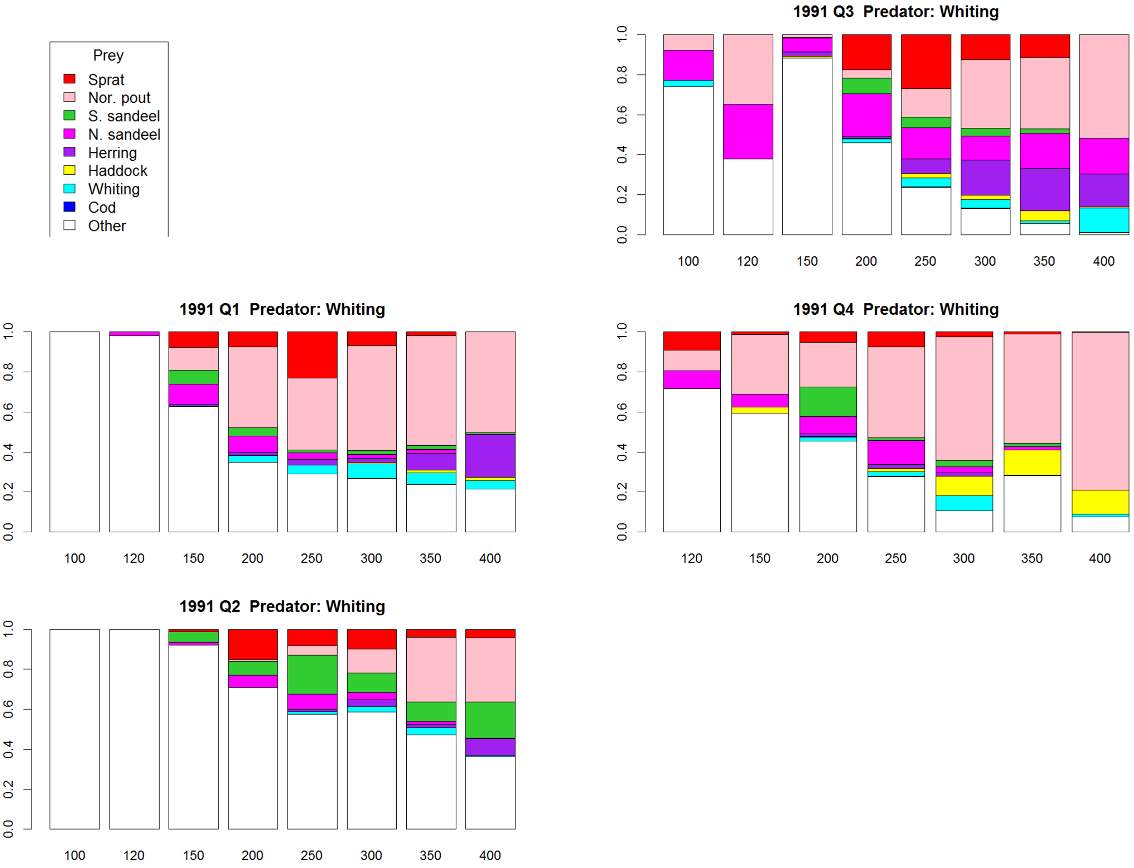

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Whiting
1991 Q1 Predator: Whiting
1991 Q4 Predator: Whiting
1991 Q2 Predator: Whiting
0.0
0.2
0.4
0.6
0.8
1.0
100
120
150
200
250
300
350
400

Table A3.1. Example of relative observed stomach contents by predator and prey length classes for Cod in 1991 quarter 1.

		Predator length class										
		150	**200**	**250**	**300**	**350**	**400**	**500**	**600**	**700**	**800**	**1000**
Prey	length											
COD	120	.	.	.	.	.	.	.	.	0.000	.	.
	150	.	.	.	.	.	.	0.003	0.003	.	.	0.007
	200	.	.	.	.	.	.	.	.	0.000	.	.
	250	.	.	.	.	.	.	.	0.003	.	0.014	.
	350	.	.	.	.	.	.	.	0.053	.	.	.
	All	.	.	.	.	.	.	0.003	0.058	0.000	0.014	0.007
HAD	length	.	.	.	.	.	.	0.001	.	.	.	.
	100											
	120	.	.	.	.	.	0.015	0.040	0.011	0.002	.	.
	150	.	.	.	.	.	0.020	0.014	0.005	0.021	0.005	.
	200	.	.	.	.	.	.	.	0.005	0.000	.	0.006
	250	.	.	.	.	.	.	.	.	.	.	0.015
	400	.	.	.	.	.	.	.	.	.	0.025	.
	All	.	.	.	.	.	0.035	0.055	0.021	0.022	0.031	0.021
HER	length	.	.	.	.	.	.	.	.	.	0.000	.
	70											
	80	.	.	.	.	0.009	.	.	.	0.000	0.002	.
	100	.	.	.	.	.	.	0.002	0.002	0.000	0.001	0.002
	120	.	.	.	.	.	0.002	0.009	0.013	0.001	0.01	0.013
	150	.	.	.	.	0.049	0.059	0.003	0.016	0.081	0.008	0.047
	200	.	.	.	.	0.016	0.017	0.079	0.105	0.04	0.076	0.028
	250	.	.	.	.	.	.	0.031	0.018	0.016	0.064	.
	All	.	.	.	.	0.074	0.077	0.125	0.154	0.137	0.161	0.090
NOP	length	.	.	.	.	.	0.004	0.003	0.002	0.001	0.001	.
	80											
	100	.	.	0.087	0.106	0.032	0.052	0.05	0.019	0.005	0.011	.
	120	.	.	.	0.024	0.184	0.045	0.075	0.031	0.053	0.009	.
	150	.	.	.	.	.	.	0.053	0.010	.	0.007	.
	All	.	.	0.087	0.129	0.217	0.101	0.181	0.062	0.058	0.028	.
NSA	length	.	.	.	0.007	0.005	0.001	.	.	.	0.000	.
	70											
	80	0.012	.	0.034	0.015	0.01	0.002	0.001	.	.	0.000	.
	100	.	.	.	0.002	0.021	0.009	.	.	.	0.000	0.000
	120	.	.	.	.	0.002	0.006	.	.	.	0.001	.
	150	.	.	.	.	.	.	.	.	0.001	0.001	.
	All	0.012	.	0.034	0.024	0.038	0.018	0.001	.	0.001	0.002	0.000
SPR	length	0.026	.	.	.	.	.	.	.	.	.	.
	50											
	70	0.181	.	.	.	.	.	.	.	0.000	.	0.000
	80	.	0.208	.	.	0.003	0.000	0.000	0.001	0.005	0.001	0.005

		Predator length class										
		150	**200**	**250**	**300**	**350**	**400**	**500**	**600**	**700**	**800**	**1000**
	100	.	.	.	.	.	0.001	.	.	0.000	.	.
	120	.	.	.	.	.	0.022	.	0.002	0.002	.	.
	All	0.207	0.208	.	.	0.003	0.023	0.000	0.003	0.007	0.001	0.005
SSA	length	.	.	.	.	0.000	.	.	.	.	.	.
	70											
	80	.	.	.	.	.	.	.	.	.	0.001	.
	100	.	0.031	.	.	0.000	0.000	.	.	0.001	0.001	.
	120	.	0.076	.	.	0.007	0.003	0.002	0.000	0.000	.	.
	150	0.071	.	.	0.001	.	0.003	0.001	0.000	.	.	.
	200	.	.	.	.	.	.	0.001	.	.	.	.
	All	0.071	0.107	.	0.001	0.007	0.006	0.004	0.000	0.001	0.002	.
WHG	length	.	.	.	.	0.034	0.016	.	0.000	0.002	0.000	0.013
	100											
	120	.	.	.	0.060	0.019	0.114	0.036	0.013	0.015	0.007	0.061
	150	.	.	.	.	0.02	0.029	0.083	0.029	0.025	0.012	0.069
	200	.	.	.	.	.	0.037	0.098	0.089	0.061	0.104	0.040
	250	.	.	.	.	.	.	0.053	0.061	0.063	0.083	0.038
	300	.	.	.	.	.	.	.	0.046	0.035	0.053	0.027
	All	.	.	.	0.060	0.073	0.197	0.270	0.238	0.202	0.259	0.248
OTH	length	0.711	0.685	0.878	0.786	0.587	0.543	0.362	0.463	0.571	0.503	0.628
	9999											
	All	0.711	0.685	0.878	0.786	0.587	0.543	0.362	0.463	0.571	0.503	0.628
All	All	1	1	1	1	1	1	1	1	1	1	1

Table A3.2. Number of stomach sampled by predator, year, quarter and predator size class (lower limit in mm).

Predator Cod

	Year														All
	1981				1985		1986		1987		1991				
	Quarter				Quarter		Quarter		Quarter		Quarter				
	1	2	3	4	1	3	1	3	1	3	1	2	3	4	
100	.	.	355	189	.	70	.	21	.	3	.	.	193	212	1043
120	.	.	.	.	.	.	.	.	.	.	42	6	55	165	268
150	251	176	232	199	91	6	639	204	209	89	117	216	4	335	2768
200	531	328	87	199	254	91	311	825	314	477	123	498	149	102	4289
250	601	370	185	233	449	217	194	935	483	655	61	331	392	80	5186
300	837	538	370	424	484	528	93	644	486	703	172	248	320	256	6103
350	.	.	.	.	353	420	128	333	357	746	207	334	158	230	3266
400	455	391	337	404	378	484	315	243	246	691	327	564	263	205	5303
500	556	392	367	453	253	311	198	232	85	230	320	428	165	119	4109
600	.	.	.	.	157	186	244	114	53	87	281	245	99	107	1573
700	684	180	257	357	105	120	171	84	50	61	186	112	41	73	2481
800	.	.	.	.	110	79	146	70	84	53	258	96	36	33	965
1000	117	19	49	54	30	15	64	15	41	13	81	29	9	9	545
All	4032	2394	2239	2512	2664	2527	2503	3720	2408	3808	2175	3107	1884	1926	37899

Predator Whiting

	Year														All
	1981				1985		1986		1987		1991				
	Quarter				Quarter		Quarter		Quarter		Quarter				
	1	2	3	4	1	3	1	3	1	3	1	2	3	4	
100	1455	435	229	522	1084	303	1414	936	1766	300	292	92	883	548	10259
120	.	.	.	.	.	.	.	.	.	.	891	495	754	673	2813
150	1604	758	317	518	1394	767	1667	1060	2232	1121	1341	2148	1061	1756	17744
200	1587	963	807	704	1691	1846	1400	1955	1666	1466	1284	3010	2387	1915	22681
250	1515	1246	1075	795	1360	1896	1243	2209	1161	1763	1262	3422	3084	2148	24179
300	1215	1024	944	711	712	1129	631	1467	619	1174	789	1742	2084	1616	15857
350	.	.	.	.	315	290	150	390	158	388	205	331	344	556	3127
400	156	64	152	107	91	68	29	83	9	53	37	81	24	68	1022
500	3	1	5	4	1	1	.	.	1	1	1	9	.	.	27
All	7535	4491	3530	3361	6648	6300	6534	8100	7612	6266	6102	11330	10621	9280	97710

Table A3.2. (Continued.) Number of stomach sampled by predator, year, quarter and predator size class (lower limit in mm).

Predator Haddock

	Year								All
	1981				1991				
	Quarter				Quarter				
	1	2	3	4	1	2	3	4	
100	238	.	772	692	19	.	590	180	2491
120	.	.	.	.	289	34	602	299	1224
150	444	576	679	812	529	482	379	413	4314
200	572	719	1049	919	445	555	763	359	5381
250	629	802	1333	947	340	526	866	527	5970
300	690	871	1451	1012	341	464	624	535	5988
350	.	.	.	.	262	350	423	304	1339
400	195	387	455	503	170	270	241	185	2406
500	42	39	82	80	45	54	46	66	454
600	.	.	.	.	1	14	5	17	37
All	2810	3394	5821	4965	2441	2749	4539	2885	29604

Predator Saithe

	Year										All
	1981				1986	1987	1991				
	Quarter				Quarter	Quarter	Quarter				
	1	2	3	4	3	3	1	2	3	4	
300	90	14	68	10	727	91	98	12	4	4	1118
350	.	.	.	.	.	.	179	258	56	73	566
400	70	7	171	62	695	361	375	455	198	499	2893
500	279	45	363	156	577	400	71	204	70	194	2359
600	.	.	.	.	.	.	38	96	27	50	211
700	324	113	278	147	97	66	20	75	15	13	1148
800	.	.	.	.	.	.	12	72	29	17	130
1000	34	6	15	174	4	4	3	10	.	6	256
All	797	185	895	549	2100	922	796	1182	399	856	8681

Table A3.2. (Continued). Number of stomach sampled by predator, year, quarter and predator size class (lower limit in mm).

Predator Mackerel

	Year								All
	1981				1991				
	Quarter				Quarter				
	1	2	3	4	1	2	3	4	
50	.	.	.	.	.	.	1	.	1
150	3	3	.	.	71	2	.	22	101
200	68	39	58	4	134	207	66	50	626
250	71	188	621	101	48	554	616	100	2299
300	83	466	1212	406	33	972	1359	274	4805
350	.	.	.	.	5	468	629	225	1327
400	16	358	307	145	1	129	126	34	1116
All	241	1054	2198	656	292	2332	2797	705	10275

Predator Grey gurnard

	Year												All
	1980	1982	1983	1987	1989	1990			1991				
	Quarter	Quarter	Quarter	Quarter	Quarter	Quarter			Quarter				
	3	3	2	3	2	1	2	3	1	2	3	4	
80	.	.	.	.	.	.	2	2	.	.	.	17	21
100	.	.	26	.	5	58	5	25	.	43	20	105	287
120	.	.	.	.	.	.	.	.	19	51	20	68	158
150	10	10	35	.	24	99	99	169	605	1682	1234	465	4432
200	10	10	136	10	53	64	92	175	587	1524	1469	485	4615
250	10	10	101	.	45	27	69	83	358	510	737	326	2276
300	10	2	2	.	21	2	42	38	248	214	356	166	1101
350	.	.	.	.	7	.	13	17	85	97	157	59	435
400	.	.	.	.	1	.	1	.	14	7	8	10	41
All	40	32	300	10	156	250	323	509	1916	4128	4001	1701	13366

Table A3.2. (Continued.) Number of stomach sampled by predator, year, quarter and predator size class (lower limit in mm).

Predator Horse Mackerel

	Year					All
	1987	1991				
	Quarter	Quarter				
	3	1	2	3	4	
100	.	.	35	.	.	35
120	.	.	12	.	2	14
150	28	.	47	119	.	194
200	100	.	180	188	19	487
250	320	1	269	495	265	1350
300	242	6	291	591	380	1510
350	15	4	83	93	89	284
400	.	.	3	3	4	10
All	705	11	920	1489	759	3884

Predator *Amblyraja radiata*

	Year				All
	1991				
	Quarter				
	1	2	3	4	
100	.	.	1	.	1
120	.	.	1	2	3
150	19	12	40	8	79
200	33	35	121	17	206
250	111	51	217	53	432
300	99	75	267	76	517
350	114	85	297	86	582
400	185	257	336	152	930
500	28	34	49	15	126
All	589	549	1330	409	2877

Table A3.3. Number of stomachs sampled by predator and year.

	Year								
	1981	1983	1985	1986	1987	1989	1990	1991	All
Predator Cod	11177	.	5191	6223	6216	.	.	9092	37899
Grey gurnard	.	300	.	.	10	156	1082	11746	13366
Haddock	16990	.	.	.	.	.	.	12614	29604
Horse Mackerel	.	.	.	.	705	.	.	3179	3884
Mackerel	4149	.	.	.	.	.	.	6126	10275
Amblyraja radiata	.	.	.	.	.	.	.	2877	2877
Saithe	2426	.	.	2100	922	.	.	3233	8681
Whiting	18917	.	12948	14634	13878	.	.	37333	97710
All	53659	300	18139	22957	21731	156	1082	86200	204296

11 APPENDIX 4: Option file for SMS-key-runs

Key-run 2020

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 A. 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. Spawning season (not used yet, but set to 1)
# 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 A. 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)
   1e+06  #        Cod
   1e+06  #    Whiting
   1e+05  #    Haddock
   1e+05  #     Saithe
   1e+06  #   Mackerel
   1e+05  #    Herring
   1e+05  #  N. sandeel
   1e+06  #  S. sandeel
   1e+06  #   Nor. pout
   1e+06  #      Sprat
   1e+06  #     Plaice
   1e+05  #       Sole
##########################################
## 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
    1988  #        Cod
    1982  #    Whiting
    1988  #    Haddock
      -1  #     Saithe
    1980  #   Mackerel
      -1  #    Herring
      -1  #  N. sandeel
      -1  #  S. sandeel
```

```
      1977  #    Nor. pout
      1981  #       Sprat
        -1  #      Plaice
        -1  #        Sole
# last year by species
        -1  #         Cod
        -1  #     Whiting
        -1  #     Haddock
        -1  #      Saithe
        -1  #    Mackerel
        -1  #     Herring
        -1  #  N. sandeel
        -1  #  S. sandeel
        -1  #   Nor. pout
        -1  #       Sprat
        -1  #      Plaice
        -1  #        Sole
##########################################
## 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 A. 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)
      0  #        Cod
      0  #      Whiting
      0  #      Haddock
      0  #       Saithe
      0  #     Mackerel
      0  #      Herring
      0  #   N. sandeel
      0  #   S. sandeel
      0  #    Nor. pout
      0  #        Sprat
      0  #       Plaice
      0  #         Sole
########################################
## 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)
      1  #        Cod
      1  #      Whiting
      1  #      Haddock
      1  #       Saithe
      1  #     Mackerel
      0  #      Herring
      0  #   N. sandeel
      0  #   S. sandeel
      0  #    Nor. pout
      0  #        Sprat
      1  #       Plaice
      1  #         Sole
########################################
## use seasonal or common combined variances for catch observation
# seasonal=0, common=1 (use 1 for annual data)
      1  #        Cod
      1  #      Whiting
      1  #      Haddock
      1  #       Saithe
      1  #     Mackerel
      0  #      Herring
      0  #   N. sandeel
      0  #   S. sandeel
      0  #    Nor. pout
      0  #        Sprat
      1  #       Plaice
      1  #         Sole
########################################
##
# catch observations: number of separate catch variance groups by species
       4   #        Cod
       5   #      Whiting
       5   #      Haddock
       3   #       Saithe
       3   #     Mackerel
       3   #      Herring
       3   #   N. sandeel
       2   #   S. sandeel
       3   #    Nor. pout
       2   #        Sprat
       3   #       Plaice
       3   #         Sole

#  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
       4   #        Cod
       4   #      Whiting
       3   #      Haddock
       2   #       Saithe
```

```
    3  #   Mackerel
    2  #    Herring
    3  # N. sandeel
    3  # S. sandeel
    3  #  Nor. pout
    3  #      Sprat
    2  #     Plaice
    1  #       Sole

#  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
   0  #         Cod
   0  #     Whiting
   0  #     Haddock
   0  #      Saithe
   0  #    Mackerel
   0  #     Herring
   0  #  N. sandeel
   0  #  S. sandeel
   0  #   Nor. pout
   0  #       Sprat
   0  #      Plaice
   0  #        Sole
##########################################
##
# catch observations: number of year groups with the same age and seasonal selection
    3  #        Cod
    3  #    Whiting
    3  #    Haddock
    2  #     Saithe
    3  #   Mackerel
    3  #    Herring
    2  # N. sandeel
    2  # S. sandeel
    2  #  Nor. pout
    1  #      Sprat
    3  #     Plaice
    2  #       Sole

#  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
      1   #        Cod
      1   #     Whiting
      1   #     Haddock
      1   #      Saithe
      1   #    Mackerel
      1   #     Herring
      1   #  N. sandeel
      1   #  S. sandeel
      1   #   Nor. pout
      1   #       Sprat
      1   #      Plaice
      1   #        Sole

#  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))
     1  #         Cod
     1  #      Whiting
     1  #      Haddock
     1  #       Saithe
     1  #     Mackerel
     1  #      Herring
     1  #   N. sandeel
     1  #   S. sandeel
     1  #    Nor. pout
     1  #        Sprat
     1  #       Plaice
     1  #         Sole
########################################
## Uncertainties 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
      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 stomach.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 size group 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_rela-
tions.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
     -1  #         Cod
     -1  #     Whiting
     -1  #     Haddock
     -1  #      Saithe
     -1  #    Mackerel
     -1  #     Herring
     -1  #   N. sandeel
     -1  #   S. sandeel
     -1  #    Nor. pout
     -1  #       Sprat
     -1  #      Plaice
     -1  #        Sole
########################################
## 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
      0  #      Fulmar
      0  #    Guillemot
      0  #    Her. Gull
      0  #    Kittiwake
      0  #    GBB. Gull
      0  #      Gannet
      0  #      Puffin
      0  #    Razorbill
      0  #   A. radiata
      0  #  G. gurnards
      0  #  W.horse mac
      0  #  N.horse mac
      0  #    Grey seal
      4  #  H. porpoise
      0  #        Hake
      0  #         Cod
      0  #     Whiting
      0  #     Haddock
      0  #      Saithe
      0  #    Mackerel
########################################
## 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
      1  #      Fulmar
      1  #    Guillemot
```

```
        1  #    Her. Gull
        1  #    Kittiwake
        1  #    GBB. Gull
        1  #       Gannet
        1  #       Puffin
        1  #    Razorbill
        1  #   A. radiata
        1  #  G. gurnards
        1  #  W.horse mac
        1  #  N.horse mac
        1  #    Grey seal
        1  #  H. porpoise
        1  #         Hake
        1  #          Cod
        1  #      Whiting
        1  #      Haddock
        1  #       Saithe
        1  #     Mackerel
########################################
## # 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
        1  #       Fulmar
        1  #    Guillemot
        1  #    Her. Gull
        1  #    Kittiwake
        1  #    GBB. Gull
        1  #       Gannet
        1  #       Puffin
        1  #    Razorbill
        1  #   A. radiata
        1  #  G. gurnards
        1  #  W.horse mac
        1  #  N.horse mac
        1  #    Grey seal
        1  #  H. porpoise
        1  #         Hake
        1  #          Cod
        1  #      Whiting
        1  #      Haddock
        1  #       Saithe
        1  #     Mackerel
########################################
## # 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
      100  #       Fulmar
      100  #    Guillemot
      100  #    Her. Gull
      100  #    Kittiwake
      100  #    GBB. Gull
      100  #       Gannet
      100  #       Puffin
      100  #    Razorbill
      100  #   A. radiata
      100  #  G. gurnards
      100  #  W.horse mac
      100  #  N.horse mac
      100  #    Grey seal
      100  #  H. porpoise
      100  #         Hake
      100  #          Cod
      100  #      Whiting
      100  #      Haddock
      100  #       Saithe
      100  #     Mackerel
########################################
## 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)
        1  #       Fulmar
        1  #    Guillemot
        1  #    Her. Gull
        1  #    Kittiwake
        1  #    GBB. Gull
        1  #       Gannet
        1  #       Puffin
        1  #    Razorbill
        1  #   A. radiata
        1  #  G. gurnards
```

```
        1  #  W.horse mac
        1  #  N.horse mac
        1  #    Grey seal
        1  #  H. porpoise
        1  #         Hake
        1  #          Cod
        1  #      Whiting
        1  #      Haddock
        1  #       Saithe
        1  #     Mackerel
########################################
## 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
        0  #       Fulmar
        0  #    Guillemot
        0  #    Her. Gull
        0  #    Kittiwake
        0  #    GBB. Gull
        0  #       Gannet
        0  #       Puffin
        0  #    Razorbill
        1  #   A. radiata
        0  #  G. gurnards
        0  #  W.horse mac
        0  #  N.horse mac
        0  #    Grey seal
        0  #  H. porpoise
        0  #         Hake
        0  #          Cod
        1  #      Whiting
        0  #      Haddock
        1  #       Saithe
        1  #     Mackerel
########################################
## Minimum observed relative stomach contents weight for inclusion in ML estimation (option min.stom.cont)
     9e-05  #       Fulmar
     9e-05  #    Guillemot
     9e-05  #    Her. Gull
     9e-05  #    Kittiwake
     9e-05  #    GBB. Gull
     9e-05  #       Gannet
     9e-05  #       Puffin
     9e-05  #    Razorbill
     9e-05  #   A. radiata
     9e-05  #  G. gurnards
     9e-05  #  W.horse mac
     9e-05  #  N.horse mac
     9e-05  #    Grey seal
     9e-05  #  H. porpoise
     9e-09  #         Hake
     9e-09  #          Cod
     9e-09  #      Whiting
     9e-09  #      Haddock
     9e-05  #       Saithe
     9e-05  #     Mackerel
########################################
## Upper limit for no of samples used for calculation of stomach observation variance (option max.stom.sampl)
      1000  #       Fulmar
      1000  #    Guillemot
      1000  #    Her. Gull
      1000  #    Kittiwake
      1000  #    GBB. Gull
      1000  #       Gannet
      1000  #       Puffin
      1000  #    Razorbill
      1000  #   A. radiata
      1000  #  G. gurnards
      1000  #  W.horse mac
      1000  #  N.horse mac
      1000  #    Grey seal
      1000  #  H. porpoise
      1000  #         Hake
      1000  #          Cod
      1000  #      Whiting
      1000  #      Haddock
      1000  #       Saithe
      1000  #     Mackerel
########################################
## Max prey size/ pred size factor for inclusion in M2 calc (option max.prey.pred.size.fac)
        5  #       Fulmar
```

```
        5  #    Guillemot
        5  #    Her. Gull
        5  #    Kittiwake
        5  #    GBB. Gull
        5  #      Gannet
        5  #      Puffin
        5  #    Razorbill
      0.5  #   A. radiata
      0.5  #  G. gurnards
      0.5  #  W.horse mac
      0.5  #  N.horse mac
       50  #    Grey seal
       50  #  H. porpoise
      0.9  #        Hake
      0.5  #         Cod
      0.9  #      Whiting
      0.5  #      Haddock
      0.5  #       Saithe
      0.5  #     Mackerel
##########################################
## 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)
        2  #      Fulmar
        2  #    Guillemot
        2  #    Her. Gull
        2  #    Kittiwake
        2  #    GBB. Gull
        2  #      Gannet
        2  #      Puffin
        2  #    Razorbill
        2  #   A. radiata
        2  #  G. gurnards
        2  #  W.horse mac
        2  #  N.horse mac
        2  #    Grey seal
        2  #  H. porpoise
        2  #        Hake
        2  #         Cod
        2  #      Whiting
        2  #      Haddock
        2  #       Saithe
        2  #     Mackerel
##########################################
## 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
# prefered 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
3
# HAD
3
# POK
1
# MAC
2
# HER
3
# NSA
5
# SSA
5
# NOP
4
# SPR
3
# Ple
6
# SOL
3
##########################################################################
# 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 an-
nual 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 2020 0 1 1 5   4 -1 1 2  # Fleet01: IBTS_Q1_gam
1992 2019 0 1 1 4   4 -1 3 2  # Fleet02: IBTS_Q3_gam
#
# WHG   ##########################
1978 1988 0 1 1 5   4 -1 1 2 # Fleet01: IBTS_Q1 -1988
1989 2020 0 0 1 5   4 -1 1 2 # Fleet02: IBTS_Q1  1989-
1991 2019 0 1 0 5   4 -1 3 3 # Fleet03: IBTS_Q3
#
# HAD   ##########################
1974 1988 0 1 1 5   3 -1 1 2 # Fleet01: IBTS_Q1
1989 2020 0 1 1 5   3 -1 1 2 # Fleet02: IBTS_Q1
1991 2019 0 1 0 5   2 -1 3 3 # Fleet03: IBTS_Q3
#
# POK   ##########################
#1992 2019 0 1 3 8   4 -1 3 2 # Fleet01: IBTS Q3
1974 2019 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 2019 0 1   3 10  5 -1 3 2  # Fleet02: Swept-idx
1980 2019 0 0.1 1  9  1 -1 1 1  # Fleet03: SAM output with noise
#
# HER   ##########################
1989 2019 0.9 1 1 7   3 -1 2 3 # Fleet01: HERAS
1984 2020 0 0 1 1   1 -1 1 1 # Fleet03: IBTS Q1
1992 2020 0 0 0 0   0 -1 3 1 # Fleet02: MIK
#

# NSA, SAN north   ##########################
2004 2019 0 1 0 2  2 -1 4 2 # Fleet01: dredge survey
1982 1998 0 1 1 3  3 -1 2 1 # Fleet02: Commercial, first half year 1982-1998
1999 2019 0 1 1 3  3 -1 2 2 # Fleet03: Commercial, first half year 1999-2019
1976 2004 0 1 0 0  0 -1 3 1 # Fleet04: Commercial, second half year (old data)
2009 2019 0.5 0.7 1 4 3 -1 2 2 # Fleet05: acoustic
#
# SSA, SAN South   ##########################
2004 2019 0 1 0 2  2 -1 4 2  # Fleet01: dredge survey
1982 1998 0 1 1 3  3 -1 2 2  # Fleet02: Commercial, first half year 1982-1998
1999 2004 0 1 1 3  3 -1 2 1  # Fleet03: Commercial, first half year 1999-2004
2005 2009 0 1 1 3  3 -1 2 1  # Fleet04: Commercial, first half year 2005-2009
```

```
2010 2019 0 1 1 3  3 -1 2 1  # Fleet05: Commercial, first half year 2010-2019
#
# NOP   ##########################
1992 2019 0 1 0 1  1 -1 3 2 # Fleet01: EGFS
1984 2020 0 0 1 3  3 -1 1 2 # Fleet03: IBTS Q1
1991 2019 0 1 2 3  3 -1 3 2 # Fleet03: IBTS Q3
1998 2019 0 1 0 1  1 -1 3 2 # Fleet04: SGFS
#
# SPR   ##########################
2006 2019 0.9 1 1 3  3 -1 2 2 # Fleet01: HERAS Acoustic Q2
1983 2020 0 0 1 3  3 -1 1 2 # Fleet01: IBTS Q1
1992 2019 0 1 1 3  3 -1 3 2 # Fleet03: IBTS Q3
#
# PLE   ##########################
1985 1995 0 1 1 8 4 -1 3 3 # Fleet01: BTS-Isis
1996 2019 0 1 1 9 4 -1 3 3 # Fleet02: BTS-Combined
1974 1999 0 1 1 6 5 -1 3 3 # Fleet03: SNS1 1974-1999
2000 2019 0 1 1 6 4 -1 3 3 # Fleet04: SNS2 2000-
1997 2019 0 1 1 9 5 -1 3 3 # Fleet05: IBTS_Q3
2007 2019 0 1 1 7 5 -1 1 3 # Fleet06: IBTS_Q1
#
# SOL ############################
1974 2019 0 1 0 6  3 -1 3 4 # Fleet01: SNS
1985 2019 0 1 1 10 4 -1 3 4 # Fleet02: BTS
1985 2019 0 1 1 9  4 -1 3 4 # Fleet03: ISIS
#
##########################################################################
# First age group in groups for estimates of variance of catchability at age
# COD   ##########################
1 2  # Fleet01: IBTS_Q1_gam
1 2  # Fleet02: IBTS_Q3_gam
#
# WHG   ##########################
1 2    # Fleet01: IBTS_Q1 -1988
1 2    # Fleet02: IBTS_Q1 1988-
0 1 2  # Fleet03: IBTS_Q3
#
# HAD   ##########################
1 2     # Fleet01: IBTS_Q1
1 2     # Fleet02: 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: Dredge 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: dredge survey
1 2  # Fleet02: Commercial, first half year 1982-1998
1    # Fleet03: Commercial, first half year 1999-2004
1    # Fleet04: Commercial, first half year 2005-2009
1    # Fleet05: Commercial, first half year 2010-2016
#
# 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   # Fleet03: IBTS Q3
#
```

```
# PLE   ##########################
1 3 5  # Fleet01: BTS-Isis-early
1 2 3  # Fleet02: BTS-Combined
1 3 5   # Fleet03: SNS1
1 3 5  # Fleet04: SNS2
1 2 3   # Fleet05: IBTS_Q3
1 3 5  # Fleet06: IBTS_Q1
#
# SOL ###########################
0 1 2 4  # Fleet01: SNS
1 2 5 7  # Fleet02: BTS
1 2 5 7  # Fleet03: ISIS
-999 # check
```

12 APPENDIX 5: Comparison of ICES assessment and SMS assessment using fixed M

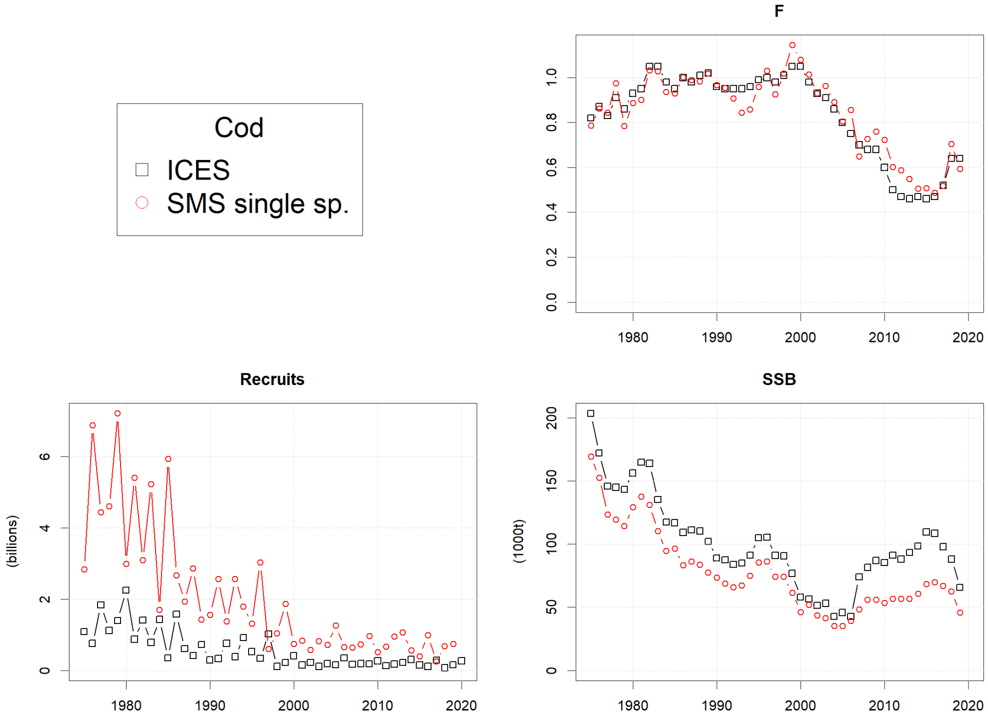


Figure A5.1. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

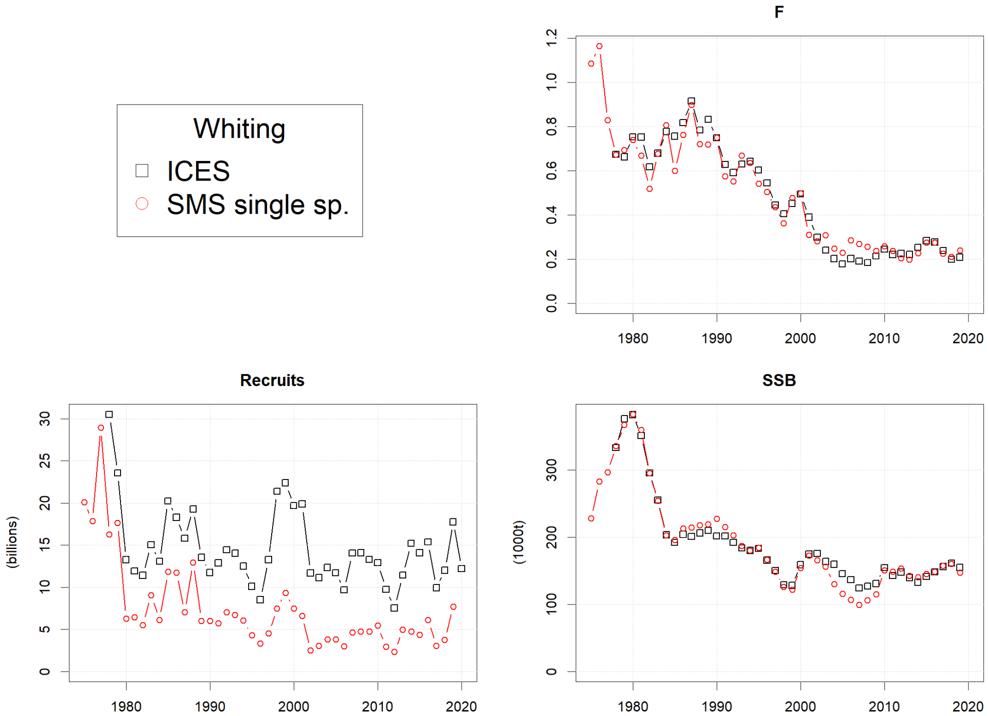


Figure A5.2. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

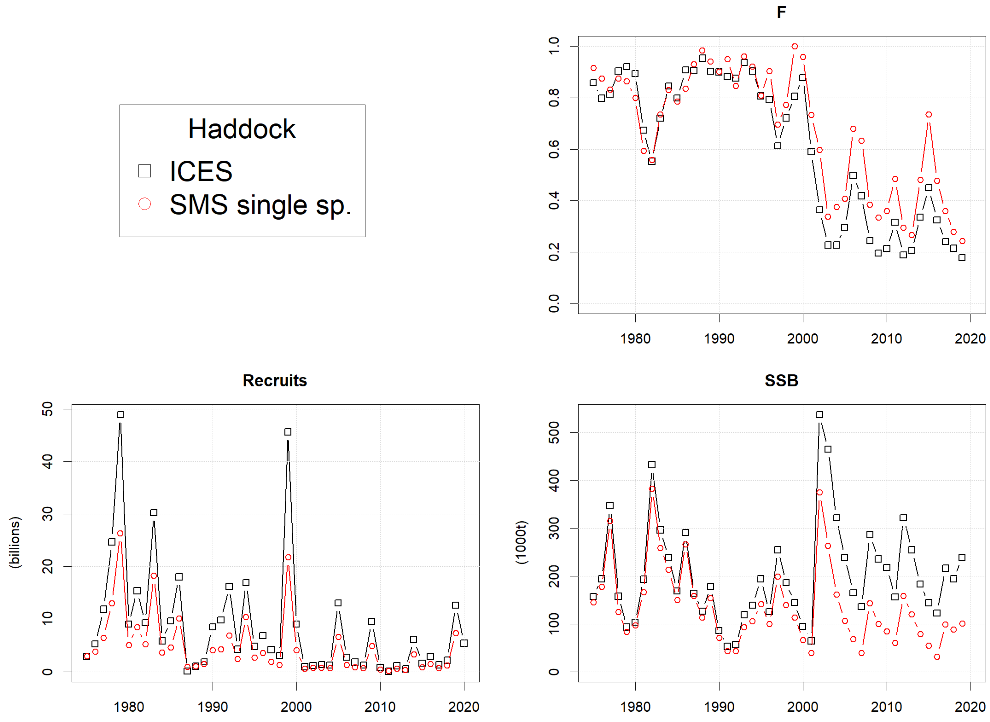


Figure A5.3. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

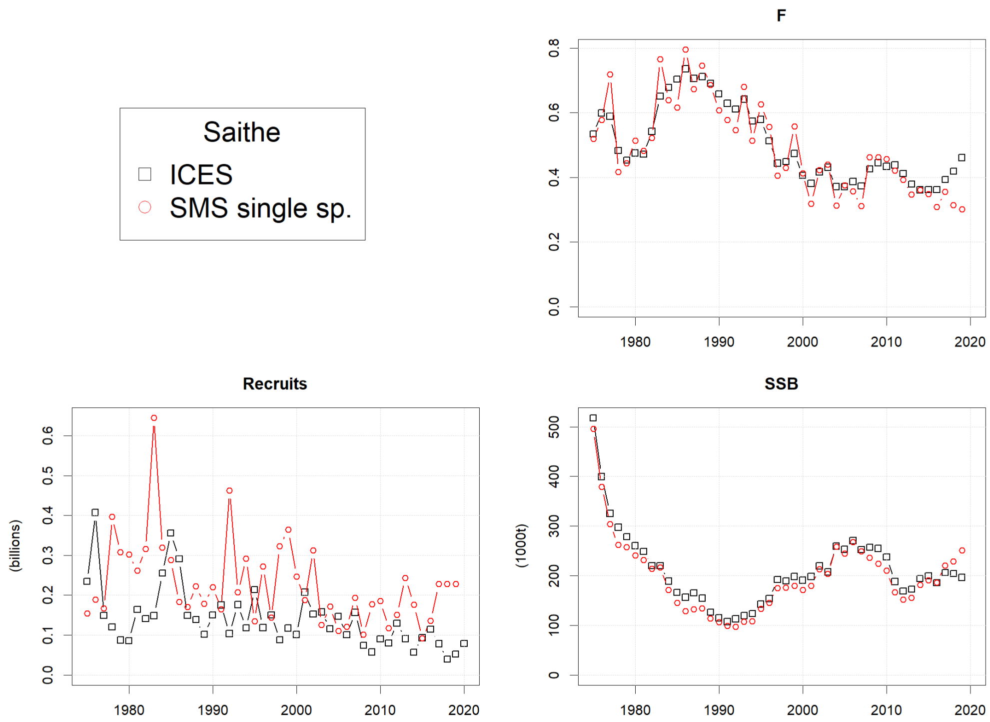


Figure A5.4. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

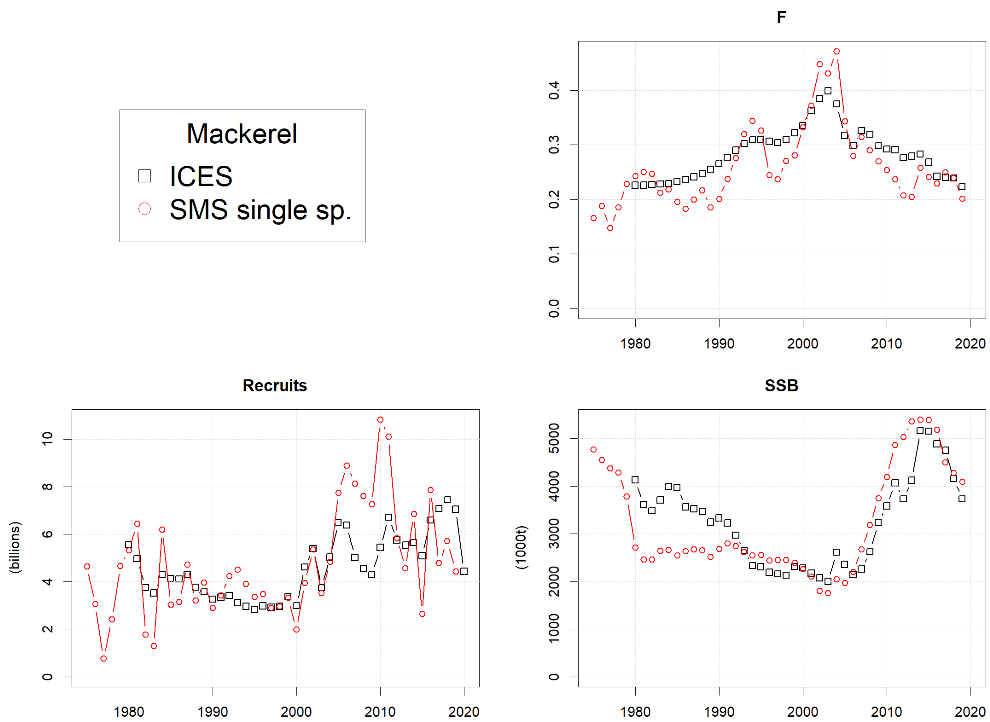


Figure A5.5. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

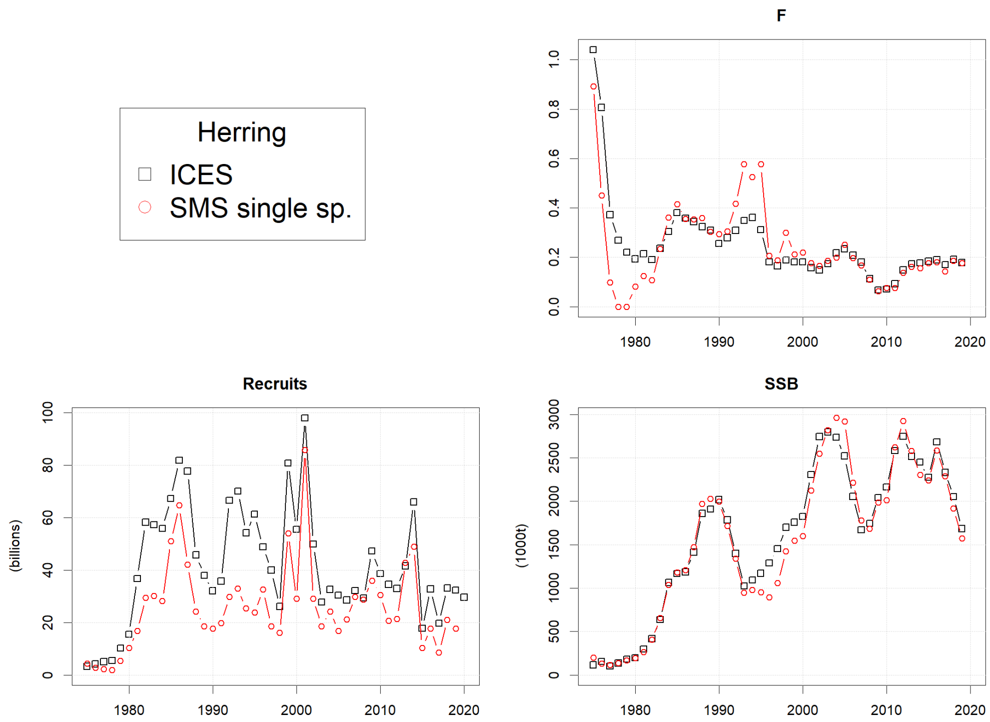


Figure A5.6. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

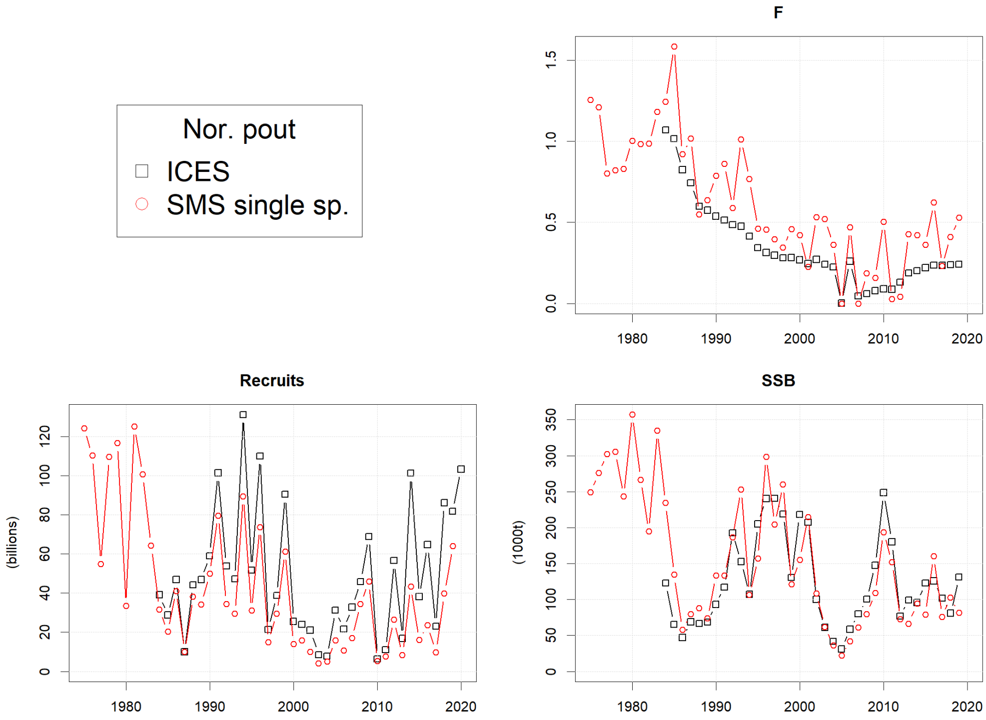


Figure A5.7. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

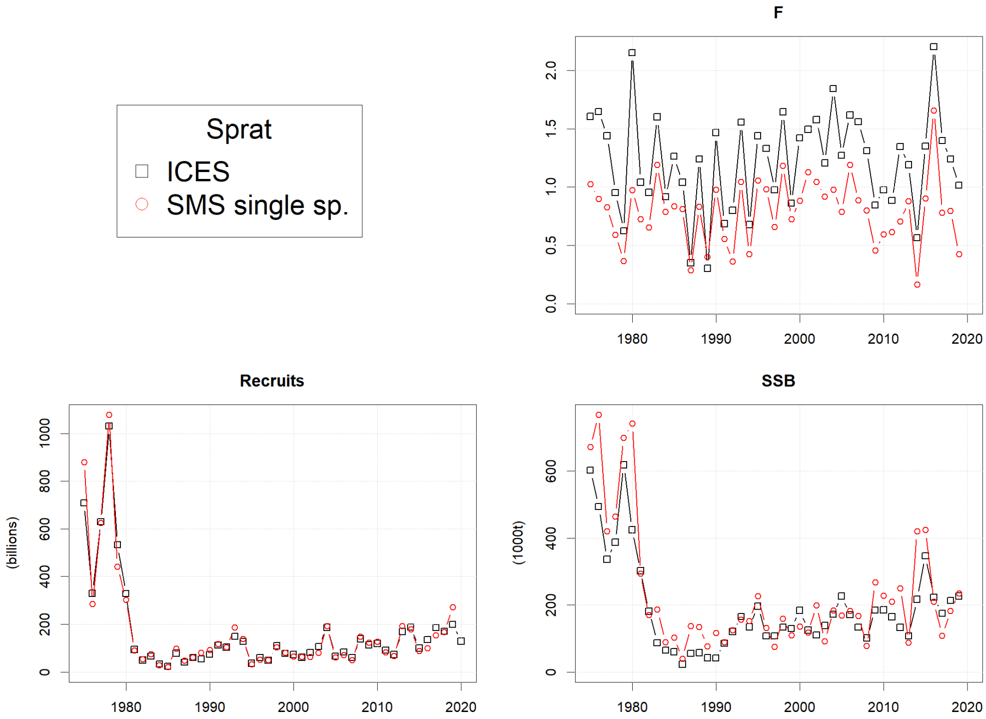


Figure A5.8. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

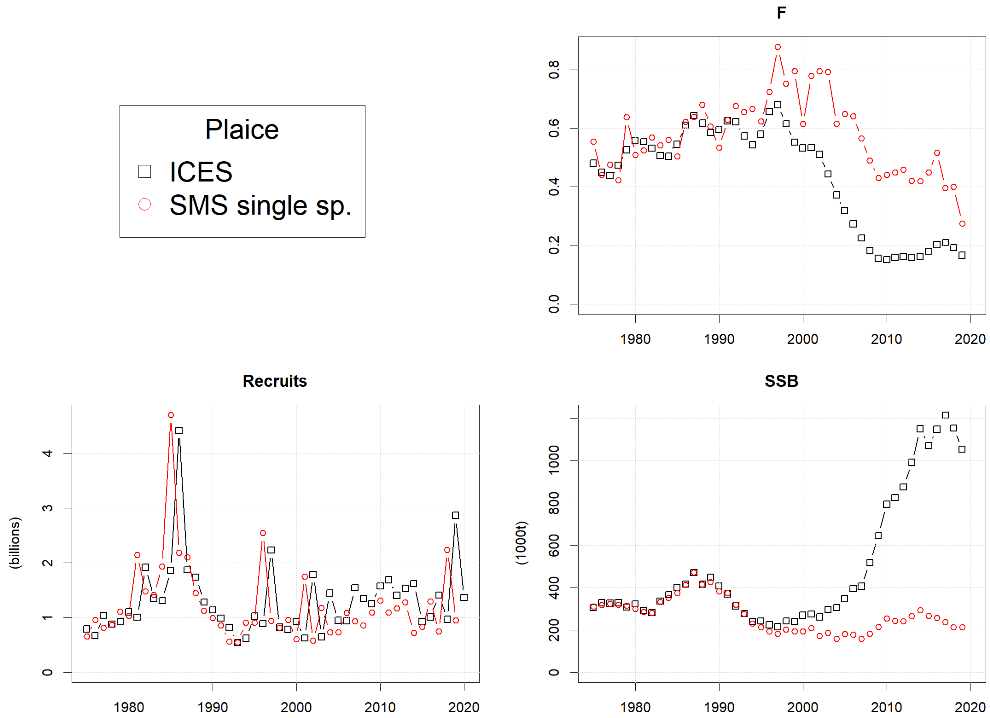


Figure A5.9. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

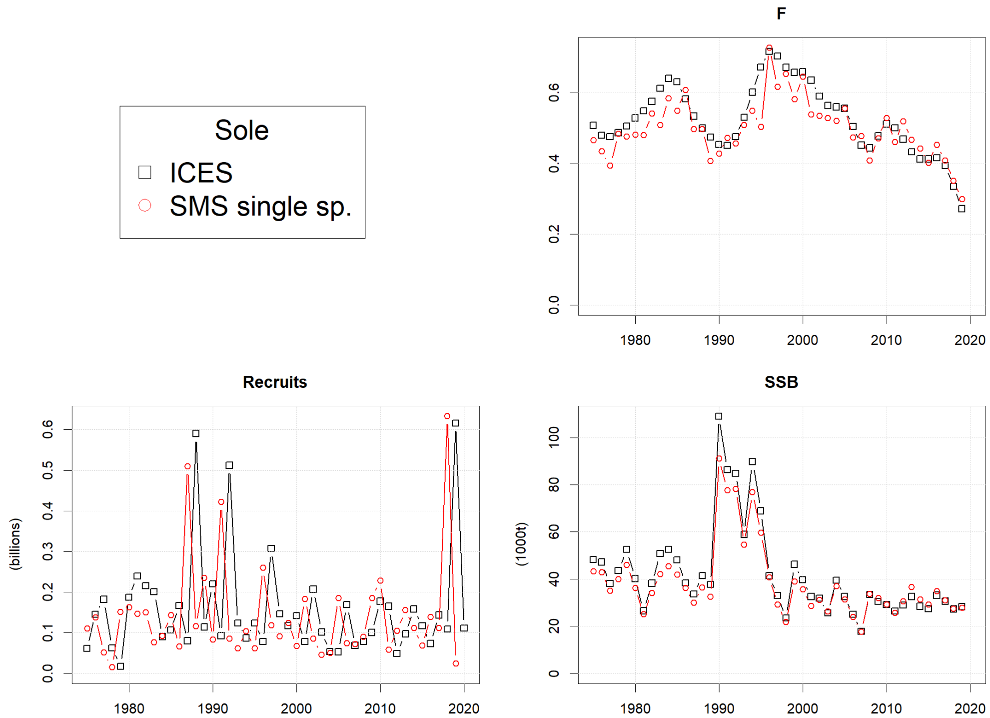


Figure A5.10. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).