4 ANNEX 4: Stock Annex for the ICES Eastern Baltic Sea SMS configuration.

Working Group	Working Group on Multispecies Assessment Methods (WGSAM)
Date	November 2019 (after the WGSAM 2019 meeting)
Predatory species	Cod (given as input population size)
Prey species	Assessed species: Herring, Sprat
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 Eastern Baltic Sea (ICES Sub-divisions 25-32, excluding the Gulf of Riga). Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix.

In the present SMS analysis, cod is a predator, and herring and sprat are preys. The population dynamics of cod were estimated outside the model, such that the population number and size distribution is assumed known without errors. For this reason and in contrast to earlier key runs for the Eastern Baltic Sea, this key run does not include predation mortality estimates on cod due to cannibalism.

Substantial changes of input data to the 2019 keyrun have been made since the last keyrun in 2012. However, the new estimated predation mortalities (M2) are consistent with the M2 values from the previous key run.

2019 key run

A key run for the Eastern Baltic Sea SMS model, including data for the period 1974–2018 was produced at the 2019 WGSAM. This key run replaces the key 2012 key run. The new key run includes revision and updates to the input data. A major modification is that cod is treated as external predator and the use of newly available data on cod stomach contents sampled mainly by the Latvian Institute.

SMS was updated with the most recent data from WGBFAS 2019, i.e. data for Herring in subdivisions 25–29 and 32, excluding the Gulf of Riga (central Baltic Sea) and for Sprat in subdivisions 22–32.

Due to age reading problems for cod in the eastern Baltic, ICES now applies and age-length based analytical assessment with the Stock Synthesis model (SS3). Natural mortality of cod is estimated within the SS3 model. Without input data by ages data, and with estimated high and time variable natural mortality SMS is no longer able to estimate cod stock numbers and predation mortality estimates on cod due to cannibalism. Instead, cod is now considered as an "other predator" where stock number and size distribution are assumed to be known without errors. Population numbers and size distributions were extracted from the SS3 output.

Consumption (food ration) of cod was revised to reflect the most recent knowledge of evacuation rates and temporal trends in cod consumption rates.

Diet data for cod were substantially extended by including the stomach content data from the EU Stomach Tender. This addition of data did not change predation rates on herring and sprat substantially, but increased the weight of the stomach data in the model likelihood, indicating a higher quality of stomach data compared to the previously used data.

5 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:

- External predator: cod;
- Prey: herring and sprat

The population dynamics of herring and sprat are estimated within the model.

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

6 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.

6.1 Analytical assessment stocks

This group of stocks includes:

1) Herring;

2) Sprat;

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

- Catch-at-age in numbers (SMS input file canum.in);
- Proportion of the catch-at-age landed, assumed 100% (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. The ICES assessments for herring and sprat 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
Herring	HER	8+	SD 25–29 and 32, excluding the Gulf of Riga (central Baltic Sea)	1947	1–8+	Year
Sprat	SPR	7+	SD 22-32	1974	1–8+	Year

Discarding is considered to be negligible for both stocks.

Quarterly catch-at-age number for herring (2002-2018) and sprat (1998-2018) were provided by ICES WGBFAS.

6.1.1 Herring

6.1.1.1 Catch data

ICES WGBFAS provided quarterly catch-at-age number and mean weights for herring for the period 2002-2018. The full data series are not presented in the WGBFAS report, but were kindly made available by Tomas Gröhsler. Older quarterly catch at age data were copied from the 2012 SMS key run.

6.1.1.2 Mean weight at age

WGBFAS assumes that mean weight at age in the sea is the same as mean weight at age in the catch. This assumption is fairly unbiased for older fish even though fisheries may be concentrated in areas (southern part of the EB) with the largest individuals. Mean weight at age in the catch for the youngest fish is higher than the mean weight in the sea as these size classes are not fully selected in the fishery. The mean weight at age as used by WGBFAS (Figure 6.1-1) shows a clear temporal trend with a decreasing mean weight in the period 1974-2000 followed by a modest increase.

The quarterly mean weight at age data from WGBFAS (2002-2018) combined with the 2012 key run data for the period 1974-2001 are presented in Figure 6.1-2 for the youngest ages 0 and 1. It is clearly seen that the mean weights for age 1 in quarter 2 do poorly link to quarter 1 and not at all to quarter 3.

It is assumed that the mean weight in the sea are the same as the observed mean weight in the catch. However, when calculation the mean weight at age in the sea, the observed mean weight at age in the catch for age 1 in quarter 2 was discarded and substituted by the mean of the observed mean weight at age in quarter 1 and 3 (Figure 6.1-3). As the observed mean weights for the ages 0-1 are highly variable, the smoothed values, ages 0 and 1, were finally used as mean weight in the sea.

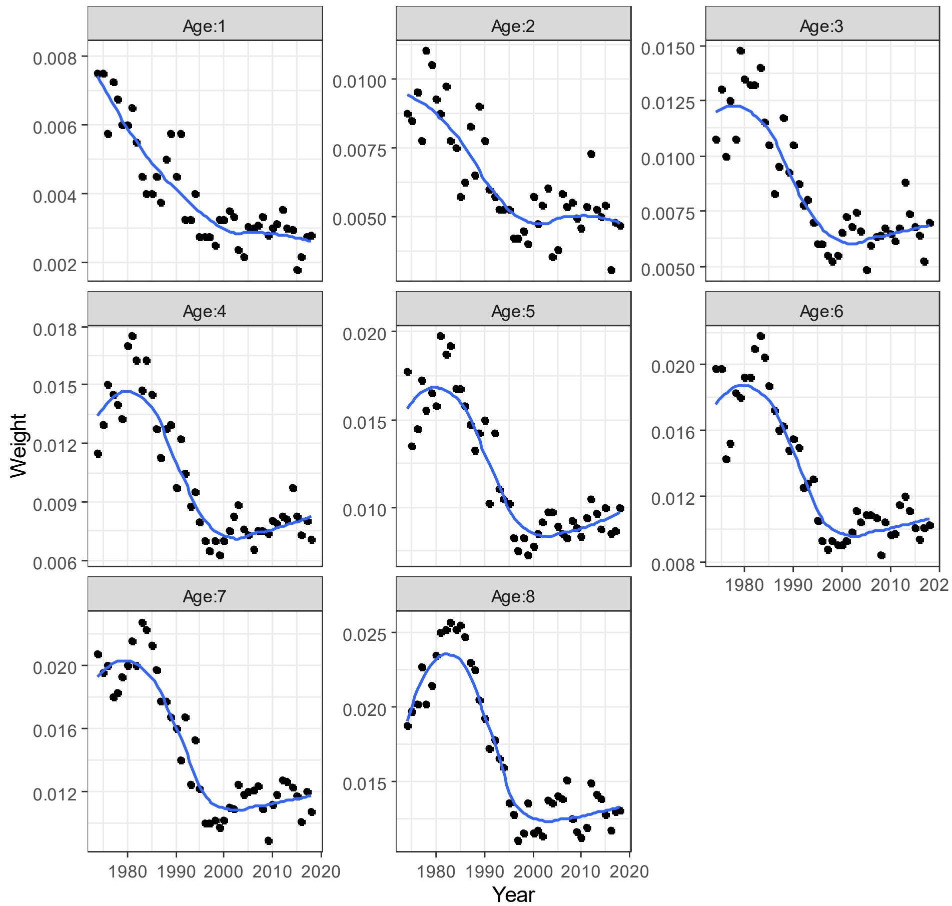

Figure 6.1-1. Herring mean weight at age in the catch (and in the sea) as used by WGBFAS. Dots show data points and the blue line is a loess smoother.

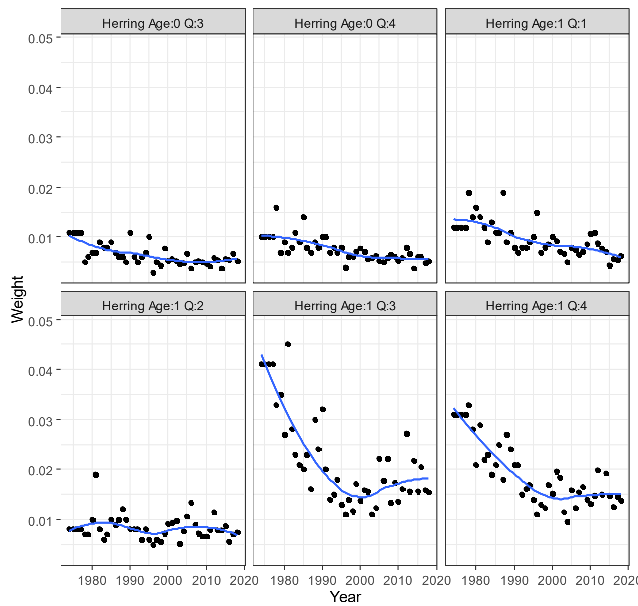

Figure 6.1-2. Quarterly herring mean weight at ages 0 and 1 in the catch as available for SMS. Dots show data points and the blue line is a loess smoother.

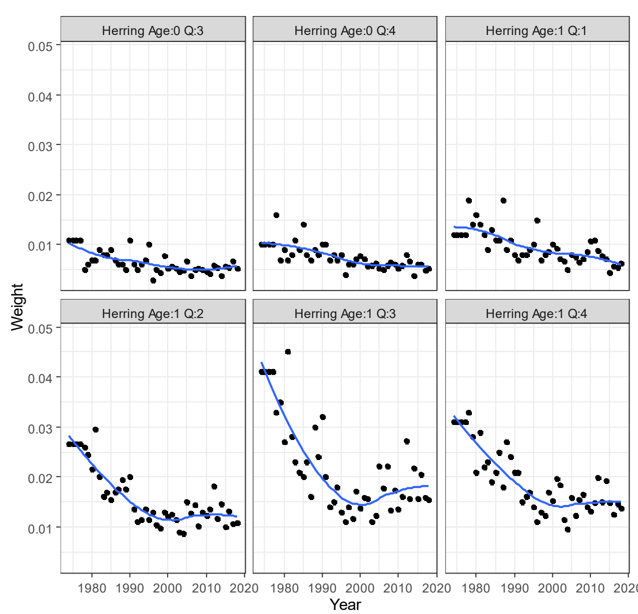

Figure 6.1-3. Quarterly herring mean weight at ages 0 and 1 in the sea as used for SMS. Dots show data points and the blue line is a loess smoother.

6.1.1.3 Other biological data

Proportion mature and M(used for "single species" SMS) at age data are copied from single-species data. WGSAM 2019 decided to use M1 at 0.025 per quarter for all ages.

The 2012 key-run applied 0.05, but for consistency with herring in the North Sea this was changed to 0.025.

6.1.1.4 Survey data

Survey data are copied from the previous key run and the ICES single-species assessment.

SMS name	Years	Ages	alfa and beta	Source
Herring_Acoustic_May	1982-1996	1–8	0.2-0.7 (Q2)	2012 key run
Herring_BIAS	1998-2018	1–7	0.0-0.3 (Q3)	WGBFAS ,2019

6.1.2 Sprat

6.1.2.1 Catch data

Quarterly catch-at-age number and mean weights for sprat, 1998-2018, were provided by ICES WGBFAS. The full data series are not presented in the WGBFAS report, but were kindly made available by Tomas Gröhsler. Older quarterly catch at age data were copied from the 2012 SMS key run.

6.1.2.2 Mean weight at age

WGBFAS assumes that mean weight at age in the sea is the same as mean weight at age in the catch. This assumption is probably unbiased for older fish even though fisheries may be concentrated in areas (south-western part of the EB) with the largest individuals. Mean weight at age in the catch for the youngest fish is probably higher than the mean weight in the sea as these size classes are not fully selected in the fishery. The mean weights at age as used by WGBFAS (Figure 6.1-4) show a clear temporal trend with a peak in mean weight around 1987 followed by a decrease until around 2003.

The quarterly mean weight at age in the catch from WGBFAS (1998-2018) combined with the 2012 key run data for the period 1974-1978 are presented in Figure 6.1-5 for the youngest ages 0 and 1. It is clearly seen that the mean weights for age 0 and age 1 in quarter 1 and 2 are highly variable from one year to the next. The same can be said about age 1 in quarter 3 and 4, but these quarters follow better the overall trend presented for the WGBFAS data (Figure 6.1-4). Due to the high (observation) variation in catch mean weights for ages 0-1, the smoothed values were used as mean weight at age in the sea (Figure 6.1-5).

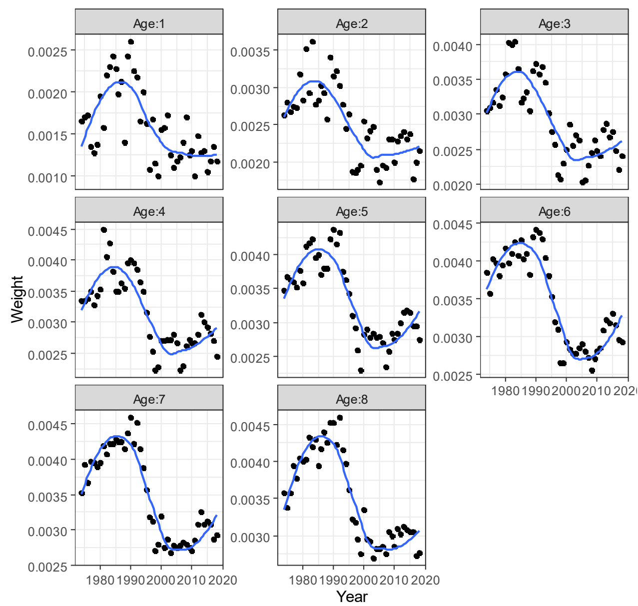

Figure 6.1-4. Sprat mean weight at age in the catch (and in the sea) as used by WGBFAS. Dots show data points and the blue line is a loess smoother.

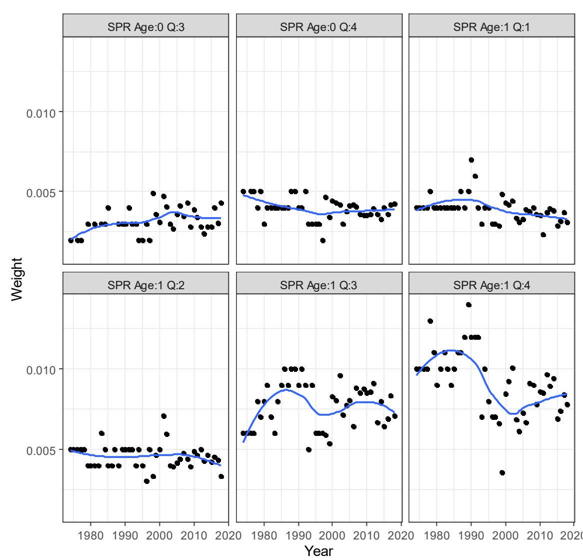

Figure 6.1-5. Quarterly sprat mean weight at ages 0 and 1 in the catch as available for SMS. Dots show data points and the blue line is a loess smoother.

6.1.2.3 Survey data

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

	Name	Years	Ages	alfa and beta	Source
1	Int acoustic in Oct.	1991-2018	1–7	0.0–0.1 (Q3)	WGBFAS 2019
2	Int_acoustic_in_May	2001–2018	1–7	0.25–0.50 (Q2)	WGBFAS 2019
3	LAT_RUS_acoustic	2001-2018	1–1	0.0-0.0 (Q1)	WGBFAS 2019

6.1.2.4 Biological data

Proportion mature and M at age data are copied from single-species data. M1 is assumed to be 0.05 per quarter for all ages.

6.2 External predators

Cod was for the first time in the Baltic SMS treated as an "external predator". This means that the stock numbers are given by input, extracted from the ICES Stock-Synthesis 3 (SS3) assessment for the stock, using the R-package "r4ss: R code for Stock Synthesis". The ICES assessment provide cod stock numbers and mean weight by a 2-cm length classes for the main length classes. These data were aggregated into length classes used by SMS (see Table 6.4-2).

The ICES SS3 assessment output is quite different from the previous age-based assessment and from the 2012 key-run (Figure 6.2-1). The SS3 assessment estimates much higher stock numbers for age 1-3 compared to the SMS estimate, and much higher stock numbers for oldest cod when the stock size peaked. SS3 and SMS use different mean weight at age, so the difference in biomass, quarter 1, (Figure 6.2-2) becomes smaller than when stock numbers were compared. Total biomass and biomass of the larger cod are estimated considerable higher in the SS3 assessment (Figure 6.2-3) such that the amount food eaten and predation mortality becomes higher when the cod estimate from SS3 is used.

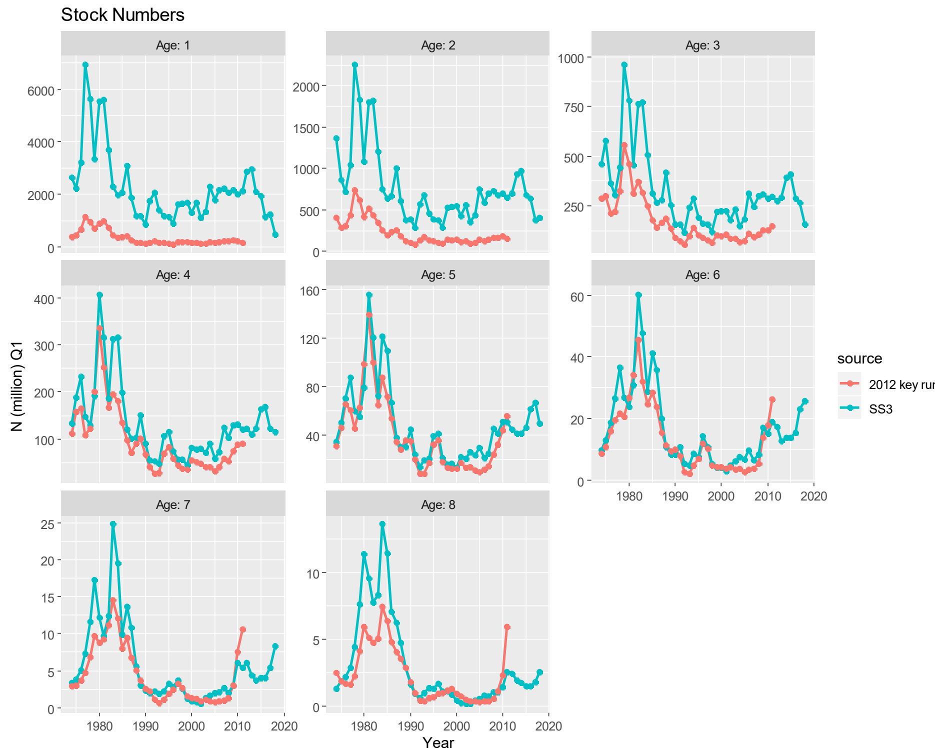

Figure 6.2-1. Comparison of stock numbers at age of cod estimated by the 2012 key-run and by the ICES SS3 assessment.

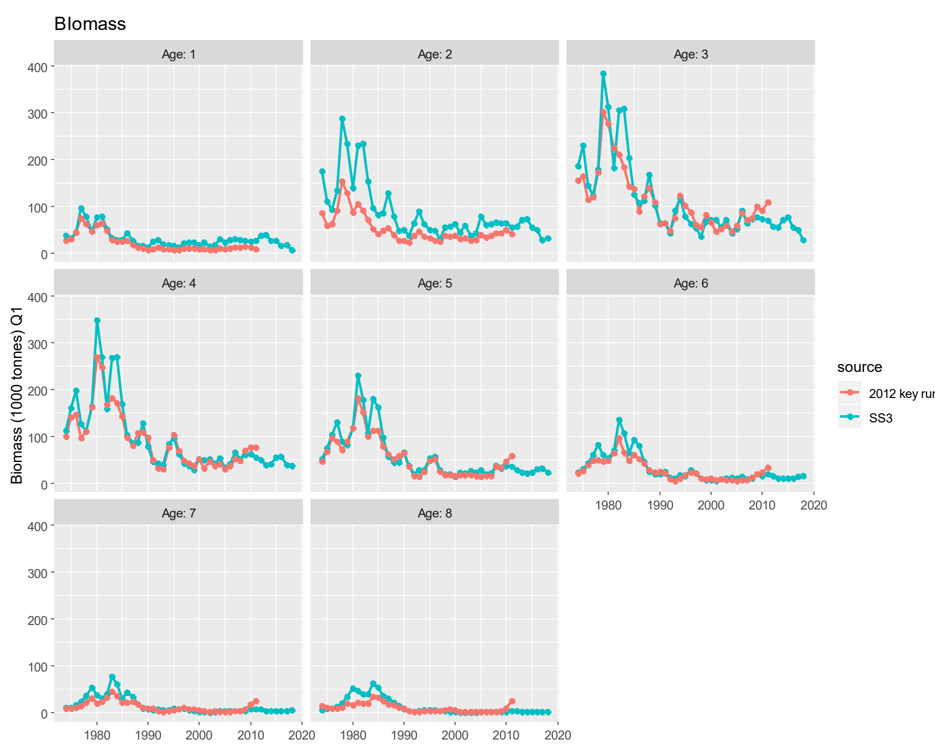

Figure 6.2-2. Comparison of biomass at age of cod estimated by the 2012 key-run and by the ICES SS3 assessment.

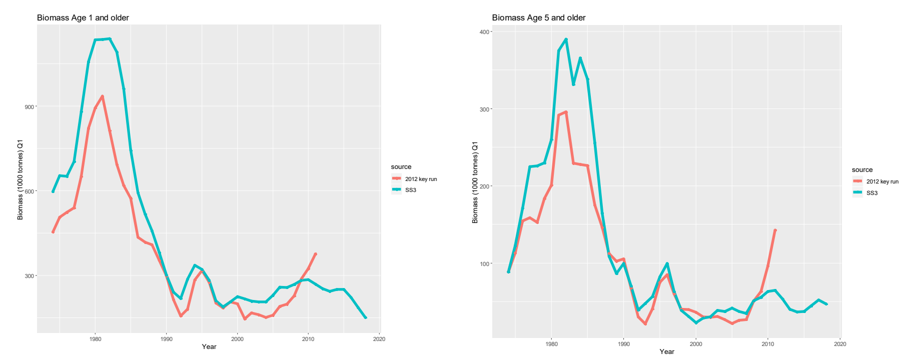

Figure 6.2-3. Comparison of cod biomass for age 1 and older (left panel) and of age 5 and older (right panel) estimated by the 2012 key-run and by the ICES SS3 assessment.

6.3 Diet and ration data

6.3.1 Fish stomach data

Two major cod stomach contents dataset are available:

- "Old": International sampled stomach content data, 1977-1992, Individual stomachs were pooled by cod size class before analysis. The recorded sizes of both predator and are given by wide size classes, e.g. sprat by the size classes 5-10-15 cm, for the oldest data in the time series.
- "New": Individually compiled stomach sampled by mainly Latvia in the period (1963) 1974-2014. Predator and prey sizes are by cm or mm.

6.3.1.1 "old" pooled stomach data

An international database of Baltic cod stomach contents contains data from 62 427 cod collected during 1977–1994. The collation of national stomach content data sets into one set for multispecies assessment has mainly been done by DIFRES (now DTU Aqua) and the result published in ICES papers (e.g. ICES 1991/J:30; ICES 1989/J:2; ICES 1990/Assess:25 and ICES 1993/J:11). Stomach content data from 1977-1992 were recompiled during WGSAM 2012 for use in SMS. The stomach contents data are available at "exchange format" from ICES (www.ices.dk).

6.3.1.1.1 Compilation of stomach contents data

The "old" data stomach contents data are recorded by year, quarter, predator, predator length, prey and prey length. The compilation of the individual stomach samples from a trawl haul into average diet of the Eastern Baltic Sea follows the technique given by ICES, 1993 and is briefly described below. Most stomachs were pooled within a haul and predator size class before analysis, such that diet data from individual fish are scarce. For part of the time series, data are only provided (pooled) by country and subdivision.

For each stomach pool, data 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 of the individual prey and prey size classes is calculated by ICES sub-division as a simple mean. 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 fully identified diet.

For a given predator the average Eastern Baltic Sea stomach contents by quarter were finally calculated as a mean of the average stomach contents by sub-division.

6.3.1.2 "new" individually sampled stomach data

More than one hundred thousand stomachs of cod in the Eastern Baltic Sea have been sampled by trawling between 1963 and 2014, by mainly the Latvian institute (Figure 6.3-1). Sampling covered the distributional area of the Eastern Baltic cod population (Bagge, 1994) except in the period 1995 to 2004, where sampling was limited to the north-eastern part. Stomach contents are provided by individual fish. Prey items in the stomachs were recorded at the highest possible taxonomic resolution with total mass, and, where identifiable, number of individuals and lengths per prey taxon. Prey sizes are given by mm or cm. Predator length was also recorded and in later years also predator weight (Huwer et al., 2014;). The stomach data are available at ICES (www.ices.dk).

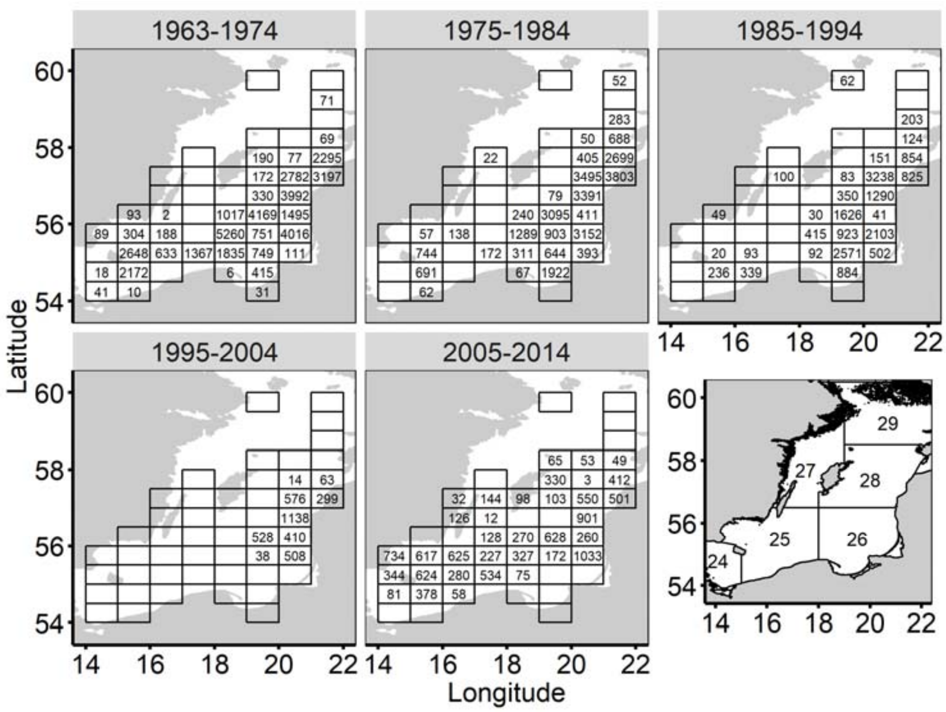

Figure 6.3-1. ICES sub-divisions (bottom right panel) and stomach sampling coverage: number of Gadus morhua stomachs by ICES statistical rectangle for each period specified on top of each panel.

6.3.1.2.1 Compilation of stomach contents data

The weight of stomach contents are given by prey species, aggregating over all recorded sizes and digestion stages. To assign weight to each prey item, a length weight relation was first made for each prey species and digestion stage, based on stomach data from predators with only one prey item of a given species. Secondly, these length weight relations were used to assign a weight to each prey with size information. The sum of these weights cannot exceed the total recorded prey weight for the individual stomach. If the sum exceeded the total prey weight (of both sizes and un-sized preys), the mean weight of the sized preys were downscaled and prey items with no size information was removed. If the sum was smaller than the recorded total weight, and the stomach included preys without size information, the difference in weight was assigned to the prey with no size information.

Having done that estimation of weight by recorded prey species and size, the compilation of stomach contents data follows the process outlined above for the "old" stomachs,

6.3.2 Estimation of food ration from stomach contents data

Average daily energy consumption rates *C* (kJ d^{-1}) were estimated using the cylinder gastric evacuation rate model (Andersen and Beyer, 2005a, b) by year and 1-cm predator length group for cod between 20 and 80 cm total length, amounting to 109 000 stomachs in this size range from the stomach database. Ambient temperature *T* was assumed constant at 5°C, corresponding roughly to the average temperature experienced by cod in the Baltic Sea (Righton *et al.*, 2010). Although cod experience varying temperature throughout the year, only significant trends in average temperature regime for the cod in their preferred habitat might potentially bias our analyses. Such trends have not been shown for the Baltic Sea. We assumed constant energy densities E_i for benthic prey (3.5 kJ g^{-1}) and consumed fishes (*Clupea harengus L.* (herring) and sprat 5.5 kJ g^{-1}, cod 4.0 kJ g^{-1} ;Pedersen and Hislop, 2001). *E* denotes the average energy densities (kJ g^{-1}) of the individually observed total stomach contents *S* (g). Using the principle that consumption rate *C* (kJ d^{-1}) on average over population and time equals evacuation rate (Pennington, 1985), and knowing cod total length *L* (cm) and the basic evacuation rate parameter $\rho_0 = 2.43 \times 10^{-3}$, we used the parametrization of the cylinder model for cod presented in Andersen (2012):

$$C = 24\,\rho_0 L^{1.30} e^{0.083T} E^{0.15} \sqrt{S} \quad (1)$$

In order to consider recent changes in cod consumption rate, the relationship between average quarterly consumption rate and total length (a priori parametrized as $C=aL^b$ with C the average quarterly consumption rate and L total length) was estimated separately for three different periods.

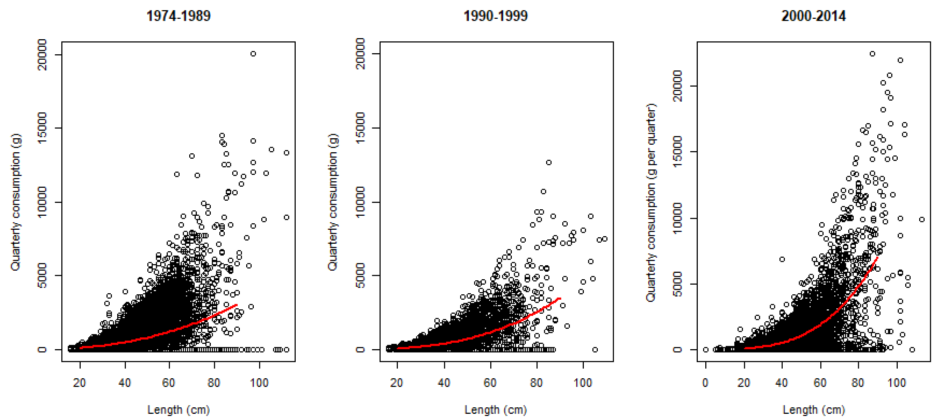

Figure 6.3-2. Scatterplots of cod total length and estimated quarterly consumption rate. The consumption rate has been estimated separately for 1974-1989, 1990-1999 and 2000-2014 in order to account for recent changes in cod consumption (Neuenfeldt et al., in press.

Table 6.3-1. Parameter estimates for the consumption rate model, $C = aL^b$.

Period	Parameter	Estimate	Std. Error
1974-1989	*a*	0.10367	0.01184
	b	2.28617	0.02834
1990-1999	*a*	0.017408	0.003971
	b	2.713702	0.054565
2000-2014	*a*	0.003230	0.000354
	b	3.243353	0.025560

The stomach data do not include 2015-2018. For this reason, the 2000-2014 estimates were applied for 2015-2018, too.

Subsequently, average quarterly consumption was multiplied by 4 to give average ye arly consumption and then distributed over quarters according to the key given in Ta ble 6.3-1.

Table 6.3-2. Distributio**n of annual consumption rate pow**er the different quarters of the year for different periods and size groups. The key was generated using all years (to account for only few data in the 3rd quarter). l.start and l.stop account for spawners and non-spawners.

year.start	year.stop	l.start	l.stop	q1_prop	q2_prop	q3_prop	q4_prop
1974	1989	15	30	0.27	0.23	0.25	0.25
1974	1989	31	120	0.22	0.16	0.30	0.32
1990	1999	15	30	0.24	0.22	0.27	0.27
1990	1999	31	120	0.21	0.19	0.31	0.29
2000	2019	15	30	0.30	0.16	0.16	0.38
2000	2019	31	120	0.38	0.19	0.11	0.32

6.3.3 Estimation of diet from stomach contents

Due to time limitations, diet of fish species was estimated with the assumption that the observed stomach contents give an unbiased estimate of the diet. This is in contrast to the estimation of food ration as outlined above.

6.4 Age length keys

Age length keys (ALK) are used by SMS to transform stock number at age into stock numbers at length used in the calculation of predation mortality. Length at age is derived from weight at age in the sea using a length-weight relation. The length distribution for each age is derived from the coefficient of variation (CV) of the mean length at age as estimated from age and length observation from the BITS survey, quarter 1 and 4, 2000-2018. A year and quarter independent CV of mean length at age was derived from the estimated values by quarter (Table 6.4-1). These CV's (row "Used" in Table 6.4-1) are afterwards used to produce a length distribution around the mean length for a given age in a given year and quarter, assuming a normal distributed length distribution for each age.

Table 6.4-1. Coefficient of variation of mean length at age derived from survey data

Species	Quarter	Age 0	1	2	3	4	5	6	7	8
Clupea harengus	1	NA	0.14	0.09	0.11	0.13	0.13	0.13	0.13	0.12
	4	0.12	0.10	0.14	0.16	0.16	0.15	0.13	0.13	0.11
	Used	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Gadus morhua	1	NA	0.32	0.24	0.21	0.18	0.17	0.17	0.16	0.19
	4	0.34	0.25	0.22	0.18	0.18	0.17	0.18	0.18	0.18
	Used	0.34	0.25	0.23	0.20	0.18	0.18	0.18	0.18	0.18
Sprattus sprattus	1	NA	0.12	0.08	0.09	0.08	0.08	0.07	0.08	0.08
	4	0.10	0.08	0.08	0.08	0.07	0.07	0.06	0.07	0.07
	Used	0.10	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

The total number of fish by length classes (Table 6.4-2) are finally calculated as the sum of contributions from each ages. The chosen length classes depends on the length classes used in the stomach data. The "new", individual sampled stomach data (see section 6.3) have used length classes by cm and mm, however boarder length classes were used due to the low number of stomachs sampled in the individual year and quarter combinations.

The "old" pooled stomach data (see section 6.3) used larger size classes, e.g. 5-10-15 cm for sprat, in the first years of sampling. This mean that the applied length classes used in the SMS configuration depends on the actual used stomach data sets used. As an example, the length classes get wider than outlined in Table 6.4-2, when both the "old" and "new" stomach data are used. When both the "old" and "new" stomach data are used, length classes are defined for each individual year, reflecting the widest length class in the particular year.

Table 6.4-2. Default length classes used for stomach data and ALK

Species	Lower length (mm)	Species	Lower length (mm)	Species	Lower length (mm)
Gadus morhua	50	Clupea harengus	50	Sprattus sprattus	50
	100		70		60
	150		85		70
	200		100		80
	250		120		90
	300		140		100
	350		160		110
	400		180		120
	500		200		130
	600		220		140
	700		240		
			260		

6.5 Predator–prey overlap

The stock area for predator cod (SD 24-32 + part of SD 23) does not completely overlap with the stock areas for herring (SD 25–29 and 32, excluding the Gulf of Riga) and sprat (SD 22-32). SMS gives the possibility to use input values for stock overlap, however for this key-run it is assumed that there is the discrepancies in stock distribution can be ignored.

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 is also estimated within SMS for a few combinations, where the “quarter effect” was estimated significantly different from 1.0.

6.6 Length-weight relations

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

Table 6.6-1. Length (mm) weight (kg) relation for herring and sprat (W=a*l^b)

Species	a	b
Herring	2.997653e-09	3.136964
Sprat	3.670895e-09	3.107974

The l-w relations were estimated from BITS Q1 & Q4 data, 2000-2018 (minus 2004 data with errors). There is a statistical significant quarter effect in condition (parameter a), however this is ignored for used in SMS, until data for Quarter 2 and 3 data become available.

6.6.1 References

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7 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 estimation of predation mortality.

Appendix 3 presents the SMS configuration (option files) used for the 2019 key run.

7.1 Fishing mortality

SMS uses a separable F model while the ICES single-species assessments use XSA for herring and sprat. XSA estimate F directly from catch observation in a VPA. Further differences; SMS is using quarterly time steps while XSA is using annual time steps.

A comparison of output from the two assessments shows quite similar results for herring (Figure 7.1-1). Due to the separable F model used in SMS, F is smoother between years than in XSA, where the catch observation at age are translated directly into F. The comparison for sprat (Figure 7.1-2) show that F and SSB have the same trend, but the levels are different. SSB is estimated the 1st January in SMS but at spawning time in the ICES assessment (the proportion of M and F before spawning is set to 40%) which may explain the two levels of SSB estimated. F is however more comparable between models, but there SMS estimates consistently a lower F.

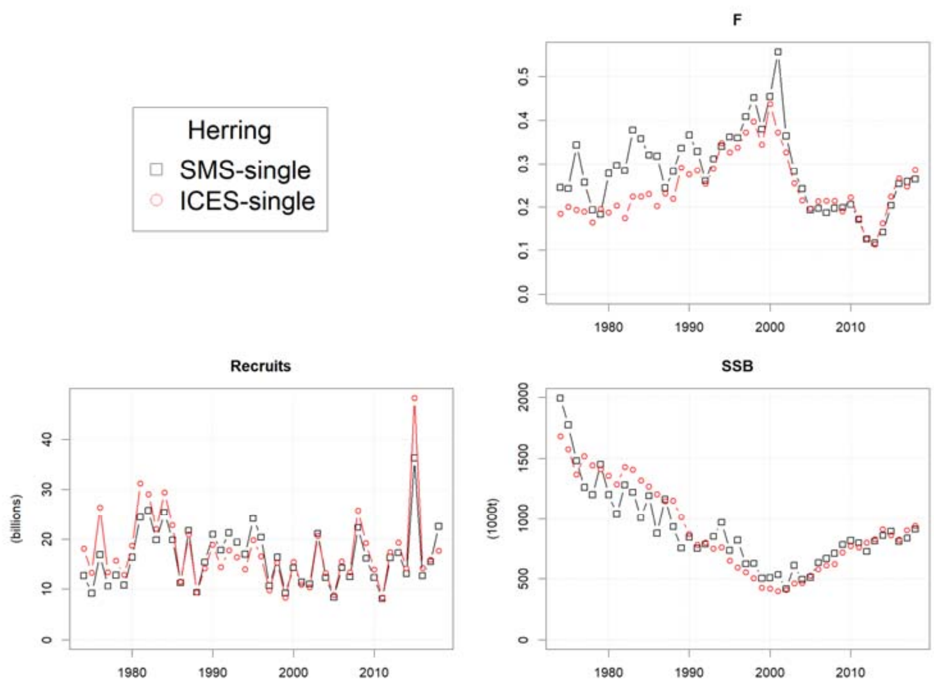


Figure 7.1-1. Comparison of the herring assessment results from SMS assessment using fixed M (from ICES assessment) and the ICES single species XSA assessment. Recruitment is at age 1.

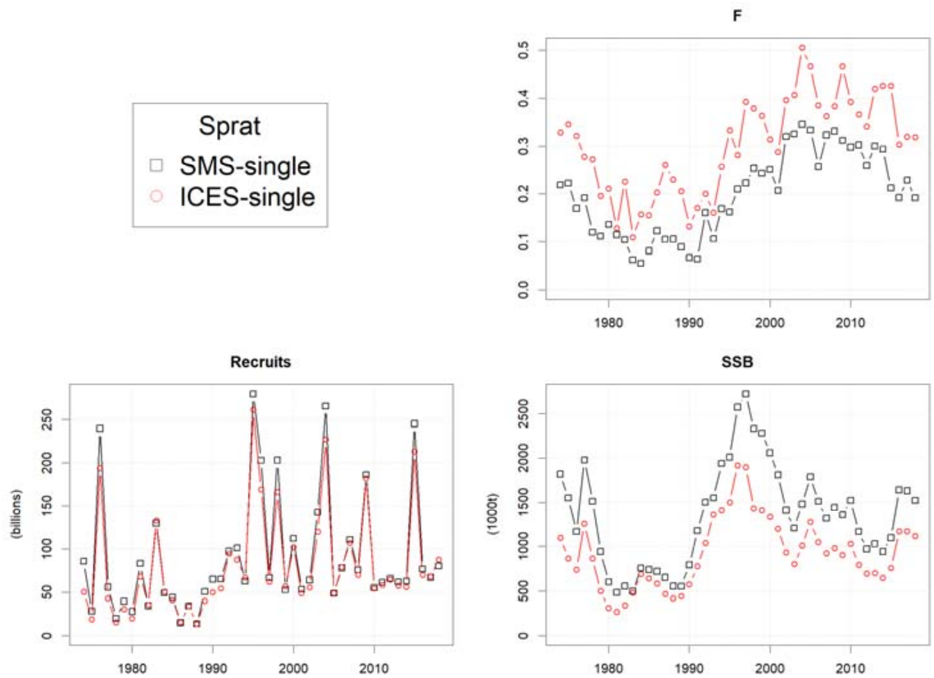


Figure 7.1-2. Comparison of the sprat assessment results from SMS assessment using fixed M (from ICES assessment) and the ICES single species XSA assessment. Recruitment is at age 1.

7.2 Configuring predation mortality options

The SMS model has three main options for size preferences of predators (see equations 11, 12 and 13 in the description of SMS model, Appendix 1) :

1. Log normal size selection: a predator has a preferred prey size ratio and a prey twice as big as the preferred size is as attractive as another half the prey size. The preferred size ration and its variance are estimated by SMS.
2. Uniform size selection: a size preference at 1 within the range of the observed size ratio and 0 outside that ratio.
3. Constraint uniform size selection: as Uniform size selection, but the size preference ratio is constrained to exclude “outliers” in the observed size ratio.

The “Constraint uniform size selection” option was chosen for the 2012 key-run. The new stomach data available for the 2019 key run include more detailed data (prey length by cm group, while the old data set has prey length by 5 cm for most years) and a SMS run using the “log normal size selection” gave actually a better model fit than both the “Uniform size selection” and “Constraint uniform size selection” the (see section 9.5). Therefore, the “log normal size selection” and was chosen option for the 2019 key-run.

8 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 and files:

- EBalticKeyRun_2019: The SMS eastern Baltic North Sea key run made at the 2019 WGSAM, including data for the period 1974–2018.
- StockAnnex_ICES_EB_SMS_Configuration.docx: This document.
- SMS_ADMB: AD Model Builder source code for the SMS the North Sea and Baltic Sea.
- SMS_R_prog: R scripts for preparing, running and presenting results from a SMS run

9 Results of the 2019 Eastern Baltic Sea SMS key run

Substantial changes of input data to the new key run and ICES benchmarks for some of the stocks since the 2012 key run have produced stock summaries (recruitment, mean F and SSB) from the 2019 key run that is somewhat different from the summaries from the 2012 key run. However, the new estimated predation mortalities (M2) are consistent with the M2 values from the previous key run.

Key run summary sheet

AREA	NORTH SEA
Model name	SMS
Type of model	Age–length structured statistical estimation model
Run year	2019
Predatory species	Assessed species: Herring , Sprat
Prey species	Herrnig, Sprat
Time range	1974–2018.
Time step	Quarterly
Area structure	Eastern Baltic Sea, ICES sub-divisions 25-29 excl Gulf of Riga
Stomach data	Cod: 1974-2014
Purpose of key run	Making historic data on natural mortality available and multispecies dynamics
Model changes since last key run	All time-series updated. More stomach data included. Cod is now an external predator estimated by WGBFAS Stock-synthesis model. Daily food ration of changed for the main fish species.
Output available at	Sharepoint/data/EBaltic_SMS_key_run and https://github.com/ices-eg/wg_WGSAM
Further details in	Report of the Working Group on Multispecies Assessment Methods 2019 (WGSAM, 2019)

9.1 Results of the 2019 key run

9.1.1 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. Key diagnostics (Table 9.1-1) show a reasonable fit for catch ("sqrt(catch variance) ~ CV:") and survey indices ("sqrt(Survey variance) ~ CV:") data. Catch and survey data fit better for herring than for sprat. The same can be seen from the catch at age residual plots (Figure 9.1-2). Herring has in general smaller residuals than for sprat, but herring residuals show a more clustered distribution with periods of either positive or negative residuals. The survey residuals show in some cases a "year effect" with all either positive or all negative residuals within a year. This often seen where the survey indices are based on an acoustic measurement.

The residual plot of stomach contents Figure 9.1-4 shows a quite randomly distributed residuals for sprat. Model estimate of the stomach contents of herring seems generally higher than the observed in the period since 1990, while the opposite pattern is seen for "other food". The same picture is seen in the boxplots of residuals (Figure 9.1-5), where the upper two rows of the plot show generally positive residuals for herring and generally negative residuals for "other food" since 1990. The bias in residuals by quarter seems limited (third row of Figure 9.1-5). The residual pattern is not independent of predator size (fourth row of Figure 9.1-5). The model overestimate the stomach contents of herring for the medium sized cod, and underestimate the stomach contents of sprat for the largest cod. This might be a result of size dependent spatial distribution of cod.

Table 9.1-1. SMS key run model diagnostics.

```
November 06, 2019 18:57:28   run time:40 seconds

objective function (negative log likelihood):  -1232.3
Number of parameters: 292
Number of observations used in likelihood: 14892
Maximum gradient: 5.5994e-007
Akaike information criterion (AIC):   -1880.6
Number of observations used in the likelihood:
                            Catch    CPUE     S/R Stomach     Sum
Species: 1, Cod                 0       0       0    1605    3210
Species: 2, Herring          1440     251      45       0    3472
Species: 3, Sprat            1260     318      45       0    3246
Sum                          5400    1138     180    3210   14892


objective function weight:
                          Catch  CPUE   S/R     Stom.    Stom N.
Species: 1, Cod           0.00  0.00  0.00       1.00       0.00
Species: 2, Herring       1.00  1.00  0.05       0.00       0.00
Species: 3, Sprat         1.00  1.00  0.05       0.00       0.00

unweighted objective function contributions (total):
                Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum
Cod               0.0     0.0    0.0  -256.2     0.0     0.00    -256
Herring        -660.4  -118.7   -8.6     0.0     0.0     0.00    -788
Sprat           -92.3  -104.0   -5.6     0.0     0.0     0.00    -202
Sum            -752.7  -222.7  -14.2  -256.2     0.0     0.00   -1246

unweighted objective function contributions (per observation):
                Catch   CPUE     S/R   Stomachs
Cod              0.00   0.00    0.00   -0.16
Herring         -0.46  -0.47   -0.19    0.00
Sprat           -0.07  -0.33   -0.12    0.00

contribution by fleet:
----------------------
Species:2, Herring
Herring Acoustic May        total: -41.296   mean:  -0.397
Herring BIAS                total: -77.452   mean:  -0.527

Species:3, Sprat
Sprat Int acoustic in Oct.  total: -72.723   mean:  -0.416
Sprat Int acoustic in May.  total: -40.115   mean:  -0.337
Sprat LAT RUS acoustic      total:   8.860   mean:   0.369


F, Year effect:
---------------
       sp. 2  sp. 3
1974:  1.000  1.000
1975:  0.972  0.982
1976:  1.317  0.747
1977:  0.920  0.777
1978:  0.663  0.486
1979:  0.644  0.442
1980:  1.063  0.516
1981:  1.189  0.392
1982:  1.169  0.324
1983:  1.598  0.167
1984:  1.574  0.137
1985:  1.458  0.195
1986:  1.494  0.294
1987:  1.154  0.267
```

```
1988:  1.360  0.304
1989:  1.000  0.278
1990:  1.109  0.223
1991:  1.004  0.229
1992:  0.788  0.611
1993:  0.924  0.424
1994:  1.016  0.728
1995:  1.103  0.721
1996:  1.108  0.971
1997:  1.264  1.061
1998:  1.402  1.190
1999:  1.135  1.124
2000:  1.348  1.000
2001:  1.708  0.813
2002:  1.162  1.228
2003:  0.907  1.249
2004:  0.778  1.319
2005:  0.622  1.253
2006:  0.644  0.992
2007:  0.618  1.258
2008:  0.665  1.333
2009:  0.682  1.283
2010:  0.708  1.231
2011:  0.581  1.215
2012:  0.414  0.999
2013:  0.376  1.140
2014:  0.451  1.156
2015:  0.642  0.849
2016:  0.796  0.751
2017:  0.783  0.905
2018:  0.763  0.782

F, season effect:
-----------------
Herring
age: 1
    1974-1988:   0.033 0.072 0.118 0.250
    1989-2018:   0.096 0.063 0.057 0.250
age: 2
    1974-1988:   0.111 0.405 0.179 0.250
    1989-2018:   0.216 0.190 0.066 0.250
age: 3 - 8
    1974-1988:   0.137 0.612 0.309 0.250
    1989-2018:   0.296 0.329 0.117 0.250

Sprat
age: 1
    1974-1999:   0.075 0.045 0.036 0.250
    2000-2018:   0.318 0.143 0.051 0.250
age: 2 - 7
    1974-1999:   0.427 0.270 0.069 0.250
    2000-2018:   0.590 0.331 0.060 0.250

F, age effect:
--------------
                 0      1      2      3      4      5      6      7      8
Herring
1974-1988:  0.000  0.090  0.141  0.148  0.163  0.201  0.201  0.201  0.201
1989-2018:  0.000  0.182  0.241  0.270  0.358  0.455  0.455  0.455  0.455
Sprat
1974-1999:  0.000  0.088  0.144  0.218  0.201  0.201  0.201  0.201
2000-2018:  0.000  0.117  0.147  0.193  0.200  0.200  0.200  0.200


Exploitation pattern (scaled to mean F=1)
-----------------------------------------
                        0      1      2      3      4      5      6      7      8
Herring
1974-1988 season 1:      0  0.013  0.067  0.087  0.096  0.118  0.118  0.118  0.118
          season 2:      0  0.028  0.245  0.389  0.429  0.527  0.527  0.527  0.527
          season 3:  0.000  0.045  0.109  0.196  0.216  0.266  0.266  0.266  0.266
          season 4:  0.000  0.096  0.152  0.159  0.175  0.215  0.215  0.215  0.215

1989-2018 season 1:      0  0.046  0.136  0.210  0.278  0.354  0.354  0.354  0.354
          season 2:      0  0.030  0.120  0.233  0.308  0.393  0.393  0.393  0.393
          season 3:  0.000  0.027  0.041  0.083  0.110  0.140  0.140  0.140  0.140
          season 4:  0.000  0.119  0.158  0.177  0.234  0.298  0.298  0.298  0.298
```

```
Sprat
1974-1999 season 1:      0  0.031  0.292  0.443  0.409  0.409  0.409  0.409
          season 2:      0  0.019  0.185  0.280  0.258  0.258  0.258  0.258
          season 3:  0.000  0.015  0.047  0.072  0.066  0.066  0.066  0.066
          season 4:  0.000  0.105  0.171  0.259  0.239  0.239  0.239  0.239

2000-2018 season 1:      0  0.153  0.356  0.467  0.485  0.485  0.485  0.485
          season 2:      0  0.069  0.200  0.262  0.273  0.273  0.273  0.273
          season 3:  0.000  0.024  0.036  0.047  0.049  0.049  0.049  0.049
          season 4:  0.000  0.120  0.151  0.198  0.206  0.206  0.206  0.206


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

Herring
 1       0.591
 2       0.378
 3       0.358
 4       0.358
 5       0.358
 6       0.358
 7       0.358
 8       0.358

Sprat
 1       0.772
 2       0.487
 3       0.391
 4       0.592
 5       0.592
 6       0.592
 7       0.592


Survey catchability:
--------------------
Herring                      age 0  age 1  age 2  age 3  age 4  age 5  age 6  age 7  age 8
 Herring Acoustic May               0.423  1.040  1.772  2.482  2.482  2.482  2.482  2.482
 Herring BIAS                       0.613  1.168  2.011  2.841  2.841  2.841  2.841
Sprat
 Sprat Int acoustic in Oct.         0.479  0.728  1.034  0.895  0.895  0.895  0.895
 Sprat Int acoustic in May.         0.295  0.675  0.996  0.945  0.945  0.945  0.945
 Sprat LAT RUS acoustic             0.282

sqrt(Survey variance) ~ CV:
---------------------------
Herring                      age 0  age 1  age 2  age 3  age 4  age 5  age 6  age 7  age 8
 Herring Acoustic May                0.37   0.37   0.37   0.43   0.43   0.43   0.43   0.43
 Herring BIAS                        0.45   0.33   0.33   0.33   0.33   0.37   0.37
Sprat
 Sprat Int acoustic in Oct.          0.48   0.35   0.35   0.41   0.41   0.41   0.41
 Sprat Int acoustic in May.          0.51   0.35   0.35   0.46   0.46   0.46   0.46
 Sprat LAT RUS acoustic              0.88


Recruit-SSB                         alfa      beta        var      sd
Herring      Geometric mean:       16.857                0.251    0.501
Sprat        Geometric mean:       18.552                0.251    0.501


Multispecies parameters
========================

stomach content variance model: Dirichlet distribution

Vulnerability pred - prey
---------------------------
           Other-food     Herring    Sprat
Cod            1.000      8.857      3.529

Size selection parameters:
---------------------------           Cod
Size selection model:               log-norm.
Sum prey sizes in likelihood:            yes
Preferred size ratio:                  5.434
Variance of size ratio:                2.789

Other food Suitability slope:
Cod                 0.4643
```

```
Stomach variance:    value    internal     max alfa0
Cod                  0.381    0.381        37.083

Predator prey season overlap
---------------------------
Predator:Cod         Other-food  Herring     Sprat
  q:1                 1           1           1
  q:2                 0.486       0.354       1
  q:3                 0.486       0.354       0.356
  q:4                 1.781       1           0.902
```

Figure 9.1-1 Observed and model predicted catch

Figure 9.1-2. Residual plots for catch at age observations by species and quarter. Residuals are not standardised. The red dot shows that the observed catch are larger than the model estimate. The yellow dots show the largest residual value.

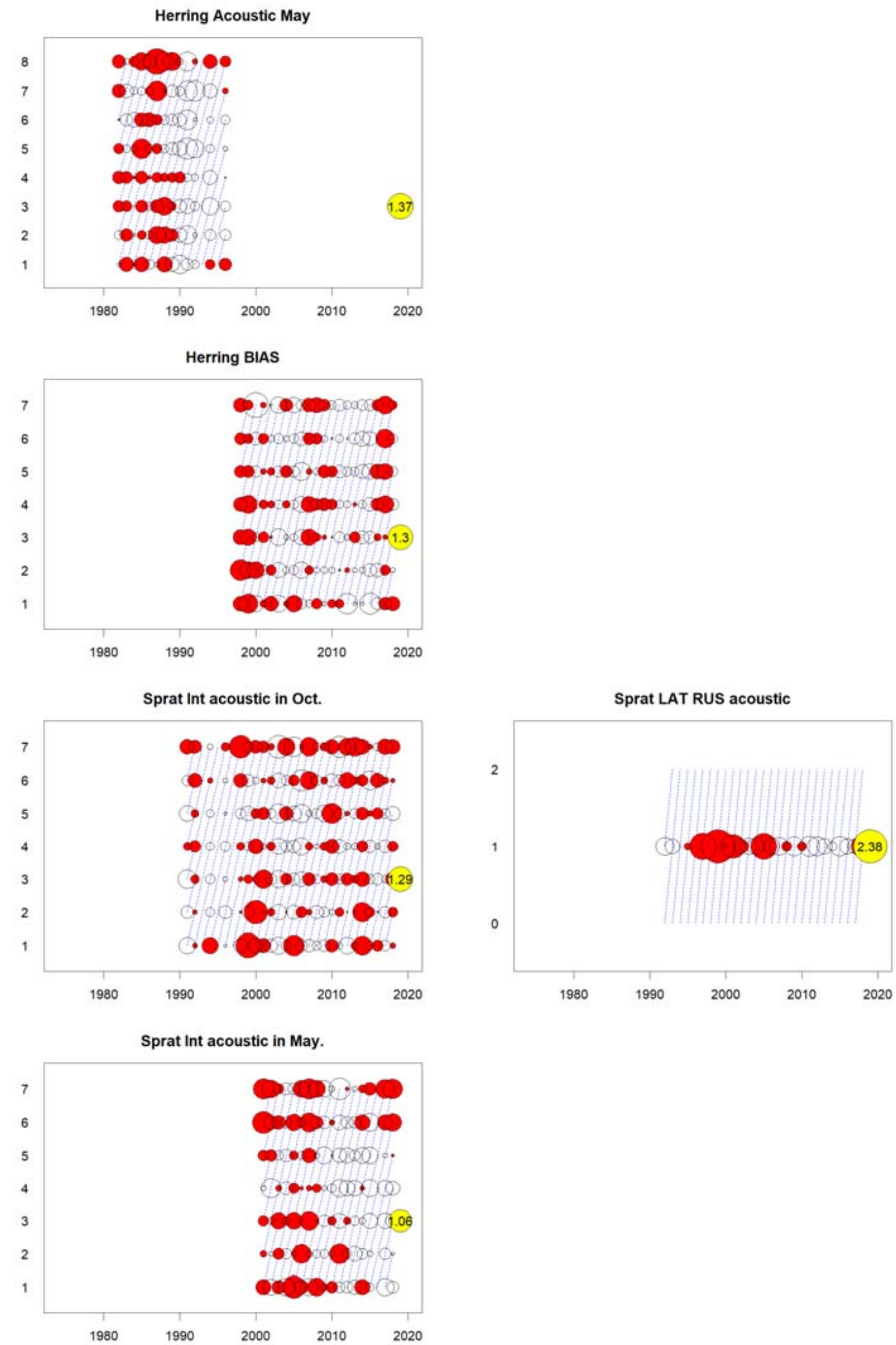


Figure 9.1-3. Residual plots for survey Catch per unit effort at age observations by species and survey. Residuals are not standardised. The red dot shows that the observed catch are larger than the model estimate. The yellow dots show the largest residual value.

Figure 9.1-4. Stomach contents residuals ("Dirichlet residuals", Peter Lewy, pers. comm.). The y-axis show prey group and predator (cod) size class. The x-axis time period, where the upper panel is sorted by year and quarter, and lower panel sorted by quarter and year. Green dots show that the observed stomach contents are lower than the model estimate.

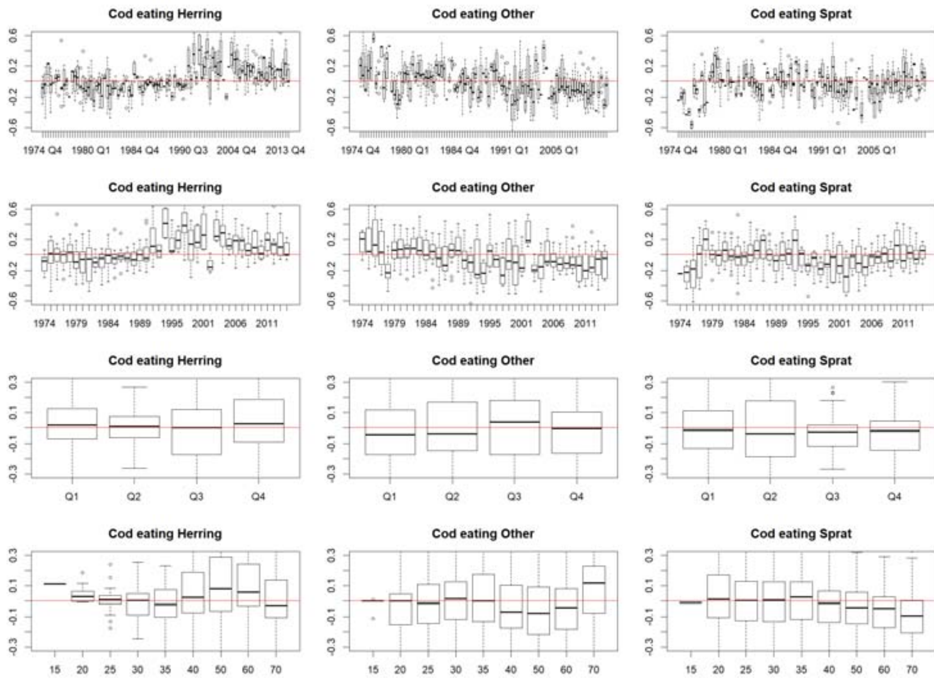


Figure 9.1-5. Box plot of stomach contents residual. Upper (first) row shows the box-plots by individual quarter and years, second row by year (quarters combined), third row by quarter and fourth row by cod size class.

9.1.2 Stock summary results

The stock summaries are presented in Figure 9.1-6 (herring) and Figure 9.1-7 (Sprat).

The estimated predation mortalities (M2) are shown in details in Figure 9.1-8 and Figure 9.1-9. Total natural mortality M=M1+M2 are tabulated in Table 9.1-2 and Table 9.1-3 Please note that M1 for herring has been changed from 0.2 in the 2012 key-run to 0.1 in the 2019 key-run. Figure 9.1-10 shows the same data using the same scale on the y-axis and with an added smoother. The smoothed M values are tabulated in Table 9.1-4 and Table 9.1-5.

A comparison of M2 from this key run with M2 from the previous key run show the some substantial changes for herring (Figure 9.1-11) and a more consistent estimate for sprat (Figure 9.1-12), even though sprat M2 is now higher for age 0 and 1. Herring M2 is now estimated considerably higher, but follows the same trend as seen in the 2012 key run. . The main difference between the two key runs is the estimate of the predator (cod) stock. The present estimate of the cod biomass is higher, and especially higher for the larger cod that eats herring. This is probably the main reason for the differences in the estimates of M2, but application of new stomach contents data, a different size selection option and new consumption estimates are also contributing.

Natural mortalities (M=M1+M2) estimated by SMS may be used as input to the ICES stock assessment of herring and sprat. If M values are used, WGSAM does recommend to update the full time series of M.

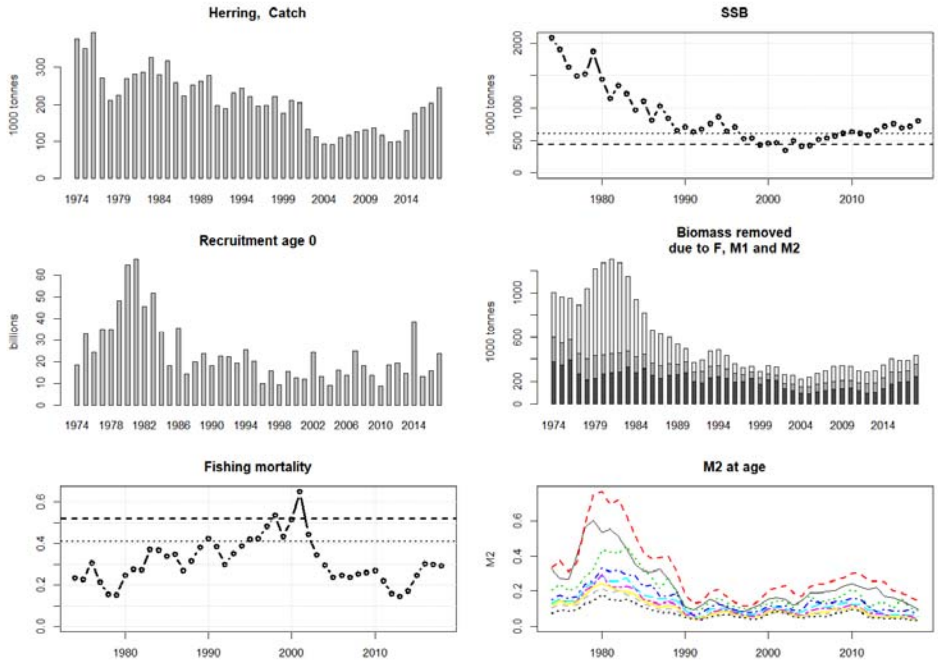


Figure 9.1-6. SMS output for Herring. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

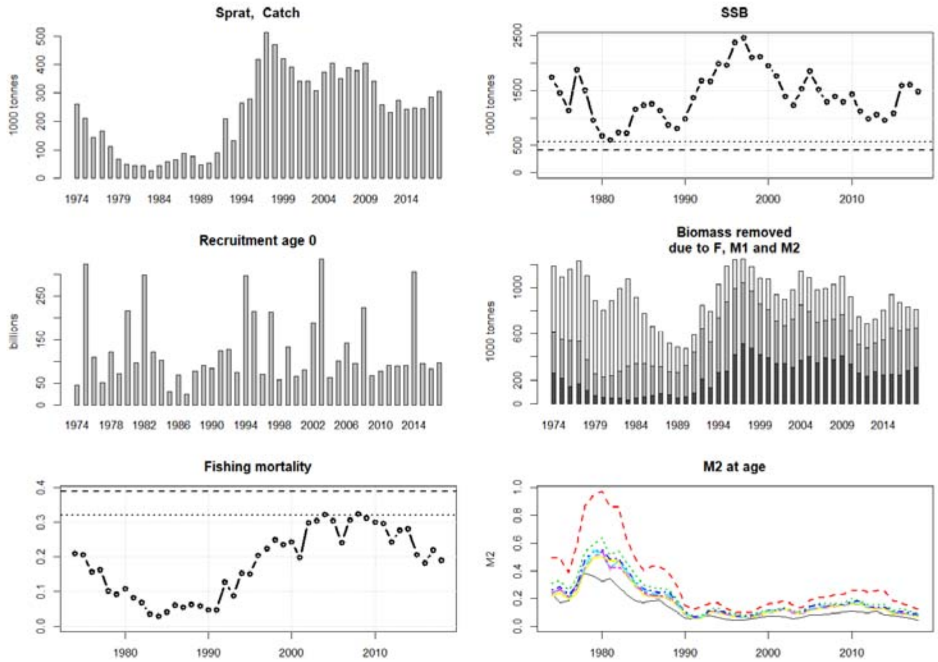


Figure 9.1-7. SMS output for Sprat. Catch weight, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

Table 9.1-2. Herring Natural mortality (sum of quarterly M1 (=0.1)+M2)

Year/Age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1974	0.375	0.433	0.307	0.251	0.233	0.220	0.219	0.205	0.176
1975	0.321	0.476	0.340	0.278	0.257	0.243	0.244	0.229	0.195
1976	0.318	0.412	0.303	0.258	0.240	0.229	0.228	0.216	0.187
1977	0.454	0.465	0.320	0.270	0.251	0.238	0.237	0.222	0.191
1978	0.610	0.676	0.385	0.342	0.322	0.302	0.278	0.262	0.233
1979	0.653	0.848	0.420	0.358	0.350	0.335	0.325	0.291	0.244
1980	0.583	0.869	0.534	0.432	0.386	0.394	0.344	0.317	0.283
1981	0.606	0.793	0.521	0.409	0.356	0.325	0.327	0.290	0.252
1982	0.560	0.821	0.514	0.423	0.358	0.320	0.301	0.301	0.242
1983	0.492	0.731	0.556	0.396	0.375	0.331	0.299	0.283	0.251
1984	0.403	0.616	0.488	0.386	0.313	0.312	0.281	0.258	0.233
1985	0.365	0.519	0.424	0.324	0.280	0.250	0.246	0.232	0.211
1986	0.360	0.483	0.378	0.336	0.267	0.245	0.227	0.213	0.190
1987	0.377	0.491	0.318	0.271	0.256	0.223	0.207	0.195	0.177
1988	0.321	0.498	0.374	0.270	0.259	0.244	0.219	0.202	0.180
1989	0.249	0.415	0.290	0.290	0.243	0.219	0.208	0.190	0.171

1990	0.163	0.281	0.209	0.189	0.195	0.170	0.163	0.157	0.149
1991	0.142	0.229	0.193	0.168	0.152	0.162	0.144	0.147	0.138
1992	0.171	0.240	0.197	0.175	0.149	0.141	0.150	0.137	0.134
1993	0.205	0.298	0.247	0.212	0.196	0.178	0.168	0.176	0.155
1994	0.182	0.308	0.257	0.230	0.201	0.190	0.178	0.164	0.163
1995	0.160	0.271	0.234	0.218	0.201	0.190	0.185	0.173	0.170
1996	0.140	0.235	0.214	0.195	0.186	0.179	0.171	0.166	0.155
1997	0.133	0.215	0.200	0.182	0.173	0.165	0.159	0.155	0.150
1998	0.156	0.222	0.193	0.180	0.166	0.158	0.151	0.150	0.139
1999	0.176	0.253	0.214	0.191	0.182	0.169	0.158	0.155	0.144
2000	0.207	0.306	0.230	0.217	0.207	0.196	0.183	0.174	0.174
2001	0.214	0.318	0.241	0.214	0.208	0.194	0.189	0.181	0.180
2002	0.205	0.331	0.249	0.220	0.199	0.191	0.183	0.177	0.176
2003	0.171	0.291	0.205	0.190	0.179	0.172	0.166	0.159	0.155
2004	0.196	0.270	0.246	0.191	0.180	0.164	0.159	0.154	0.147
2005	0.239	0.323	0.276	0.248	0.207	0.186	0.172	0.165	0.155
2006	0.240	0.342	0.239	0.235	0.224	0.202	0.177	0.169	0.160
2007	0.248	0.344	0.243	0.228	0.210	0.204	0.179	0.169	0.154
2008	0.253	0.364	0.259	0.241	0.221	0.197	0.206	0.183	0.172
2009	0.278	0.374	0.279	0.241	0.232	0.208	0.191	0.204	0.183
2010	0.294	0.403	0.308	0.258	0.229	0.225	0.210	0.195	0.193
2011	0.276	0.400	0.281	0.255	0.224	0.204	0.199	0.185	0.186
2012	0.260	0.363	0.211	0.217	0.195	0.174	0.168	0.159	0.149
2013	0.272	0.355	0.231	0.181	0.188	0.169	0.156	0.153	0.146
2014	0.221	0.353	0.234	0.196	0.165	0.171	0.156	0.150	0.144
2015	0.212	0.298	0.203	0.185	0.167	0.155	0.155	0.148	0.142
2016	0.195	0.288	0.254	0.185	0.174	0.164	0.156	0.151	0.144
2017	0.173	0.268	0.207	0.195	0.164	0.158	0.148	0.139	0.136
2018	0.145	0.244	0.188	0.162	0.160	0.142	0.141	0.139	0.133

Table 9.1-3. Sprat Natural mortality (sum of quarterly M1 (=0.2)+M2)

Year/Age	0	1	2	3	4	5	6	7+
1974	0.335	0.690	0.507	0.462	0.441	0.441	0.420	0.436
1975	0.271	0.695	0.529	0.486	0.464	0.464	0.443	0.459
1976	0.284	0.586	0.462	0.429	0.413	0.413	0.397	0.410
1977	0.414	0.783	0.544	0.491	0.468	0.468	0.439	0.463
1978	0.484	1.067	0.736	0.682	0.631	0.617	0.609	0.610
1979	0.463	1.144	0.789	0.740	0.745	0.690	0.692	0.707
1980	0.422	1.174	0.839	0.749	0.733	0.744	0.699	0.720
1981	0.444	1.061	0.712	0.679	0.622	0.624	0.671	0.603
1982	0.386	1.063	0.751	0.690	0.670	0.627	0.669	0.680
1983	0.332	0.828	0.663	0.611	0.596	0.579	0.566	0.565

1984	0.283	0.688	0.576	0.519	0.516	0.500	0.493	0.487
1985	0.271	0.603	0.498	0.471	0.461	0.444	0.424	0.435
1986	0.281	0.631	0.480	0.456	0.442	0.424	0.415	0.411
1987	0.285	0.626	0.472	0.440	0.422	0.418	0.409	0.398
1988	0.243	0.594	0.465	0.452	0.429	0.413	0.405	0.396
1989	0.205	0.495	0.399	0.376	0.371	0.360	0.354	0.351
1990	0.157	0.354	0.303	0.299	0.293	0.286	0.287	0.282
1991	0.152	0.324	0.272	0.268	0.263	0.258	0.257	0.258
1992	0.168	0.341	0.280	0.270	0.267	0.260	0.259	0.257
1993	0.179	0.369	0.329	0.315	0.308	0.305	0.301	0.297
1994	0.163	0.369	0.328	0.314	0.305	0.303	0.300	0.299
1995	0.152	0.327	0.298	0.296	0.290	0.287	0.285	0.284
1996	0.144	0.299	0.287	0.275	0.273	0.269	0.268	0.269
1997	0.143	0.298	0.277	0.272	0.265	0.260	0.260	0.258
1998	0.155	0.306	0.283	0.278	0.275	0.268	0.266	0.267
1999	0.163	0.336	0.302	0.292	0.292	0.290	0.284	0.281
2000	0.173	0.362	0.309	0.312	0.308	0.305	0.303	0.298
2001	0.176	0.374	0.323	0.312	0.313	0.308	0.310	0.311
2002	0.169	0.385	0.332	0.329	0.323	0.323	0.322	0.322
2003	0.154	0.351	0.308	0.303	0.303	0.299	0.302	0.303
2004	0.167	0.335	0.309	0.293	0.288	0.289	0.288	0.289
2005	0.185	0.385	0.353	0.341	0.321	0.317	0.315	0.318
2006	0.186	0.405	0.362	0.356	0.348	0.332	0.328	0.328
2007	0.191	0.411	0.362	0.348	0.347	0.345	0.334	0.326
2008	0.192	0.431	0.364	0.357	0.348	0.353	0.355	0.341
2009	0.203	0.429	0.364	0.353	0.349	0.346	0.349	0.346
2010	0.210	0.457	0.399	0.376	0.368	0.367	0.365	0.365
2011	0.204	0.463	0.384	0.378	0.369	0.361	0.363	0.358
2012	0.201	0.448	0.358	0.342	0.340	0.333	0.331	0.332
2013	0.208	0.455	0.355	0.336	0.328	0.327	0.326	0.326
2014	0.182	0.453	0.357	0.339	0.327	0.321	0.322	0.328
2015	0.177	0.380	0.315	0.304	0.299	0.294	0.290	0.296
2016	0.169	0.367	0.326	0.304	0.294	0.293	0.290	0.291
2017	0.159	0.350	0.307	0.300	0.288	0.283	0.283	0.284
2018	0.145	0.322	0.288	0.282	0.280	0.273	0.270	0.271

Table 9.1-4. Herring GAM-Smoothed Natural mortality (sum of quarterly M1 (=0.1)+M2)

Year/Age	0	1	2	3	4	5	6	7	8
1974	0.297	0.366	0.281	0.232	0.217	0.206	0.208	0.195	0.170
1975	0.370	0.457	0.312	0.262	0.245	0.234	0.231	0.216	0.187
1976	0.439	0.544	0.343	0.291	0.273	0.261	0.254	0.236	0.204
1977	0.498	0.622	0.374	0.319	0.298	0.285	0.274	0.254	0.219
1978	0.544	0.685	0.406	0.344	0.320	0.305	0.291	0.269	0.232
1979	0.571	0.730	0.437	0.366	0.336	0.319	0.302	0.280	0.241
1980	0.577	0.754	0.469	0.383	0.347	0.327	0.308	0.287	0.247
1981	0.565	0.757	0.495	0.395	0.351	0.329	0.309	0.288	0.249
1982	0.538	0.742	0.512	0.400	0.350	0.325	0.304	0.284	0.246
1983	0.502	0.711	0.514	0.396	0.342	0.315	0.294	0.276	0.240
1984	0.459	0.666	0.497	0.382	0.328	0.300	0.280	0.263	0.230
1985	0.413	0.609	0.459	0.358	0.308	0.281	0.261	0.245	0.217
1986	0.367	0.547	0.409	0.327	0.284	0.259	0.241	0.226	0.202
1987	0.322	0.483	0.354	0.293	0.259	0.237	0.220	0.206	0.186
1988	0.281	0.422	0.303	0.262	0.236	0.216	0.201	0.188	0.172
1989	0.245	0.370	0.263	0.236	0.216	0.199	0.185	0.174	0.162
1990	0.215	0.329	0.239	0.218	0.201	0.187	0.175	0.165	0.155
1991	0.192	0.299	0.227	0.207	0.191	0.178	0.168	0.160	0.151
1992	0.174	0.277	0.223	0.201	0.184	0.173	0.165	0.158	0.149
1993	0.162	0.262	0.223	0.198	0.181	0.171	0.164	0.158	0.150
1994	0.156	0.253	0.223	0.197	0.180	0.170	0.164	0.159	0.151
1995	0.155	0.249	0.222	0.197	0.180	0.171	0.165	0.161	0.153
1996	0.157	0.248	0.220	0.197	0.182	0.173	0.167	0.162	0.155
1997	0.161	0.251	0.217	0.197	0.184	0.175	0.168	0.164	0.156
1998	0.167	0.256	0.216	0.198	0.187	0.177	0.169	0.164	0.158
1999	0.173	0.263	0.216	0.199	0.188	0.178	0.170	0.164	0.159
2000	0.180	0.272	0.219	0.200	0.189	0.179	0.170	0.164	0.159
2001	0.186	0.282	0.223	0.202	0.190	0.179	0.169	0.163	0.159
2002	0.194	0.293	0.229	0.205	0.192	0.180	0.170	0.163	0.159
2003	0.204	0.305	0.236	0.210	0.195	0.183	0.172	0.164	0.160
2004	0.215	0.318	0.244	0.217	0.201	0.187	0.175	0.167	0.162
2005	0.229	0.331	0.253	0.226	0.207	0.192	0.180	0.172	0.165
2006	0.242	0.344	0.260	0.234	0.214	0.197	0.185	0.177	0.168
2007	0.254	0.356	0.266	0.241	0.220	0.201	0.189	0.181	0.170
2008	0.264	0.366	0.269	0.244	0.222	0.203	0.192	0.183	0.172
2009	0.270	0.372	0.268	0.243	0.221	0.203	0.191	0.183	0.171
2010	0.273	0.375	0.265	0.237	0.216	0.199	0.188	0.180	0.169
2011	0.271	0.374	0.259	0.229	0.209	0.194	0.183	0.175	0.166
2012	0.264	0.368	0.251	0.219	0.200	0.187	0.177	0.169	0.162
2013	0.253	0.357	0.242	0.209	0.191	0.180	0.170	0.162	0.157
2014	0.238	0.341	0.233	0.200	0.183	0.172	0.164	0.157	0.152

2015	0.218	0.320	0.225	0.192	0.176	0.165	0.158	0.151	0.147
2016	0.196	0.296	0.216	0.184	0.169	0.158	0.152	0.146	0.141
2017	0.172	0.269	0.207	0.177	0.162	0.151	0.146	0.141	0.136
2018	0.147	0.242	0.198	0.170	0.156	0.145	0.140	0.136	0.130

Table 9.1-5. Sprat GAM-Smoothed Natural mortality (sum of quarterly M1 (=0.1)+M2).

Year/Age	0	1	2	3	4	5	6	7+
1974	0.276	0.567	0.448	0.408	0.390	0.392	0.365	0.386
1975	0.323	0.698	0.520	0.477	0.456	0.454	0.432	0.450
1976	0.367	0.819	0.589	0.541	0.518	0.512	0.496	0.509
1977	0.403	0.923	0.648	0.597	0.572	0.563	0.551	0.560
1978	0.428	1.000	0.694	0.640	0.614	0.602	0.595	0.600
1979	0.438	1.041	0.723	0.667	0.641	0.627	0.622	0.625
1980	0.431	1.042	0.732	0.675	0.650	0.634	0.632	0.632
1981	0.412	1.010	0.722	0.666	0.643	0.625	0.626	0.623
1982	0.384	0.952	0.697	0.644	0.623	0.604	0.606	0.601
1983	0.352	0.880	0.661	0.611	0.592	0.574	0.575	0.570
1984	0.320	0.801	0.615	0.570	0.554	0.536	0.536	0.530
1985	0.292	0.722	0.564	0.525	0.511	0.494	0.493	0.487
1986	0.267	0.646	0.511	0.479	0.466	0.451	0.447	0.441
1987	0.245	0.576	0.458	0.434	0.422	0.408	0.403	0.398
1988	0.226	0.513	0.411	0.392	0.381	0.370	0.363	0.358
1989	0.207	0.459	0.372	0.357	0.348	0.338	0.330	0.327
1990	0.191	0.415	0.342	0.330	0.322	0.314	0.307	0.304
1991	0.177	0.380	0.321	0.311	0.303	0.297	0.291	0.289
1992	0.165	0.354	0.307	0.297	0.290	0.285	0.281	0.279
1993	0.156	0.336	0.298	0.289	0.283	0.278	0.276	0.275
1994	0.152	0.325	0.293	0.284	0.279	0.275	0.274	0.273
1995	0.151	0.320	0.290	0.283	0.278	0.275	0.274	0.272
1996	0.152	0.320	0.290	0.283	0.280	0.276	0.276	0.274
1997	0.155	0.323	0.292	0.286	0.283	0.280	0.278	0.277
1998	0.158	0.328	0.295	0.290	0.287	0.283	0.282	0.280
1999	0.161	0.334	0.299	0.294	0.291	0.287	0.285	0.284
2000	0.163	0.340	0.304	0.298	0.295	0.291	0.289	0.289
2001	0.164	0.347	0.310	0.303	0.299	0.296	0.294	0.294
2002	0.166	0.356	0.316	0.309	0.305	0.301	0.300	0.300
2003	0.169	0.365	0.324	0.316	0.311	0.308	0.306	0.307
2004	0.174	0.376	0.334	0.325	0.319	0.316	0.315	0.314
2005	0.179	0.389	0.344	0.335	0.329	0.325	0.324	0.322
2006	0.186	0.402	0.354	0.344	0.338	0.334	0.333	0.330
2007	0.192	0.415	0.363	0.352	0.346	0.342	0.341	0.336

2008	0.197	0.427	0.370	0.358	0.351	0.348	0.346	0.341
2009	0.201	0.438	0.374	0.361	0.354	0.350	0.349	0.344
2010	0.204	0.446	0.374	0.360	0.353	0.349	0.348	0.345
2011	0.204	0.451	0.372	0.356	0.349	0.345	0.344	0.343
2012	0.202	0.451	0.366	0.350	0.343	0.339	0.338	0.338
2013	0.197	0.443	0.358	0.342	0.334	0.330	0.329	0.331
2014	0.190	0.428	0.348	0.332	0.324	0.320	0.319	0.321
2015	0.181	0.407	0.335	0.320	0.313	0.308	0.307	0.310
2016	0.170	0.380	0.321	0.308	0.300	0.295	0.294	0.297
2017	0.158	0.350	0.305	0.294	0.287	0.282	0.280	0.282
2018	0.145	0.318	0.290	0.281	0.274	0.268	0.266	0.268

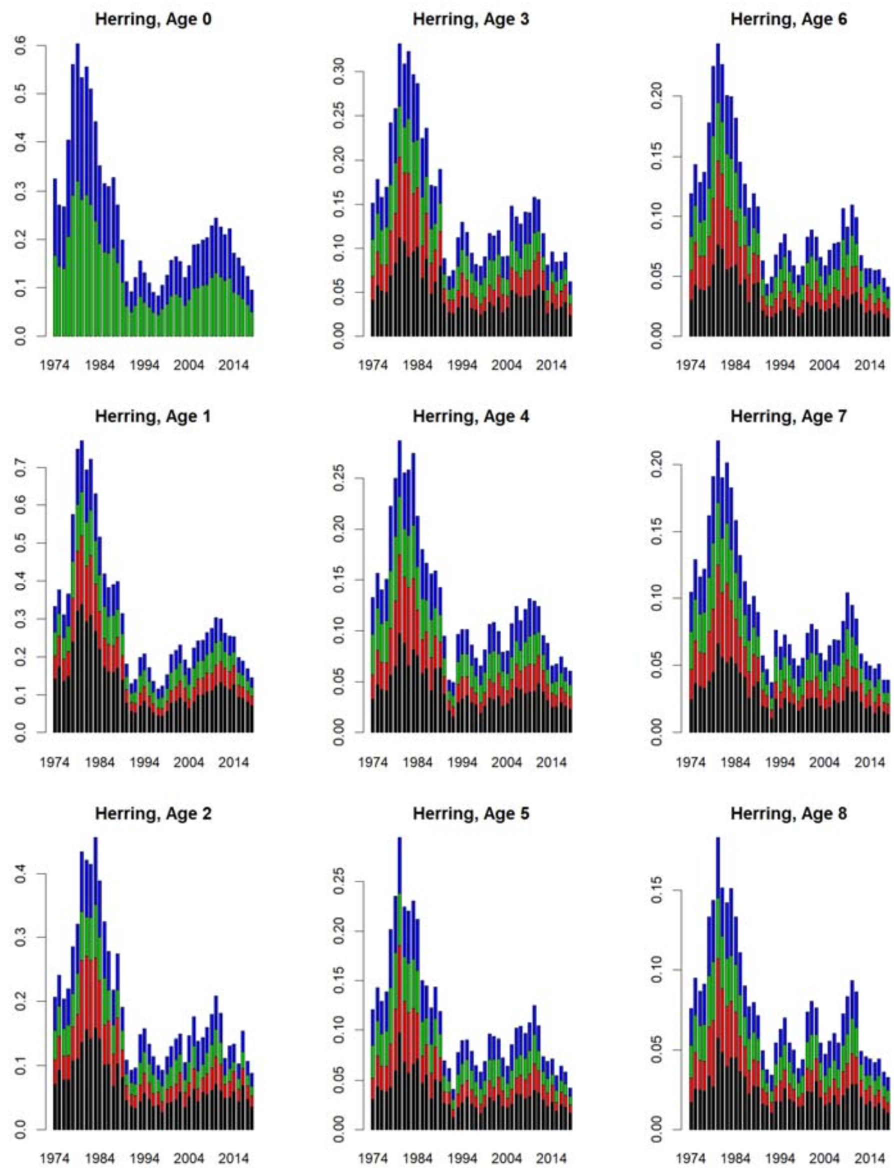


Figure 9.1-8. Annual predation mortality (M2) of herring the colours show M2 by quarter (green Q3, blue Q4, black Q1 and red Q4).

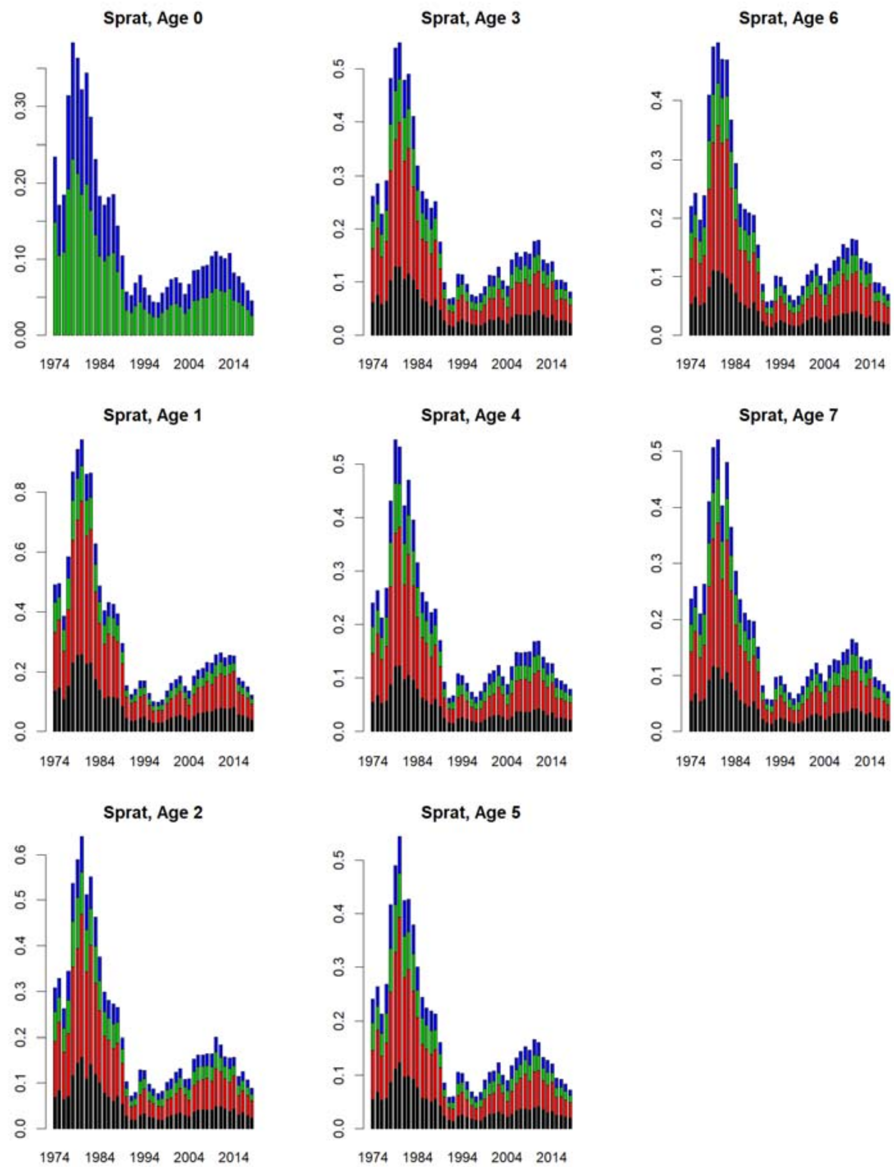
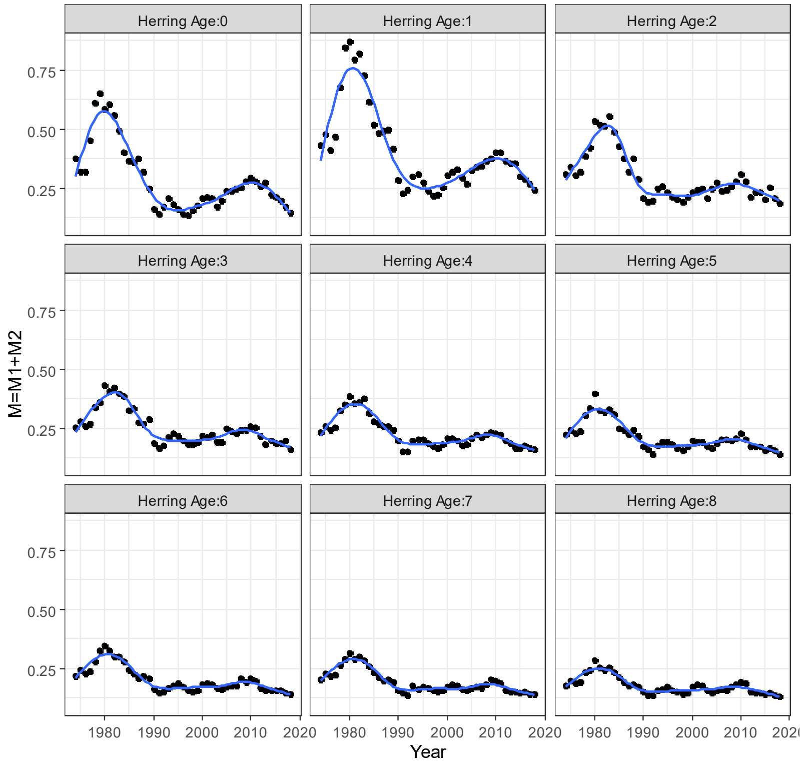


Figure 9.1-9. Annual predation mortality (M2) of herring the colours show M2 by quarter (green Q3, blue Q4, black Q1 and red Q4).



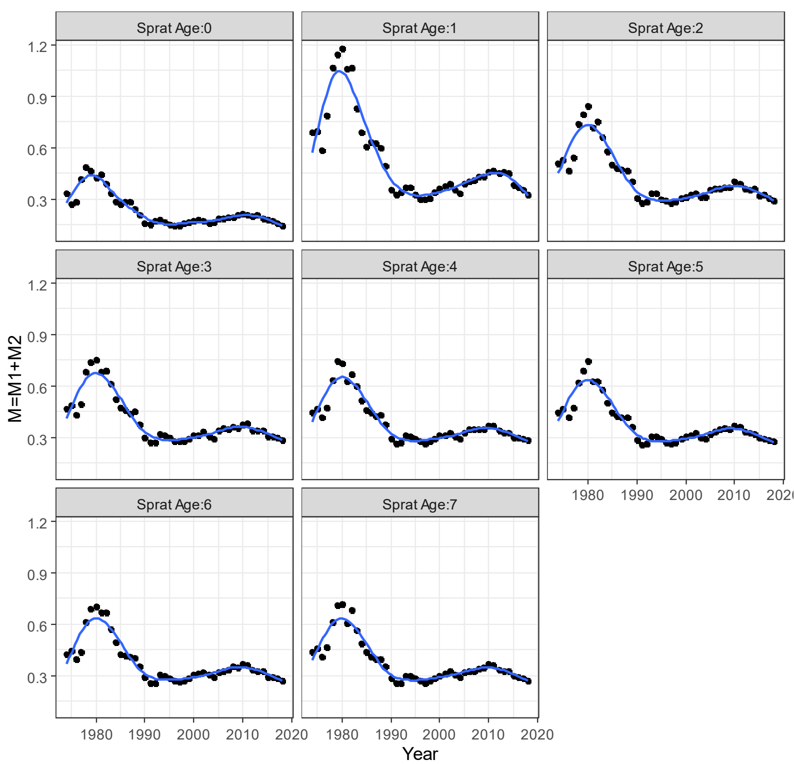


Figure 9.1-10. Annual natural mortalities (M=M1+M2) by species and age. Black dots are the sum of quarterly M1 and M2; the blue line is a gam spline estimate.

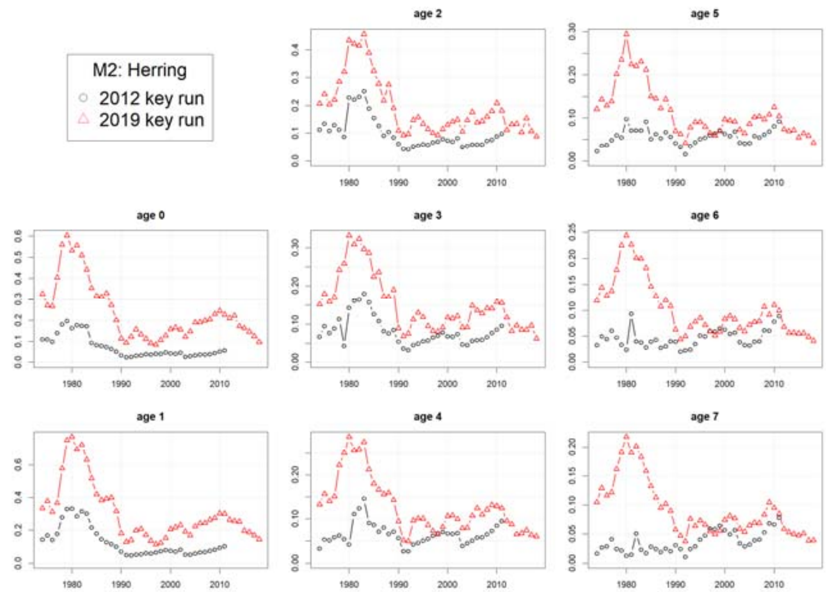


Figure 9.1-11. Herring. Comparison of predation mortality (M2) estimated by the 2012 key-run and by the 2019 key run.

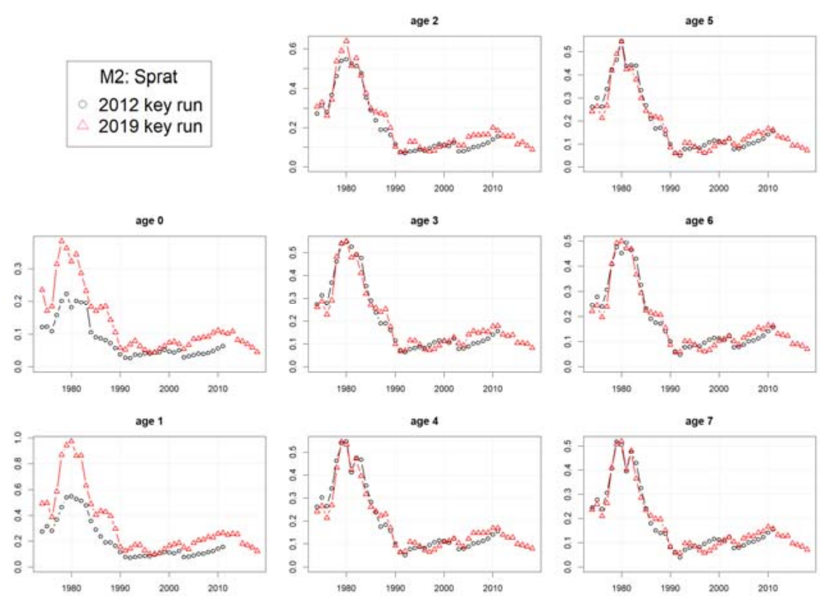


Figure 9.1-12. Sprat. Comparison of predation mortality (M2) estimated by the 2012 key-run and by the 2019 key run.

9.1.3 Uncertainties of parameters and output

SMS estimate the uncertainties of selected output variables using the Hessian matrix and the 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 the "external predators" cod are assumed known without errors. With cod as the only predator, this combination of estimated and assumed "known" variables will certainly lead to an underestimate of the uncertainties of e.g. predation mortality.

Therefore, the uncertainties estimated from the Hessian matrix are not presented in details.

An example of estimated uncertainties is presented in Figure 9.1-13. The confidence interval seems too tight!

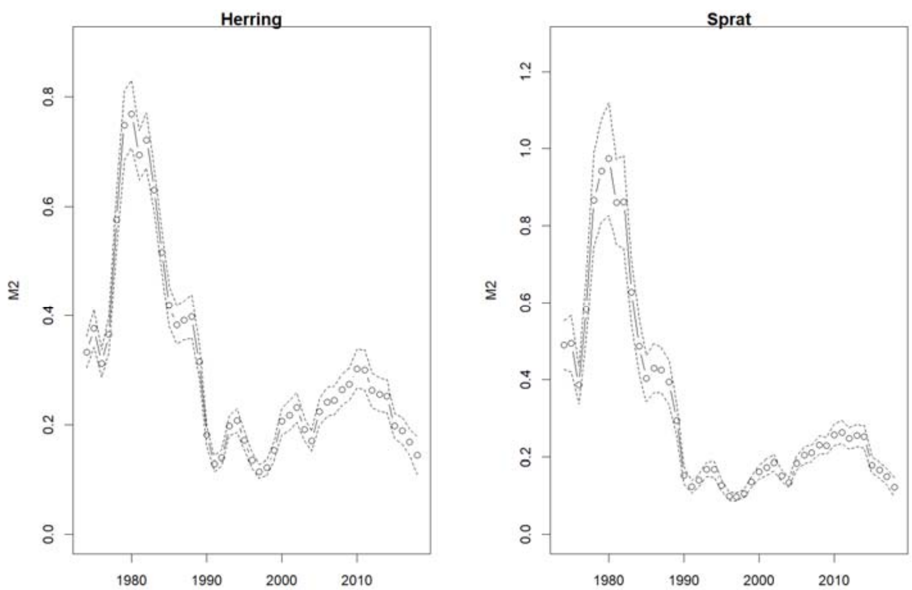


Figure 9.1-13. Values of M2 and 95% confidence interval (+- 2*standard deviation) for age 1 of herring and sprat

9.2 Sensitivity test

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

1. Retrospective analysis (5 year peel of all input data)
2. Sensitivity to stomach data (old vs. new stomach data set)
3. Sensitivity to stomach data (aggregation stomach data over a 5 or 10 years period)
4. Sensitivity towards using different assumptions for size selection
5. Sensitivity towards using or not using an overlap index for Other Food
6. Sensitivity towards consumption rates
7. Comparison with the old 2012 keyrun
8. Comparison with the Gadget model run.

9.3 Retrospective analysis (5 year peel of all input data)

The retrospective analysis shows variable estimates of recruitment, SSB and F for the terminal years in the time series, (Figure 9.3-1). Comparison with the same kind of output for the ICES assessment (WGBFAS, 2019) reveals however a similar variability in the ICES single species assessment output.

The retrospective analysis show a consistent estimate of predation mortalities (Figure 9.3-2). This consistent estimate is probably also because all runs use the same stomach contents data; the last year with stomach data is 2014. As for all other retrospective assessment analysis, values (M2) in the terminal year of the time-series have larger uncertainties.

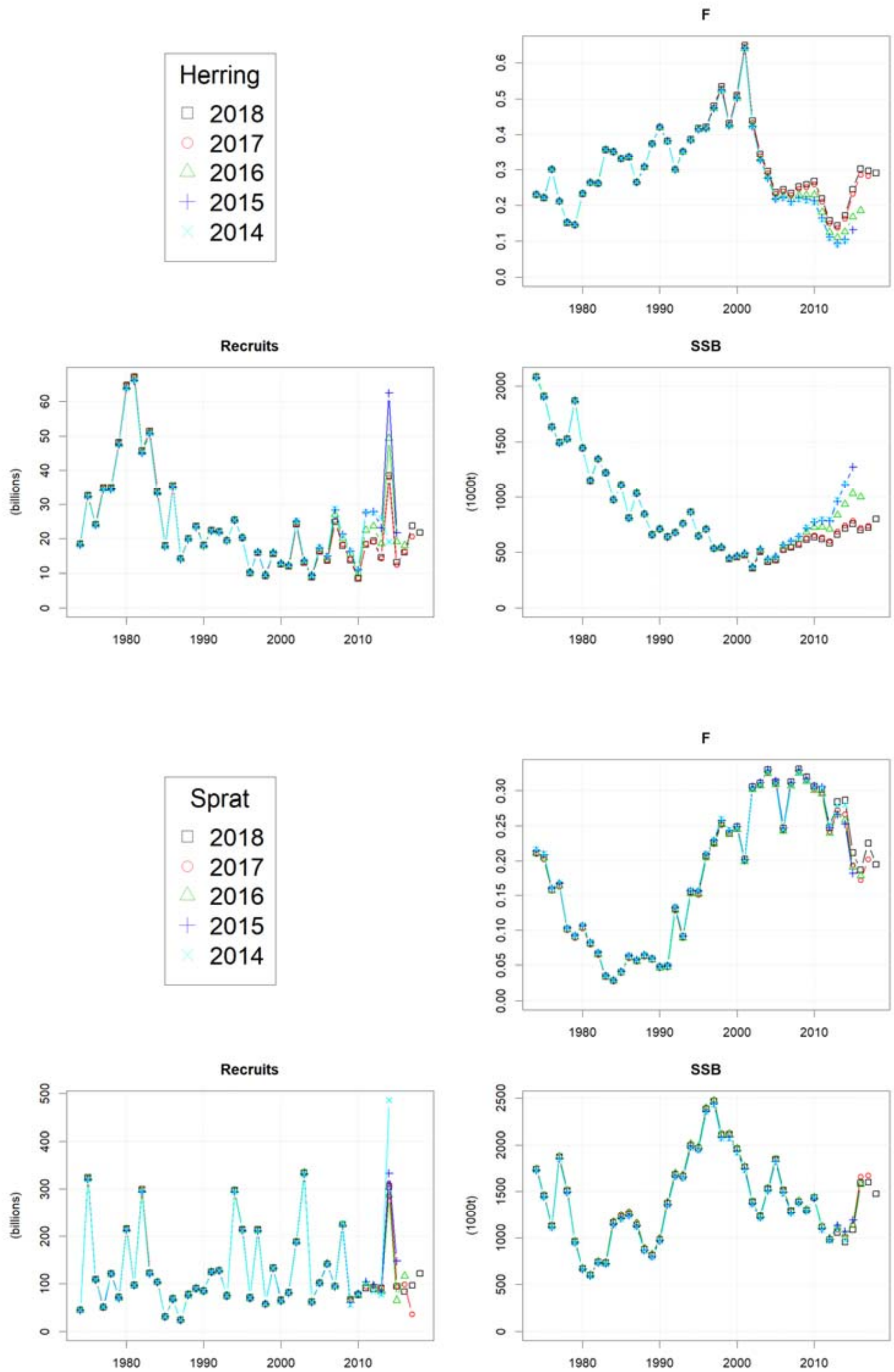
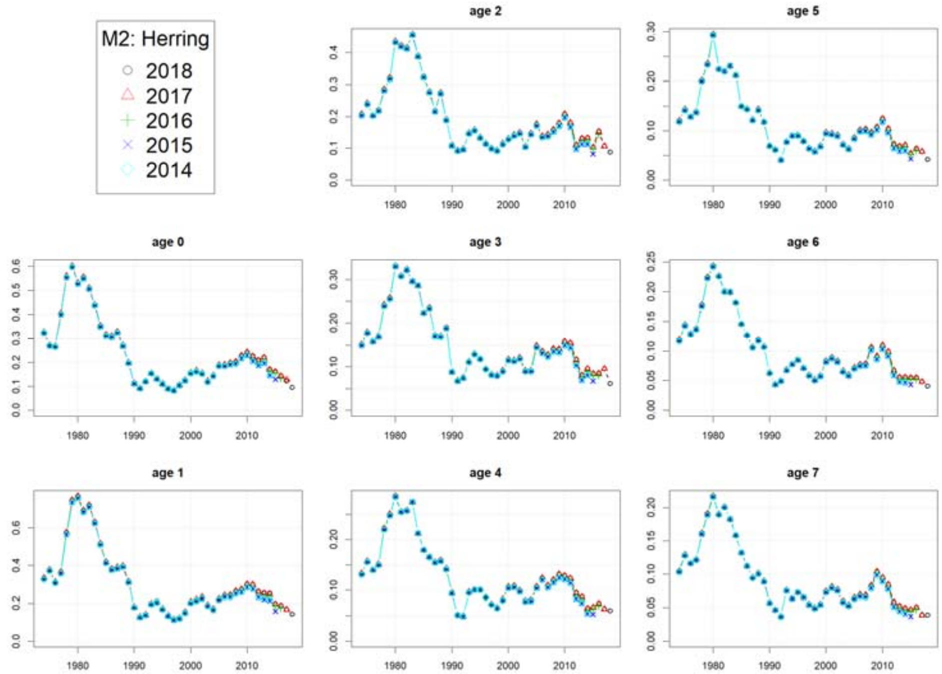


Figure 9.3-1. Retrospective analysis for herring and sprat. Summary output.



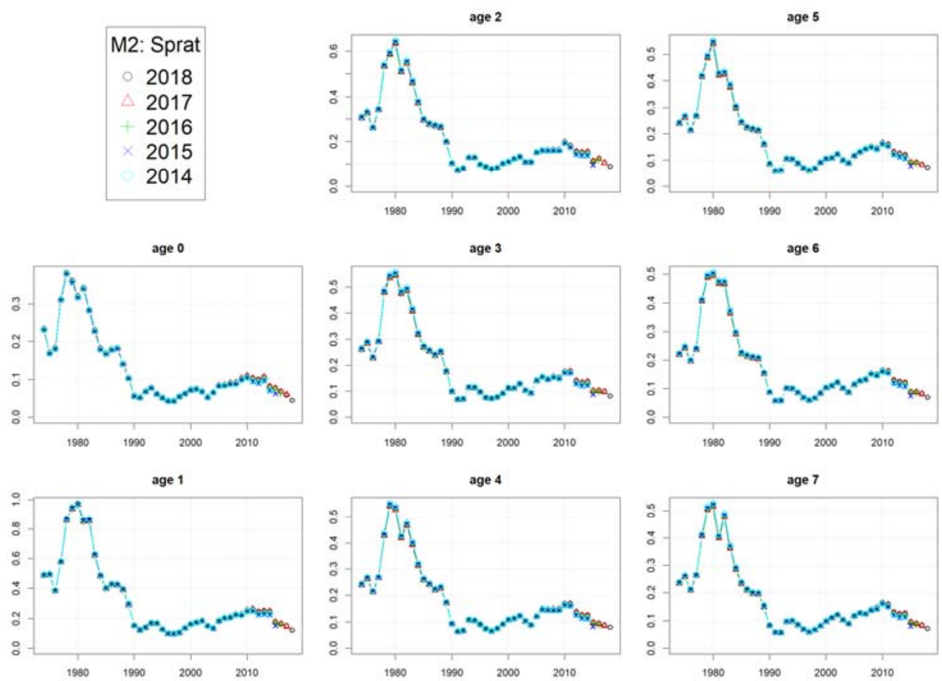


Figure 9.3-2. Retrospective analysis for herring and sprat, M2 at age

9.4 Sensitivity to stomach data (old vs. new stomach data set)

The choice of stomach contents data, "old", "new" and combined has limited effect on the SMS stock summary output (Figure 9.4-2) or predation mortalities (Figure 9.4-2)

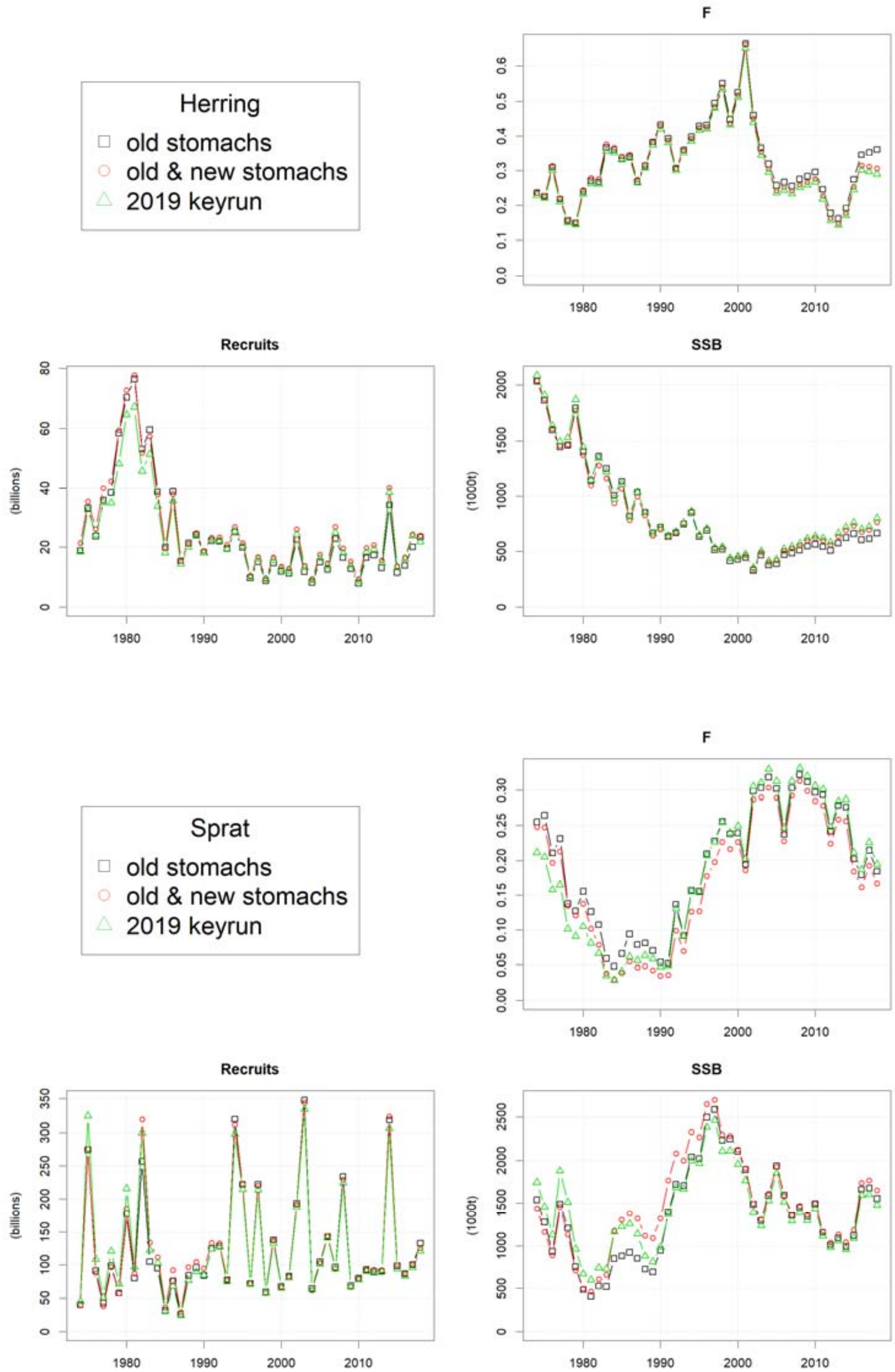


Figure 9.4-1. Comparison of output from SMS runs with combinations of contents data: "old" pooled stomach data, "new" individually sample stomachs. The key run uses only the "new" data.

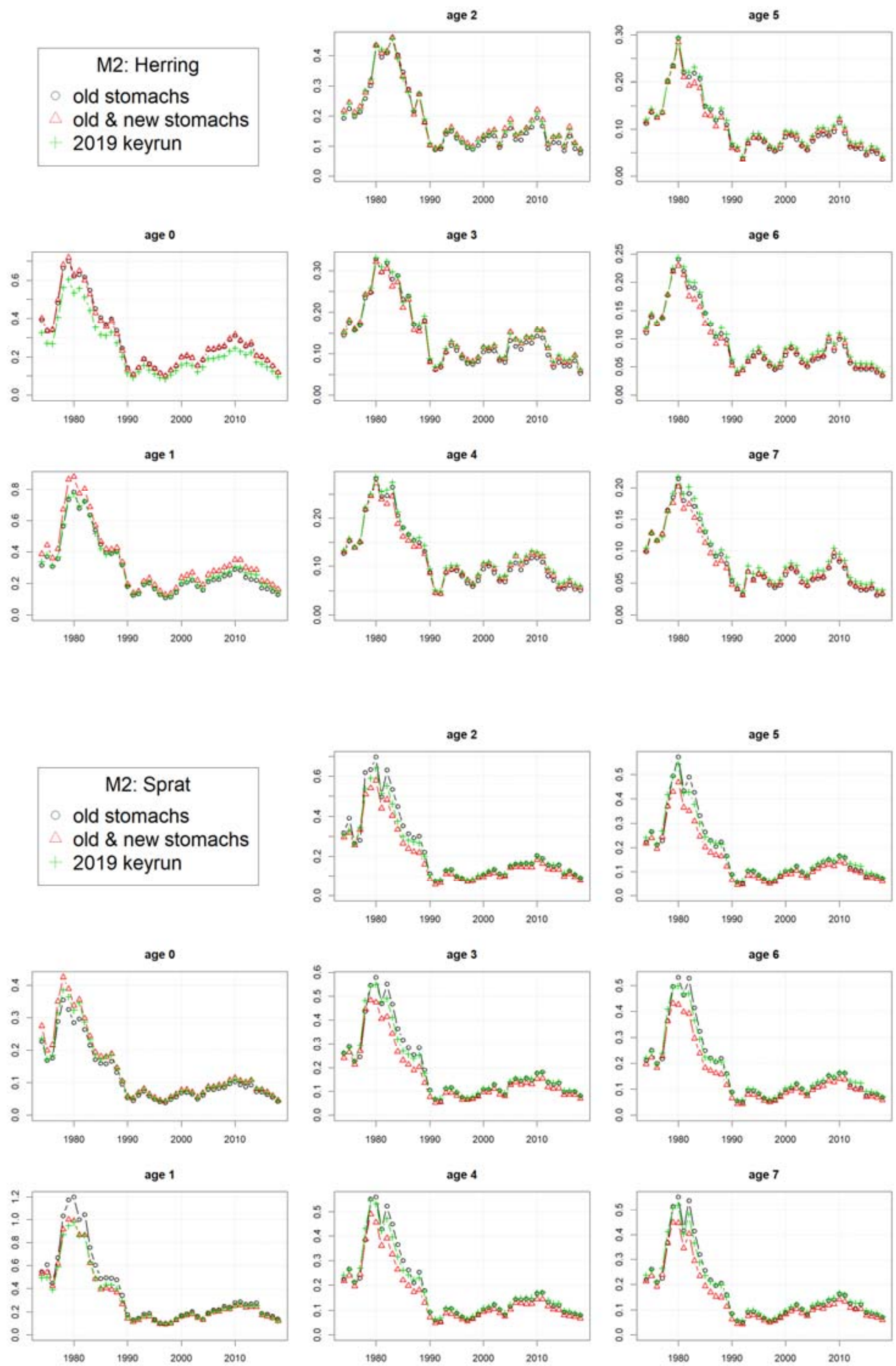


Figure 9.4-2. Comparison of M2 values from SMS runs with combinations of contents data: "old" pooled stomach data, "new" individually sampled stomachs. The key run uses only the "new" data.

9.5 Sensitivity towards using different assumptions for size selection

Three options for predator prey size selection were tried:

1. Log normal size selection (key run): a predator has a preferred prey size ratio and a prey twice as big as the preferred size is as attractive as another half the prey size. The preferred size ration and its variance are estimated by SMS.
2. Uniform size selection: a size preference at 1 within the range of the observed size ratio and 0 outside that ratio.
3. Constraint uniform size selection: as Uniform size selection, but the size preference ratio is constrained to exclude "outliers" from the observed size ratio, estimated from a quantile regression (Figure 9.5-1).

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The main performance statistics of a SMS run for the three size selection models (Table 9.5-1) show the best model likelihood and AIC for the keyrun.

Stock summary output (Figure 9.5-2) and M2 (Figure 9.5-3) are quite sensitive to the choice of size selection option. It seems as if the "constraint uniform" option excludes interactions from medium sized cod on larger herring (Figure 9.5-1) such that M2 on herring ages 4-8 becomes very low. The (unconstraint) "uniform" options includes the full observed predator/prey size ratio which results in a higher M2 for the older herring than for the "constraint uniform" option.

The "constraint uniform" option performed well in the 2012 key run, however there is difference in the quality of stomach contents data used in the old and the new 2019 key run. The old key runs made use of stomach contents data with large size classes for predator preys, e.g. sprat 5-10-15 cm, while the new stomach data uses a much smaller size classes, e.g. by cm group for sprat. With wider size classes, the in predator/prey size ratio becomes imprecise, such that the cutting of "outliers" by the "constraint uniform" options had a limited effect. With the new data, the full range of observations should probably be used, if a uniform size selection option is used.

Table 9.5-1. SMS main performance statistics from a SMS run with the "uniform size selection", "constraint uniform size selection" and the keyrun.

uniform size selection

```
objective function (negative log likelihood):  -1166.15
Number of parameters: 289
Number of observations used in likelihood: 14892
Maximum gradient: 0.000624719
Akaike information criterion (AIC):   -1754.31

Number of observations used in the likelihood:
unweighted objective function contributions (total):
                Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum
Cod               0.0     0.0    0.0  -173.4     0.0      0.00    -173
Herring        -667.6  -117.3  -12.5     0.0     0.0      0.00    -797
Sprat          -100.9  -106.0   -5.5     0.0     0.0      0.00    -212
Sum            -768.6  -223.3  -18.0  -173.4     0.0      0.00   -1183
```

constraint uniform size selection

```
objective function (negative log likelihood):  -1110.12
Number of parameters: 289
Number of observations used in likelihood: 14892
Maximum gradient: 3.75233e-005
Akaike information criterion (AIC):   -1642.24

unweighted objective function contributions (total):
                Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum
Cod               0.0     0.0    0.0  -182.5     0.0      0.00    -183
Herring        -645.5  -121.1   -8.2     0.0     0.0      0.00    -775
Sprat           -56.8  -103.5   -5.2     0.0     0.0      0.00    -166
Sum            -702.4  -224.7  -13.4  -182.5     0.0      0.00   -1123
```

Log-normal size selection (key run)

```
objective function (negative log likelihood):  -1232.3
Number of parameters: 292
Number of observations used in likelihood: 14892
Maximum gradient: 5.5994e-007
Akaike information criterion (AIC):   -1880.6
unweighted objective function contributions (total):
                Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum
Cod               0.0     0.0    0.0  -256.2     0.0      0.00    -256
Herring        -660.4  -118.7   -8.6     0.0     0.0      0.00    -788
Sprat           -92.3  -104.0   -5.6     0.0     0.0      0.00    -202
Sum            -752.7  -222.7  -14.2  -256.2     0.0      0.00   -1246
```

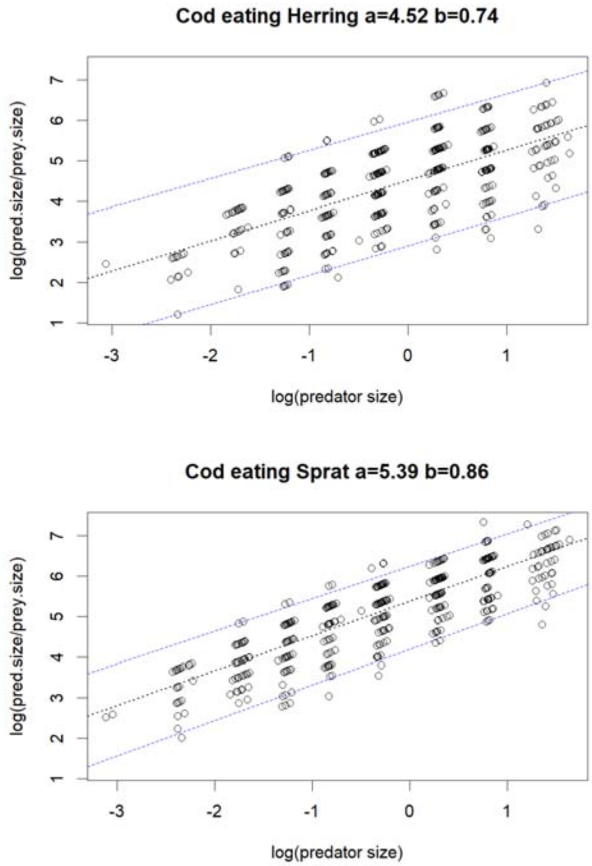

Figure 9.5-1. Quantile regression with observations of predator and predator/prey sizes. The blue lines shows the 2.5% and 97.5 % percentile lines, which defines the "size selection window".

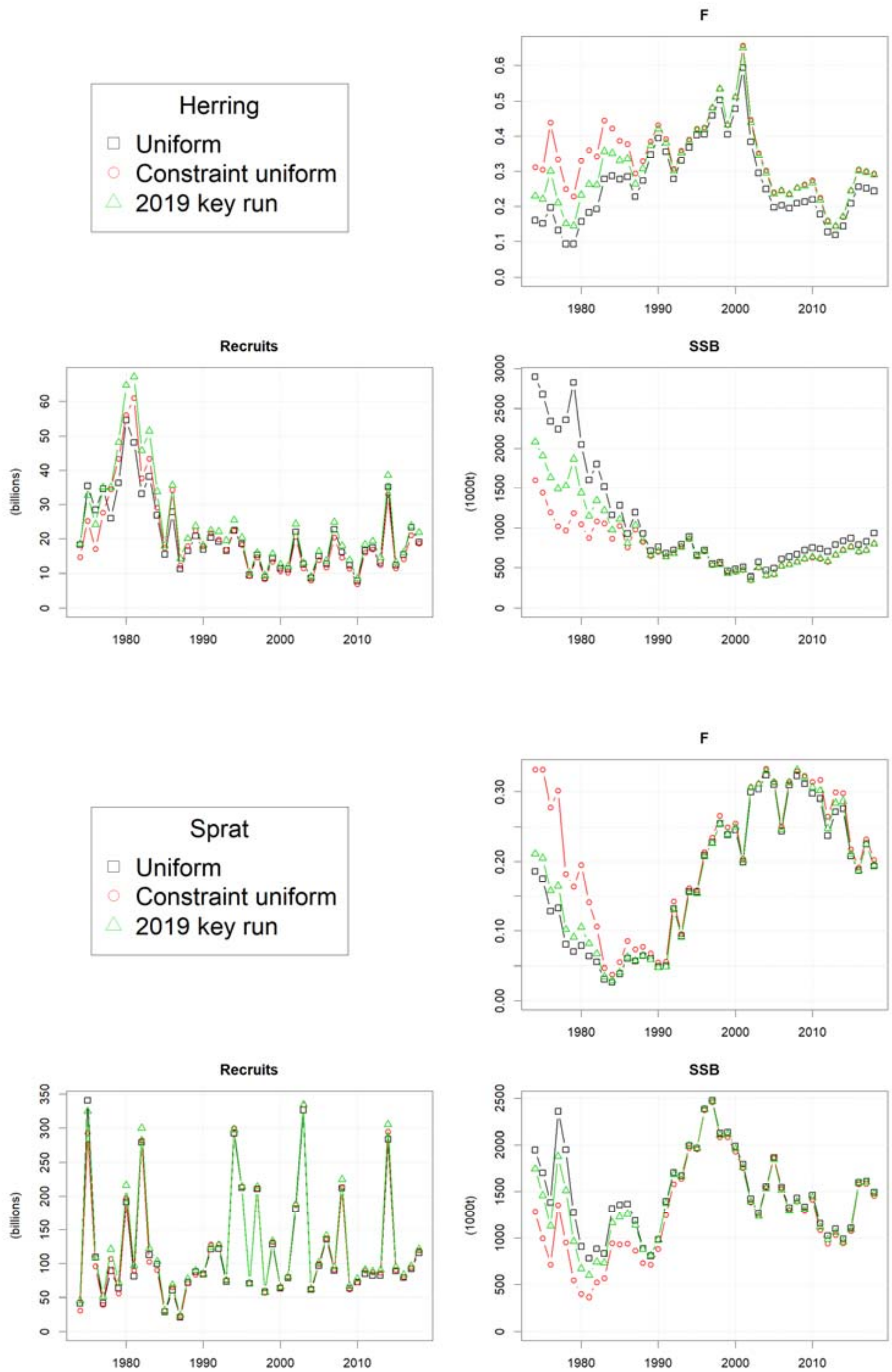

Figure 9.5-2. Comparison of output from SMS runs with three options for predator prey size selection.

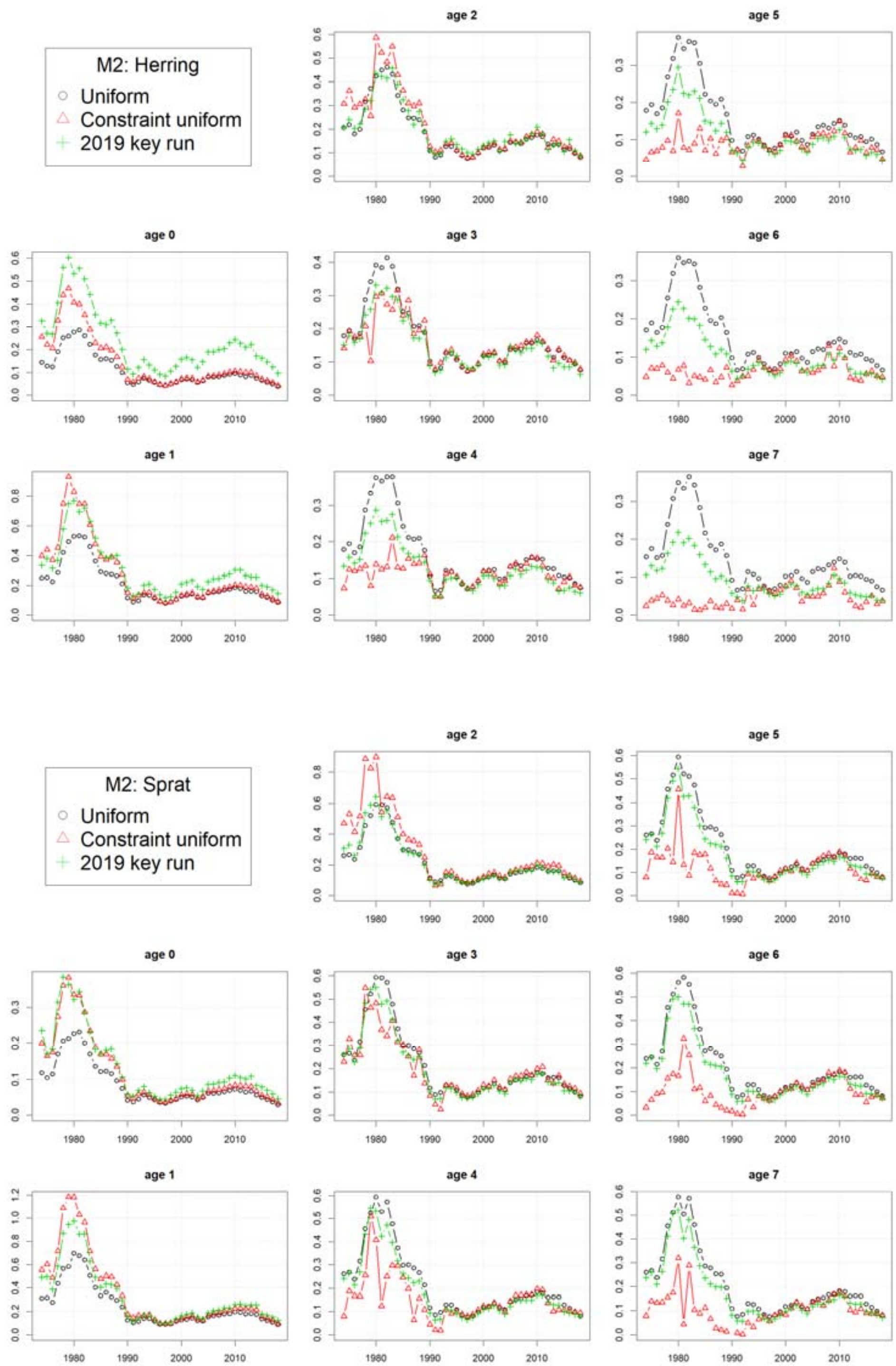

Figure 9.5-3. Comparison of M2 values from SMS runs with three options for predator prey size selection.

9.6 Sensitivity to stomach data (aggregation over a 5 or 10 years period)

Stomachs data are by default aggregated for each combination of year and quarter of the year. For most cases this leads to a rather few stomachs for some of the predator length classes and uncertainties on how partly identified prey items should be assigned. Aggregating stomach data over more years, e.g. 5 or 10 years, provides a larger sample size and a smaller observation uncertainties, but an e.g. ″10 years diet″ will not reflect the variability in available food for the individual years.

The average likelihood contribution (Table 9.6-1) show that likelihood per stomach contents observation becomes better (more negative) when data are aggregated over some years compared to the keyrun which uses data by year. The best average likelihood for stomach data is obtained using a 5-years aggregation. This may be interpreted that pooling stomach data between year gives a higher precision (more stomachs) of data used by SMS. However, using a very wide year range may negatively affect the fit between “observed” stomach contents and the model estimate of stomach contents calculated for the midpoint of the years used in the data aggregation. Likelihood contributions from For Catch, CPUE and S/R observations are quite the same for the three configurations.

M2 values for the three configurations are differ mainly for age 0 and 1 of herring and sprat (Figure 9.6-1).

Table 9.6-1. Objective function contributions (per observation) from SMS models using stomach contents data aggregated over 5, 10 years and from the keyrun.

5 years aggregation:

	Catch	CPUE	S/R	Stomachs
Cod	0.00	0.00	0.00	-0.28
Herring	-0.46	-0.46	-0.18	0.00
Sprat	-0.08	-0.33	-0.12	0.00

10 years aggregation:

	Catch	CPUE	S/R	Stomachs
Cod	0.00	0.00	0.00	-0.26
Herring	-0.47	-0.45	-0.18	0.00
Sprat	-0.09	-0.33	-0.11	0.00

Keyrun:

	Catch	CPUE	S/R	Stomachs
Cod	0.00	0.00	0.00	-0.16
Herring	-0.46	-0.47	-0.19	0.00
Sprat	-0.07	-0.33	-0.12	0.00

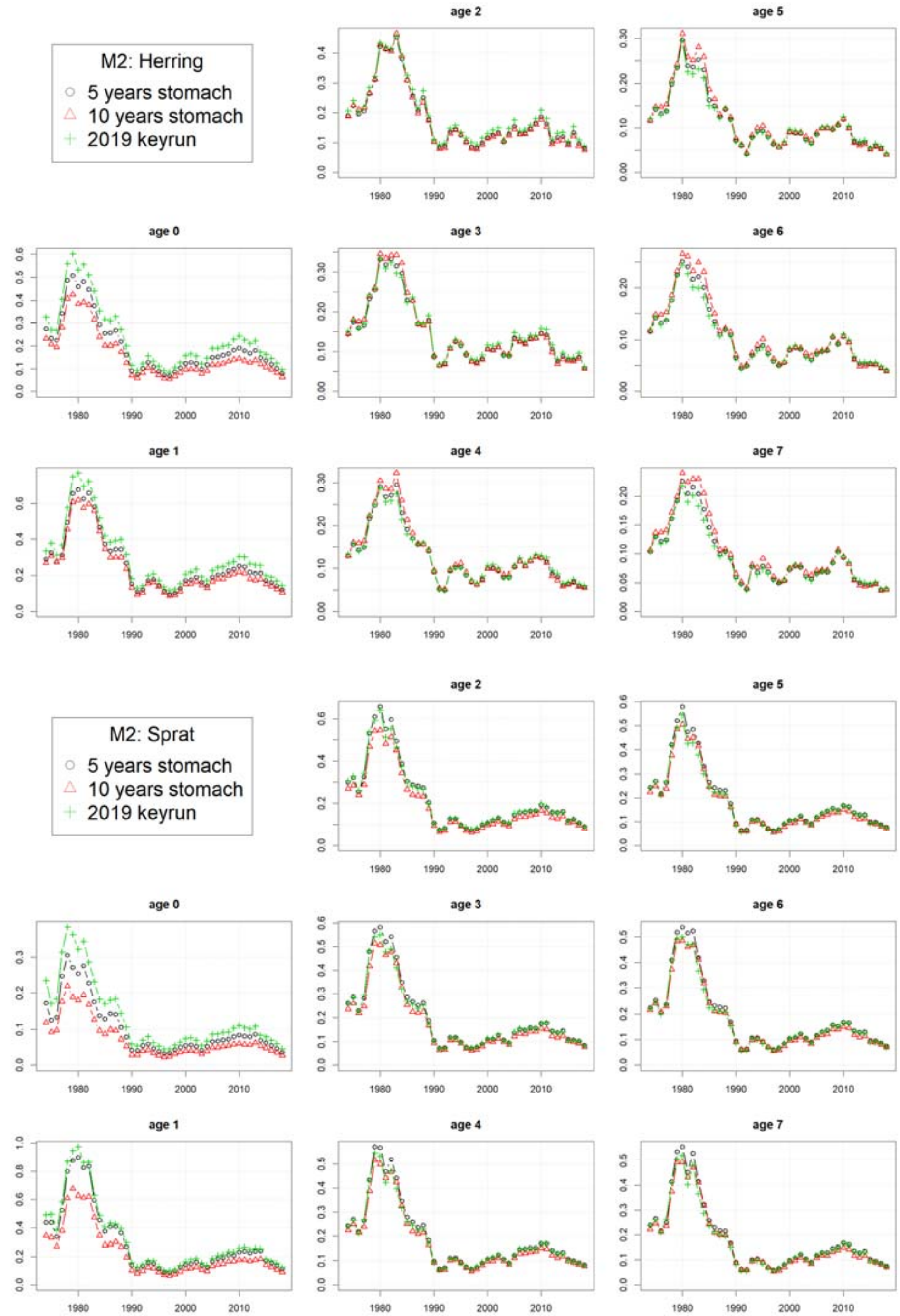

Figure 9.6-1. M2 estimated from SMS runs using stomach contents data aggregated over 5, 10 years and from the keyrun.

9.7 Sensitivity towards using an overlap index for Other Food

The "other food" prey *Saduria entomon* is an important benthic prey item for cod. The occurrence of this prey depends on the oxygen level at the bottom, which have changed considerably in the model timespan.

A time-series of total area (km^2) of hypoxic bottoms (between 20 and 100 m depth) was used to develop an index for overlap with *Saduria entomon* and other benthic components, assuming ≤1 ml l^{-1} (approx. 1.4 mg l^{-1}) as threshold for oxygen concentration to indicate failure in benthic productivity. With A_h indicating the hypoxic bottom area, the index was defined as $(A_h / maxA_h)^{-1}$, yielding higher values the smaller the hypoxic area was in a given year. We applied a 5-yr running mean. Weighting the areas with the sub-division specific cod distribution did not change the index time series except for the last two years with data, 2013 and 2014.

The overlap index between cod and the prey species herring and sprat was left unchanged (assumed 1 throughout the period)

The performance statistics (Table 9.7-1) for the runs with input overlap index and the keyrun are almost the same, even though the key run has a better total model likelihodd. The likelihood contributions from stomach observations are the same for the two models.

Stomach contents residuals (Figure 9.7-1) are similar to the keyrun residuals (Figure 9.1-4) but residuals are actually less clustered in positive and negative residuals when the input overlap index is applied.

Table 9.7-1. SMS main performance statistics from a SMS run with input overlap index for Other Food and the keyrun.

Log-normal size selection (key run)

```
objective function (negative log likelihood):  -1232.3
Number of parameters: 292
Number of observations used in likelihood: 14892
Maximum gradient: 5.5994e-007
Akaike information criterion (AIC):   -1880.6
unweighted objective function contributions (total):
                Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum
Cod               0.0     0.0    0.0  -256.2     0.0      0.00    -256
Herring        -660.4  -118.7   -8.6     0.0     0.0      0.00    -788
Sprat           -92.3  -104.0   -5.6     0.0     0.0      0.00    -202
Sum            -752.7  -222.7  -14.2  -256.2     0.0      0.00   -1246
```

With input overlap index for Other Food

```
Objective function (negative log likelihood):  -1210.41
Number of parameters: 292
Number of observations used in likelihood: 14892
Maximum gradient: 1.62572e-006
Akaike information criterion (AIC):   -1836.83

unweighted objective function contributions (total):
                Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum
Cod               0.0     0.0    0.0  -256.3     0.0      0.00    -256
Herring        -662.2  -116.4  -20.4     0.0     0.0      0.00    -799
Sprat           -71.9  -102.3   -5.9     0.0     0.0      0.00    -180
Sum            -734.1  -218.7  -26.3  -256.3     0.0      0.00   -1235
```

Figure 9.7-1. Stomach contents residuals ("Dirichlet residuals", Peter Lewy, pers. comm.). The y-axis show prey group and predator (cod) size class. The x-axis is time period sorted by year and quarter. Green dots show that the observed stomach contents are lower than the model estimate.

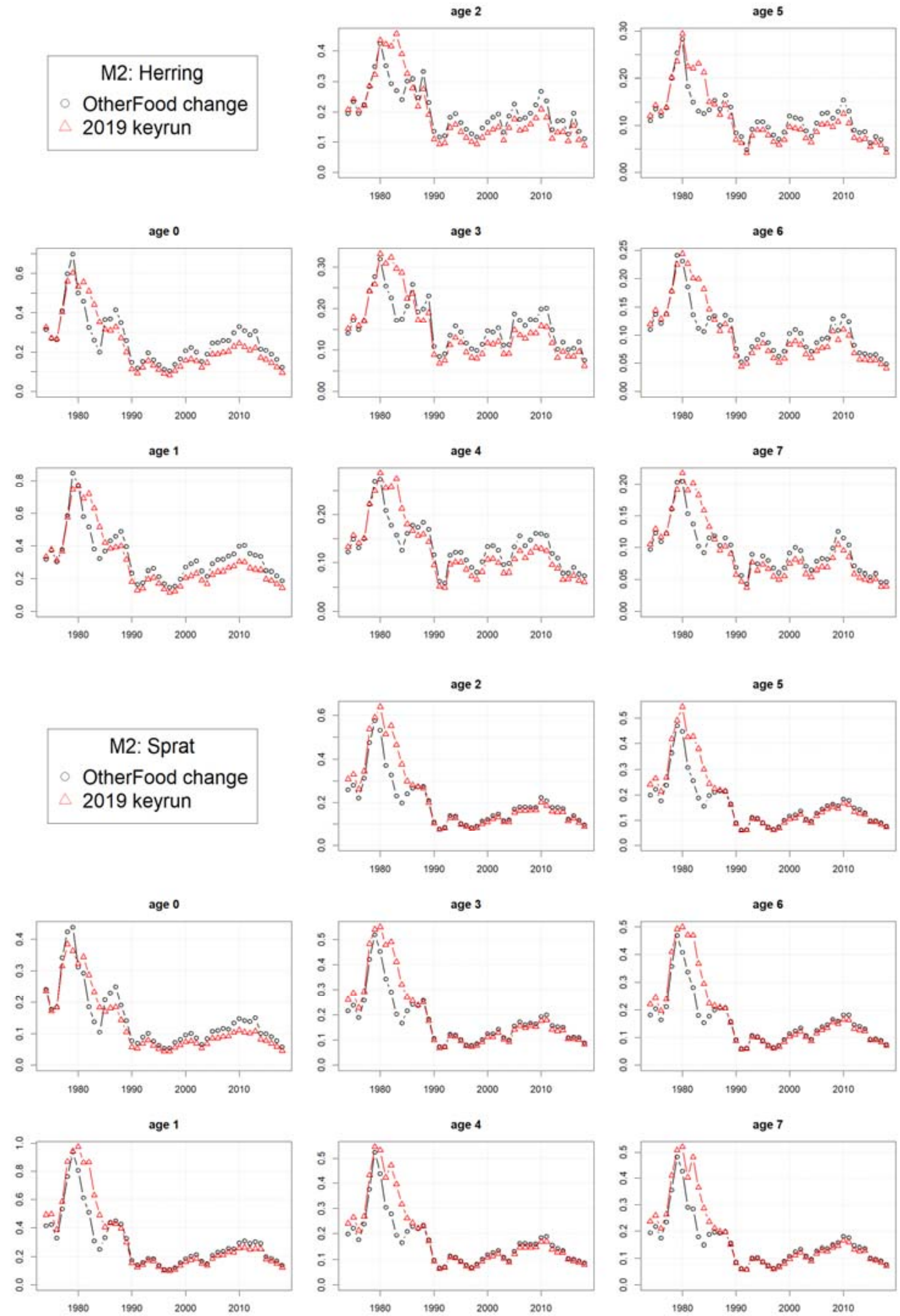

Figure 9.7-2. M2 estimated from a SMS run with input overlap index for Other Food and from the keyrun.

9.8 Sensitivity towards consumption rates

SMS can estimate a scaling factor for the input consumption rate by species. For cod this was estimated to 0.47, with a standard deviation at 0.07. This run was used to illustrate the sensitivity of M2 to consumption rates.

The performance statistics (Table 9.8-1 and Table 6.4-1) show a slightly better fit, when the factor to the input consumption rate is applied. Likelihood contribution from stomach becomes better on the cost of the likelihood for catch at age.

M2 values are lower when a considerably lower consumption rate are applied, but the reduction is not linear to the reduction in consumption, as expected (Figure 9.8-1). The reduction in M2 is larger for herring than for sprat.

Table 9.8-1 SMS main performance statistics from a SMS run with input overlap index for Other Food and the keyrun.

Log-normal size selection (key run)

```
objective function (negative log likelihood):  -1232.3
Number of parameters: 292
Number of observations used in likelihood: 14892
Maximum gradient: 5.5994e-007
Akaike information criterion (AIC):   -1880.6
unweighted objective function contributions (total):
                Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum
Cod               0.0     0.0    0.0  -256.2     0.0      0.00    -256
Herring        -660.4  -118.7   -8.6     0.0     0.0      0.00    -788
Sprat           -92.3  -104.0   -5.6     0.0     0.0      0.00    -202
Sum            -752.7  -222.7  -14.2  -256.2     0.0      0.00   -1246
```

With input consumption rates *0.47

```
objective function (negative log likelihood):  -1244.78
Number of parameters: 293
Number of observations used in likelihood: 14892
Maximum gradient: 6.23567e-005
Akaike information criterion (AIC):   -1903.57

unweighted objective function contributions (total):
                Catch    CPUE    S/R   Stom.  Stom N.  Penalty     Sum
Cod               0.0     0.0    0.0  -273.5     0.0      0.00    -273
Herring        -659.6  -119.9  -16.1     0.0     0.0      0.00    -796
Sprat           -87.2  -103.6   -5.4     0.0     0.0      0.00    -196
Sum            -746.7  -223.5  -21.5  -273.5     0.0      0.00   -1265
```

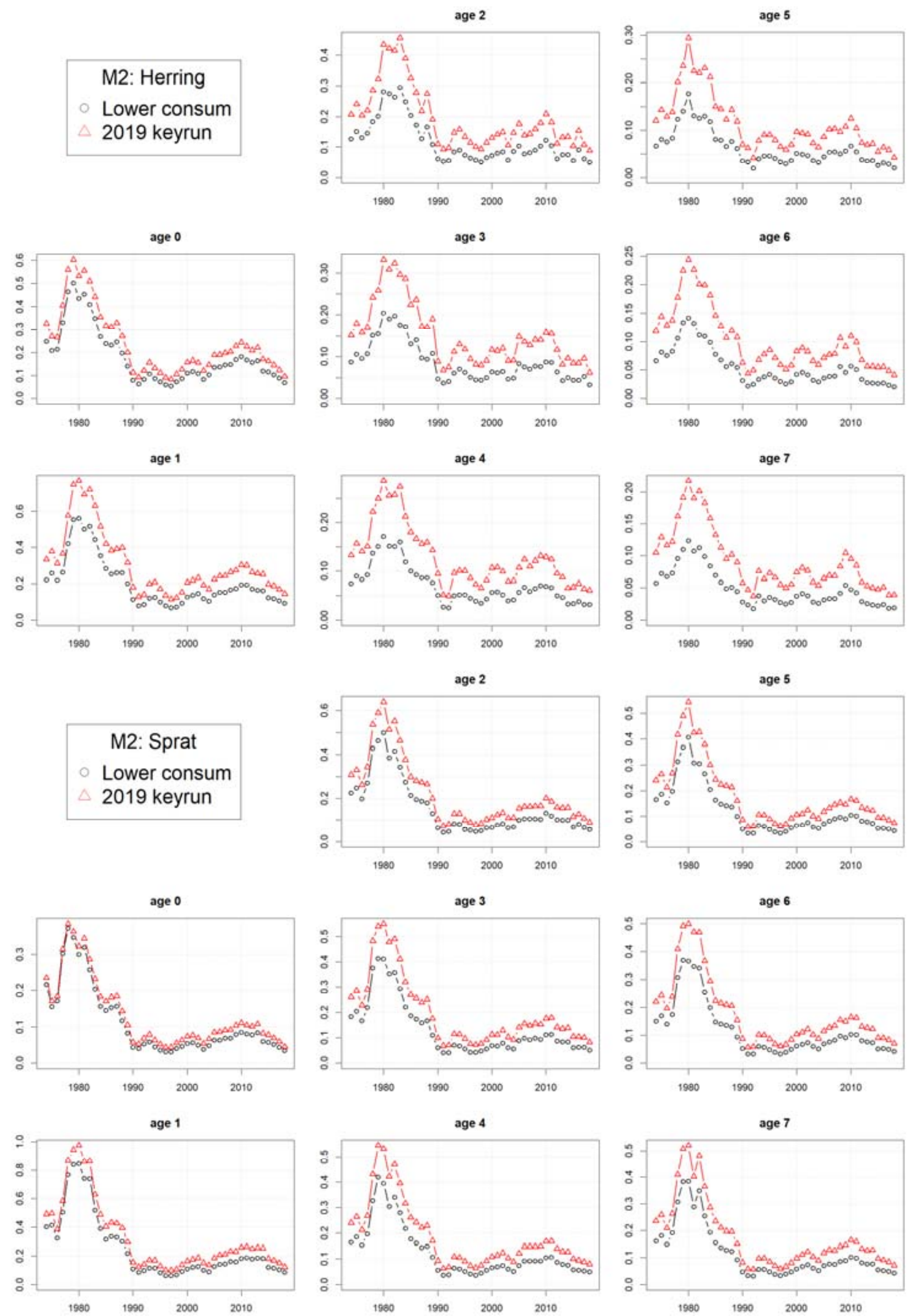

Figure 9.8-1. M2 estimated from a SMS run with lower (47%) consumption rates the keyrun.

9.9 Comparison with the old 2012 keyrun

Even though the 2012 and the 2019 key run are based on different stomach data, different assumption about the only predator species and different M1, the two key runs shows quite similar results for the summary output recruitment, SSB and mean F (Figure 9.9-1). Herring F and SSB are similar, while recruitment is considerably higher in the beginning of the time series in the 2019 key run, probably as an effect of the assumed larger cod stock. For Sprat, the trend in SSB and F is the same in the two runs, but F in the 2019 keyrun is consistently estimated lower and SSB higher.

The difference in M2 for the two runs is more pronounced, especially for herring (Figure 9.9-2). Herring M2 is now estimated higher for all ages, and much higher for the first part of the time series. The difference is probably due to the assumption of a larger cod stock (especially of larger cod) in the 2019 key run, and the application of the predator-prey size selection model in the new keyrun, whereas the old version used a "constrainted uniform" size selection. Herring M2 follows better the stock size of cod in the new run which may indicate that the uniform size selection option was not the best choice for the 2012 key run.

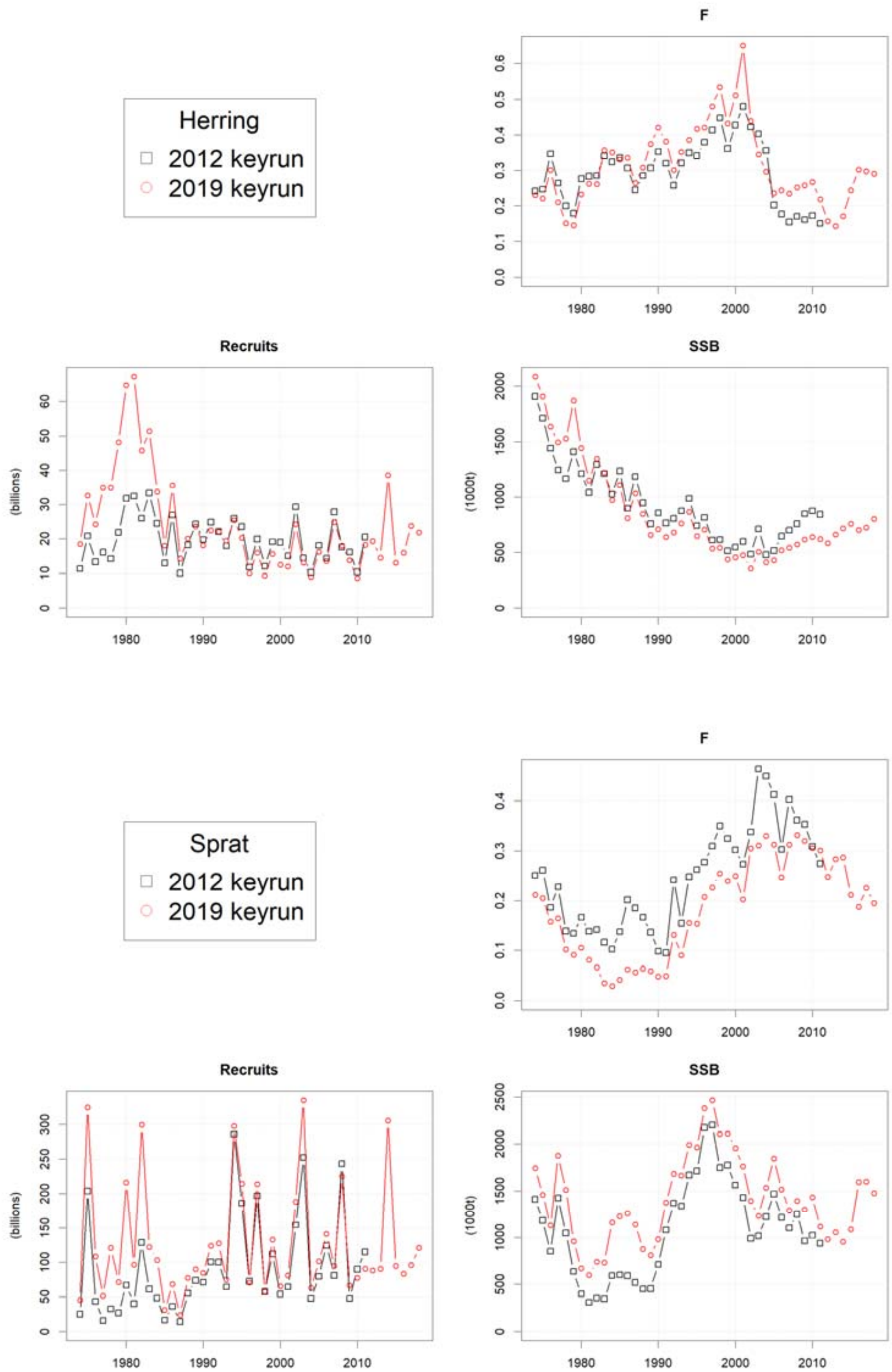

Figure 9.9-1. Comparison of the 2012 key run and the new 2019 key run. Summary output.

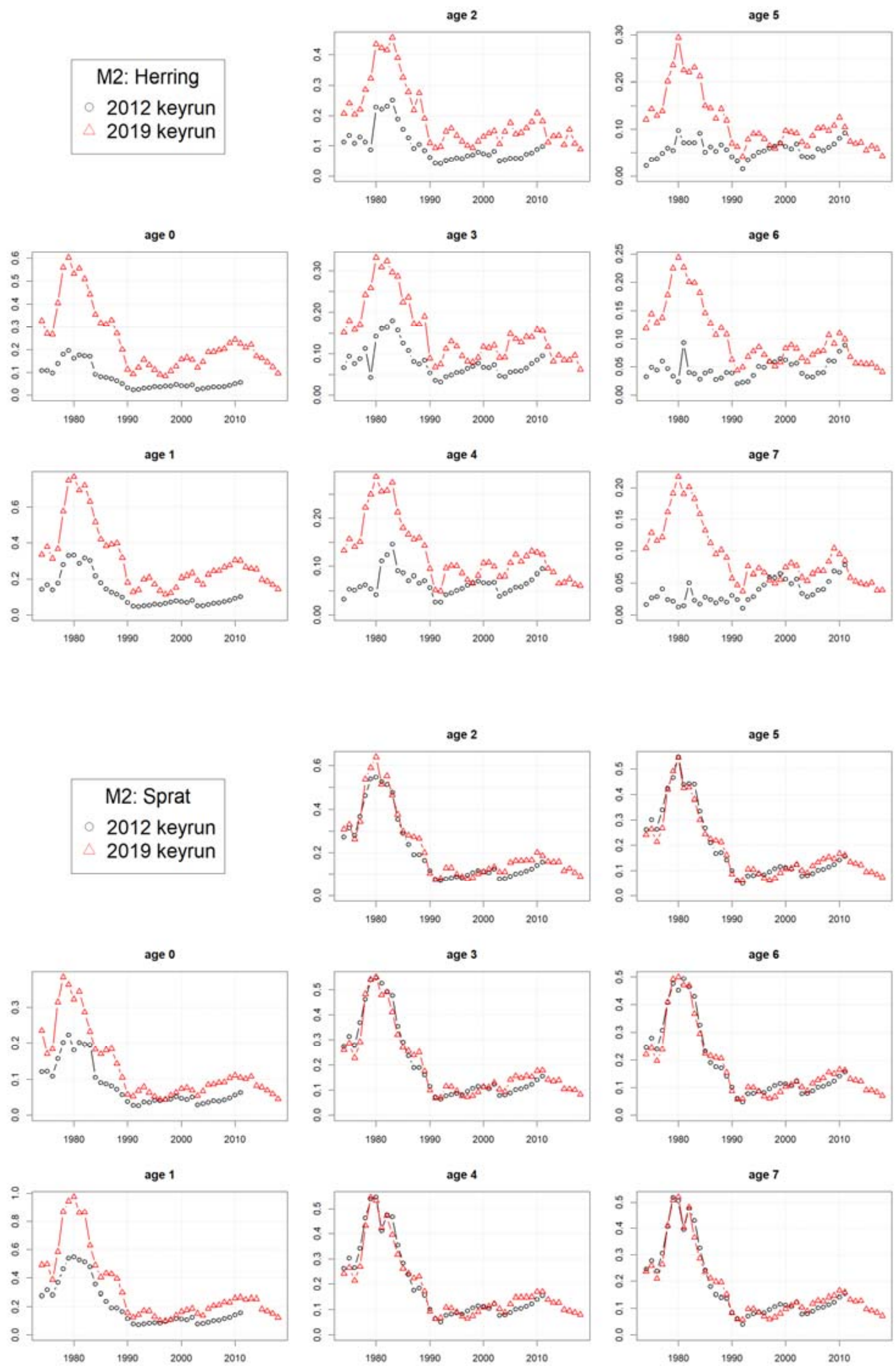

Figure 9.9-2. Comparison of the 2012 key run and the new 2019 key run. Predation mortality (M2)

9.10 Comparison with the Gadget model run.

A comparison of the SMS results and the results from the Gadget model presented the last day of WGSAM is presented for herring (Figure 9.10-1) and for sprat (Figure 9.10-2). The estimated M values are quite similar.

Figure 9.10-1. Comparison of M (M=M1+M2) values for herring from the SMS keyrun and the Gadget configuration.

Figure 9.10-2. Comparison of M (M=M1+M2) values for sprat from the SMS keyrun and the Gadget configuration.

9.11 Conclusion, 2019 key run

WGSAM 2019 discussed and reviewed the changes in input data and the results in detail and concluded that:

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 2012.

However, there are also clear limitations with the approach and results have been shown to be sensitive to e.g., consumption rates, assumptions regarding M1 and treatment of "Other Food" as well as the size selectivity of cod. In addition, the results depend to a large extent on the outcome of the ICES Eastern Baltic cod assessment. Any bias in this assessment directly influences the predation mortality estimates. Assumptions around other food and constant vulnerabilities may also bias the natural mortality estimates to some extent. Contrarily, the very similar results from the Gadget model run are encouraging and increase the credibility of the provided M time series.

WGSAM does not recommend using the uncertainty estimates around M as these are underestimated due to the assumption that the cod population is known without error.

9.12 Identified areas of priority research

The WGSAM 2019 recommended

1. More analyses on stomach data to get a better process understanding what is driving the systematic changes in relative stomach contents.

2. A split of Other Food in parts where the time dynamic can be taken into account (e.g., flatfish and *Saduria entomon*) and a part that still needs to be assumed constant in time may be beneficial.

3. The inclusion of spatial dynamics (either directly or via overlap coefficients) may improve the fit to data sources.

4. A run with age 1 as recruits could be tried because input for the 0 group is highly uncertain.

5. Account for the uncertainty in cod numbers in the model.

10 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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10.1 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.

10.2 Model Structure

10.2.1 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.

10.2.2 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.

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

10.2.3 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 10.2.3.2 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:

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

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

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

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

10.2.3.1 Use of size distribution by age

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

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

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

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

Assuming that F and M1 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).

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

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.

10.2.3.2 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.

10.2.3.2.1 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, σ^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.

10.2.3.2.2 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:

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

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:

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

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.

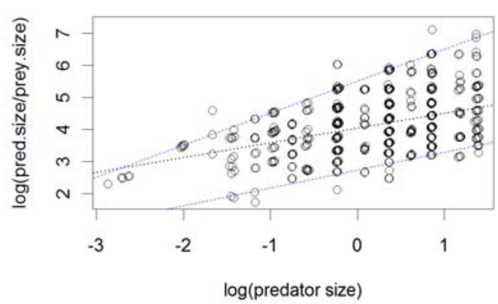

Figure 7.1. Quantile regression of stomach contents observations (Baltic cod eating cod), with 2.5%, 50% and 97.5% lines shown. Predator and prey size in weight.

10.2.4 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.

10.2.5 Growth

Not implemented yet!

10.2.6 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.

10.2.7 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).

10.2.7.1 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).

10.2.7.2 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.

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

10.3 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.

10.3.1 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:

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

Where

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

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

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

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

10.3.1.1 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.

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

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

10.3.2 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.

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

10.3.3 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:

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

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:

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

10.3.3.1 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.

10.3.4 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 $R_{s,y} = R\left(SSB_{s,y} | \, \alpha_s, \beta_s\right)$ penalty function is included in the likelihood function.

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

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

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

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

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

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

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

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

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

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

10.4 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.

Appendage 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.

10.5 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.

10.5.1 Recruitment

Recruitment is estimated from the available stock–recruitment relationships, f(SSB), (see Section 10.3.4) 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, $\sigma^2_{SR_S}$ (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).

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

10.5.2 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.

10.6 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 $\bar{\bar{\theta}}_i$ 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 $\bar{\bar{\theta}}_i$.

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 $\bar{\bar{\theta}}_i$.

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.

10.7 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.

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Appendage 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	parameter for 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

11 APPENDIX 2: Diet composition used in the model

The following figures show the relative stomach content composition of herring, sprat and “Other food”. For each predator the stomach contents are shown by observed predator size classes (showing the lower length in mm for the size class). The number on top of each bar is the number of stomachs sampled within the length class. On the figures, all length classes of preys are merged, however the darkness of each main colour indicate the sizes of the preys, with darkest colour for the largest preys. Stomach contents have been aggregated over 10 years and only the “new” stomachs are presented here. Figures by year for both the “old” and the “new” data set can be found on the Github.

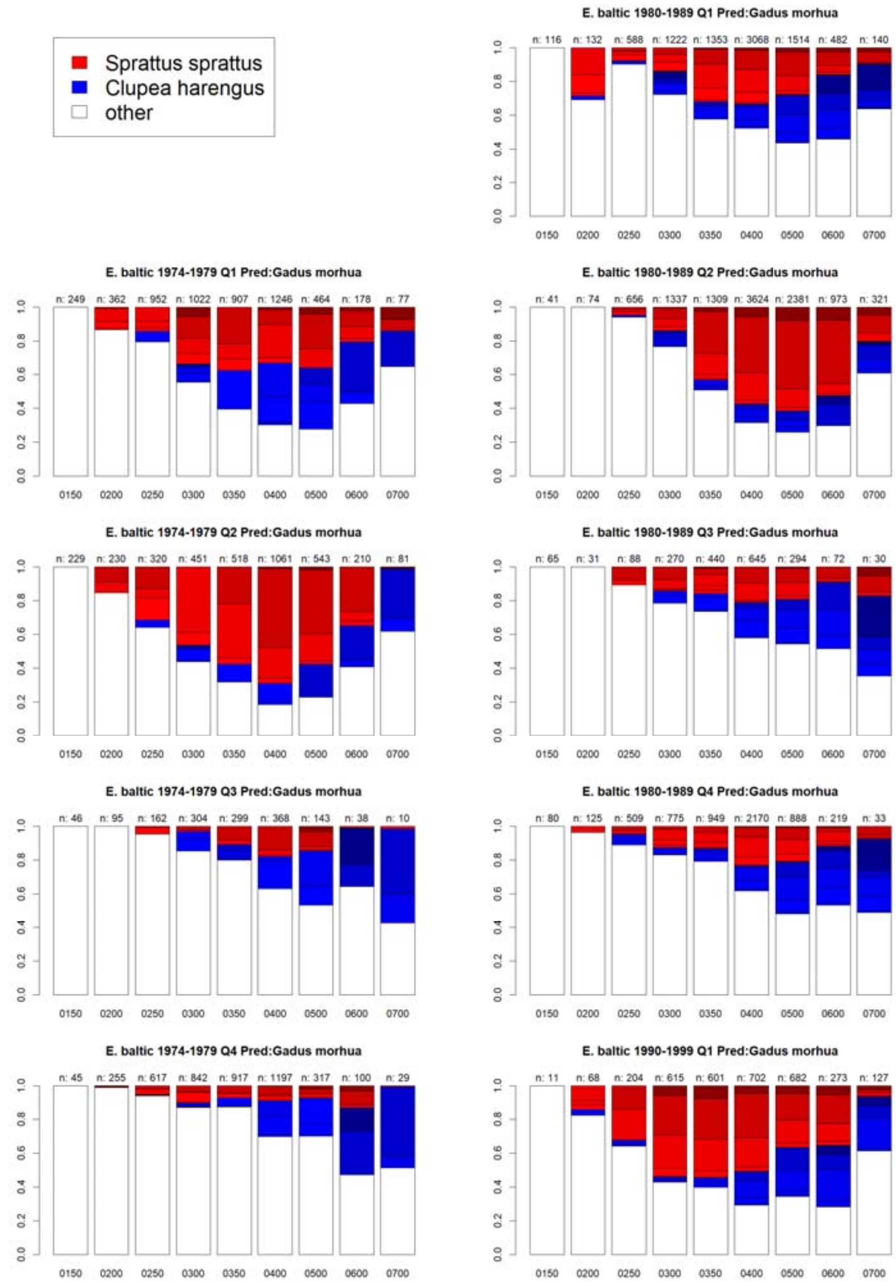

Figure 1, Appendix 2. Relative stomach contents weight of cod by decade, quarter and cod size class for the "new" stomachs. For each prey, the darkness of the prey colour indicates the size of the prey. The number on top of each bar shows the number of stomachs sampled.

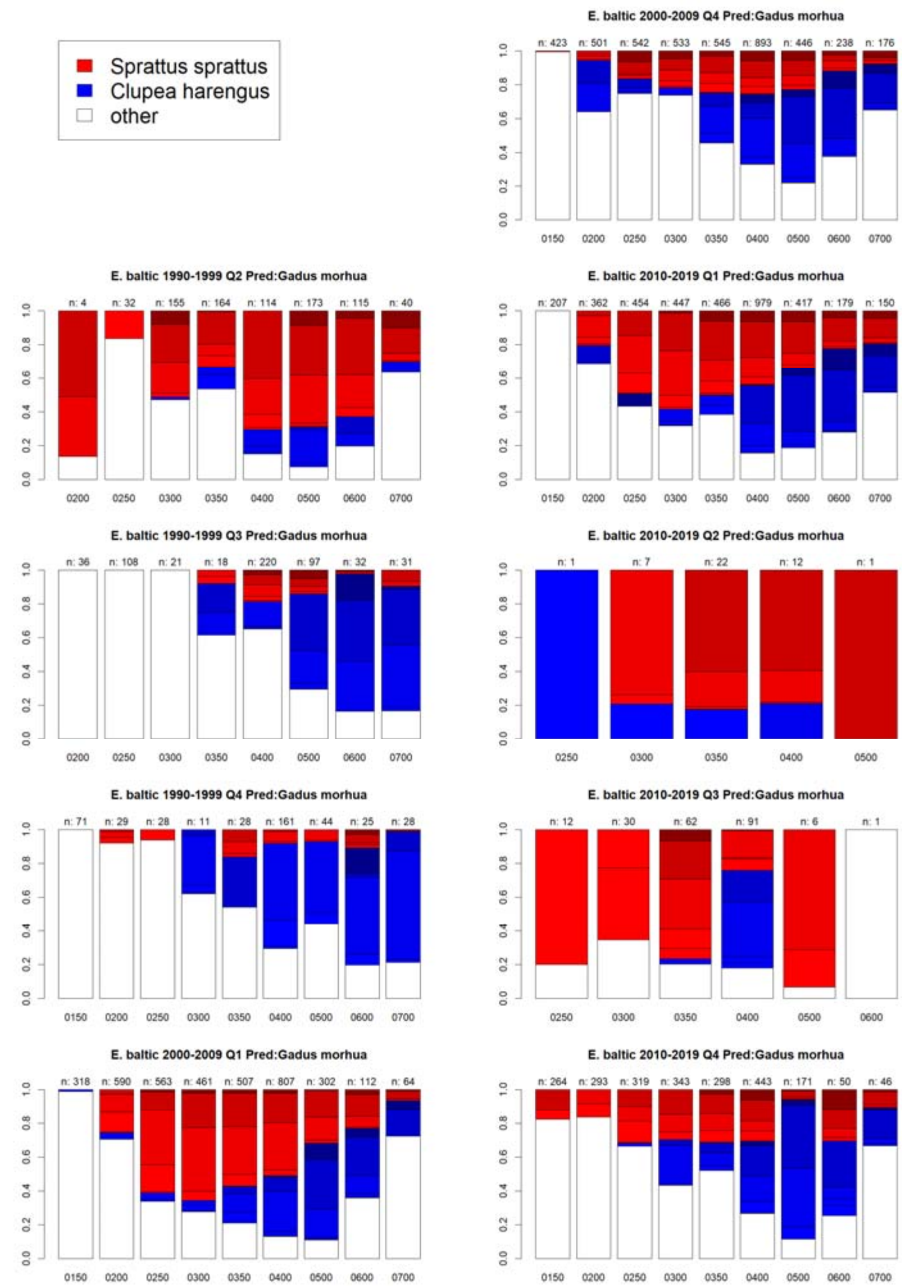

Figure 2, Appendix 2. Relative stomach contents weight of cod by decade, quarter and cod size class for the "new" stomachs. For each prey, the darkness of the prey colour indicates the size of the prey. The number on top of each bar shows the number of stomachs sampled.

12 APPENDIX 3: Option file for SMS-key-runs

Key-run 2019

```
# 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
1
########################################
# 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)
2018
########################################
## last year used in the model (option last.year.model)
2018
########################################
##  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)
3
########################################
# Species names, for information only. See file species_names.in
```

```
#  Cod Herring Sprat
########################################
## 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)
11
########################################
## 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,
#      61=STN Ricker for sprat. Input from file Sprat_rec_61.in
#      71=STN special SSB/R for cod. Input from file Cod_rec_71.in
#      >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
11 0 0 0 0 0 2 0  0 0 0   # 1 Cod as other predator
 8 1 5 0 8 1 0 1  3 0 0   # 2 Herring
 7 1 4 0 7 0 0 1  3 0 0   # 3 Sprat
########################################
## 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  #      Herring
    1e+06  #       Sprat
########################################
## 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
       -1  #      Herring
     1990  #       Sprat
# last year by species
       -1  #      Herring
       -1  #       Sprat
########################################
## 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   1 0  # 1 Cod
1 1 0.05 0 0  # 2 Herring
1 1 0.05 0 0  # 3 Sprat
########################################
```

```
## 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)
0.1
########################################
## 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  #     Herring
     0  #      Sprat
########################################
## 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)
     0  #     Herring
     0  #      Sprat
########################################
## use seasonal or common combined variances for catch observation
# seasonal=0, common=1 (use 1 for annual data)
     1  #     Herring
     1  #      Sprat
########################################
##
# catch observations: number of separate catch variance groups by species
      3   #    Herring
      4   #     Sprat

#  first age group in each catch variance group
1 2 3        #  Herring
1 2 3 4      #  Sprat
########################################
##
# catch observations: number of separate catch seasonal component groups by species
      3   #    Herring
      2   #     Sprat
#  first ages in each seasonal component group by species
1 2 3        #  Herring
1 2          #  Sprat
########################################
## first and last age in calculation of average F by species (option avg.F.ages)
3 6  # Herring
3 5  # Sprat
```

```
########################################
## 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  #     Herring
     0  #      Sprat
########################################
##
# catch observations: number of year groups with the same age and seasonal selection
      2  #    Herring
      2  #     Sprat
#  first year in each group (please note #1 will always be changed to first model year)
1974 1989 #  Herring
1974 2000  #  Sprat
########################################
##
# number of nodes for year effect Fishing mortality spline
# 1=no spline (use one Fy for each year), >1 number of nodes
      1   #    Herring
      1   #     Sprat
#  first year in each group
1976        #  Herring
1976        #  Sprat
########################################
## 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
0
########################################
## 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
0
########################################
## Factor for fixing last season effect in F-model (default=1) (fix.F.factor))
     1  #     Herring
     1  #      Sprat
########################################
## 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
5
########################################
## 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
0
########################################
## 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.vari-
ance)
#  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)
0
########################################
## Size selection model based on (option size.select.model)
#  1=length:
#     M2 calculation:
#        Size preference:
#          Predator length at age from file: lsea.in
#          Prey     length at age from file: lsea.in
#        Prey mean weight is weight in the sea from file: west.in
#     Likelihood:
#        Size preference:
#          Predator mean length per length group (file: stom_pred_length_at_sizecl.in)
#          Prey mean length per ength group (file stomlen_at_length.in
#        Prey mean weight from mean weight per prey length group (file: stomweight_at_length.in
#  2=weight:
#     M2 calculation:
#        Size preference:
#          Predator weight at age from file: west.in
#          Prey     weight at age from file: west.in
#        Prey mean weight is weight in the sea from file: west.in
#     Likelihood:
```

```
#       Size preference
#                   Predator mean weight is based on mean length per predator length group (file: stom_pred_length_at_sizecl.in)
#           and l-w relation (file: length_weight_relations.in),
#         Prey mean weight per prey length group (file: stomweight_at_length.in)
#       Prey mean weight from mean weight per prey length group (file: stomweight_at_length.in
#  3=weight:
#      M2 calculation: Same as option 2
#      Likelihood:
#       Size preference:
#                   Predator mean weight is based on mean length per predator length group (file: stom_pred_length_at_sizecl.in)
#           and l-w relation (file: length_weight_relations.in),
#                 Prey mean weight per prey length group (file: stomlen_at_length.in) and l-w relation (file:length_weight_relations.in)
#        Prey mean weight from prey mean length per prey length group (file: stomlen_at_length.in) and l-w relation (file: length_weight_relations.in)
#  4=weight:
#      M2 calculation:
#       Size preference:
#         Predator mean weight from file lsea.in (length in the sea) and l-w relation (file: length_weight_relations.in)
#       Prey mean weight from file lsea.in (length in the sea) and l-w relation (file: length_weight_relations.in)
#      Likelihood:  Same as option 3
#  5=weight in combination with simple.ALK=1:
#      M2 calculation:
#       Size preference:
#          Predator weight based on length from file ALK_all.in (length distribution at age) and l-w relation (file: length_weight_relations.in)
#         Prey     weight based on length from file ALK_all.in (length distribution at age) and l-w relation (file: length_weight_relations.in)
#         Prey mean weight based on length from file ALK_all.in (length distribution at age) and l-w relation (file: length_weight_relations.in)
#      Likelihood: Same as for option 2
#  6=weight in combination with simple.ALK=1:
#      M2 calculation: Same as option 5
#      Likelihood: Same as option 3
2
########################################
# Adjust Length at Age distribution by a mesh selection function (option L50.mesh)
#  Please note that options simple.ALK shoud be 1 and option size.select.model should be 5
# L50 (mm) is optional given as input. Selection Range is estimated by the model
# L50= -1 do not adjust
# L50=0, estimate L50 and selection range
# L50>0, input L50 (mm) and estimate selection range
# by VPA species
      -1  #     Herring
      -1  #      Sprat
########################################
## 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
       1 #        Cod
########################################
## 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  #         Cod
########################################
## # Use estimated scaling factor to link number of observation to variance for stomach observation likeli-
hood (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  #         Cod
########################################
## # 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
      1000  #         Cod
########################################
## Scaling factor (to bring parameters close to one) for relation between no of stomachs sampling and vari-
ance
#  value=0: use default values i.e. 1.00 for no size selection and otherwise 0.1 (option var.scale.stom)
       0  #         Cod
########################################
## 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
       1  #         Cod
########################################
## Minimum observed relative stomach contents weight for inclusion in ML estimation (option
min.stom.cont)
      0.001  #         Cod
########################################
## Upper limit for no of samples used for calculation of stomach observation variance (option
max.stom.sampl)
    500 # 1e+06  #         Cod
########################################
## Max prey size/ pred size factor for inclusion in M2 calc (option max.prey.pred.size.fac)
      0.3  #         Cod
########################################
## inclusion of individual stomach contents observations in ML for weight proportions (option stom.type.in-
clude)
# 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)
       1  #         Cod
########################################
## 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)
2
# 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)
2
# season overlap (default=-1) (option phase.season.overlap)
3
# 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
########################################
```