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Stock Annex for the ICES North Sea SMS configuration

Working Group	Working Group on Multispecies Assessment Methods (WGSAM)
Date	November 2017 (after the WGSAM 2017 meeting in October)
Predatory species	Assessed species: Cod, haddock, saithe, whiting, mackerel

Species with given input population size: North Sea horse mackerel, western horse mackerel, grey gurnard, starry ray, hake, fulmar, gannet, great black backed gull, guillemot, herring gull, kittiwake, puffin, razorbill, grey seal, harbour porpoise.

Prey species	Assessed species: Cod, haddock, herring, Norway pout, southern North Sea sandeel, northern North Sea sandeel, sprat, whiting,
Stock Assessor	Morten Vinther

Summary

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

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

2017 key run

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

All stock assessment models were updated with the most recent data and stock numbers were corrected where the stock area did not correspond to the key run area (the North Sea proper, Division 4). New estimates of quarterly mean weight-at-age in the stock produced for stocks where this information was not available from the stock assessments. These values were lower than previous estimates and this increased the range of age groups of cod consumed by marine mammals to also include significant impacts on cod of age 3. To improve the inclusion of mackerel in the model, this species was included as a fully modelled predator in the model, and the proportion of the mackerel stock, which occurs in the North Sea in each quarter, was reviewed, and new estimates produced. Consumption (ration) of the main fish predators, including mackerel and horse mackerel, was revised to reflect the most recent knowledge of evacuation rates leading to changes for mackerel and horse mackerel (lower consumption rates). Finally, the quarterly overlap of the species with sandeel was evaluated and adapted to better mirror the stomach contents observed. Diet data for the predatory fish were bias corrected to take into account that evacuation rate is a function of prey energy density, prey armament and ambient temperature. This correction gave in general lower diet proportion of the SMS prey fish and higher proportion of "other food" compared to the observed stomach contents which previously have been used directly as diet. Diet data for harbour porpoise were corrected for differences in residence time of otoliths from different species and size of prey and the resulting consumption showed a larger contribution from sandeel and herring while whiting was less important than previously estimated.

1 Model description

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

The following predator and prey stocks are available:

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

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

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

2 Input data

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

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

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

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

Additional data: Miscellaneous data.

2.1 Analytical assessment stocks

This group of stocks includes:

1) Cod;
2) Haddock;
3) Whiting;
4) Saithe;
5) Mackerel;
6) Herring;
7) Northern sandeel;
8) Southern sandeel;
9) Sprat;
10) Norway pout;
11) Plaice;
12) Sole.

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

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

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

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

Species	SMS		ICES Assessment				
	Species code	Max age	Stock area	First year	Age range (data)	time step	catch categories
Cod	COD	10+	North Sea, eastern English Channel, Skagerrak	1963	1–15	year	D+L
Whiting	WHG	8+	North Sea and eastern English Channel	1978	1–15	year	D+I+L
Haddock	HAD	10+	North Sea, West of Scotland, Skagerrak	1972	1–15	year	D+I+L
Saithe	POK	10+	North Sea, Rockall and West of Scotland, Skagerrak and Kattegat	1967	3–10+	year	D+L
Herring	HER	9+	North Sea, Skagerrak and Kattegat, eastern English Channel	1947	0–8+	year	C
Northern sandeel	NSA	4+	Mix of sandeel stocks	1986	0–4+	semester	C
Southern sandeel	SSA	4+	Mix of sandeel stocks	1983	0–4+	semester	C
Sprat	SPR	3+	North Sea	1974	0–3+	quarter	C
Norway pout	NOP	3	North Sea, Skagerrak, and Kattegat	1984	0–3+	quarter	C
Plaice	PLE	10	North Sea, Skagerrak	1957	1–10+	year	D+L
Sole	SOL	10	North Sea	1957	1–15+	year	D+L

2.1.1 Quarterly catch data

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

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

Table 2.1.2. Year range for available InterCatch data (August 2017).

SPECIES	INTERCATCH YEARS
Cod	2002–2016
Whiting	2011–2016
Haddock	2010–2016
Saithe	2002–2016
Mackerel	2015–2015
Plaice	2011–2016
Sole	2011–2015

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

STOCK	YEAR RANGE
Herring	2005–2016*
Northern sandeel	1982–2016*
Southern sandeel	1982–2016*
Sprat	1974–2016
Norway pout	1982–2016

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

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

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

2.1.2 Cod

2.1.2.1 Catch data

Annual catch data (catch-at-age in number and mean weight-at-age, for landings and discards and combined) are available from the ICES assessment working group for the

North Sea stocks (see ICES, WGNSSK 2017). For cod, annual scaling factors of observed catches, 1993–2005, are estimated by the ICES SAM assessments. The input catch numbers are raised by this factor before used in SMS.

2.1.2.2 Survey data

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

	NAME	YEARS	AGES	ALFA AND BETA	SOURCE
1	IBTS Q1, Gam	1983–2017	1–5	0–0.25	WGNSSK 2017
2	IBTS Q3, Gam	1992–2016	1–4	0.5–0.75	WGNSSK 2017

2.1.2.3 Biological data

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

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

In SMS it is assumed that the mean weight-at-age for age 2 and younger is constant over the years. Data from the old North Sea MSVPA (ICES CM 1997/Assess:16) are used for these younger ages. MSVPA data give weight by age and quarter, but the weights do not change between years. For age 3 and older, the ratio between weight per quarter (and age) as specified in MSVPA data is maintained, but raised to the annual mean weight used in single-species assessment. Raising is done from the simple mean of quarterly mean weights and the annual single-species mean weight in the particular year. The mean weight for quarter 1 will thereby be lower than the single-species stock weights, which lead to a smaller SSB (quarter 1) in SMS, compared to the single-species SSB. This was changed from previous practice in 2017 to ensure that a consistent method was used in all years. Figure 2.1.1 compares the two sets of mean weights.

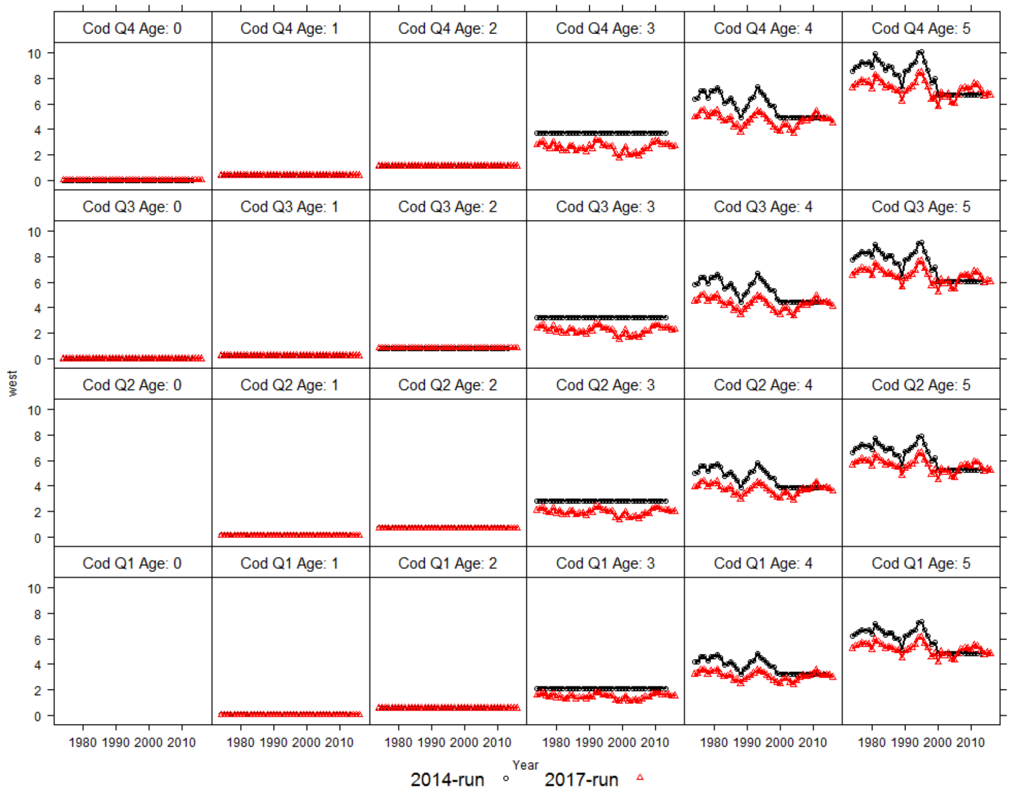


Figure 2.1.1. Mean weight-at-age in the sea of cod by quarter as used in the 2014 and 2017 key runs.

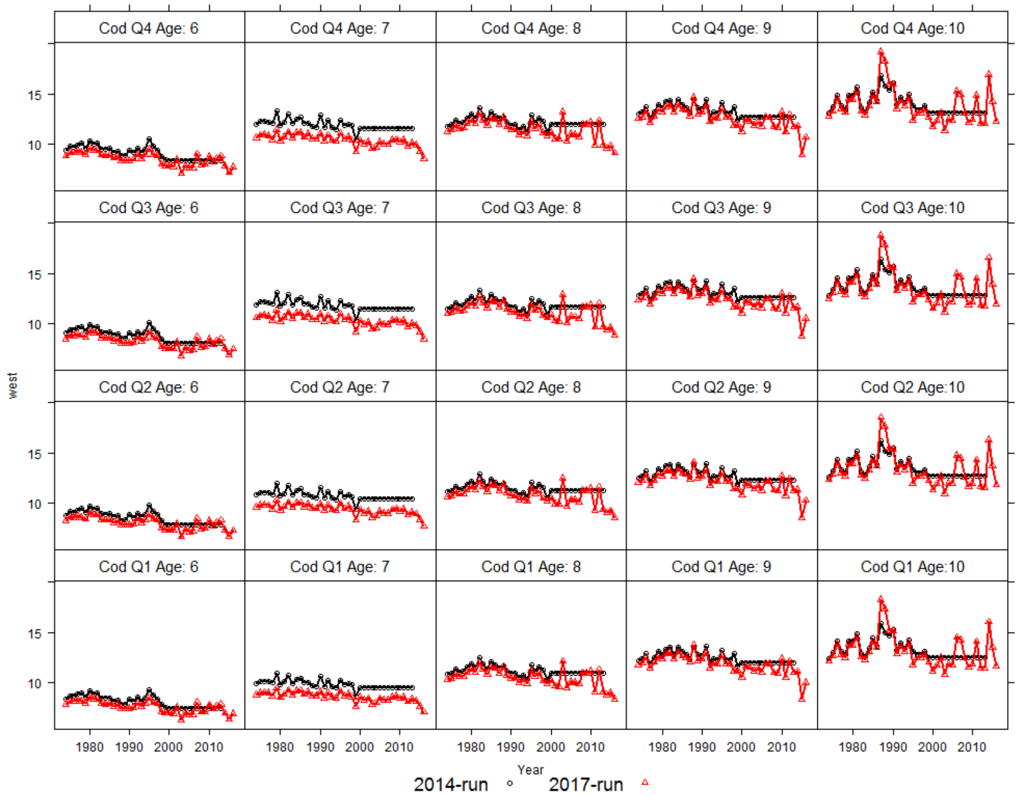


Figure 2.1.1. Continued. Mean weight-at-age in the sea of cod by quarter as used in the 2014 and 2017 key runs.

2.1.2.4 Stock distribution

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

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

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

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

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

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

Results for cod

The observed proportion of the stock within and outside the North Sea is shown for Quarter 1 (Figure 2.1.3) and quarter 3 (Figure 2.1.4) and Figure 2.1.5 show the observed proportion within the North Sea (excluding the English Channel data, as those exist only for the last ten years) and the fitted proportion assuming a smooth temporal change. There is a highly significant trend for age 1 and age 2 in quarter 1. In quarter 3, the trend for age 3 is statistical significant, but the temporal change in proportion is limited. Even though it is not statistical significant, the trend for age 1 and age 2 in quarter 3 follows the general trend for the same age groups in quarter 1 (**Figure 2.1.6**)

The proportion of cod stock within the Eastern Channel based on survey data cannot be determined for a longer time-series. Available data suggest a proportion below 5%. The commercial catch of cod is mainly determined by the individual TACs for three areas North Sea, Skagerrak and the English Channel (east and western combined), however catch data reported to ICES (WGNSSK 2017) show that 4% of the cod stock catch has been taken from the Eastern Channel for the years 2007–2016. This proportion, if it is representing the stock distribution, is small and therefore ignored for SMS purposes.

For Quarter 1, the fitted survey proportions for age 1 to 5+ are used to exclude cod in the Skagerrak/Kattegat from the SMS consumption model. For quarter 3, only data back to 1991 are available. The difference between the fitted proportions by quarter for age 1 and older is quite small (Figure 2.1.6), and therefore the Quarter 1 proportions are assumed to apply also to quarter 3. For age 0 in quarter 3, the observations are highly variable and it is therefore assumed that the proportion of age 0 in quarter 3 follows the proportion of age 1 in quarter 1. These methods result in the proportion of the stock within the North Sea presented in Table 2.1.4. The proportions are assumed to be the same for all quarters.

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

Year	Age				
	0&1	2	3	4	5+
1974	0.94	0.91	0.89	0.93	0.96
1975	0.93	0.91	0.89	0.93	0.96
1976	0.92	0.90	0.88	0.93	0.96
1977	0.91	0.90	0.88	0.93	0.95
1978	0.91	0.90	0.88	0.93	0.95
1979	0.90	0.89	0.88	0.93	0.95
1980	0.89	0.89	0.88	0.93	0.95
1981	0.88	0.89	0.88	0.93	0.95
1982	0.86	0.88	0.88	0.93	0.95
1983	0.85	0.88	0.88	0.93	0.95
1984	0.84	0.88	0.88	0.92	0.95
1985	0.82	0.87	0.88	0.92	0.95
1986	0.81	0.87	0.87	0.92	0.95
1987	0.79	0.86	0.87	0.92	0.95
1988	0.78	0.86	0.87	0.92	0.95
1989	0.76	0.85	0.87	0.92	0.95
1990	0.74	0.85	0.87	0.92	0.95
1991	0.73	0.85	0.87	0.92	0.95
1992	0.71	0.84	0.87	0.91	0.95
1993	0.69	0.84	0.87	0.91	0.95
1994	0.68	0.83	0.87	0.91	0.94
1995	0.66	0.83	0.86	0.91	0.94
1996	0.65	0.82	0.86	0.91	0.94
1997	0.63	0.82	0.86	0.91	0.94
1998	0.62	0.81	0.86	0.91	0.94
1999	0.61	0.80	0.86	0.90	0.94
2000	0.60	0.80	0.86	0.90	0.94
2001	0.59	0.79	0.86	0.90	0.94
2002	0.58	0.79	0.86	0.90	0.94
2003	0.57	0.78	0.85	0.90	0.94
2004	0.57	0.77	0.85	0.90	0.94
2005	0.56	0.77	0.85	0.90	0.94
2006	0.56	0.76	0.85	0.89	0.94
2007	0.55	0.76	0.85	0.89	0.94
2008	0.55	0.75	0.85	0.89	0.94
2009	0.55	0.74	0.85	0.89	0.93
2010	0.55	0.74	0.85	0.89	0.93
2011	0.55	0.73	0.85	0.89	0.93
2012	0.55	0.72	0.84	0.89	0.93
2013	0.55	0.71	0.84	0.88	0.93
2014	0.55	0.71	0.84	0.88	0.93
2015	0.55	0.70	0.84	0.88	0.93
2016	0.55	0.69	0.84	0.88	0.93

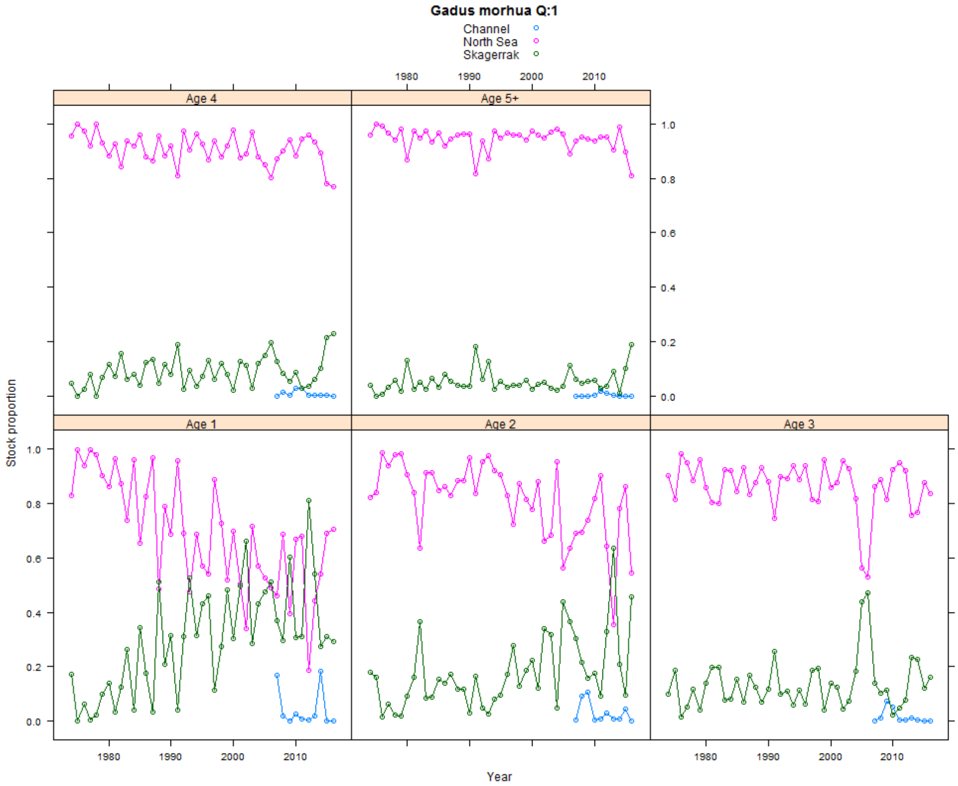


Figure 2.1.2. Stock distribution, Cod quarter 1. Please note that data for the English Channel were available since 2007.

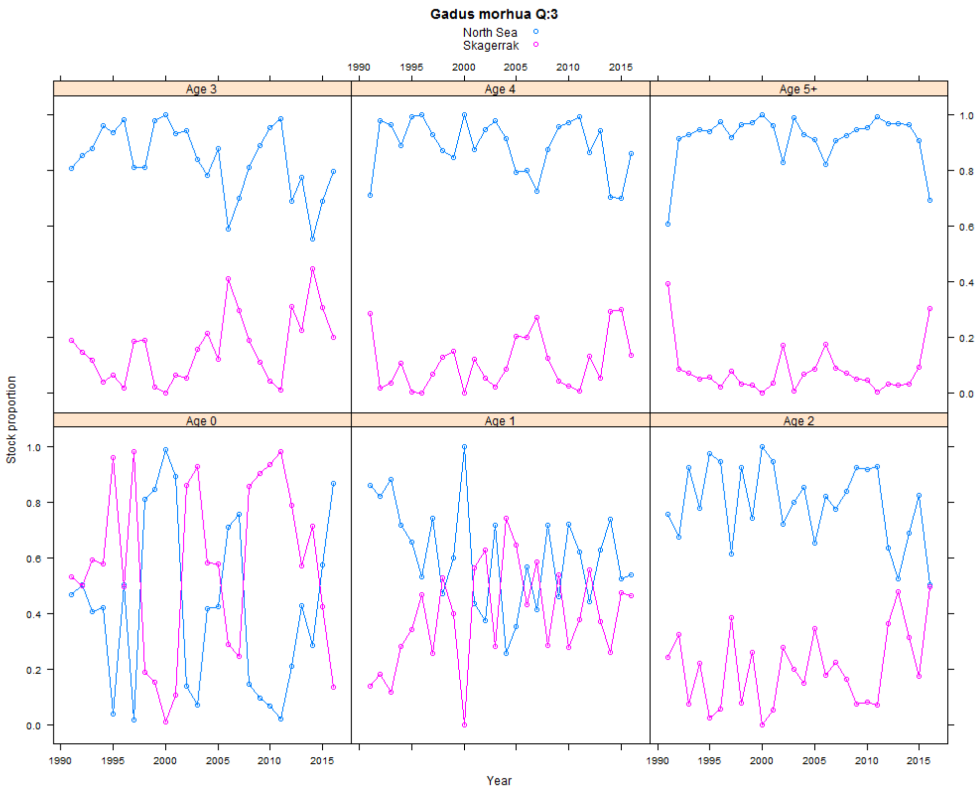


Figure 2.1.3. Stock distribution, Cod quarter 3.

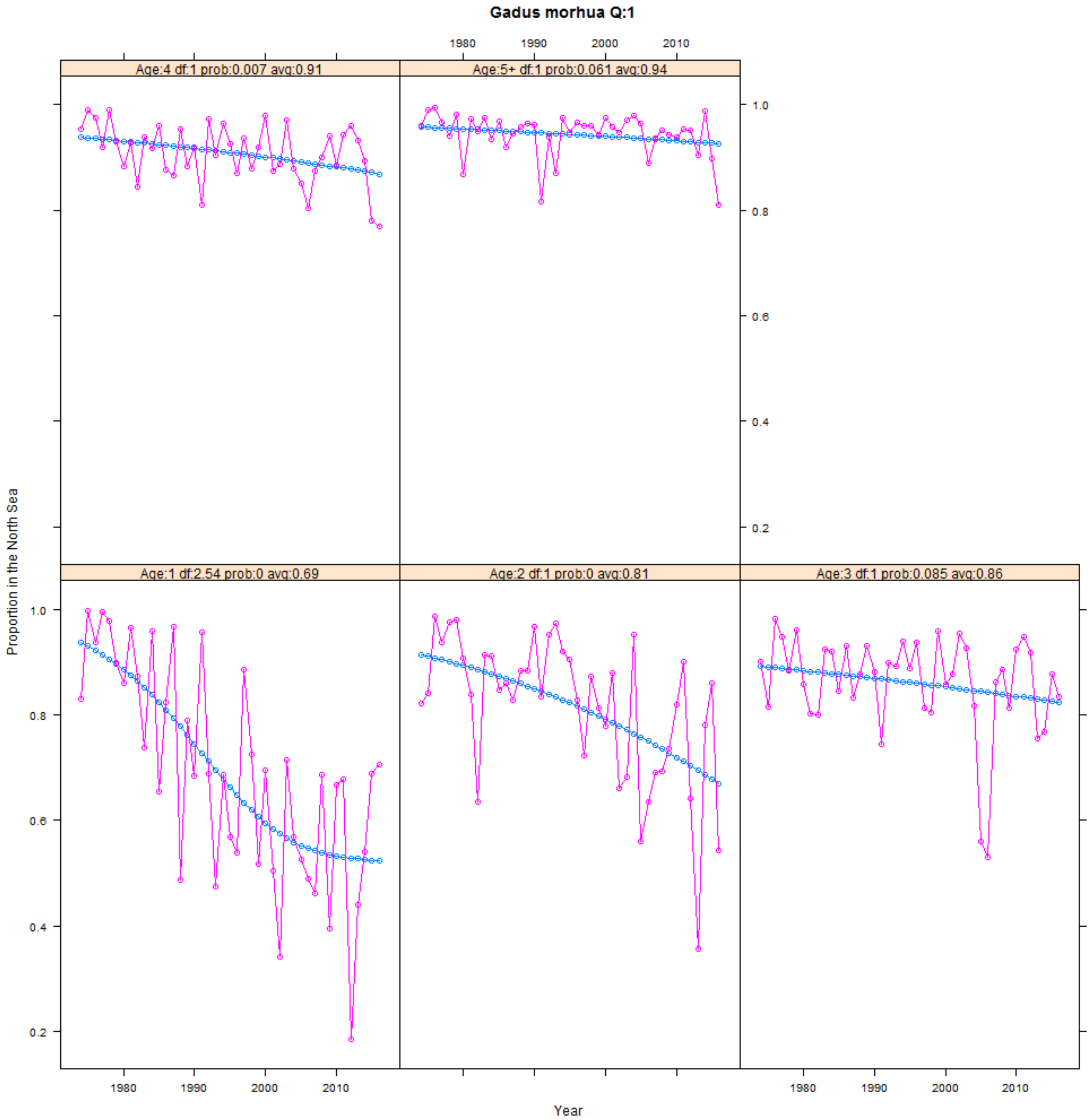


Figure 2.1.4. Observed and fitted proportion of the cod stock (North Sea & Skagerrak data) within the North Sea. For each age the degree of freedom for the fit, the significance of the fit and the average proportion is shown.

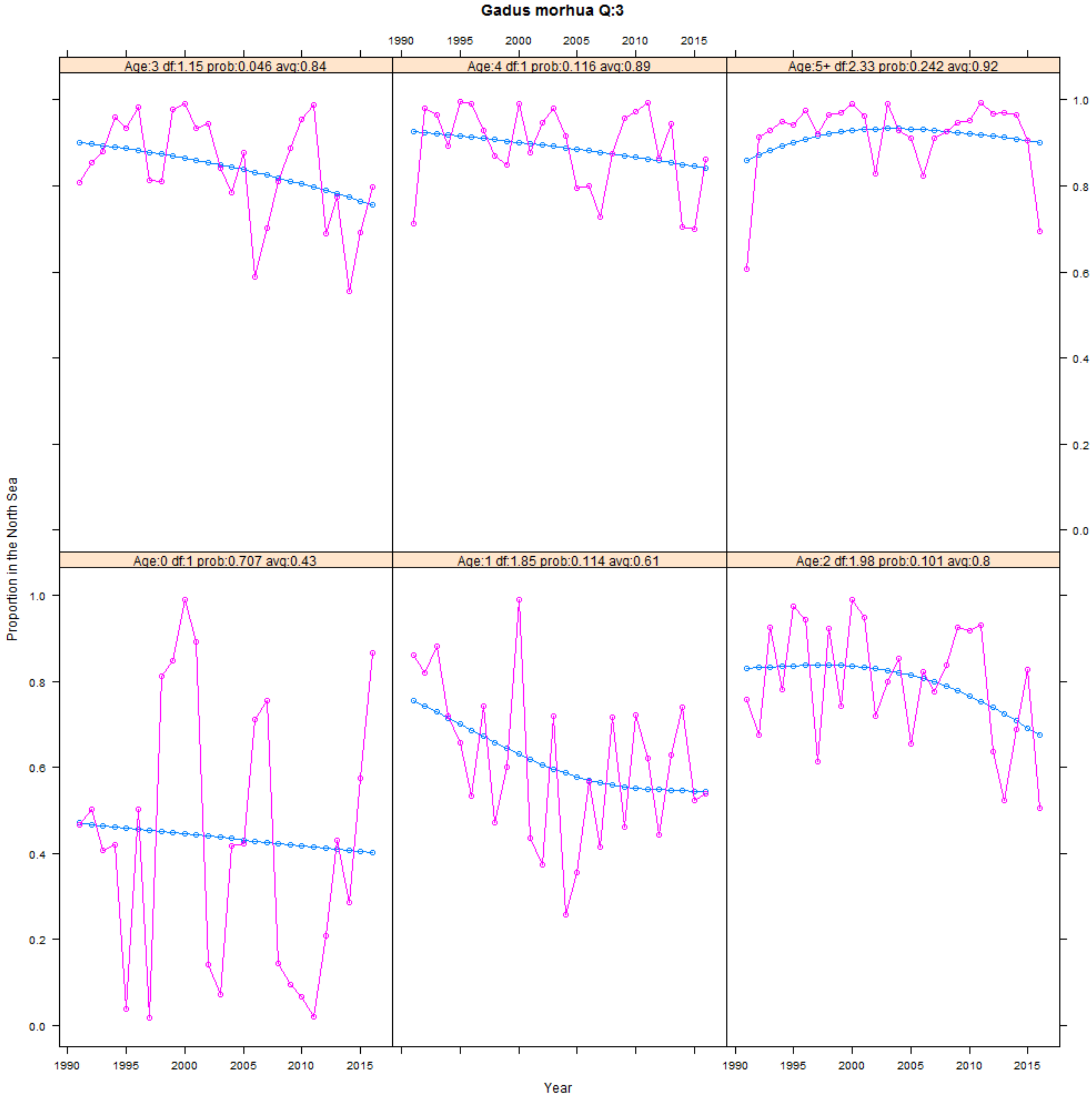


Figure 2.1.5. Observed and fitted proportion of the cod stock (North Sea & Skagerrak data) within the North Sea. For each age the degree of freedom for the fit, the significance of the fit and the average proportion is shown.

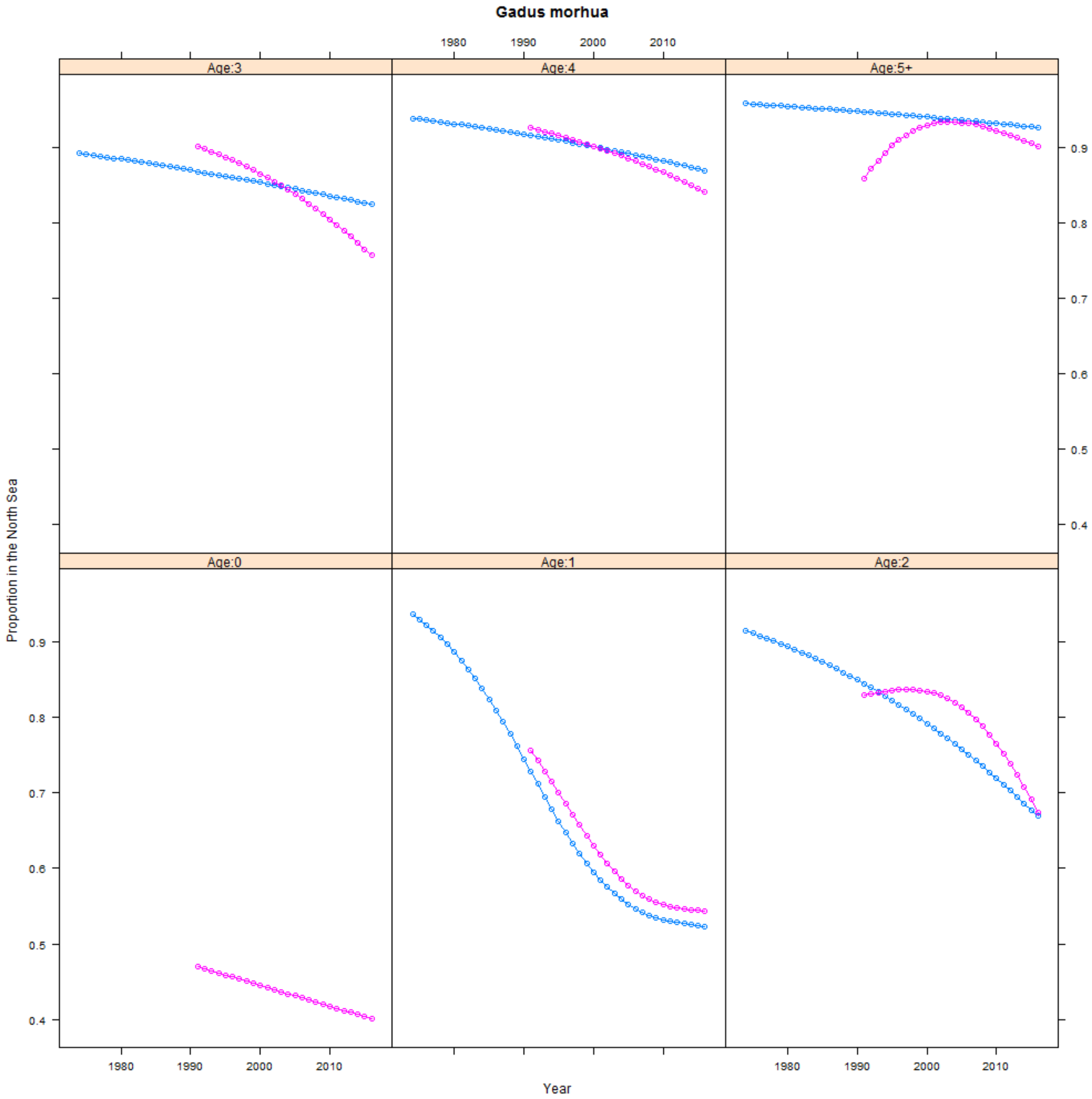


Figure 2.1.6. Fitted proportion of the cod stock (North Sea & Skagerrak data) within the North Sea for quarter 1 (1974–2016) and quarter 3 (1991–2016).

2.1.3 Whiting

2.1.3.1 Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2017) since 1978. Catch data 1974–1977 from MSVPA (ICES CM 1997/Assess:16) were not updated. It is assumed that the proportion landed for the period 1974–1977 is equal to the average proportion landed 1987–1992.

2.1.3.2 Survey data

Survey data are copied from the single-species assessment.

	Name	Years	Ages	Alfa and beta	Source
1	IBTS Q1	1978–2017	1–5	0–0.25	WGNSSK 2017
2	IBTS Q3	1991–2016	0–5	0.5–0.75	WGNSSK 2017

2.1.3.3 Biological data

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

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

2.1.3.4 Stock distribution

Survey data for the English Channel are only available for Quarter 1 since 2007 (Figure 2.1.7) but show that the proportion within the Channel is variable but low, and decreasing by age. Estimates of commercial catches within each area (WGNSSK 2017) show that the proportion of catches from the North Sea decreases from around 90% in 1995 to around 75% in 2015, but the trend is not statistically significant. Based on the short survey time-series and commercial catch statistics, it is assumed that 90% of the ICES (North Sea & eastern English Channel) whiting stock is situated within the North Sea. This is assumed for all years, quarter and ages in SMS.

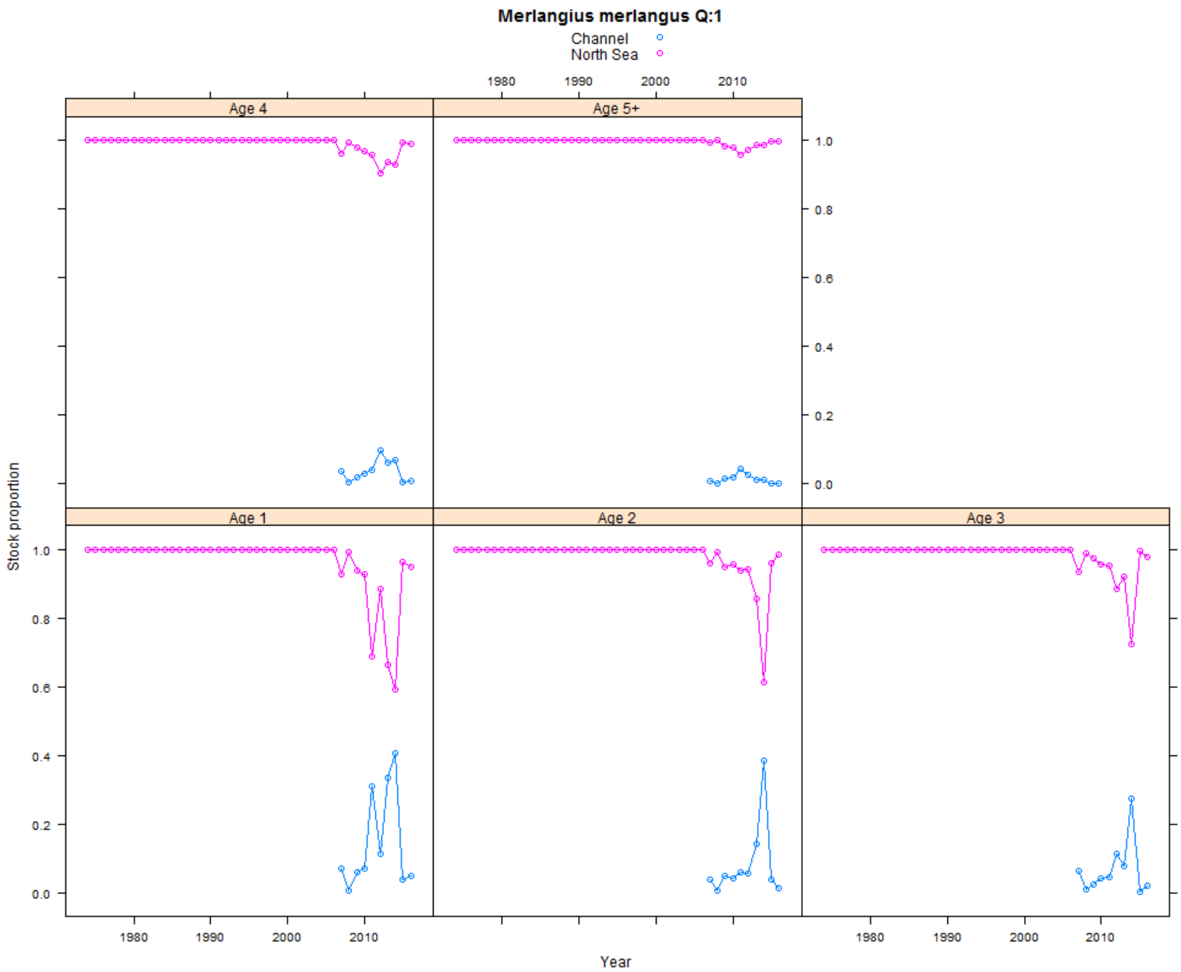


Figure 2.1.7. Stock distribution, Whiting quarter 1. Please note that data for the English Channel were available since 2007.

2.1.4 Haddock

2.1.4.1 Catch data

Annual catch-at-age data are available from the assessment (WGNSSK, 2017) since 1965, and were used in SMS.

2.1.4.2 Survey data

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

	Name	Years	Ages	alfa and beta	Source
1	IBTS Q1	1974–2017	1–5	0–0.25	WGNSSK 2017
2	IBTS Q3	1991–2016	0–5	0.5–0.75	WGNSSK 2017

2.1.4.3 Biological data

Proportion mature data are copied from the single-species input (WGNSSK 2017).

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

2.1.4.4 Stock distribution

Survey data for Area 6 are not analysed here. Catch data (WGNSSK 2017) show that 12% of the catches are taken "West of Scotland". For SMS, it is assumed that 88% of the stock is within the North Sea for all years, quarters and ages. For age 1 and older, a variable but small proportion is found in Skagerrak/Kattegat. This proportion is however ignored in SMS.

2.1.5 Saithe

2.1.5.1 Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2017) since 1967, and were used in SMS.

2.1.5.2 Survey data

Survey data (fleet 1) are copied from the single-species assessment. With this tuning fleet only, the SMS assessment gives a rather different assessment result compared with the ICES single-species assessment. The ICES assessment make use of a combined (commercial cpue) biomass index, which cannot be used in SMS. To get a more consistent SMS assessment the stock numbers estimated by ICES the single-species assessment were used a survey data (fleet 2). Saithe in SMS acts as predator only and the stock dynamic of other SMS species does not affect saithe, which makes it possible to use this approach to get a more consistent (compared to the ICES assessment) result. A CV of 0.3 (rlnorm(x,meanlog=0,sdlog=0.3)) was assumed for this artificial index for all ages and years.

	NAME	YEARS	AGES	ALFA AND BETA	SOURCE
1	IBTS Q3	1992–2016	3–8	0.62–0.62	WGNSSK 2017
2	Stock assessment N	1997–2016	3–9	0–0	WGNSSK 2017

2.1.5.3 Biological data

Proportion mature and M are copied from the single-species input (WGNSSK 2017).

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

2.1.5.4 Stock distribution

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

2.1.6 Mackerel

The ICES assessment of this Northeast Atlantic mackerel is conducted with data from 1980 for age 0–12+ (WGWIDE 2017). Given the wide stock area of the mackerel, mackerel found in the North Sea constitutes a low and variable proportion of the full stock. The inclusion of mackerel as one assessed stock rather than two external predators (western and North Sea mackerel) is new in 2017 key run and follows the decisions made at the mackerel benchmarks, that mackerel in Northeast Atlantic is one stock (with three spawning components: western, southern, and North Sea).

2.1.6.1 Catch data

Annual catch numbers and mean weight-at-age in the catch are copied from the ICES assessment (WGWIDE 2017).

For the period before 1980 (1974–1979) estimates of total catch weight are provided by WGWIDE (Table 8.3.1.1, WGWIDE 2016)

YEAR	TOTAL CATCH WEIGHT (TONNES)
1974	607 586
1975	784 014
1976	828 235
1977	620 247
1978	736 726
1979	843 155

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

2.1.6.2 Survey data

The mackerel assessment uses an SSB index (from egg sampling) and tagging data in addition to two cpue indices. Due to uncertain catch-at-age data in the first half of the time-series and other issues, the assessment is highly sensitive to the survey data used in the assessment. To get an assessment result, which is close to the single-species output, estimated stock numbers from the single-species assessment are used as cpue indices in the SMS model. A CV of 0.3 (rlnorm(x,meanlog=0,sdlog=0.3)) was assumed for this artificial index for all ages and years. (**After looking at the SMS estimates of uncertainties on mean F and SSB, which is very low, the CV for the artificial should have been set higher!**).

	Name	Years	Ages	alfa and beta	Source
1	Swept area	2010–2017	3–10	0.58–0.75	WGWIDE 2017
2	Stock assessment N	1980–2016	0–9	0–0	WGWIDE 2017

2.1.6.3 Biological data

Constant quarterly mean weight-at-age data in the sea are copied from the MSVPA input data (ICES CM 1997/Assess:16) and as basis for all years. The plus group (10+) mean weight is calculated as a simple mean of ages 10–12 in the MSVPA data. Where annual catch mean weight is available (1980–2016) from the assessment (WGWIDE 2017), these were used to scale the year independent MSVPA data in a similar way as for cod (Figure 2.1.8).

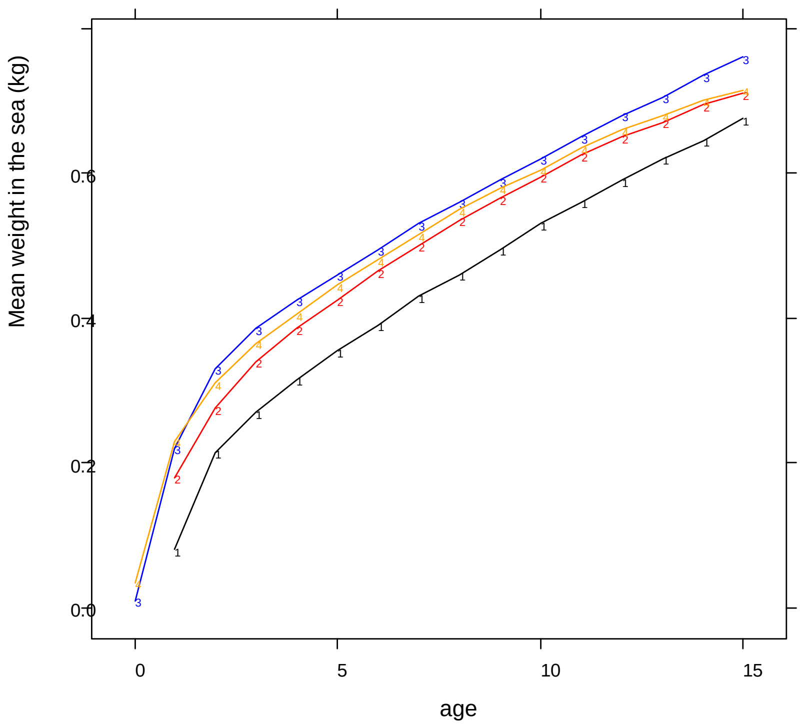


Figure 2.1.8. Mean weight-at-age in the sea by quarter as used in MSVPA (ICES CM 1997/Assess:16) and used as basis for SMS input.

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

2.1.6.4 Stock distribution

Historically, information on the proportion of the mackerel stocks (at that time the western and North Sea stocks) which was inside the North Sea was provided by the relevant assessment working groups (see Table 2.1.5 and Table 2.1.6 below). However, data have not been updated by the assessment working groups since 1997. The proportion of the stock by spawning component (North Sea, Western and Southern) can be estimated from the egg survey data and an additional assumption on the relative size of the North Sea component, which not has been surveyed at the same time (Table 2.1.7).

WGSAM (2017) reviewed the historical information from catch distribution together with the reported proportions. In later years, the proportion of the catches of the Northeast Atlantic mackerel taken in the North Sea has decreased and the majority of the catches seem to have been taken in areas north of the North Sea (Figure 2.1.8).

Table 2.1.5. Percentage of the west mackerel stock to be present in the North Sea. Data from: Table 7.4 ICES CM 1990/Assess:19 for juveniles, age group 1 and 2; Table 2 from ICES CM 1989/H:20 for 3+ for the period 1974–1985; and Table 12.3 from ICES CM 1997/Assess:3.

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

Table 2.1.6. Percentage of the North Sea mackerel component to be present in the North Sea. Data from: Figure app 1–2 ICES CM 1985/Assess:7 for period 1974–1984; Figure 9.1 and 9.2 ICES CM 1986/Assess:12 for period 1985; and Table 8.3 ICES CM 1987/Assess:11 for 1986–1997.

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

Table 2.1.7. WGSAM 2017 estimates of relative contribution from the North Sea, Western and southern components estimated from the egg-survey data (1989, 1992, 1995, 1998, 2001, 2004, 2007, 2010, 2013 and 2016) and assumptions about the relative contributions from the North Sea component. Data for the period before 1989 are copied from Table 2.4.4.2 ICES CM 2005/ACFM:08.

YEAR	NORTH SEA	WESTERN	SOUTHERN
1974	0.221	0.651	0.128
1975	0.205	0.668	0.128
1976	0.201	0.671	0.128
1977	0.177	0.695	0.128
1978	0.136	0.736	0.128
1979	0.125	0.747	0.128
1980	0.116	0.756	0.128
1981	0.081	0.786	0.133
1982	0.080	0.792	0.128
1983	0.074	0.798	0.128
1984	0.037	0.835	0.128
1985	0.037	0.835	0.128
1986	0.037	0.835	0.128
1987	0.037	0.835	0.128
1988	0.037	0.835	0.128
1989	0.037	0.835	0.128
1990	0.037	0.835	0.128
1991	0.037	0.835	0.128
1992	0.037	0.835	0.128
1993	0.037	0.835	0.128
1994	0.037	0.835	0.128
1995	0.029	0.842	0.129
1996	0.029	0.842	0.129
1997	0.029	0.842	0.129
1998	0.029	0.764	0.207
1999	0.029	0.764	0.207
2000	0.029	0.764	0.207
2001	0.029	0.847	0.124
2002	0.029	0.847	0.124
2003	0.029	0.847	0.124

Year	North Sea	Western	Southern
2004	0.029	0.872	0.099
2005	0.029	0.872	0.099
2006	0.029	0.872	0.099
2007	0.029	0.858	0.113
2008	0.029	0.858	0.113
2009	0.029	0.858	0.113
2010	0.029	0.777	0.194
2011	0.029	0.777	0.194
2012	0.029	0.777	0.194
2013	0.029	0.748	0.223
2014	0.029	0.748	0.223
2015	0.029	0.748	0.223
2016	0.038	0.856	0.105

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

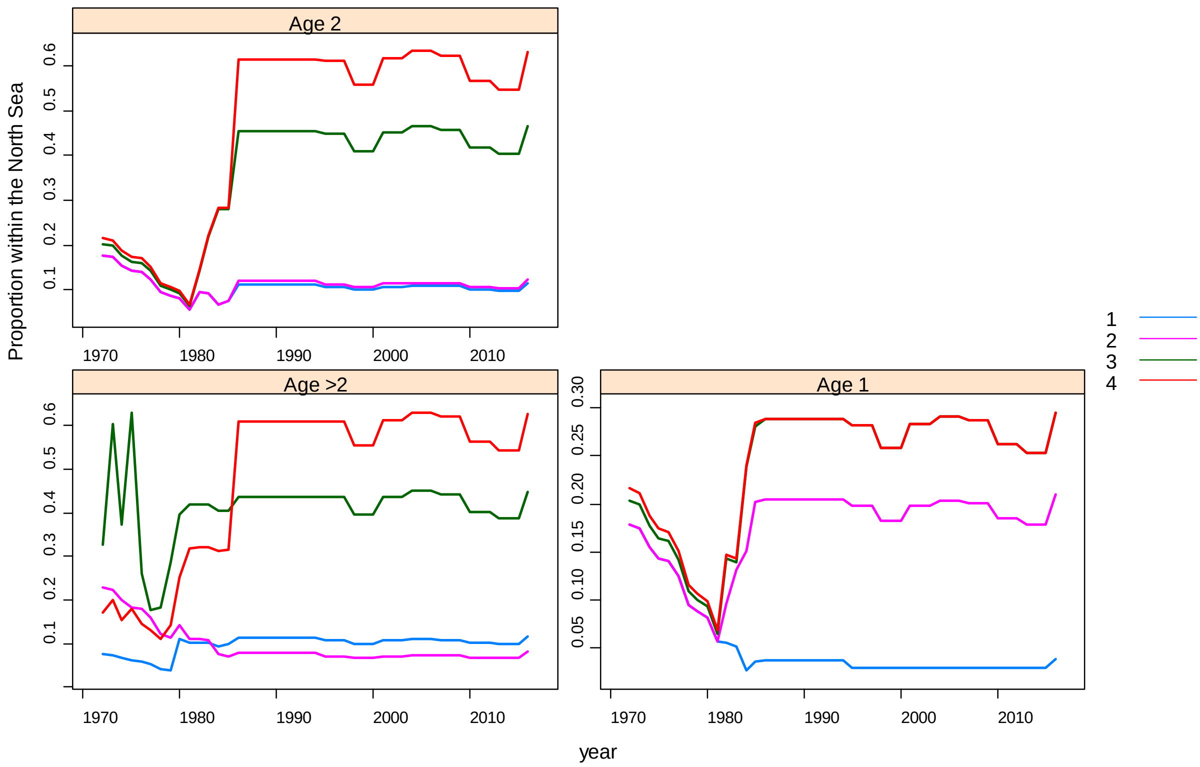


Figure 2.1.9. Preliminary estimate of proportion of the Northeast Atlantic Mackerel stock by age group and quarter (1–4) within the North Sea calculated from stock distributions presented in Table 2.1.4–Table 2.1.6.

This proportion presented in the figure assumes however that that the proportions of the various components have been constant since 1997, which is not the case. The spatial catch distribution show a northerly and easterly expansion of the catch areas (WGWIDE 2017) which is also reflected in the catch proportion from the North Sea (Figure 2.1.10). The contribution of North Sea catches has roughly been halved in the period 2000–2016. Using this trend as an indicator of the proportion of the total stock within the North Sea since 2000, the proportion estimated (Figure 2.1.9) becomes smaller for the period since 2000 (Figure 2.1.11)

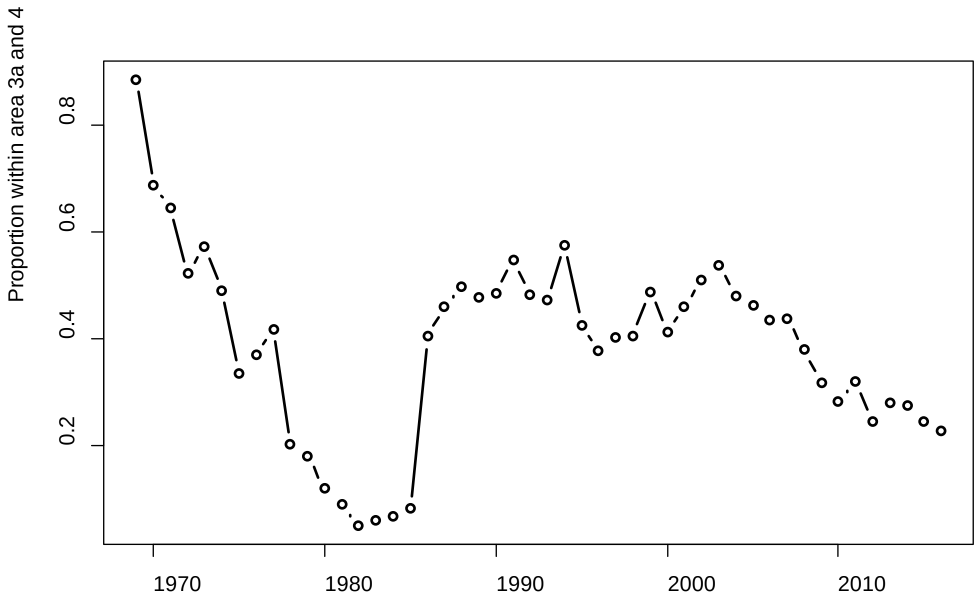


Figure 2.1.10. Proportion of mackerel catches in the North Sea. Data from WGWIDE 2017.

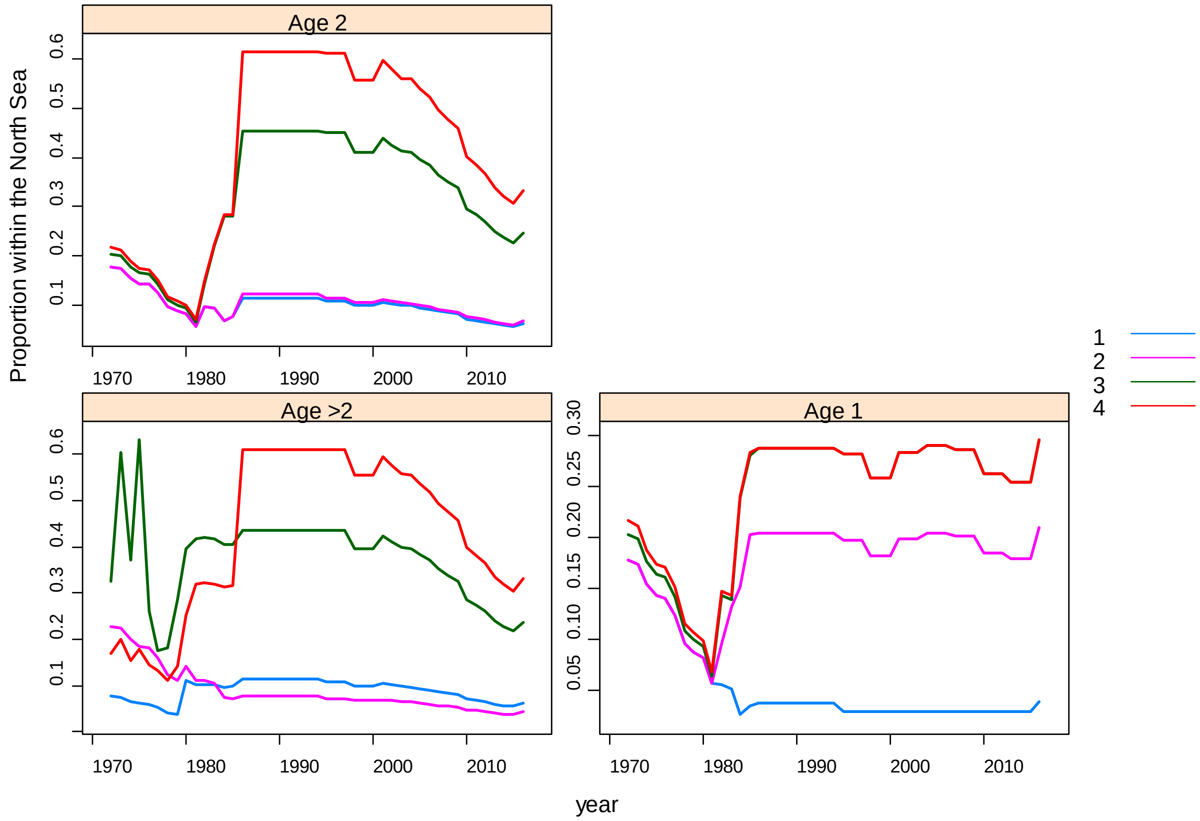


Figure 2.1.11. Estimate of proportion of the Northeast Atlantic Mackerel stock by age group and quarter (1–4) within the North Sea calculated from stock distributions presented in Table 4–Table 6 and the trend in proportions caught within the North Sea since 2000 (Figure 2.1.10).

WGSAM, 2107 concluded to use the proportion of the stock within the North Sea as presented by Figure 2.1.11. It was recognised that this estimate is based on a series of assumptions, however the estimate seems the best available.

2.1.7 Herring

In 2017, the age range was changed from 0–7+ to 0–9+ to follow the single-species configuration.

2.1.7.1 Catch data

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

2.1.7.2 Survey data

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

	Name	Years	Ages	alfa and beta	Source
1	HERAS	1989–2016	1–7 (9)	0.54–0.56	HAWG 2017
2	IBTS Q1	1984–2017	1–5	0.08–0.17	HAWG 2017
3	MIK	1992–2017	0–0	0–0	HAWG 2017

2.1.8 Sandeel

The ICES sandeel assessments (2017) for the North Sea area include six individually assessed stocks. Ideally, SMS should follow the same division to provide relevant natural mortalities for sandeel in the different stocks. However, using all stocks separately would give problems with limited catch-at-age and diet data availability for some of the stocks. Instead, sandeel in SMS are divided using the previously used Northern and Southern sandeel areas (Figure 2.1.12).

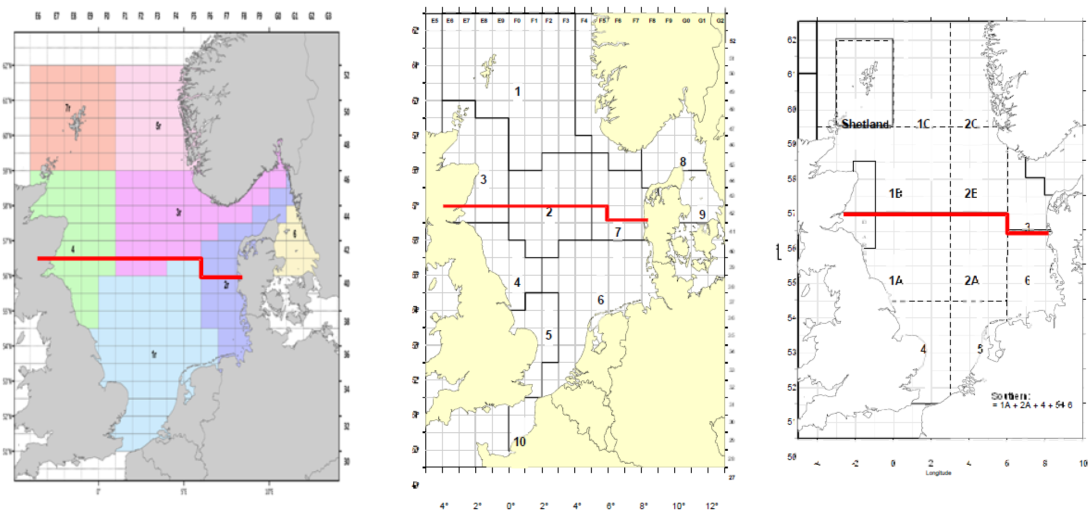


Figure 2.1.12. Sandeel stock and data compilation areas: The left plot shows the stock areas as applied by ICES in 2017. The red line shows the division between the previously used "Northern" and "Southern" sandeel areas. The plot in the middle show the ICES roundish areas, which are used as strata in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

Catch data since 1983 are available by ICES rectangle (HAWG 2017, Anna Rindorf pers. comm.) and were aggregated into the two stocks. Data 1974–1982 are available from the 1999 ICES assessment, where assessment data are aggregated into a Northern and Southern stock. In the estimation of sandeel as prey, it is assumed that sandeel found in stomachs from fish sampled in roundfish area 1, 2, 3 and 7 are northern sandeel and southern sandeel are from roundfish area 4, 5 and 6. This split aligns fairly well with the two stock areas (Figure 2.1.12).

Estimating mean weight in the stock is a special concern for sandeel, as weight of one year olds and older fish in the catch in the months from July onwards is likely to be biased towards lower mean weights due to differences in the onset of burying of large and small sandeel (Pedersen *et al.*, 1999; Rindorf *et al.*, 2016). Moreover, weight in the catch of 0-group is highly variable as the 0-group fishery only occurs in part of the time-series and the exact timing of it varies. The stock mean weight of sandeel age 1+

in quarter 2 and 3 were estimated from the long-term (1982–2016) mean catch weight in the first and second half year, respectively. Quarter 1 mean weight was estimated as 79% of that in quarter 2 to reflect the recorded difference in condition between the two quarters (Rindorf *et al.*, 2016). Quarter 4 mean weight was estimated as 89% of that in quarter 3, accounting for half the condition loss between quarter 3 and quarter 1 (Rindorf *et al.*, 2016). The mean weight of 0-groups in quarter 4 was estimated as the long-term average weight of 0-group in the catch the second half year. The 0-group in quarter 3 is assumed to be the half of the mean weight in quarter 4. This procedure was used as the mean weight of 0-groups in catches in quarter 3 was substantially higher than that observed in the stomachs, indicating that the fisheries selection may exclude smaller individuals.

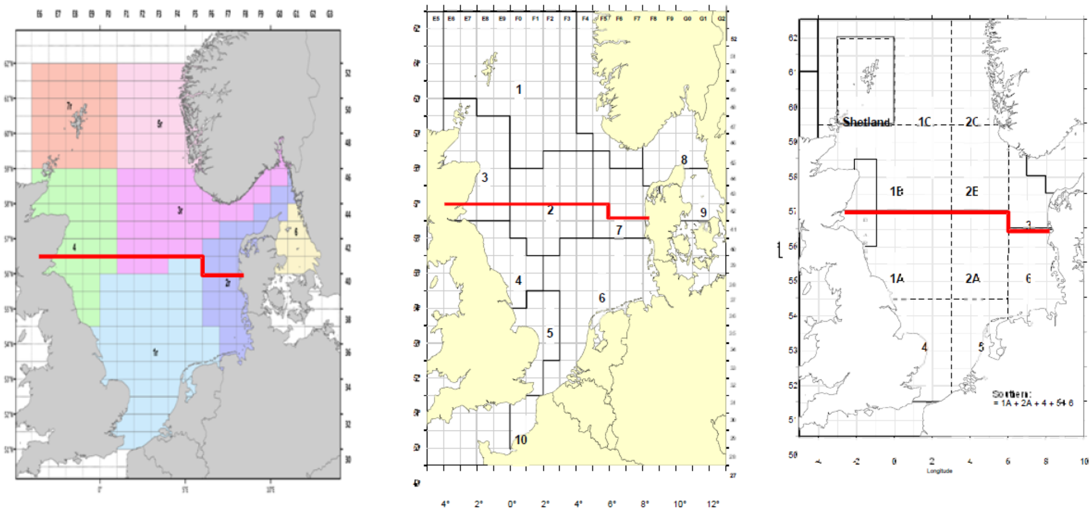


Figure 2.1.13. Northern and southern sandeel areas in relation to (2017) assessment areas (left), roundfish areas (middle) and historical industrial sampling areas (right).

2.1.8.1 Survey data

Survey data are derived from data used in the single-species assessments in areas 1–3 using the same model but deriving sandeel surveys indices for the northern and southern North Sea. In addition to this, three commercial time-series were used to parallel the use of effort tuning of F in the sandeel assessment. These commercial cpue time-series replace the effort time-series used by the ICES single-species effort. A separate time-series was used for the north and south sandeel, but fleet 4 was only used for northern sandeel, as there has not historically been a substantial fishery in the southern North Sea in the second half year.

	Name	Years	Ages	alfa and beta	Source
1	Dredge survey	2004–2016	0–1	0.75–1	HAWG 2017
2	Commercial 1 half year	1982–1989	1–3	0.25–0.5	HAWG 2017
3	Commercial 1 half year	1999–2016	1–3	0.25–0.5	HAWG 2017
4	Commercial 2 half year	1976–2004	1–3	0.25–0.5	Sandeel assessment 2005

2.1.9 Sprat

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

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

If singles-species quarter is Q3 or Q4 then {

multispecies Quarter=single-species Q – 2

multispecies Year=single-species Year + 1

multispecies Age=single-species Age + 1

}

2.1.9.1 Catch data

Quarterly catch data are copied from the single-species assessment (HAWG 2017), using the above mentioned data transformation of year, quarter and ages.

2.1.9.2 Survey data

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

	Name	Years	Ages	alfa and beta	Source
1	IBTS Q1	1975–2017	1–3+	0.0–0.0	HAWG 2017
2	HERAS	2001–2016	1–3+	0.25–0.50	HAWG 2017
3	IBTS Q3	1991–2016	1–3+	0.5–0.75	HAWG 2017

2.1.9.3 Biological data

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

2.1.10 Norway pout

The single-species sprat assessment (WGNSSK 2017) uses quarterly data for the period since 1974. To accommodate mortality due to spawning stress, the oldest age group (age 3) in the SMS model run is not a plus group (i.e. all Norway pout die when turning four years old).

2.1.10.1 Catch data

Quarterly catch data are copied from the single-species assessment.

2.1.10.2 Survey data

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

	Name	Years	Ages	alfa and beta	Source
1	EGFS	1982–1991	0–3	0.5–0.75	WGNSSK 2017
2	EGFS	1992–2017	0–2	0.5–0.75	WGNSSK 2017
3	IBTS Q1	1974–2017	1–3	0.0–0.25	WGNSSK 2017

2.1.10.3 Biological data

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

2.1.11 Plaice

2.1.11.1 Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2017) since 1957, and were used in SMS.

2.1.11.2 Survey data

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

	Name	Years	Ages	alfa and beta	Source
1	BTS-Isis-early	1985–1995	1–8	0.66–0.75	WGNSSK 2017
2	BTS-Combined	1996–2016	1–9	0.66–0.75	WGNSSK 2017
3	SNS1	1974–1999	1–6	0.66–0.75	WGNSSK 2017
4	SNS2	2000–2016	1–6	0.66–0.75	WGNSSK 2017
5	IBTS Q3	1997–2016	1–9	0.63–0.63	WGNSSK 2017
6	IBTS Q1	2007–2016	1–7	0.10–0.10	WGNSSK 2017

2.1.11.3 Biological data

Proportion mature data are copied from the single-species input (WGNSSK 2017).

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

2.1.12 Sole

2.1.12.1 Catch data

Annual catch-at-age data are available from the assessment (WGNSSK 2017) since 1957, and were used in SMS.

2.1.12.2 Survey data

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

	Name	Years	Ages	alfa and beta	Source
1	BTS-Isis	1985–2016	1–9	0.66–0.75	WGNSSK 2017
2	SNS	1974–2016	1–6	0.66–0.75	WGNSSK 2017

2.1.12.3 Biological data

Proportion mature data are copied from the single-species input (WGNSSK 2017).

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

2.2 External predators

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

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

Time-series of their abundance are given in Figure 2.2.1.

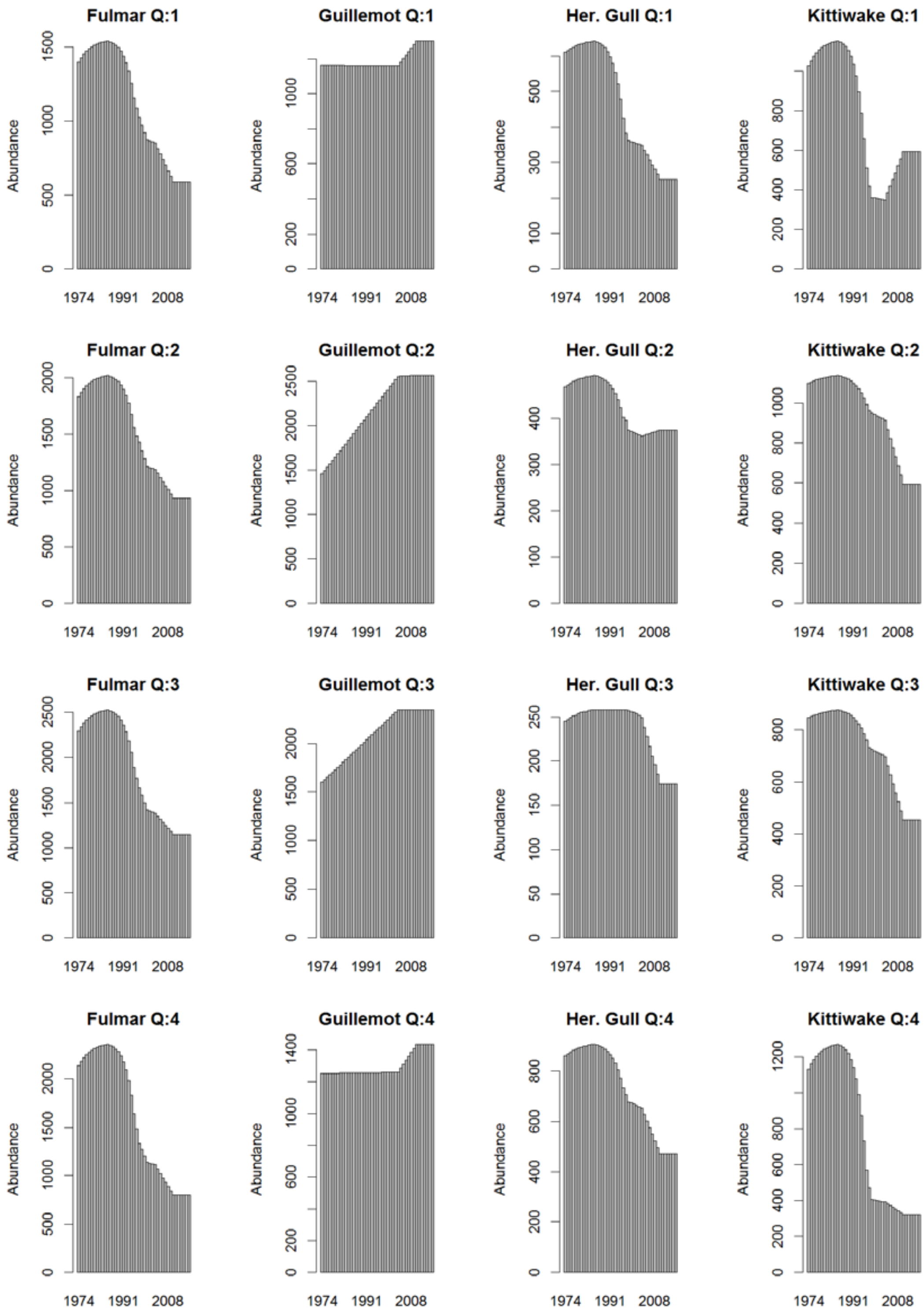


Figure 2.2.1. Estimates as used by SMS of the abundance of "external predators" present in the North Sea. (Abundance of birds and marine mammals are given as numbers (1000), and as population biomass (1000 t) for fish species.

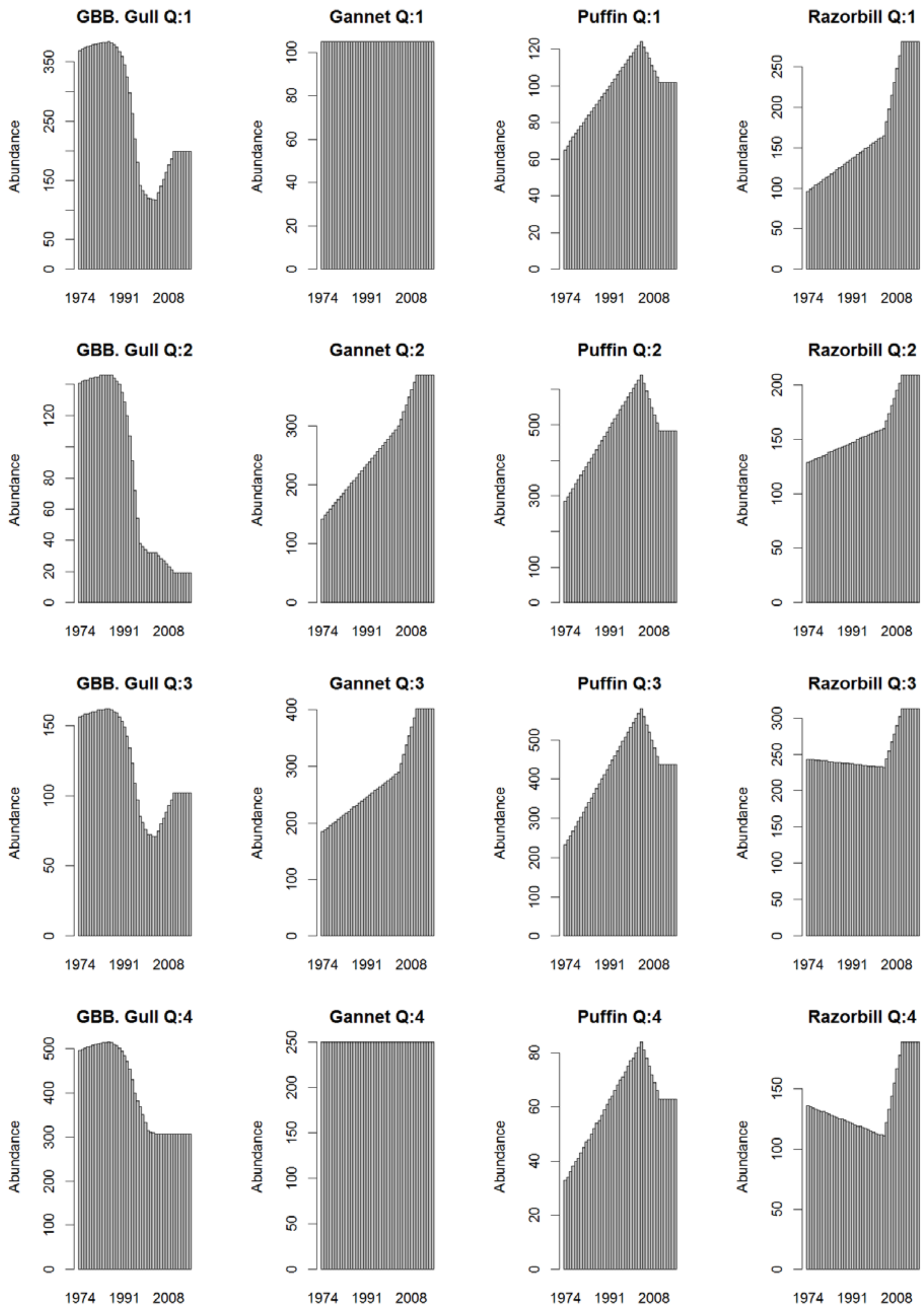


Figure 2.2.1. (Continued.) Estimates as used by SMS of the abundance of "external predators" present in the North Sea. (Abundance of birds and marine mammals are given as numbers (1000), and as population biomass (1000 t) for fish species.

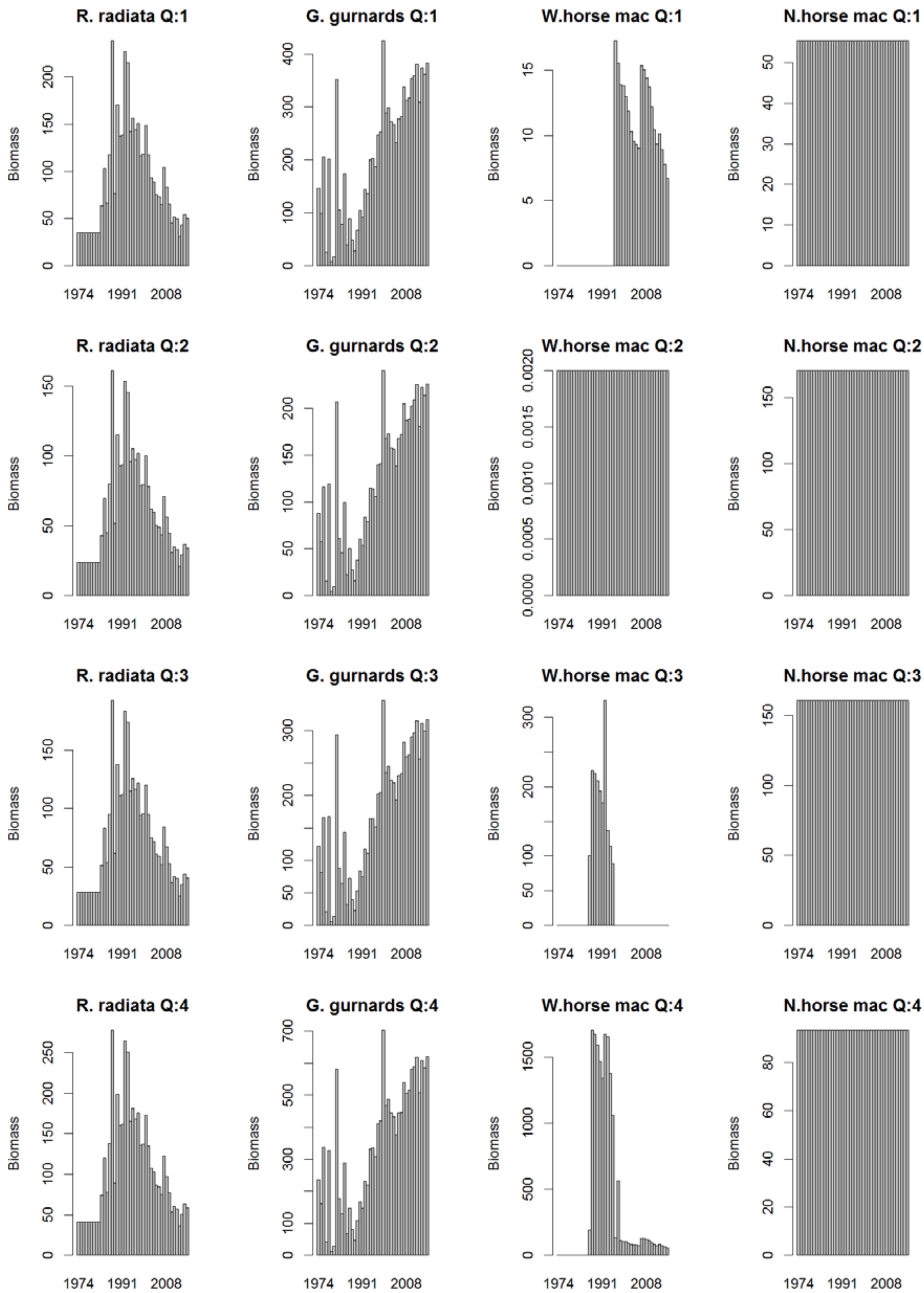


Figure 2.2.1. (Continued.) Estimates as used by SMS of the abundance of "external predators" present in the North Sea. (Abundance of birds and marine mammals are given as numbers (1000), and as population biomass (1000 t) for fish species.

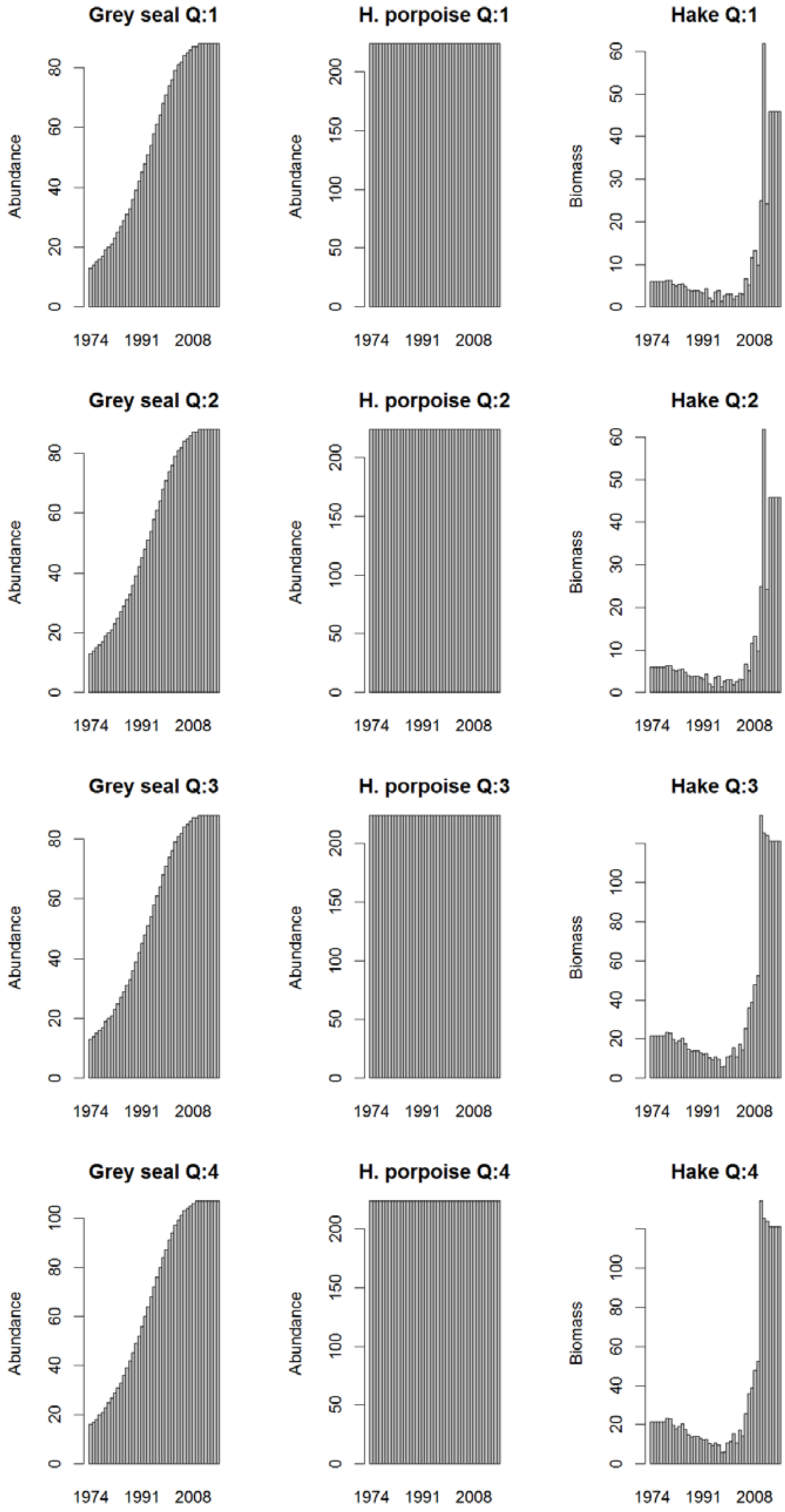


Figure 2.2.1. (Continued.) Estimates as used by SMS of the abundance of "external predators" present in the North Sea. (Abundance of birds and marine mammals are given as numbers (1000), and as population biomass (1000 t) for fish species.

2.2.1 Birds

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

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

2.2.2 Starry rays and grey gurnards

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

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

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

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

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

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

2.2.3 Horse mackerel

ICES considers horse mackerel (*Trachurus trachurus*) in the Northeast Atlantic to be separated into three stocks. The southern stock is found in the Atlantic waters of the Iberian Peninsula, the North Sea stock in the eastern English Channel and North Sea area, and the western stock on the northeast Nontinental Shelf of Europe, stretching from the Bay of Biscay in the south to Norway in the north. ICES makes an analytical (absolute) assessment of the western stock, while the North Sea stock is assessed from survey indices and an absolute stock biomass is not estimated.

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

The western horse mackerel stock assessment reports have previously reported the proportion of western horse mackerel entering the North Sea in each quarter (Table 2.2.1).

Table 2.2.1. Percentage of the western horse mackerel stock entering the North Sea by quarter. Sources: Table 12.3 in ICES CM 2000/ACFM:5 for 1998; Table 12.2 in ICES CM 1999/ACFM:6 for 1997; Table 12.x in ICES CM 1998/Assess:6 for 1996; Table 12.5 in ICES CM 1997/Assess:3 for 1995; Table 12.5 in ICES CM 1996/Asess:7 for 1994; Table 18.5 in ICES CM 1995/Assess:2 for 1993; Table 16.5 in ICES CM 1993/Assess:19 for 1992; Table 13.5 in ICES CM 1992/assess:17 for 1991).

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

This information has not been available since 1998, but the proportion of western stock horse mackerel caught in the North Sea (all horse mackerel caught in Subarea 4a) is still reported (Figure 2.2.2). Based on these data, it was decided to assume that 10% of the western horse mackerel stock was present in the North Sea in quarter 4. In quarters 2 and 3, no western horse mackerel were present in the North Sea. In quarter 1, horse mackerel are not feeding and hence it is not relevant to know their abundance in the North Sea.

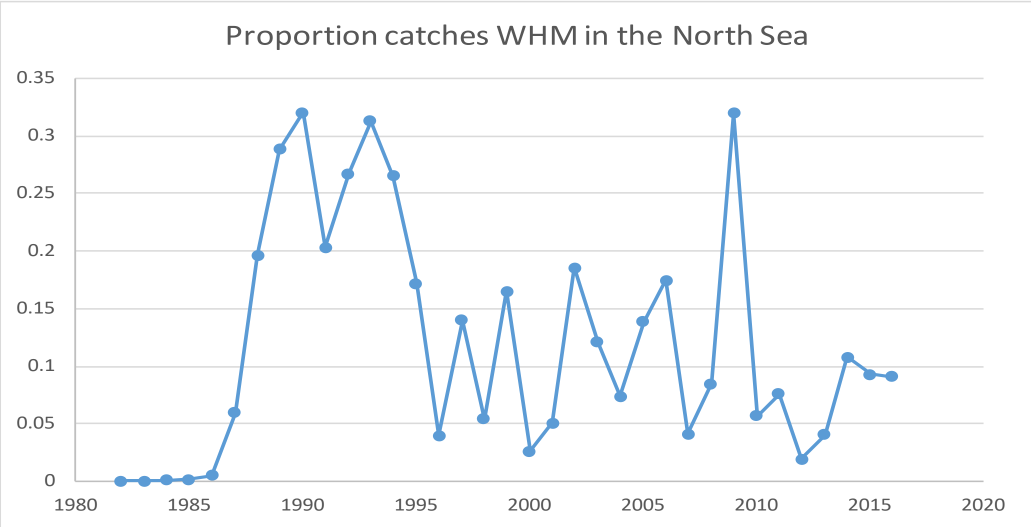


Figure 2.2.1. Proportion of western horse mackerel catches in the North Sea (data from WGWIDE 2017)

2.2.4 Hake

Hake was included in the 2014 key run as an "external predator". Since 2000, considerably more hake has been caught in the IBTS survey and information from the fishing industry points to increasing hake abundance in the North Sea. In 2014, there was only an assessment for northern hake. This assessment included all sea areas from the northern Bay of Biscay up to the Norwegian Sea. Three different surveys (IBTS, SWC-IBTS, EVOHE; all from the second half of the year) were available for the years 1997–2013 from DATRAS to calculate the proportion of the total Northern hake abundance and biomass resident in the North Sea in the second half of the year. When using cpue per rectangle * number of rectangles in the survey area as index, it was estimated that 10–15% of the hake stock in numbers were in the North Sea (WGSAM 2014) while the biomass percentage is much larger as the hake found in the North Sea in the second half of the year are larger than average. For the years before 1997, it is assumed that the proportion of the northern hake stock in the North Sea stays constant at the average from the years 1997–2001, i.e. before cpue started to increase in the IBTS.

The overall biomass and abundance present in the North Sea were divided into size categories by using the size distribution observed in Q3 IBTS hake catches. Based on the diet composition it was decided to have three size classes of hake in the model (<250 mm; 250–<600 mm; >=600 mm). From the biomass and abundances obtained for the second half of the year, the abundances in the first half of the year were calculated by multiplying the abundances in the second half of the year with the ratio of cpue per size class observed between the 1st quarter and 3rd quarter IBTS. While small and medium sized hake are present in both quarters, large hake are caught to a much lesser extent in the first quarter.

For the 2017 key run, the development in IBTS Q1 and Q3 was inspected and as there was no trend in the catch rates since 2013, the stock numbers in 2014–1016 were assumed equal to stock numbers in 2013.

2.2.5 Grey seal

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

2.2.6 Harbour porpoise

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

2.3 Diet and ration data

2.3.1 Seabirds

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

2.3.2 Mammals

2.3.2.1 Data on grey seals

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

An aggregated estimate of grey seal diet composition based on the 1985 and 2002 collections was calculated for each of these years weighted according to the number of seals using each haul-out site. The sizes of fish consumed by the seals were inferred from otolith measurements which are corrected for the effects of digestion. The resulting size distribution for sandeels in grey seal diet suggests that a considerable proportion of the diet in 1985 consisted of sandeels greater than 20cm in length. Because sandeels caught by the fishery are generally smaller than this, there is some uncertainty whether these sandeels are *Ammodytes marinus*, and it has been suggested that they may instead be a different sandeel species such as *Hyperoplus lanceolatus*. To avoid this problem, sandeel larger than 20 cm were assumed to be 'other food'. Net consumption was assumed to be 5.5 kg per seal per day.

2.3.2.2 Data on harbour porpoise

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

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

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

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

The corrected size distributions of the six fish species were scaled to the fraction of the food (mass) requirement of the harbour porpoise population in the North sea constituted by these species (i.e. 87.0%, 82.2% and 69.8% of total food requirement for the decades 1985–1994, 1995–2004, and 2005–2014, respectively). Weight–length relationships from the 3rd quarter were used, which is also a change from previously. The correction compared to previously resulted in a 50% increase in herring, 267% increase in sandeel, a 54% decrease for whiting and smaller changes for other species (Figure 2.3.1).

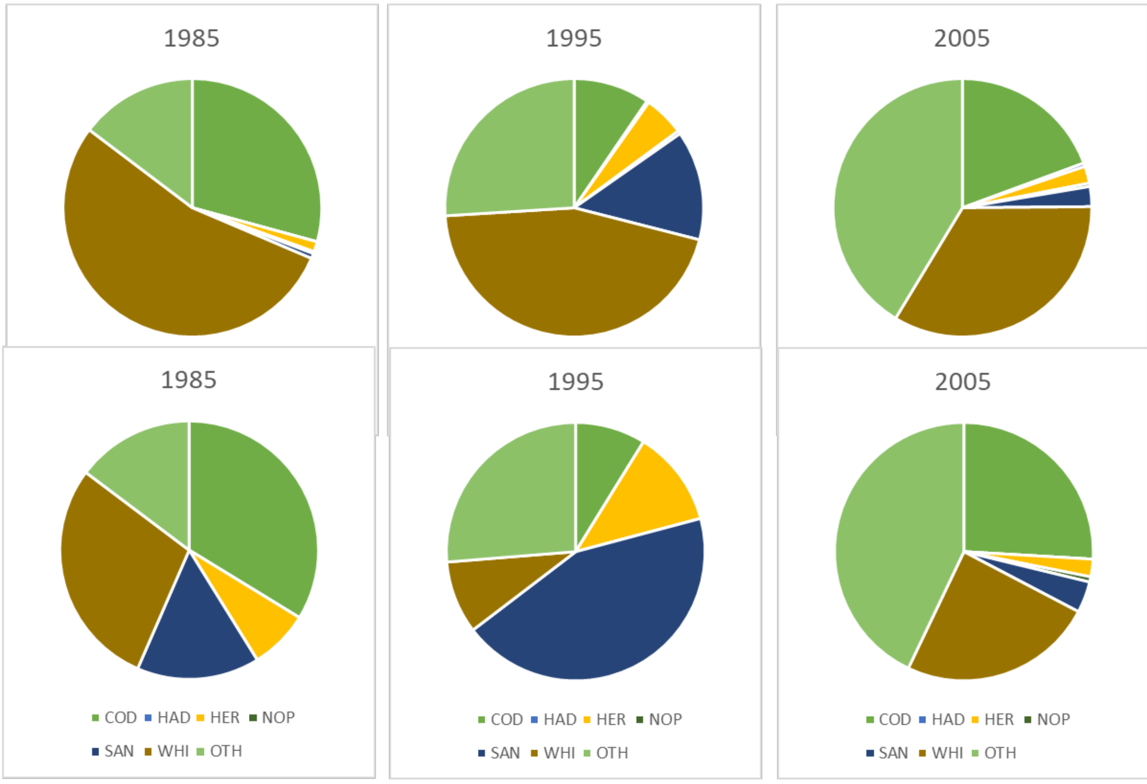


Figure 2.3.1. Harbour porpoise stomach content recorded (top) and consumption rates after correcting for differences in residence times (bottom).

2.3.3 Fish stomach data

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

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

2.3.3.1 Compilation of stomach contents data

Stomach contents data are given by year, quarter, predator, predator length/age, prey and prey length/age. The compilation of the individual stomach samples from a trawl haul into average diet of the North Sea follows the technique given by ICES 1996 and is briefly described below. Most stomachs have been pooled within a haul for each of the predator length groups considered.

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

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

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

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

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

2.3.4 Estimation of food ration from stomach contents data

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

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

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

M= armament of individual prey (group) i b=proportion of prey (group) i

T= temperature (OC)

L= length (cm) of the predator

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

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

S = average stomach contents in grams

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

Table 2.3.2. Parameter values of the generic cylinder model of gastric evacuation.

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

The estimated rations by individual strata (year, quarter, predator and predator size class used in sampling) are combined into one equation for ration from mean weight (ration=a*W^b) where a and b dependent on quarter (Table 2.3.3).

Table 2.3.3. Parameters for estimating quarterly ration per individual from its mean weight (ration= a*W^b).

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

Calculated consumption rates expressed as daily ration per kg body weight (Figure 2.3.2) generally decreased with size of the predator with the exception of mackerel, saithe and horse mackerel, where consumption increased with predator size. All three species feed mostly on zooplankton at small ages, and the estimates may be a result of underestimation of zooplankton consumption. This should have a limited effect on fish consumption (the amount eaten will be smaller but the relative contribution of fish will be higher).

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

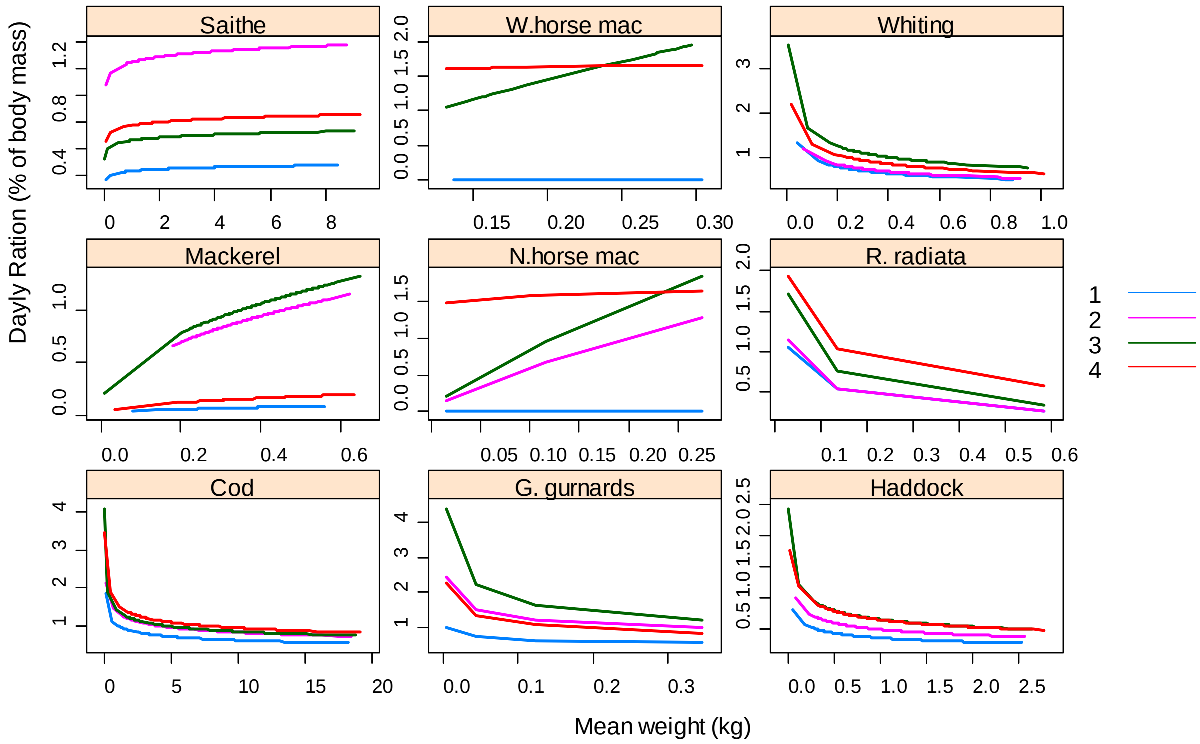


Figure 2.3.2. Daily consumption rates as used in SMS calculated from the method of Andersen. Colours show quarter of the year.

2.3.5 Estimation of diet from stomach contents

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

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

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

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

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

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

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

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

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

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

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

2.3.6 New stomach data

New data were collected in 2013 on mackerel diet composition. Unfortunately, the length of the prey items was not recorded, and therefore, the data cannot be used without assigning the prey types to specific length groups. This estimation could not be performed at WGSAM in 2017, but should be the focus of work in preparation for the next key run.

2.3.6.1 References

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

Andersen N.G., Beyer J.E. 2005a. Mechanistic modelling of gastric evacuation applying the square root model to describe surface-dependent evacuation in predatory gadoids. J Fish Biol 67:1392–1412.

Andersen N.G., Beyer J.E. 2005b. Gastric evacuation of mixed stomach contents in predatory gadoids – an expanded application of the square root model to estimate food rations. Journal of Fish Biology 67:1413–1433.

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

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

2.4 Other input data

In addition to the data mentioned above SMS uses data on predator–prey overlap, length–weight relations, residual natural mortality (M1) and age–length keys (ALK)

2.4.1 Predator–prey overlap

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

2.4.2 Length–weight relations

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

Table 2.4.1. Length (mm) weight (kg) relation parameters: Weight=a*length^b.

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

2.4.2.1 References

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

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

2.4.3 Age to length conversion keys

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

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

An example of the age–length conversion keys is shown in the table below.

Table 2.4.2. Example of age–length conversion key: Whiting. The table shows the percentage of a given size class for a given age and quarter.

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

2.4.4 Residual natural mortality (M1)

M1 (residual natural mortality) by quarter is set to 0.05 for the species cod, whiting, haddock, saithe, the two sandeel stocks, Norway pout, sprat and 0.0375 for mackerel, and 0.025 for herring, plaice and sole. M1 for non-prey species is the annual natural mortality (M) used in the single-species assessment divided on 4 quarters.

3 Model configuration

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

Appendix 4 presents the SMS configuration (option files) used for the 2017 key run.

3.1 Fishing mortality

SMS uses a separable F model while some of the ICES single-species models use a more flexible model for F (e.g. SAM using random walk F, or XSA where F are estimated directly from catch observation). Further, some models use types of abundances indices (e.g. SSB or tagging data) and estimate process noise, which have not been implemented in SMS. The SMS single-species assessment will therefore not be able to replicate the ICES single-species output, but the results should be quite close.

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

3.1.1 Cod

The 2017 SMS model run for cod in single-species mode mirrors the ICES assessment in the development of F (Appendix 5, Figure A5.1). SSB is somewhat lower due to the use of quarter 1 mean weight in the stock in SMS whereas the ICES assessments use annual average weight-at-age when estimating SSB. SMS uses the ICES mean weights as an annual mean weight, but uses a fixed quarterly growth increment factor, which means that mean weight in quarter 1, as used in the calculation of SSB, becomes smaller in SMS than in the ICES assessment. Recruitment in SMS is always at age zero in quarter 3, while the ICES assessment uses age 1 at the beginning of the year. This difference in recruitment timing makes it difficult to compare the two recruitment estimates.

3.1.2 Whiting

The whiting assessment has undergone an inter-benchmark between the 2015 and 2017 multispecies key run. While the 2017 SMS run mirrors the development in F from the ICES assessment directly (Appendix 5, Figure A5.2), the SSB level is lower in the SMS assessment than in the ICES assessment, part of which is explained by the difference in mean weight-at-age (quarterly vs annual).

3.1.3 Haddock

The 2017 SMS assessment of haddock followed the trend of F and SSB from the ICES assessment quite well, but F is larger and SSB is lower in the SMS run (Appendix 5, Figure A5.3).

3.1.4 Saithe

F and SSB are quite similar between the two runs (Appendix 5, Figure A5.4), but recruitment seems different due to recruitment at age 0 in SMS and at age 3 in ICES assessment. The 2017 SMS model run for saithe estimated a higher recruitment in later years. The high similarity between the two assessment was only possible because of the stock numbers of ages 3–9 from the ICES assessment were introduced as survey tuning series into the 2017 SMS model run for 1997–2016, assuming a CV of 0.3 for this "survey" time-series. As this species is only a predator in the model, this means that the natural moralities induced by saithe are consistent with the stock size as estimated in the latest ICES assessment, however uncertainties of SMS output in general might be biased.

3.1.5 Mackerel

In general, the SMS assessment is similar to the ICES assessment for recruitment and from 1990 onwards for F and SSB (Appendix 5, Figure A5.5). It does however not fully mirror the development in SSB in the ICES assessment for the period from 1980 to 1990. For this period, the ICES model is down-weighting the observed catches but this feature was not implemented in the SMS version. If the ICES assessment is more correct, this may lead to an underestimation of natural mortality of sprat and sandeel in the period from 1980 to 1990 as the abundance of large mackerel may be underestimated.

3.1.6 Herring

The 2017 SMS assessment of herring follows the ICES assessment reasonably well, even though the development of F is smoother in the ICES assessment which models F as a random walk process (Appendix 5, Figure A5.6). Difference in spawning time in the two models will give differences in estimated SSB, but does not fully explain the difference in SSB from the two models.

3.1.7 Norway pout

There has been a benchmark in 2016, and the 2015 SMS run is based on different data and therefore not strictly comparable. The ICES assessment estimates SSB on November 1st, whereas the SMS uses SSB by January 1st, and since natural mortality is larger than growth in the period between the two, the ICES values are substantially lower than the SMS ones. The 2017 SMS run shows similar developments in F and recruitment as the ICES assessment (Appendix 5, Figure A5.7).

3.1.8 Sandeel

The sandeel are assessed in sub-stocks that are not identical to those in the multispecies SMS implementation. Therefore, the results were compared to the 2015 key run with the changes made in the 2016 sandeel benchmark. This included the division of effort (here cpue) series into five periods (–1988, 1989–1998, 1999–2004, 2005–2009, 2010–) that was also implemented in the 2017 SMS run. Both sandeel stocks showed similar dynamics in the two runs (figure not shown).

3.1.9 Sprat

The 2017 SMS output is not directly comparable with the ICES assessments for SSB as SSB in SMS was estimated on January 1st whereas the ICES assessment uses the estimate by July 1st. Further, the age-range for F-bar is different (age 1.5–age 2.5 in the ICES assessment). Recruitment is directly comparable as date is the same and here the two assessments show the same temporal pattern (Appendix 5, Figure A5.8).

3.1.10 Plaice and sole

Plaice and sole are not a predators or preys in SMS, so the final SMS assessment is equal to the single-species SMS presented (Appendix 5, Figure A5.8 and A5.9). The stock dynamics are estimated quite similarly from the two models, but SMS has a more modest increase in plaice SSB in recent years compared to the ICES assessment.

3.2 Configuring predation mortality options

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

WGSAM 2011 considered that size selection should either be for all predators or none, or at least consistent within groups such as fish and mammals. Given that the model likelihood was only slightly improved by introducing size selection, that fitting parameters close to their bounds may give unwanted results inside the model (for technical reasons) and that the fits of the diets themselves were not improved for all species, it was decided to use uniform selection for all predator species, as done since the 2007 key run. This practice was continued in the 2017 key run, such that model options for predation mortality have been kept constant since the 2014 key run, except for harbour porpoise.

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

4 Other issues

The SMS model, and input and input can be found at Github https://github.com/ices-eg/wg_WGSAM .

The Github include several directories:

- NortSeaKeyRun_2014: The SMS North Sea key run made at the 2014 WGSAM, including data for the period 1974–2013. The version here has been corrected in 2015 for an input error.
- NortSeaKeyRun_2017: The SMS North Sea key run made at the 2017 WGSAM, including data for the period 1974–2016.
- input_output: Detailed presentation of input and output file for the 2017 key run
- SMS_ADMB: AD Model Builder source code for the SMS North Sea program
- SMS_R_prog: R scripts for preparing, running and presenting results from a SMS run

5 Results of the 2017 North Sea SMS key run

Substantial changes of input data to the new key run and ICES benchmarks for some of the stocks since the 2014 key run have produced stock summaries (recruitment, mean F and SSB) from the 2017 key run that is somewhat different from the summaries from the 2014 key run. However, the new estimated predation mortalities (M2) are consistent with the M2 values from the previous key run. The robustness of the estimate of predation mortality corresponds well to the conclusion made by the long row of ICES working groups using the SMS model or previous model versions like 4M and MSVPA, that the estimate of M2 is robust to e.g. changes in consumption rates and the amount of "other food" in the diet, level of M1 or amount of other predators.

Key run summary sheet

AREA	NORTH SEA
Model name	SMS
Type of model	Age–length structured statistical estimation model
Run year	2017
Predatory species	Assessed species: Cod, haddock, saithe, whiting, mackerel Species with given input population size: North Sea horse mackerel, western horse mackerel, grey gurnard, starry ray, hake, fulmar, gannet, great black backed gull, guillemot, herring gull, kittiwake, puffin, razorbill, grey seal, harbour porpoise
Prey species	Cod, haddock, herring, Norway pout, southern North Sea sandeel, northern North Sea sandeel, sprat, whiting,
Time range	1974–2016.
Time step	Quarterly
Area structure	North Sea
Stomach data	Fish species: 1981, 1985, 1986, 1987, 1991, 2005, 2013 Grey seals: 1985, 2002 Harbour porpoise: Decadal 1985, 1995, 2005
Purpose of key run	Making historic data on natural mortality available and multispecies dynamic
Model changes since last key run	All time-series updated. Mackerel included as a modelled stock. Proportion of the stock within the North Sea given as input and used for estimating M2. Daily food ration of changed for the main fish species. Bias correction of diet composition of harbour porpoise and the main predatory fish.
Output available at	Sharepoint/data/North_Sea_key_run and https://github.com/ices-eg/wg_WGSAM
Further details in	Report of the Working Group on Multispecies Assessment Methods 2017

5.1 Results of the 2017 key run

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

Detailed input- and output data on ASCII and HTML files, and presented on graphs can be downloaded from WGSAM SharePoint/data/North_Sea_key_run or from https://github.com/ices-eg/wg_WGSAM .

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

Input

Configuration

Option files for SMS configuration

c.obs

- plots of observed catch numbers-at-age from the 2014- and 2017 key runs

OtherPredators

- plots of stock size of external predators from the 2014- and 2017 key runs

West

- plots of mean weight-at-age in the sea from the 2014- and 2017 key runs

PropMat

- plots of proportion mature-at-age in the sea from the 2014- and 2017 key runs

Ration

- plots of consumption (food ration) at age from the 2014- and 2017 key runs

StomachContents

- plots of relative stomach contents

Output

Diagnostics

Diagnostic overview file

Residual plots (catch and survey)

- Stomachs
- Plots of observed and predicted stomach contents

StockSummary

- Stock summaries as plots and tables
- ASCII files with all input and output variables by year, quarter, species and age

Uncertainties

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

NaturalMortalities

Tables with M2 and M=M1+M2 values

PartialM2

Plots of M2 by year (and quarter) for each age group of prey species, showing the partial M2 from each predator

WhoEatsWhom

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

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

Comparisons

Plots of stock summaries from the 2014- and 2017 key runs

Plots of M2-at-age from the 2014- and 2017 key runs

ICEScomparison

Comparison of ICES single-species assessment and SMS in single-species mode

Retrospective

Plots of stock summaries, retrospective analysis 2013 to 2016

Plots of M2 at age, retrospective analysis 2013 to 2016

Text **in bold** shows directory names.

The key-run including executable and source file for SMS can be found in the directory **SMS-key-run-2017**

5.1.1 Model diagnostics

The population dynamics of all species except 'external predators' were estimated within the model. The key-run converged and the uncertainties of parameters and key output variables were obtained from the inverse Hessian matrix. Key diagnostics (Table 5.1.1) show a reasonable fit for catch and survey indices data for most species. For Norway pout and sprat the fit to catch data is poor; however better for survey indices. The two sandeel stocks show a reasonable fit to catch data in the main fishing season (quarter 2) but the fit is poor for quarter 3. Stock–recruitment relationships are estimated quite well (reasonable sigma value) for the stocks except for haddock.

Table 5.1.1. Key SMS model diagnostics.

November 14, 2017 13:16:46 run time:362 seconds

objective function (negative log likelihood): -5126.37
Number of parameters: 1817
Number of observations used in likelihood: 15348
Maximum gradient: 0.00958871
Akaike information criterion (AIC): -6618.74

Number of observations used in the likelihood:

	Catch	CPUE	S/R	Stomach	Sum
Species: 1, Fulmar	0	0	0	144	144
Species: 2, Guillemot	0	0	0	144	144
Species: 3, Her. Gull	0	0	0	168	168
Species: 4, Kittiwake	0	0	0	132	132
Species: 5, GBB. Gull	0	0	0	204	204
Species: 6, Gannet	0	0	0	96	96
Species: 7, Puffin	0	0	0	96	96
Species: 8, Razorbill	0	0	0	132	132
Species: 9, A. radiata	0	0	0	64	64
Species:10, G. gurnards	0	0	0	149	149
Species:11, W.horse mac	0	0	0	14	14
Species:12, N.horse mac	0	0	0	34	34
Species:13, Grey seal	0	0	0	54	54
Species:14, H. porpoise	0	0	0	19	19
Species:15, Hake	0	0	0	33	33
Species:16, Cod	430	275	43	881	1629
Species:17, Whiting	344	356	43	586	1329
Species:18, Haddock	430	376	43	130	979
Species:19, Saithe	344	290	43	188	865
Species:20, Mackerel	430	433	43	105	1011
Species:21, Herring	1634	440	43	0	2117
Species:22, N. sandeel	774	204	43	0	1021
Species:23, S. sandeel	774	144	43	0	961
Species:24, Nor. pout	602	300	43	0	945
Species:25, Sprat	516	241	43	0	800
Species:26, Plaice	430	779	41	0	1250
Species:27, Sole	387	530	41	0	958
Sum	7095	4368	512	3373	15348

unweighted objective function contributions (total):

	Catch	CPUE	S/R	Stom.	Stom N.	Penalty	Sum
Fulmar	0.0	0.0	0.0	-323.9	0.0	0.00	-324
Guillemot	0.0	0.0	0.0	-204.3	0.0	0.00	-204
Her. Gull	0.0	0.0	0.0	-388.3	0.0	0.00	-388
Kittiwake	0.0	0.0	0.0	-237.4	0.0	0.00	-237
GBB. Gull	0.0	0.0	0.0	-502.8	0.0	0.00	-503
Gannet	0.0	0.0	0.0	-135.6	0.0	0.00	-136
Puffin	0.0	0.0	0.0	-104.2	0.0	0.00	-104
Razorbill	0.0	0.0	0.0	-149.9	0.0	0.00	-150
A. radiata	0.0	0.0	0.0	-35.8	0.0	0.00	-36
G. gurnards	0.0	0.0	0.0	-80.0	0.0	0.00	-80
W.horse mac	0.0	0.0	0.0	2.1	0.0	0.00	2
N.horse mac	0.0	0.0	0.0	-9.8	0.0	0.00	-10
Grey seal	0.0	0.0	0.0	-124.7	0.0	0.00	-125
H. porpoise	0.0	0.0	0.0	-26.7	0.0	0.00	-27
Hake	0.0	0.0	0.0	-17.9	0.0	0.00	-18
Cod	-416.4	-137.5	-5.5	-1463.6	0.0	0.00	-2023
Whiting	-241.5	-193.6	-20.9	-668.0	0.0	0.00	-1124
Haddock	-208.0	-96.3	15.1	-82.1	0.0	0.00	-371
Saithe	-282.2	-107.4	-17.5	-108.0	0.0	0.00	-515
Mackerel	-410.2	-145.7	-11.1	-83.2	0.0	0.00	-650
Herring	272.9	-106.8	-6.3	0.0	0.0	0.00	160
N. sandeel	126.0	27.6	8.2	0.0	0.0	0.00	162
S. sandeel	78.9	-51.3	1.9	0.0	0.0	0.00	30
Nor. pout	178.0	0.4	-8.0	0.0	0.0	0.00	170
Sprat	364.2	7.1	-6.3	0.0	0.0	0.00	365
Plaice	-398.1	-150.5	-26.3	0.0	0.0	0.00	-575
Sole	-445.6	123.5	-3.0	0.0	0.0	0.00	-325
Sum	-1382.1	-830.6	-79.6	-4743.9	0.0	0.00	-7036

```
sqrt(catch variance) ~ CV:
--------------------------
Cod
 1       0.627
 2       0.146
 3       0.146
 4       0.146
 5       0.146
 6       0.146
 7       0.230
 8       0.230
 9       0.437
10       0.437
Whiting
 0       1.147
 1       0.482
 2       0.198
 3       0.198
 4       0.198
 5       0.312
 6       0.312
 7       0.312
 8       0.312

Haddock
 0       0.795
 1       0.468
 2       0.228
 3       0.228
 4       0.228
 5       0.228
 6       0.365
 7       0.365
 8       0.622
 9       0.622
10       0.622

Saithe
 3       0.451
 4       0.451
 5       0.197
 6       0.197
 7       0.197
 8       0.255
 9       0.255
10       0.255

Mackerel
 1       0.396
 2       0.414
 3       0.204
 4       0.204
 5       0.204
 6       0.204
 7       0.204
 8       0.204
 9       0.204
10       0.204
Herring
              season
--------------------------------------
age        1       2       3       4

 0                       0.717   0.906
 1       0.898   0.650   0.643   0.554
 2       0.898   0.650   0.643   0.554
 3       0.898   0.650   0.643   0.554
 4       0.898   0.650   0.643   0.554
 5       0.898   0.650   0.643   0.554
 6       0.898   0.650   0.643   0.554
 7       0.898   0.650   0.643   0.554
 8       1.350   0.788   0.604   1.070
 9       1.350   0.788   0.604   1.070

N. sandeel
              season
--------------------------------------
```

age	1	2	3	4
0			1.351	
1		0.559	1.321	
2		0.559	1.321	
3		0.559	1.321	
4		1.188	1.131	

S. sandeel

	season			
age	1	2	3	4
0			1.414	
1		0.445	1.085	
2		0.445	1.085	
3		0.445	1.085	
4		0.445	1.085	

Nor. pout

	season			
age	1	2	3	4
0			1.414	1.226
1	0.708	0.687	0.633	0.729
2	0.708	0.687	0.633	0.729
3	0.956	1.042	1.132	0.969

Sprat

	season			
age	1	2	3	4
1	1.398	1.414	1.023	0.850
2	1.414	1.092	1.016	0.848
3	1.414	1.414	1.181	1.414

Plaice

1	0.391
2	0.156
3	0.239
4	0.239
5	0.239
6	0.239
7	0.239
8	0.239
9	0.239
10	0.239

Sole

2	0.415
3	0.174
4	0.174
5	0.174
6	0.174
7	0.174
8	0.174
9	0.174
10	0.174

sqrt(Survey variance) ~ CV:

Cod	age 0	age 1	age 2	age 3	age 4	age 5	age 6
Cod IBTS Q1		0.55	0.31	0.31	0.31	0.31	
Cod IBTS Q3		0.47	0.36	0.36	0.36		
Whiting							
Whg IBTS Q1 1974-1988		0.41	0.43	0.43	0.43	0.43	
Whg IBTS Q1 1989-		0.40	0.32	0.32	0.32	0.32	
Whg IBTS Q3	0.67	0.38	0.28	0.28	0.28	0.28	
Haddock							
Had IBTS Q1		0.51	0.51	0.51	0.51	0.51	
Had IBTS Q3	0.52	0.28	0.28	0.51	0.51	0.51	
Saithe							
Pok IBTS Q3				0.96	0.96	0.68	0.68
Pok SAM N				0.22	0.22	0.22	0.22
Mackerel							
Mac Swept area		0.89	0.60	0.60	0.60	0.60	0.60
Mac SAM assessment	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Herring							
HERAS		0.44	0.29	0.37	0.37	0.37	0.37
Her IBTS Q1		0.31	0.85	0.85	0.85	0.85	
Her MIK	0.46						
N. sandeel							
Dregde 2004-	0.66	0.58	0.58				
Commercial 1982-1998		0.62	0.62	0.62			
Commercial 1999-		0.79	0.54	0.54			
Commercial 2 1976-2004	1.21						
Acoustic		0.78	0.78	0.67	0.67		
S. sandeel							
Dregde 2004-	0.48	0.85	0.85				
Commercial 1982-1998		0.58	0.43	0.43			
Commercial 1999-2004		0.20	0.20	0.20			
Commercial 2005-2009		0.20	0.20	0.20			
Commercial 2010-2016		0.49	0.49	0.49			
Nor. pout							
Nop ENGFS 1982-1991	1.12	0.47	1.17	1.17			
Nop ENGFS 1992-	0.96	0.37	0.64				
Nop IBTS Q1 1974		0.54	0.59	0.59			
Nop SGOGFS 1998	0.62	0.46	0.46				
Sprat							
Spr IBTS Q1 1974-		0.62	0.62	0.62			
Spr HERAS-Acoustic 2003-		0.40	0.47	0.47			
Spr IBTS Q3 1991-		0.77	0.64	0.86			
Plaice							
Ple BTS 1985-1995		0.49	0.49	0.65	0.65	0.63	0.63
Ple BTS-1996-		0.32	0.36	0.46	0.46	0.46	0.46
Ple SNS 1974-1999		0.42	0.42	0.91	0.91	1.18	1.18
Ple SNS 2000-		0.34	0.34	0.73	0.73	1.29	1.29
Ple IBTS Q3 1997-		0.45	0.33	0.36	0.36	0.36	0.36
Ple IBTS Q1 2007-		0.33	0.33	0.25	0.25	0.41	0.41
Sole							
Sol BTS 1985-		0.53	0.41	0.60	0.60	0.60	1.20
Sol SNS 1974-		0.55	0.59	0.59	0.59	1.27	1.27

Recruit-SSB		alfa	beta	recruit s2	recruit s
Cod	Hockey st. -break.:	135.736	1.180e+005	0.253	0.503
Whiting	Hockey st. -break.:	83.438	1.840e+005	0.111	0.334
Haddock	Hockey st. -break.:	40.148	1.000e+005	1.042	1.021
Saithe	Ricker:	2.842	4.491e-006	0.163	0.404
Mackerel	Geometric mean:	15.242		0.202	0.449
Herring	Ricker:	58.172	8.901e-007	0.275	0.524
N. sandeel	Ricker:	2327.920	3.987e-006	0.540	0.735
S. sandeel	Ricker:	1286.318	2.588e-006	0.402	0.634
Nor. pout	Ricker:	1442.563	4.459e-006	0.246	0.496
Sprat	Hockey st. -break.:	949.209	9.000e+004	0.259	0.509
Plaice	Ricker:	6.068	1.611e-006	0.102	0.319
Sole	Ricker:	7.224	2.554e-005	0.318	0.564

5.1.1.1 Retrospective analysis for M2

The retrospective analysis of M2 shows a consistent estimate of predation mortalities (Figure 5.1.1 to Figure 5.1.8). As for all other retrospective assessment analysis, this analysis also shows that values (M2) in the terminal year of the time-series have larger uncertainties; however this uncertainty is not huge. The largest retrospective variability is seen for southern sandeel (Figure 5.1.6), which is probably due to the variability in the stock number estimate from catch and survey observation, rather than due to variability from one year to next in parameter estimates related to predation. Southern sandeel assessment make use of a short survey indices time-series, 2010–2016, which provide uncertain and variable stock estimates when reduced further in the retrospective analysis.

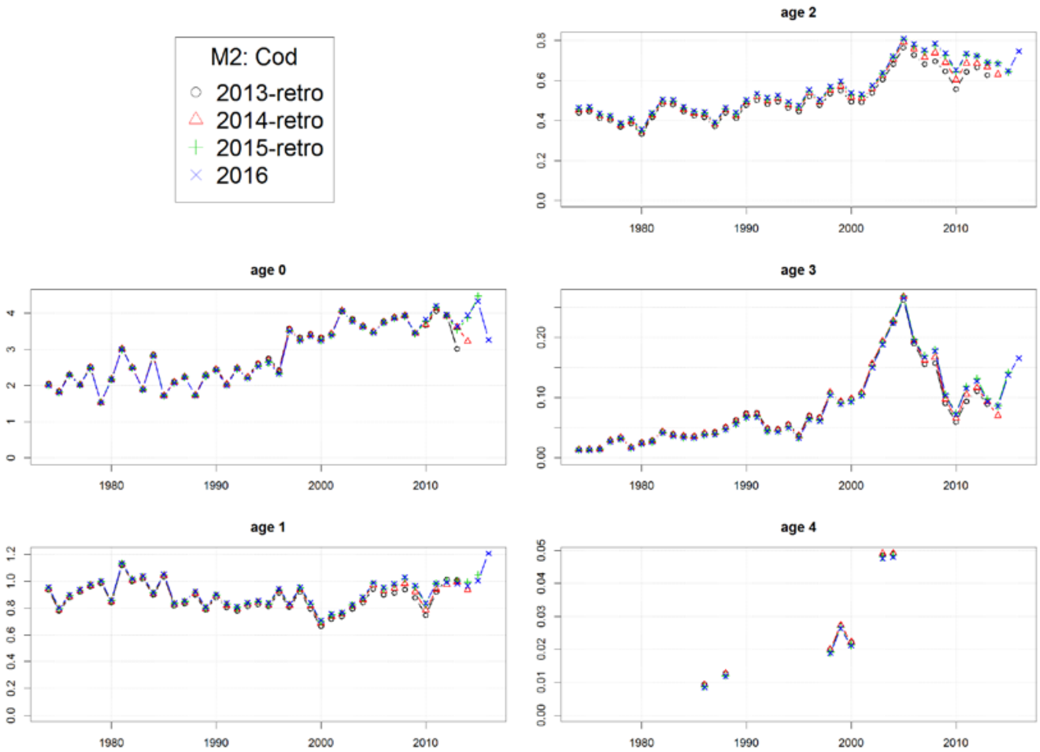


Figure 5.1.1. Retrospective analysis of M2 for cod.

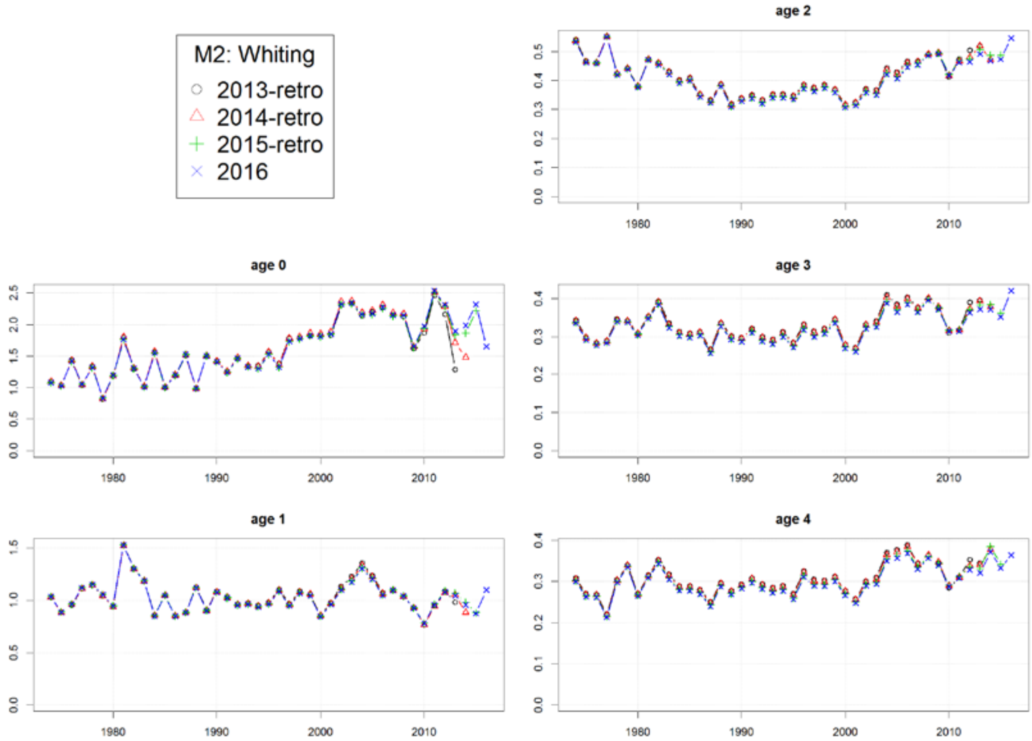


Figure 5.1.2. Retrospective analysis of M2 for whiting.

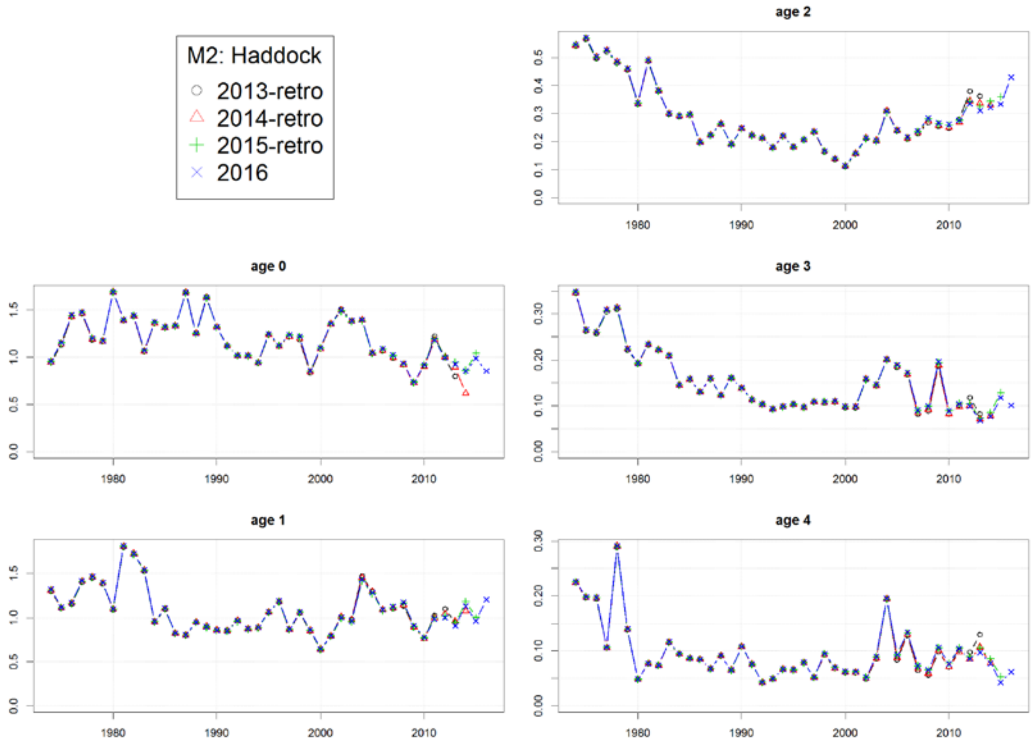


Figure 5.1.3. Retrospective analysis of M2 for haddock.

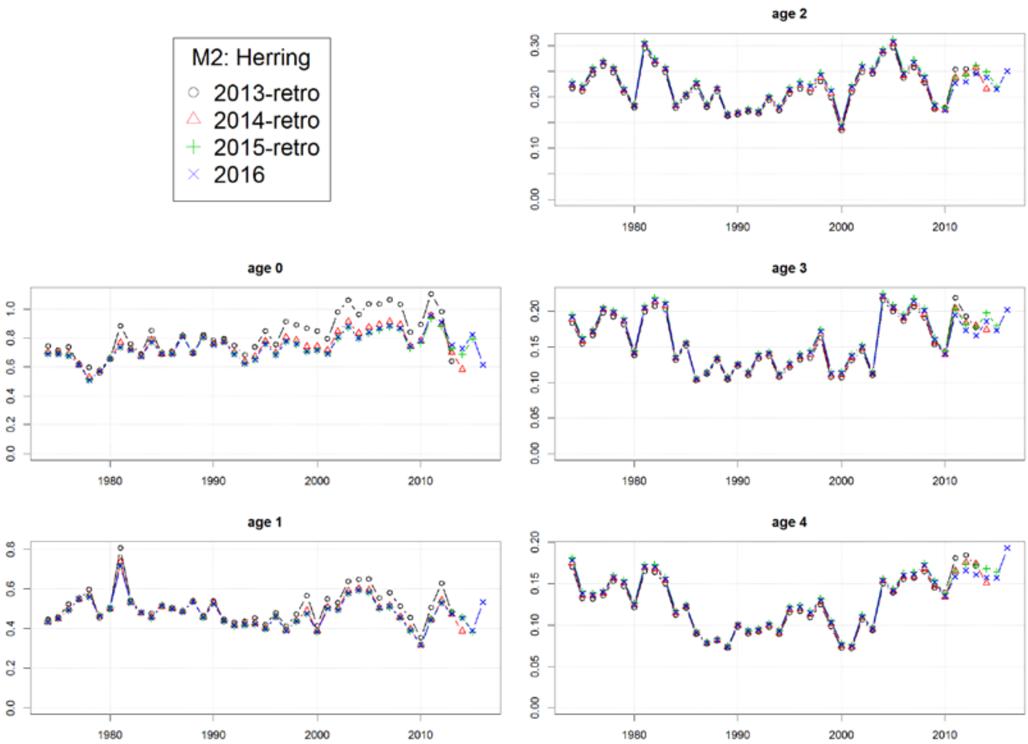


Figure 5.1.4. Retrospective analysis of M2 for herring.

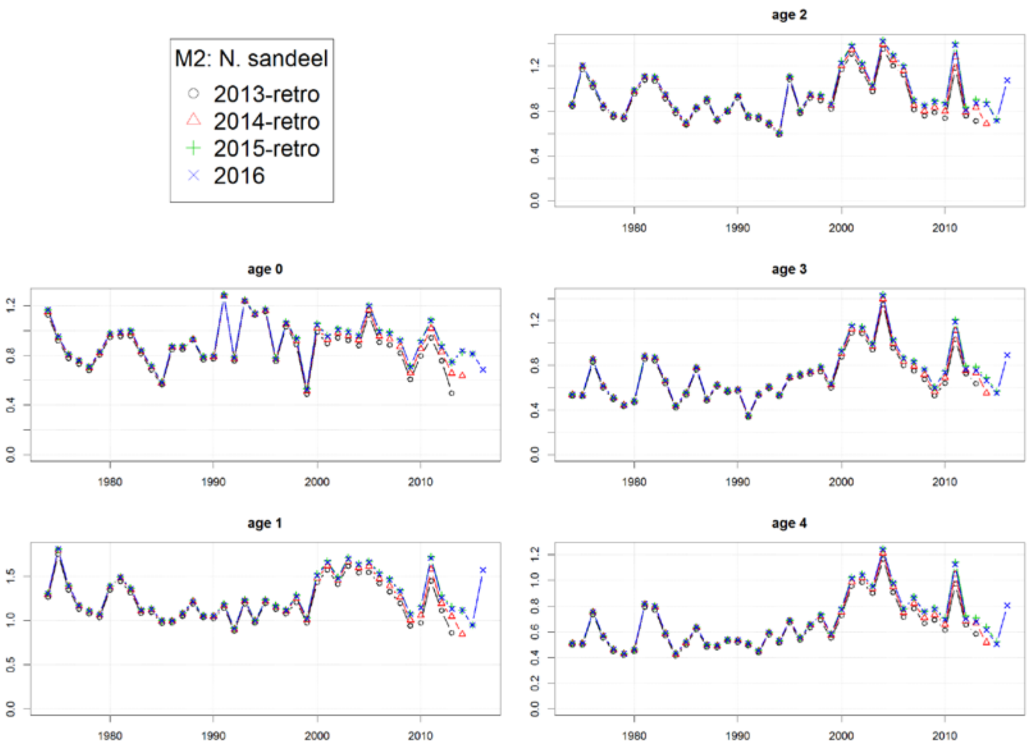


Figure 5.1.5. Retrospective analysis of M2 for northern sandeel.

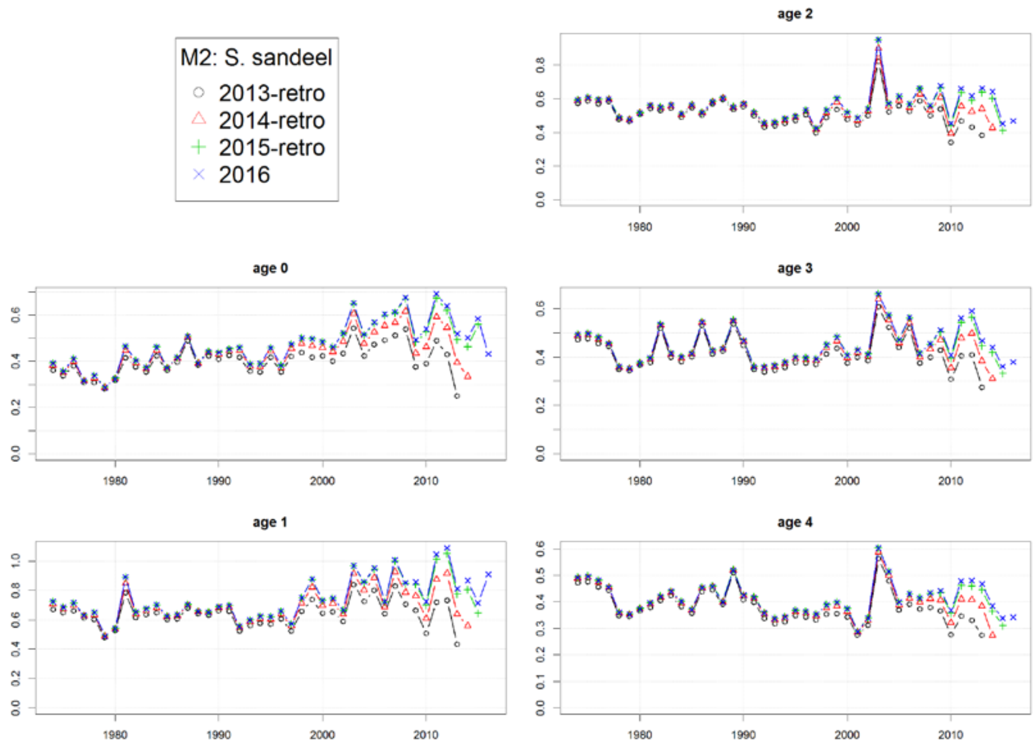


Figure 5.1.6. Retrospective analysis of M2 for southern sandeel.

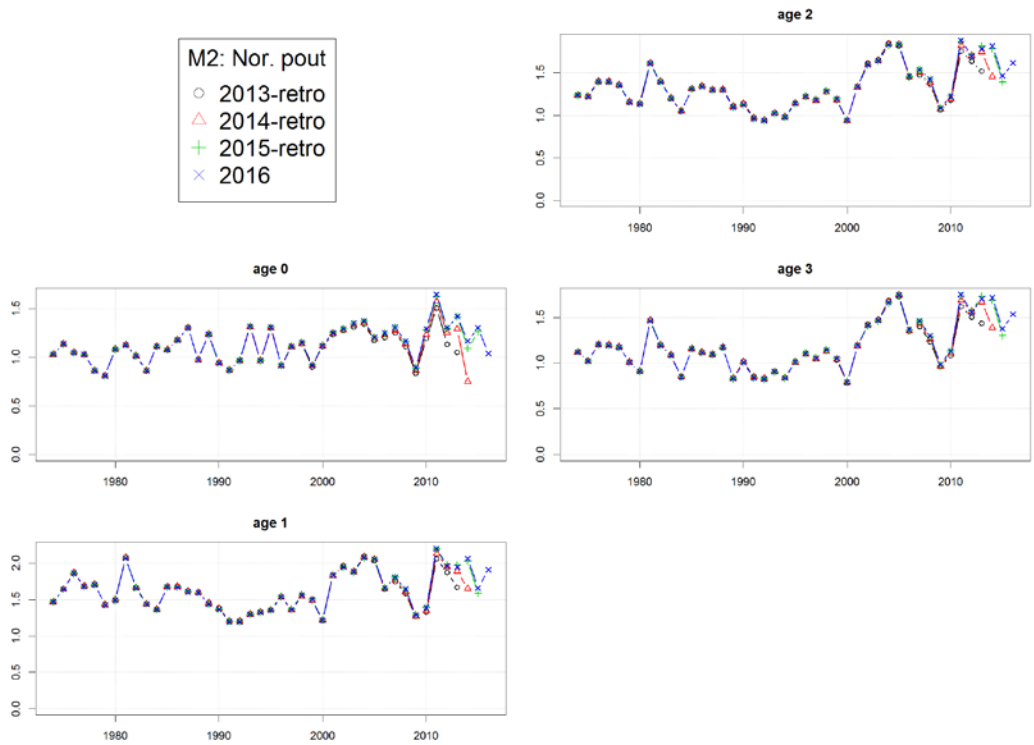


Figure 5.1.7. Retrospective analysis of M2 for Norway pout.

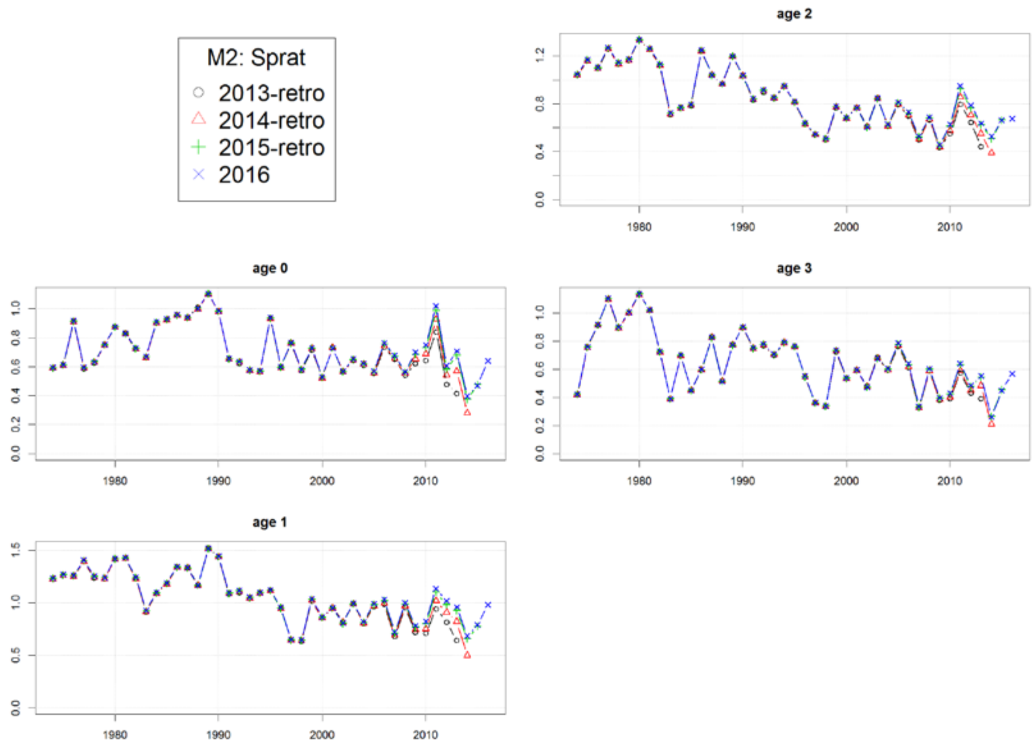


Figure 5.1.8. Retrospective analysis of M2 for sprat.

5.1.2 Stock summary results

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

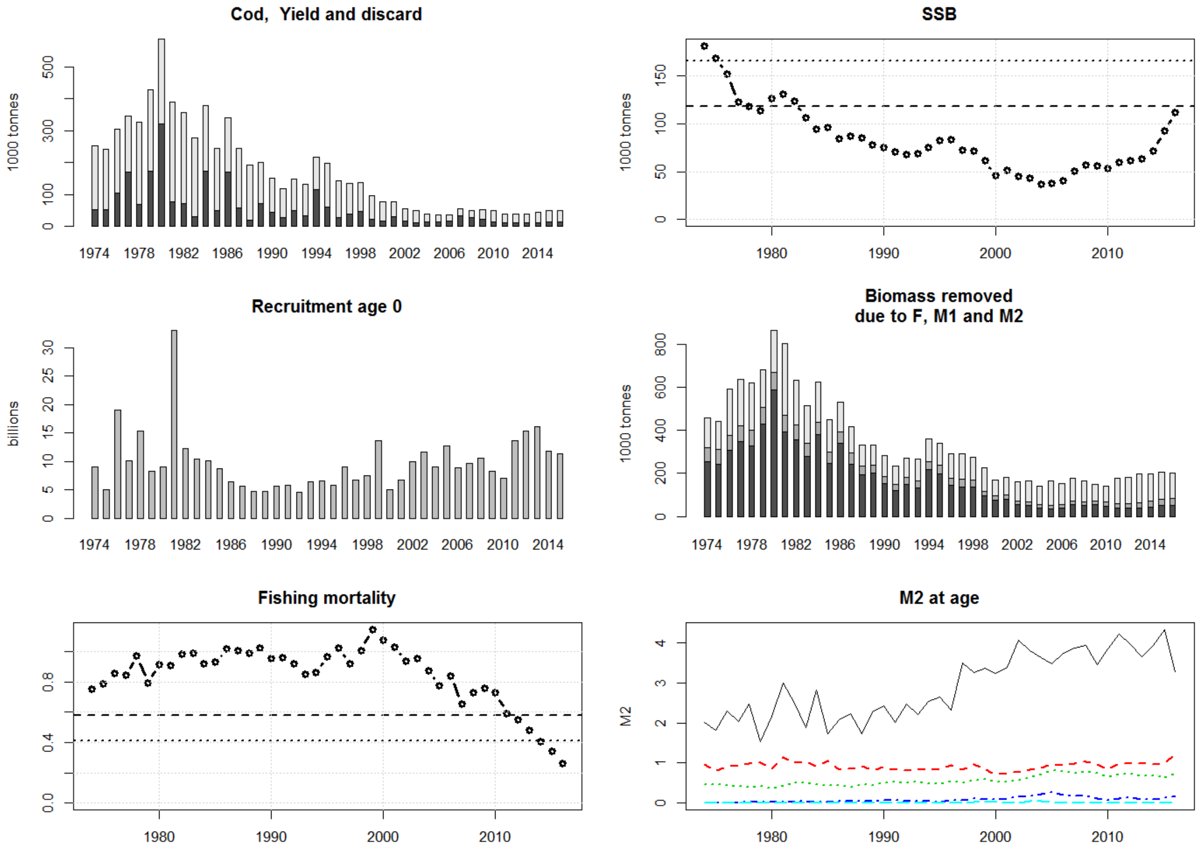


Figure 5.1.9. SMS output for cod. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the second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

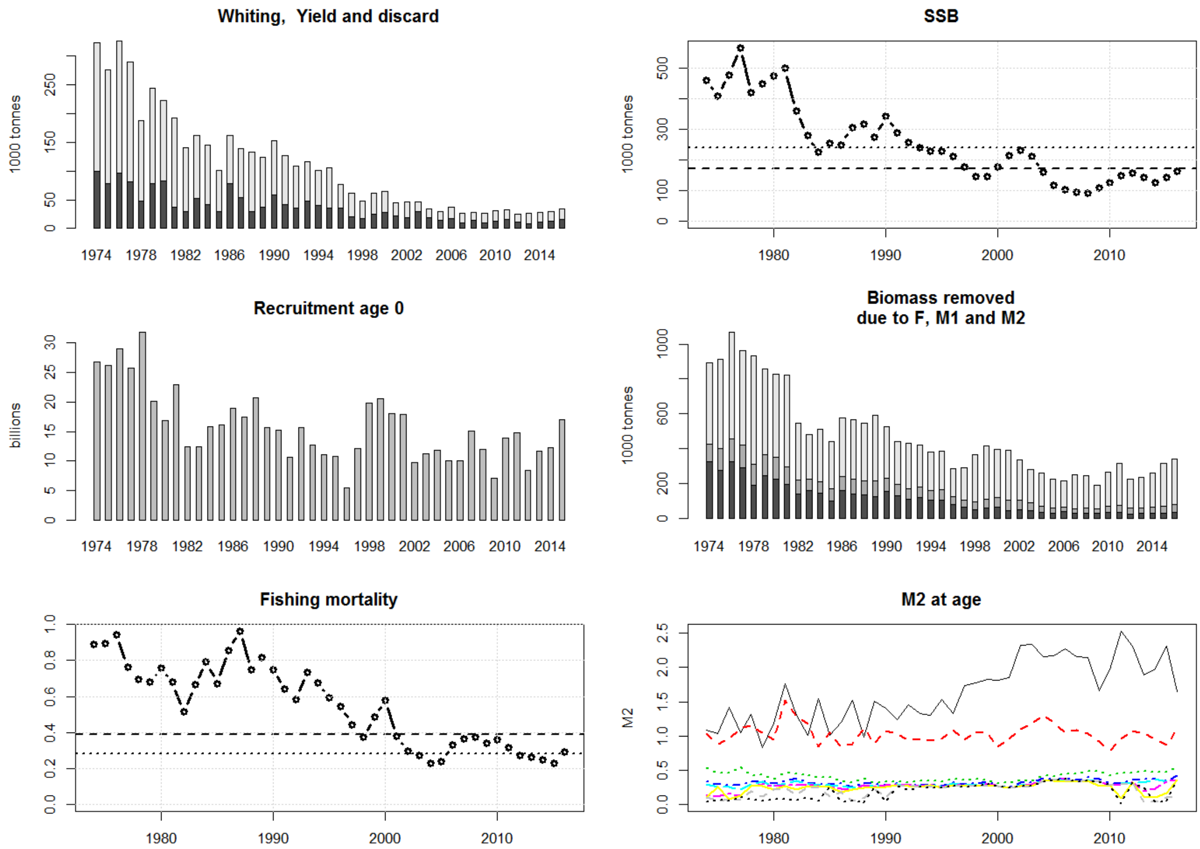


Figure 5.1.10. SMS output for whiting. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the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

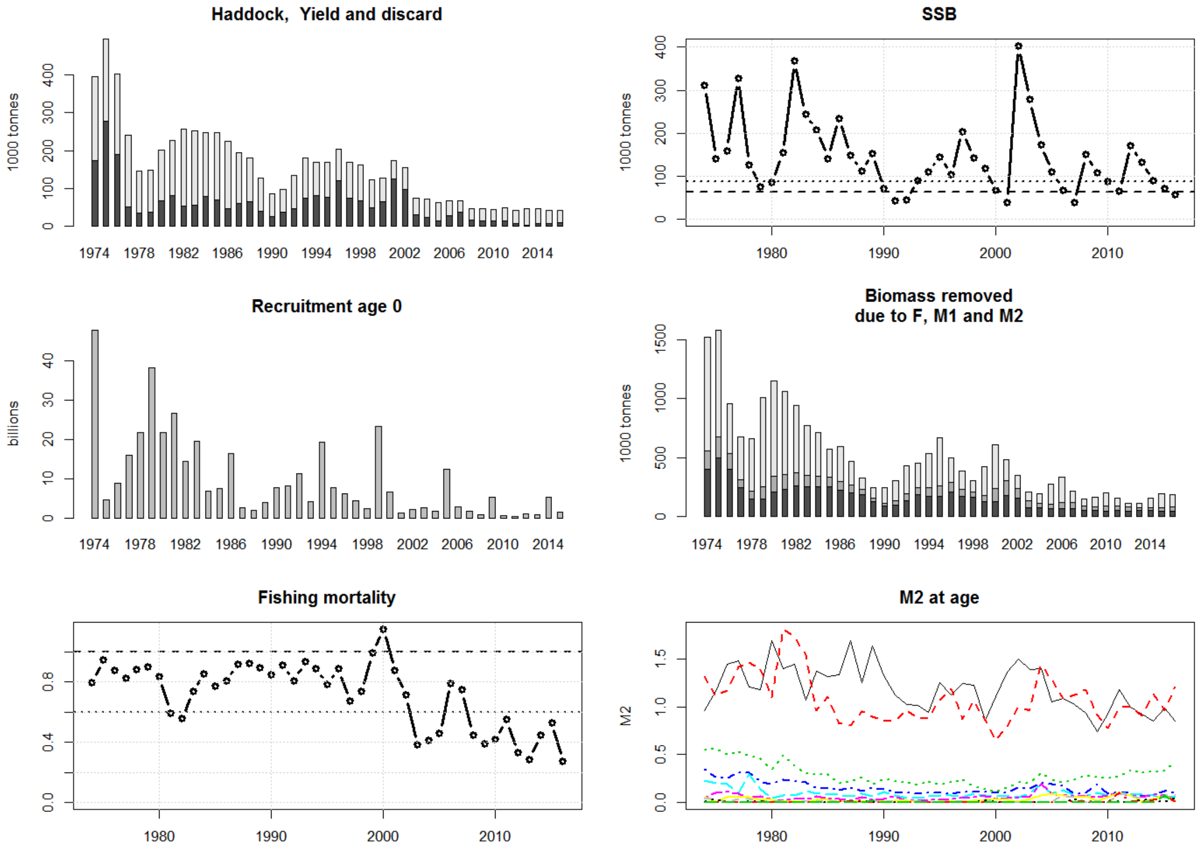


Figure 5.1.11. SMS output for haddock. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the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

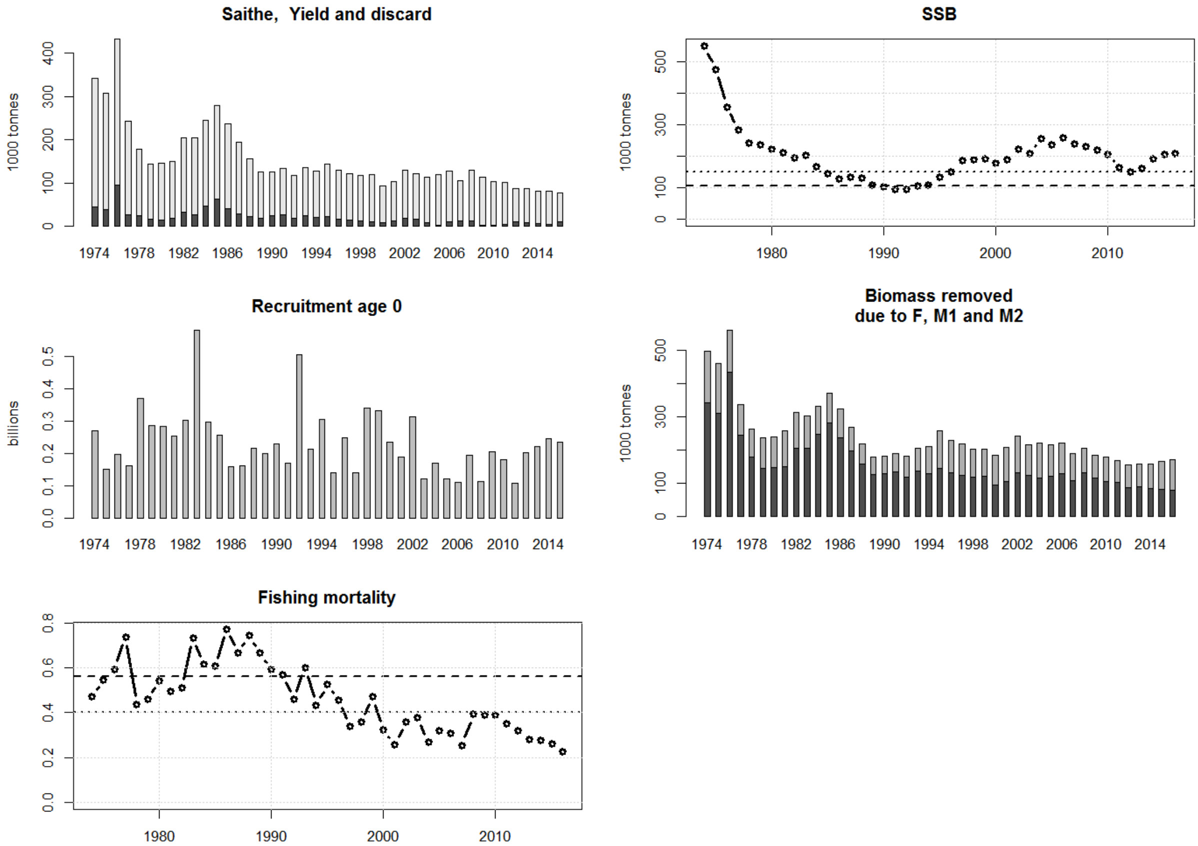


Figure 5.1.12. SMS output for saithe. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB and Biomass removed due to fishery (F).

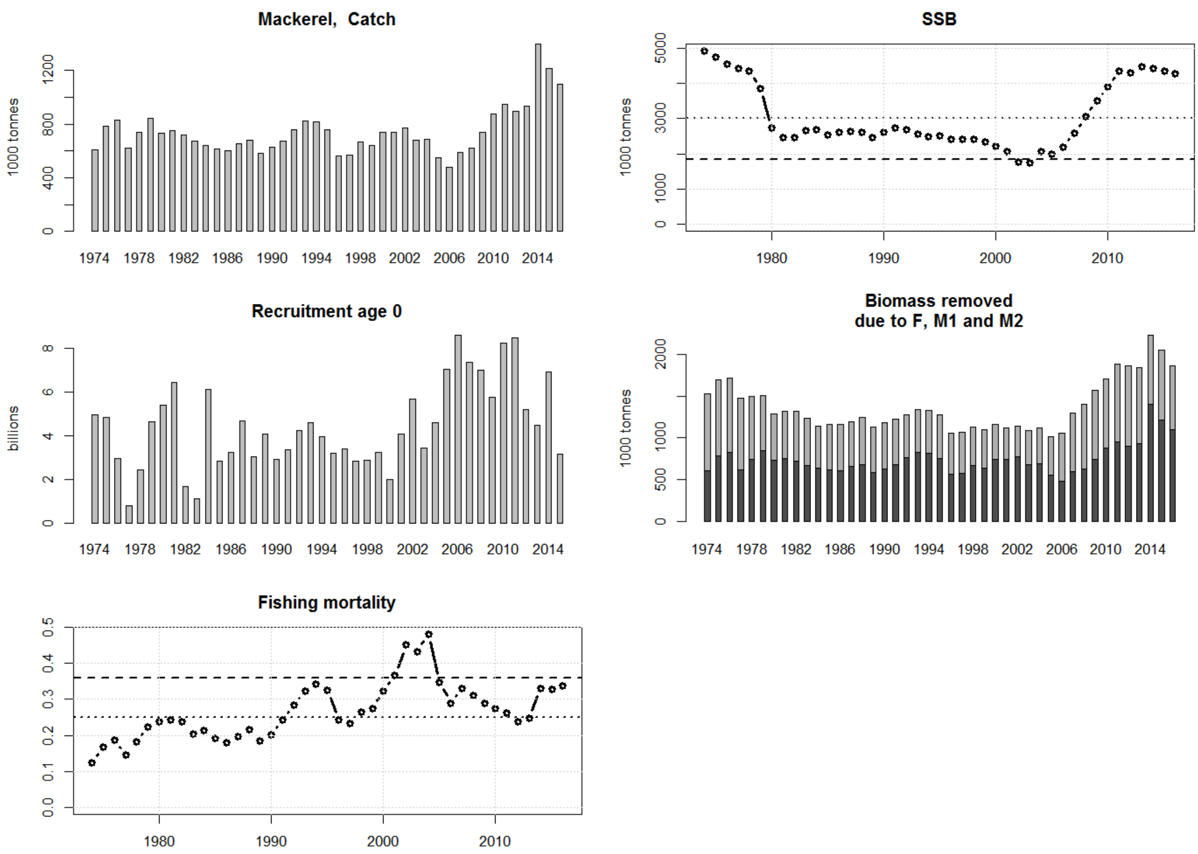


Figure 5.1.13. SMS output for Mackerel. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB and Biomass removed due to fishery (F).

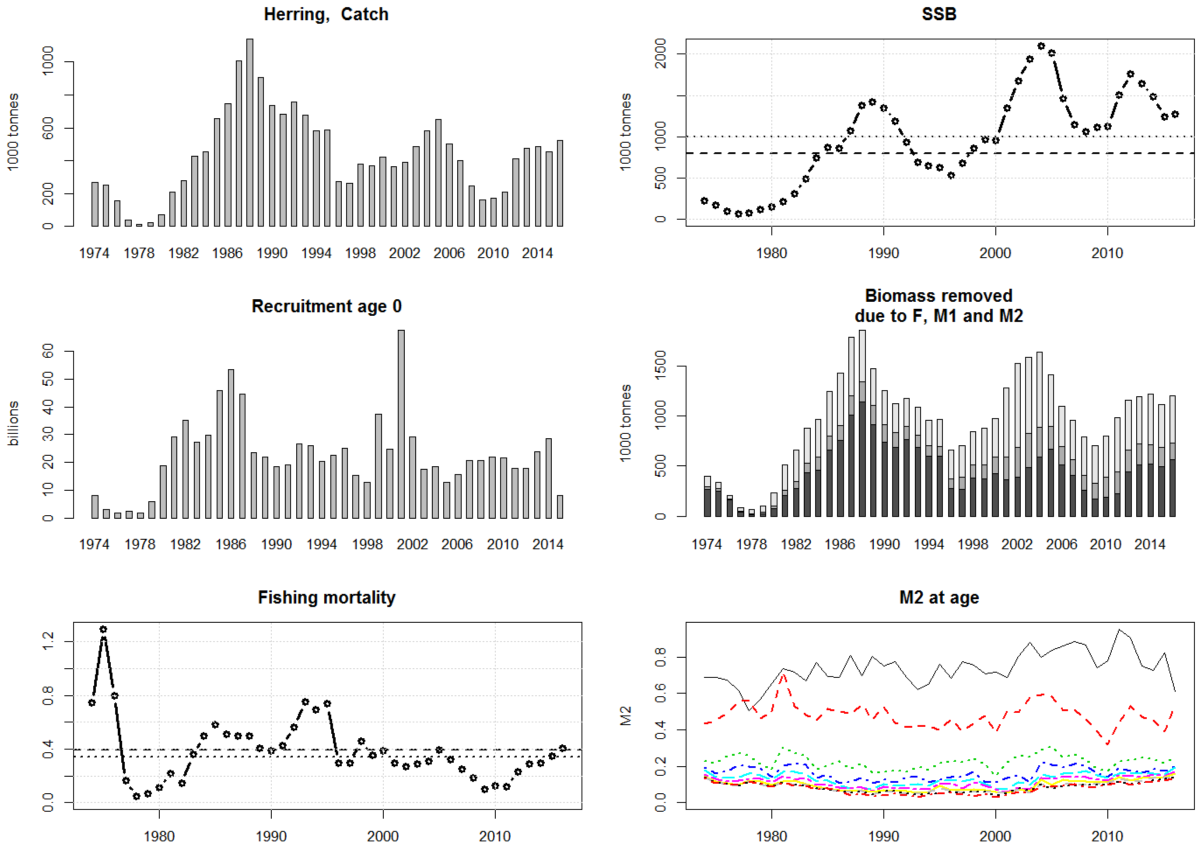


Figure 5.1.14. SMS output for Herring. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the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

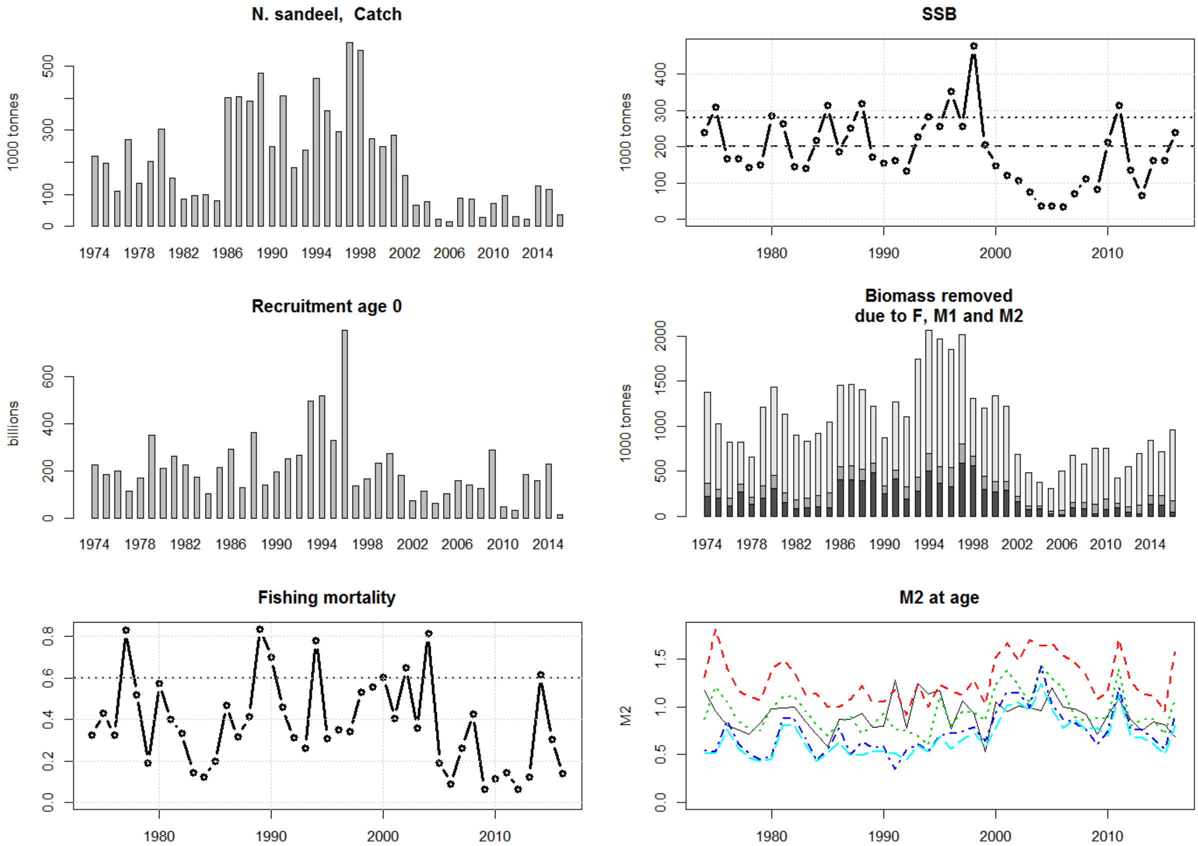


Figure 5.1.15. SMS output for Northern Sandeel. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line)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

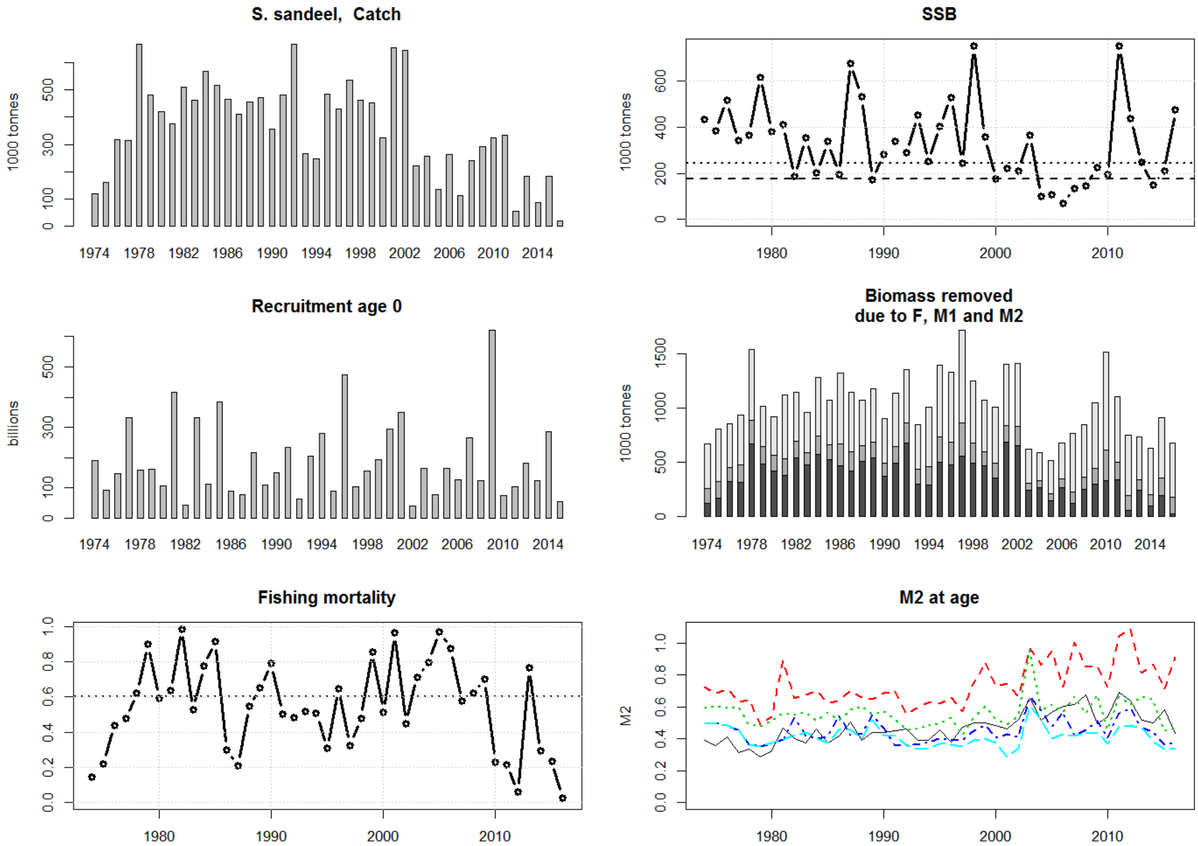


Figure 5.1.16. SMS output for Southern Sandeel. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line)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

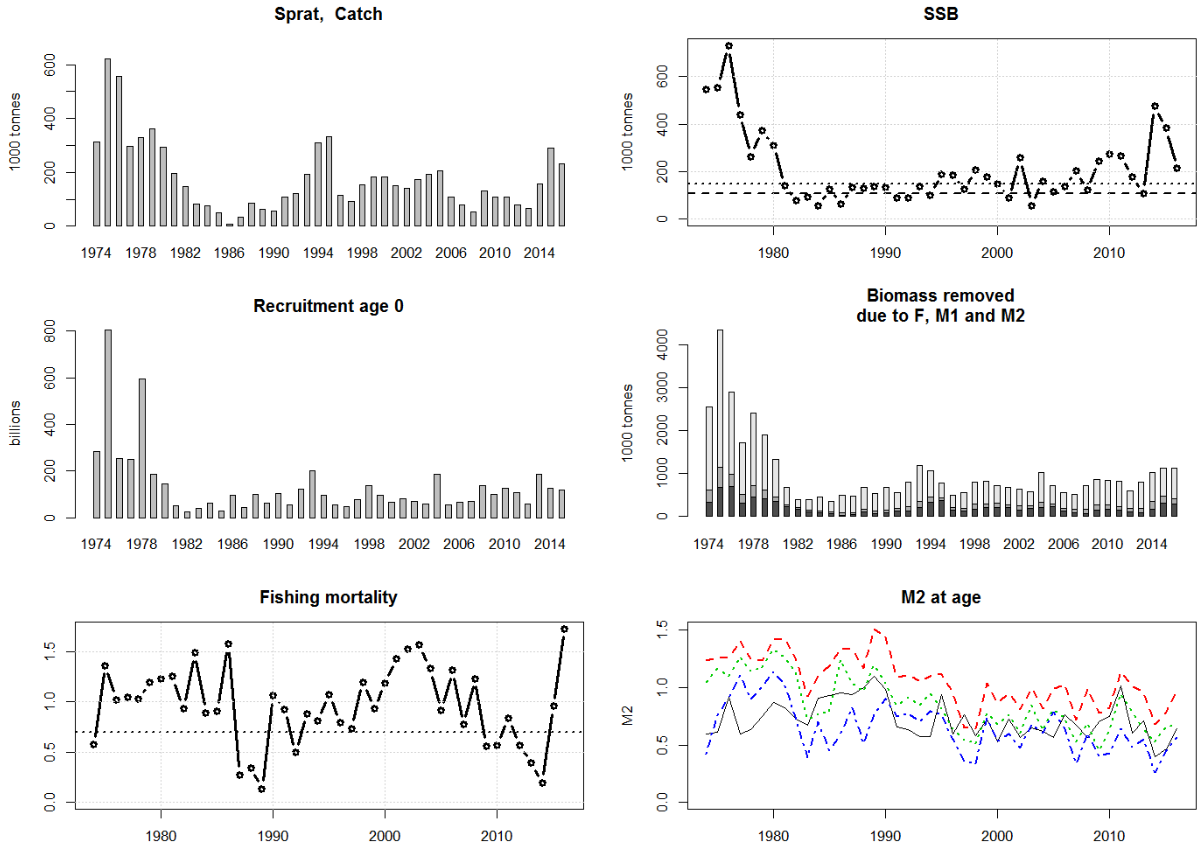


Figure 5.1.17. SMS output for Sprat. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for the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

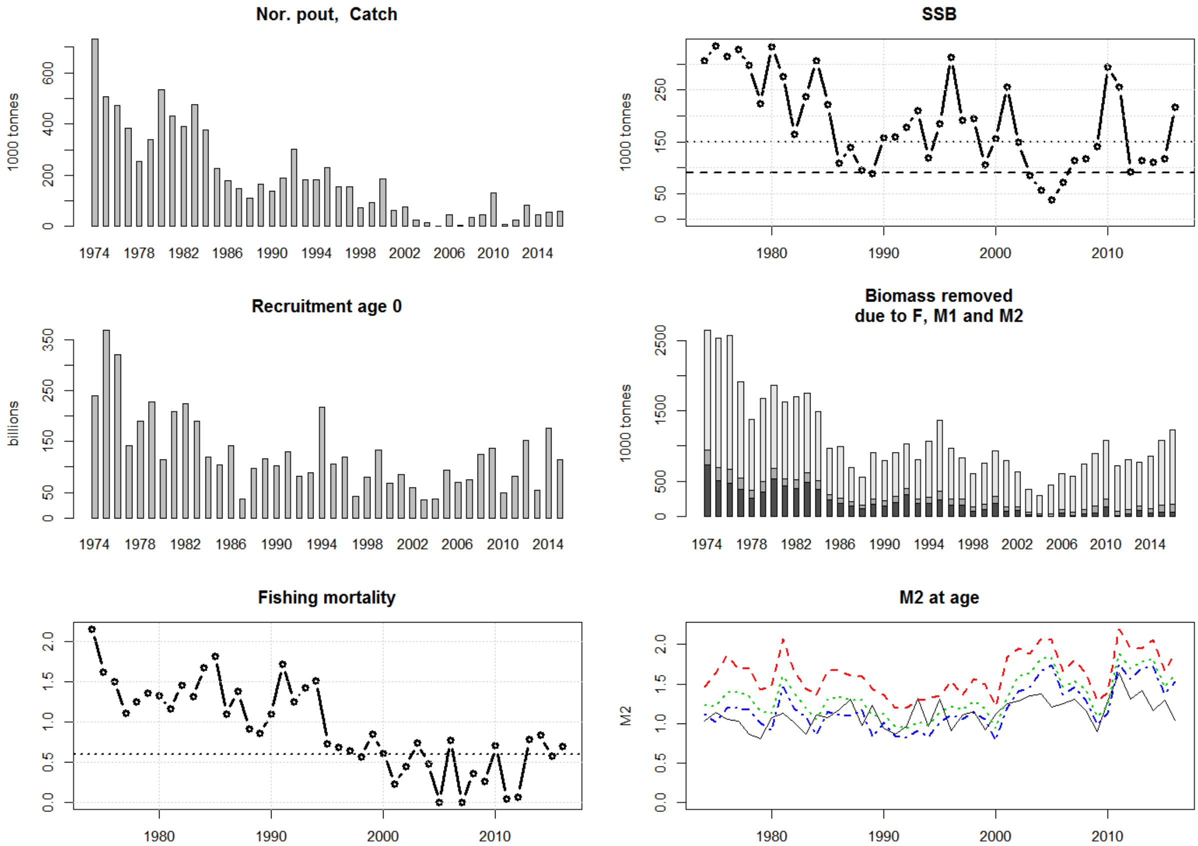


Figure 5.1.18. SMS output for Norway pout. Catch weight divided into yield (landings) and discards, Recruitment, F, SSB, Biomass removed due to fishery (F), predation by SMS species (M2) and residual natural mortality (M1). The predation mortality (M2) presented by the 0-group (black solid line) is for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

5.1.3 Who eats whom

5.1.3.1 Eaten biomass by predator

Biomass of eaten SMS prey species biomass decreased from more than 6 billion tons in the mid-seventies to around 3 billion tonnes in recent years (Figure 5.1.19).

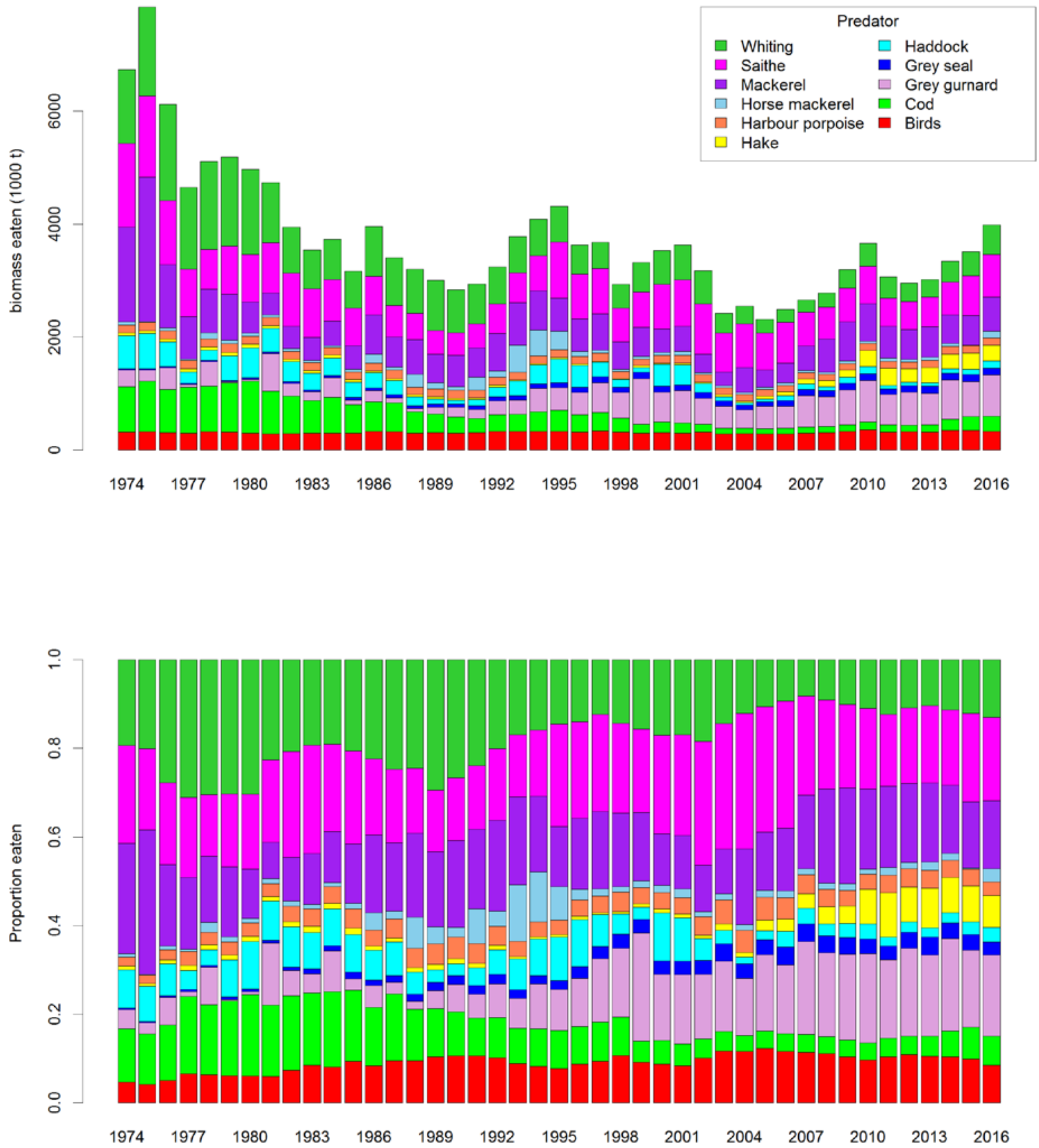


Figure 5.1.19. Eaten total biomass of prey species by individual predator (groups). Upper figure shows the absolute weight eaten and the lower figure shows relative weight eaten.

5.1.3.2 Eaten biomass by prey

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

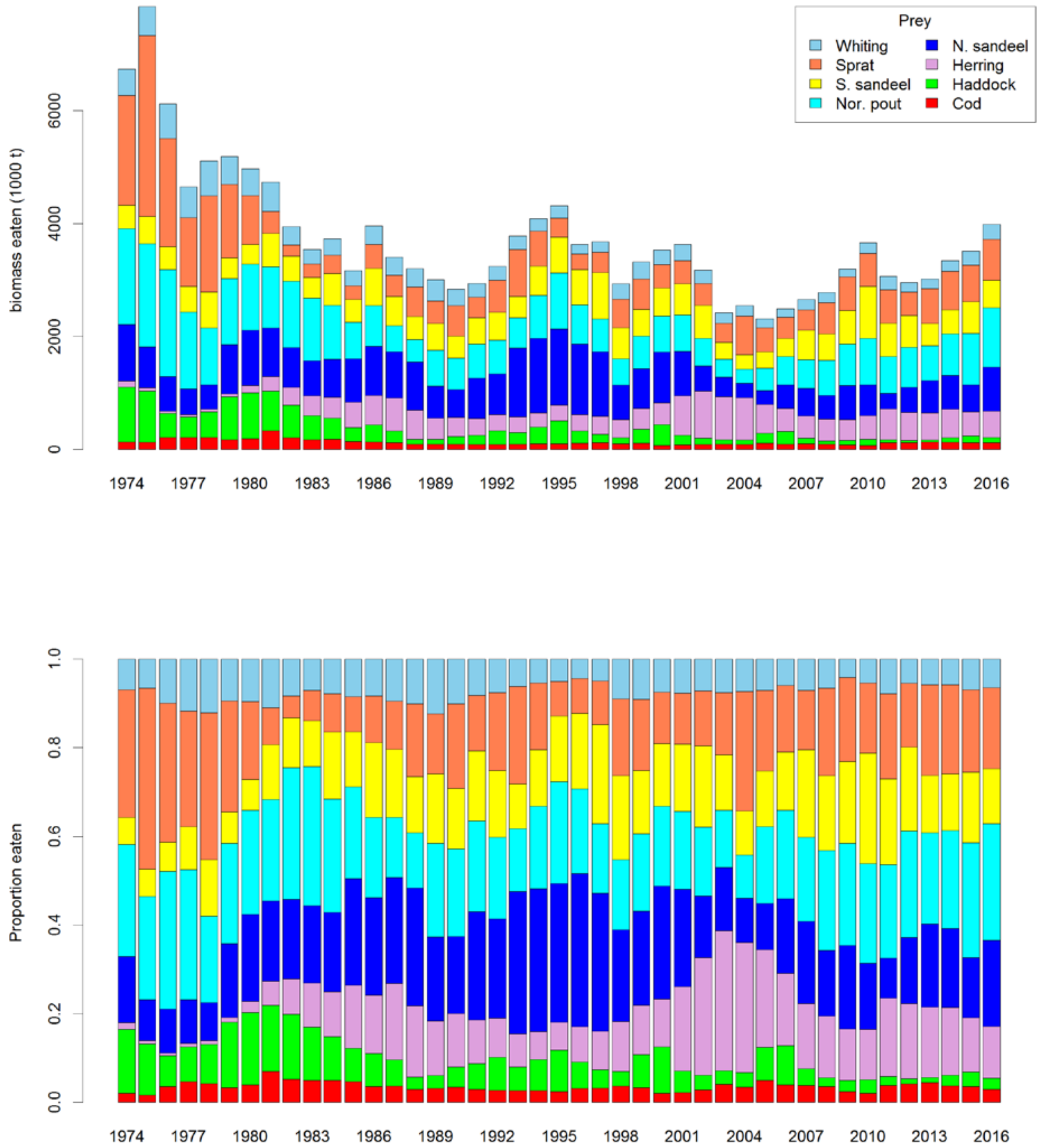


Figure 5.1.20. Eaten biomass of the individual prey species. Upper figure shows the absolute weight eaten and the lower figure shows relative weight eaten.

5.1.3.3 Eaten biomass by individual prey species

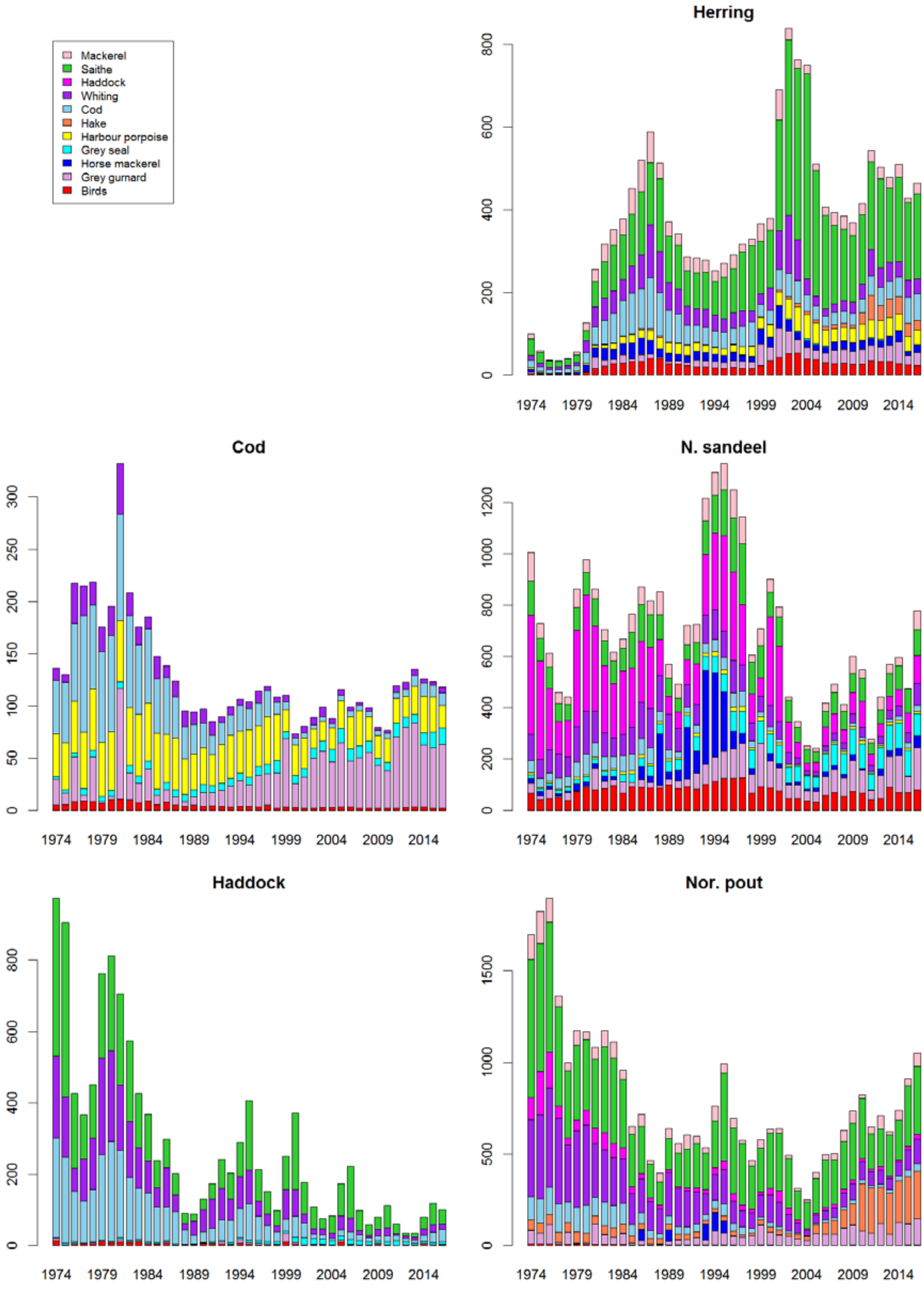


Figure 5.1.21. Eaten biomass of the individual prey species by predator (groups).

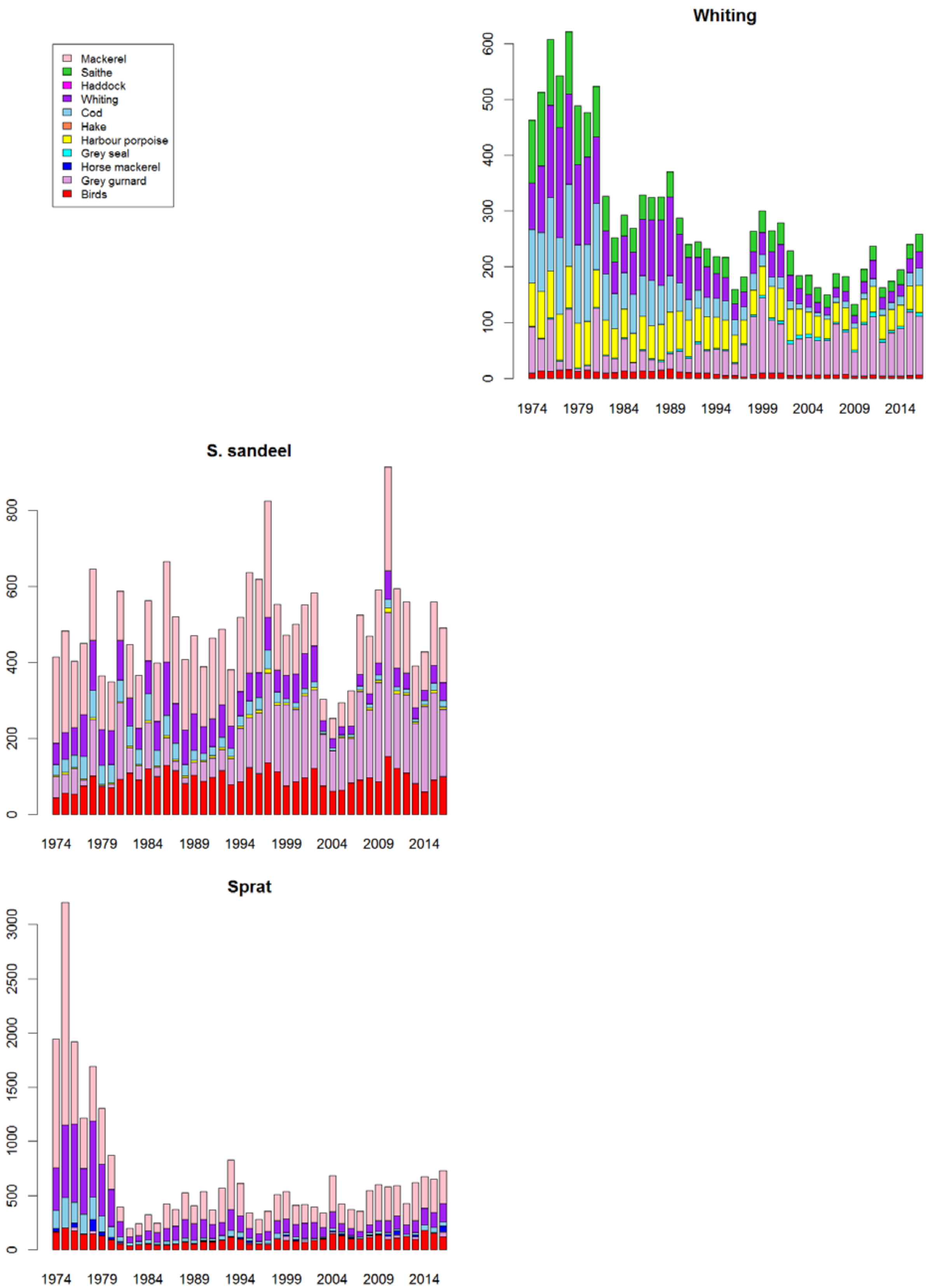


Figure 5.1.21. (Continued). Eaten biomass of the individual prey species by predator (grouped for birds and horse mackerel).

5.1.4 Predation mortalities (M2)

The overall picture of M2 at-age (Figure 5.1.22) is highly variable between species. For cod and whiting, the steep increase in abundance of the predator grey gurnard has led to increase in M2 of 0-group fish in recent years. Further, mortality of 3-year old cod has increased substantially as a result of the recent increase in grey seal abundance. Haddock natural mortality particularly of age 2 fish has decreased over time with the decreased in the biomass of large cod followed by an increase in most recent years. The same trend is seen for 2+ herring, but here the effect is counteracted in later years as the biomass of large hake has increased. Similarly, the decrease in herring natural mortality induced by cod is counteracted by an increase in grey gurnard predation.

The two sandeel stocks show markedly different patterns in the main predators, with cod, mackerel, whiting, saithe, seabirds and in later years, grey seals all exerting a significant impact on northern sandeel whereas grey gurnards, mackerel, whiting and seabirds are the main predators on southern sandeel. Natural mortality of southern sandeel seems to have increased over the period whereas that of northern sandeel and has fluctuated without a clear trend. Natural mortality of Norway pout increased in the late 1990s whereas the mortality of sprat has decreased more or less monotonically since the mid-1980s.

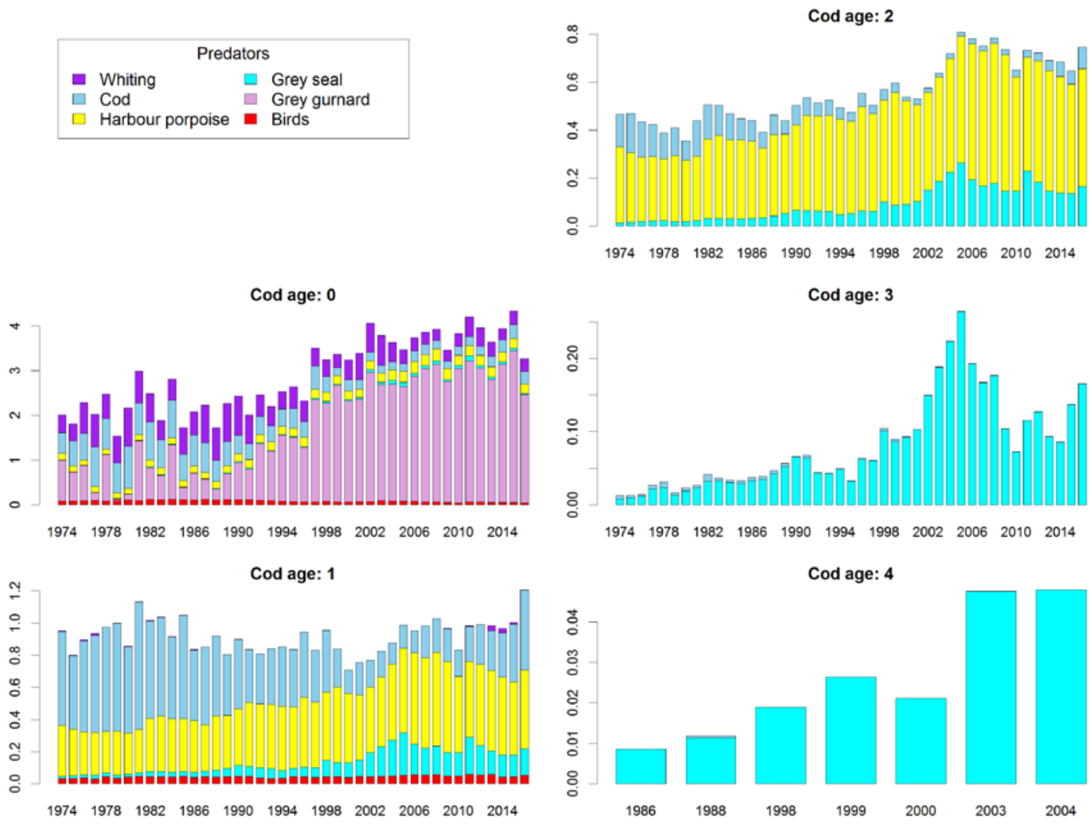


Figure 5.1.22 Annual predation mortality (M2) by prey species and age inflicted by predator species.

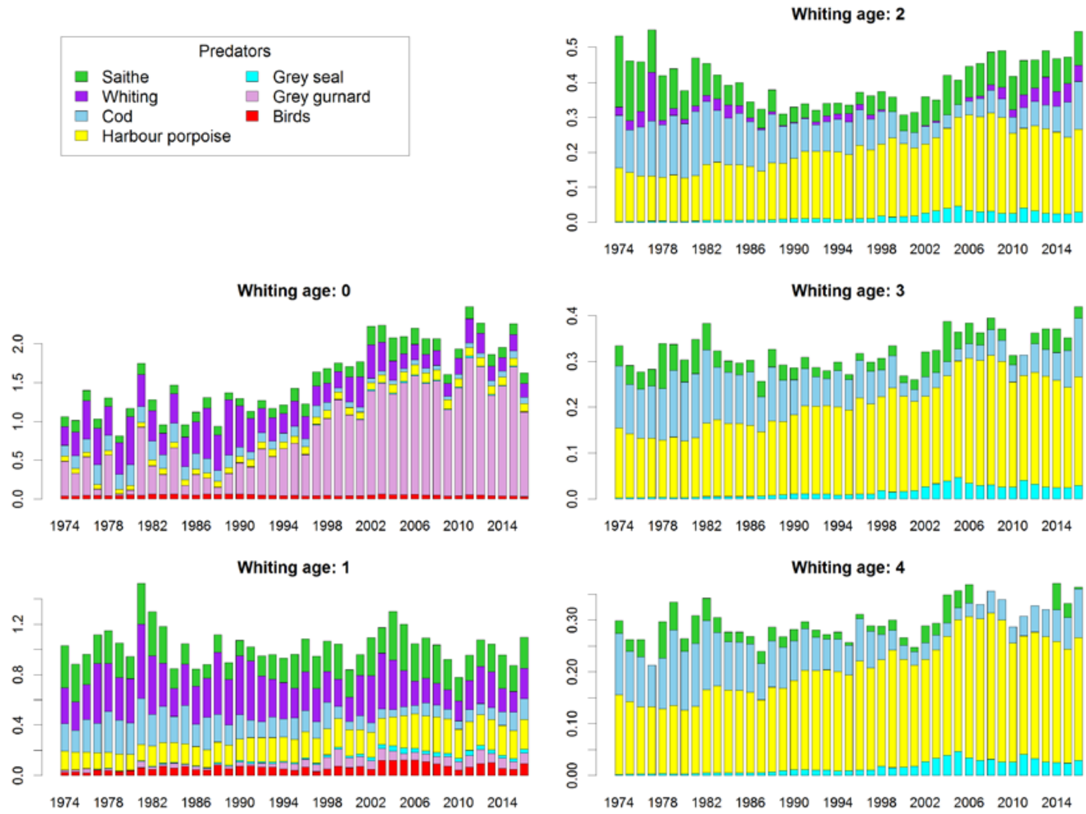


Figure 5.1.22. (Continued). Annual predation mortality (M2) by prey species and age inflicted by predator species.

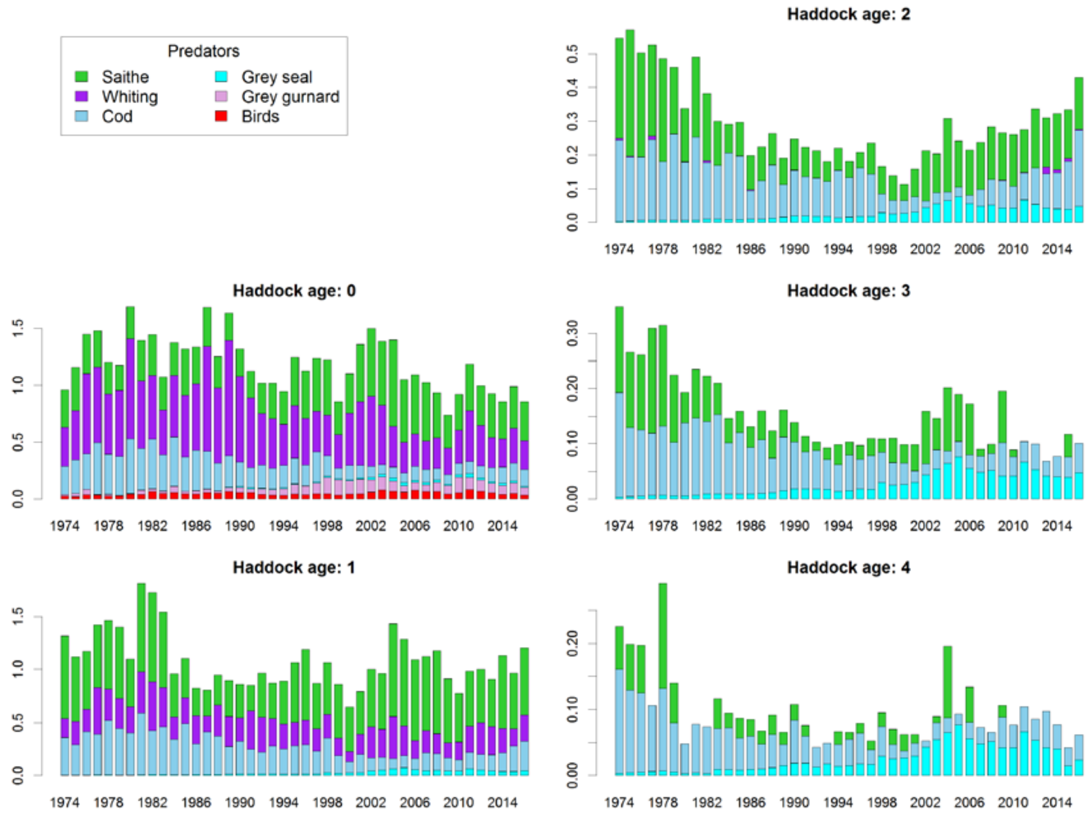


Figure 5.1.22. (Continued). Annual predation mortality (M2) by prey species and age inflicted by predator species.

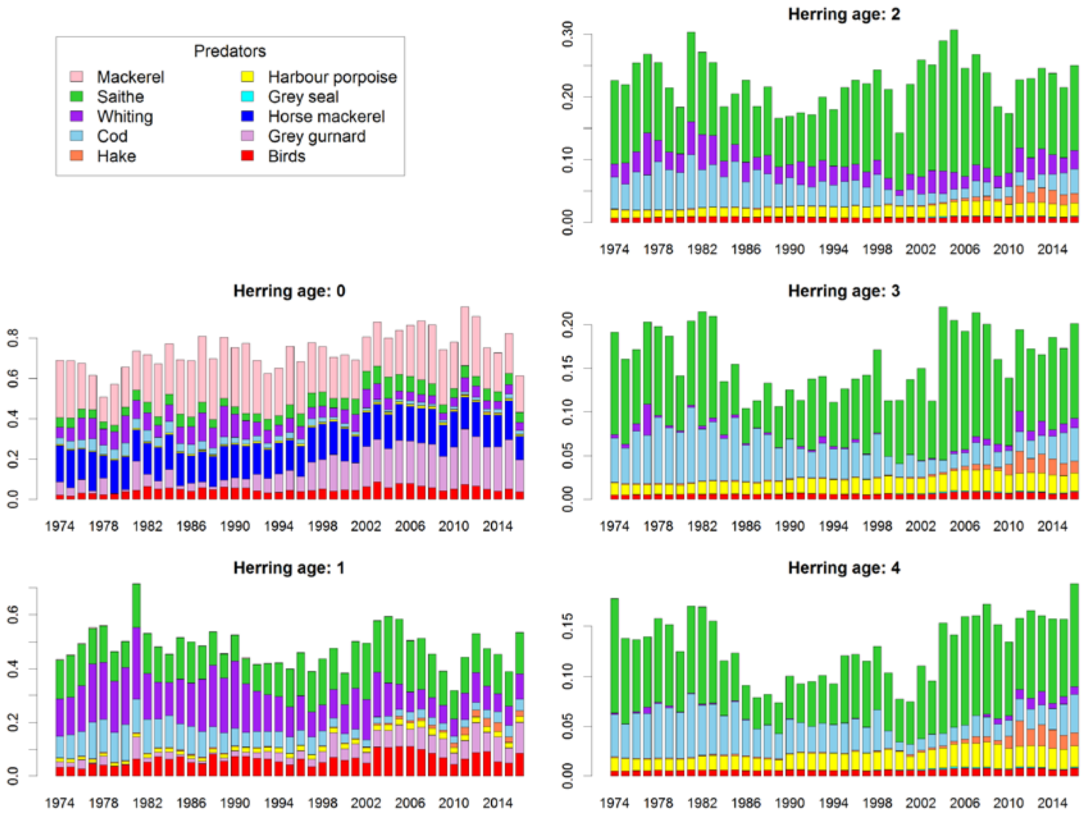


Figure 5.1.22. (Continued). Annual predation mortality (M2) by prey species and age inflicted by predator species.

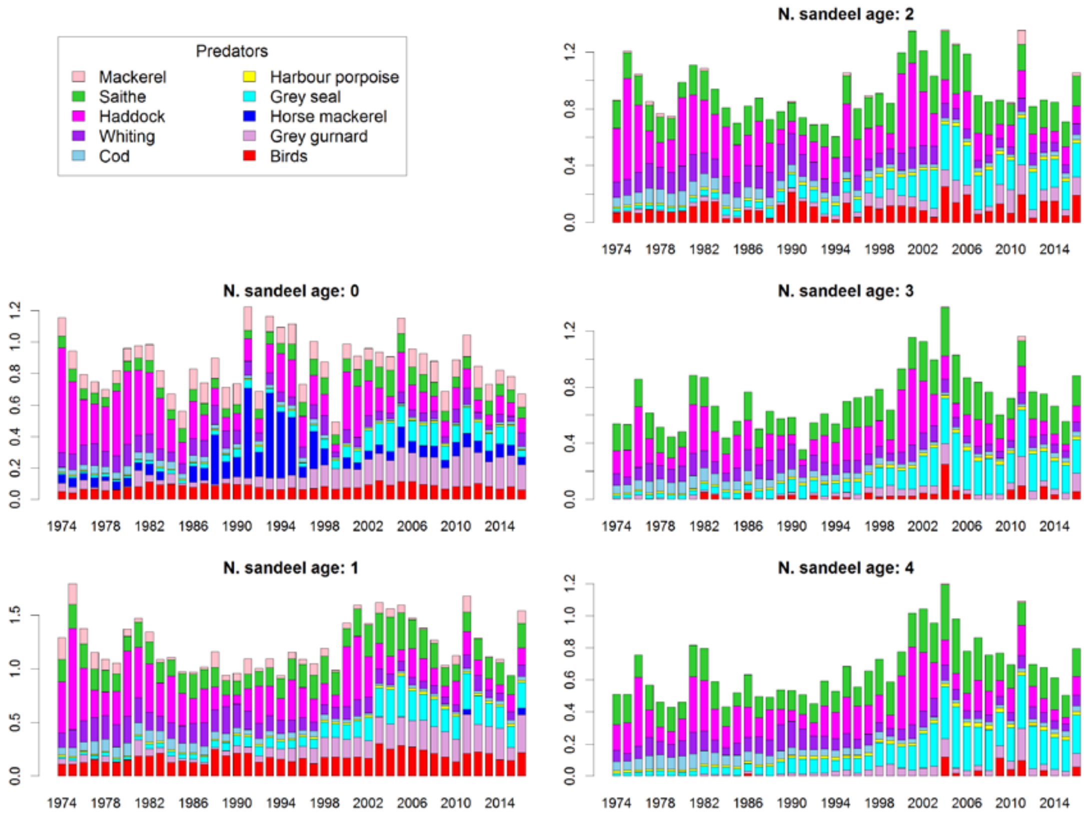


Figure 5.1.22. (Continued). Annual predation mortality (M2) by prey species and age inflicted by predator species.

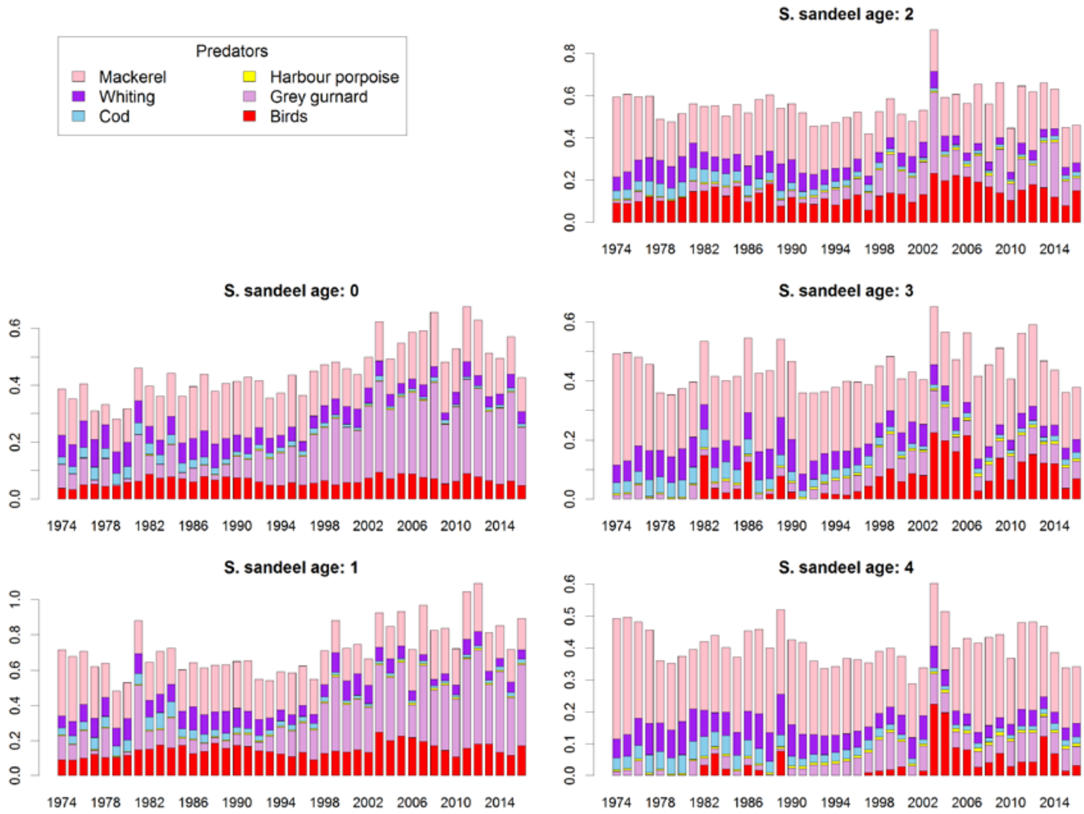


Figure 5.1.22. (Continued). Annual predation mortality (M2) by prey species and age inflicted by predator species.

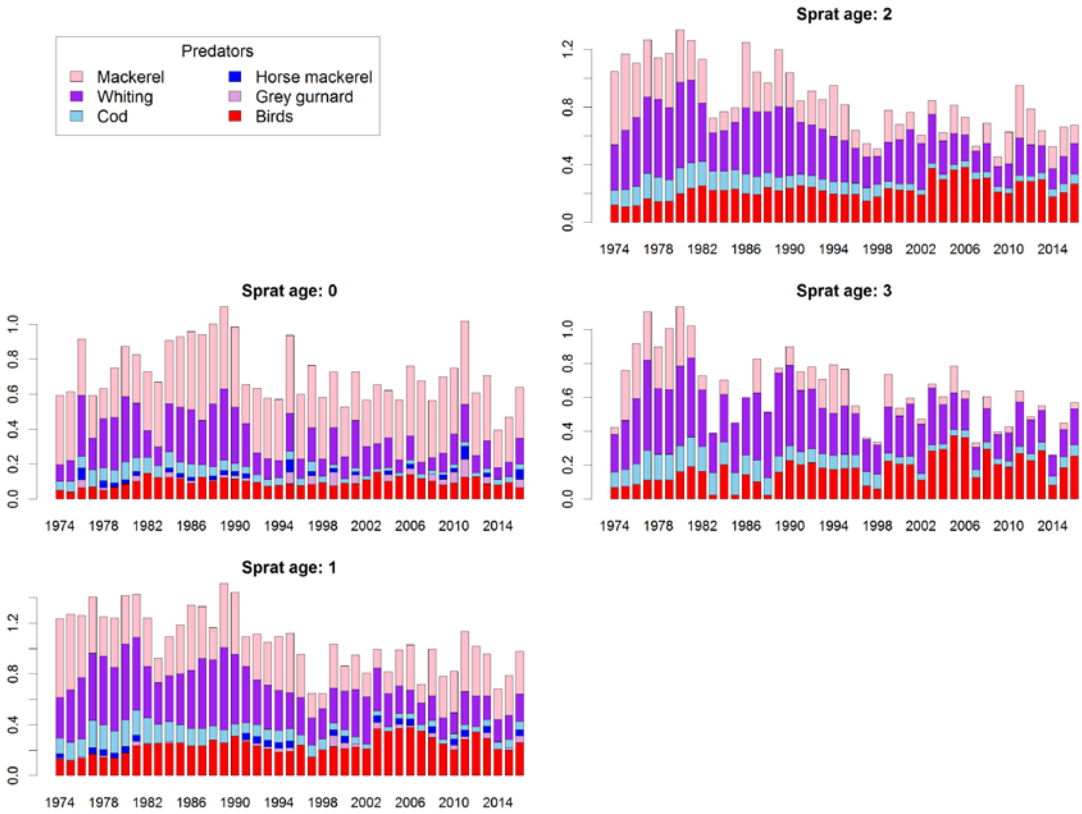


Figure 5.1.22. (Continued). Annual predation mortality (M2) by prey species and age inflicted by predator species.

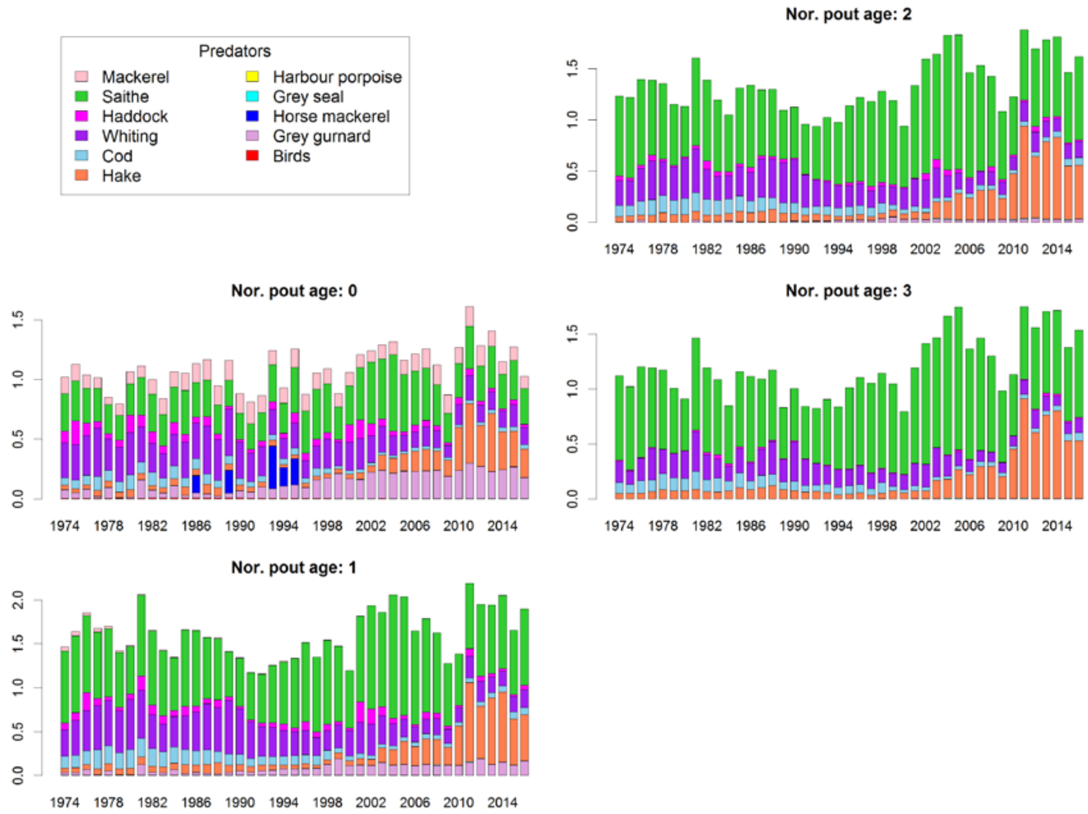


Figure 5.1.22. (Continued). Annual predation mortality (M2) by prey species and age inflicted by predator species.

5.1.5 Uncertainties of key output

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

5.1.5.1 Uncertainties of SSB

The uncertainties presented as a Coefficient of Variation (1 standard deviation of the value divided by the value itself) of SSB (Figure 5.1.23) show the highest uncertainties for the prey species Southern sandeel, Northern sandeel, sprat and Norway pout. The uncertainties for mackerel and for saithe seem too low, probably because of the use of stock numbers from the ICES assessment as artificial survey indices in SMS (see Section 2.1.6.2). A higher CV on the artificial indices should probably have been used to better reflect the uncertainties in the SMS assessment!

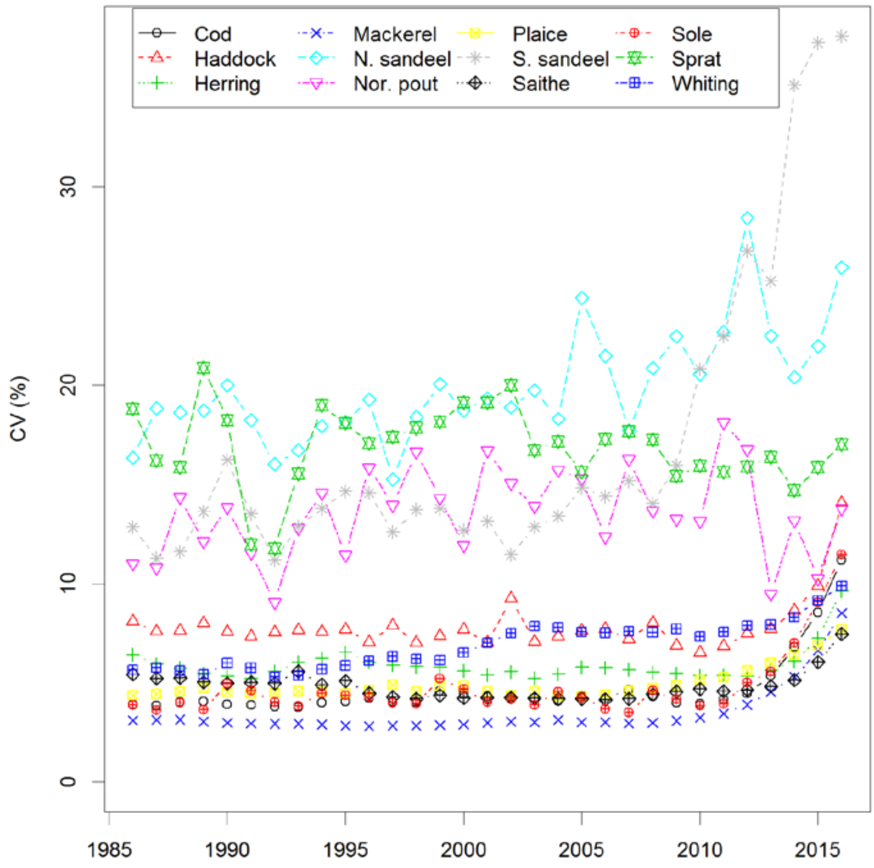


Figure 5.1.23. Uncertainties (1 sd / value) of estimated SSB as estimated by SMS.

5.1.5.2 Uncertainties of mean F

The uncertainties of mean F show a similar pattern as for SSB with the highest CVs are estimated for the prey species. F has been close to zero for some years for herring, which gives a very high CV in some years. For Norway pout, catches are set to zero for a few years, which result in a low (0) CV.

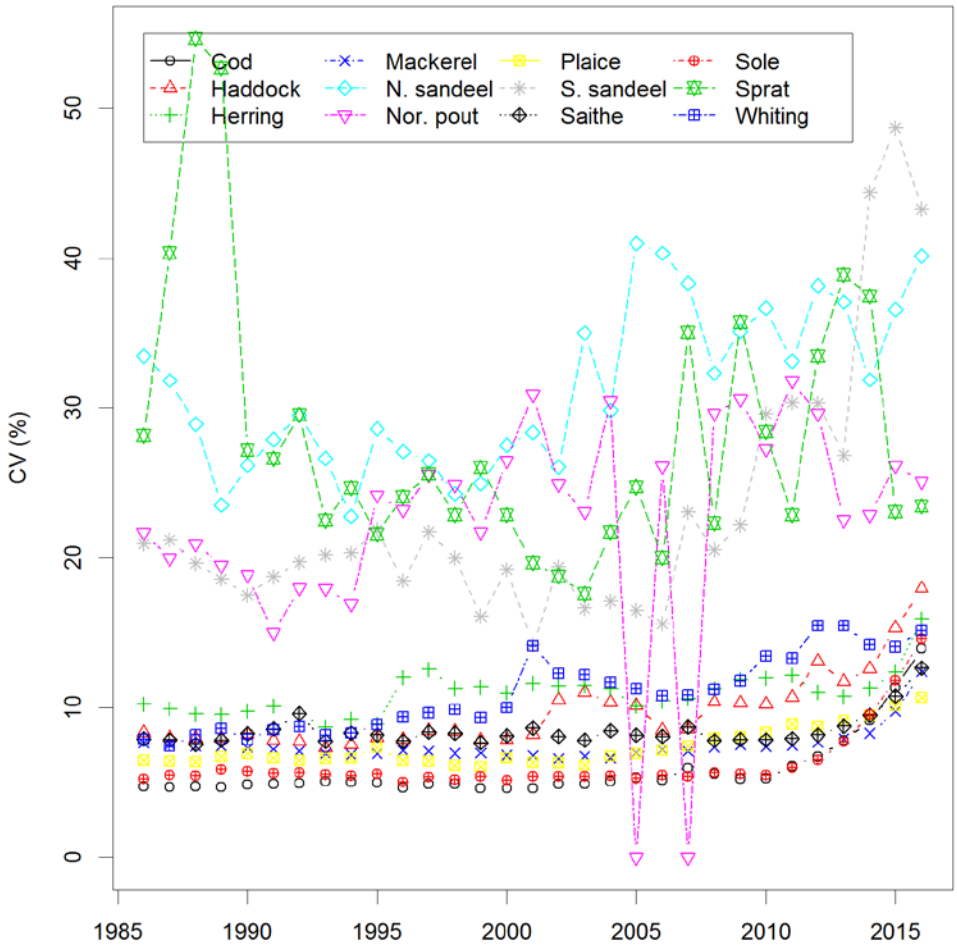


Figure 5.1.24. Uncertainties (1 sd / value) of estimated mean F as estimated by SMS.

5.1.5.3 Uncertainties of recruitment

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

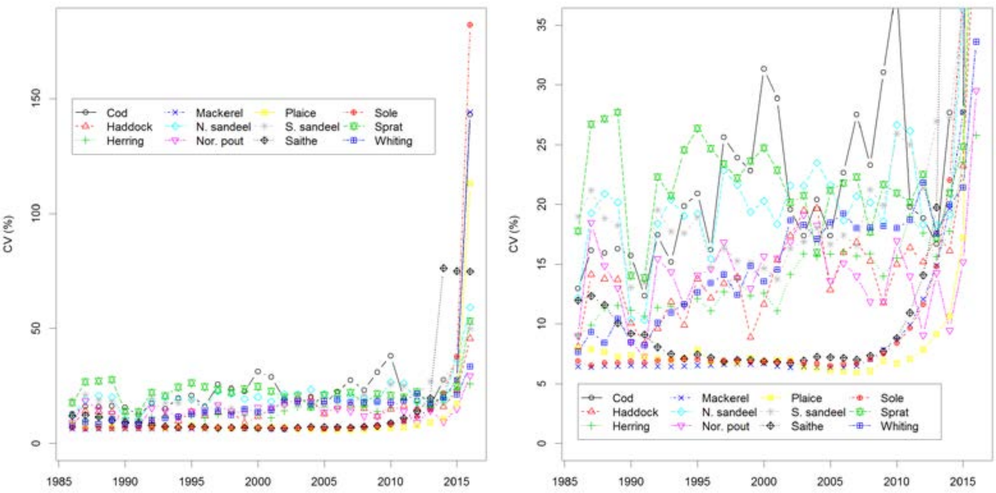
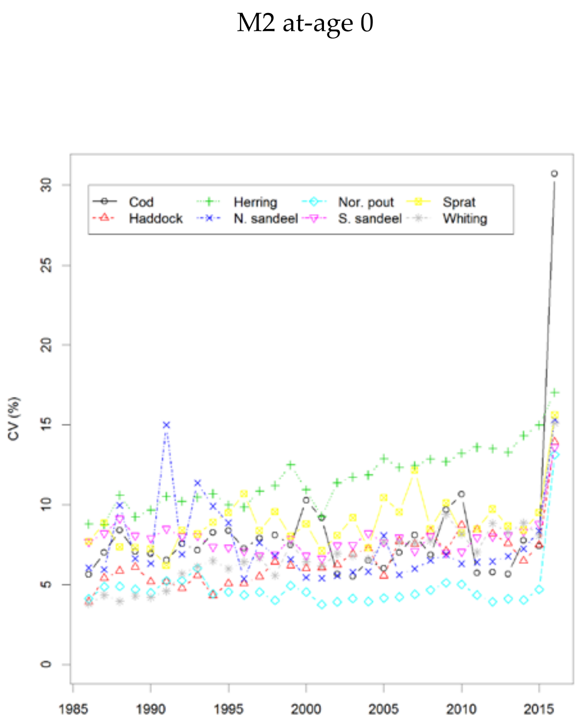
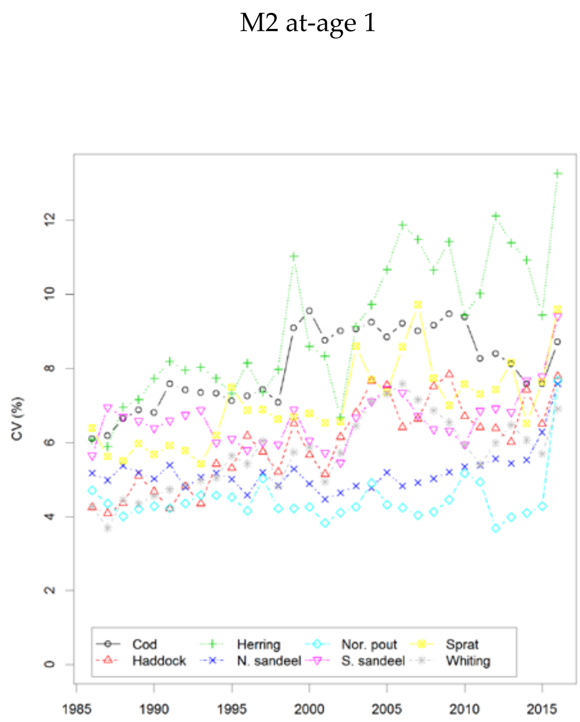


Figure 5.1.25. Uncertainties (1 sd / value) of estimated recruitment as estimated by SMS. Left panel shows the full range of uncertainties and the right panel shows uncertainties up to 35%.

5.1.5.4 Uncertainties of Predation mortality (M2)





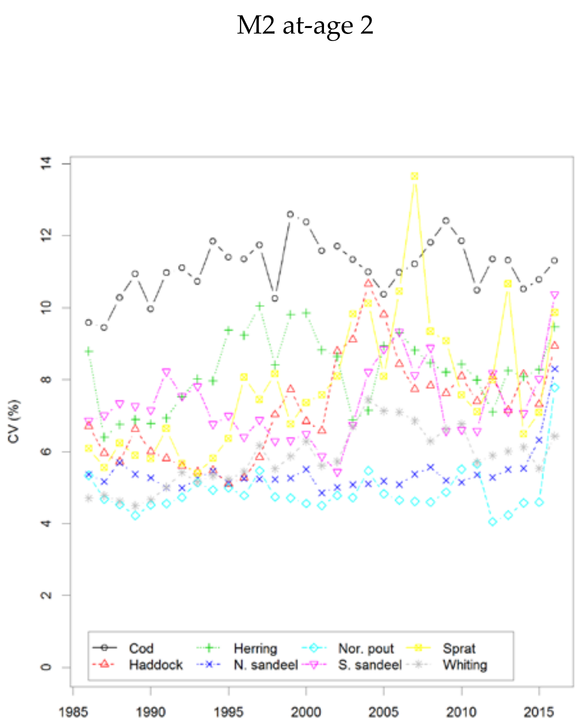


Figure 5.1.26. Uncertainties (1 sd / value) of estimated predation mortality (sum of quarterly M2) as estimated by SMS.

The CVs of M2 are typically in the range 5–10% (Figure 5.1.26), which is in the same range as CV of mean F for the predator species (Figure 5.1.24) and CV of M2 is below the CV of mean F for prey species. For age 0 the CV of M2 increases significantly, due to the uncertainty on recruitment in the most recent year. CV is lowest for all ages for the species Norway pout and northern sandeel, which might be due to the (too) low uncertainty on abundance of their main predators, saithe and mackerel. Saithe is also a main predator on herring, but the CV on herring M2 is relatively high for all ages. CV of M2 is relatively high for cod ages 1 and 2. It is mainly cod itself, with a low uncertainty on stock abundance of older cod (SSB, Figure 5.1.23) and marine mammals, with stock abundance given as input, that predate on cod ages 1–2. The CV on M2 seems therefore mainly to arise from high uncertainties on the model parameters for predation from marine mammals and older cod.

Uncertainties presented as CV may give a biased impression for low values (of the "mean"). Figure 5.1.27 to Figure 5.1.29 show the estimated M2 vales for ages 0–2, with added lines for plus–minus 2 times the standard deviation. The overall picture is that the annual M2 values are statistically different for both examples of M2 without no temporal trend (e.g. ages 0–1 for Norway pout) and examples with a trend (e.g. cod age 0 and age 2).

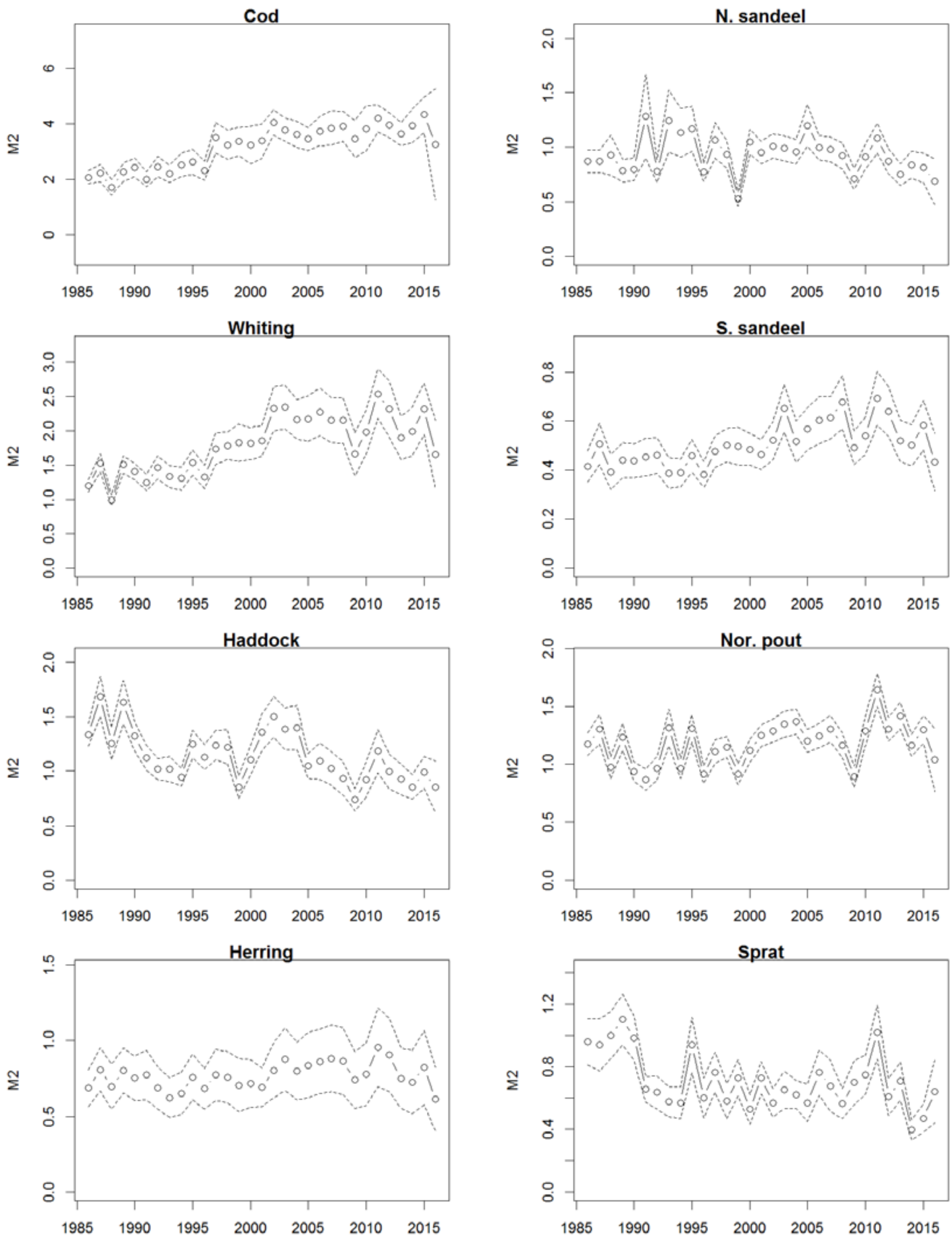


Figure 5.1.27. M2 value with plus–minus 2 times the standard deviation as estimated by SMS.

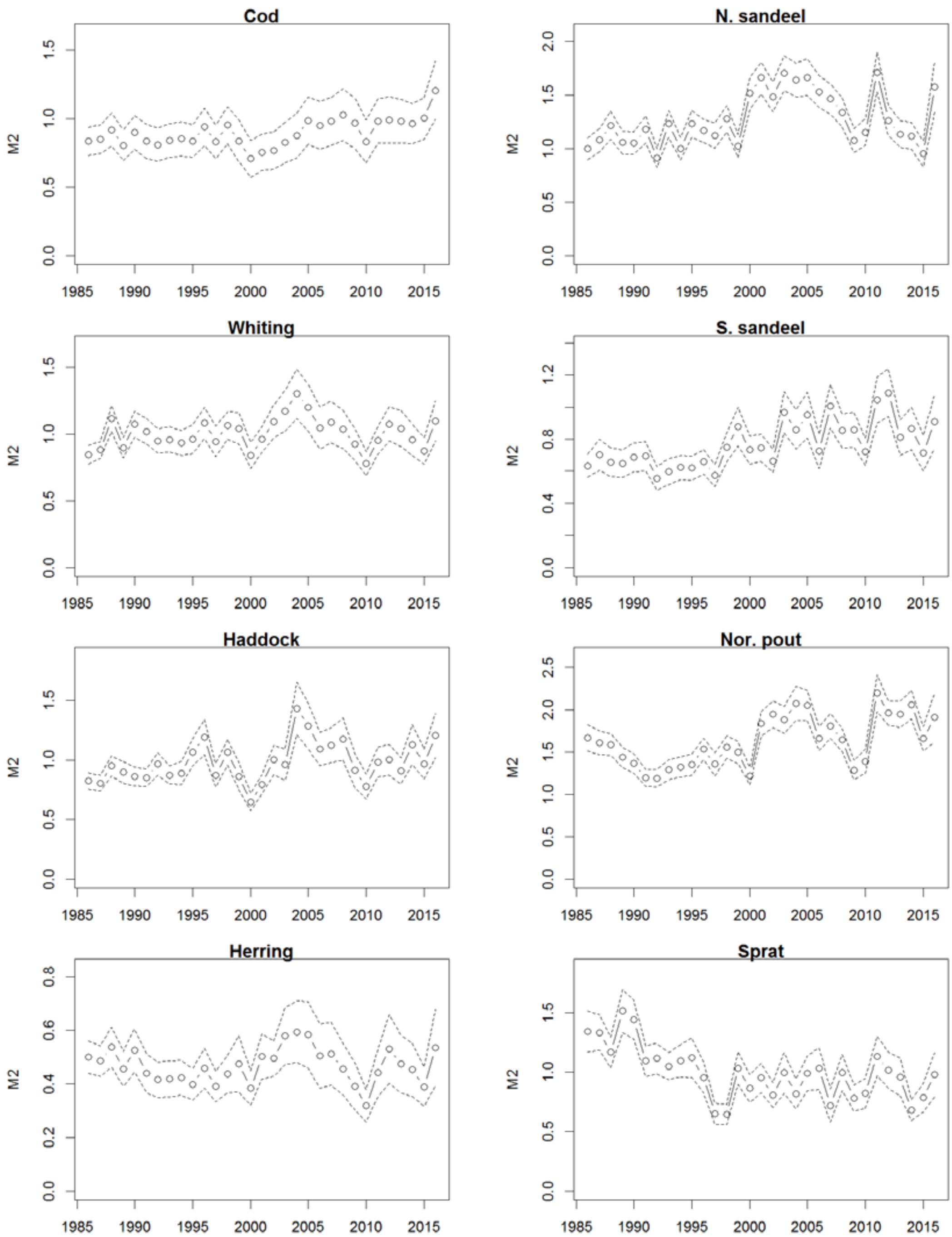


Figure 5.1.28. M2 value with plus–minus 2 times the standard deviation as estimated by SMS.

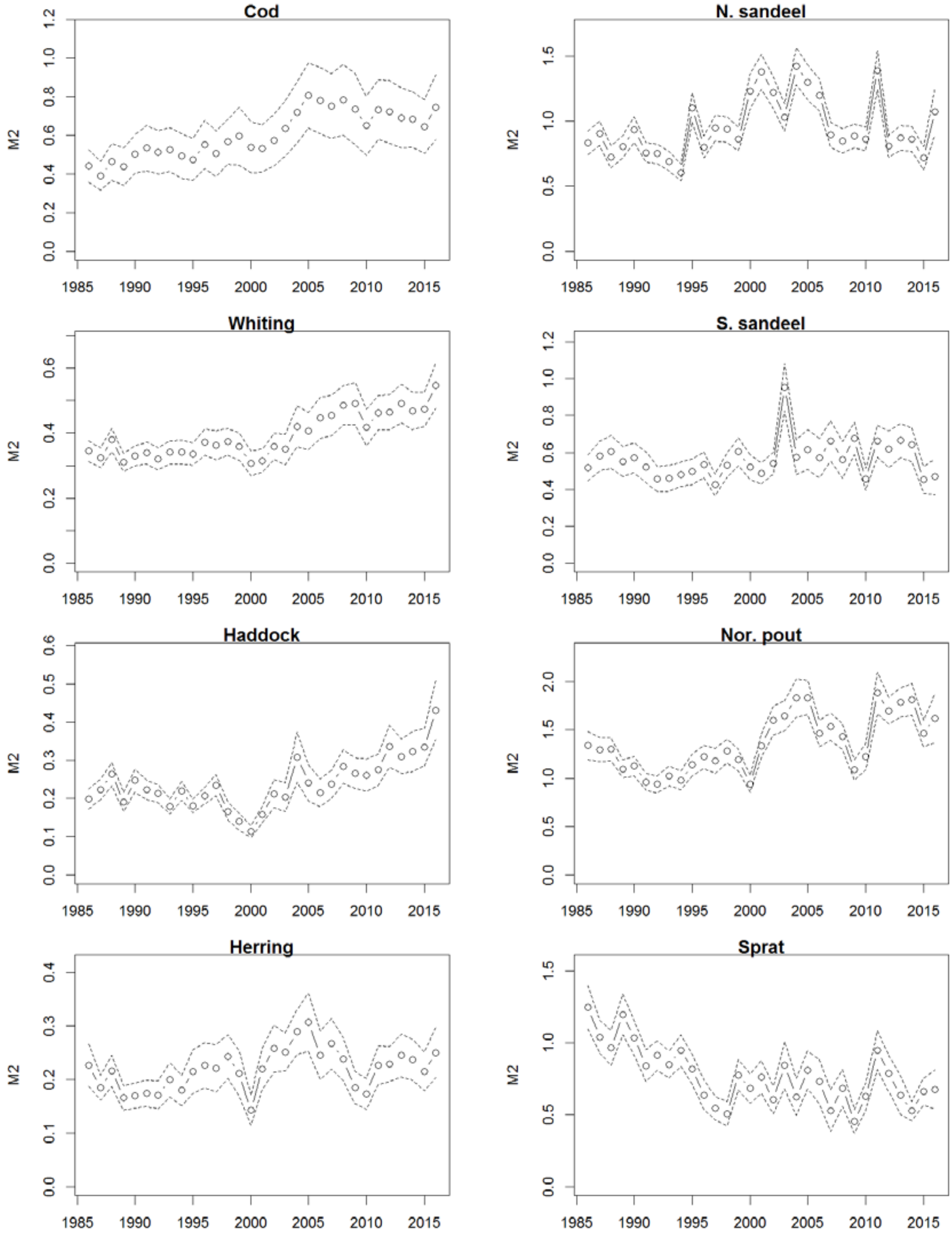


Figure 5.1.29. M2 value with plus–minus 2 times the standard deviation as estimated by SMS.

5.1.6 Natural mortalities (M1+M2)

This section tables the sum of estimated predation mortalities (M2) and the residual natural mortality (M1) given as input to SMS. Natural mortalities (M=M1+M2) estimated by SMS are used as input to the ICES stock assessment. If M values are used, WGSAM does not recommend updating existing (old) dataseries of natural mortality by simply adding the latest three new years. The comparison of M2 from this key run with M2 from the previous key run show the same trend for the two estimates, but the level might be slightly different (see Section 5.2). For example, herring shows an increased natural mortality over the past decade, but adding only the latest three years will give the impression that natural mortality has decreased over the last five years. In addition, a retrospective analysis of M2 shows higher variability of M2 estimates for the terminal years. It has not been tested if the "converged" parts of the estimated M2 values from the two key-runs are statistically different.

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

Year/Age	0	1	2	3	4	5	6	7	8	9	10
1974	2.115	1.153	0.664	0.213	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1975	1.911	1.001	0.668	0.213	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1976	2.390	1.096	0.634	0.214	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1977	2.125	1.137	0.623	0.227	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1978	2.575	1.175	0.587	0.232	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1979	1.638	1.201	0.609	0.217	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1980	2.270	1.058	0.555	0.224	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1981	3.095	1.332	0.638	0.227	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1982	2.586	1.218	0.705	0.242	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1983	1.988	1.236	0.702	0.237	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1984	2.917	1.116	0.668	0.234	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1985	1.820	1.251	0.647	0.234	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1986	2.179	1.036	0.641	0.238	0.209	0.200	0.200	0.200	0.200	0.200	0.200
1987	2.332	1.052	0.591	0.239	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1988	1.827	1.121	0.664	0.247	0.212	0.200	0.200	0.200	0.200	0.200	0.200
1989	2.369	1.006	0.638	0.257	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1990	2.528	1.100	0.702	0.267	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1991	2.112	1.035	0.734	0.268	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1992	2.562	1.010	0.713	0.244	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1993	2.305	1.040	0.725	0.243	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1994	2.634	1.053	0.693	0.250	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1995	2.741	1.036	0.674	0.234	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1996	2.426	1.144	0.753	0.264	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1997	3.603	1.032	0.704	0.262	0.200	0.200	0.200	0.200	0.200	0.200	0.200
1998	3.348	1.154	0.768	0.304	0.219	0.200	0.200	0.200	0.200	0.200	0.200
1999	3.468	1.039	0.795	0.290	0.226	0.200	0.200	0.200	0.200	0.200	0.200
2000	3.344	0.907	0.738	0.294	0.221	0.200	0.200	0.200	0.200	0.200	0.200
2001	3.493	0.956	0.730	0.304	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2002	4.157	0.969	0.774	0.351	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2003	3.890	1.026	0.837	0.389	0.248	0.200	0.200	0.200	0.200	0.200	0.200
2004	3.730	1.078	0.919	0.424	0.248	0.200	0.200	0.200	0.200	0.200	0.200
2005	3.567	1.188	1.007	0.465	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2006	3.844	1.153	0.980	0.394	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2007	3.961	1.181	0.951	0.368	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2008	4.029	1.229	0.984	0.378	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2009	3.558	1.167	0.935	0.304	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2010	3.934	1.034	0.850	0.273	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2011	4.305	1.184	0.932	0.316	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2012	4.061	1.192	0.922	0.328	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2013	3.737	1.182	0.890	0.294	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2014	4.041	1.166	0.883	0.286	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2015	4.435	1.204	0.846	0.337	0.200	0.200	0.200	0.200	0.200	0.200	0.200
2016	3.367	1.408	0.945	0.366	0.200	0.200	0.200	0.200	0.200	0.200	0.200

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

Year/Age	0	1	2	3	4	5	6	7	8
1974	1.180	1.231	0.733	0.534	0.499	0.347	0.307	0.307	0.244
1975	1.130	1.083	0.662	0.491	0.462	0.317	0.462	0.259	0.266
1976	1.518	1.161	0.659	0.477	0.462	0.349	0.278	0.278	0.249
1977	1.154	1.316	0.750	0.483	0.413	0.335	0.335	0.264	0.299
1978	1.418	1.348	0.620	0.539	0.497	0.468	0.468	0.399	0.271
1979	0.931	1.250	0.639	0.537	0.534	0.491	0.465	0.316	0.255
1980	1.295	1.143	0.577	0.504	0.464	0.464	0.422	0.422	0.275
1981	1.865	1.724	0.670	0.548	0.509	0.486	0.468	0.448	0.279
1982	1.404	1.497	0.654	0.583	0.542	0.481	0.418	0.336	0.264
1983	1.113	1.382	0.622	0.523	0.505	0.482	0.474	0.474	0.299
1984	1.650	1.047	0.592	0.501	0.477	0.475	0.457	0.446	0.252
1985	1.107	1.244	0.599	0.497	0.477	0.460	0.452	0.321	0.452
1986	1.298	1.044	0.544	0.502	0.468	0.435	0.383	0.383	0.241
1987	1.627	1.080	0.524	0.456	0.440	0.425	0.421	0.255	0.255
1988	1.086	1.314	0.579	0.527	0.486	0.478	0.439	0.292	0.228
1989	1.604	1.097	0.510	0.492	0.468	0.461	0.446	0.432	0.446
1990	1.510	1.272	0.529	0.486	0.482	0.482	0.452	0.303	0.242
1991	1.342	1.219	0.539	0.509	0.496	0.482	0.482	0.472	0.467
1992	1.562	1.149	0.521	0.487	0.481	0.480	0.473	0.481	0.404
1993	1.429	1.159	0.541	0.480	0.472	0.471	0.462	0.462	0.462
1994	1.402	1.132	0.541	0.499	0.477	0.477	0.477	0.457	0.448
1995	1.631	1.161	0.535	0.472	0.456	0.456	0.449	0.449	0.443
1996	1.426	1.283	0.572	0.518	0.511	0.478	0.478	0.469	0.469
1997	1.837	1.145	0.562	0.499	0.489	0.477	0.464	0.464	0.463
1998	1.878	1.265	0.574	0.507	0.488	0.474	0.469	0.469	0.469
1999	1.924	1.241	0.559	0.534	0.500	0.493	0.483	0.483	0.493
2000	1.910	1.040	0.507	0.469	0.466	0.466	0.466	0.466	0.466
2001	1.948	1.159	0.515	0.460	0.447	0.447	0.442	0.447	0.447
2002	2.422	1.294	0.559	0.520	0.489	0.470	0.465	0.465	0.465
2003	2.438	1.374	0.550	0.524	0.493	0.490	0.465	0.462	0.465
2004	2.263	1.501	0.620	0.587	0.549	0.549	0.549	0.549	0.530
2005	2.273	1.399	0.607	0.564	0.556	0.554	0.552	0.554	0.556
2006	2.372	1.245	0.646	0.584	0.568	0.566	0.528	0.562	0.566
2007	2.253	1.290	0.654	0.563	0.530	0.530	0.535	0.535	0.530
2008	2.249	1.235	0.686	0.595	0.556	0.541	0.541	0.556	0.547
2009	1.757	1.122	0.691	0.571	0.539	0.539	0.465	0.539	0.539
2010	2.074	0.978	0.617	0.513	0.487	0.483	0.487	0.483	0.487
2011	2.635	1.154	0.663	0.514	0.507	0.502	0.297	0.502	0.221
2012	2.414	1.275	0.664	0.562	0.527	0.527	0.527	0.519	0.519
2013	1.993	1.241	0.691	0.571	0.520	0.389	0.319	0.238	0.444
2014	2.086	1.156	0.668	0.571	0.571	0.435	0.306	0.234	0.234
2015	2.417	1.071	0.673	0.551	0.532	0.532	0.368	0.307	0.241
2016	1.751	1.297	0.746	0.620	0.563	0.559	0.559	0.339	0.559

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

Year/Age	0	1	2	3	4	5	6	7	8	9	10
1974	1.059	1.519	0.746	0.548	0.426	0.244	0.254	0.244	0.214	0.200	0.200
1975	1.258	1.320	0.771	0.466	0.398	0.301	0.214	0.238	0.238	0.206	0.200
1976	1.547	1.371	0.703	0.461	0.397	0.313	0.260	0.202	0.204	0.220	0.200
1977	1.578	1.621	0.727	0.509	0.306	0.294	0.270	0.237	0.201	0.200	0.203
1978	1.304	1.665	0.685	0.514	0.491	0.257	0.256	0.235	0.212	0.200	0.200
1979	1.276	1.599	0.660	0.424	0.340	0.263	0.231	0.213	0.213	0.209	0.200
1980	1.794	1.301	0.537	0.393	0.248	0.227	0.227	0.208	0.205	0.205	0.202
1981	1.498	2.015	0.690	0.435	0.277	0.223	0.212	0.215	0.203	0.202	0.203
1982	1.545	1.925	0.582	0.422	0.274	0.236	0.207	0.206	0.206	0.200	0.200
1983	1.172	1.742	0.500	0.410	0.316	0.238	0.215	0.215	0.202	0.204	0.204
1984	1.475	1.158	0.492	0.346	0.295	0.269	0.226	0.212	0.201	0.200	0.202
1985	1.421	1.308	0.496	0.358	0.287	0.242	0.232	0.210	0.203	0.200	0.200
1986	1.437	1.025	0.399	0.331	0.285	0.236	0.213	0.215	0.205	0.208	0.200
1987	1.787	1.006	0.424	0.359	0.267	0.221	0.208	0.207	0.208	0.206	0.201
1988	1.354	1.150	0.464	0.323	0.291	0.258	0.210	0.204	0.208	0.218	0.202
1989	1.733	1.097	0.391	0.361	0.265	0.229	0.223	0.206	0.201	0.201	0.218
1990	1.422	1.062	0.447	0.339	0.308	0.240	0.215	0.210	0.202	0.201	0.200
1991	1.222	1.051	0.423	0.314	0.276	0.263	0.223	0.206	0.204	0.201	0.200
1992	1.121	1.165	0.413	0.303	0.243	0.218	0.221	0.203	0.201	0.200	0.200
1993	1.120	1.075	0.380	0.293	0.249	0.221	0.212	0.211	0.201	0.201	0.200
1994	1.046	1.090	0.420	0.298	0.267	0.227	0.204	0.203	0.203	0.201	0.200
1995	1.350	1.267	0.381	0.304	0.266	0.226	0.208	0.202	0.205	0.204	0.200
1996	1.228	1.390	0.407	0.297	0.279	0.241	0.216	0.225	0.200	0.201	0.202
1997	1.340	1.072	0.435	0.309	0.252	0.249	0.210	0.210	0.202	0.200	0.200
1998	1.323	1.265	0.367	0.309	0.295	0.255	0.223	0.204	0.204	0.202	0.200
1999	0.956	1.063	0.339	0.310	0.270	0.265	0.233	0.227	0.220	0.201	0.200
2000	1.203	0.847	0.313	0.298	0.262	0.238	0.235	0.203	0.206	0.200	0.200
2001	1.460	0.995	0.358	0.298	0.262	0.245	0.228	0.204	0.200	0.202	0.200
2002	1.600	1.201	0.413	0.359	0.252	0.251	0.215	0.215	0.201	0.200	0.200
2003	1.489	1.163	0.404	0.346	0.290	0.264	0.234	0.203	0.201	0.200	0.200
2004	1.501	1.632	0.508	0.401	0.396	0.391	0.274	0.204	0.201	0.200	0.200
2005	1.150	1.485	0.441	0.389	0.293	0.296	0.293	0.208	0.202	0.201	0.200
2006	1.192	1.291	0.415	0.372	0.334	0.275	0.275	0.273	0.203	0.201	0.200
2007	1.125	1.324	0.438	0.290	0.273	0.268	0.260	0.260	0.240	0.208	0.200
2008	1.035	1.377	0.483	0.299	0.266	0.266	0.266	0.205	0.205	0.207	0.200
2009	0.839	1.112	0.466	0.396	0.306	0.255	0.221	0.208	0.201	0.201	0.202
2010	1.021	0.977	0.461	0.289	0.277	0.277	0.261	0.204	0.201	0.201	0.201
2011	1.284	1.184	0.476	0.304	0.304	0.304	0.298	0.290	0.212	0.298	0.200
2012	1.097	1.202	0.536	0.299	0.285	0.273	0.273	0.273	0.201	0.211	0.201
2013	1.027	1.110	0.510	0.268	0.297	0.253	0.214	0.238	0.238	0.210	0.200
2014	0.955	1.330	0.523	0.277	0.277	0.288	0.237	0.222	0.213	0.228	0.200
2015	1.089	1.165	0.534	0.317	0.243	0.276	0.276	0.276	0.207	0.268	0.271
2016	0.955	1.405	0.630	0.301	0.262	0.224	0.216	0.277	0.245	0.208	0.200

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

Year/Age	0	1	2	3	4	5	6	7	8	9
1974	0.739	0.534	0.326	0.292	0.278	0.253	0.247	0.239	0.239	0.236
1975	0.737	0.552	0.319	0.261	0.238	0.229	0.215	0.210	0.208	0.208
1976	0.725	0.594	0.354	0.272	0.236	0.218	0.208	0.203	0.203	0.203
1977	0.665	0.652	0.368	0.303	0.240	0.219	0.199	0.194	0.192	0.199
1978	0.558	0.661	0.355	0.298	0.258	0.231	0.223	0.217	0.217	0.217
1979	0.621	0.564	0.315	0.287	0.252	0.232	0.217	0.204	0.204	0.202
1980	0.706	0.603	0.284	0.242	0.225	0.213	0.195	0.186	0.186	0.186
1981	0.785	0.817	0.403	0.304	0.270	0.247	0.218	0.209	0.209	0.209
1982	0.768	0.632	0.371	0.315	0.270	0.227	0.220	0.198	0.198	0.192
1983	0.721	0.581	0.355	0.310	0.255	0.235	0.203	0.197	0.192	0.192
1984	0.822	0.555	0.284	0.235	0.216	0.195	0.186	0.177	0.177	0.173
1985	0.742	0.616	0.305	0.255	0.223	0.197	0.180	0.174	0.172	0.179
1986	0.737	0.600	0.327	0.205	0.191	0.182	0.170	0.163	0.163	0.163
1987	0.859	0.586	0.285	0.213	0.179	0.176	0.165	0.158	0.152	0.138
1988	0.747	0.637	0.316	0.233	0.182	0.182	0.168	0.162	0.158	0.151
1989	0.854	0.557	0.266	0.206	0.174	0.163	0.160	0.146	0.146	0.134
1990	0.803	0.625	0.270	0.225	0.200	0.187	0.170	0.163	0.163	0.141
1991	0.823	0.540	0.275	0.214	0.193	0.176	0.164	0.159	0.164	0.149
1992	0.738	0.516	0.271	0.238	0.195	0.178	0.161	0.150	0.150	0.141
1993	0.673	0.520	0.300	0.241	0.201	0.172	0.154	0.148	0.146	0.130
1994	0.701	0.523	0.280	0.211	0.192	0.171	0.157	0.157	0.148	0.145
1995	0.810	0.499	0.315	0.226	0.221	0.199	0.190	0.179	0.151	0.148
1996	0.733	0.559	0.326	0.238	0.222	0.205	0.166	0.166	0.157	0.154
1997	0.825	0.490	0.321	0.242	0.215	0.177	0.166	0.153	0.151	0.142
1998	0.808	0.537	0.343	0.271	0.230	0.211	0.174	0.160	0.158	0.133
1999	0.756	0.576	0.312	0.213	0.203	0.191	0.168	0.160	0.160	0.147
2000	0.766	0.484	0.243	0.214	0.177	0.174	0.157	0.154	0.141	0.128
2001	0.741	0.602	0.320	0.238	0.174	0.159	0.155	0.155	0.153	0.141
2002	0.855	0.595	0.358	0.250	0.210	0.180	0.171	0.171	0.179	0.156
2003	0.929	0.679	0.351	0.213	0.196	0.175	0.164	0.156	0.161	0.154
2004	0.850	0.695	0.389	0.321	0.253	0.236	0.224	0.203	0.203	0.188
2005	0.888	0.684	0.407	0.305	0.241	0.229	0.197	0.181	0.173	0.189
2006	0.913	0.604	0.345	0.292	0.260	0.241	0.225	0.204	0.194	0.190
2007	0.934	0.613	0.368	0.314	0.261	0.238	0.217	0.202	0.193	0.200
2008	0.915	0.555	0.338	0.301	0.272	0.243	0.218	0.198	0.196	0.184
2009	0.791	0.491	0.284	0.260	0.252	0.228	0.210	0.201	0.197	0.188
2010	0.830	0.418	0.274	0.239	0.235	0.222	0.213	0.208	0.201	0.199
2011	1.005	0.542	0.327	0.294	0.258	0.249	0.243	0.231	0.216	0.216
2012	0.957	0.630	0.329	0.273	0.266	0.246	0.223	0.216	0.202	0.195
2013	0.801	0.574	0.345	0.266	0.261	0.239	0.236	0.222	0.209	0.208
2014	0.777	0.554	0.338	0.286	0.257	0.253	0.234	0.234	0.222	0.215
2015	0.873	0.489	0.315	0.273	0.257	0.243	0.238	0.236	0.229	0.223
2016	0.664	0.635	0.350	0.302	0.293	0.270	0.259	0.247	0.240	0.233

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

Year/Age	**0**	**1**	**2**	**3**	**4**
1974	1.266	1.506	1.064	0.739	0.711
1975	1.053	2.012	1.407	0.734	0.711
1976	0.907	1.596	1.247	1.056	0.955
1977	0.861	1.372	1.050	0.817	0.767
1978	0.811	1.310	0.967	0.712	0.663
1979	0.930	1.273	0.950	0.645	0.630
1980	1.076	1.590	1.187	0.682	0.662
1981	1.090	1.691	1.309	1.084	1.017
1982	1.098	1.562	1.301	1.070	0.998
1983	0.942	1.322	1.147	0.863	0.791
1984	0.812	1.331	1.011	0.640	0.632
1985	0.681	1.198	0.899	0.757	0.722
1986	0.971	1.197	1.033	0.980	0.834
1987	0.970	1.279	1.107	0.700	0.698
1988	1.028	1.417	0.925	0.827	0.693
1989	0.886	1.254	1.004	0.774	0.738
1990	0.896	1.252	1.135	0.785	0.735
1991	1.382	1.381	0.959	0.553	0.708
1992	0.881	1.110	0.950	0.746	0.653
1993	1.341	1.430	0.892	0.811	0.795
1994	1.234	1.198	0.805	0.738	0.730
1995	1.268	1.429	1.304	0.899	0.886
1996	0.872	1.365	1.001	0.922	0.755
1997	1.163	1.320	1.147	0.944	0.856
1998	1.035	1.477	1.137	0.986	0.931
1999	0.627	1.225	1.063	0.837	0.788
2000	1.146	1.715	1.432	1.129	0.975
2001	1.053	1.861	1.581	1.355	1.217
2002	1.109	1.681	1.420	1.338	1.244
2003	1.089	1.902	1.230	1.194	1.155
2004	1.058	1.837	1.624	1.628	1.441
2005	1.299	1.864	1.500	1.228	1.180
2006	1.094	1.731	1.400	1.066	0.979
2007	1.079	1.663	1.094	1.034	1.064
2008	1.021	1.535	1.049	0.966	0.957
2009	0.809	1.275	1.085	0.803	0.978
2010	1.010	1.353	1.064	0.939	0.896
2011	1.180	1.911	1.591	1.392	1.324
2012	0.970	1.462	1.008	0.967	0.899
2013	0.848	1.335	1.072	0.956	0.879
2014	0.938	1.317	1.064	0.865	0.814
2015	0.912	1.151	0.916	0.755	0.704
2016	0.785	1.774	1.275	1.093	1.005

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

Year/Age	0	1	2	3	4
1974	0.491	0.924	0.793	0.693	0.692
1975	0.457	0.886	0.806	0.696	0.696
1976	0.510	0.915	0.795	0.681	0.681
1977	0.416	0.829	0.798	0.656	0.656
1978	0.438	0.849	0.689	0.560	0.560
1979	0.385	0.688	0.675	0.552	0.552
1980	0.424	0.739	0.715	0.574	0.574
1981	0.565	1.091	0.761	0.596	0.596
1982	0.503	0.853	0.750	0.735	0.620
1983	0.472	0.876	0.763	0.615	0.639
1984	0.561	0.901	0.711	0.601	0.601
1985	0.472	0.824	0.764	0.615	0.571
1986	0.515	0.834	0.718	0.745	0.654
1987	0.607	0.901	0.781	0.626	0.658
1988	0.491	0.856	0.804	0.635	0.600
1989	0.540	0.850	0.751	0.751	0.719
1990	0.538	0.888	0.771	0.667	0.625
1991	0.552	0.895	0.720	0.560	0.617
1992	0.559	0.755	0.656	0.559	0.559
1993	0.488	0.797	0.659	0.565	0.536
1994	0.489	0.824	0.681	0.578	0.543
1995	0.558	0.819	0.696	0.599	0.568
1996	0.482	0.858	0.732	0.596	0.563
1997	0.575	0.773	0.625	0.592	0.553
1998	0.601	0.951	0.732	0.651	0.589
1999	0.597	1.076	0.804	0.683	0.599
2000	0.585	0.933	0.720	0.608	0.574
2001	0.563	0.947	0.687	0.630	0.488
2002	0.621	0.866	0.742	0.611	0.539
2003	0.752	1.168	1.153	0.862	0.803
2004	0.616	1.059	0.774	0.774	0.715
2005	0.668	1.151	0.815	0.672	0.600
2006	0.703	0.924	0.770	0.764	0.630
2007	0.713	1.207	0.863	0.616	0.615
2008	0.776	1.053	0.761	0.655	0.633
2009	0.592	1.057	0.877	0.711	0.642
2010	0.640	0.924	0.655	0.607	0.569
2011	0.792	1.245	0.862	0.762	0.679
2012	0.739	1.289	0.818	0.790	0.681
2013	0.619	1.011	0.865	0.668	0.668
2014	0.602	1.066	0.843	0.641	0.585
2015	0.684	0.914	0.652	0.561	0.538
2016	0.532	1.110	0.669	0.579	0.542

Norway pout : Natural mortality (sum of quarterly M1+M2)

Year/Age	**0**	**1**	**2**	**3**
1974	1.130	1.666	1.434	1.320
1975	1.236	1.842	1.421	1.221
1976	1.148	2.060	1.596	1.401
1977	1.126	1.880	1.591	1.392
1978	0.962	1.904	1.554	1.372
1979	0.906	1.626	1.354	1.207
1980	1.179	1.689	1.333	1.108
1981	1.225	2.268	1.806	1.661
1982	1.113	1.856	1.590	1.391
1983	0.962	1.636	1.398	1.285
1984	1.212	1.560	1.250	1.050
1985	1.174	1.872	1.512	1.356
1986	1.275	1.868	1.538	1.313
1987	1.403	1.808	1.496	1.292
1988	1.073	1.791	1.499	1.372
1989	1.335	1.638	1.297	1.030
1990	1.039	1.564	1.325	1.204
1991	0.966	1.394	1.161	1.039
1992	1.065	1.393	1.138	1.023
1993	1.418	1.495	1.224	1.104
1994	1.066	1.523	1.176	1.036
1995	1.408	1.553	1.339	1.211
1996	1.014	1.736	1.421	1.305
1997	1.210	1.559	1.380	1.252
1998	1.249	1.759	1.483	1.342
1999	1.017	1.697	1.390	1.248
2000	1.219	1.417	1.142	0.991
2001	1.349	2.035	1.535	1.393
2002	1.390	2.146	1.796	1.610
2003	1.447	2.081	1.843	1.666
2004	1.469	2.276	2.028	1.863
2005	1.305	2.255	2.033	1.944
2006	1.348	1.861	1.662	1.566
2007	1.407	2.007	1.737	1.660
2008	1.264	1.844	1.628	1.500
2009	0.994	1.488	1.287	1.184
2010	1.390	1.592	1.426	1.332
2011	1.743	2.398	2.081	1.949
2012	1.405	2.161	1.898	1.758
2013	1.518	2.146	1.984	1.903
2014	1.266	2.261	2.013	1.914
2015	1.401	1.860	1.665	1.576
2016	1.138	2.109	1.818	1.734

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

Year/Age	0	1	2	3
1974	0.693	1.434	1.246	0.622
1975	0.714	1.468	1.369	0.959
1976	1.016	1.460	1.303	1.115
1977	0.693	1.604	1.468	1.303
1978	0.732	1.450	1.343	1.098
1979	0.851	1.438	1.372	1.205
1980	0.974	1.619	1.535	1.335
1981	0.927	1.630	1.461	1.221
1982	0.829	1.441	1.330	0.927
1983	0.769	1.125	0.923	0.588
1984	1.008	1.295	0.970	0.901
1985	1.028	1.388	0.994	0.649
1986	1.058	1.543	1.447	0.797
1987	1.040	1.532	1.241	1.026
1988	1.101	1.366	1.167	0.712
1989	1.202	1.715	1.398	0.972
1990	1.083	1.641	1.237	1.099
1991	0.755	1.294	1.043	0.952
1992	0.735	1.314	1.113	0.979
1993	0.677	1.250	1.051	0.905
1994	0.670	1.297	1.148	0.993
1995	1.038	1.322	1.017	0.964
1996	0.699	1.156	0.838	0.750
1997	0.865	0.849	0.745	0.561
1998	0.682	0.844	0.708	0.537
1999	0.827	1.234	0.977	0.934
2000	0.627	1.063	0.882	0.736
2001	0.829	1.151	0.964	0.794
2002	0.667	1.006	0.805	0.672
2003	0.753	1.193	1.045	0.877
2004	0.722	1.018	0.825	0.805
2005	0.668	1.190	1.011	0.983
2006	0.863	1.230	0.930	0.839
2007	0.775	0.920	0.729	0.533
2008	0.665	1.196	0.886	0.804
2009	0.800	0.982	0.654	0.597
2010	0.849	1.022	0.827	0.628
2011	1.118	1.334	1.148	0.839
2012	0.707	1.218	0.988	0.685
2013	0.807	1.158	0.836	0.750
2014	0.496	0.883	0.726	0.461
2015	0.570	0.988	0.861	0.649
2016	0.740	1.178	0.875	0.767

5.2 Comparison with the 2015 key run

Since the last key run in 2014, (which was updated in 2015) there have been several changes in input data to the SMS:

- Update of "single-species data" (catch-at-age numbers, mean weights, proportion mature, survey indices, etc.) with use of the most recent ICES assessment input data. Re-estimation of quarterly mean weight-at-age in the sea from ICES annual data and quarterly differences from existing SMS data. Some stocks have been benchmarked since the 2014 key run, giving substantial changes in both the ICES and the SMS assessments.
- Inclusion of mackerel as a dynamic species, which replaces the "external predators" North Sea mackerel and Western stock mackerel. With both approaches the proportion of the North Atlantic mackerel within the North Sea needs to be known. In lack of a documented time-series for that, WGSAM made their own estimate of stock distribution, where used in SMS.
- Re-calculation of "single-species data" for the two sandeel stocks, as the present ICES stock areas for sandeel fit poorly into the northern and southern sandeel areas used in SMS.
- Update of consumption estimates (daily ration) of fish predators, particularly mackerel and horse mackerel using updated parameter for the evacuation model.
- Bias correction of diet estimate from observed stomach contents taking variable evacuation rate of prey species, stomach fullness and temperature into account for the fish stocks (cod, whiting, haddock saithe and mackerel) and taking variable evacuation rates of otolith (sizes) into account for harbour porpoise.
- Inclusion of distribution of fish stocks making calculations of M2 based only on the predator and prey stock numbers within the North Sea area.

The following sections describes the changes in the main output variable between the (in 2015 updated) 2014 key run and the new 2017 key run.

5.2.1 Cod

The main differences for cod between the two key runs are a somewhat higher recruitment in the last two decades in the 207 key run (Figure 5.2.1, upper panel). The higher recruitment fits very well to the higher M2 in the new run (Figure 5.2.1, upper panel).

There has been very little change in the predation mortality of cod of age 1 and 2 between the 2014 and 2017 key runs.

Predation mortality of cod age 3 has increased substantially since the last key run. This is a result of the updated time-series for weight-at-age of cod in the stock, which results in lower mean, weights which are consistently within the range, which can be consumed by both harbour porpoise and grey seals. Harbour porpoise has been observed to eat 3.029 kg cod, grey seal up to 4.066 kg. This means that 4-year olds are not consistently included in the diet since they are only occasionally below 4 kg. The high predation mortality of age 3 cod around year 2000 corresponds to the increase in the grey seal population (see Section 5.3). When age 4 is predated on, M2 is always low.

5.2.2 Whiting

Recruitment is pretty much the same in the two runs which is in line similar M2 for ages 0–1 (Figure 5.2.2). Predation mortality of older age groups has decreased in the new run. This is partly a result of the correction of harbour porpoise consumption to account for longer residence times of whiting otoliths in porpoise stomachs than those of e.g. herring and sandeel. The bias correction of diet data for fish predator may also influence.

5.2.3 Haddock

Predation of haddock is largely the same between the two key runs (Figure 5.2.3). The two series may be different due to the updated time-series for weight-at-age of haddock in the stock and substantial changes in the stock numbers of the main predator saithe due to changes (benchmark) in the ICES saithe assessment. SSB is estimated lower in the new run, probably due to the lower mean weight-at-age used in 2017.

5.2.4 Saithe

The two saithe assessments are quite similar; despite the saithe assessment has been benchmarked since the last key run (Figure 5.2.4).

5.2.5 Herring

The two herring assessments are quiet similar (Figure 5.2.5), however with slightly higher F and lower SSB in the 2017. There has been little change in the predation mortality of herring of age 1 and 2 between the 2014 and 2017 key runs. Predation mortality of age 0 has increased further, while that of age 3 and 4 has decreased. The changes to predation mortality-at-age 0 seems to be linked to the changes in mackerel and horse mackerel biomass, consumption and diet, as mackerel now feeds less on sandeel and hence more on alternative prey. Predation mortality of age 3 and older herring has decreased compared to earlier key runs as the mean weight and consumption of larger cod and saithe has decreased due to the change of the assumption of constant mean weights and rations at-age of the predators.

5.2.6 Northern sandeel

There is a substantial difference in the recruitment, F and SSB for the two assessments (Figure 5.2.6). The predation mortalities of older northern sandeel has become more variable as the mean weight of sandeel now varies from year to year and furthermore exhibits trends over the time-series. Values for older age groups have increased somewhat, likely as a result of the lower mean weight-at-age in the second half of the time period. Re-estimation of single-species data (new stock definition) may also influence the results.

5.2.7 Southern sandeel

The predation mortalities of older northern sandeel has become more variable as the mean weight of sandeel now varies from year to year and furthermore exhibits trends over the time-series (Figure 5.2.7). Values for older age groups have increased somewhat, likely as a result of the lower mean weight-at-age in the second half of the time period which has increased the predation of grey gurnards and whiting on older sandeel. Re-estimation of single-species data (new stock definition) may also influence the results.

5.2.8 Norway pout

The assessment of Norway pout has changed considerably between the two key runs (Figure 5.2.8), probably linked to the benchmark and inter-benchmark for this stock in the period. Predation mortality of Norway pout is very similar in the 2017 key run to those of the 2014 key run. At the end of the time period, hake becomes an important predator and is responsible for the increase in recent years (see Section 5.3).

5.2.9 Sprat

The sprat assessment has changed (benchmark) which is also reflected in the stock summary (Figure 5.2.9) for the two key-runs. M2 from the 2017-run are more variable than in the previous key run, but the trend in the two time-series is the same. The higher variability in the 2017 is probably due the variable mean weight in the sea used in the 2017 run.

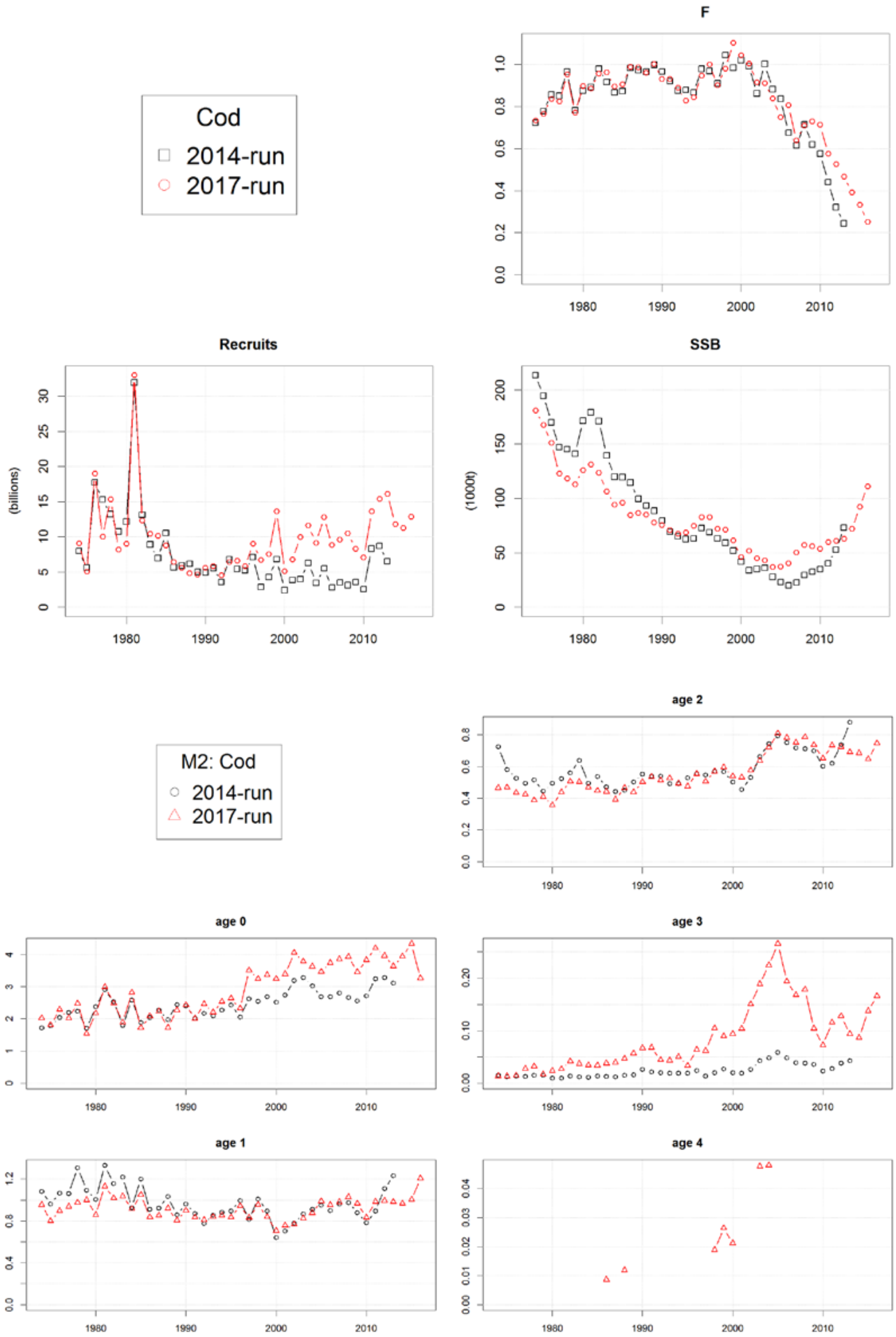


Figure 5.2.1. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of cod from the 2014 and 2017 key runs.

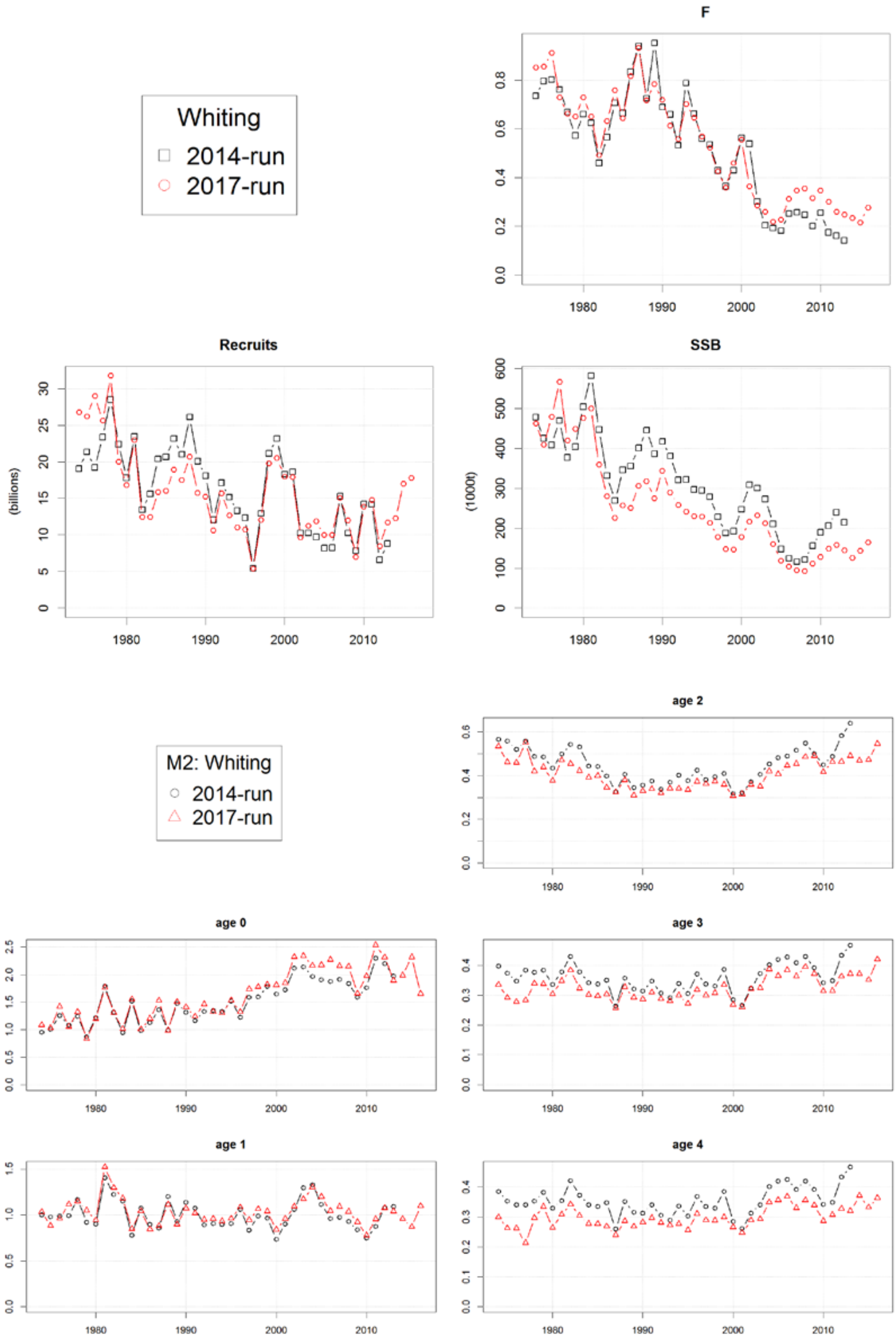


Figure 5.2.2. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of whiting from the 2015 and 2017 key runs.

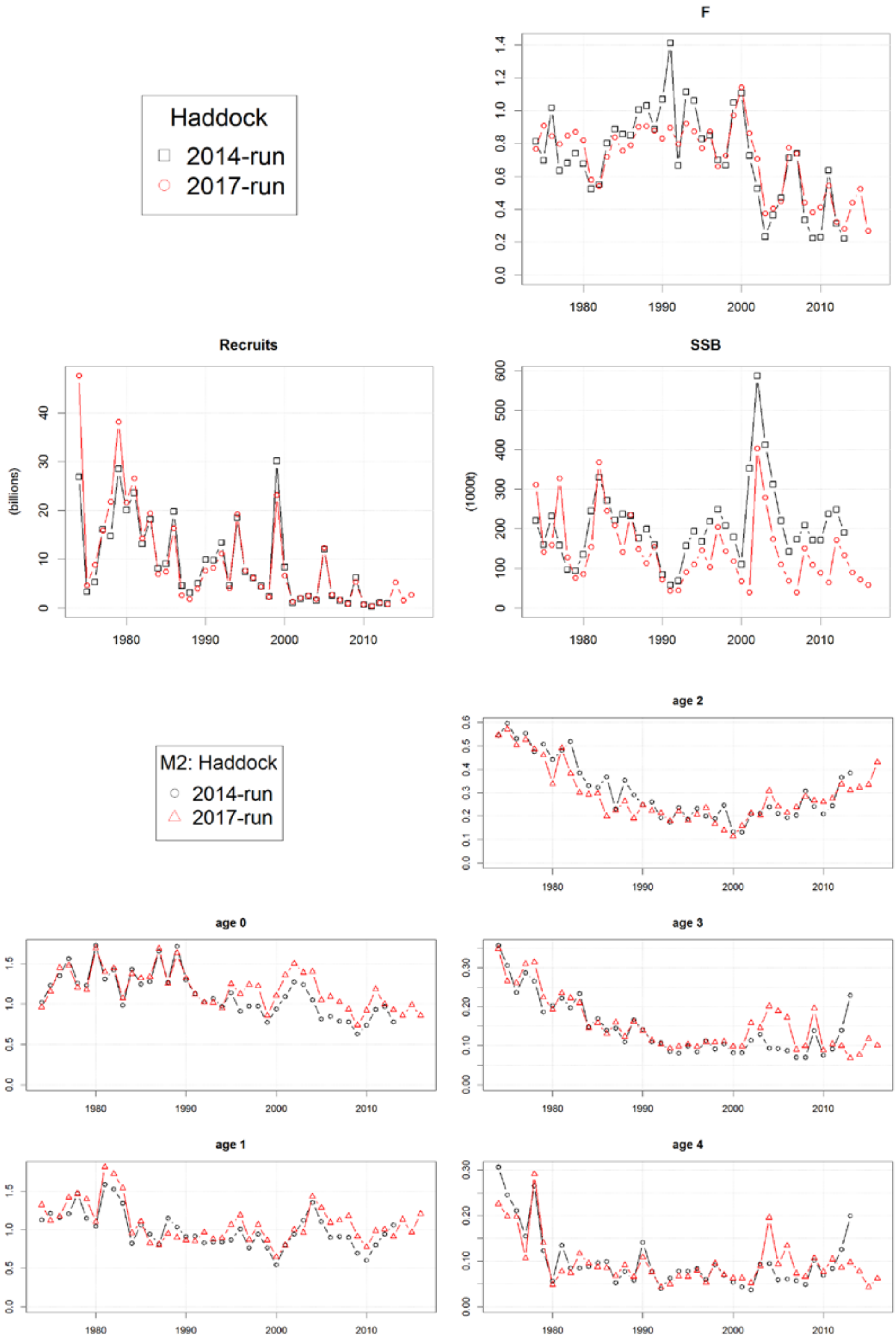


Figure 5.2.3. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of haddock from the 2014 and 2017 key runs.

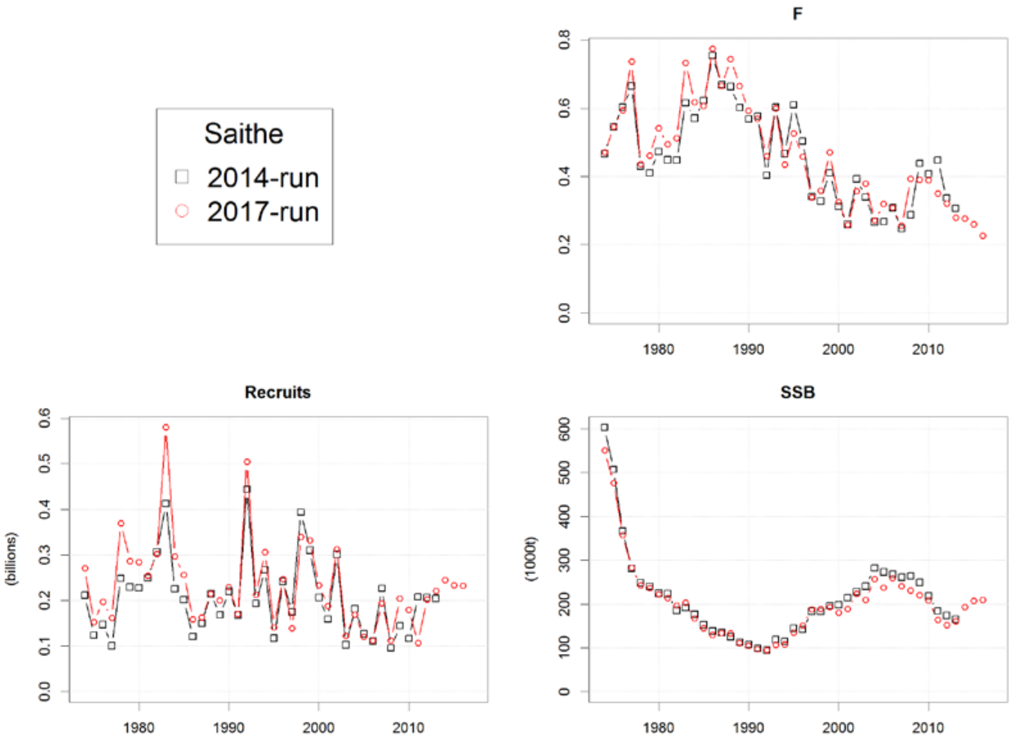


Figure 5.2.4. Comparison of estimated recruitment, mean F and SSB of Saithe from the 2014 and 2017 key runs.

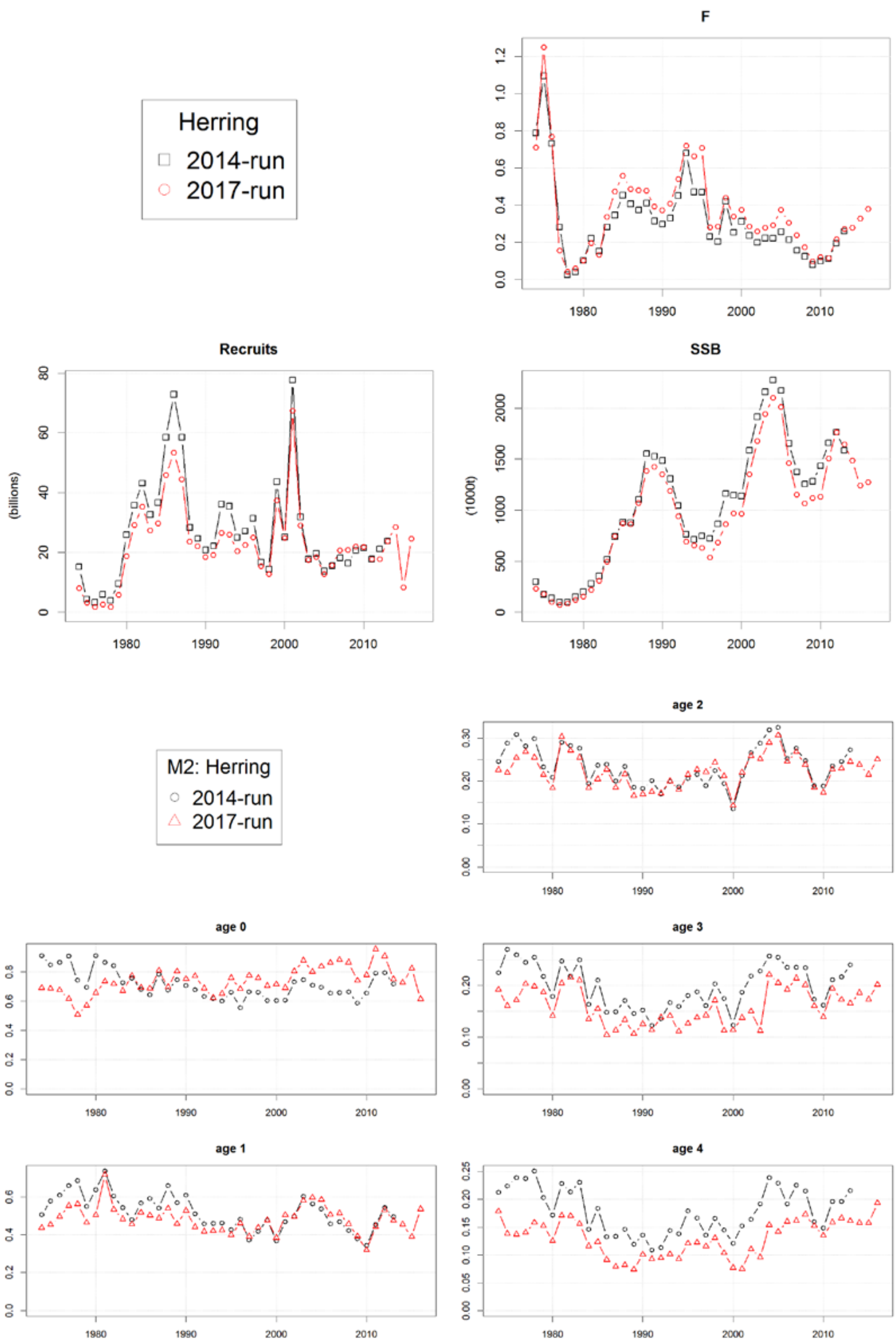


Figure 5.2.5. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of herring from the 2015 and 2017 key runs.

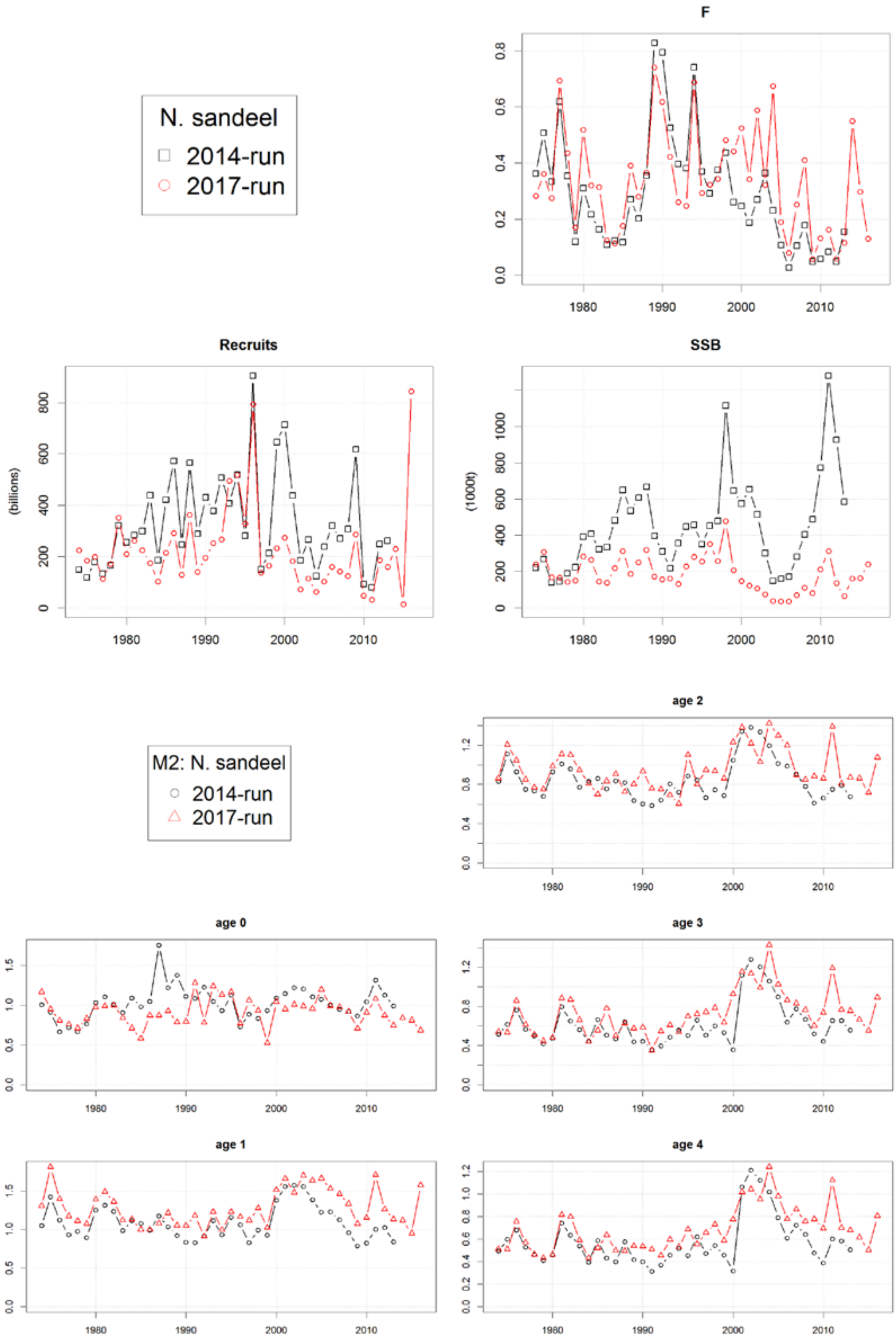


Figure 5.2.6. Comparison of estimated recruitment, mean F, SSB and predation mortality (M2) of northern sandeel from the 2015 and 2017 key runs.

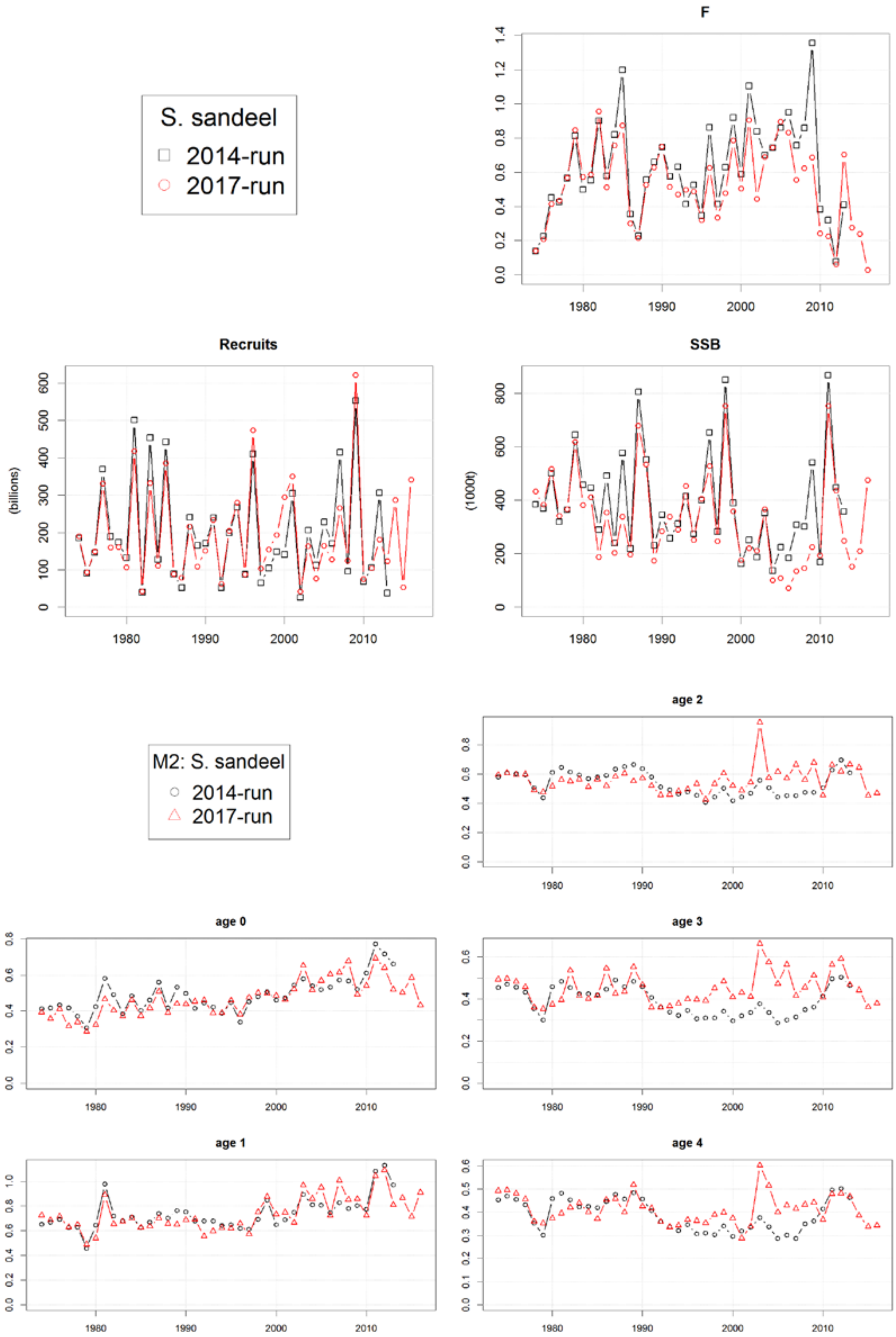


Figure 5.2.7. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of southern sandeel from the 2014 and 2017 key runs.

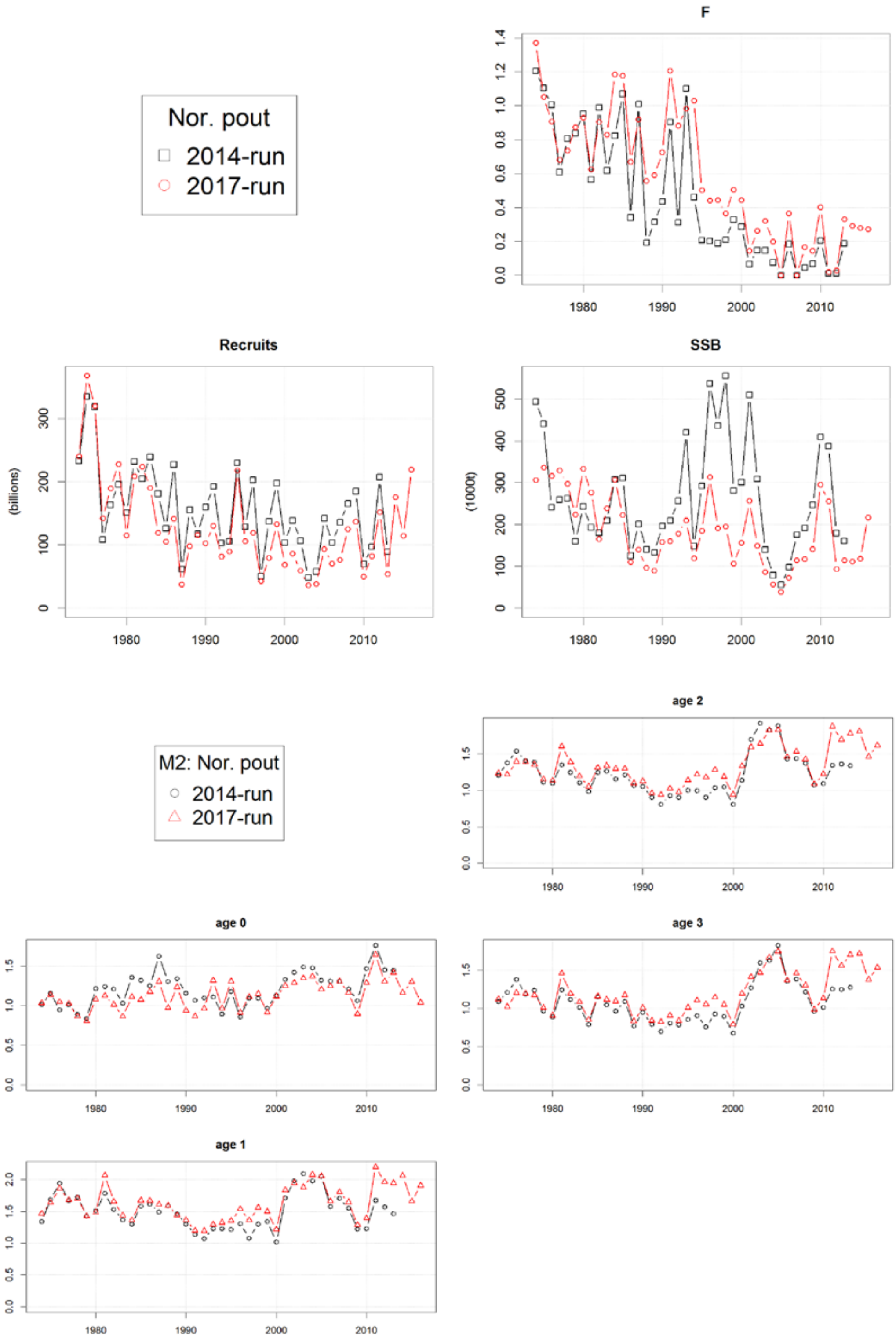


Figure 5.2.8. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of Norway pout from the 2014 and 2017 key runs.

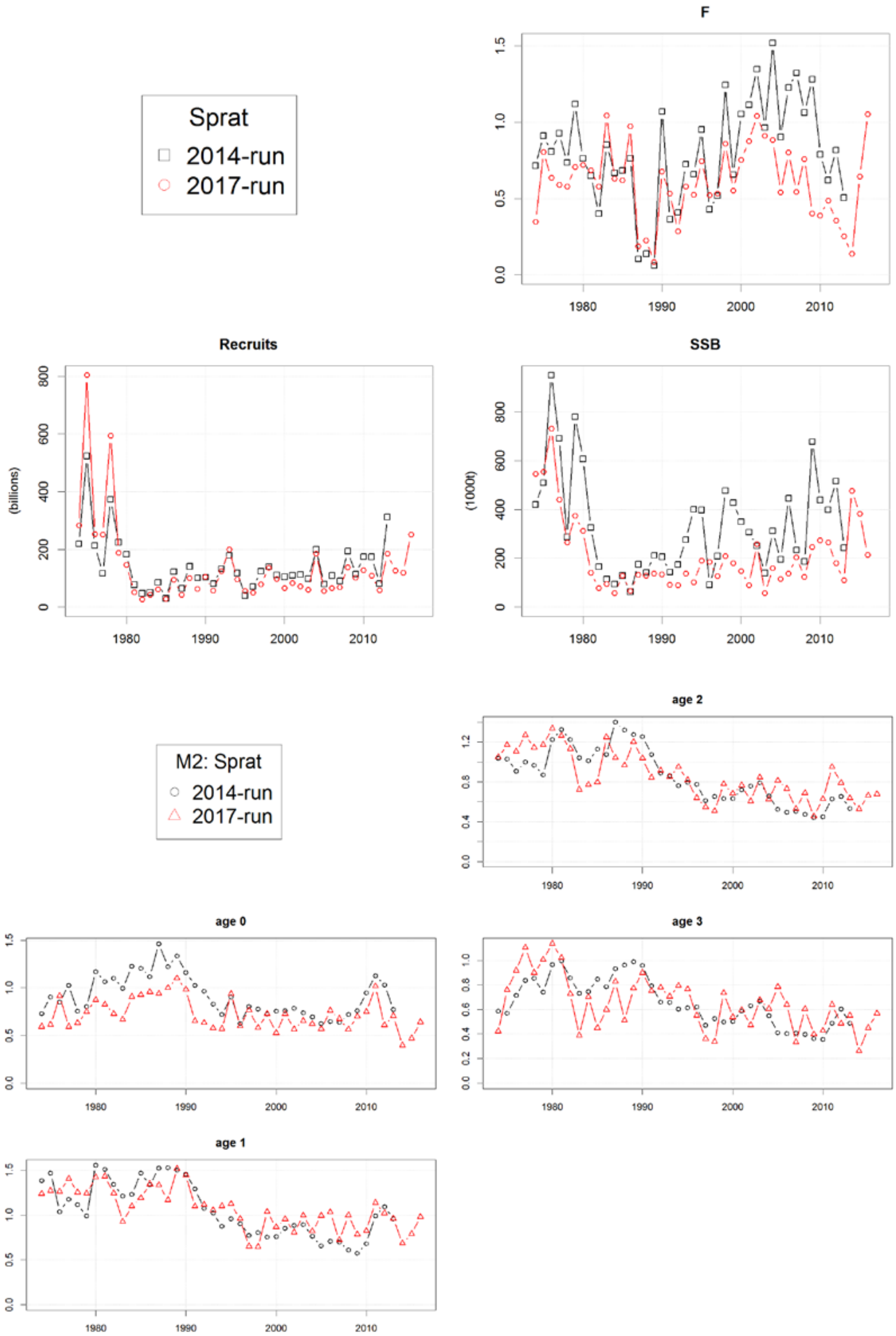


Figure 5.2.9. Comparison of estimates recruitment, mean F, SSB and predation mortality (M2) of sprat from the 2014 and 2017 key runs.

5.3 Conclusion, 2017 key run

WGSAM 2017 discussed the changes in input data and the results in detail and concluded that:

- The new time-series is seen as more accurate than the previous time-series as the change in input data is based on the best available knowledge;
- M2 seems consistently estimated between key runs and shows a very limited retrospective pattern using the last key run an excluding 1–4 years of data. Changes in ration and diet data also had a rather limited effect on M2 values;
- Some ICES assessments make use of the estimated natural mortalities (M1+M2) from SMS and update those in benchmark. If used, WGSAM does not recommend updating existing dataseries of natural mortality by simply adding the latest three new years. The time-series as a whole shows patterns which are not retained by this procedure. For example, herring shows an increased natural mortality over the past decade, but adding only the latest three years will give the impression that natural mortality has decreased over the last five years.

5.4 Identified areas of priority research

WGSAM 2017 considers that the following topics should be priority areas of study prior to the next North Sea key run:

- estimating the proportion of hake, mackerel and horse mackerel stocks present in the North Sea and their distribution in northern and southern areas for a better estimation of M2 for the two sandeel stocks;
- estimating distributions of seabirds in southern and northern North Sea;
- reviewing the method used to estimate grey gurnard and starry ray abundance to identify the reference period and sizes to which the average biomass estimates apply. Consider if the SMS model by it likelihood statistics can estimate a likely mean biomass over a given period;
- Update the number of seabirds, grey seals and harbour porpoise with the most recent information;
- Update the diet and consumption data for grey seal with the most recent data;
- Assigning prey to length groups for the 2013 mackerel stomach data;
- establishing quarterly catch histories for the all predator species (cod, whiting, haddock, saithe, mackerel) as initiated with data from InterCatch;
- Investigate changes to modelling performance when including overwintering mortality of sandeel (M1, possible condition or weight-at-age dependent);
- Investigate the most appropriate species and size selection of different predators.

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7 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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7.1 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.

7.2 Model Structure

7.2.1 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.

7.2.2 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.

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

7.2.3 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 7.2.3.2 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:

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

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

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

As no analytical solution for $M2$ exists, $M2$ has to be found numerically. If the time step considered is sufficiently small, for instance a quarter, $M2$ becomes small and can optionally be approximated by replacing the average number during the season, $\overline{N}$, 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.

7.2.3.1 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 ($\overline{N}_{prey,a,y,q}\ =\ \overline{N}_{prey,l_{prey},y,q}$)

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

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

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

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

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

where

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

and where

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

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

7.2.3.2 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:

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

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.

7.2.3.2.1 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, $\sigma^2_{PREF}$is the "variance" of relative preferred size ration, expressing how selective a predator is with respect to the size of a prey and where $W_{l_s}$is the mean weight for a species size group.

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

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

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

7.2.3.2.2 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:

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

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

7.2.3.2.2.1. Constraint uniform size selection

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

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

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.

7.2.4 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.

7.2.5 Growth

Not implemented yet!

7.2.6 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.

7.2.7 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).

7.2.7.1 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).

7.2.7.2 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.

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

7.3 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.

7.3.1 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:

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

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

7.3.1.1 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.

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

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

7.3.2 Survey indices

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

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

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.

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

7.3.3 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:

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

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:

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

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

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

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

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:

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

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:

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

Insertion of Eq. 13 into Eq. 11 results in that:

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

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

Assuming that the diet observations for the predator/length groups are independent the negative log likelihood function including all predators/length groups are derived from Eq. 9:

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

7.3.3.1 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.

7.3.4 Stock–recruitment

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

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

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

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

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

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

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

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

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

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

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

7.4 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.

7.5 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.

7.5.1 Recruitment

Recruitment is estimated from the available stock–recruitment relationships, f(SSB), (see Section 7.3.4) and optionally a lognormal distributed noise term with standard deviation std.

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

Where NORM(0,1) is a random number drawn from a normal distribution with mean=0 and standard deviation 1. A default value for std can be obtained from the estimated variance of stock–recruitment relationship, σ^2_{SRs} (Eq. 19).

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

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

7.5.2 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.

7.6 Model validation

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

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

1) Estimate model parameters using the SMS model and available North Sea data.
2) Generate 100 set of input data from SMS output (expected catch numbers, survey indices and stomach observations) and their associated variance of these values).
3) Let SMS estimate 100 sets of parameters from the 100 sets of input data.

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

The test showed that parameters are identifiable for most "real" North Sea configurations. For some species with relatively few diet observations, size selection parameters (Eq. 11) and the variance parameter (V) linking the stomach sampling level to the variance of Dirichlet distribution (Eq. 12 and Eq. 13), were outside the 95% confidence interval of $\bar{\hat{\theta}}_i$.

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

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

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

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

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

If we assume that $W_{r,j},\ j = 1, \dots, k$ 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.

7.7 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.

7.8 References

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Appendage 1. Notation, parameters and variables

Indices

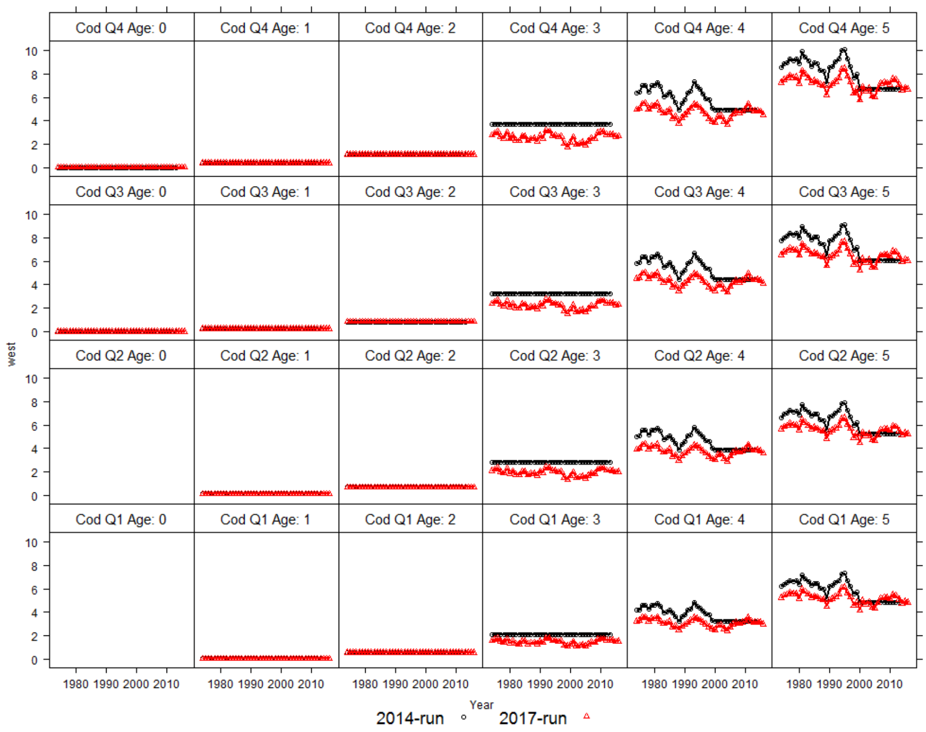
a	age
area	area with specific predation mortality
A1, A2	group of ages
Fa	first age group in the model
i	prey entity, combination of prey species and prey size group
j	predator entity, combination of predator group and predator size group
l	species size class
lpred	predator size class
lprey	prey size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

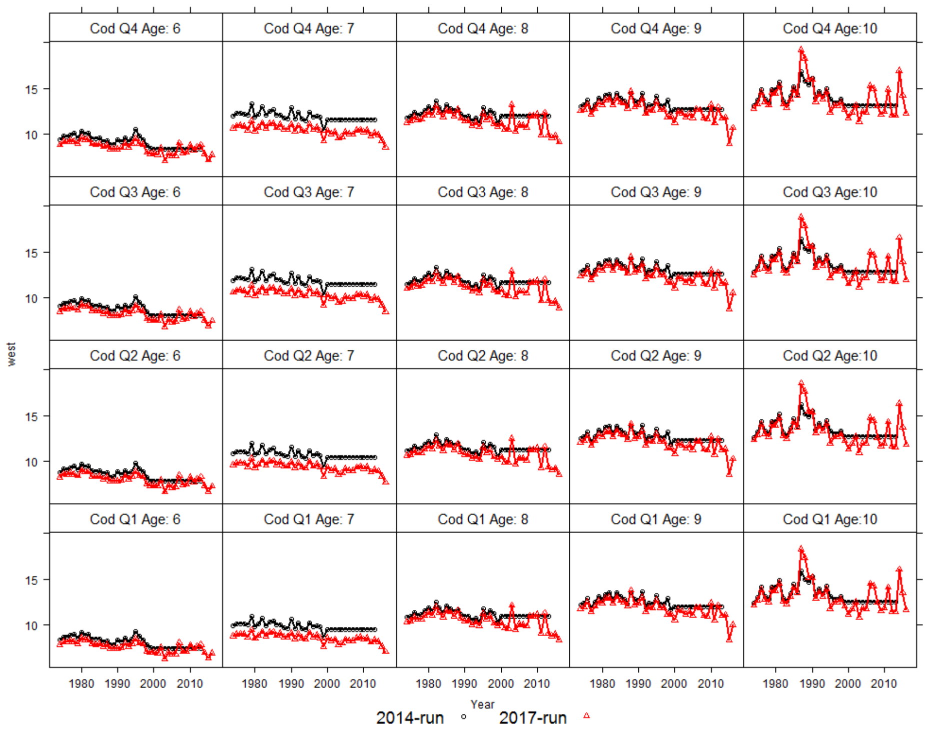
Parameters and variables

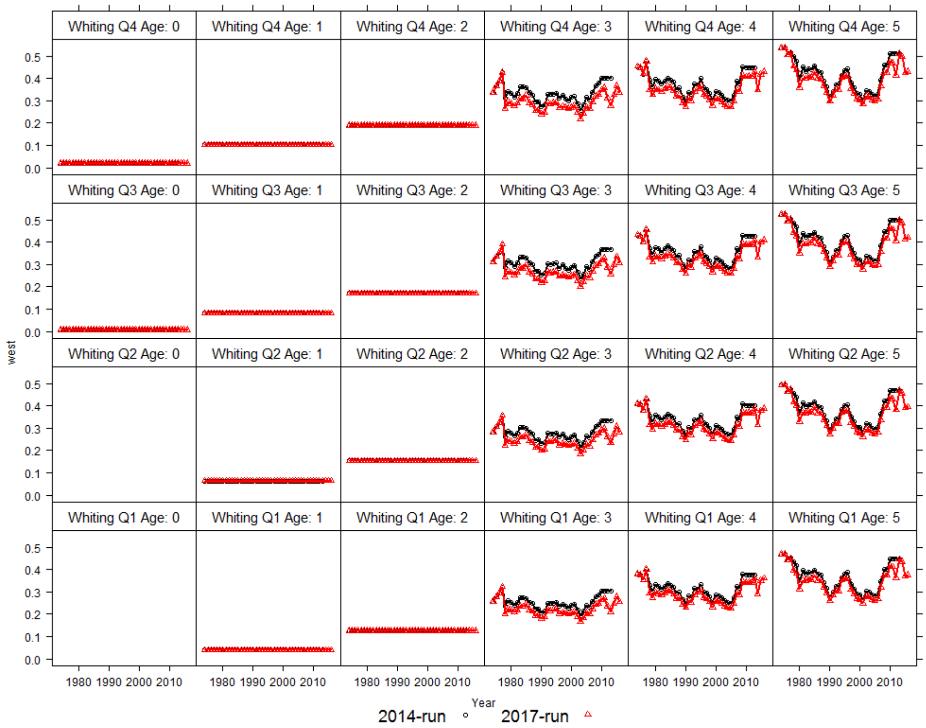
AB	available (suitable) prey biomass for a predator
ALK	proportion at-size for a given age group. Input
C	catch in numbers. Observations
Cpue	catch in numbers per unit of effort. Observations
D	number died
DM1	number died due to M1
DM2	number died due to M2
DF	number died due to F
F	instantaneous rate 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

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



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Whiting Q4 Age: 2
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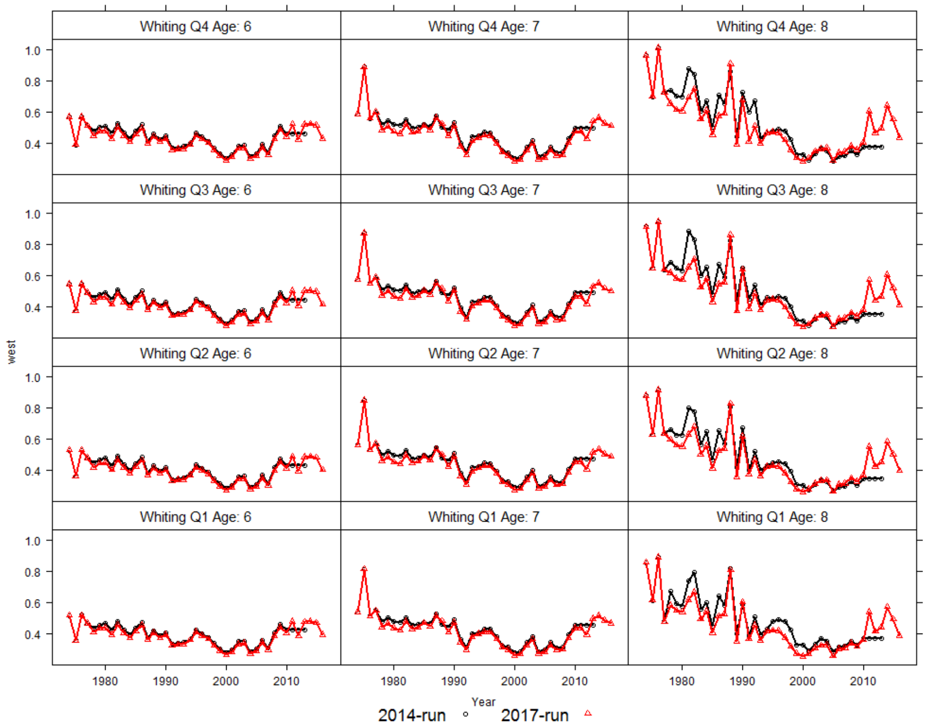
Year
2014-run
2017-run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Whiting Q3 Age: 8
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Whiting Q2 Age: 8
Whiting Q1 Age: 6
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Whiting Q1 Age: 8
west
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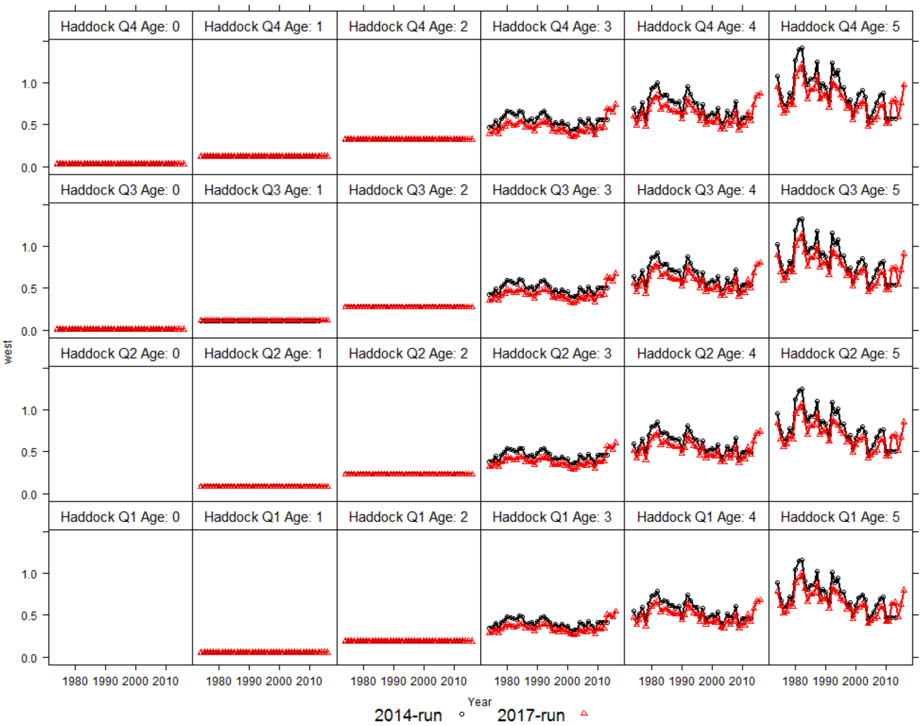
1980 1990 2000 2010
Year
2014-run
2017-run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Haddock Q3 Age: 1
Haddock Q3 Age: 2
Haddock Q3 Age: 3
Haddock Q3 Age: 4
Haddock Q3 Age: 5
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Haddock Q2 Age: 3
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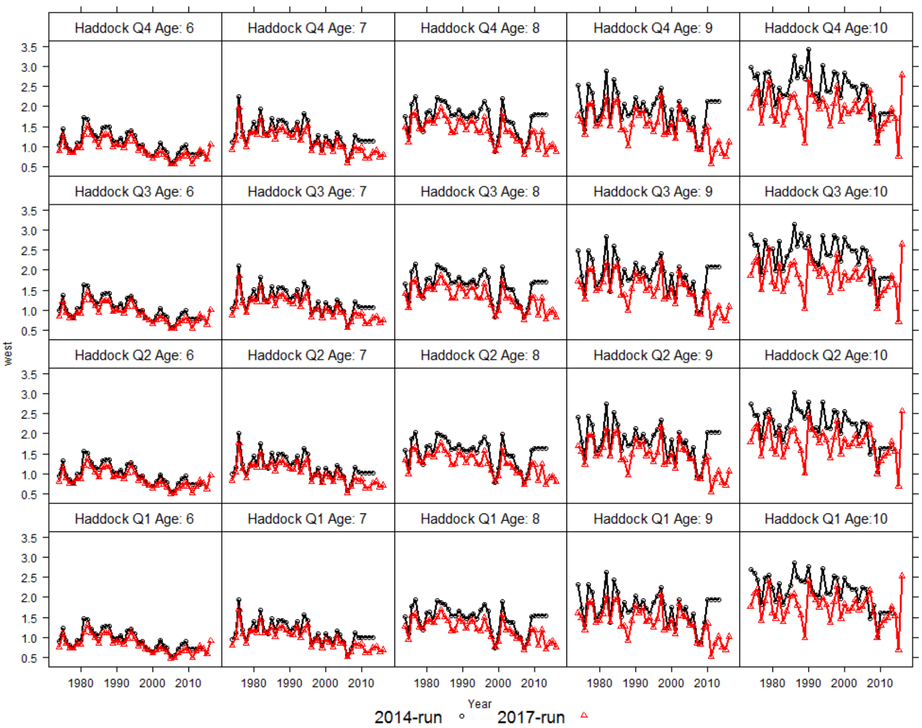
Haddock Q1 Age: 5
west
Year
2014-run
2017-run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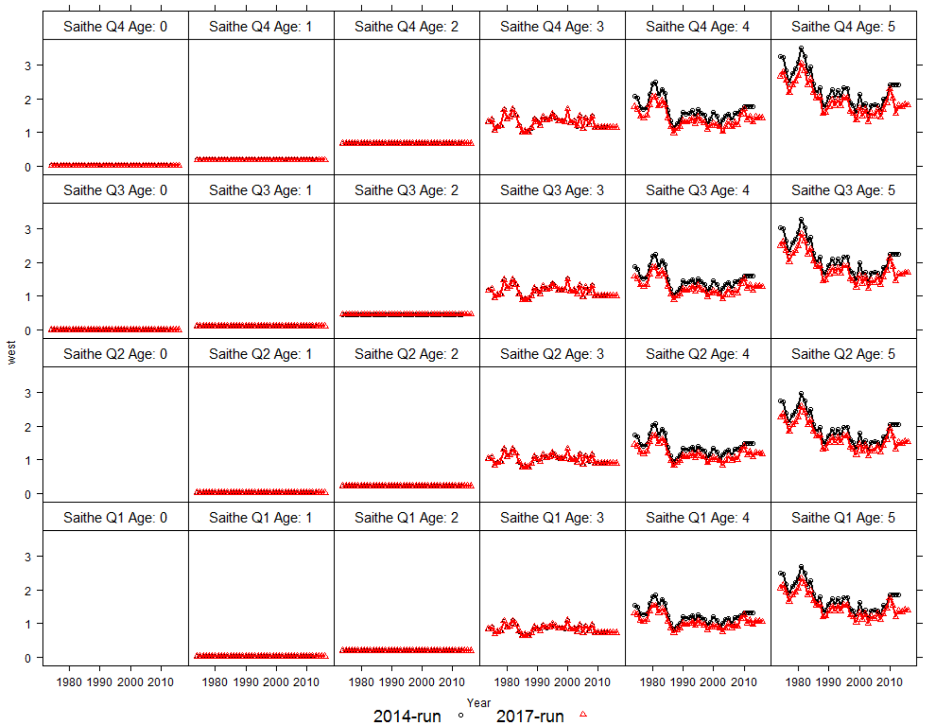
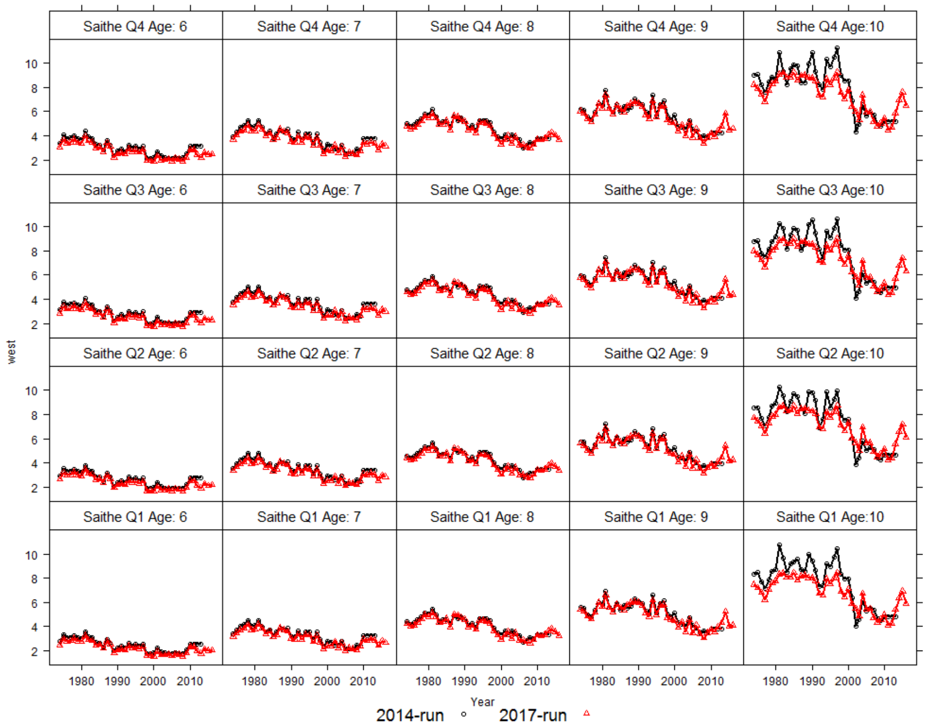
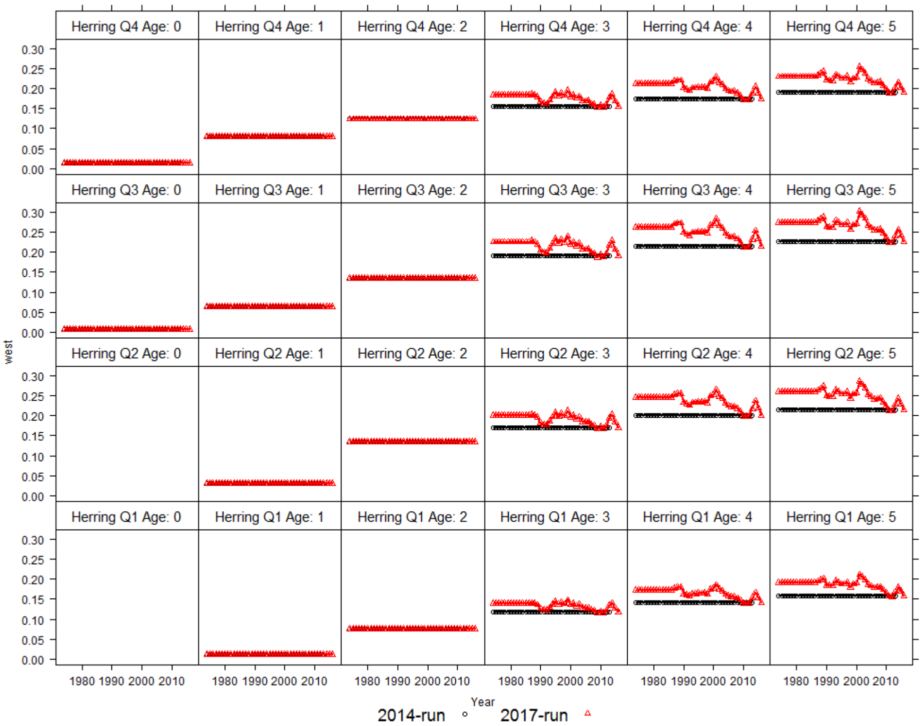
Haddock Q3 Age: 8
Haddock Q3 Age: 9
Haddock Q3 Age:10
Haddock Q2 Age: 6
Haddock Q2 Age: 7
Haddock Q2 Age: 8
Haddock Q2 Age: 9
Haddock Q2 Age:10
Haddock Q1 Age: 6
Haddock Q1 Age: 7
Haddock Q1 Age: 8
Haddock Q1 Age: 9
Haddock Q1 Age:10
west
Year
2014-run
2017-run


Saithe Q4 Age: 0
Saithe Q4 Age: 1
Saithe Q4 Age: 2
Saithe Q4 Age: 3
Saithe Q4 Age: 4
Saithe Q4 Age: 5
Saithe Q3 Age: 0
Saithe Q3 Age: 1
Saithe Q3 Age: 2
Saithe Q3 Age: 3
Saithe Q3 Age: 4
Saithe Q3 Age: 5
Saithe Q2 Age: 0
Saithe Q2 Age: 1
Saithe Q2 Age: 2
Saithe Q2 Age: 3
Saithe Q2 Age: 4
Saithe Q2 Age: 5
Saithe Q1 Age: 0
Saithe Q1 Age: 1
Saithe Q1 Age: 2
Saithe Q1 Age: 3
Saithe Q1 Age: 4
Saithe Q1 Age: 5
west
Year
2014-run
2017-run


Saithe Q4 Age: 6
Saithe Q4 Age: 7
Saithe Q4 Age: 8
Saithe Q4 Age: 9
Saithe Q4 Age:10
Saithe Q3 Age: 6
Saithe Q3 Age: 7
Saithe Q3 Age: 8
Saithe Q3 Age: 9
Saithe Q3 Age:10
Saithe Q2 Age: 6
Saithe Q2 Age: 7
Saithe Q2 Age: 8
Saithe Q2 Age: 9
Saithe Q2 Age:10
Saithe Q1 Age: 6
Saithe Q1 Age: 7
Saithe Q1 Age: 8
Saithe Q1 Age: 9
Saithe Q1 Age:10
west
Year
2014-run
2017-run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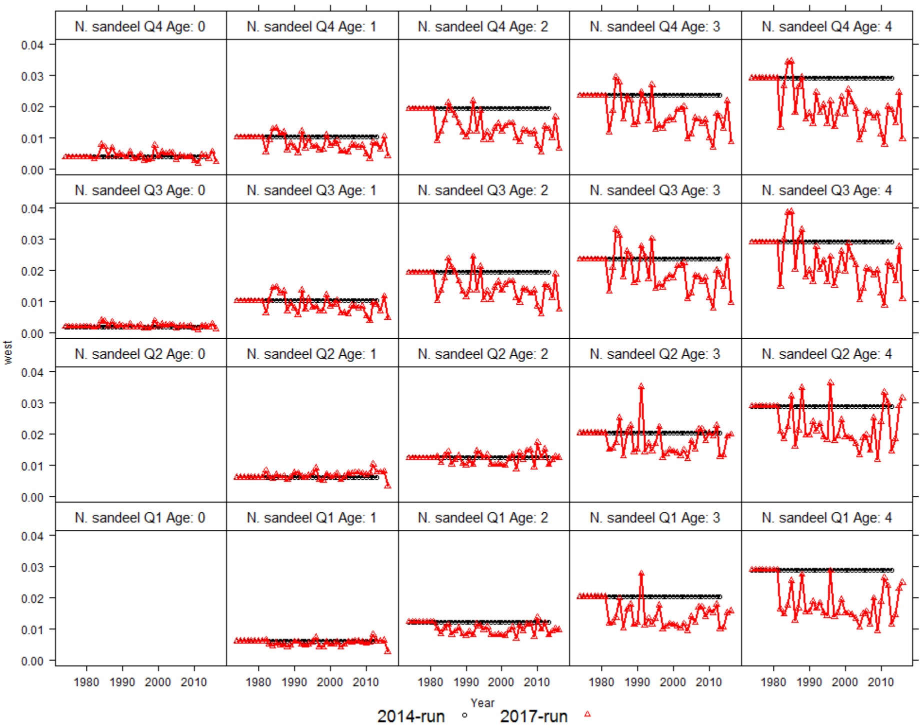
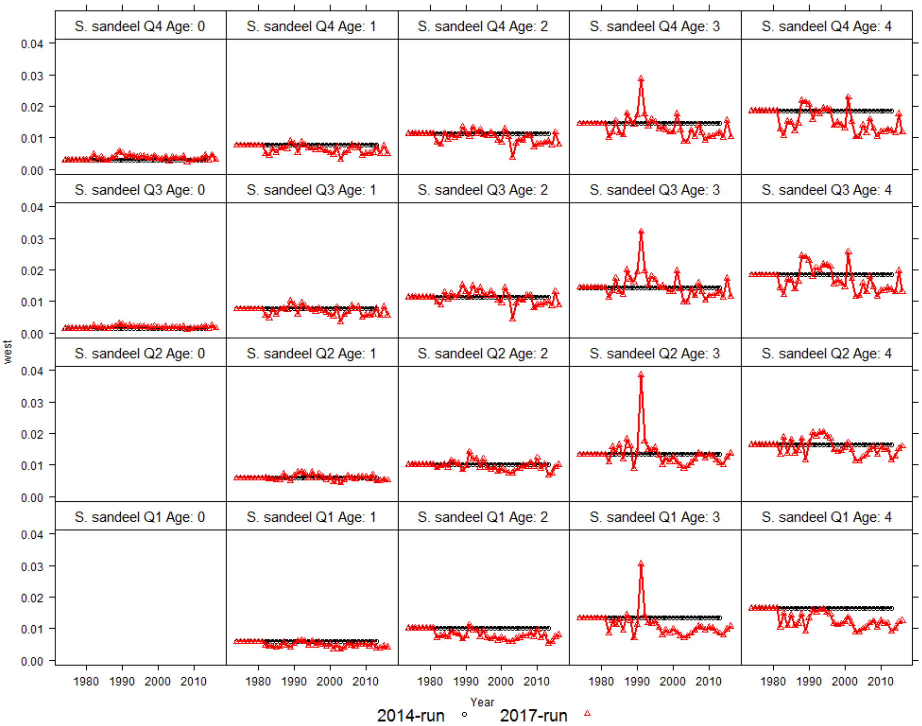
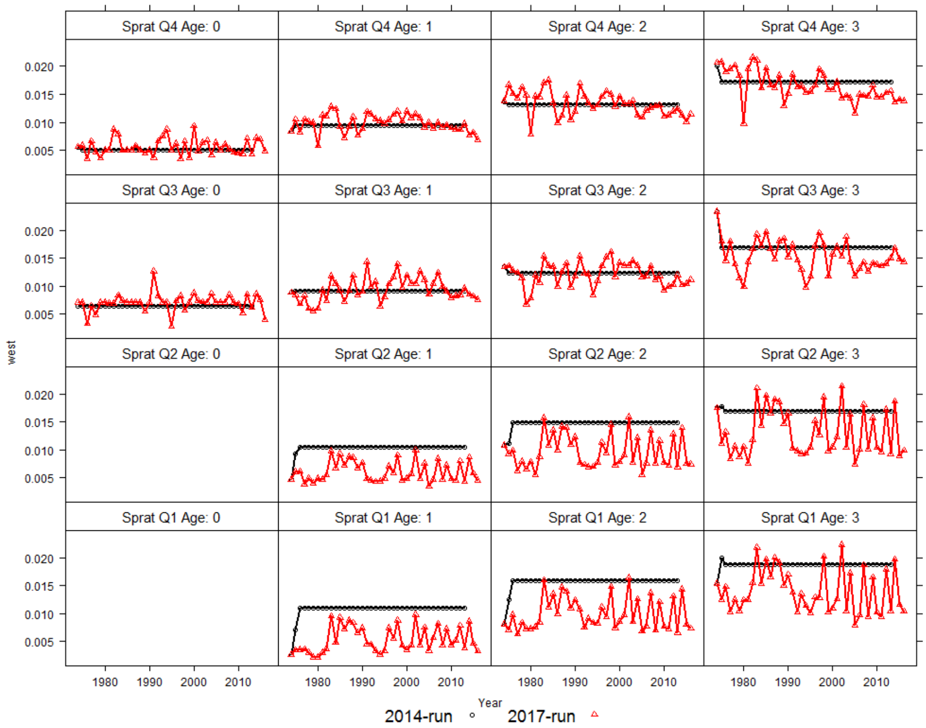
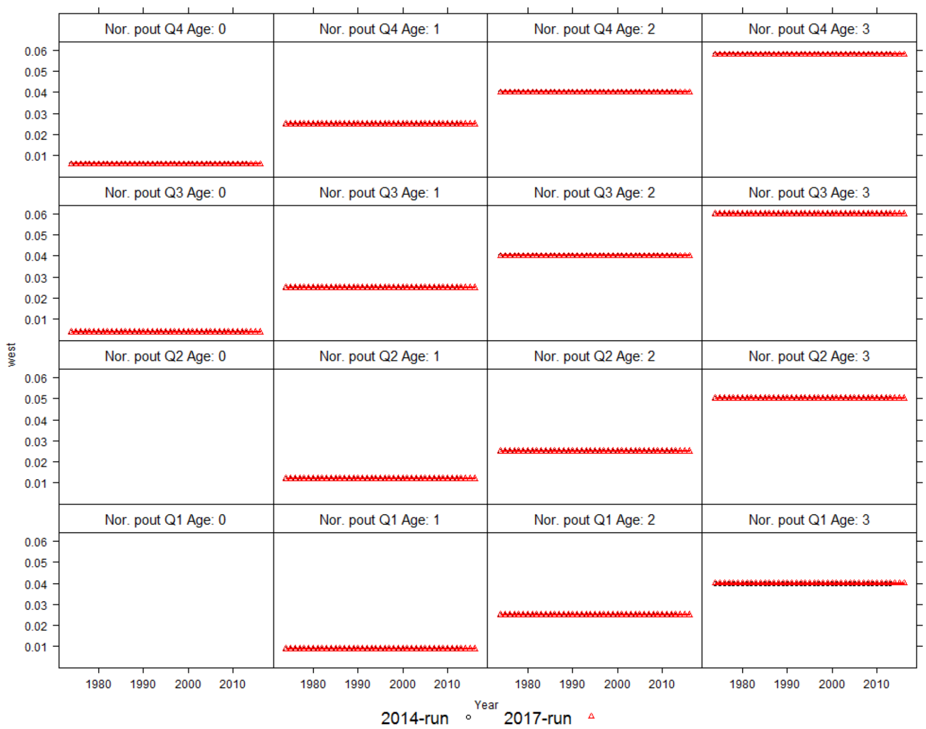
Herring Q4 Age: 1
Herring Q4 Age: 2
Herring Q4 Age: 3
Herring Q4 Age: 4
Herring Q4 Age: 5
Herring Q3 Age: 0
Herring Q3 Age: 1
Herring Q3 Age: 2
Herring Q3 Age: 3
Herring Q3 Age: 4
Herring Q3 Age: 5
Herring Q2 Age: 0
Herring Q2 Age: 1
Herring Q2 Age: 2
Herring Q2 Age: 3
Herring Q2 Age: 4
Herring Q2 Age: 5
Herring Q1 Age: 0
Herring Q1 Age: 1
Herring Q1 Age: 2
Herring Q1 Age: 3
Herring Q1 Age: 4
Herring Q1 Age: 5
west
Year
2014-run
2017-run

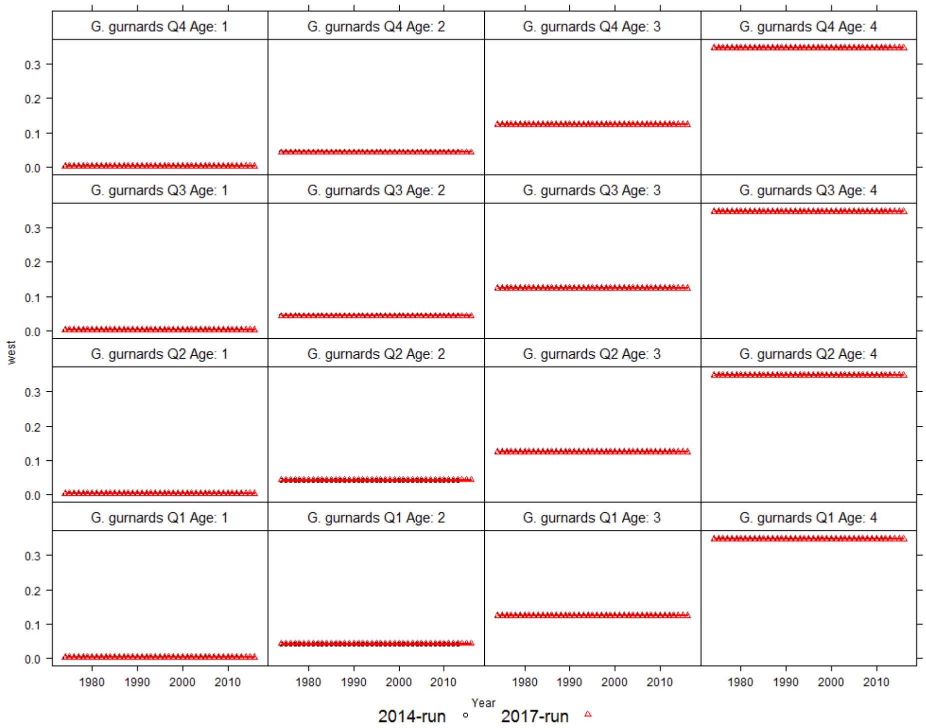

Herring Q4 Age: 6
Herring Q4 Age: 7
Herring Q4 Age: 8
Herring Q4 Age: 9
Herring Q3 Age: 6
Herring Q3 Age: 7
Herring Q3 Age: 8
Herring Q3 Age: 9
Herring Q2 Age: 6
Herring Q2 Age: 7
Herring Q2 Age: 8
Herring Q2 Age: 9
Herring Q1 Age: 6
Herring Q1 Age: 7
Herring Q1 Age: 8
Herring Q1 Age: 9
west
Year
2014-run
2017-run

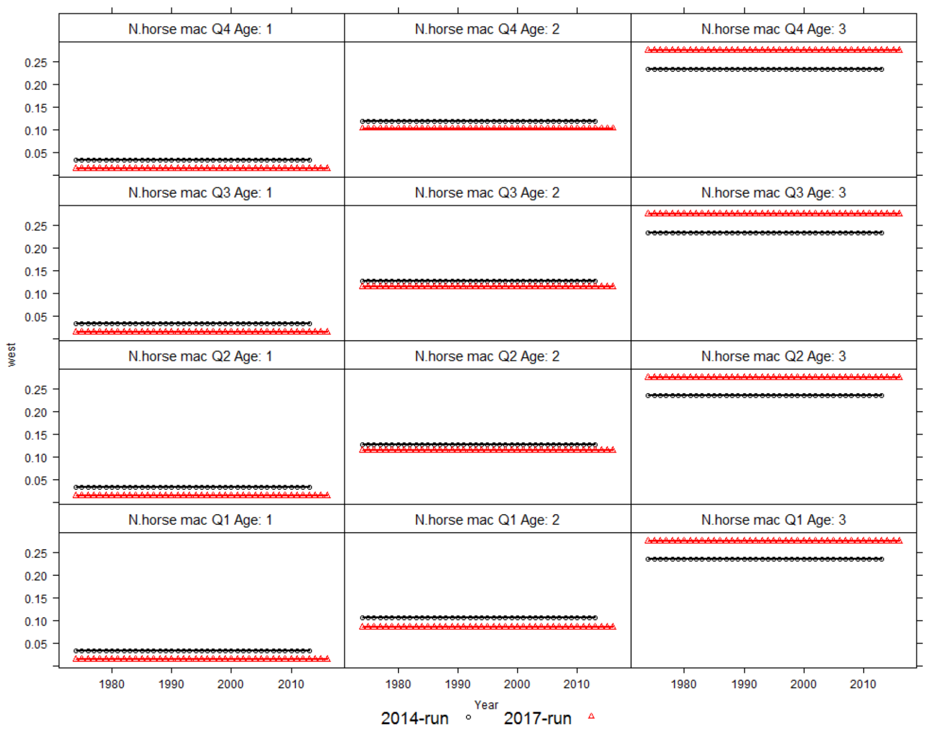

N. sandeel Q4 Age: 0
N. sandeel Q4 Age: 1
N. sandeel Q4 Age: 2
N. sandeel Q4 Age: 3
N. sandeel Q4 Age: 4
N. sandeel Q3 Age: 0
N. sandeel Q3 Age: 1
N. sandeel Q3 Age: 2
N. sandeel Q3 Age: 3
N. sandeel Q3 Age: 4
N. sandeel Q2 Age: 0
N. sandeel Q2 Age: 1
N. sandeel Q2 Age: 2
N. sandeel Q2 Age: 3
N. sandeel Q2 Age: 4
N. sandeel Q1 Age: 0
N. sandeel Q1 Age: 1
N. sandeel Q1 Age: 2
N. sandeel Q1 Age: 3
N. sandeel Q1 Age: 4
west
Year
2014-run
2017-run

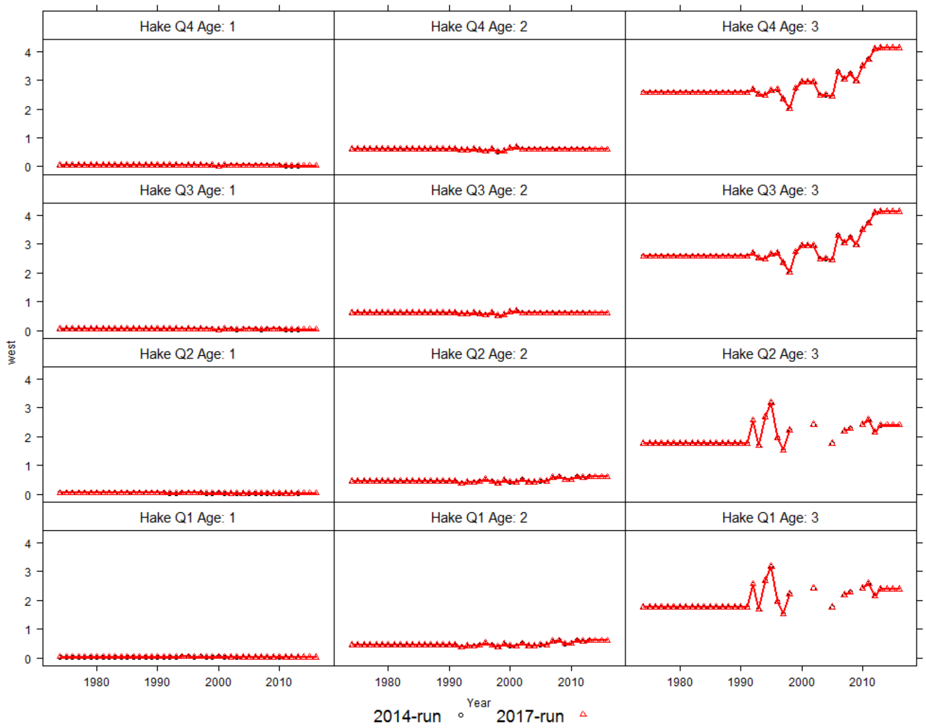

S. sandeel Q4 Age: 0
S. sandeel Q4 Age: 1
S. sandeel Q4 Age: 2
S. sandeel Q4 Age: 3
S. sandeel Q4 Age: 4
S. sandeel Q3 Age: 0
S. sandeel Q3 Age: 1
S. sandeel Q3 Age: 2
S. sandeel Q3 Age: 3
S. sandeel Q3 Age: 4
S. sandeel Q2 Age: 0
S. sandeel Q2 Age: 1
S. sandeel Q2 Age: 2
S. sandeel Q2 Age: 3
S. sandeel Q2 Age: 4
S. sandeel Q1 Age: 0
S. sandeel Q1 Age: 1
S. sandeel Q1 Age: 2
S. sandeel Q1 Age: 3
S. sandeel Q1 Age: 4
west
Year
2014-run
2017-run


Sprat Q4 Age: 0
Sprat Q4 Age: 1
Sprat Q4 Age: 2
Sprat Q4 Age: 3
Sprat Q3 Age: 0
Sprat Q3 Age: 1
Sprat Q3 Age: 2
Sprat Q3 Age: 3
Sprat Q2 Age: 0
Sprat Q2 Age: 1
Sprat Q2 Age: 2
Sprat Q2 Age: 3
Sprat Q1 Age: 0
Sprat Q1 Age: 1
Sprat Q1 Age: 2
Sprat Q1 Age: 3
west
0.020
0.015
0.010
0.005
1980
1990
2000
2010
Year
2014-run
2017-run


Nor. pout Q4 Age: 0
Nor. pout Q4 Age: 1
Nor. pout Q4 Age: 2
Nor. pout Q4 Age: 3
Nor. pout Q3 Age: 0
Nor. pout Q3 Age: 1
Nor. pout Q3 Age: 2
Nor. pout Q3 Age: 3
Nor. pout Q2 Age: 0
Nor. pout Q2 Age: 1
Nor. pout Q2 Age: 2
Nor. pout Q2 Age: 3
Nor. pout Q1 Age: 0
Nor. pout Q1 Age: 1
Nor. pout Q1 Age: 2
Nor. pout Q1 Age: 3
west
0.06
0.05
0.04
0.03
0.02
0.01
1980
1990
2000
2010
Year
2014-run
2017-run

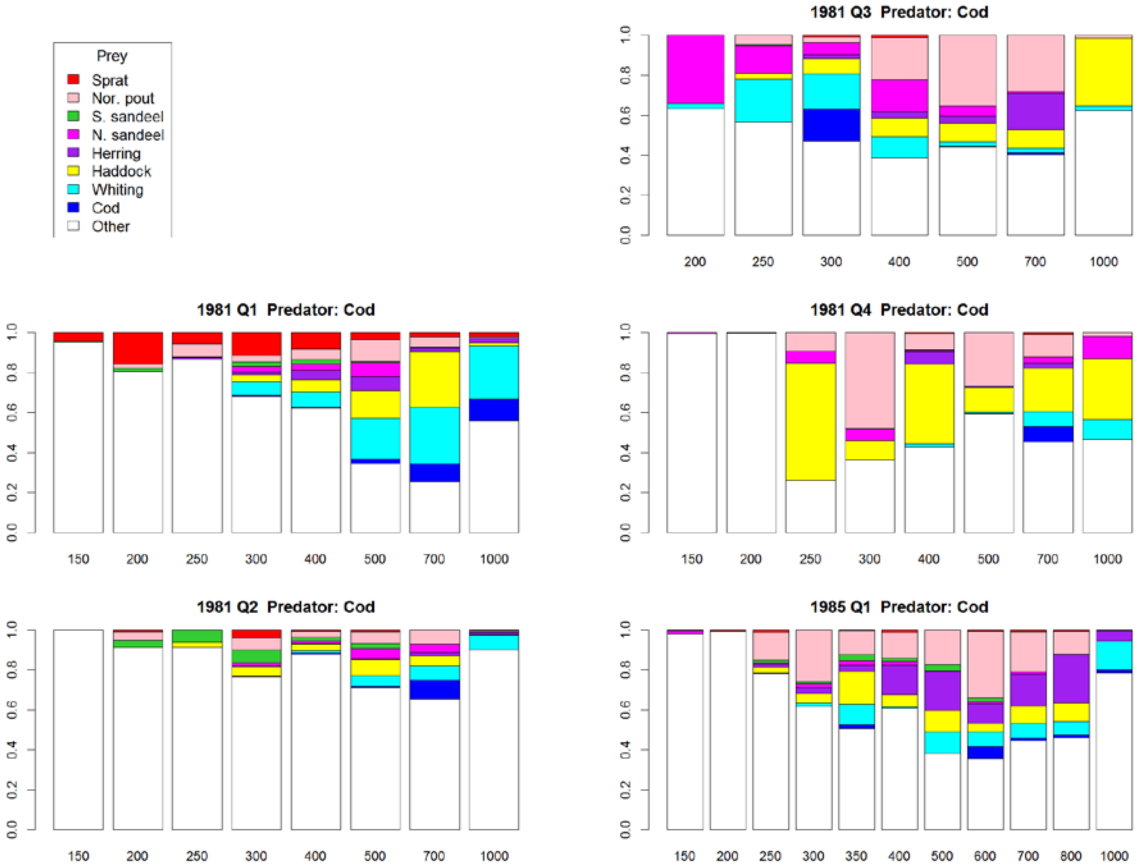

G. gurnards Q4 Age: 1
G. gurnards Q4 Age: 2
G. gurnards Q4 Age: 3
G. gurnards Q4 Age: 4
G. gurnards Q3 Age: 1
G. gurnards Q3 Age: 2
G. gurnards Q3 Age: 3
G. gurnards Q3 Age: 4
G. gurnards Q2 Age: 1
G. gurnards Q2 Age: 2
G. gurnards Q2 Age: 3
G. gurnards Q2 Age: 4
G. gurnards Q1 Age: 1
G. gurnards Q1 Age: 2
G. gurnards Q1 Age: 3
G. gurnards Q1 Age: 4
west
Year
2014-run
2017-run


N.horse mac Q4 Age: 1
N.horse mac Q4 Age: 2
N.horse mac Q4 Age: 3
N.horse mac Q3 Age: 1
N.horse mac Q3 Age: 2
N.horse mac Q3 Age: 3
N.horse mac Q2 Age: 1
N.horse mac Q2 Age: 2
N.horse mac Q2 Age: 3
N.horse mac Q1 Age: 1
N.horse mac Q1 Age: 2
N.horse mac Q1 Age: 3
west
Year
2014-run
2017-run

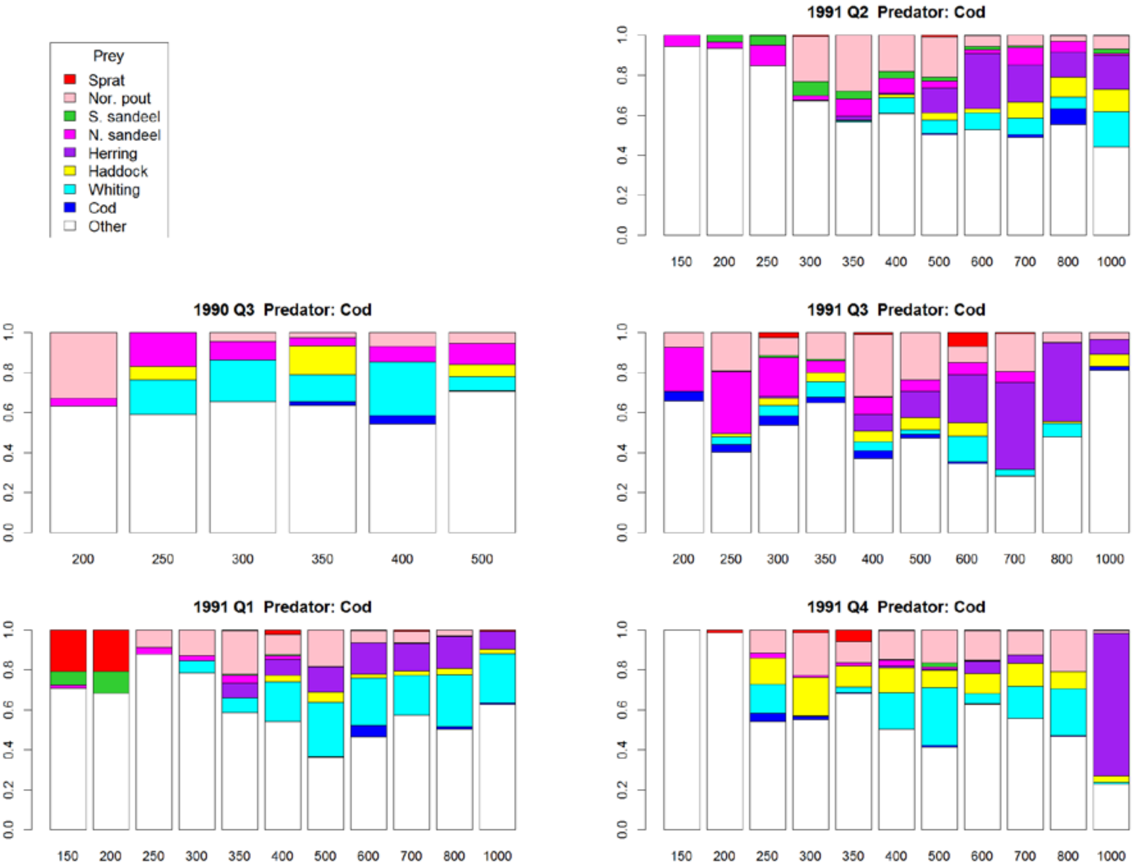

Hake Q4 Age: 1
Hake Q4 Age: 2
Hake Q4 Age: 3
Hake Q3 Age: 1
Hake Q3 Age: 2
Hake Q3 Age: 3
Hake Q2 Age: 1
Hake Q2 Age: 2
Hake Q2 Age: 3
Hake Q1 Age: 1
Hake Q1 Age: 2
Hake Q1 Age: 3
west
Year
2014-run
2017-run

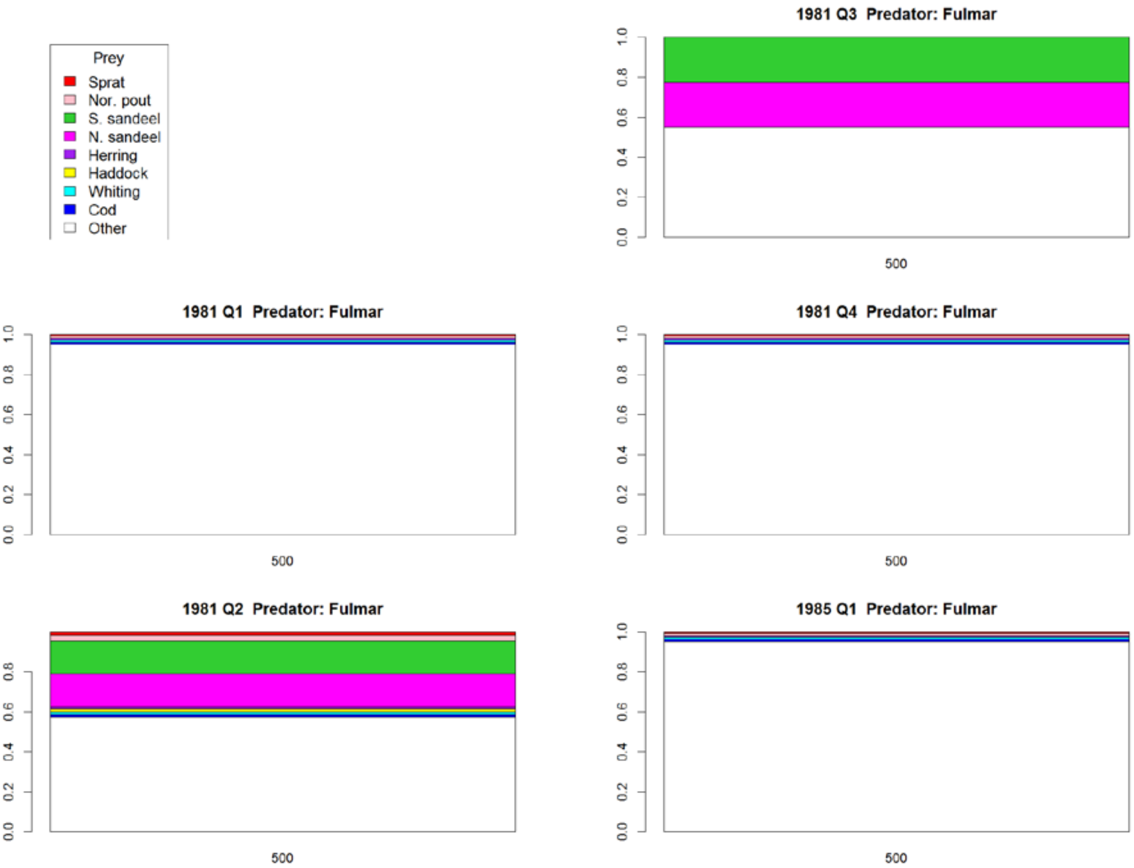
9 APPENDIX 3: Diet composition used in the model

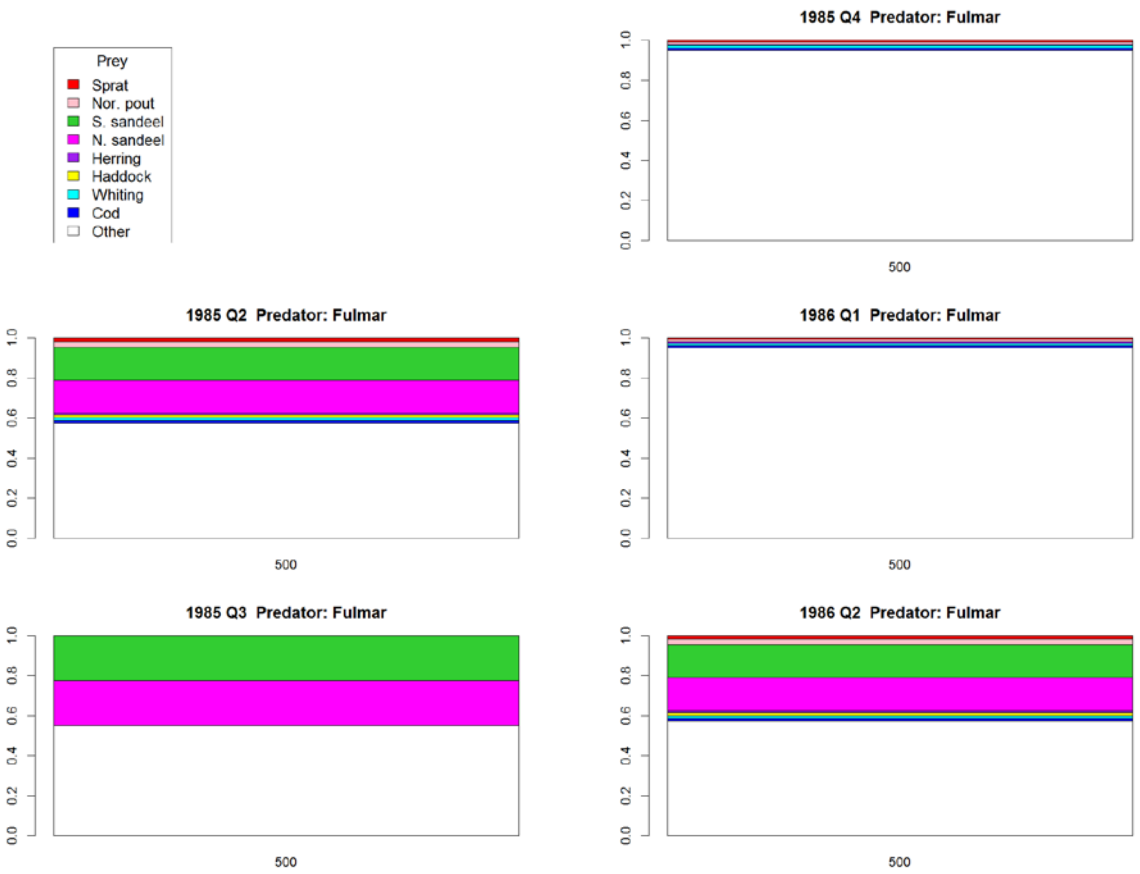
The following figures show the stomach content composition of fish and the diet composition (after correction of stomach contents for evacuation rate differences) for mammals. For each predator the stomach content is shown by observed predator size classes (showing the lower length in mm for the size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

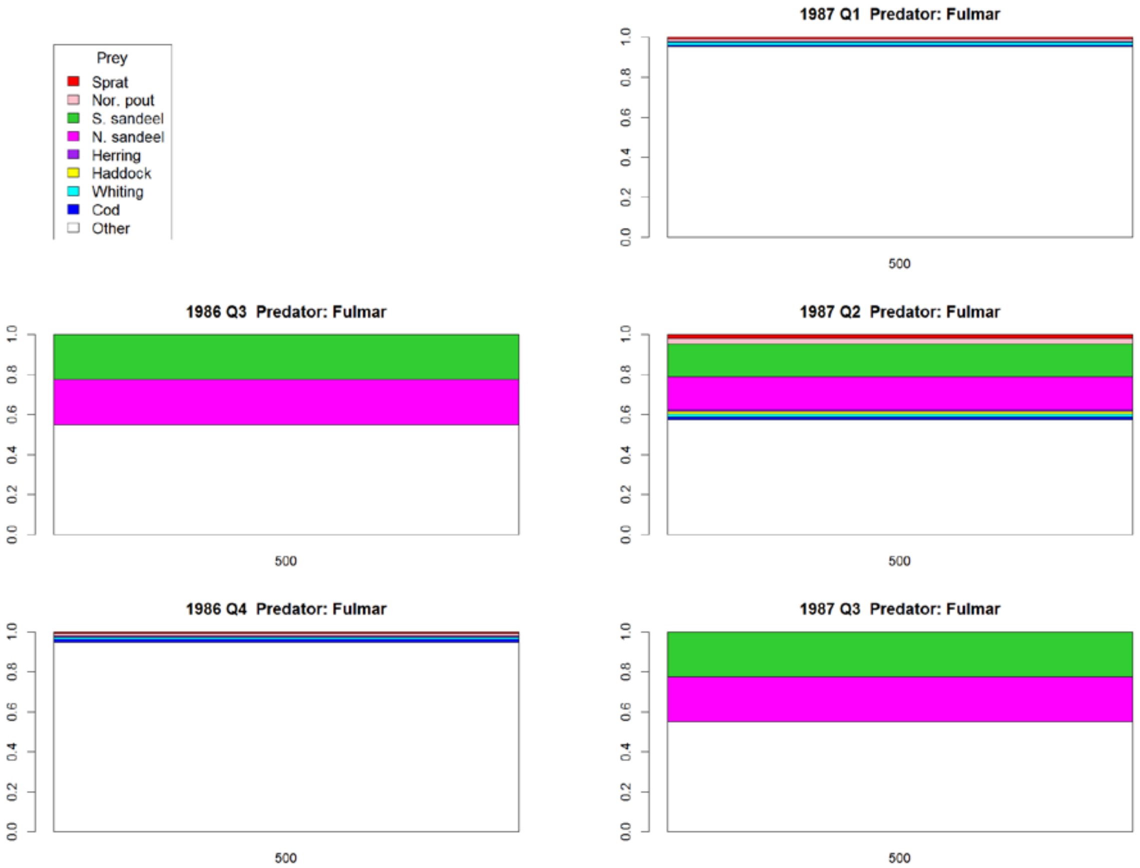

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Cod
1981 Q1 Predator: Cod
1981 Q4 Predator: Cod
1981 Q2 Predator: Cod
1985 Q1 Predator: Cod

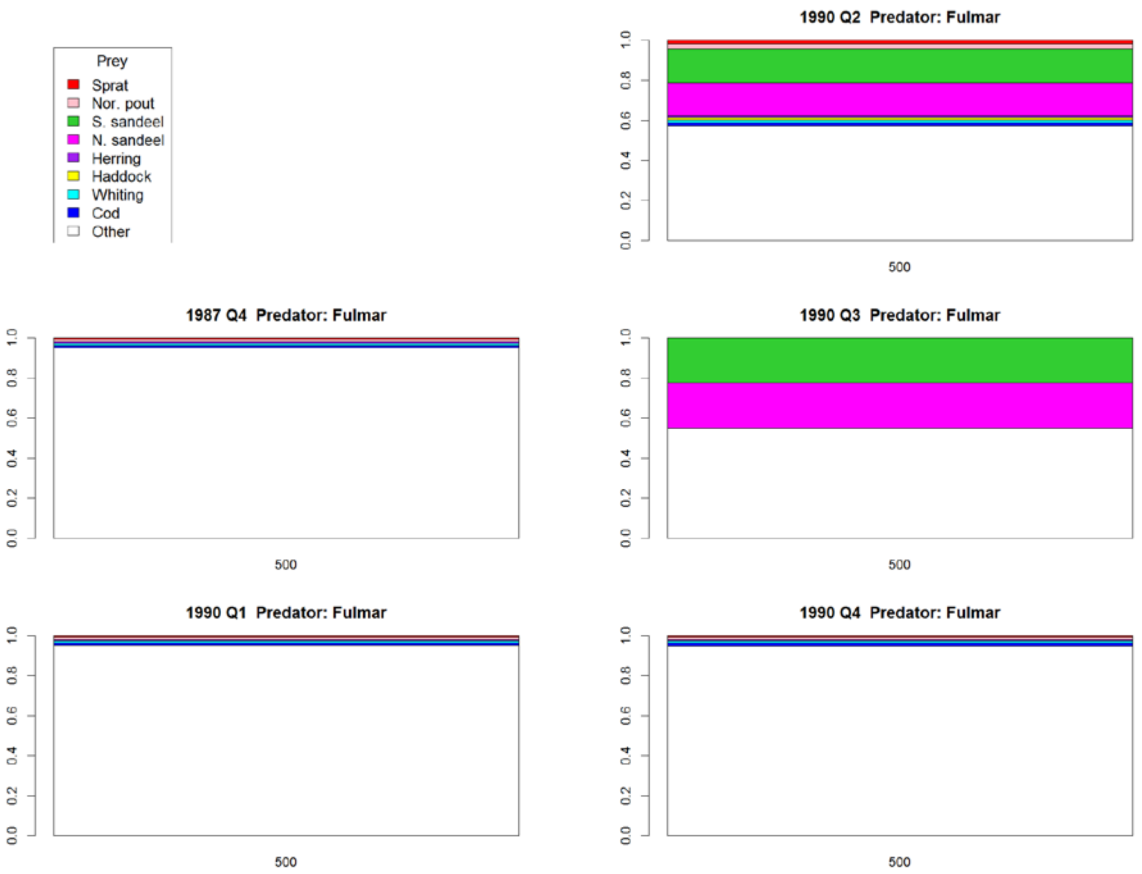

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1986 Q3 Predator: Cod
1985 Q3 Predator: Cod
1987 Q1 Predator: Cod
1986 Q1 Predator: Cod
1987 Q3 Predator: Cod

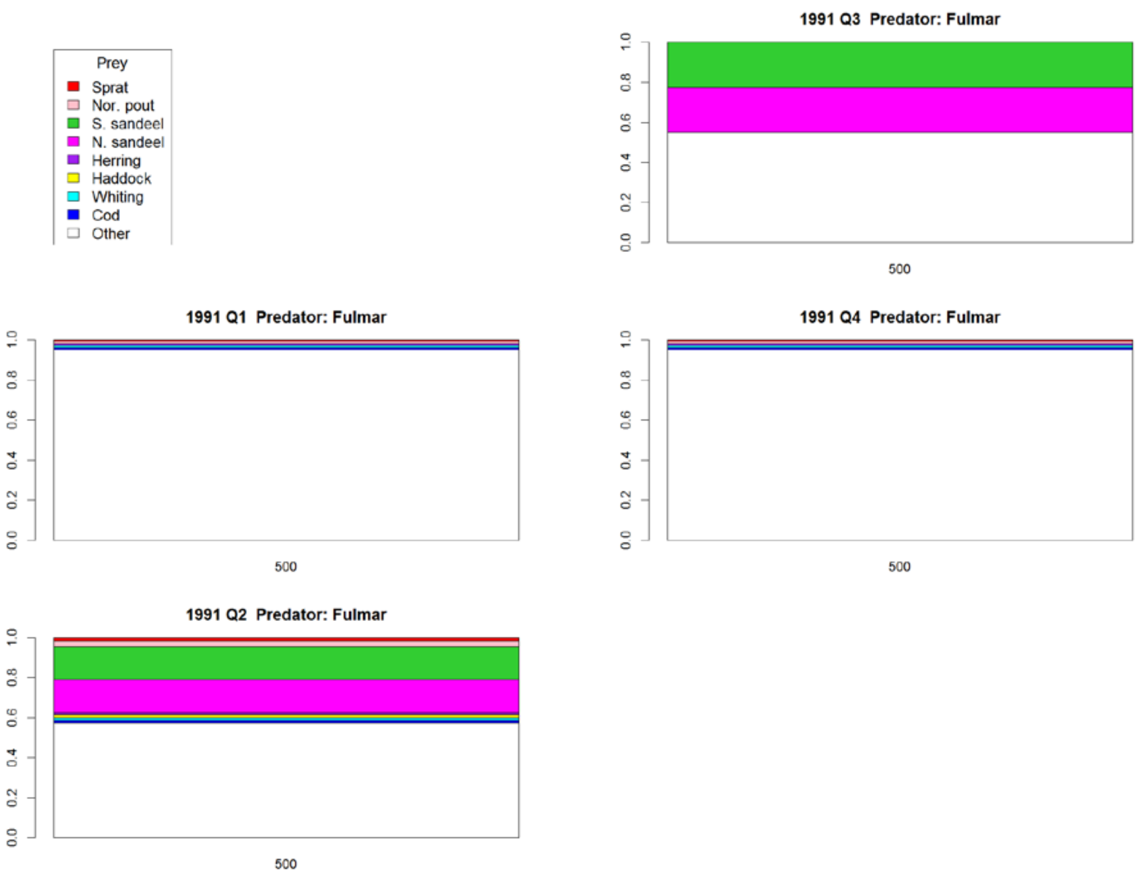

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q2 Predator: Cod
150 200 250 300 350 400 500 600 700 800 1000
1990 Q3 Predator: Cod
200 250 300 350 400 500
1991 Q3 Predator: Cod
200 250 300 350 400 500 600 700 800 1000
1991 Q1 Predator: Cod
150 200 250 300 350 400 500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

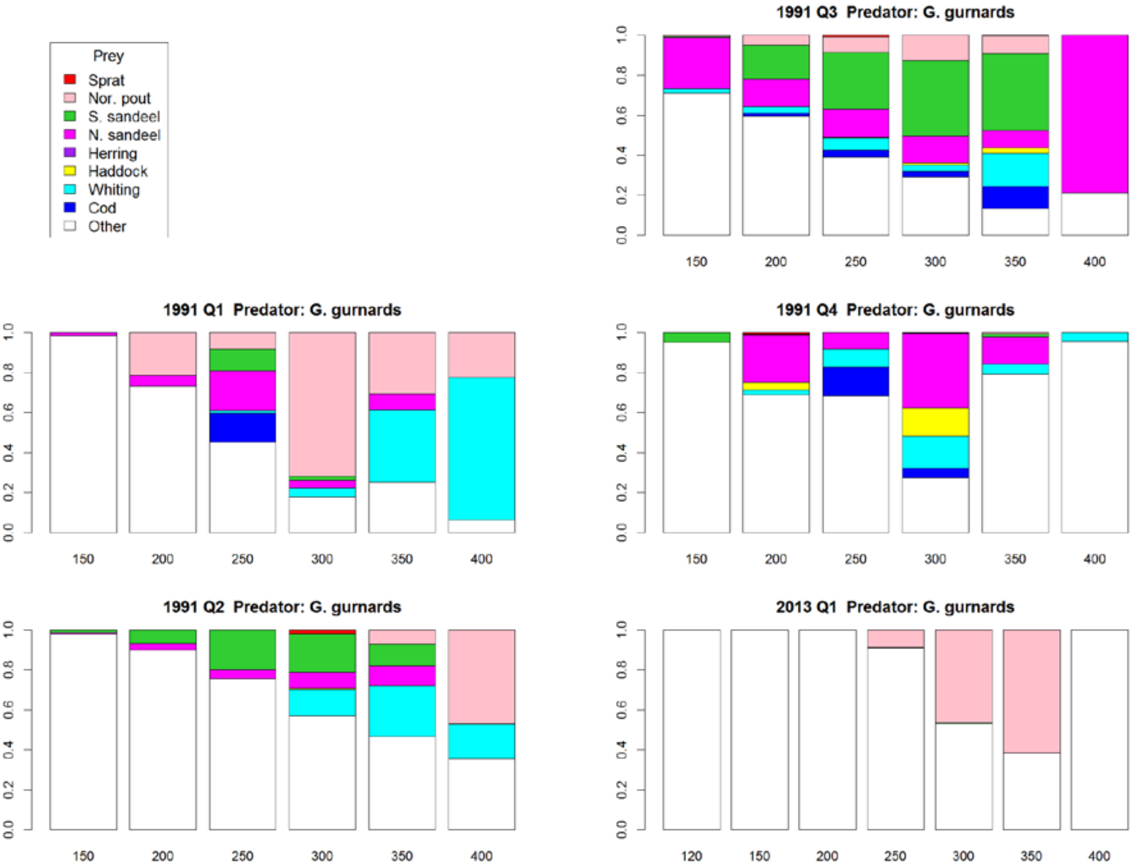

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Fulmar
1981 Q1 Predator: Fulmar
1981 Q4 Predator: Fulmar
1981 Q2 Predator: Fulmar
1985 Q1 Predator: Fulmar
500
0.0 0.2 0.4 0.6 0.8 1.0

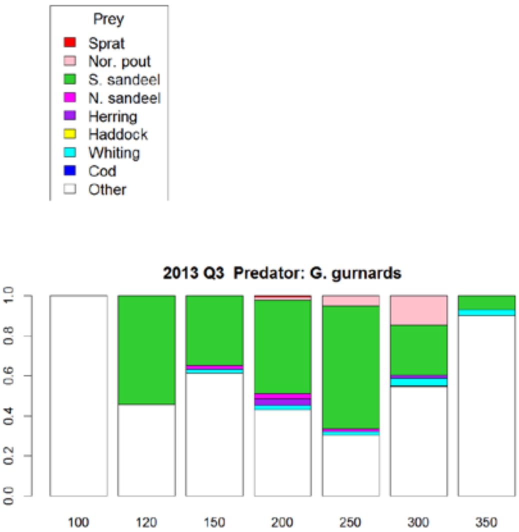

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Fulmar
1985 Q2 Predator: Fulmar
1986 Q1 Predator: Fulmar
1985 Q3 Predator: Fulmar
1986 Q2 Predator: Fulmar
0.0
0.2
0.4
0.6
0.8
1.0
500

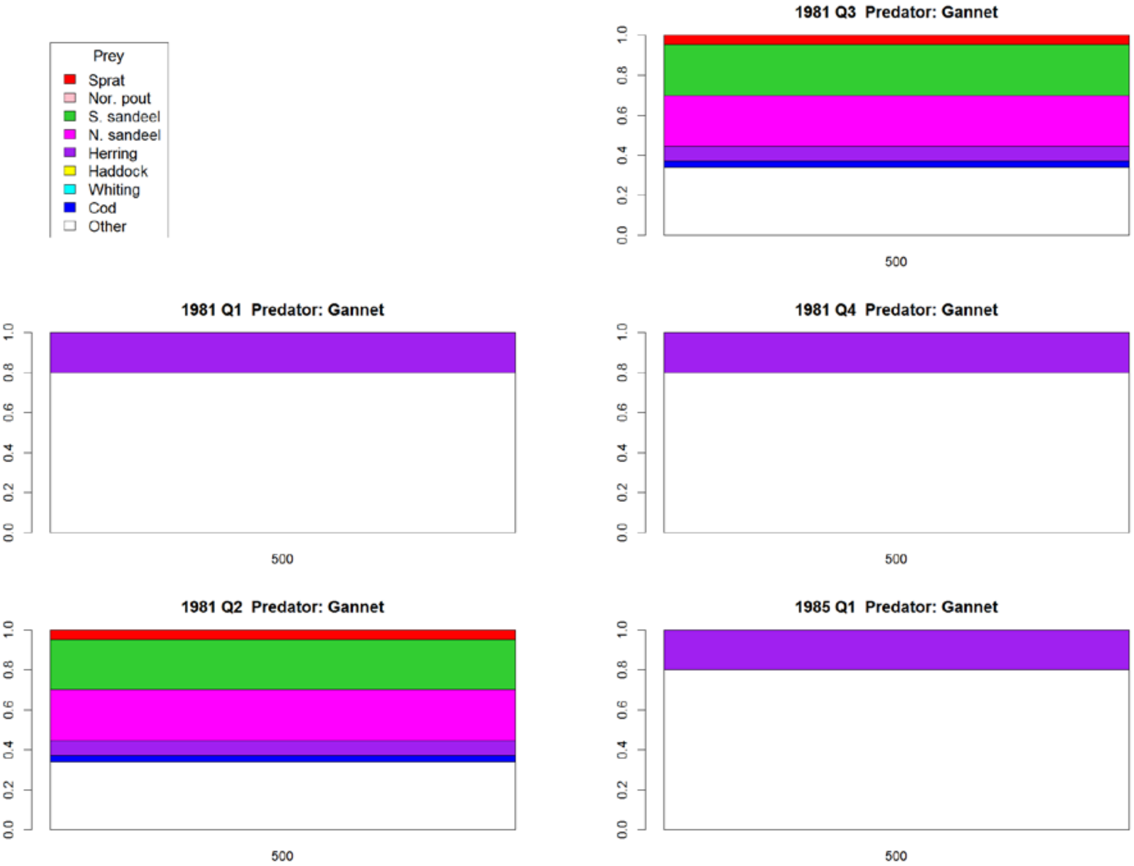

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Fulmar
1986 Q3 Predator: Fulmar
1987 Q2 Predator: Fulmar
1986 Q4 Predator: Fulmar
1987 Q3 Predator: Fulmar
0.0
0.2
0.4
0.6
0.8
1.0
500

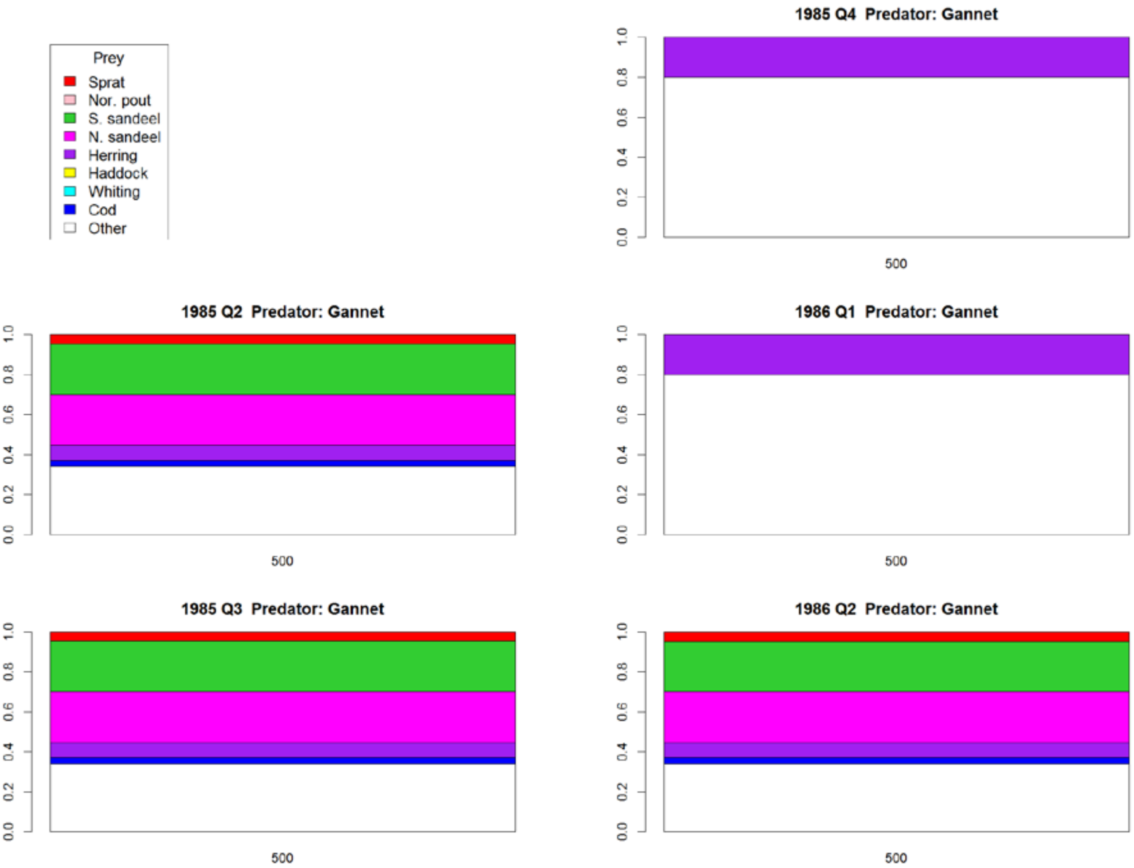

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Fulmar
1987 Q4 Predator: Fulmar
1990 Q3 Predator: Fulmar
1990 Q1 Predator: Fulmar
1990 Q4 Predator: Fulmar
0.0
0.2
0.4
0.6
0.8
1.0
500

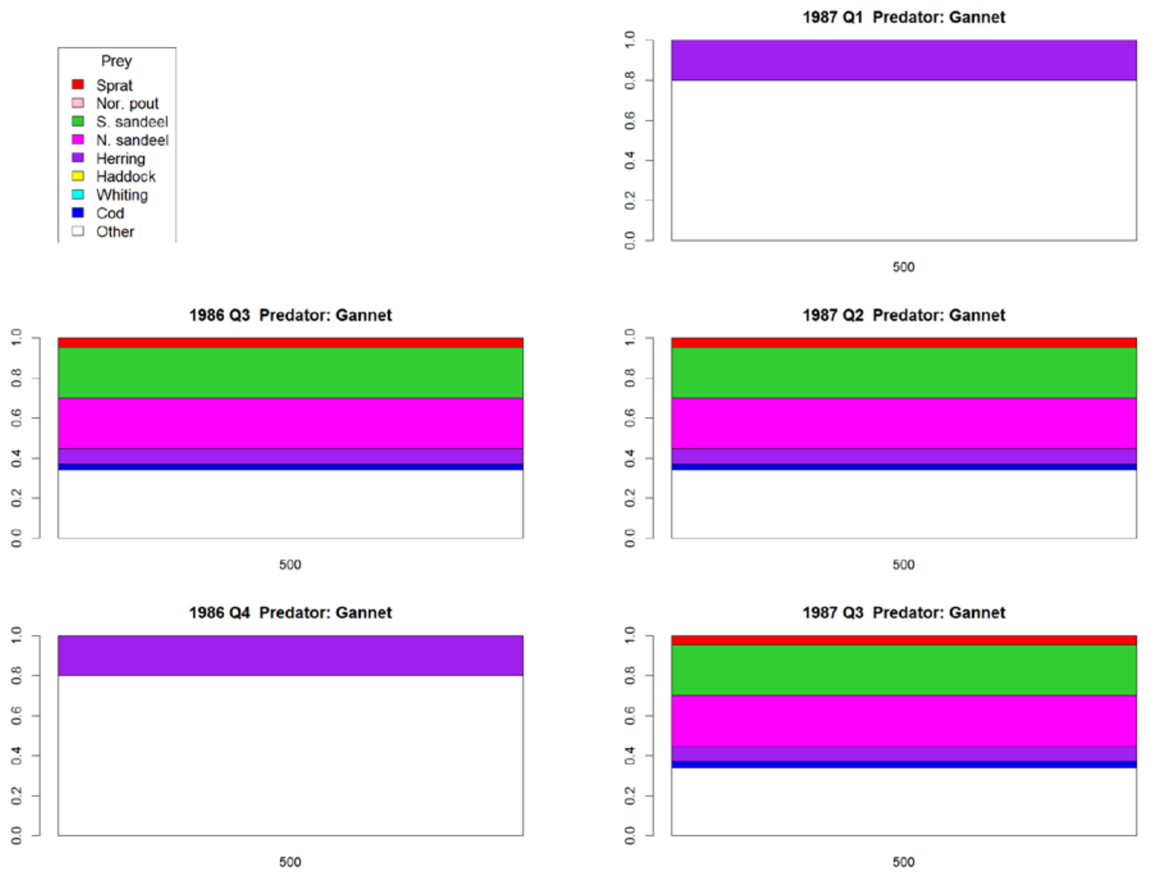

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Fulmar
1991 Q1 Predator: Fulmar
1991 Q4 Predator: Fulmar
1991 Q2 Predator: Fulmar
0.0
0.2
0.4
0.6
0.8
1.0
500

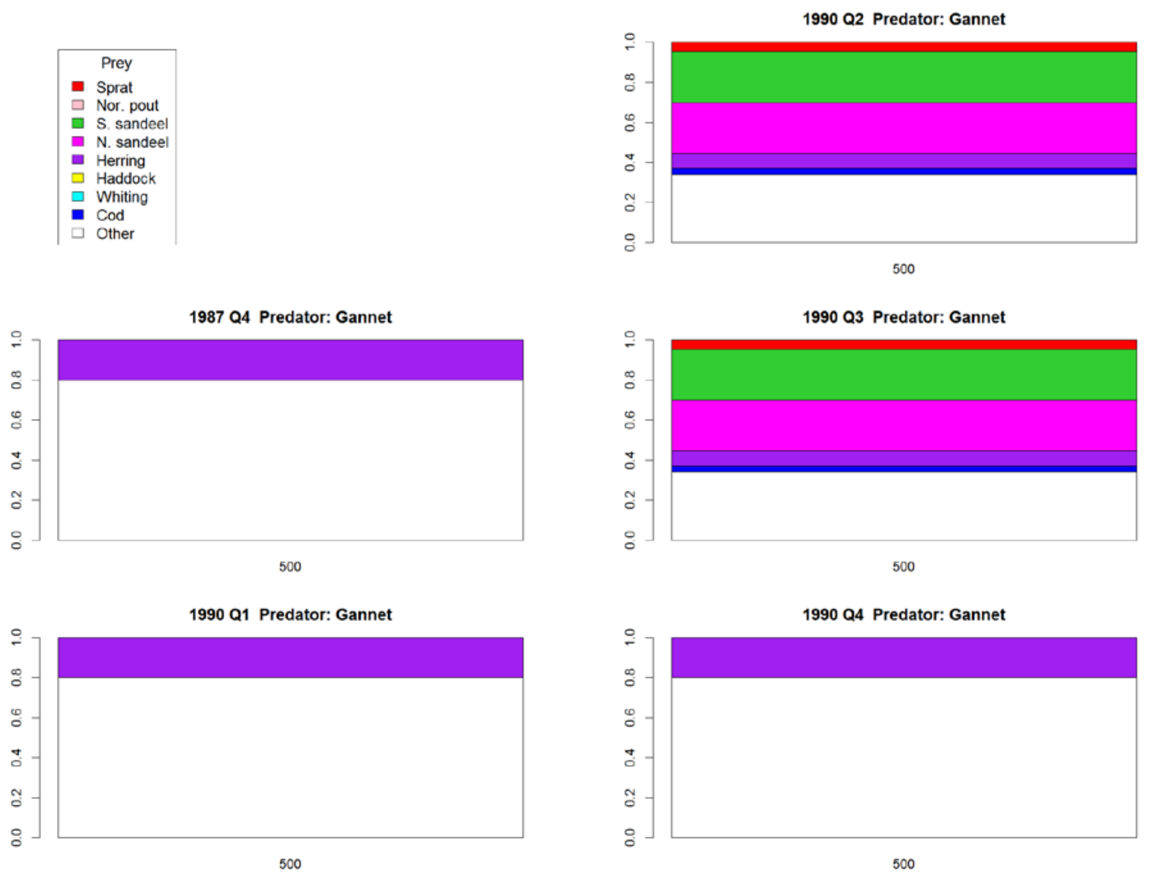

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: G. gurnards
1991 Q1 Predator: G. gurnards
1991 Q4 Predator: G. gurnards
1991 Q2 Predator: G. gurnards
2013 Q1 Predator: G. gurnards

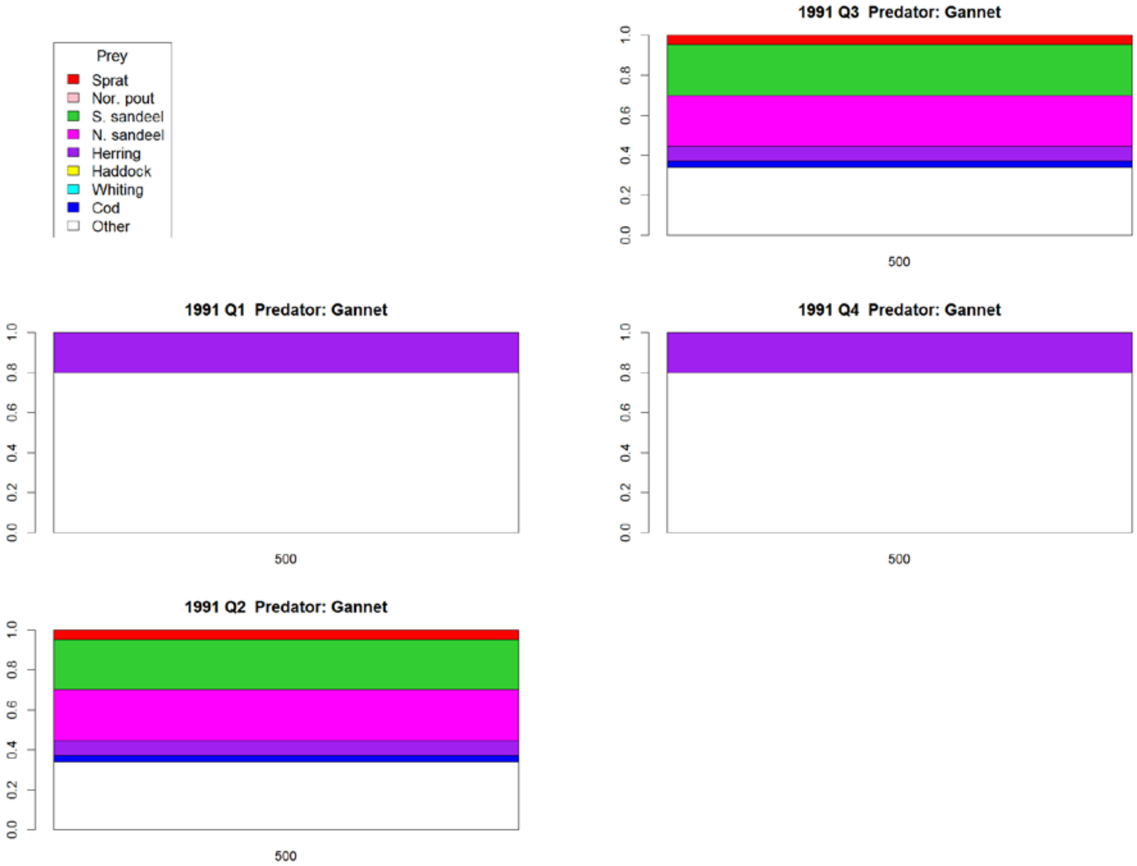

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
2013 Q3 Predator: G. gurnards

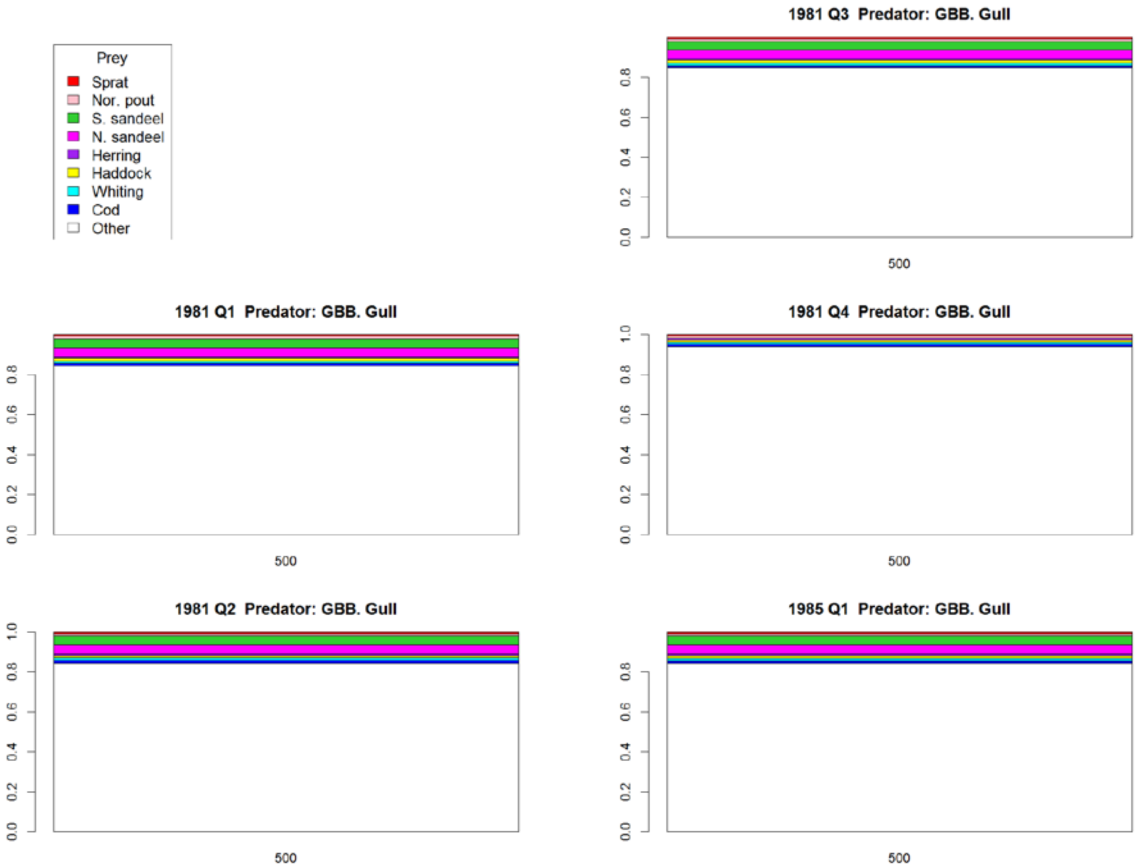

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Gannet
1981 Q1 Predator: Gannet
1981 Q4 Predator: Gannet
1981 Q2 Predator: Gannet
1985 Q1 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

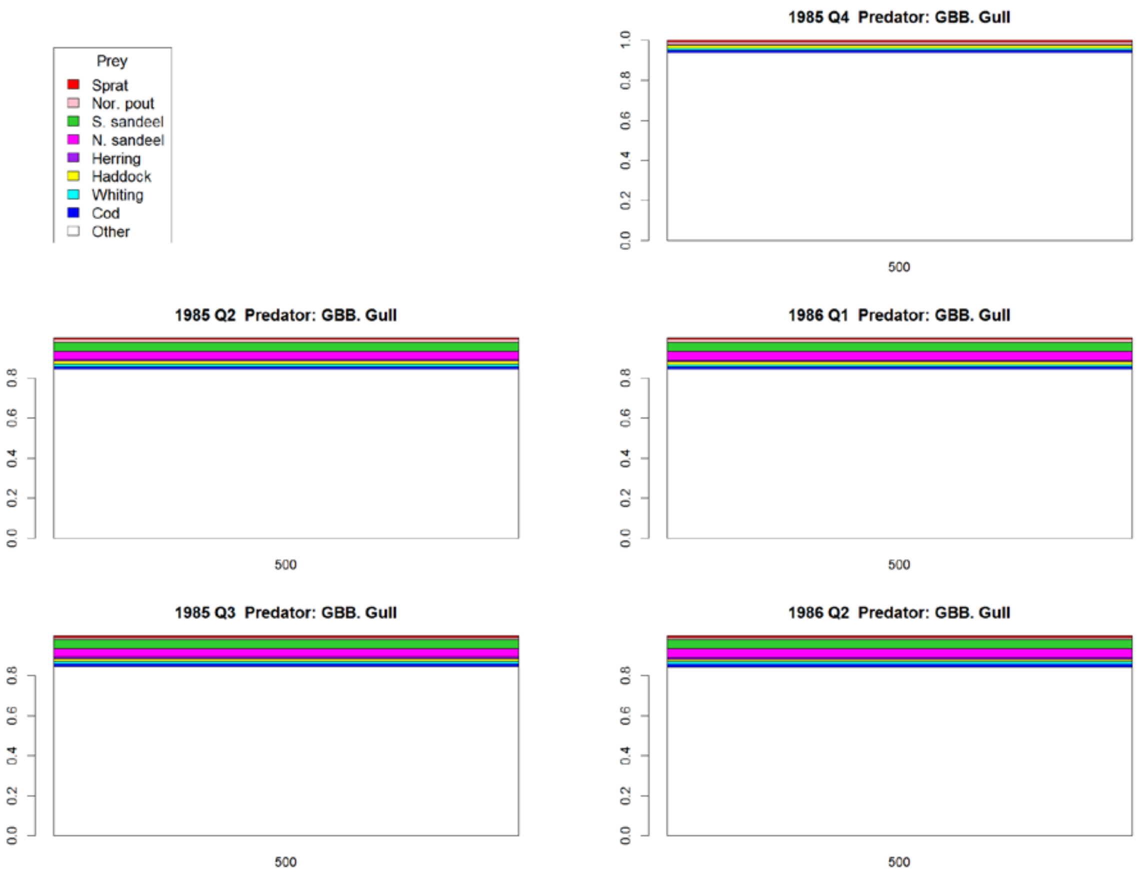

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Gannet
1985 Q2 Predator: Gannet
1986 Q1 Predator: Gannet
1985 Q3 Predator: Gannet
1986 Q2 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

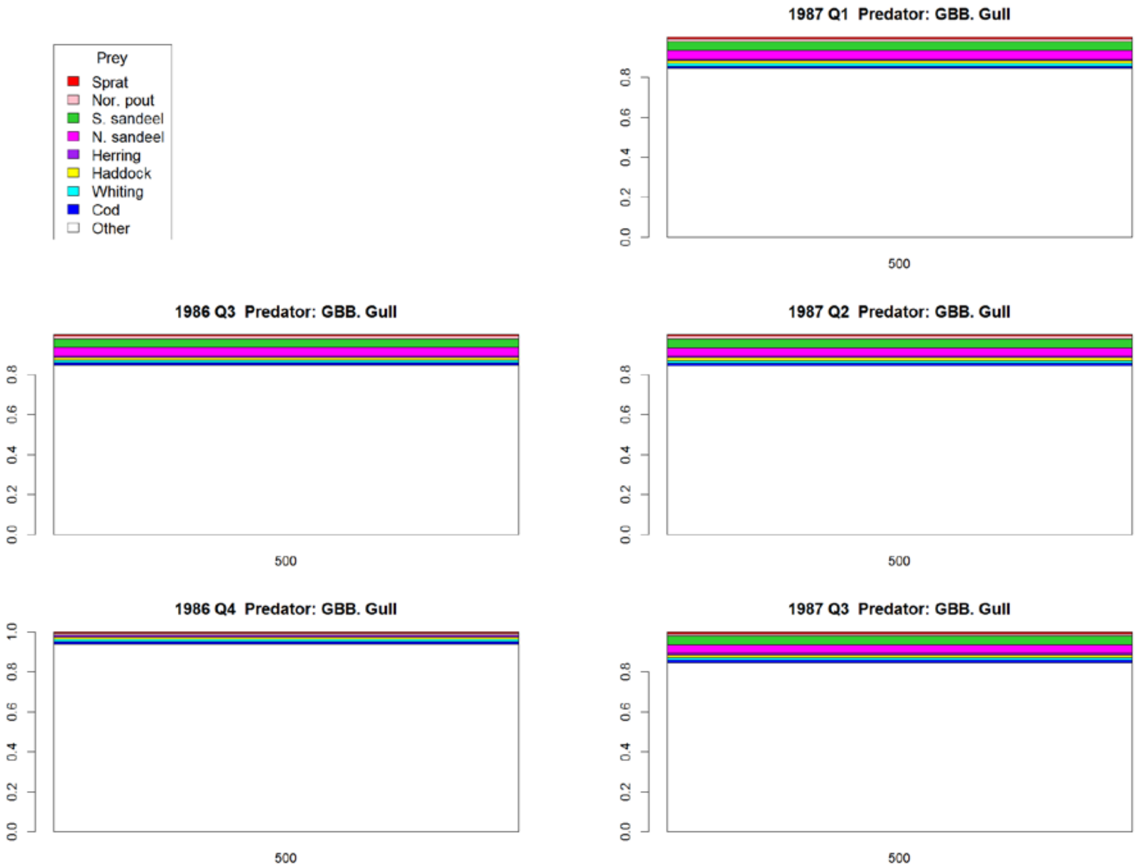

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Gannet
1986 Q3 Predator: Gannet
1987 Q2 Predator: Gannet
1986 Q4 Predator: Gannet
1987 Q3 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

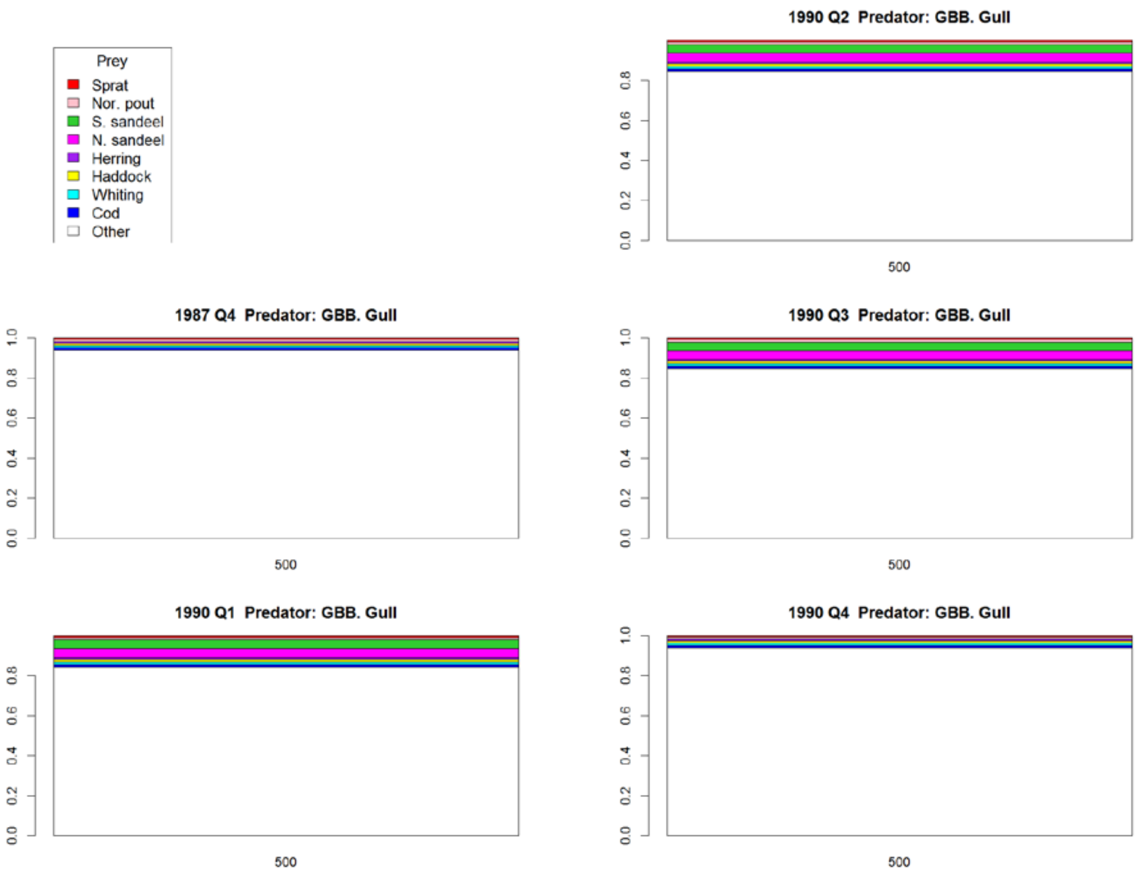

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Gannet
1987 Q4 Predator: Gannet
1990 Q3 Predator: Gannet
1990 Q1 Predator: Gannet
1990 Q4 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

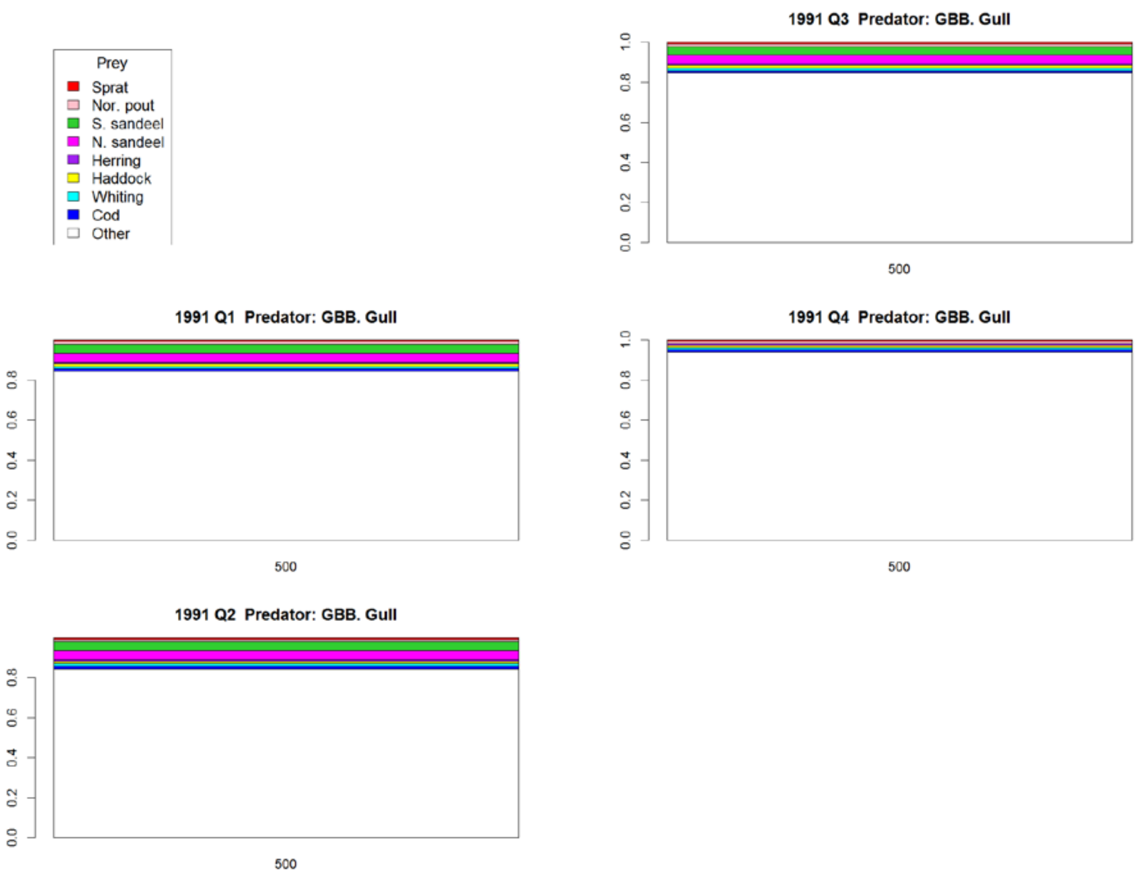

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Gannet
1991 Q1 Predator: Gannet
1991 Q4 Predator: Gannet
1991 Q2 Predator: Gannet
0.0
0.2
0.4
0.6
0.8
1.0
500

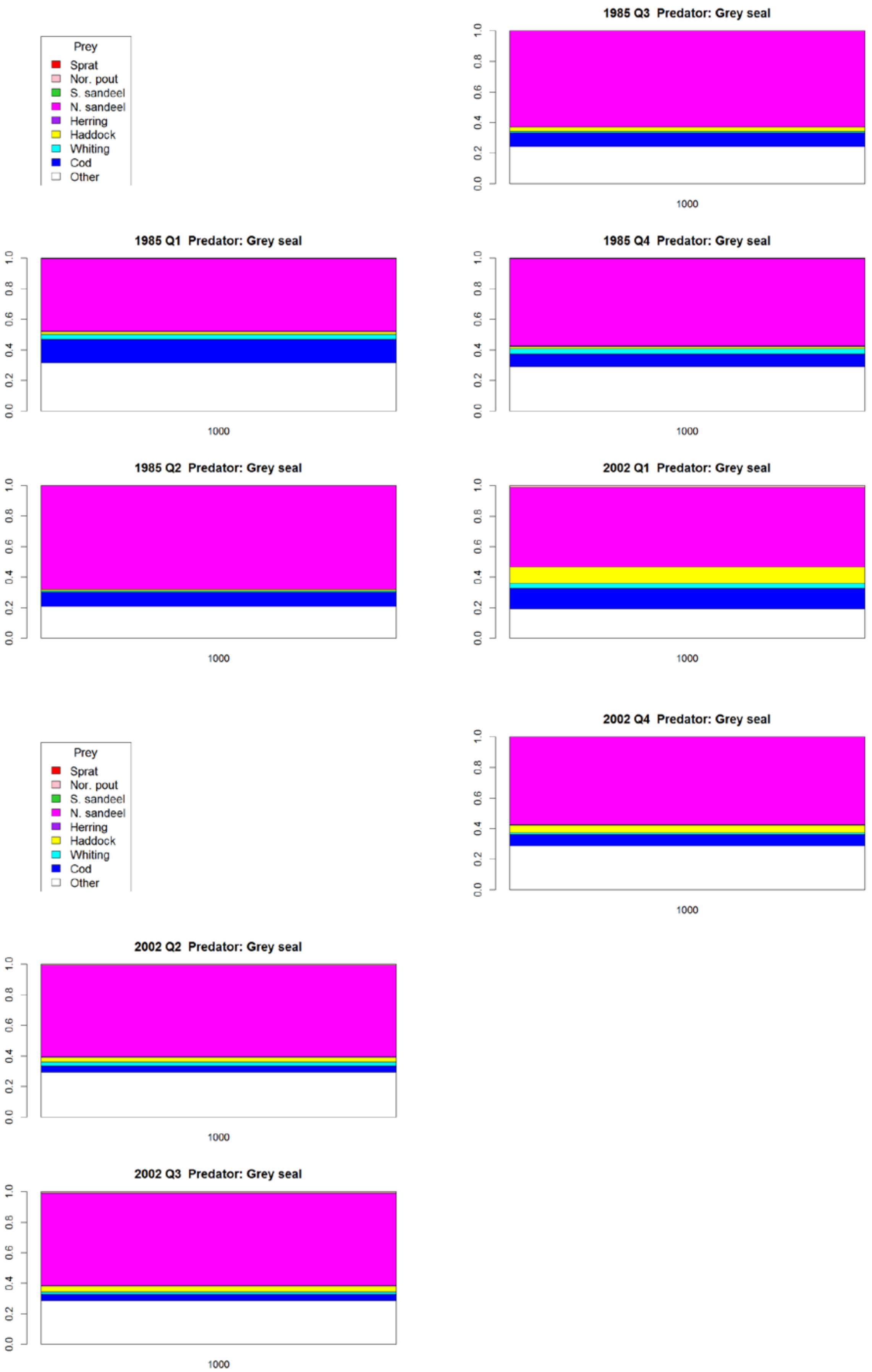

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: GBB. Gull
1981 Q1 Predator: GBB. Gull
1981 Q4 Predator: GBB. Gull
1981 Q2 Predator: GBB. Gull
1985 Q1 Predator: GBB. Gull
0.0
0.2
0.4
0.6
0.8
1.0
500

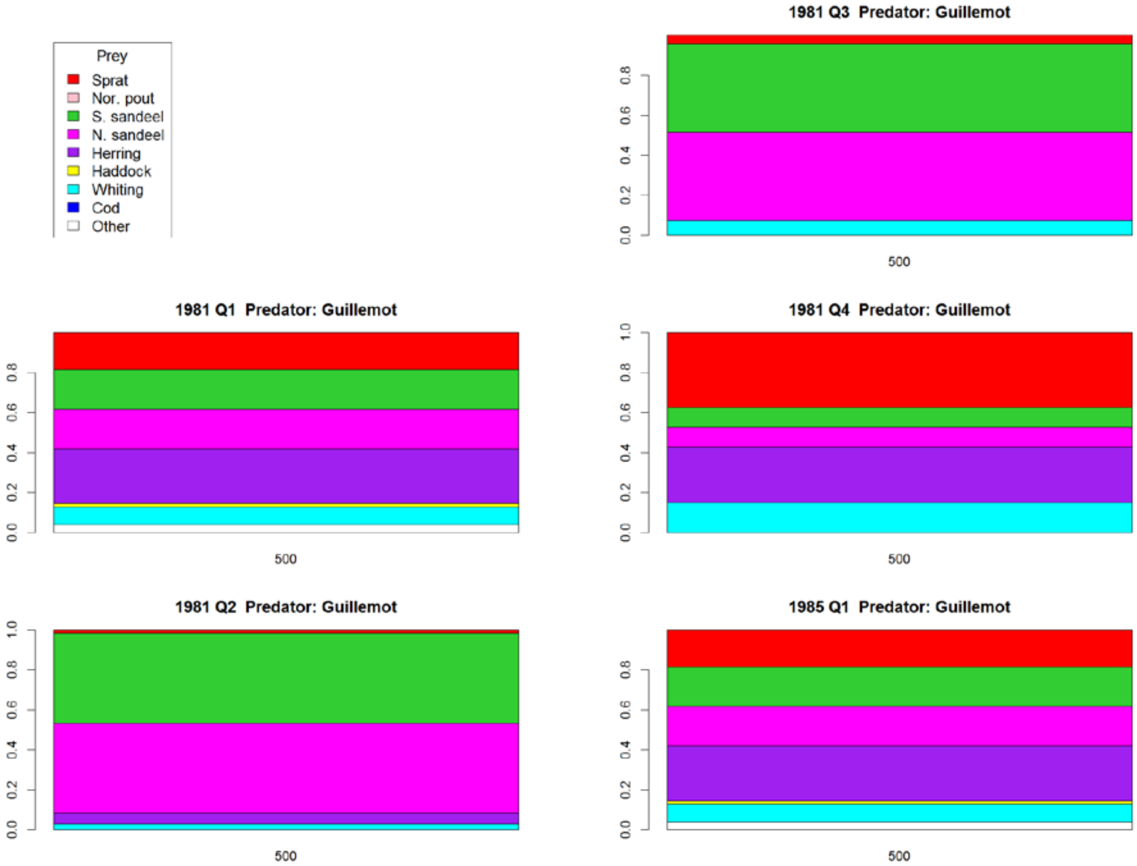

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: GBB. Gull
1985 Q2 Predator: GBB. Gull
1986 Q1 Predator: GBB. Gull
1985 Q3 Predator: GBB. Gull
1986 Q2 Predator: GBB. Gull
500

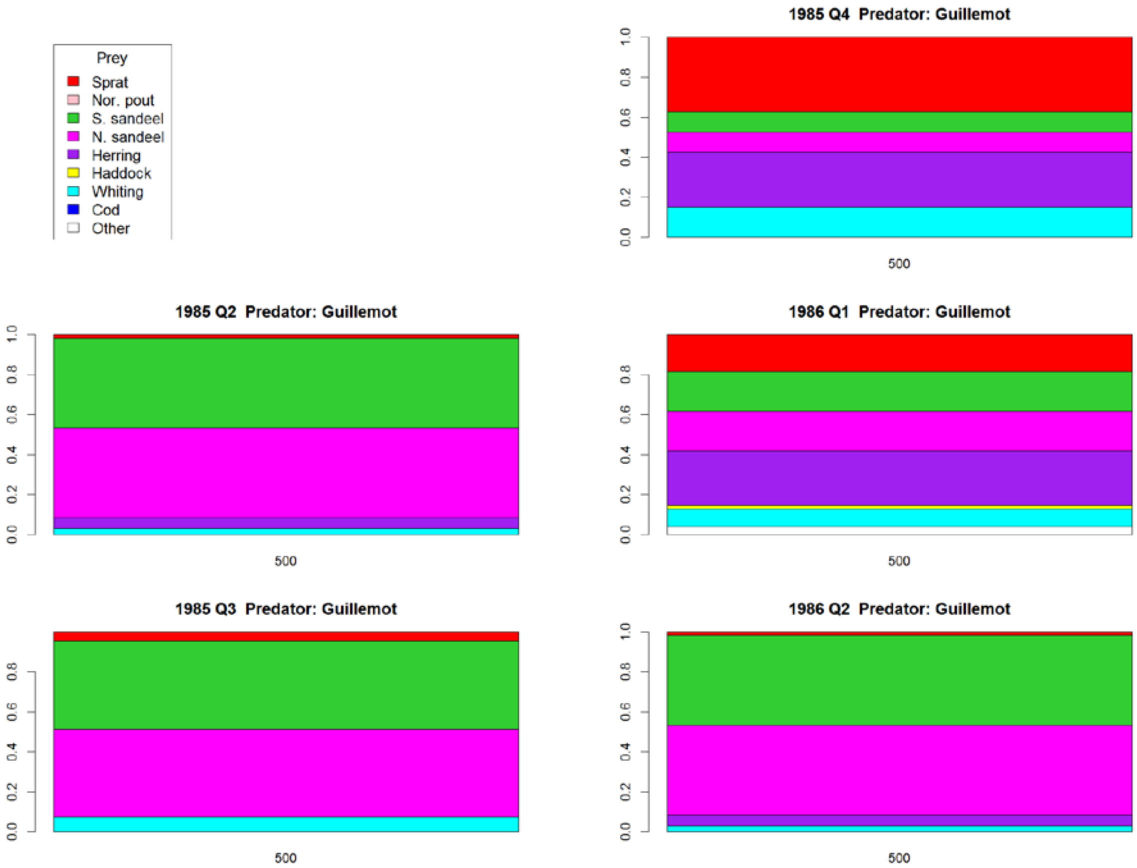

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: GBB. Gull
1986 Q3 Predator: GBB. Gull
1987 Q2 Predator: GBB. Gull
1986 Q4 Predator: GBB. Gull
1987 Q3 Predator: GBB. Gull
500

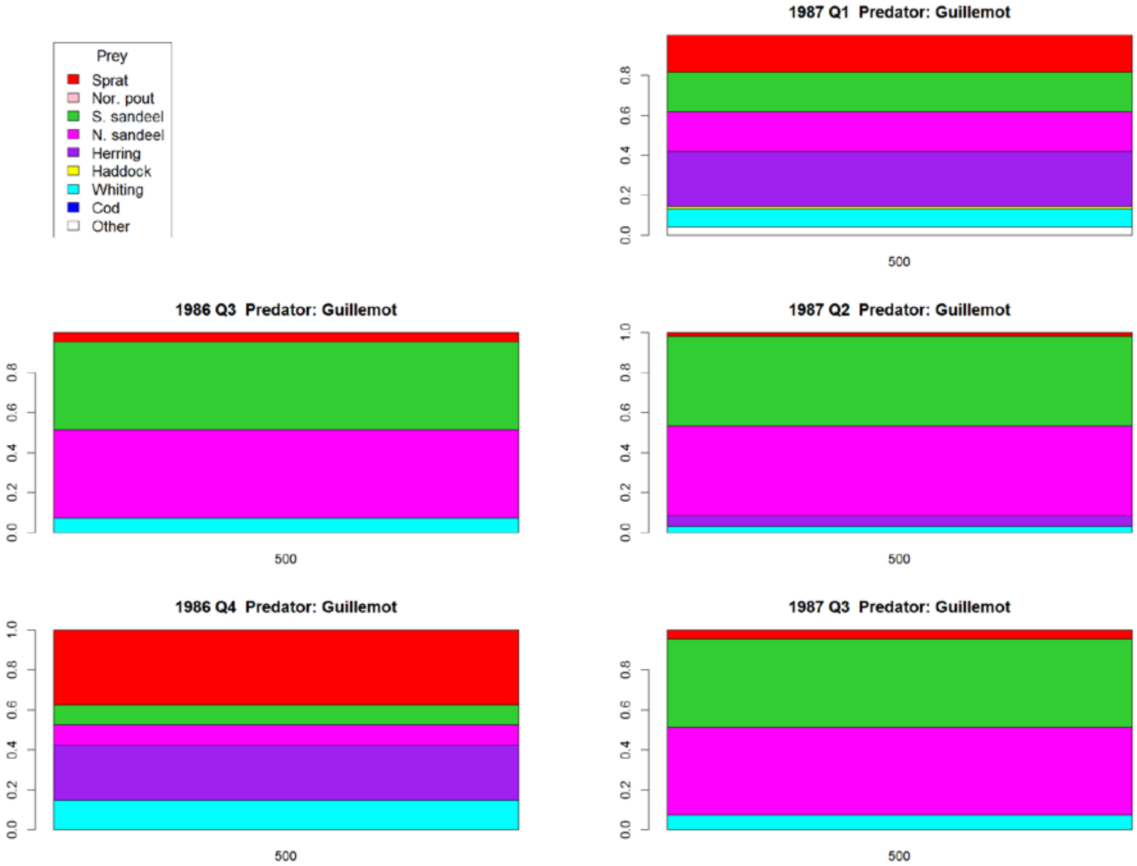

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: GBB. Gull
1987 Q4 Predator: GBB. Gull
1990 Q3 Predator: GBB. Gull
1990 Q1 Predator: GBB. Gull
1990 Q4 Predator: GBB. Gull
500

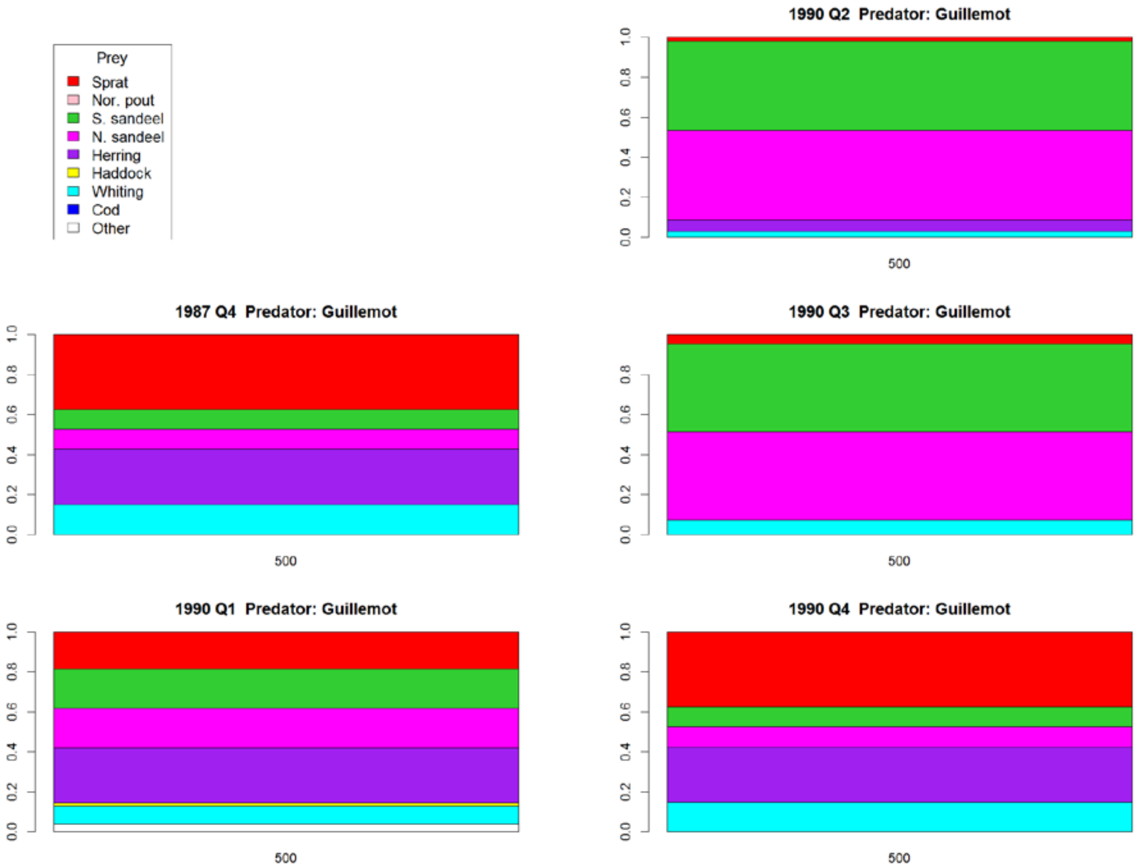

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: GBB. Gull
1991 Q1 Predator: GBB. Gull
1991 Q4 Predator: GBB. Gull
1991 Q2 Predator: GBB. Gull
500

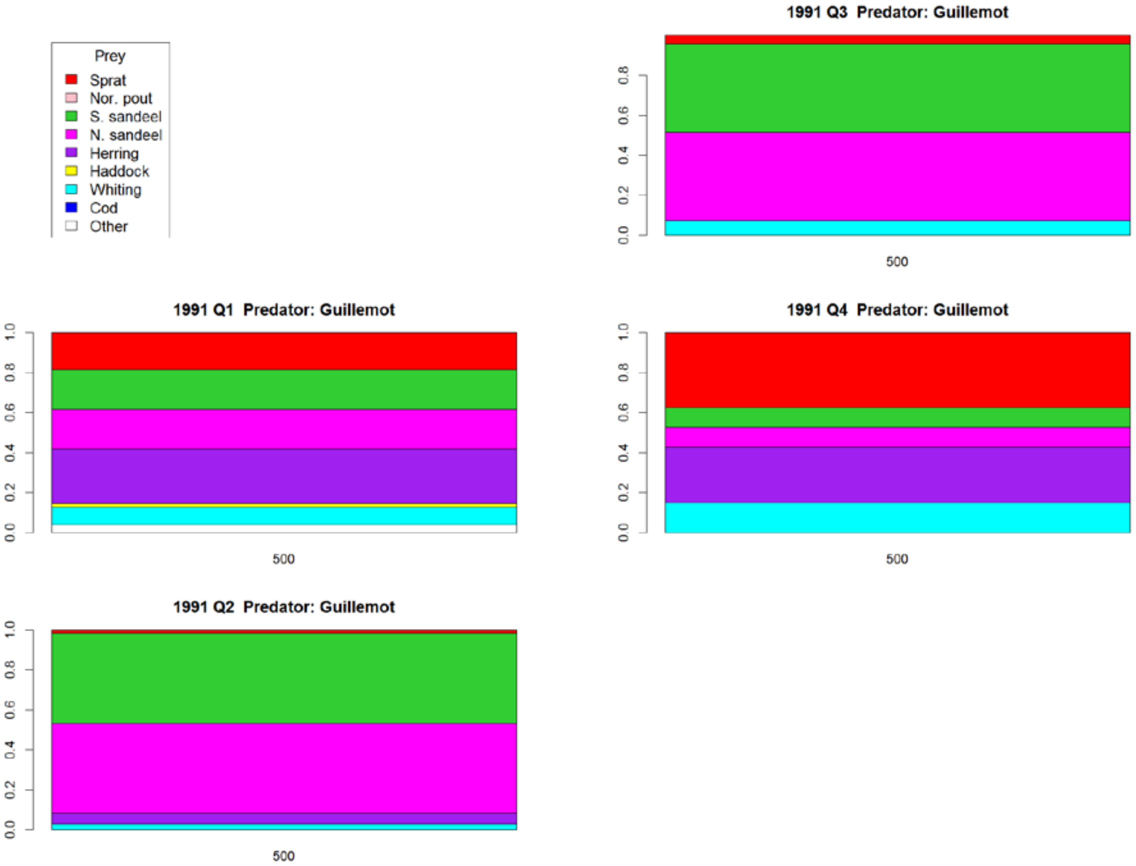

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q3 Predator: Grey seal
1985 Q1 Predator: Grey seal
1985 Q4 Predator: Grey seal
1985 Q2 Predator: Grey seal
2002 Q1 Predator: Grey seal
2002 Q4 Predator: Grey seal
Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock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

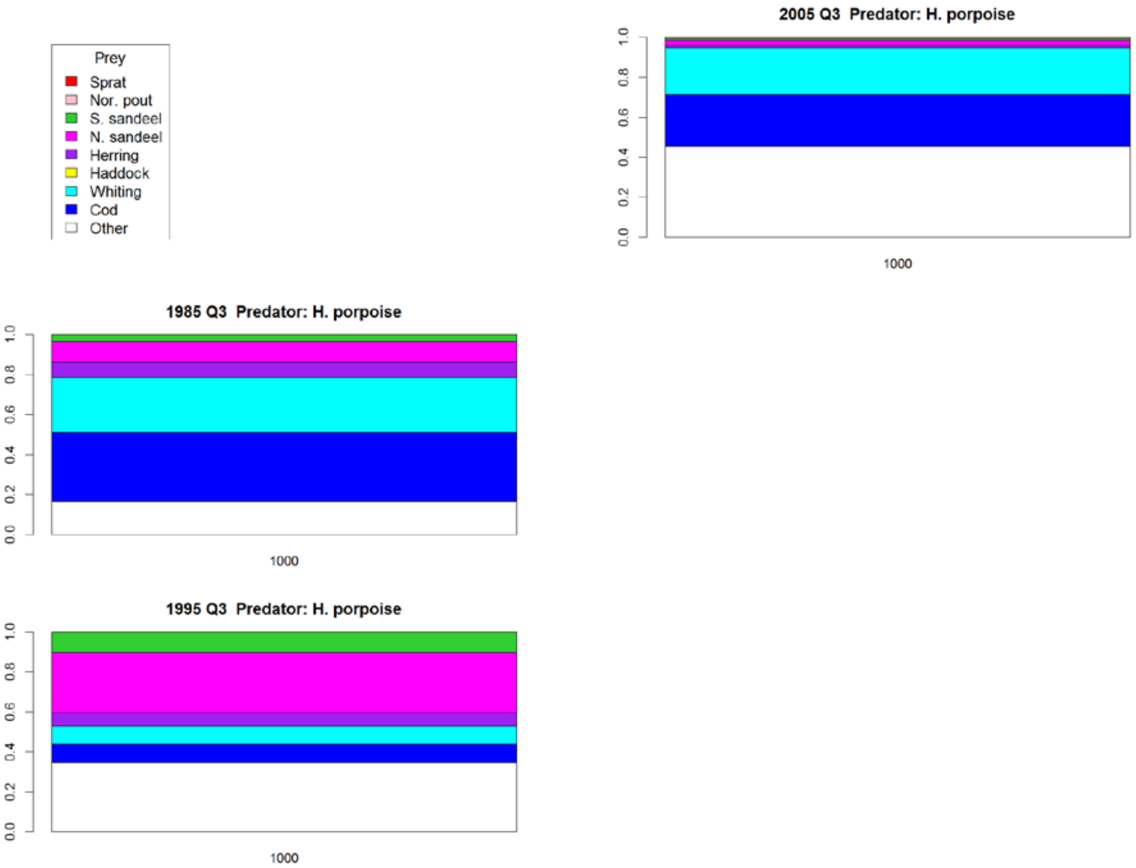

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Guillemot
1981 Q1 Predator: Guillemot
1981 Q4 Predator: Guillemot
1981 Q2 Predator: Guillemot
1985 Q1 Predator: Guillemot
0.0
0.2
0.4
0.6
0.8
1.0
500

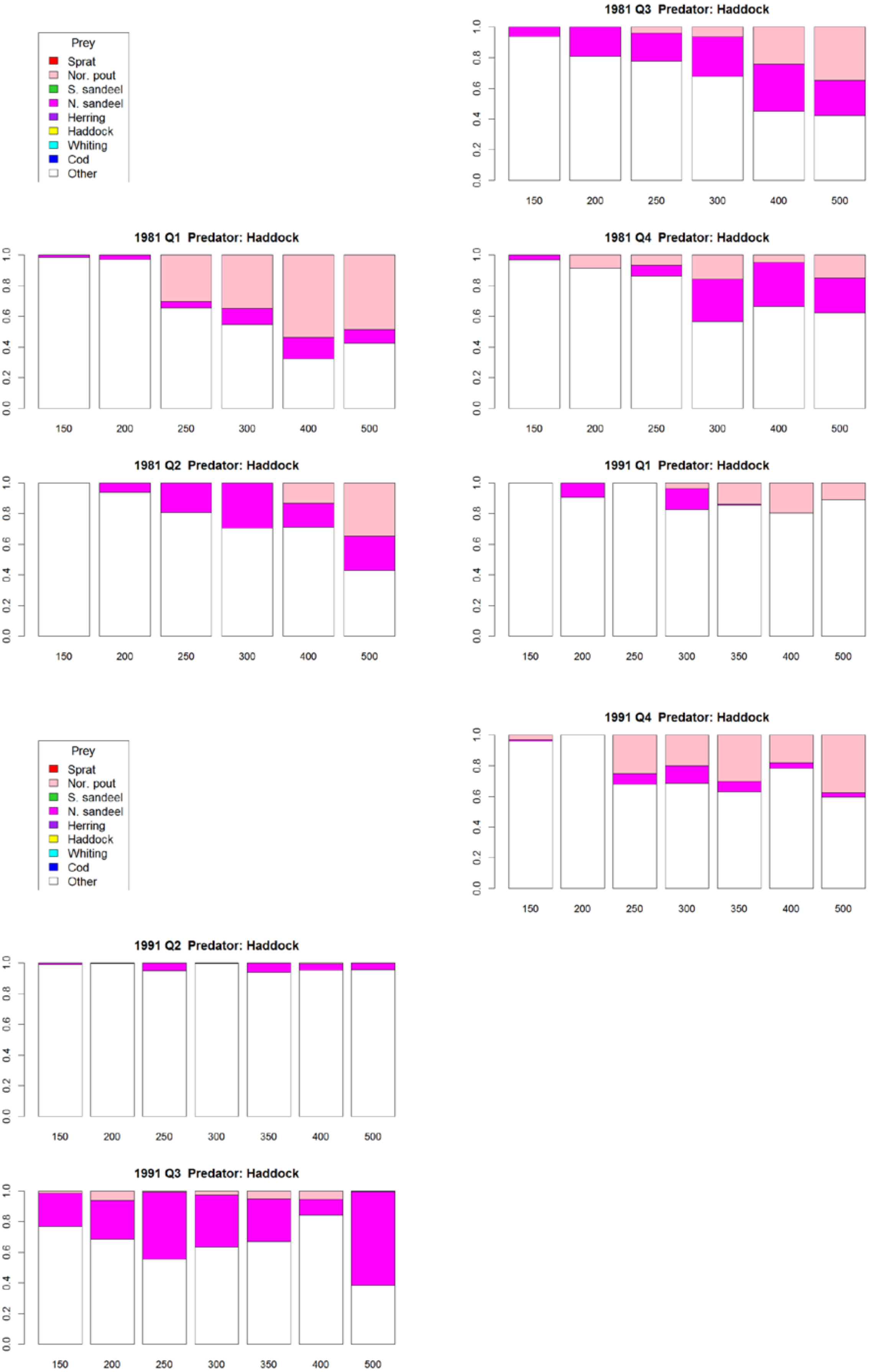

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Guillemot
1985 Q2 Predator: Guillemot
1986 Q1 Predator: Guillemot
1985 Q3 Predator: Guillemot
1986 Q2 Predator: Guillemot
0.0
0.2
0.4
0.6
0.8
1.0
500

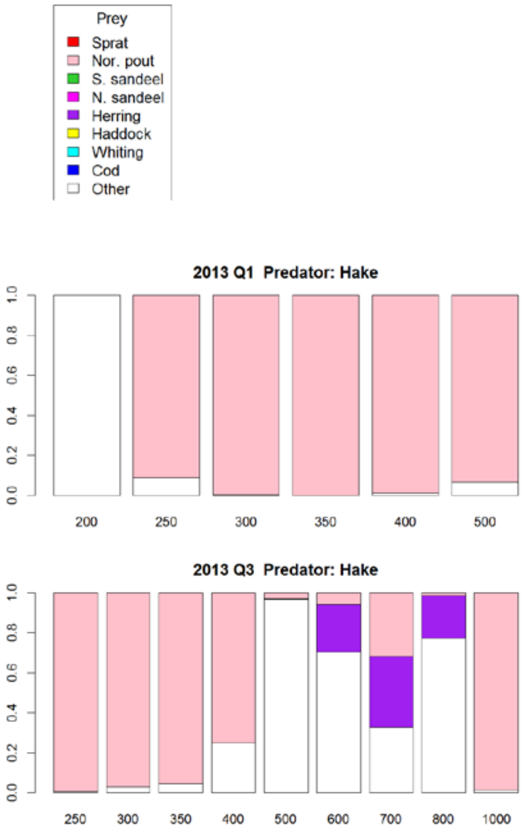

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Guillemot
1986 Q3 Predator: Guillemot
1987 Q2 Predator: Guillemot
1986 Q4 Predator: Guillemot
1987 Q3 Predator: Guillemot
0.0
0.2
0.4
0.6
0.8
1.0
500

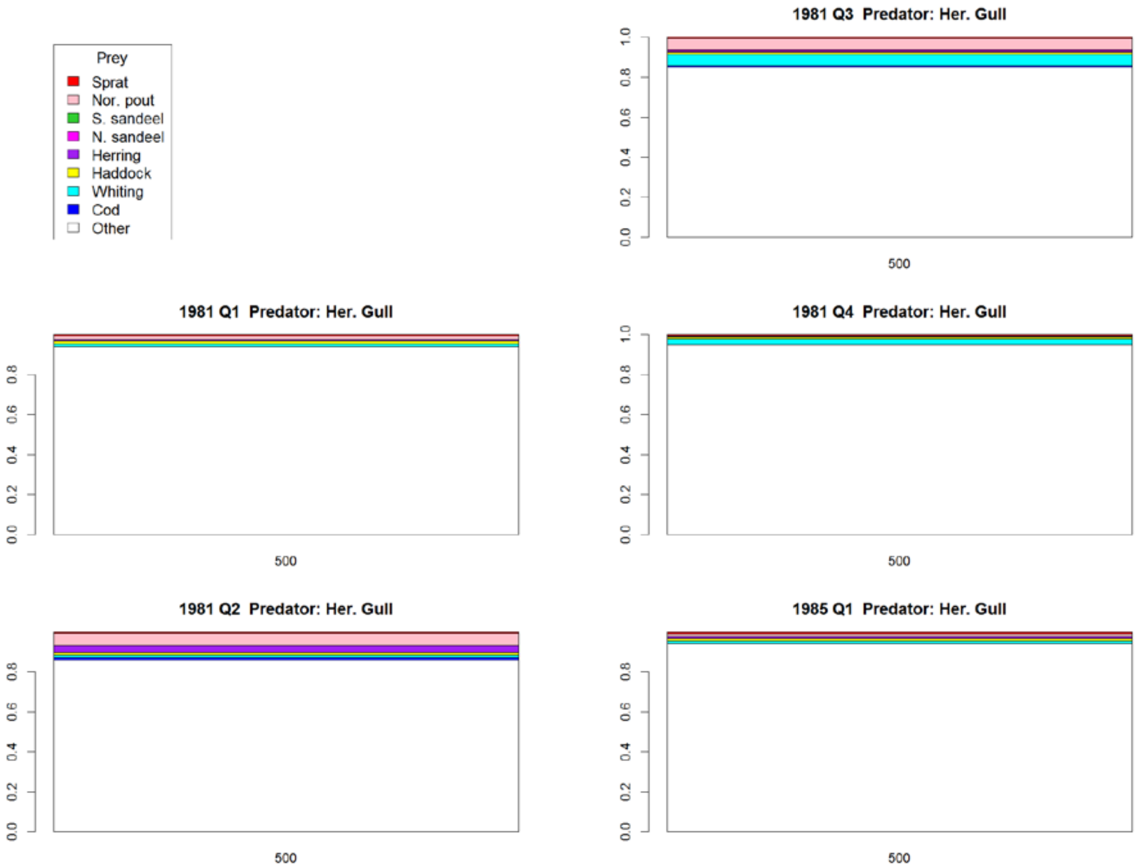

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Guillemot
1987 Q4 Predator: Guillemot
1990 Q3 Predator: Guillemot
1990 Q1 Predator: Guillemot
1990 Q4 Predator: Guillemot
0.0
0.2
0.4
0.6
0.8
1.0
500

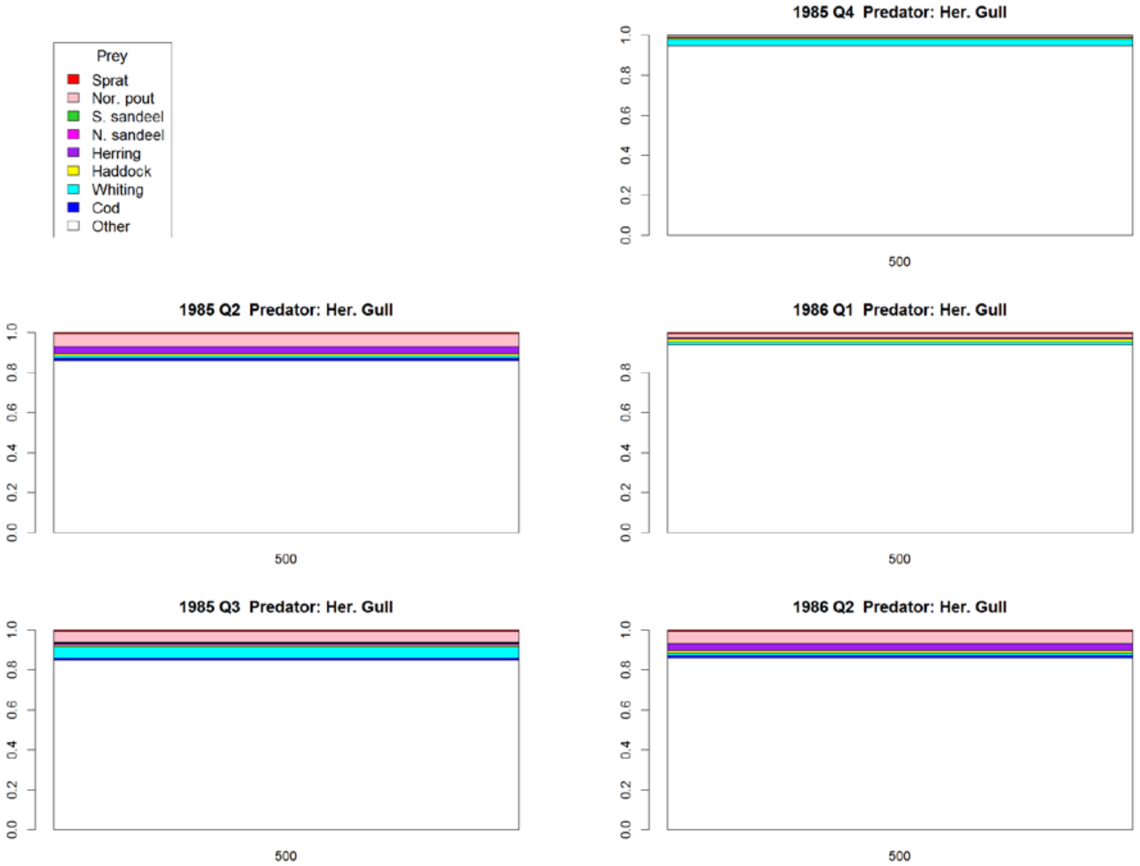

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Guillemot
1991 Q1 Predator: Guillemot
1991 Q4 Predator: Guillemot
1991 Q2 Predator: Guillemot
0.0
0.2
0.4
0.6
0.8
1.0
500

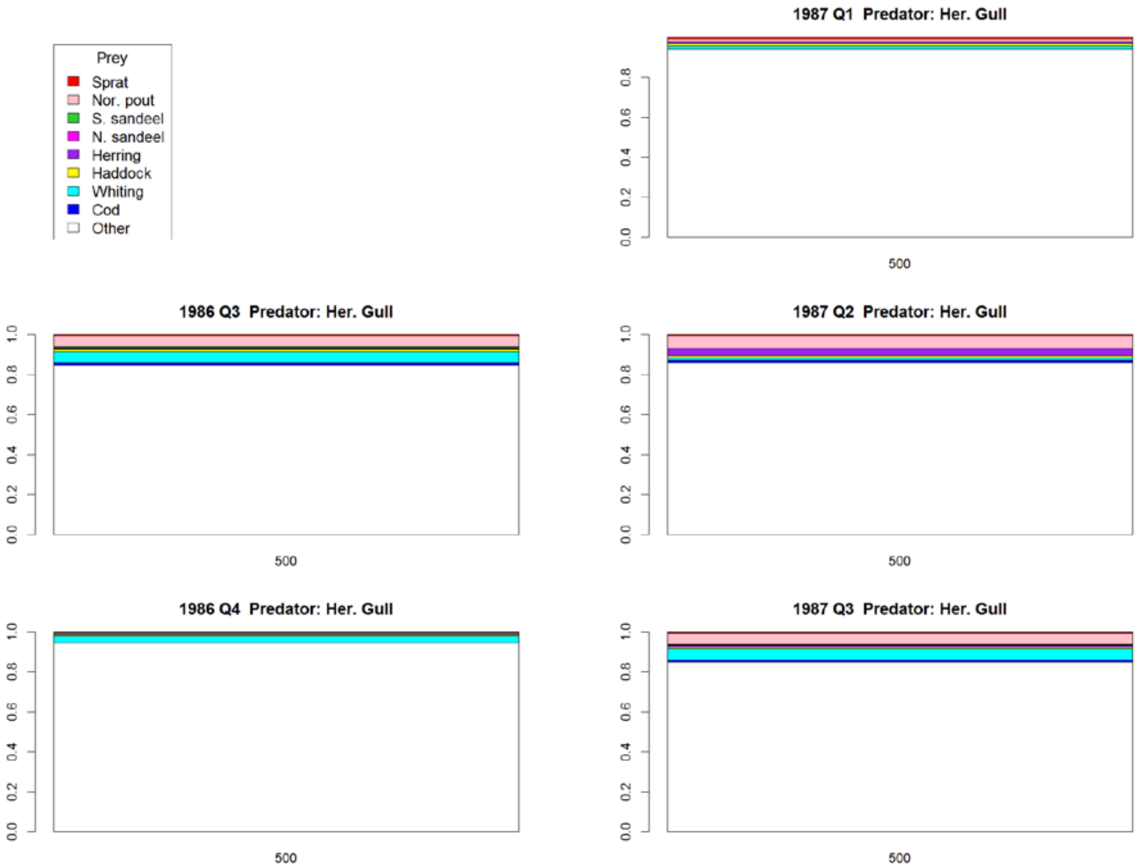

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
2005 Q3 Predator: H. porpoise
1985 Q3 Predator: H. porpoise
1995 Q3 Predator: H. porpoise
0.0
0.2
0.4
0.6
0.8
1.0
1000

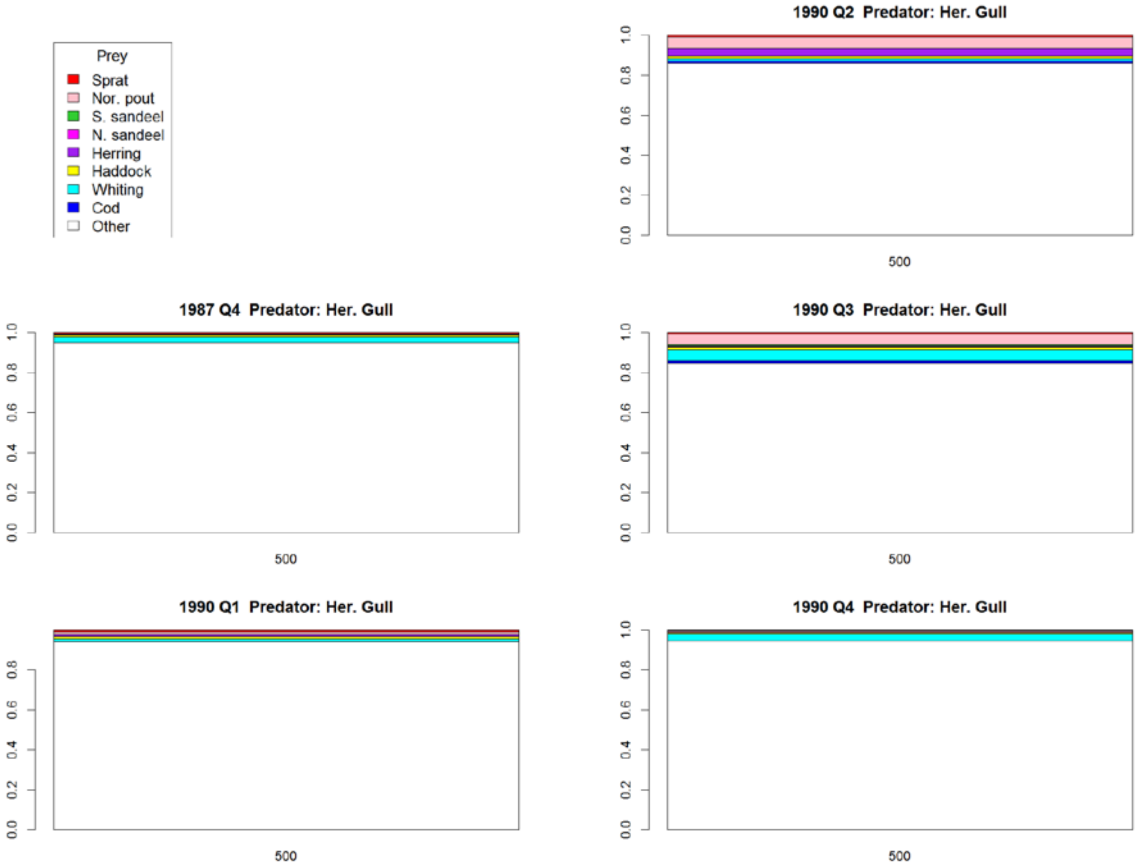

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Haddock
1981 Q1 Predator: Haddock
1981 Q4 Predator: Haddock
1981 Q2 Predator: Haddock
1991 Q1 Predator: Haddock
Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q4 Predator: Haddock
1991 Q2 Predator: Haddock
1991 Q3 Predator: Haddock
0.0 0.2 0.4 0.6 0.8 1.0
150 200 250 300 350 400 500

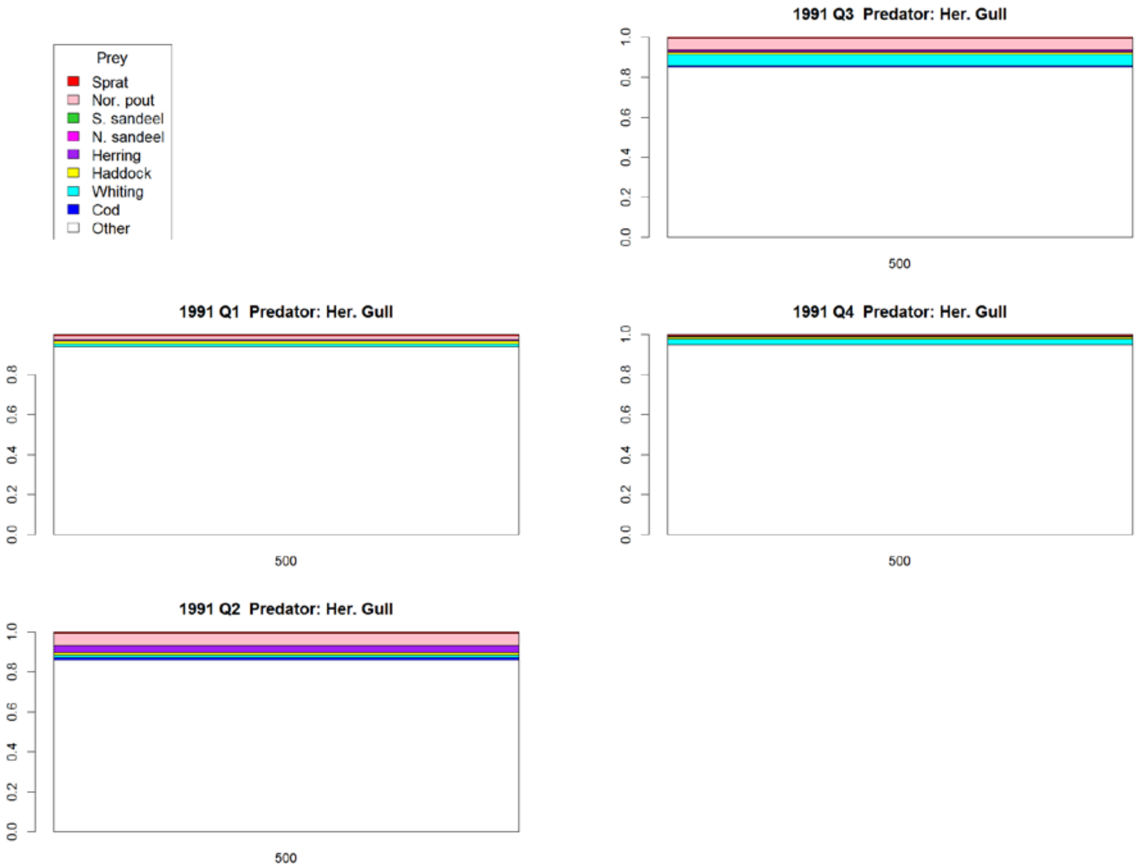

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
2013 Q1 Predator: Hake
0.0 0.2 0.4 0.6 0.8 1.0
200 250 300 350 400 500
2013 Q3 Predator: Hake
0.0 0.2 0.4 0.6 0.8 1.0
250 300 350 400 500 600 700 800 1000

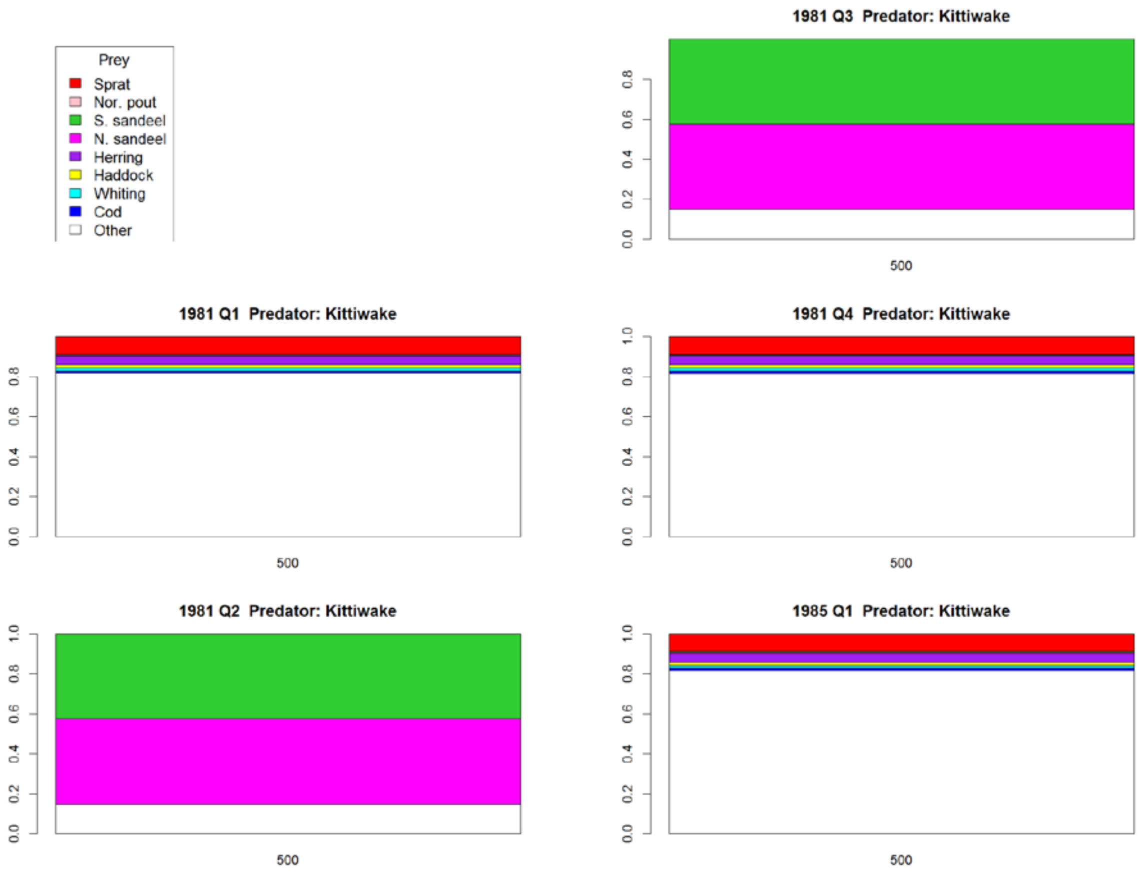

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Her. Gull
1981 Q1 Predator: Her. Gull
1981 Q4 Predator: Her. Gull
1981 Q2 Predator: Her. Gull
1985 Q1 Predator: Her. Gull
0.0 0.2 0.4 0.6 0.8 1.0
500

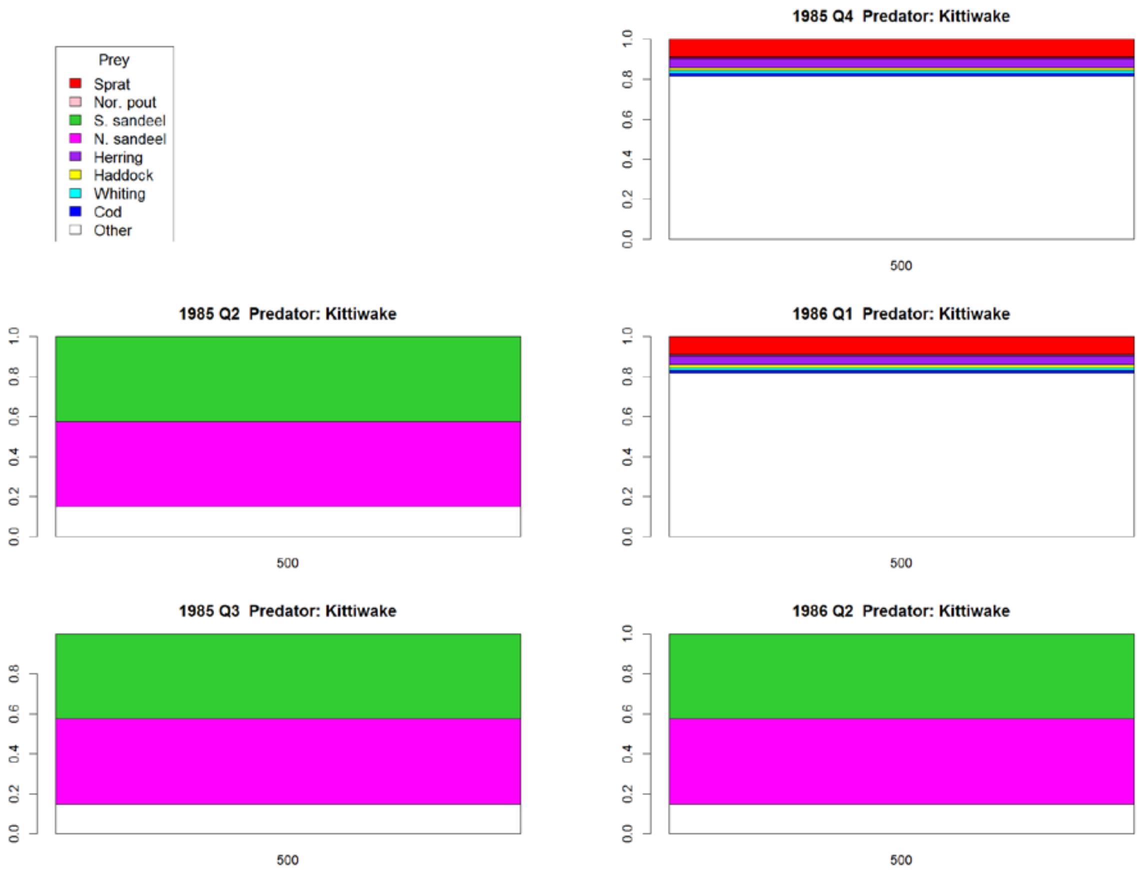

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Her. Gull
1985 Q2 Predator: Her. Gull
1986 Q1 Predator: Her. Gull
1985 Q3 Predator: Her. Gull
1986 Q2 Predator: Her. Gull
500

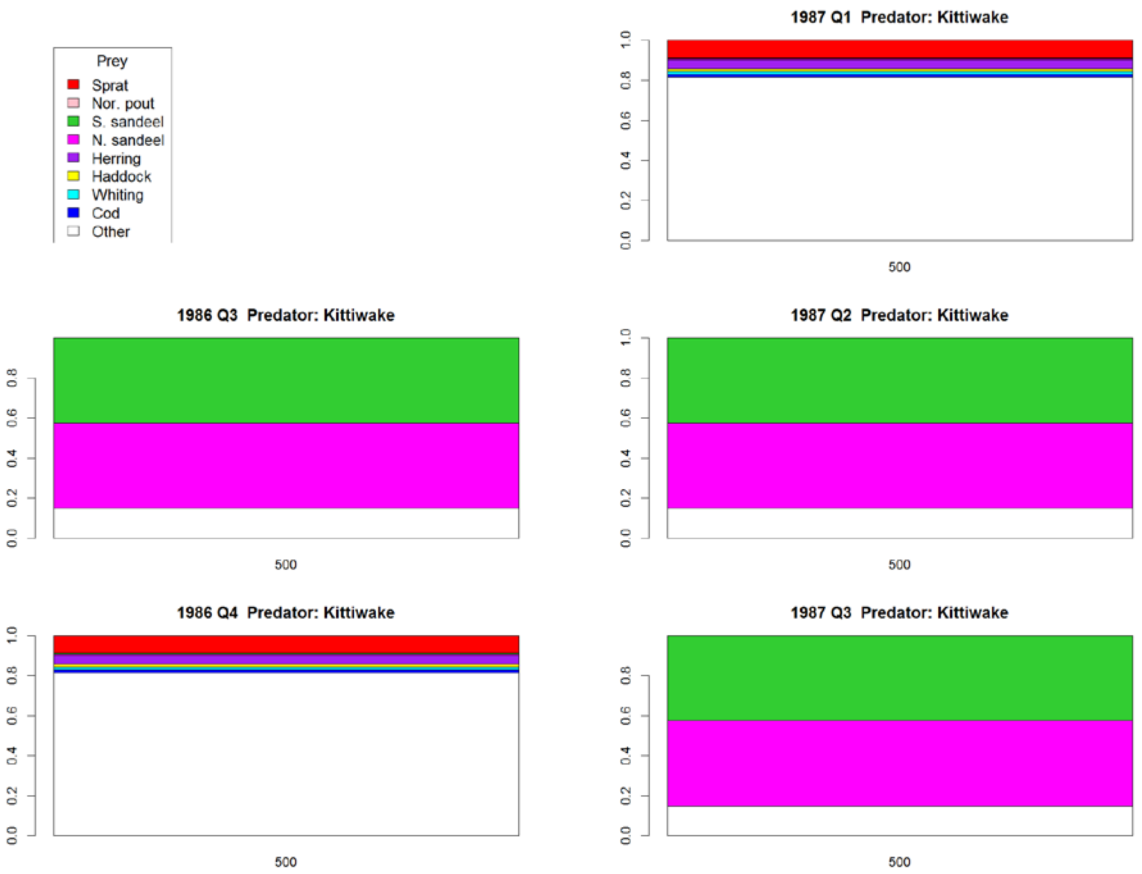

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Her. Gull
1986 Q3 Predator: Her. Gull
1987 Q2 Predator: Her. Gull
1986 Q4 Predator: Her. Gull
1987 Q3 Predator: Her. Gull
500

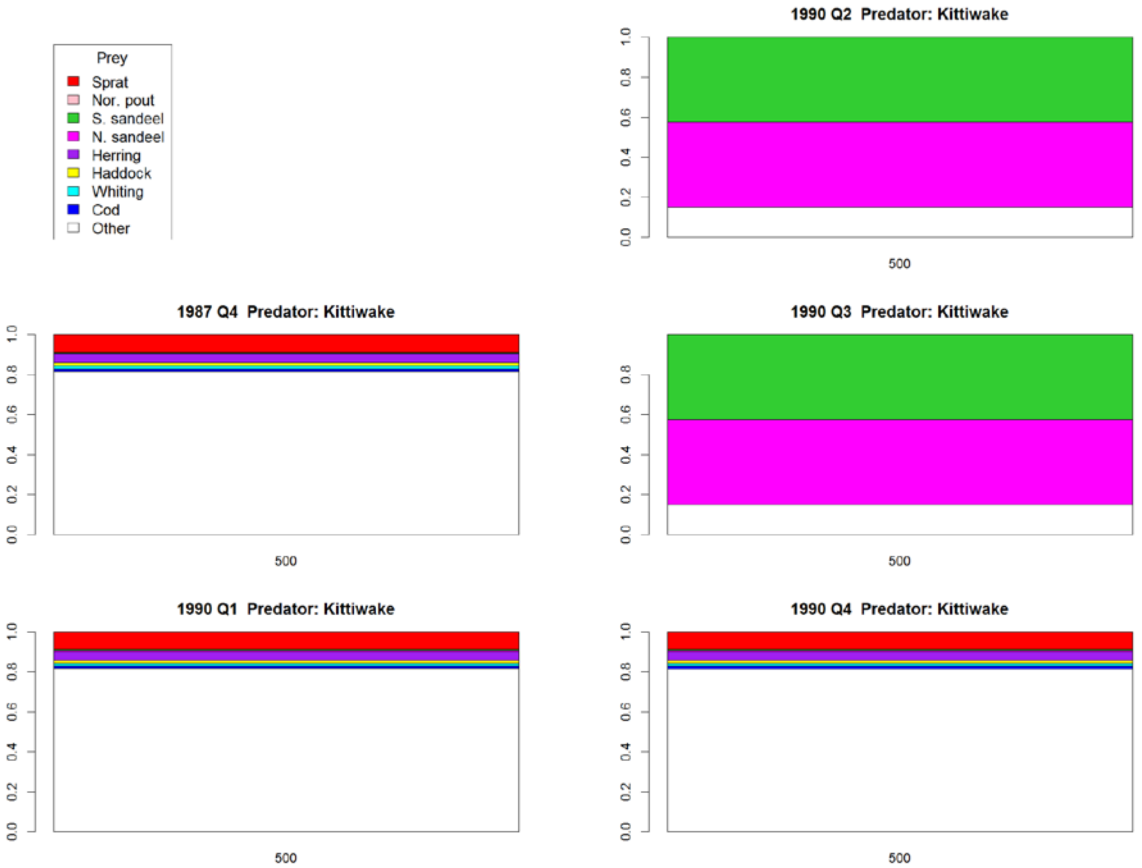

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Her. Gull
1987 Q4 Predator: Her. Gull
1990 Q3 Predator: Her. Gull
1990 Q1 Predator: Her. Gull
1990 Q4 Predator: Her. Gull
500

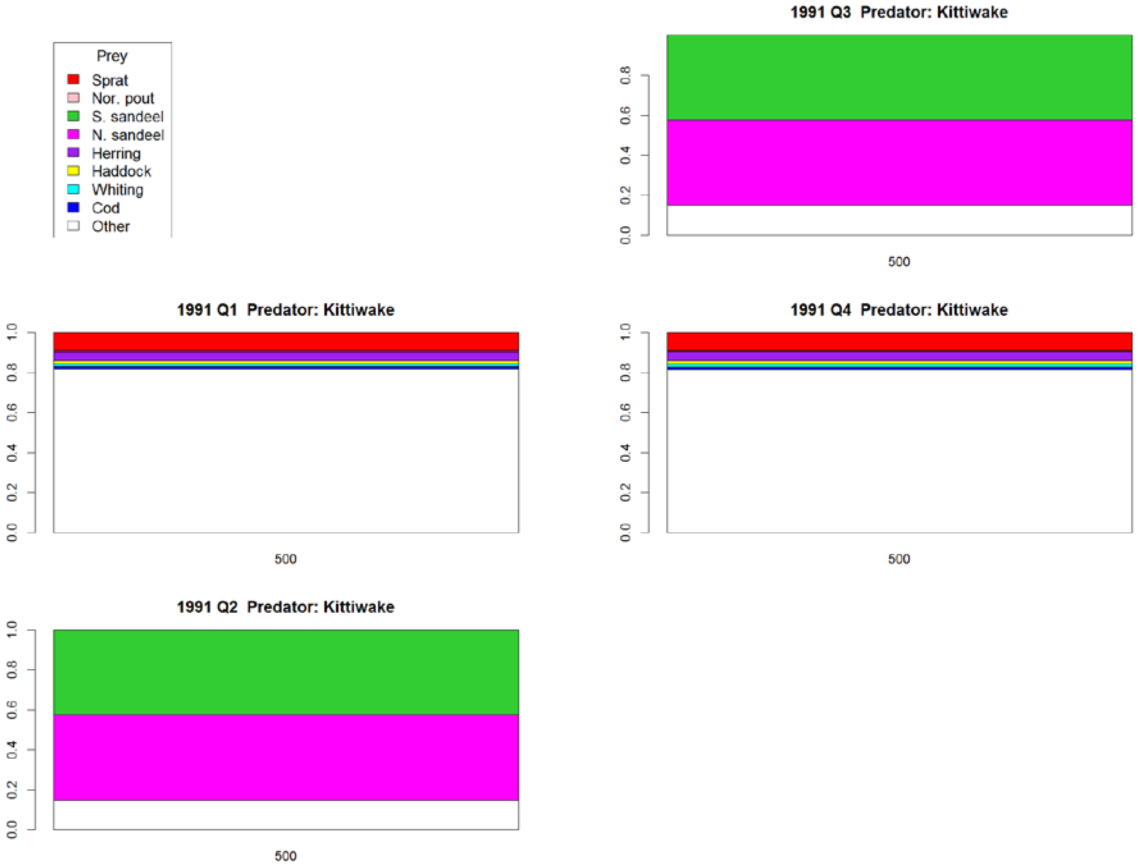

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Her. Gull
1991 Q1 Predator: Her. Gull
1991 Q4 Predator: Her. Gull
1991 Q2 Predator: Her. Gull
500

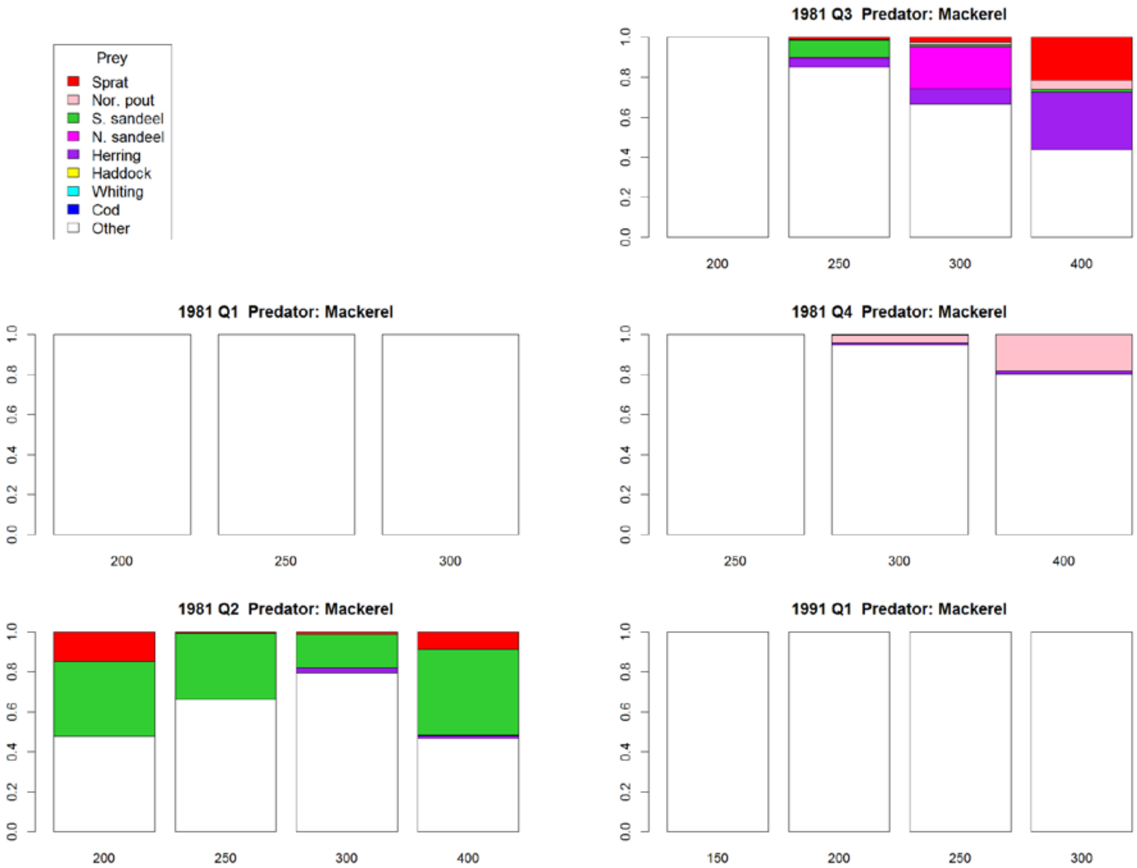

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Kittiwake
1981 Q1 Predator: Kittiwake
1981 Q4 Predator: Kittiwake
1981 Q2 Predator: Kittiwake
1985 Q1 Predator: Kittiwake
500

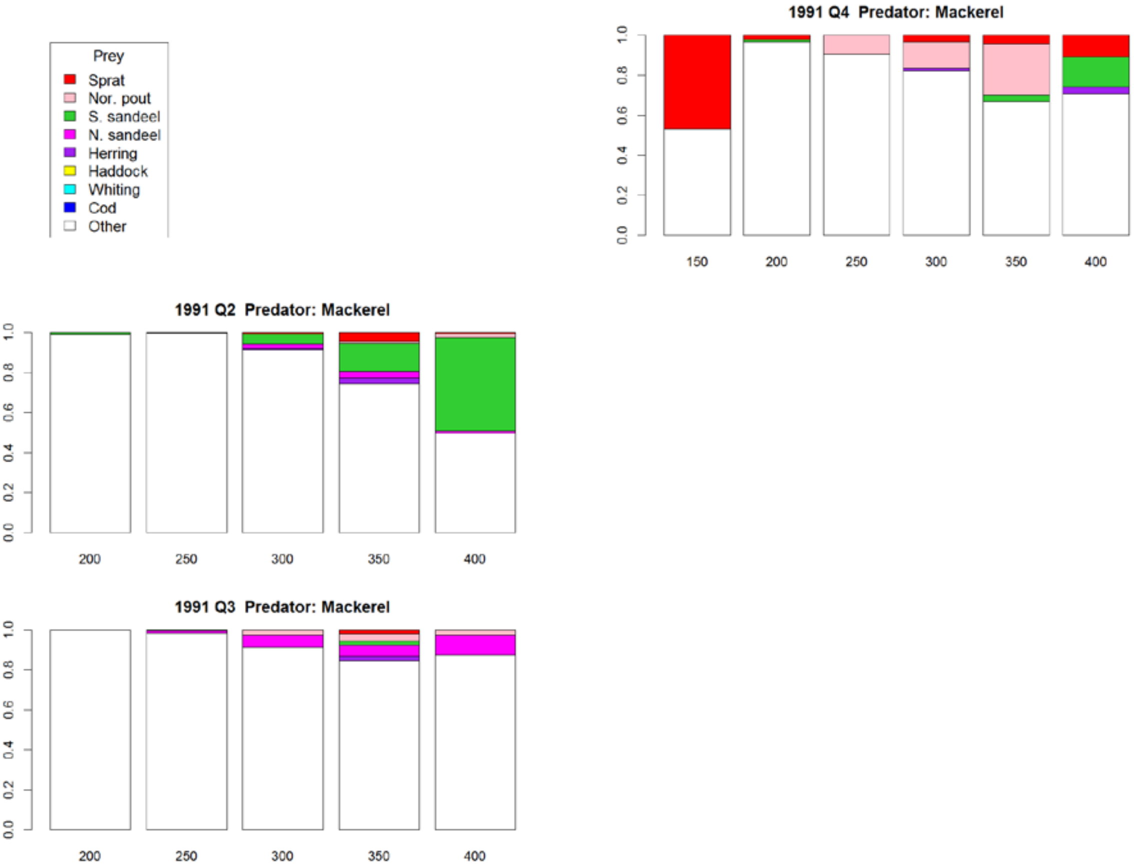

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Kittiwake
1985 Q2 Predator: Kittiwake
1986 Q1 Predator: Kittiwake
1985 Q3 Predator: Kittiwake
1986 Q2 Predator: Kittiwake
500

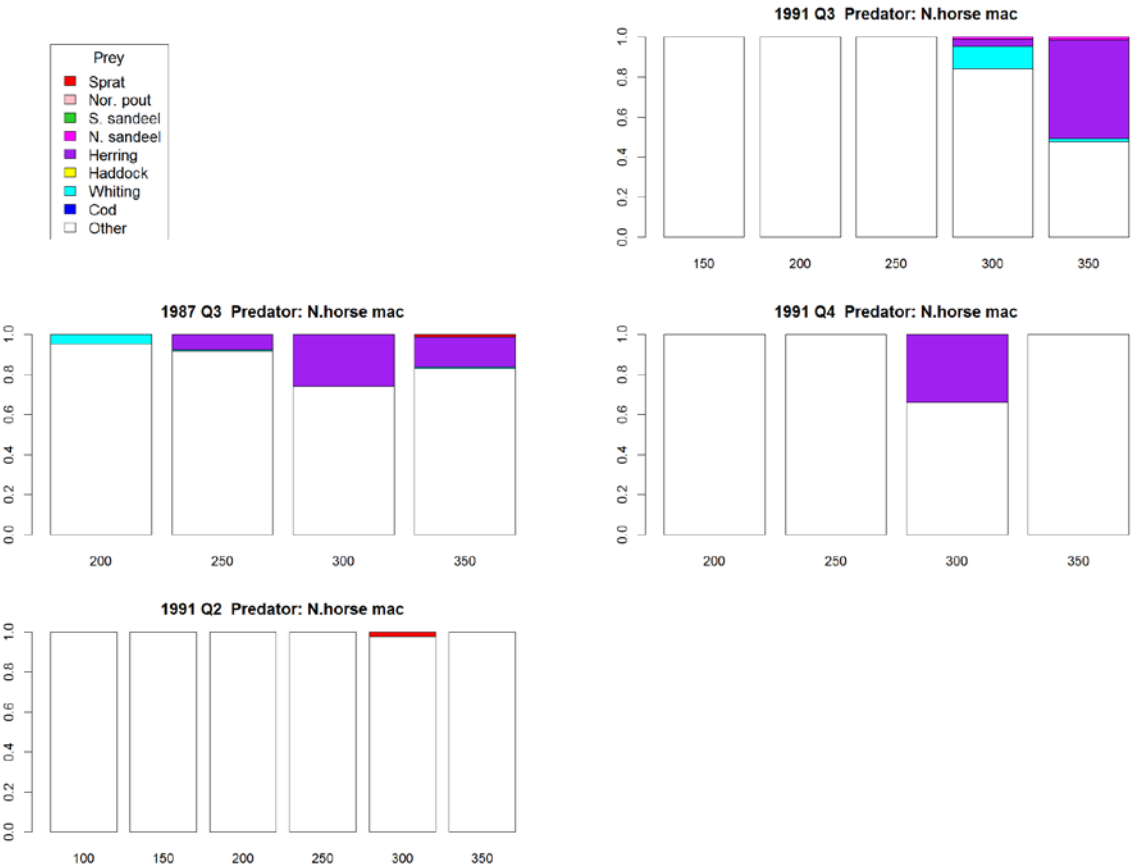

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Kittiwake
1986 Q3 Predator: Kittiwake
1987 Q2 Predator: Kittiwake
1986 Q4 Predator: Kittiwake
1987 Q3 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500

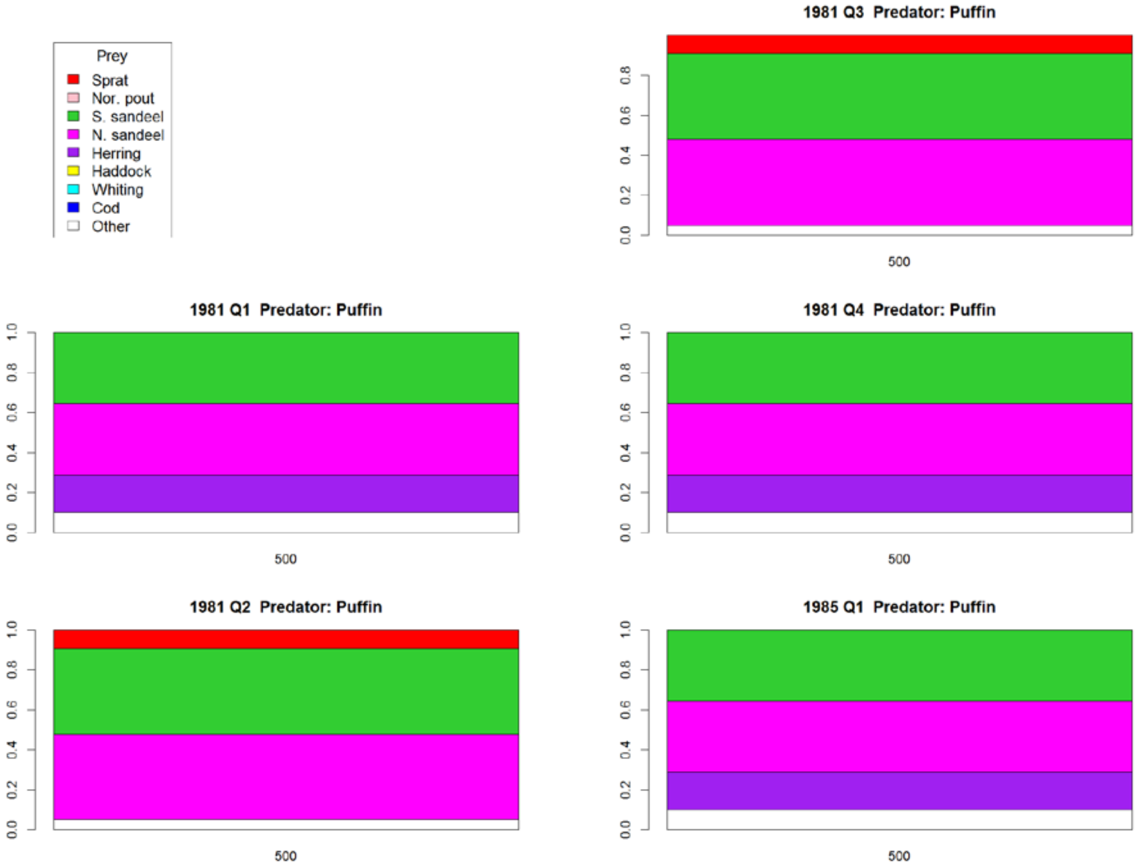

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Kittiwake
1987 Q4 Predator: Kittiwake
1990 Q3 Predator: Kittiwake
1990 Q1 Predator: Kittiwake
1990 Q4 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500

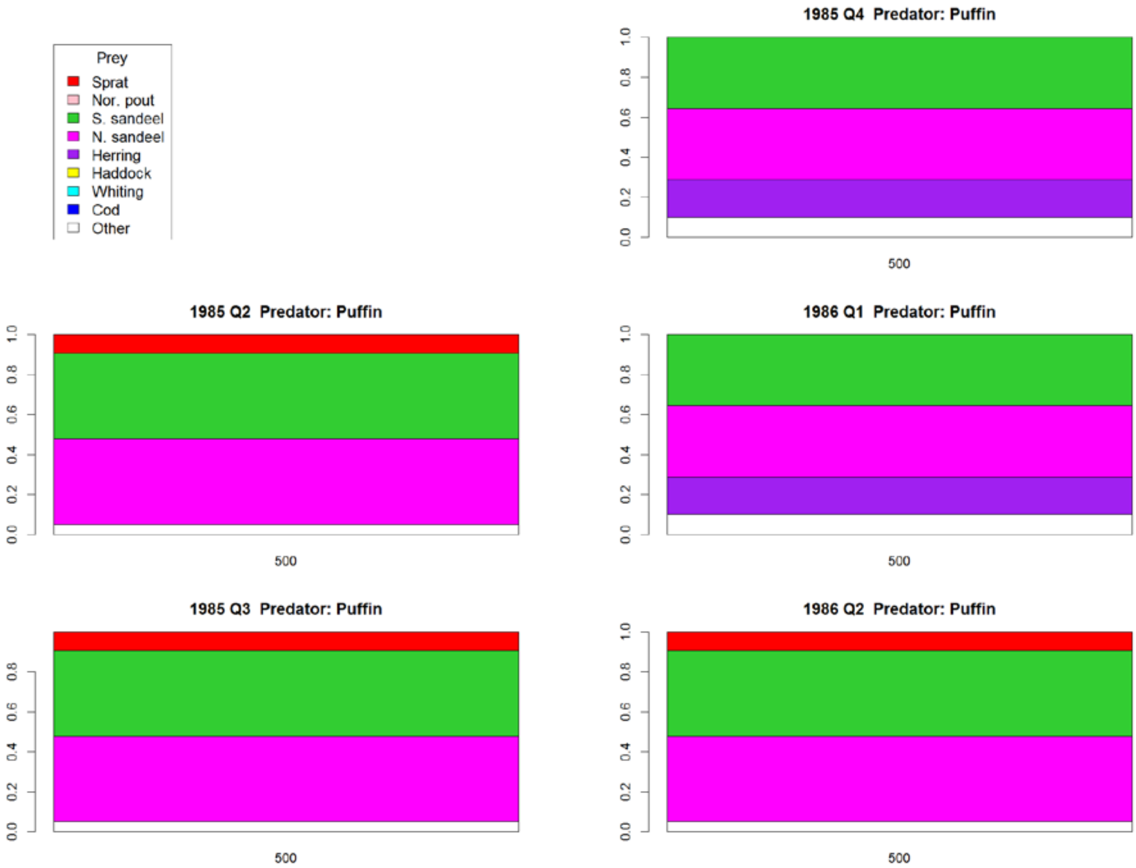

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Kittiwake
1991 Q1 Predator: Kittiwake
1991 Q4 Predator: Kittiwake
1991 Q2 Predator: Kittiwake
0.0
0.2
0.4
0.6
0.8
1.0
500

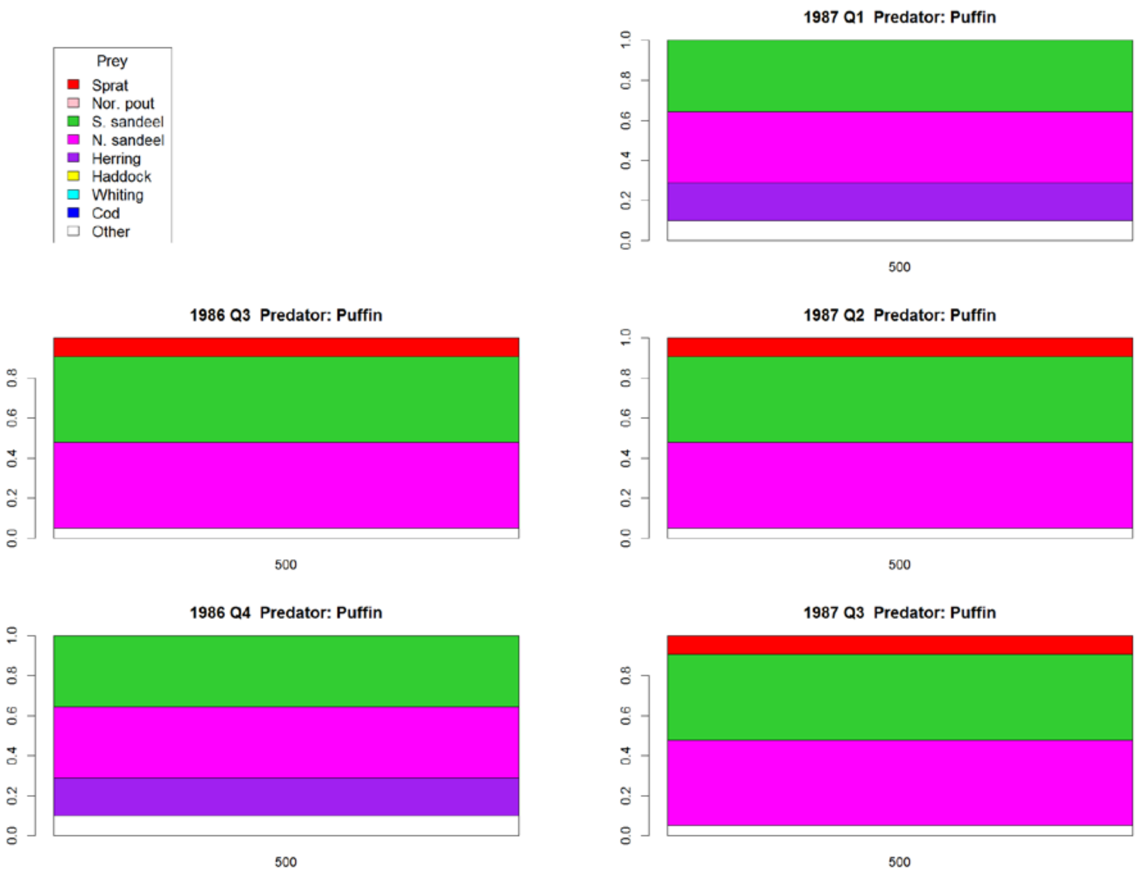

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Mackerel
1981 Q1 Predator: Mackerel
1981 Q4 Predator: Mackerel
1981 Q2 Predator: Mackerel
1991 Q1 Predator: Mackerel
0.0
0.2
0.4
0.6
0.8
1.0
150
200
250
300
400

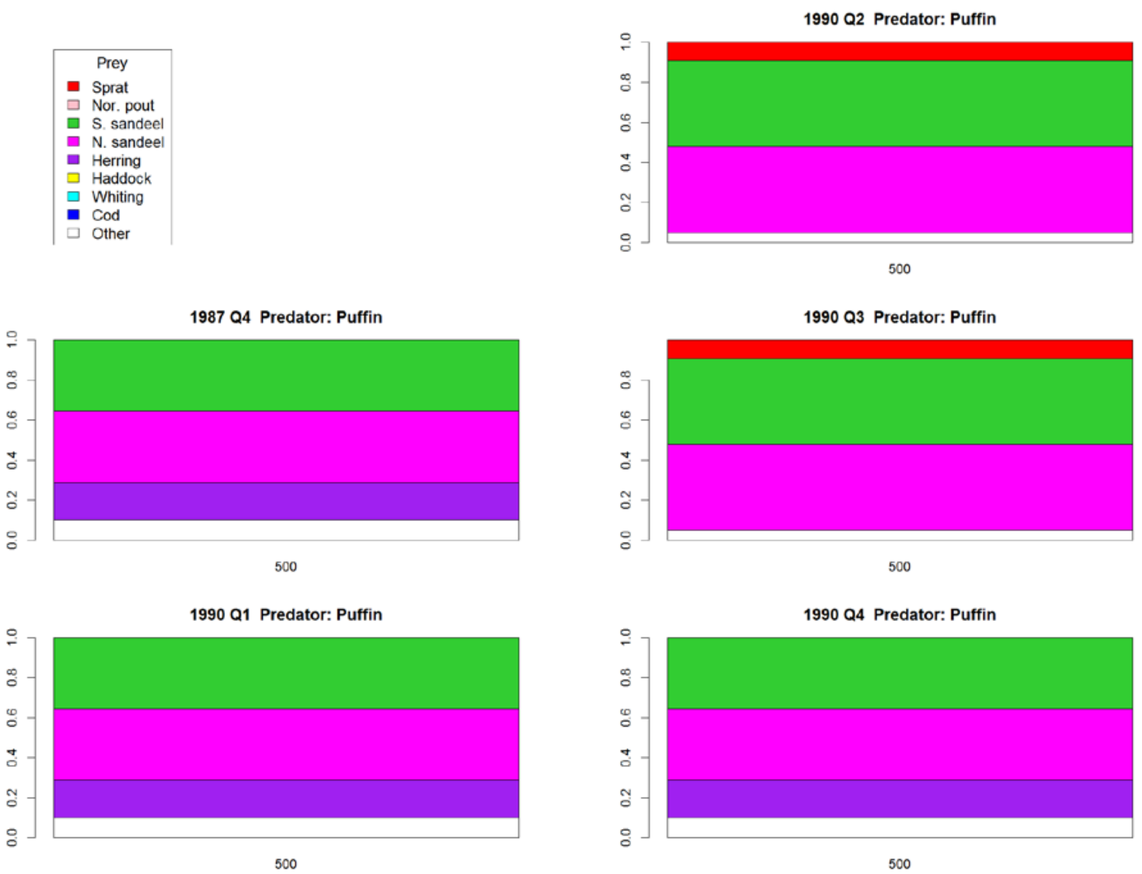

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q4 Predator: Mackerel
1991 Q2 Predator: Mackerel
1991 Q3 Predator: Mackerel

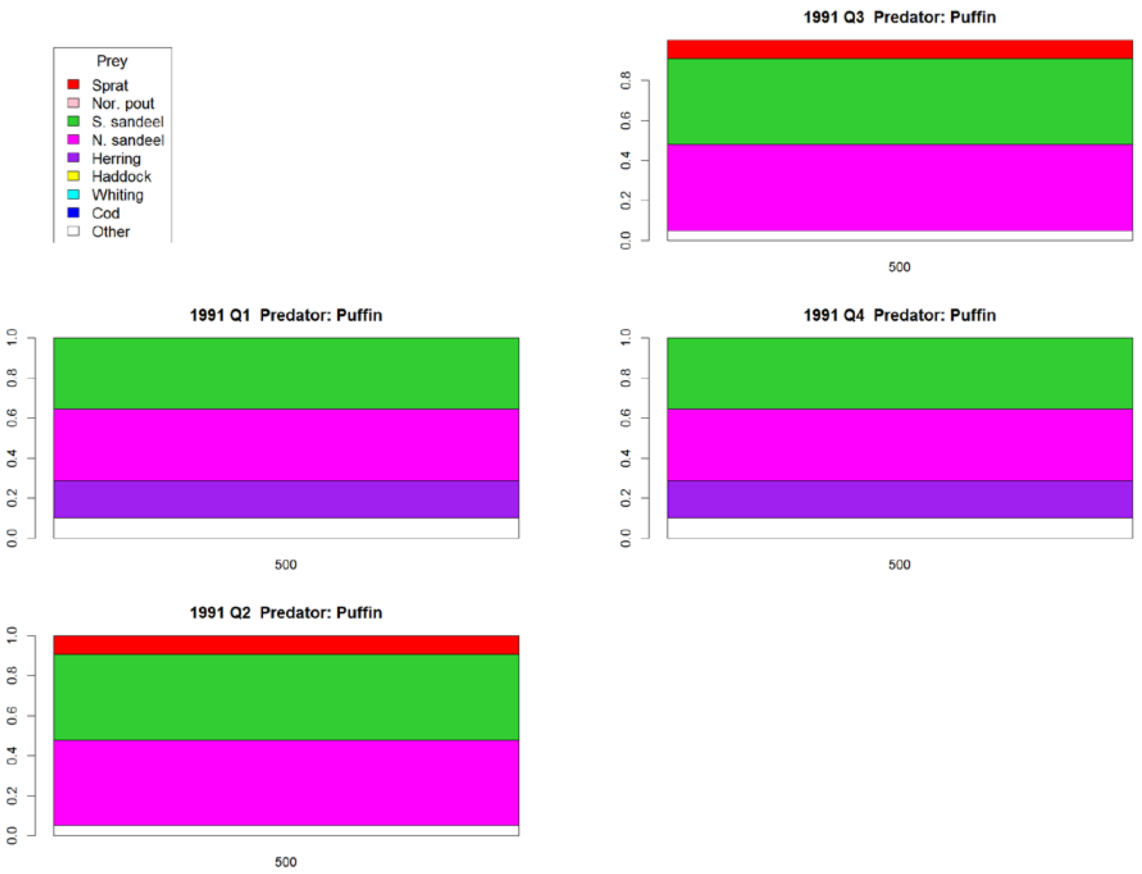

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: N.horse mac
1987 Q3 Predator: N.horse mac
1991 Q4 Predator: N.horse mac
1991 Q2 Predator: N.horse mac

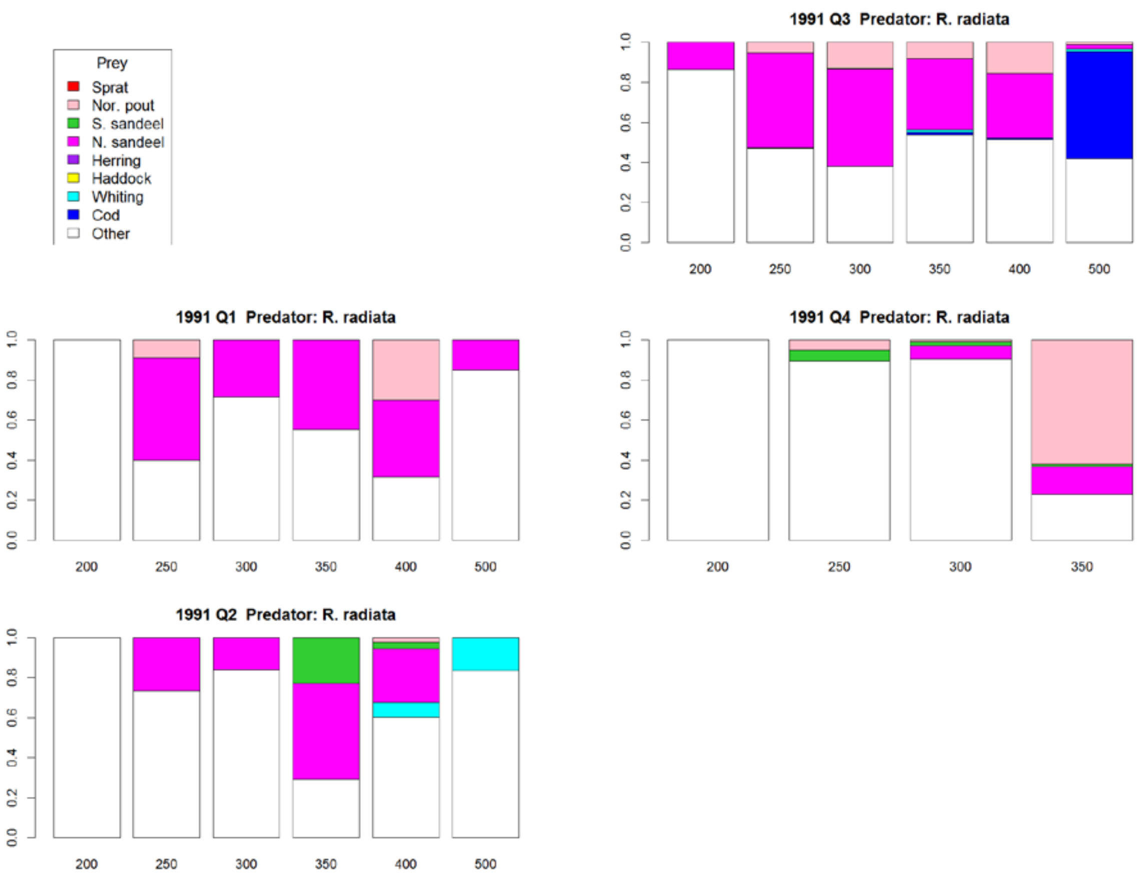

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Puffin
1981 Q1 Predator: Puffin
1981 Q4 Predator: Puffin
1981 Q2 Predator: Puffin
1985 Q1 Predator: Puffin
500

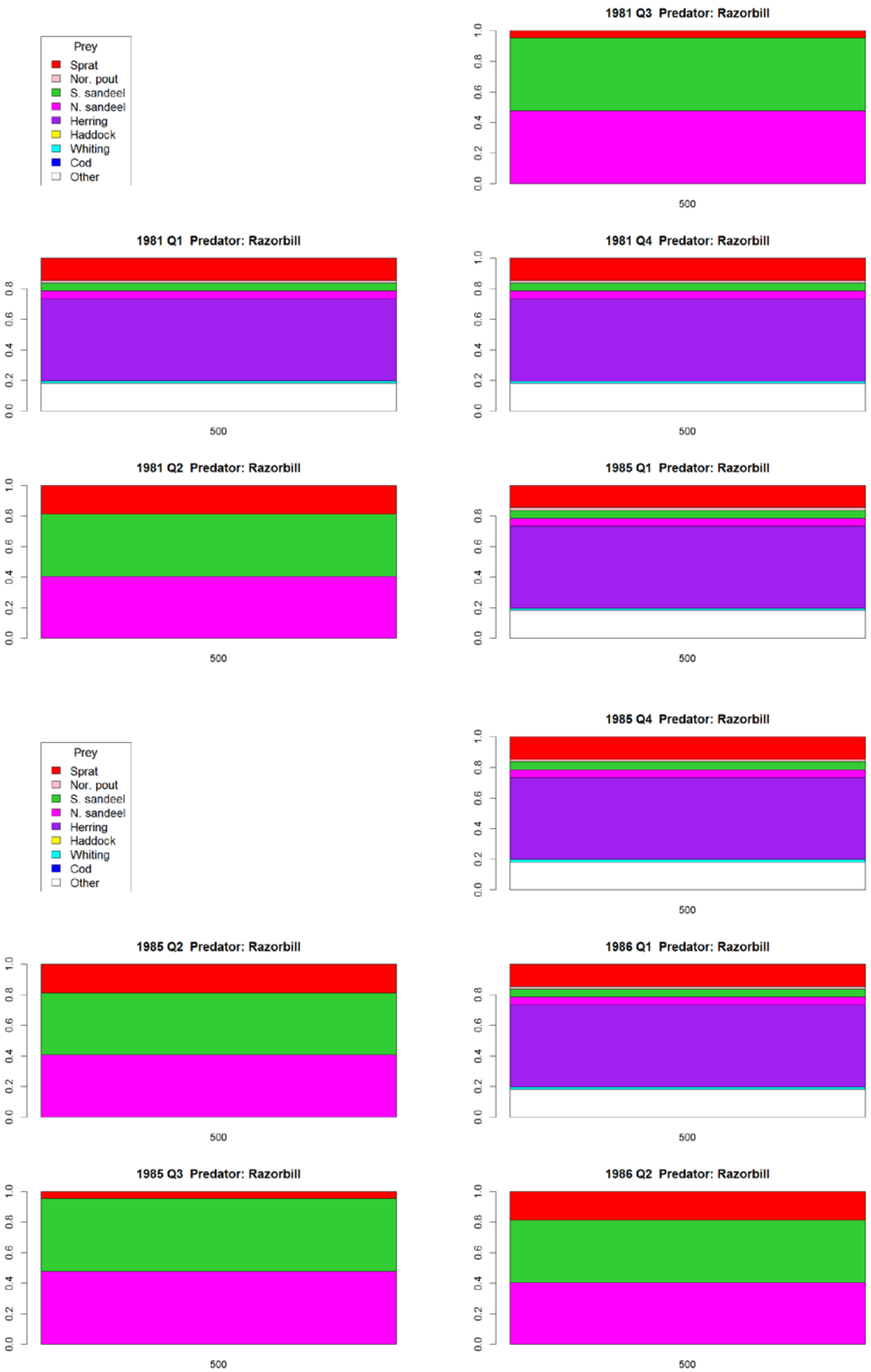

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Puffin
1985 Q2 Predator: Puffin
1986 Q1 Predator: Puffin
1985 Q3 Predator: Puffin
1986 Q2 Predator: Puffin
500

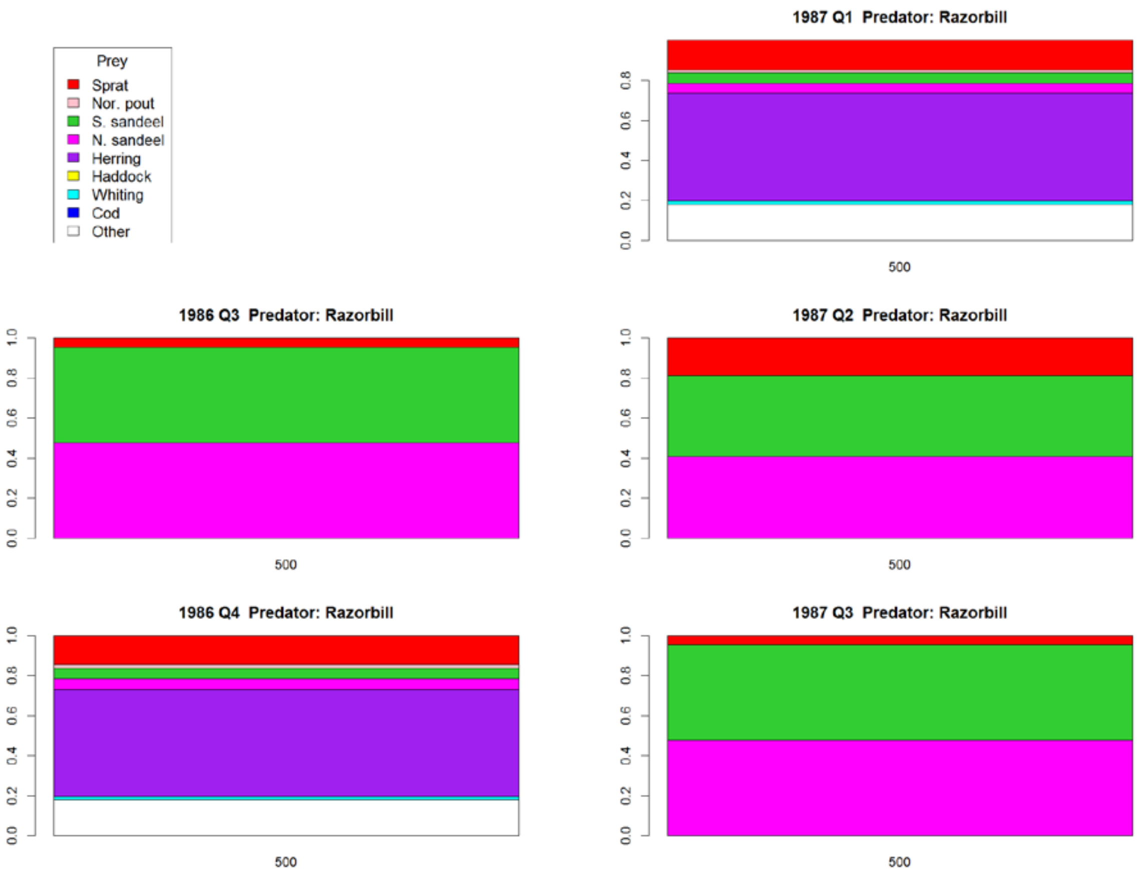

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Puffin
1986 Q3 Predator: Puffin
1987 Q2 Predator: Puffin
1986 Q4 Predator: Puffin
1987 Q3 Predator: Puffin
500

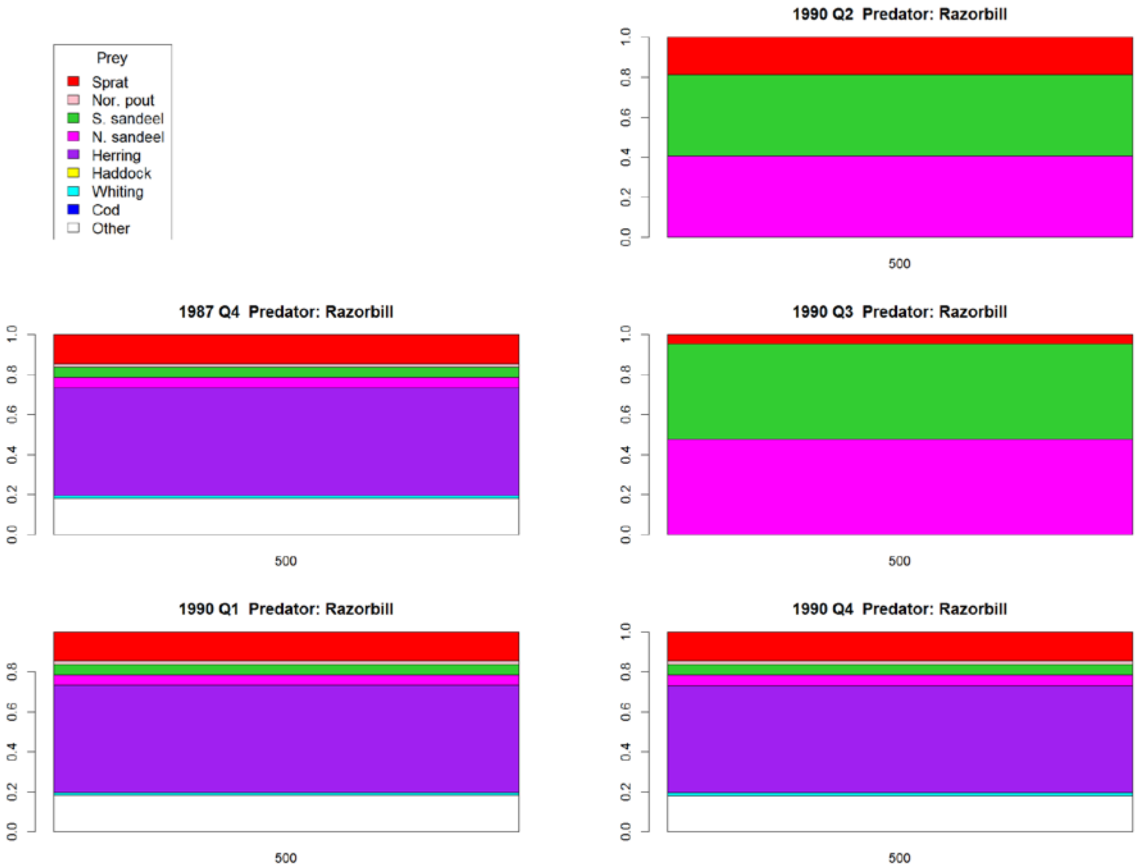

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Puffin
1987 Q4 Predator: Puffin
1990 Q3 Predator: Puffin
1990 Q1 Predator: Puffin
1990 Q4 Predator: Puffin
500

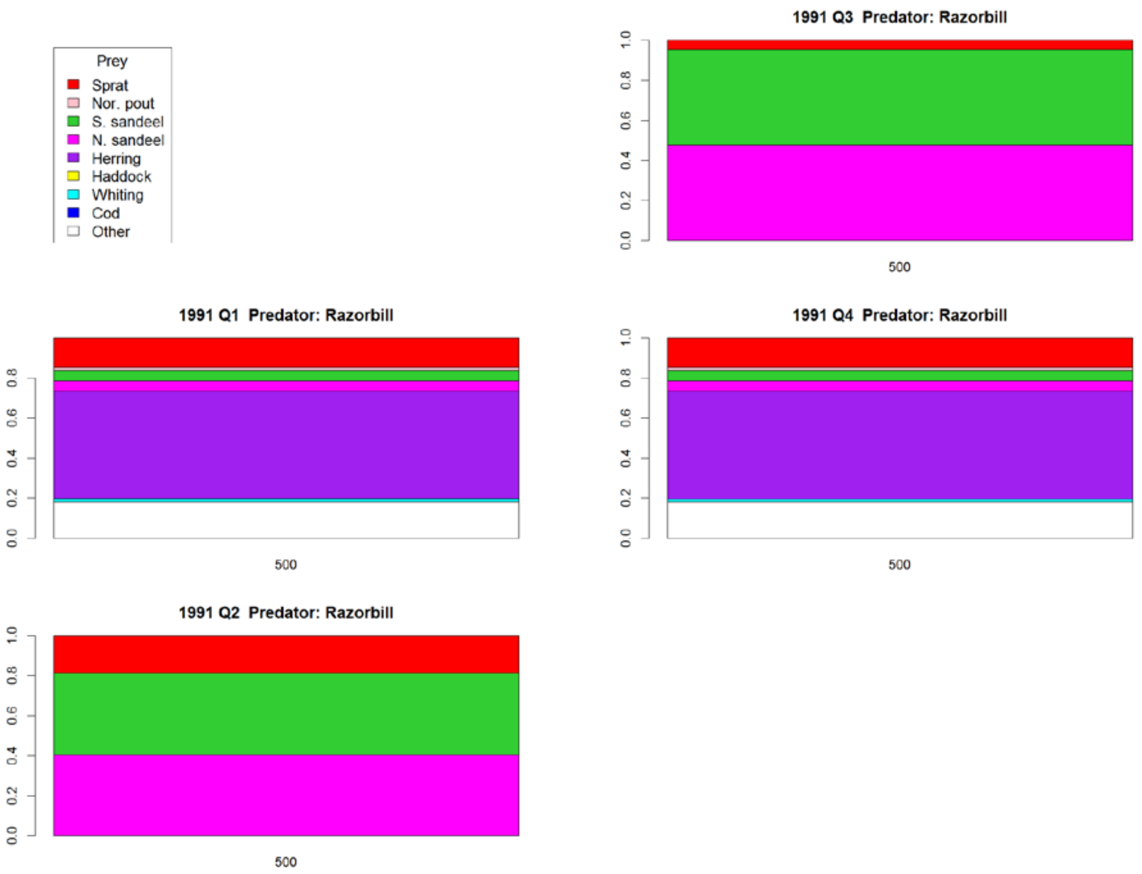

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Puffin
1991 Q1 Predator: Puffin
1991 Q4 Predator: Puffin
1991 Q2 Predator: Puffin
0.0 0.2 0.4 0.6 0.8 1.0
500

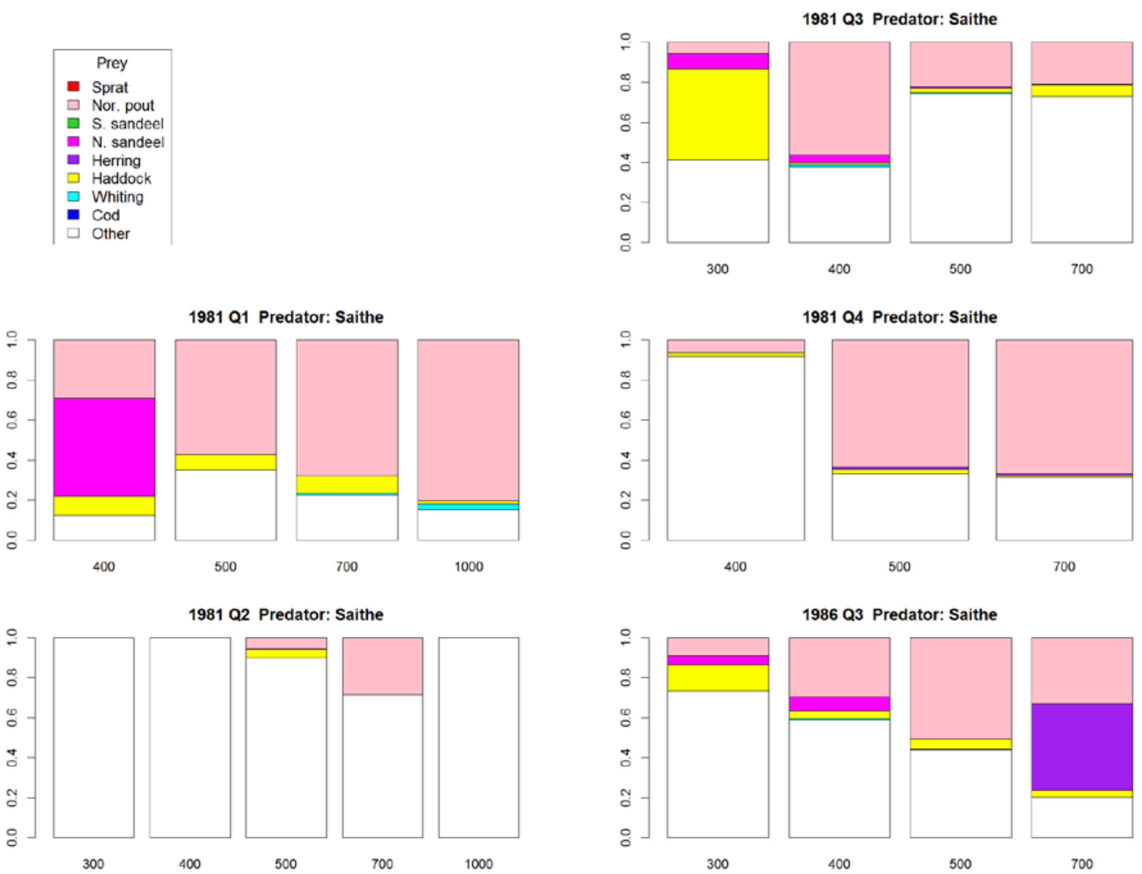

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: R. radiata
1991 Q1 Predator: R. radiata
1991 Q4 Predator: R. radiata
1991 Q2 Predator: R. radiata
0.0 0.2 0.4 0.6 0.8 1.0
200 250 300 350 400 500

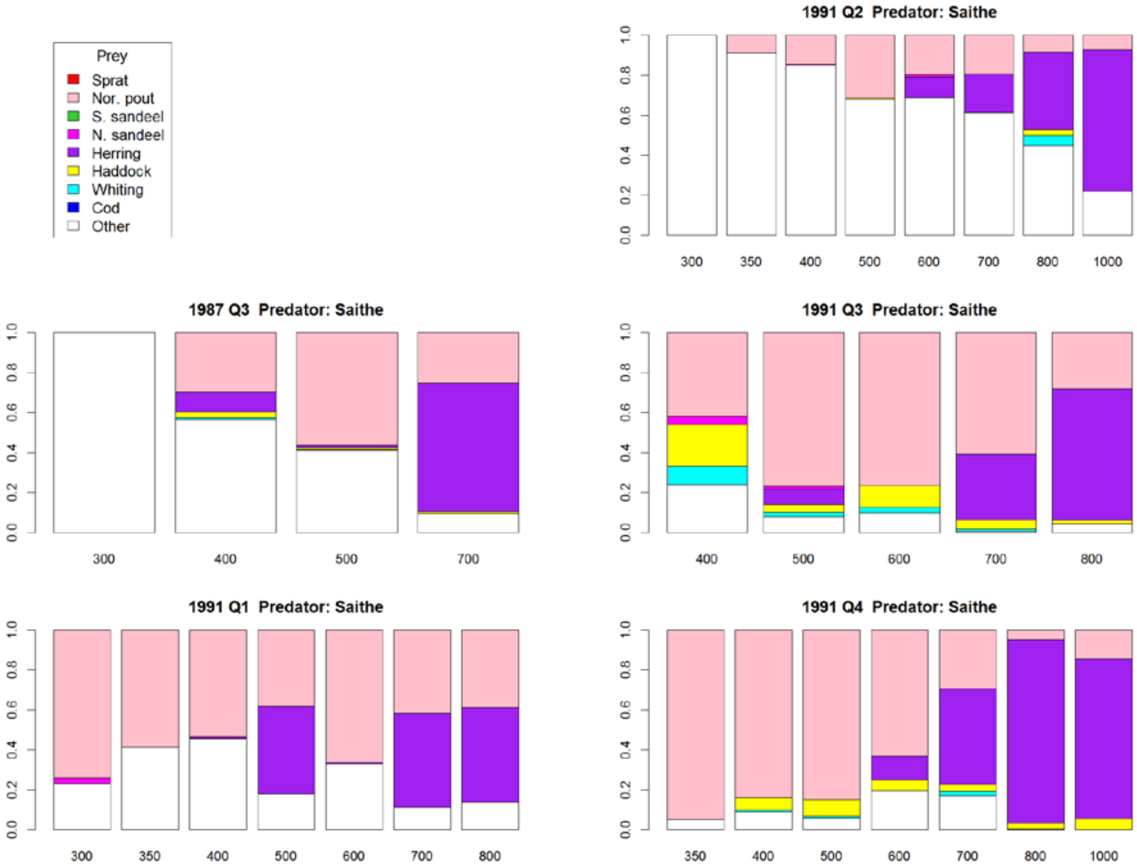

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Razorbill
1981 Q1 Predator: Razorbill
1981 Q4 Predator: Razorbill
1981 Q2 Predator: Razorbill
1985 Q1 Predator: Razorbill
Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1985 Q4 Predator: Razorbill
1985 Q2 Predator: Razorbill
1986 Q1 Predator: Razorbill
1985 Q3 Predator: Razorbill
1986 Q2 Predator: Razorbill
0.0
0.2
0.4
0.6
0.8
1.0
500

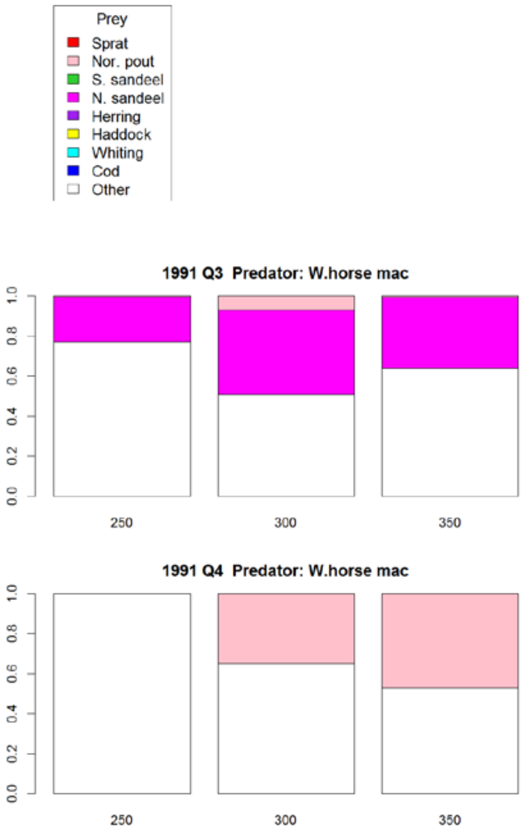

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1987 Q1 Predator: Razorbill
1986 Q3 Predator: Razorbill
1987 Q2 Predator: Razorbill
1986 Q4 Predator: Razorbill
1987 Q3 Predator: Razorbill
500

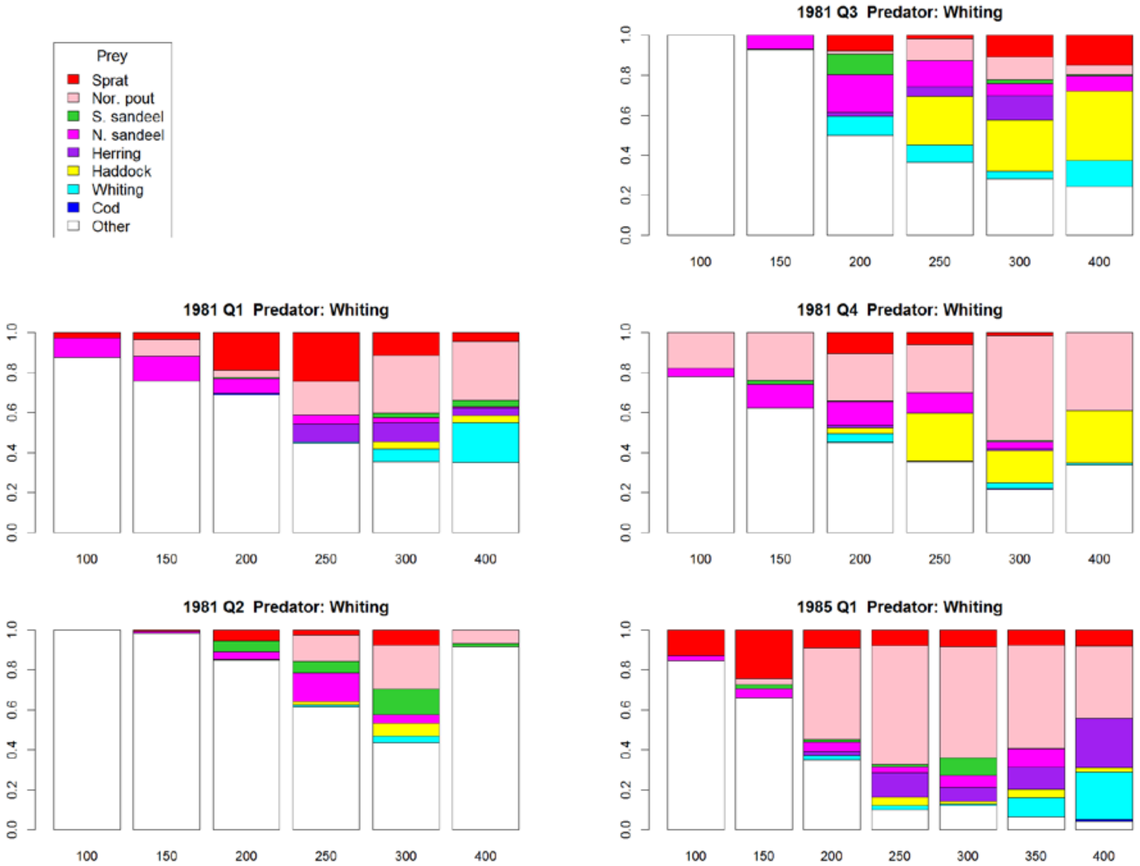

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1990 Q2 Predator: Razorbill
1987 Q4 Predator: Razorbill
1990 Q3 Predator: Razorbill
1990 Q1 Predator: Razorbill
1990 Q4 Predator: Razorbill
500

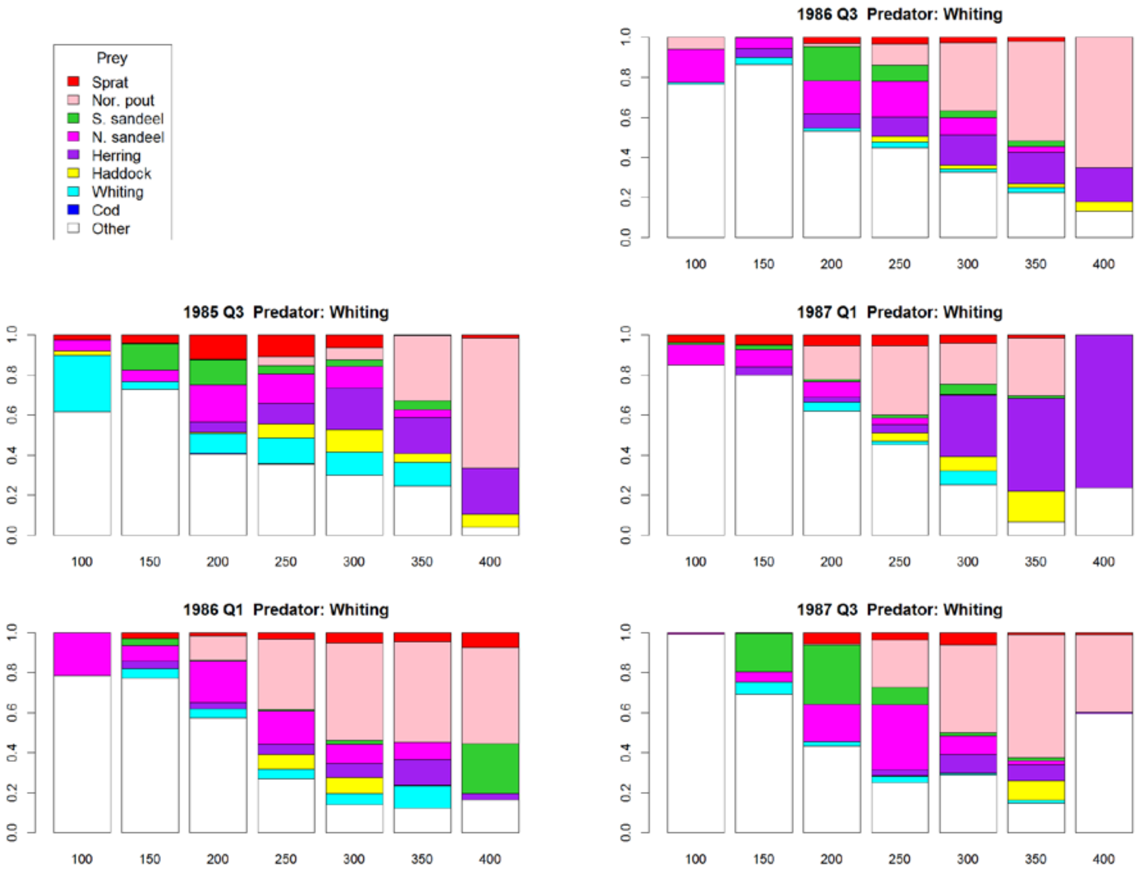

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Razorbill
1991 Q1 Predator: Razorbill
1991 Q4 Predator: Razorbill
1991 Q2 Predator: Razorbill
0.0
0.2
0.4
0.6
0.8
1.0
500


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


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q2 Predator: Saithe
0.0 0.2 0.4 0.6 0.8 1.0
300 350 400 500 600 700 800 1000
1987 Q3 Predator: Saithe
0.0 0.2 0.4 0.6 0.8 1.0
300 400 500 700
1991 Q3 Predator: Saithe
0.0 0.2 0.4 0.6 0.8 1.0
400 500 600 700 800
1991 Q1 Predator: Saithe
0.0 0.2 0.4 0.6 0.8 1.0
300 350 400 500 600 700 800
1991 Q4 Predator: Saithe
0.0 0.2 0.4 0.6 0.8 1.0
350 400 500 600 700 800 1000


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


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1981 Q3 Predator: Whiting
1981 Q1 Predator: Whiting
1981 Q4 Predator: Whiting
1981 Q2 Predator: Whiting
1985 Q1 Predator: Whiting
0.0 0.2 0.4 0.6 0.8 1.0
100 150 200 250 300 350 400


Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1986 Q3 Predator: Whiting
1985 Q3 Predator: Whiting
1987 Q1 Predator: Whiting
1986 Q1 Predator: Whiting
1987 Q3 Predator: Whiting
0.0 0.2 0.4 0.6 0.8 1.0
100 150 200 250 300 350 400

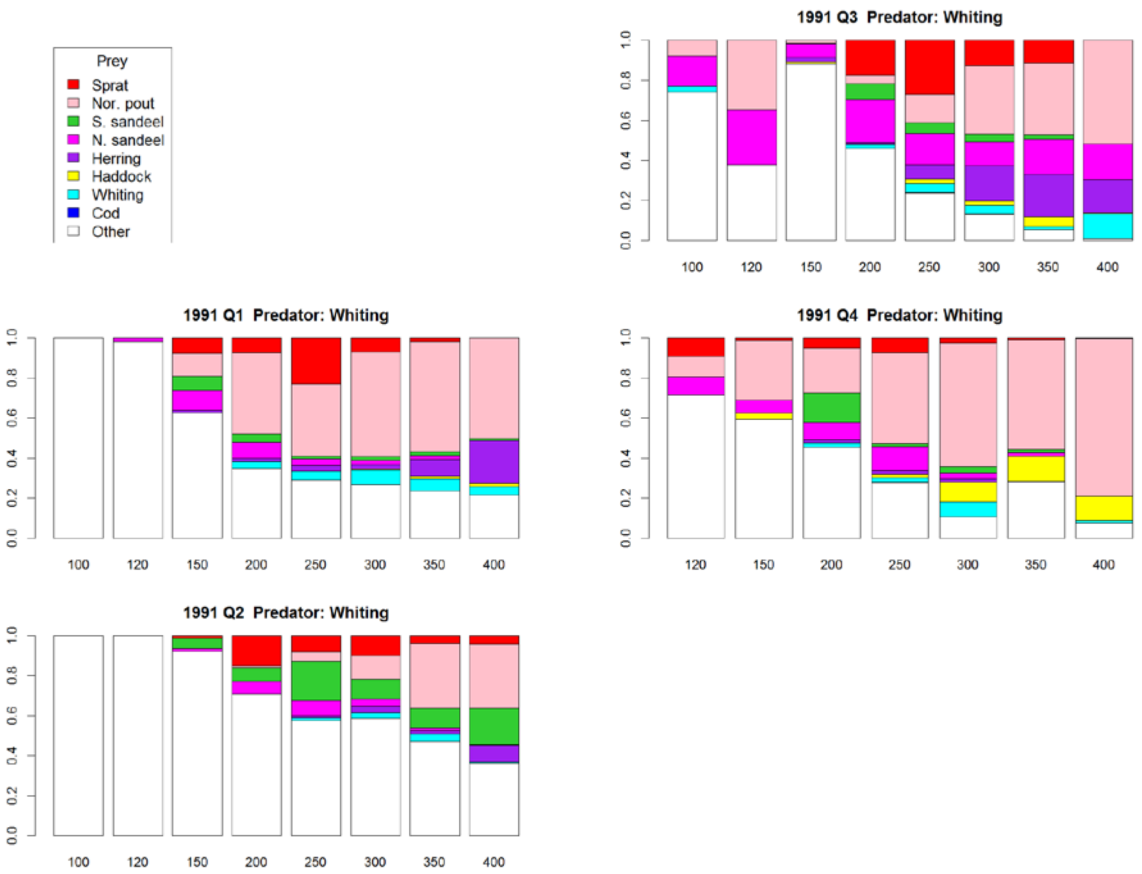

Prey
Sprat
Nor. pout
S. sandeel
N. sandeel
Herring
Haddock
Whiting
Cod
Other
1991 Q3 Predator: Whiting
1991 Q1 Predator: Whiting
1991 Q4 Predator: Whiting
1991 Q2 Predator: Whiting
0.0
0.2
0.4
0.6
0.8
1.0
100
120
150
200
250
300
350
400

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

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

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

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

Predator Cod

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

Predator Whiting

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

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

Predator Haddock

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

Predator Saithe

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

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

Predator Mackerel

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

Predator Grey gurnard

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

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

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

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

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

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

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

Key-run 2017

```
# sms.dat option file
# the character "#" is used as comment character,
# such that all text and numbers after # are skipped by the SMS program
#
########################################
# Produce test output (option test.output)
#  0 no test output
#  1 output file sms.dat and  file fleet.info.dat as read in
#  2 output all single-species input files as read in
#  3 output all multi species input files as read in
#  4 output option overview
#
# 11 output between phases output
# 12 output iteration (obj function) output
# 13 output stomach parameters
# 19 Both 11, 12 and 13
#
# Forecast options
# 51 output hcr_option.dat file as read in
# 52 output prediction output summary
# 53 output prediction output detailed
0
########################################
# Produce output for SMS-OP program. 0=no, 1=yes
0
########################################
# Single/Multispecies mode (option VPA.mode)
# 0=single-species mode
# 1=multi species mode, but Z=F+M
#    (used for initial food suitability parm. est.)
# 2=multi species mode, Z=F+M1+M2
0
########################################
# Number of areas for multispecies run (default=1)
1
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
#
# single-species parameters
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
#
## first year of input data (option first.year)
1974
########################################
## first year used in the model (option first.year.model)
1974
########################################
## last year of input data (option last.year)
2016
########################################
## last year used in the model (option last.year.model)
2016
########################################
##  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
42
########################################
## number of species (option no.species)
27
########################################
## first age all species (option first.age)
0
########################################
## recruitment season (option rec.season). Use 1 for annual data
3
########################################
## maximum age for any species(max.age.all)
10
```

```
########################################
## various information by species
# 1. last age
# 2. first age where catch data are used (else F=0 assumed)
# 3. last age with age dependent fishing selection
# 4. Esimate F year effect from effort data. 0=no, 1=yes
# 5. Last age included in the catch-at-age likelihood (normally last age)
# 6. plus group, 0=no plus group, 1=plus group
# 7. predator species, 0=no, 1=VPA predator, 2=Other predator
# 8. prey species, 0=no, 1=yes
# 9. Stock Recruit relation
#      1=Ricker, 2=Beverton & Holt, 3=Geom mean,
#      4= Hockey stick, 5=hockey stick with smoother,
#      51=Ricker with estimated temp effect,
#      52=Ricker with known temp effect,
#      >100= hockey stick with known breakpoint (given as input)
# 10. Additional data for Stock-Recruit relation
# 11. Additional data for Stock-Recruit relation
##
1 0 0 0 0 0 2 0 0 0 0  # 1 Fulmar
1 0 0 0 0 0 2 0 0 0 0  # 2 Guillemot
1 0 0 0 0 0 2 0 0 0 0  # 3 Her. Gull
1 0 0 0 0 0 2 0 0 0 0  # 4 Kittiwake
1 0 0 0 0 0 2 0 0 0 0  # 5 GBB. Gull
1 0 0 0 0 0 2 0 0 0 0  # 6 Gannet
1 0 0 0 0 0 2 0 0 0 0  # 7 Puffin
1 0 0 0 0 0 2 0 0 0 0  # 8 Razorbill
3 0 0 0 0 0 2 0 0 0 0  # 9 A. radiata
4 0 0 0 0 0 2 0 0 0 0  # 10 G. gurnards
2 0 0 0 0 0 2 0 0 0 0  # 11 W.horse mac
3 0 0 0 0 0 2 0 0 0 0  # 12 N.horse mac
1 0 0 0 0 0 2 0 0 0 0  # 13 Grey seal
1 0 0 0 0 0 2 0 0 0 0  # 14 H. porpoise
3 0 0 0 0 0 2 0 0 0 0  # 15 Hake
10 1 9 0 10 1 1 1 118000 0 0  # 16 Cod
8 0 6 0 8 1 1 1 1  84000 0 0  # 17 Whiting
10 0 7 0 10 1 1 1  1e+05 0 0  # 18 Haddock
10 3 8 0 10 1 1 0      1 0 0  # 19 Saithe
10 1 7 0 10 1 1 0      3 0 0  # 20 Mackerel
9  0 5 0 9 1 0 1 1 0 0  # 21 Herring
4  0 3 0 4 1 0 1 1 0 0  # 22 N. sandeel
4  0 3 0 4 1 0 1 1 0 0  # 23 S. sandeel
3  0 2 0 3 0 0 1 1 0 0  # 24 Nor. pout
3  1 2 0 3 1 0 1 90000 0 0  # 25 Sprat
10 1 7 0 10 1 0 0 1 0 0  # 26 Plaice
10 2 7 0 10 1 0 0 1 0 0  # 27 Sole
########################################
## use input recruitment estimate (option use.known.rec)
#   0=estimate all recruitments
#   1=yes use input recruitment from file known_recruitment.in
0
########################################
## adjustment factor to bring the beta parameter close to one (option beta.cor)
      1e+06  #          Cod
      1e+06  #      Whiting
      1e+05  #      Haddock
      1e+05  #       Saithe
      1e+06  #     Mackerel
      1e+05  #      Herring
      1e+05  #   N. sandeel
      1e+06  #   S. sandeel
      1e+06  #    Nor. pout
      1e+06  #        Sprat
      1e+06  #       Plaice
      1e+05  #         Sole
########################################
## year range for data included to fit the R-SSB relation
#   (option SSB.R.year.range)
# first (option SSB.R.year.first) and last
#    (option SSB.R.year.last) year to consider.
# the value -1 indicates the use of the first (and last) available year
#    in the time-series
# first year by species
       1988  #          Cod
       1982  #      Whiting
       1988  #      Haddock
         -1  #       Saithe
```

```
       1980  #     Mackerel
         -1  #      Herring
         -1  #   N. sandeel
         -1  #   S. sandeel
       1977  #    Nor. pout
       1981  #        Sprat
         -1  #       Plaice
         -1  #         Sole
# last year by species
         -1  #          Cod
         -1  #      Whiting
         -1  #      Haddock
         -1  #       Saithe
         -1  #     Mackerel
         -1  #      Herring
         -1  #   N. sandeel
         -1  #   S. sandeel
         -1  #    Nor. pout
         -1  #        Sprat
         -1  #       Plaice
         -1  #         Sole
########################################
## Objective function weighting by species (option objective.function.weight)
# first=catch observations,
# second=cpue observations,
# third=SSB/R relations
# fourth=stomach observations, weight proportions
# fifth=stomach observations, number-at-length
##
0 0 0 0.1 1  # 1 Fulmar
0 0 0 0.1 1  # 2 Guillemot
0 0 0 0.1 1  # 3 Her. Gull
0 0 0 0.1 1  # 4 Kittiwake
0 0 0 0.1 1  # 5 GBB. Gull
0 0 0 0.1 1  # 6 Gannet
0 0 0 0.1 1  # 7 Puffin
0 0 0 0.1 1  # 8 Razorbill
0 0 0 1 1  # 9 A. radiata
0 0 0 1 1  # 10 G. gurnards
0 0 0 1 1  # 11 W.horse mac
0 0 0 1 1  # 12 N.horse mac
0 0 0 1 1  # 13 Grey seal
0 0 0 1 1  # 14 H. porpoise
0 0 0 1 1  # 15 Hake
1 1 0.1 1 0  # 16 Cod
1 1 0.1 1 0  # 17 Whiting
1 1 0.1 1 0  # 18 Haddock
1 1 0.3 1 0  # 19 Saithe
1 1 0.1 1 0  # 20 Mackerel
1 1 0.1 0 0  # 21 Herring
1 1 0.1 0 0  # 22 N. sandeel
1 1 0.1 0 0  # 23 S. sandeel
1 1 0.1 0 0  # 24 Nor. pout
1 1 0.1 0 0  # 25 Sprat
1 1 0.1 0 0  # 26 Plaice
1 1 0.1 0 0  # 27 Sole
########################################
## parameter estimation phases for single-species parameters
# phase.rec (stock numbers, first age) (default=1)
1
# phase.rec.older (stock numbers, first year and all ages) (default=1)
1
# phase.F.y (year effect in F model) (default=1)
1
# phase.F.y.spline (year effect in F model, implemented as spline function)
-1
# phase.F.q (season effect in F model) (default=1)
1
# phase.F.a (age effect in F model) (default=1)
1
# phase.catchability (survey catchability) (default=1)
1
# phase.SSB.R.alfa (alfa parameter in SSB-recruitment relation) (default=1)
1
# phase.SSB.R.beta (beta parameter in SSB-recruitment relation) (default=1)
1
########################################
```

```
## minimum CV of catch observation used in ML-estimation (option min.catch.CV)
0.1
########################################
## minimum CV of catch SSB-recruitment relation used in ML-estimation (option
min.SR.CV)
0.2
########################################
## Use proportion landed information in calculation of yield (option calc.dis-
card)
#    0=all catches are included in yield
#    1=yield is calculated from proportion landed (file proportion_landed.in)
          1  #         Cod
          1  #     Whiting
          1  #     Haddock
          1  #      Saithe
          0  #    Mackerel
          0  #     Herring
          0  #  N. sandeel
          0  #  S. sandeel
          0  #   Nor. pout
          0  #       Sprat
          1  #      Plaice
          1  #        Sole
########################################
## use seasonal or annual catches in the objective function
#     (option combined.catches)
# do not change this options from default=0, without looking in the manual
#0=annual catches with annual time steps or seasonal catches with seasonal time
steps
#1=annual catches with seasonal time steps, read seasonal relative F from file
F_q_ini.in (default=0)
          1  #         Cod
          1  #     Whiting
          1  #     Haddock
          1  #      Saithe
          1  #    Mackerel
          0  #     Herring
          0  #  N. sandeel
          0  #  S. sandeel
          0  #   Nor. pout
          0  #       Sprat
          1  #      Plaice
          1  #        Sole
########################################
## use seasonal or common combined variances for catch observation
# seasonal=0, common=1 (use 1 for annual data)
          1  #         Cod
          1  #     Whiting
          1  #     Haddock
          1  #      Saithe
          1  #    Mackerel
          0  #     Herring
          0  #  N. sandeel
          0  #  S. sandeel
          0  #   Nor. pout
          0  #       Sprat
          1  #      Plaice
          1  #        Sole
########################################
##
# catch observations: number of separate catch variance groups by species
           4   #         Cod
           4   #     Whiting
           5   #     Haddock
           3   #      Saithe
           3   #    Mackerel
           3   #     Herring
           3   #  N. sandeel
           2   #  S. sandeel
           3   #   Nor. pout
           3   #       Sprat
           3   #      Plaice
           2   #        Sole

#  first age group in each catch variance group
1 2 7 9        #  Cod
0 1 2 5        #  Whiting
```

```
0 1 2 6 8      #  Haddock
3 5 8  #  Saithe
1 2 3  #  Mackerel
0 1 8  #  Herring
0 1 4  #  N. sandeel
0 1    #  S. sandeel
0 1 3  #  Nor. pout
1 2 3  #  Sprat
1 2 3  #  Plaice
2 3    #  Sole
########################################
##
# catch observations: number of separate catch seasonal component groups by species
           4   #         Cod
           4   #     Whiting
           3   #     Haddock
           2   #      Saithe
           3   #    Mackerel
           2   #     Herring
           3   #  N. sandeel
           3   #  S. sandeel
           3   #   Nor. pout
           3   #       Sprat
           2   #      Plaice
           1   #        Sole

#  first ages in each seasonal component group by species
1 2 3 5        #  Cod
0 1 2 3        #  Whiting
0 1 2  #  Haddock
3 4    #  Saithe
1 2 4  #  Mackerel
0 1    #  Herring
0 1 2  #  N. sandeel
0 1 2  #  S. sandeel
0 1 3  #  Nor. pout
1 2 3  #  Sprat
1 2    #  Plaice
2      #  Sole
########################################
## first and last age in calculation of average F by species (option avg.F.ages)
2 4  # Cod
2 6  # Whiting
2 6  # Haddock
3 6  # Saithe
4 8  # Mackerel
2 6  # Herring
1 2  # N. sandeel
1 2  # S. sandeel
1 2  # Nor. pout
1 2  # Sprat
3 6  # Plaice
2 6  # Sole
########################################
## minimum 'observed' catch, (option min.catch).
#   You cannot log zero catch-at-age!
#
# 0 ignore observation in likelihood
#
          0  #         Cod
          0  #     Whiting
          0  #     Haddock
          0  #      Saithe
          0  #    Mackerel
          0  #     Herring
          0  #  N. sandeel
          0  #  S. sandeel
          0  #   Nor. pout
          0  #       Sprat
          0  #      Plaice
          0  #        Sole
########################################
##
# catch observations: number of year groups with the same age and seasonal selection
           3   #         Cod
```

```
           3   #     Whiting
           3   #     Haddock
           2   #      Saithe
           3   #    Mackerel
           4   #     Herring
           2   #  N. sandeel
           2   #  S. sandeel
           2   #   Nor. pout
           2   #       Sprat
           3   #      Plaice
           2   #        Sole

#  first year in each group (please note
#   first value should always be first model year)
1974 1993 2007        #  Cod
1974 1991 2007        #  Whiting
1974 1985 2000        #  Haddock
1974 1992             #  Saithe
1974 1980 2004        #  Mackerel
1974 1978 1983 1998   #  Herring
1974 2005             #  N. sandeel
1974 2005             #  S. sandeel
1974 2003             #  Nor. pout
1974 1996             #  Sprat
1974 1990 2003        #  Plaice
1974 1990             #  Sole
########################################
##
# number of nodes for year effect Fishing mortality spline
# 1=no spline (use one Fy for each year), >1 number of nodes
           1   #         Cod
           1   #     Whiting
           1   #     Haddock
           1   #      Saithe
           1   #    Mackerel
           1   #     Herring
           1   #  N. sandeel
           1   #  S. sandeel
           1   #   Nor. pout
           1   #       Sprat
           1   #      Plaice
           1   #        Sole

#  first year in each group
1975   #  Cod
1975   #  Whiting
1975   #  Haddock
1975   #  Saithe
1975   #  Mackerel
1975   #  Herring
1975   #  N. sandeel
1975   #  S. sandeel
1975   #  Nor. pout
1975   #  Sprat
1975   #  Plaice
1975   #  Sole
########################################
## year season combinations with zero catch (F=0)
#   (option zero.catch.year.season)
# 0=no, all year-seasons have catchs,
# 1=yes there are year-season combinations with no catch.
#   Read from file zero_catch_seasons_ages.in
# default=0
1
########################################
## season age combinations with zero catch (F=0)
#   (option zero.catch.season.ages)
# 0=no, all seasons have catches,
# 1=yes there are seasons with no catch.
#   Read from file zero_catch_season_ages.in
# default=0
1
########################################
## Factor for fixing last season effect in F-model (default=1) (fix.F.factor))
          1  #         Cod
          1  #     Whiting
          1  #     Haddock
```

```
          1  #       Saithe
          1  #     Mackerel
          1  #      Herring
          1  #   N. sandeel
          1  #   S. sandeel
          1  #    Nor. pout
          1  #        Sprat
          1  #       Plaice
          1  #         Sole
########################################
## Uncertainties for catch, cpue and SSB-R observations (option calc.est.sigma)
#  values: 0=estimate sigma as a parameter (the right way of doing it)
#          1=Calculate sigma and truncate if lower limit is reached
#          2=Calculate sigma and use a penalty function to avoid lower limit
#  catch-observation, cpue-obs, Stock–recruit
           0            0            0
########################################
# Read HCR_option file (option=read.HCR) default=0
#  0=no  1=yes
0
########################################
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
#
# multispecies parameters
#
#&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
#
# Exclude year,season and predator combinations where stomach data are not
#    incl.(option incl.stom.all)
#   0=no, all stomach data are used in likelihood
#   1=yes there are combinations for which data are not included in the likeli-
hood.
#      Read from file: incl_stom.in
#   default(0)
1
########################################
##  N in the beginning of the period or N bar for calculation of M2 (option
use.Nbar)
#  0=use N in the beginning of the time step (default)
#  1=use N bar
0
########################################
## Maximum M2 iterations (option M2.iterations) in case of use.Nbar=1
3
########################################
## convergence criteria (option max.M2.sum2) in case of use.Nbar=1
#   use max.M2.sum2=0.0 and M2.iterations=7 (or another high number) to make
Hessian
3
########################################
## likelihood model for stomach content observations (option stom.likelihood)
#  1 =likelihood from prey weight proportions only (see option below)
#  2 =likelihood from prey weight proportions and from prey numbers to estimate
size selection
#  3 =Gamma distribution for prey absolute weight and size selection from prey
numbers
1
########################################
# Variance used in likelihood model for stomach contents as prey weight propor-
tion
# (option stomach.variance)
#  0 =not relevant,
#  1 =log normal distribution,
#  2 =normal distribution,
#  3 =Dirichlet distribution
3
########################################
## Usage of age–length-keys for calc of M2 (option simple.ALK))
#  0=Use only one size group per age (file lsea.in or west.in)
#  1=Use size distribution per age (file ALK_all.in)
0
########################################
## Usage of food-rations from input values or from size and regression parameters
(option consum)
#  0=Use input values by age (file consum.in)
```

```
#   1=use weight-at-age (file west.in) and regression parameters (file con-
sum_ab.in)
#  2=use length-at-age (file lsea.in), l-w relation and regression parameters
(file consum_ab.in)
1
########################################
## Size selection model based on (option size.select.model)
#  1=length:
#      M2 calculation:
#         Size preference:
#           Predator length-at-age from file: lsea.in
#           Prey     length-at-age from file: lsea.in
#         Prey mean weight is weight in the sea from file: west.in
#      Likelihood:
#         Size preference:
#                       Predator   mean   length   per   length   group   (file:
stom_pred_length_at_sizecl.in)
#           Prey mean length per ength group (file stomlen_at_length.in
#            Prey mean weight from mean weight per prey length group (file:
stomweight_at_length.in
#  2=weight:
#      M2 calculation:
#         Size preference:
#           Predator weight-at-age from file: west.in
#           Prey     weight-at-age from file: west.in
#         Prey mean weight is weight in the sea from file: west.in
#      Likelihood:
#         Size preference
#           Predator mean weight is based on mean length per predator length
#             group (file: stom_pred_length_at_sizecl.in)
#             and l-w relation (file: length_weight_relations.in),
#        Prey mean weight per prey length group (file: stomweight_at_length.in)
#           Prey mean weight from mean weight per prey length group (file:
stomweight_at_length.in
2
########################################
# Adjust Length-at-age distribution by a mesh selection function (option
L50.mesh)
#  Please note that options simple.ALK shoud be 1 and option size.select.model
should be 5
# L50 (mm) is optional given as input. Selection Range is estimated by the model
# L50= -1 do not adjust
# L50=0, estimate L50 and selection range
# L50>0, input L50 (mm) and estimate selection range
# by VPA species
         -1  #          Cod
         -1  #      Whiting
         -1  #      Haddock
         -1  #       Saithe
         -1  #     Mackerel
         -1  #      Herring
         -1  #   N. sandeel
         -1  #   S. sandeel
         -1  #    Nor. pout
         -1  #        Sprat
         -1  #       Plaice
         -1  #         Sole
########################################
## spread of size selection (option size.selection)
#   0=no size selection, predator/preys size range defined from observations
#   1=normal distribution size selection
#   3=Gamma distribution size distribution
#   4=no size selection, but range defined by input min and max
#       regression parameters (file pred_prey_size_range_param.in)
#   5=Beta distributed size distribution, within observed size range
#   6=log-Beta size distributed, within observed size range
#
# by predator
          0  #       Fulmar
          0  #    Guillemot
          0  #    Her. Gull
          0  #    Kittiwake
          0  #    GBB. Gull
          0  #       Gannet
          0  #       Puffin
          0  #    Razorbill
          0  #   A. radiata
```

```
          0  #  G. gurnards
          0  #  W.horse mac
          0  #  N.horse mac
          0  #    Grey seal
          4  #  H. porpoise
          0  #         Hake
          0  #          Cod
          0  #      Whiting
          0  #      Haddock
          0  #       Saithe
          0  #     Mackerel
########################################
## sum stomach contents over prey size for use in likelihood for prey weight proportions (option sum.stom.like)
#   0=no, use observations as they are; 1=yes, sum observed and predicted stomach contents before used in likelihood for prey weight proportions
#
# by predator
          1  #       Fulmar
          1  #    Guillemot
          1  #    Her. Gull
          1  #    Kittiwake
          1  #    GBB. Gull
          1  #       Gannet
          1  #       Puffin
          1  #    Razorbill
          1  #   A. radiata
          1  #  G. gurnards
          1  #  W.horse mac
          1  #  N.horse mac
          1  #    Grey seal
          1  #  H. porpoise
          1  #         Hake
          1  #          Cod
          1  #      Whiting
          1  #      Haddock
          1  #       Saithe
          1  #     Mackerel
########################################
## # Use estimated scaling factor to link number of observation to variance for stomach observation likelihood (option stom_obs_var)
#     0=no, do not estiamte factor (assumed=1);  1=yes, estimate the factor; 2=equal weight (1) for all samples
#
# by predator
          1  #       Fulmar
          1  #    Guillemot
          1  #    Her. Gull
          1  #    Kittiwake
          1  #    GBB. Gull
          1  #       Gannet
          1  #       Puffin
          1  #    Razorbill
          1  #   A. radiata
          1  #  G. gurnards
          1  #  W.horse mac
          1  #  N.horse mac
          1  #    Grey seal
          1  #  H. porpoise
          1  #         Hake
          1  #          Cod
          1  #      Whiting
          1  #      Haddock
          1  #       Saithe
          1  #     Mackerel
########################################
## # Upper limit for Dirichlet sumP. A low value (e.g. 10) limits the risk of overfitting. A high value (e.g. 100) allows a full fit. (option stom_max_sumP)
# by predator
        100  #       Fulmar
        100  #    Guillemot
        100  #    Her. Gull
        100  #    Kittiwake
        100  #    GBB. Gull
        100  #       Gannet
        100  #       Puffin
        100  #    Razorbill
```

```
       100  #   A. radiata
       100  #  G. gurnards
       100  #  W.horse mac
       100  #  N.horse mac
       100  #    Grey seal
       100  #  H. porpoise
       100  #         Hake
       100  #          Cod
       100  #      Whiting
       100  #      Haddock
       100  #       Saithe
       100  #     Mackerel
########################################
## Scaling factor (to bring parameters close to one) for relation between no of
stomachs sampling and variance
#  value=0: use default values i.e. 1.00 for no size selection and otherwise 0.1
(option var.scale.stom)
         1  #       Fulmar
         1  #    Guillemot
         1  #    Her. Gull
         1  #    Kittiwake
         1  #    GBB. Gull
         1  #       Gannet
         1  #       Puffin
         1  #    Razorbill
         1  #   A. radiata
         1  #  G. gurnards
         1  #  W.horse mac
         1  #  N.horse mac
         1  #    Grey seal
         1  #  H. porpoise
       100  #         Hake
         1  #          Cod
         1  #      Whiting
         1  #      Haddock
         1  #       Saithe
         1  #     Mackerel
########################################
## other food suitability size dependency  (option size.other.food.suit)
#  0=no size dependency
#  1=yes, other food suitability is different for different size classes
         0  #       Fulmar
         0  #    Guillemot
         0  #    Her. Gull
         0  #    Kittiwake
         0  #    GBB. Gull
         0  #       Gannet
         0  #       Puffin
         0  #    Razorbill
         1  #   A. radiata
         0  #  G. gurnards
         0  #  W.horse mac
         0  #  N.horse mac
         0  #    Grey seal
         0  #  H. porpoise
         0  #         Hake
         0  #          Cod
         1  #      Whiting
         1  #      Haddock
         1  #       Saithe
         1  #     Mackerel
########################################
## Minimum observed relative stomach contents weight for inclusion in ML esti-
mation (option min.stom.cont)
     9e-05  #       Fulmar
     9e-05  #    Guillemot
     9e-05  #    Her. Gull
     9e-05  #    Kittiwake
     9e-05  #    GBB. Gull
     9e-05  #       Gannet
     9e-05  #       Puffin
     9e-05  #    Razorbill
     9e-05  #   A. radiata
     9e-05  #  G. gurnards
     9e-05  #  W.horse mac
     9e-05  #  N.horse mac
     9e-05  #    Grey seal
```

```
      9e-05  #  H. porpoise
      9e-09  #         Hake
      9e-09  #          Cod
      9e-09  #      Whiting
      9e-09  #      Haddock
      9e-05  #       Saithe
      9e-05  #     Mackerel
########################################
## Upper limit for no of samples used for calculation of stomach observation
variance (option max.stom.sampl)
       1000  #       Fulmar
       1000  #    Guillemot
       1000  #    Her. Gull
       1000  #    Kittiwake
       1000  #    GBB. Gull
       1000  #       Gannet
       1000  #       Puffin
       1000  #    Razorbill
       1000  #   A. radiata
       1000  #  G. gurnards
       1000  #  W.horse mac
       1000  #  N.horse mac
       1000  #    Grey seal
       1000  #  H. porpoise
       1000  #         Hake
       1000  #          Cod
       1000  #      Whiting
       1000  #      Haddock
       1000  #       Saithe
       1000  #     Mackerel
########################################
## Max prey size/ pred size factor for inclusion in M2 calc (option
max.prey.pred.size.fac)
          5  #       Fulmar
          5  #    Guillemot
          5  #    Her. Gull
          5  #    Kittiwake
          5  #    GBB. Gull
          5  #       Gannet
          5  #       Puffin
          5  #    Razorbill
        0.5  #   A. radiata
        0.5  #  G. gurnards
        0.5  #  W.horse mac
        0.5  #  N.horse mac
         50  #    Grey seal
         50  #  H. porpoise
        0.9  #         Hake
        0.5  #          Cod
        0.9  #      Whiting
        0.5  #      Haddock
        0.5  #       Saithe
        0.5  #     Mackerel
########################################
## inclusion of individual stomach contents observations in ML for weight pro-
portions (option stom.type.include)
# 1=Observed data
# 2= + (not observed) data within the observed size range (=fill in)
# 3= + (not observed) data outside an observed size range. One obs below and one
above (=tails)
# 4= + (not observed) data for the full size range of a prey species irrespective
of predator size (=expansion)
          2  #       Fulmar
          2  #    Guillemot
          2  #    Her. Gull
          2  #    Kittiwake
          2  #    GBB. Gull
          2  #       Gannet
          2  #       Puffin
          2  #    Razorbill
          2  #   A. radiata
          2  #  G. gurnards
          2  #  W.horse mac
          2  #  N.horse mac
          2  #    Grey seal
          2  #  H. porpoise
          2  #         Hake
```

```
          2  #          Cod
          2  #      Whiting
          2  #      Haddock
          2  #       Saithe
          2  #     Mackerel
########################################
## use overlap input values by year and season (use.overlap)
#   0: overlap assumed constant or estimated within the model
#    1: overlap index from file overlap.in (assessment only, use overlap from
last year in forecast)
#   2: overlap index from file overlap.in (assessment and forecast)
0
########################################
## parameter estimation phases for predation parameters
#  the number gives the phase, -1 means no estimation
#
#  vulnerability (default=2) (phase phase.vulnera)
2
# other food suitability slope (default=-1) (option phase.other.suit.slope)
2
# prefered size ratio (default=2) (option phase.pref.size.ratio)
-1
# predator size ratio adjustment factor (default=-1)
#  (option phase.pref.size.ratio.correction))
-1
# prey species size adjustment factor (default=-1)
#  (option phase.prey.size.adjustment)
-1
# variance of prefered size ratio (default=2) (option phase.var.size.ratio)
-1
# season overlap (default=-1) (option phase.season.overlap)
2
# Stomach variance parameter (default=2) (option phase.Stom.var)
2
#   Mesh   size   selection   of   stomach   age–length   key   (default=-1)
#    (option phase.mesh.adjust)
-1
########################################
```

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

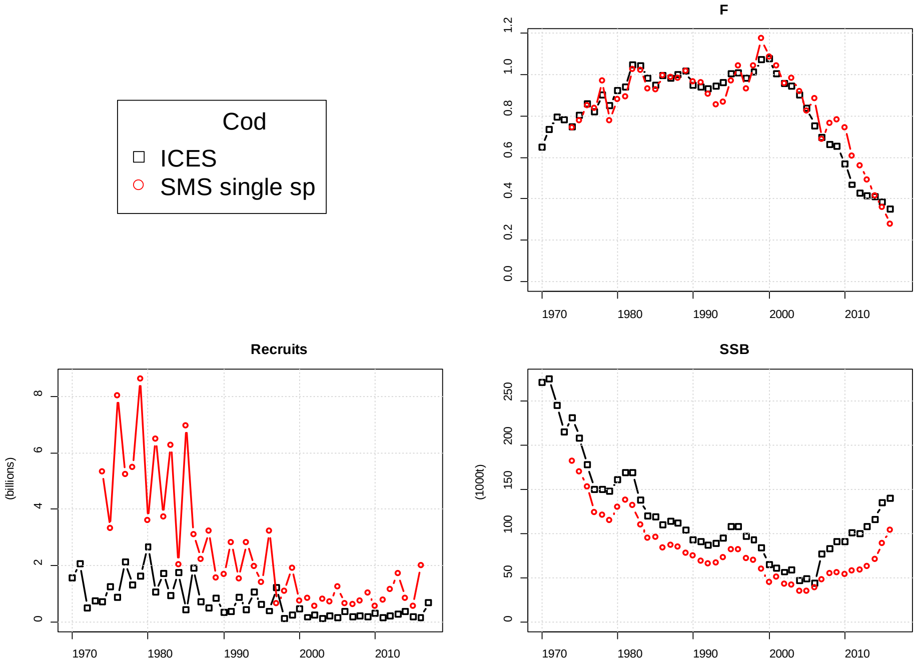


Figure A5.1. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

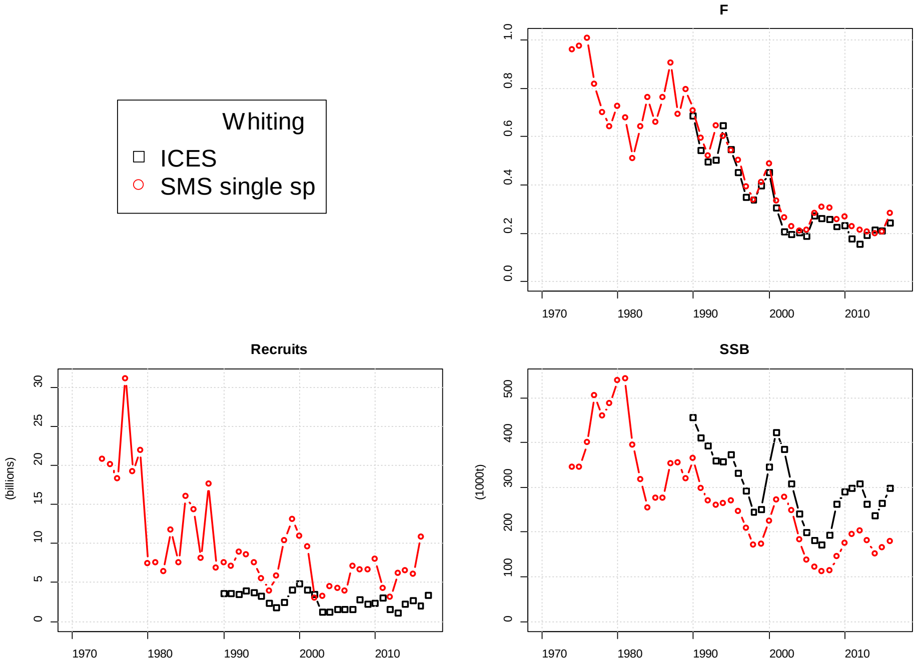


Figure A5.2. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

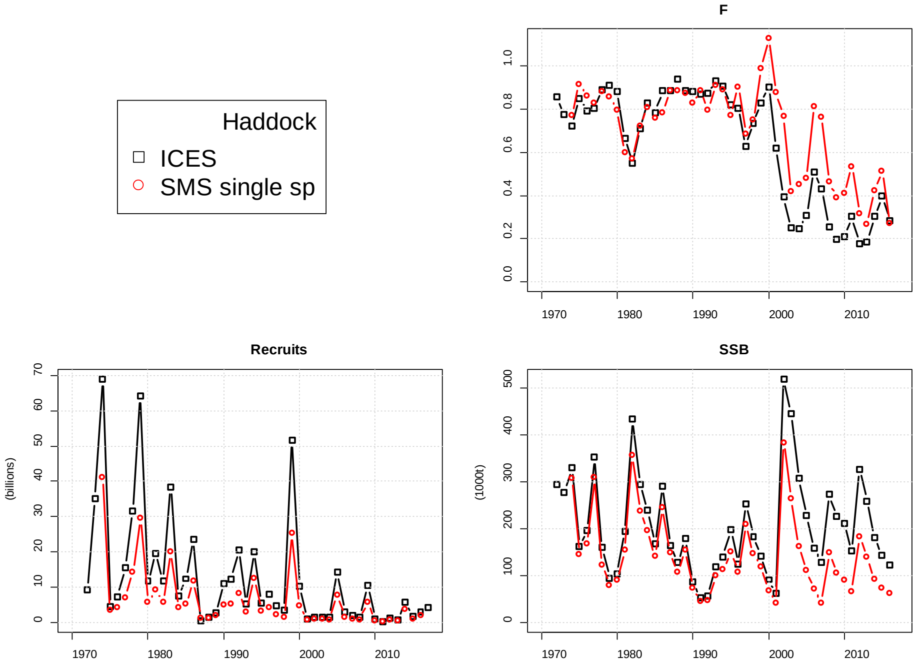


Figure A5.3. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

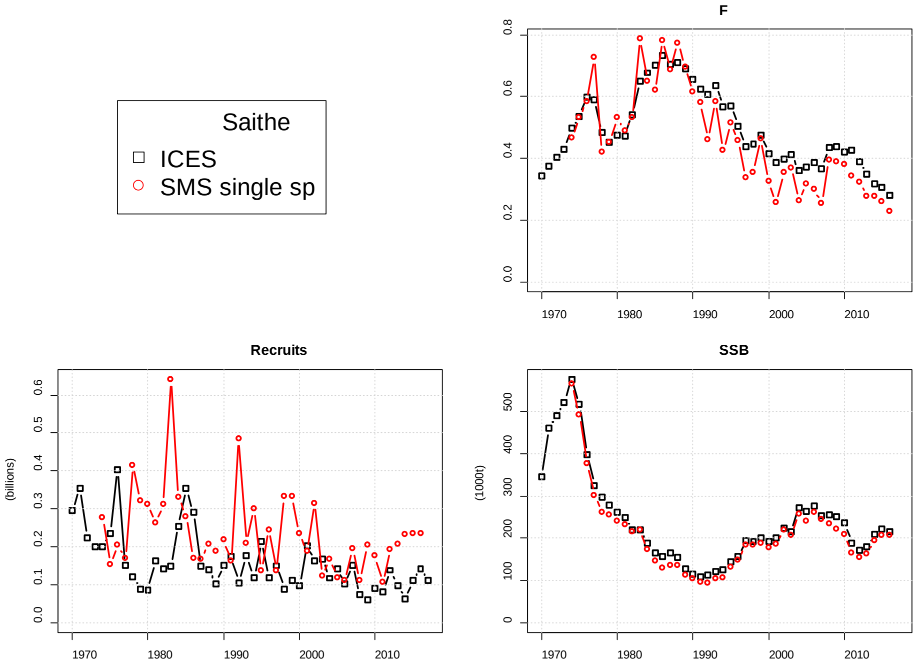


Figure A5.4. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

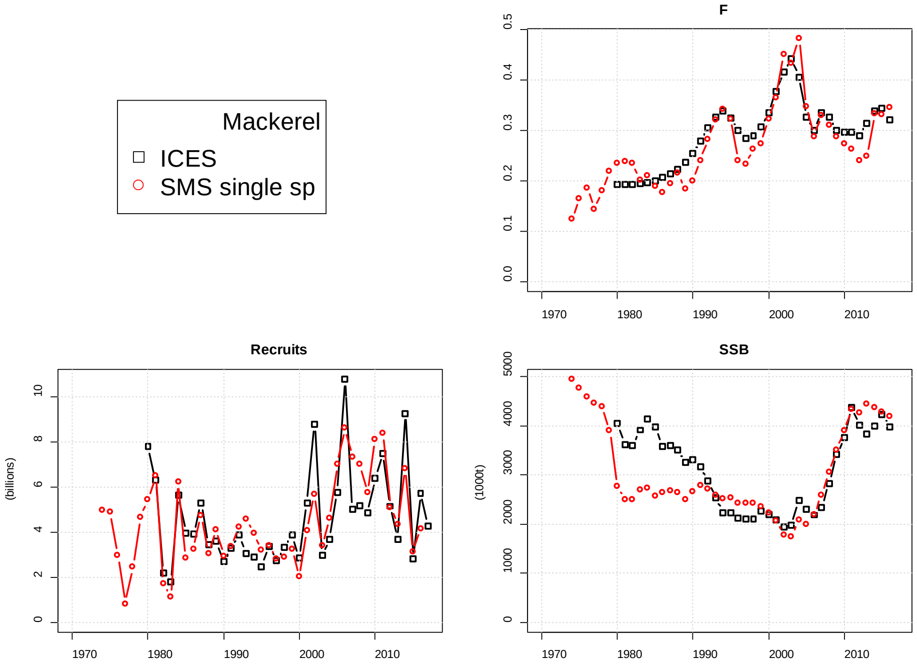


Figure A5.5. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

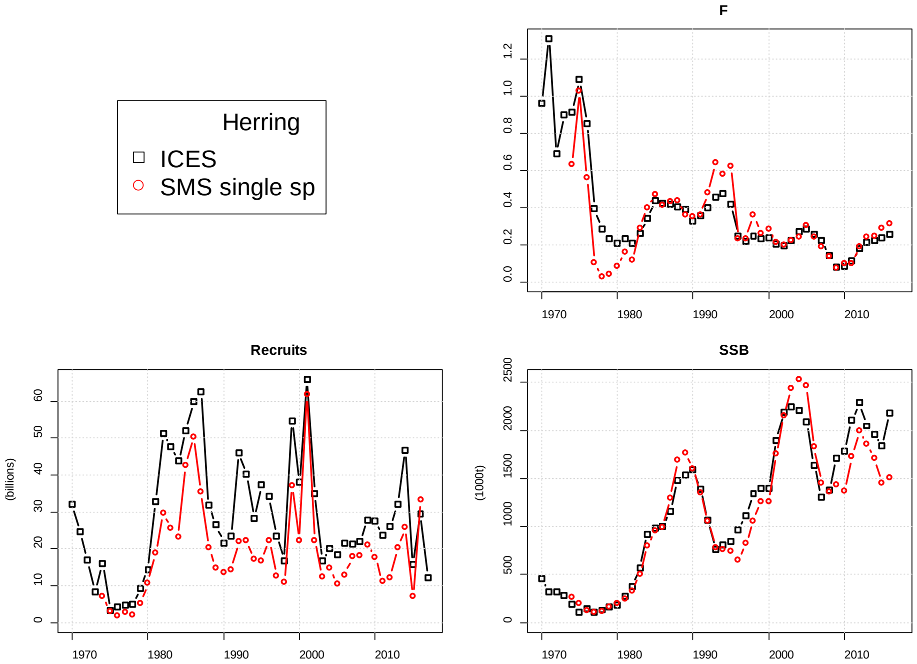


Figure A5.6. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

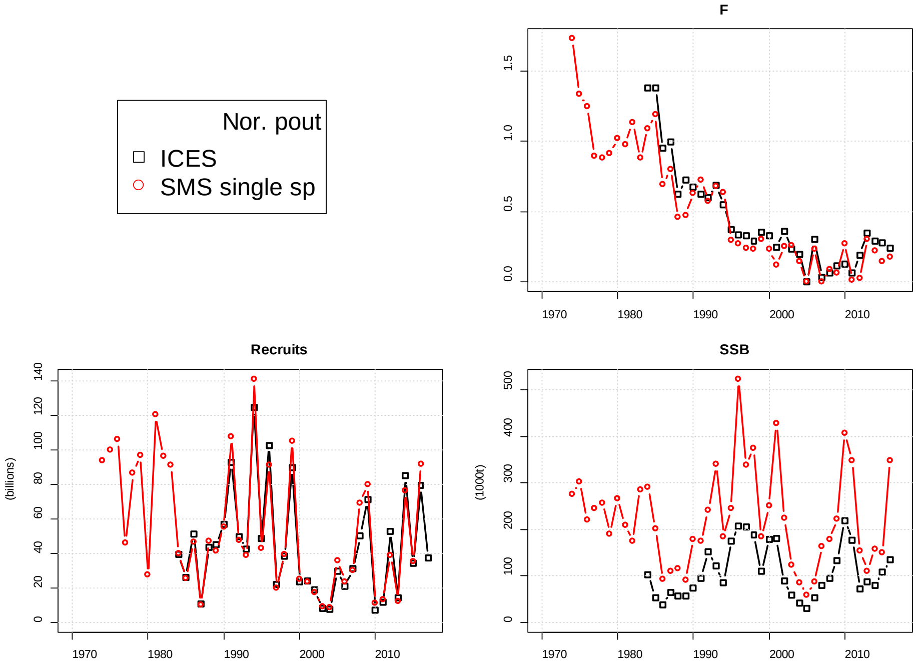


Figure A5.7. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

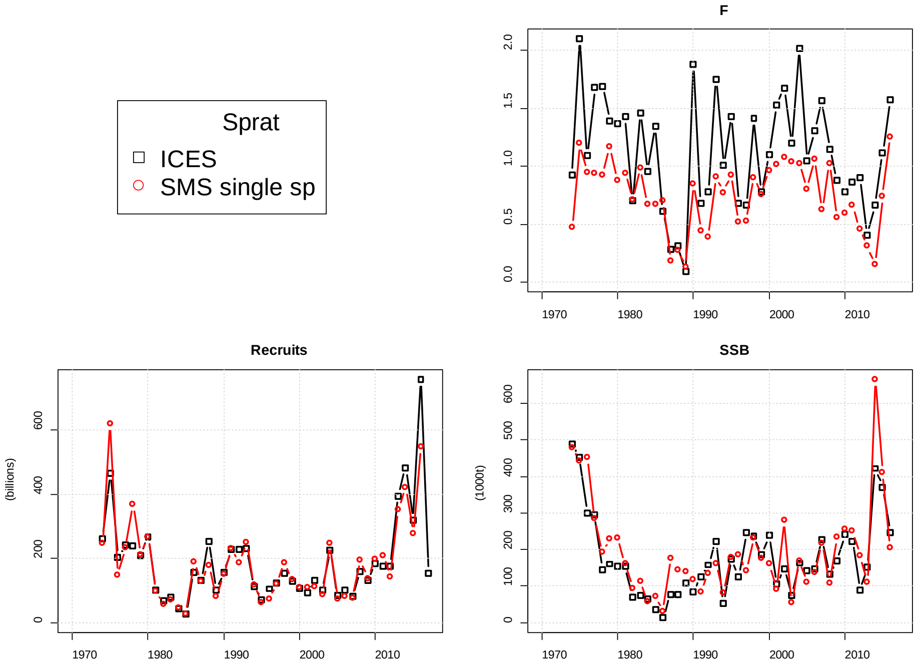


Figure A5.8. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

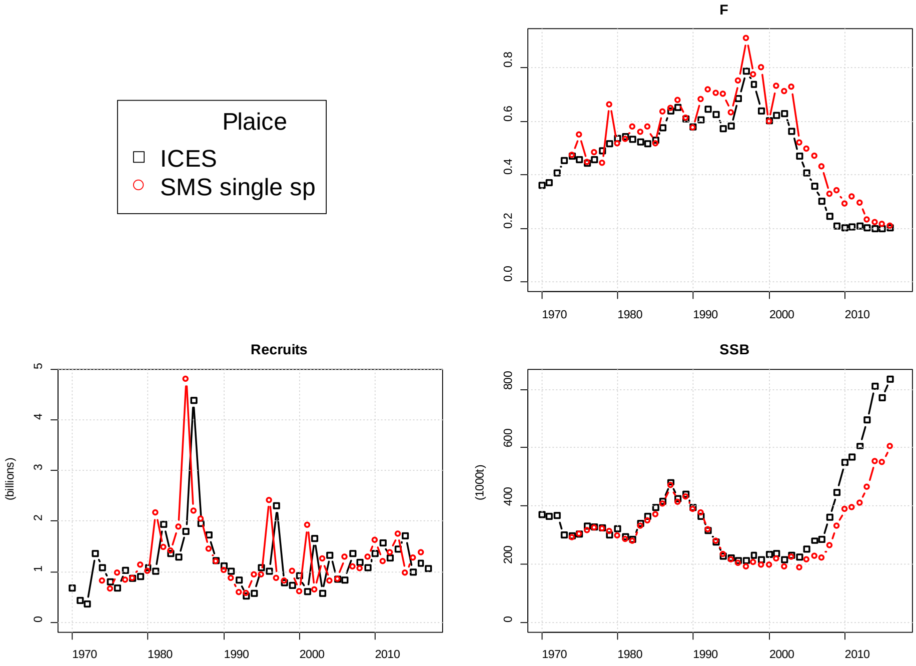


Figure A5.9. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

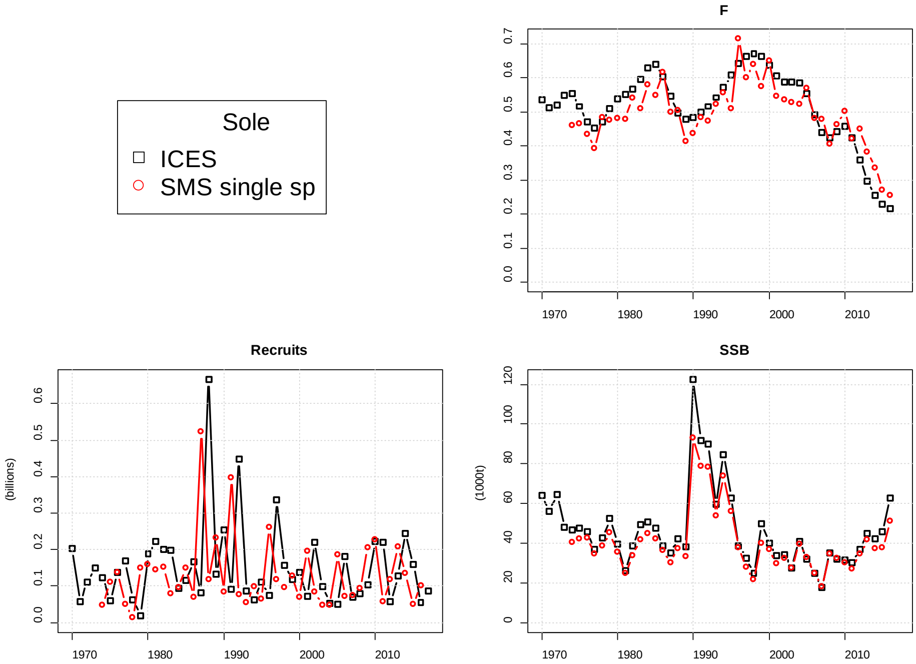
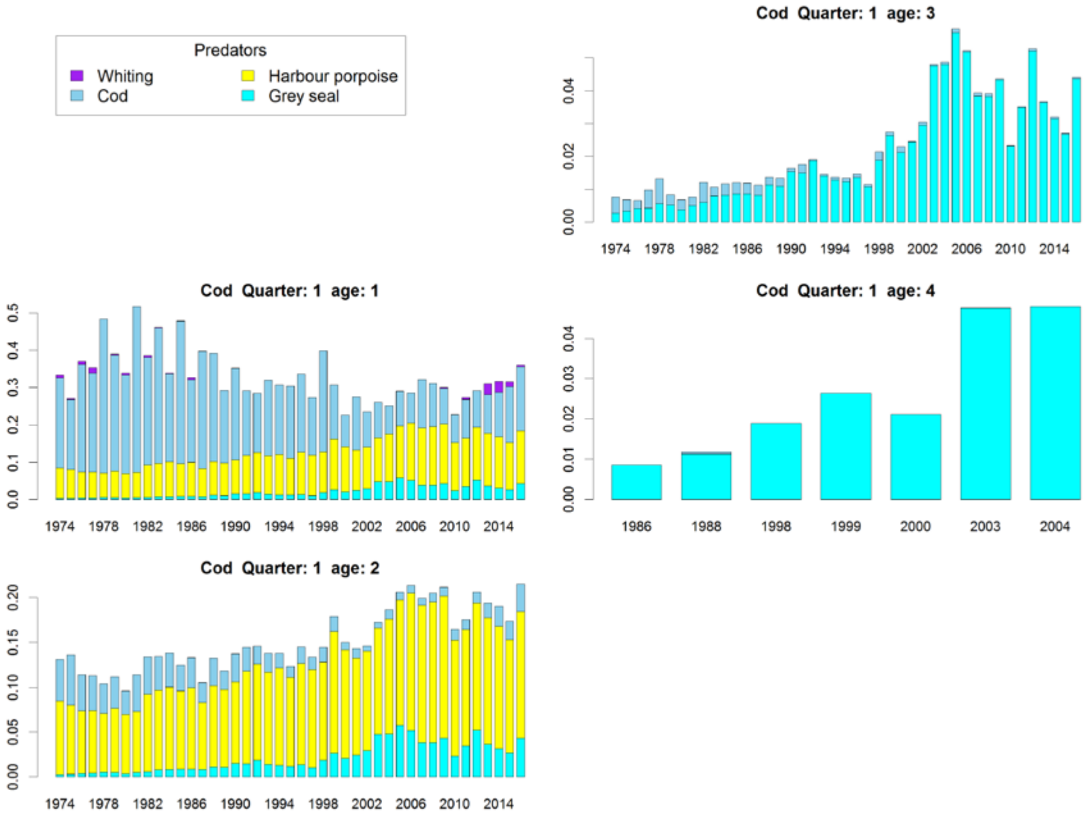
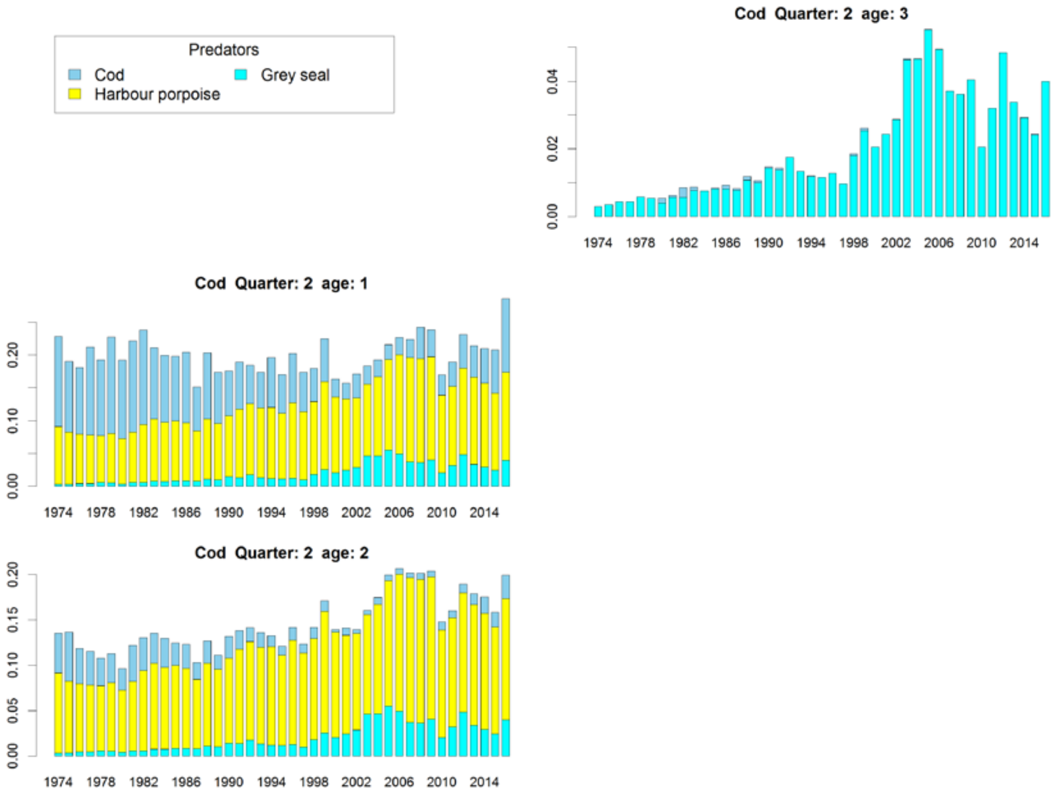


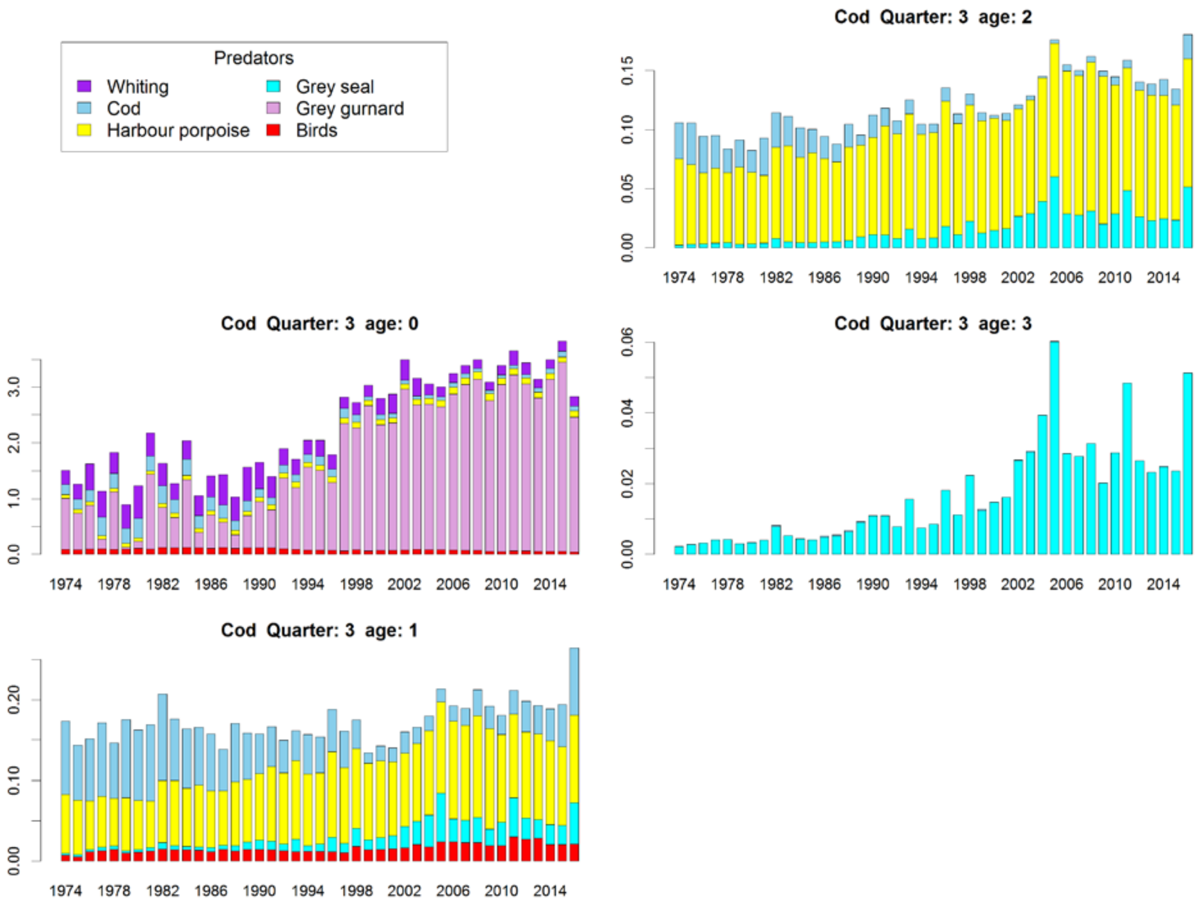
Figure A5.10. Stock summary comparison, ICES single-species assessment and SMS in single-species mode (constant M).

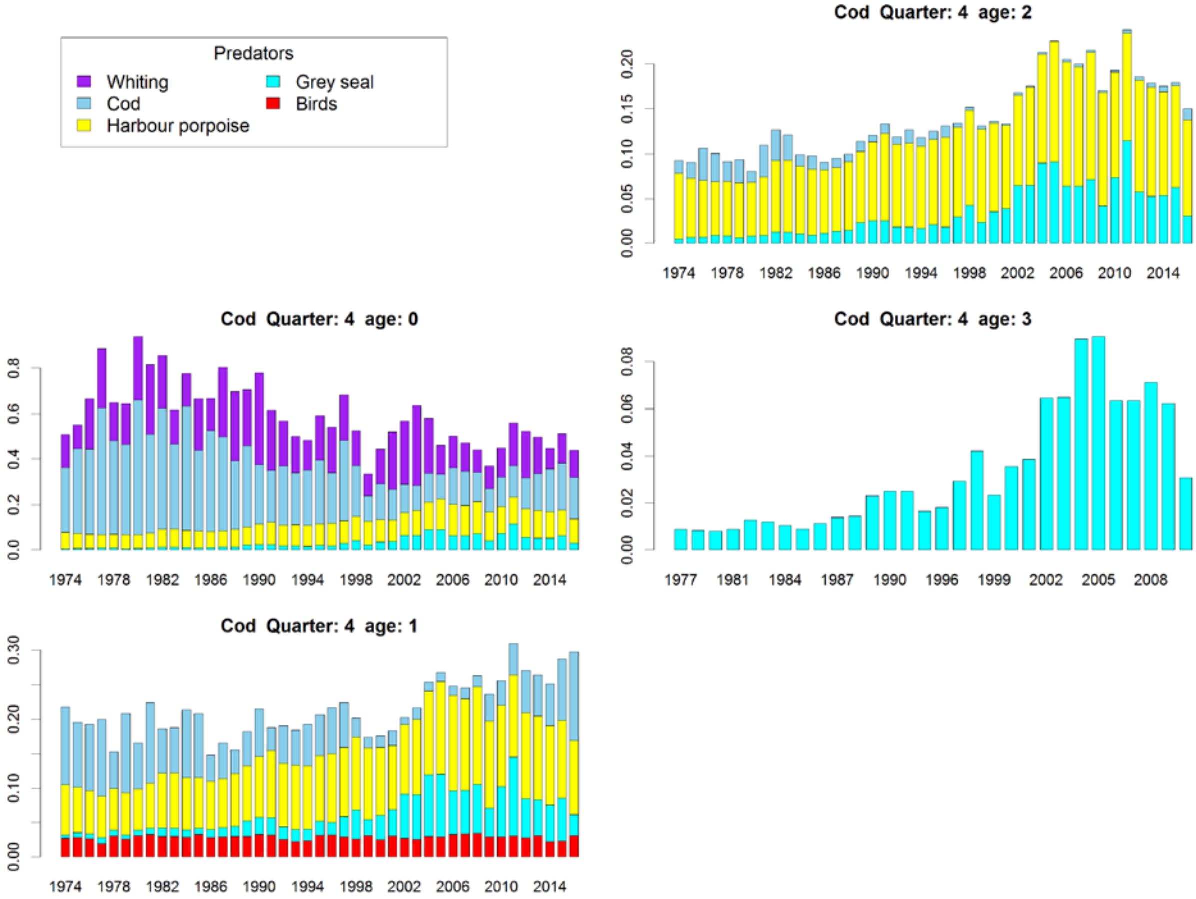
12 APPENDIX 6: Quarterly predation mortality by prey species and age

Predation mortality for Cod

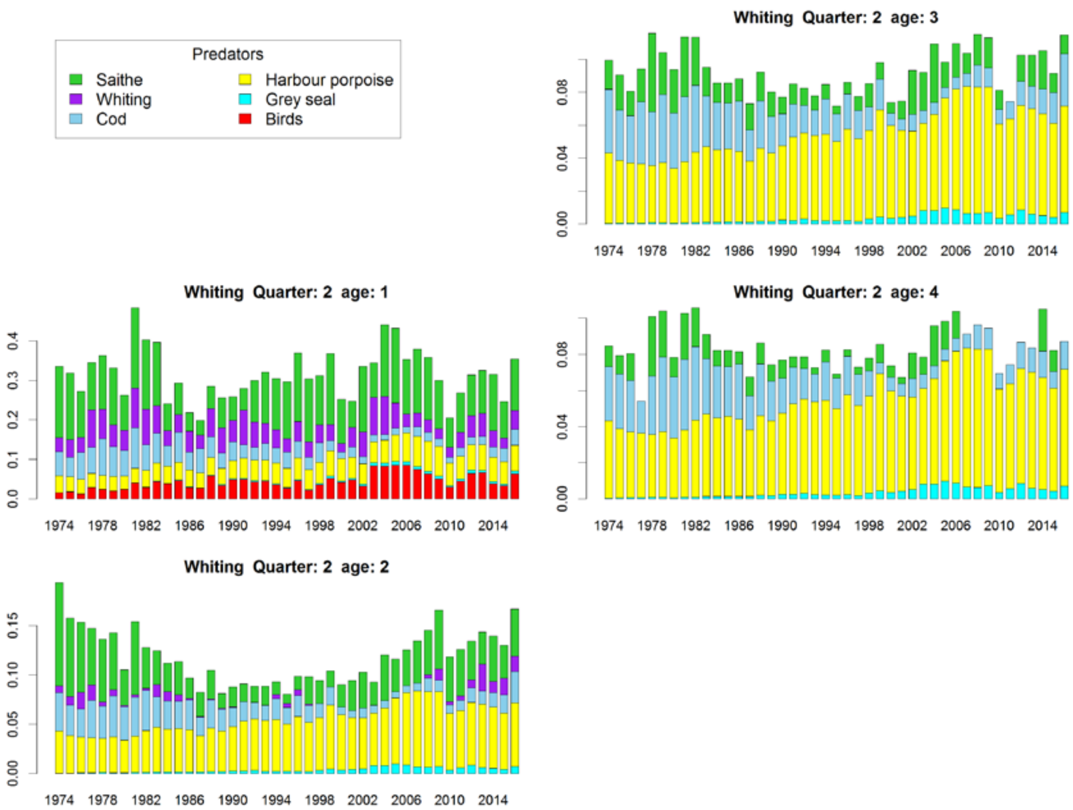



Predators
Cod
Grey seal
Harbour porpoise
Cod Quarter: 2 age: 3
Cod Quarter: 2 age: 1
Cod Quarter: 2 age: 2


Predators
Whiting
Grey seal
Cod
Grey gurnard
Harbour porpoise
Birds
Cod Quarter: 3 age: 2
Cod Quarter: 3 age: 0
Cod Quarter: 3 age: 3
Cod Quarter: 3 age: 1


Predators
Whiting
Cod
Harbour porpoise
Grey seal
Birds
Cod Quarter: 4 age: 2
Cod Quarter: 4 age: 0
Cod Quarter: 4 age: 3
Cod Quarter: 4 age: 1
1974 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014
1977 1981 1984 1987 1990 1996 1999 2002 2005 2008

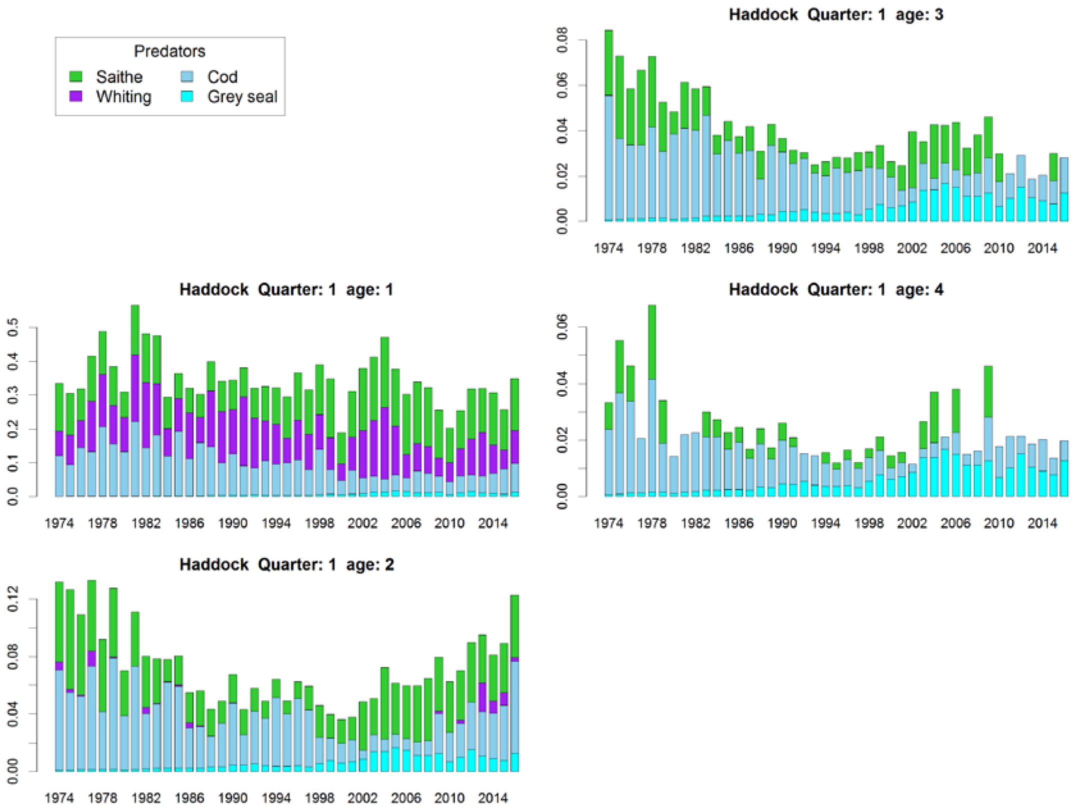
Predation mortality for Whiting

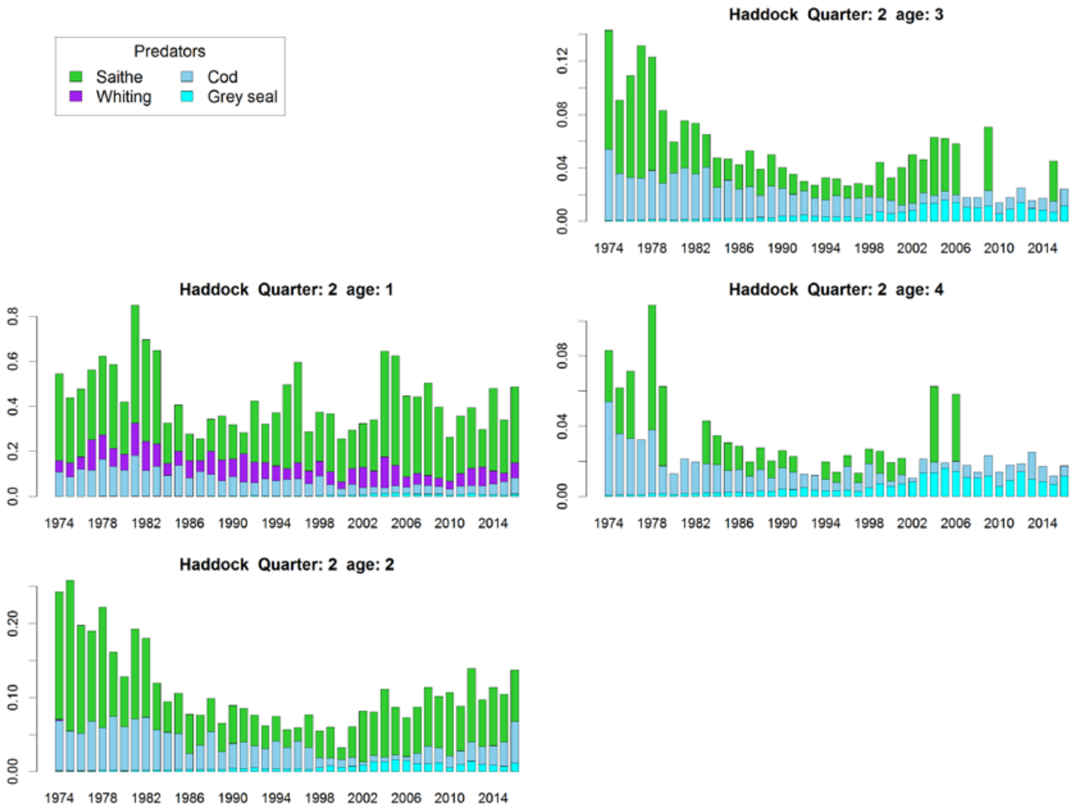


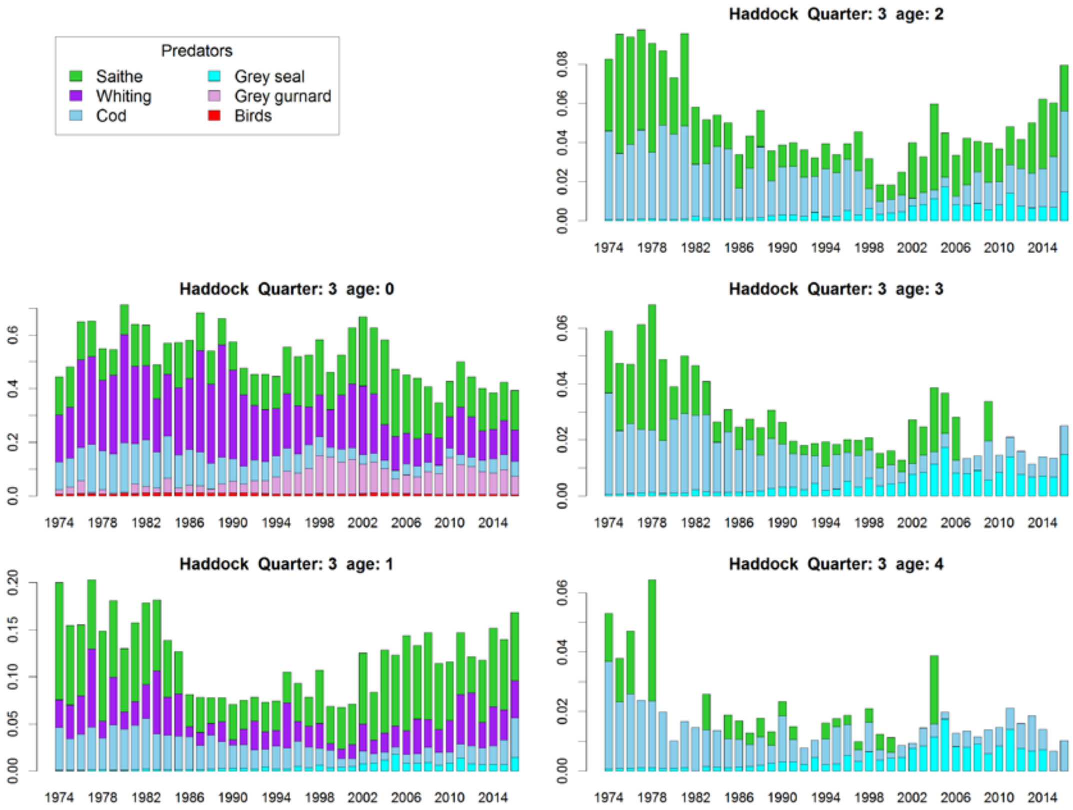

Predators
Saithe
Whiting
Cod
Harbour porpoise
Grey seal
Grey gurnard
Birds
Whiting Quarter: 3 age: 2
Whiting Quarter: 3 age: 0
Whiting Quarter: 3 age: 3
Whiting Quarter: 3 age: 1
Whiting Quarter: 3 age: 4

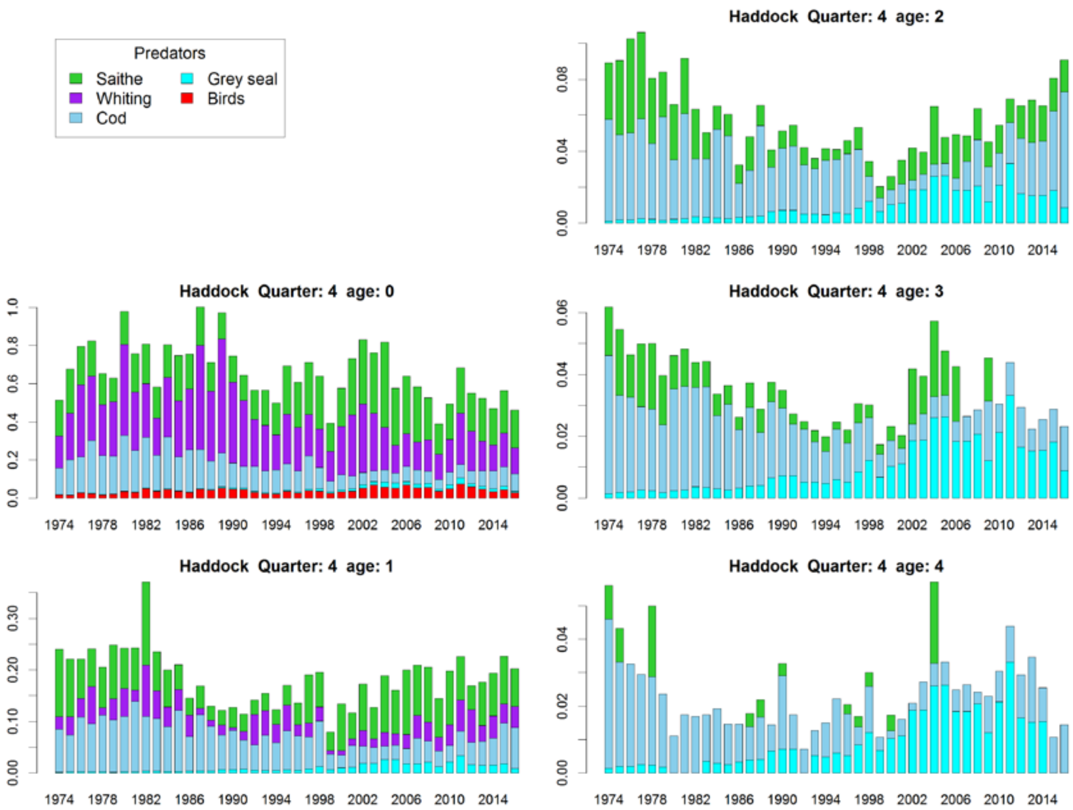

Predators
Saithe
Whiting
Cod
Harbour porpoise
Grey seal
Grey gurnard
Birds
Whiting Quarter: 4 age: 2
Whiting Quarter: 4 age: 0
Whiting Quarter: 4 age: 3
Whiting Quarter: 4 age: 1
Whiting Quarter: 4 age: 4

Predation mortality for Haddock

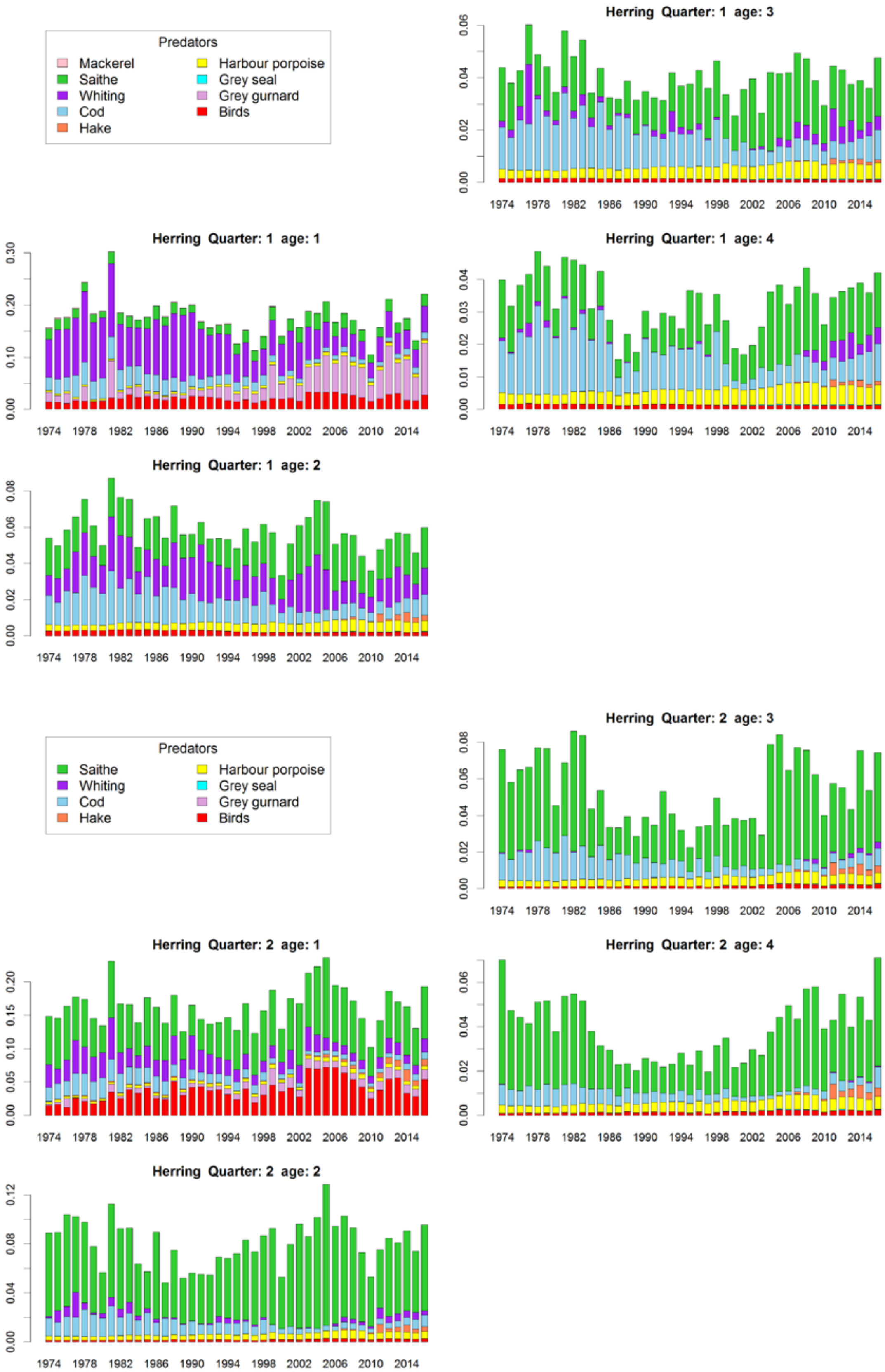


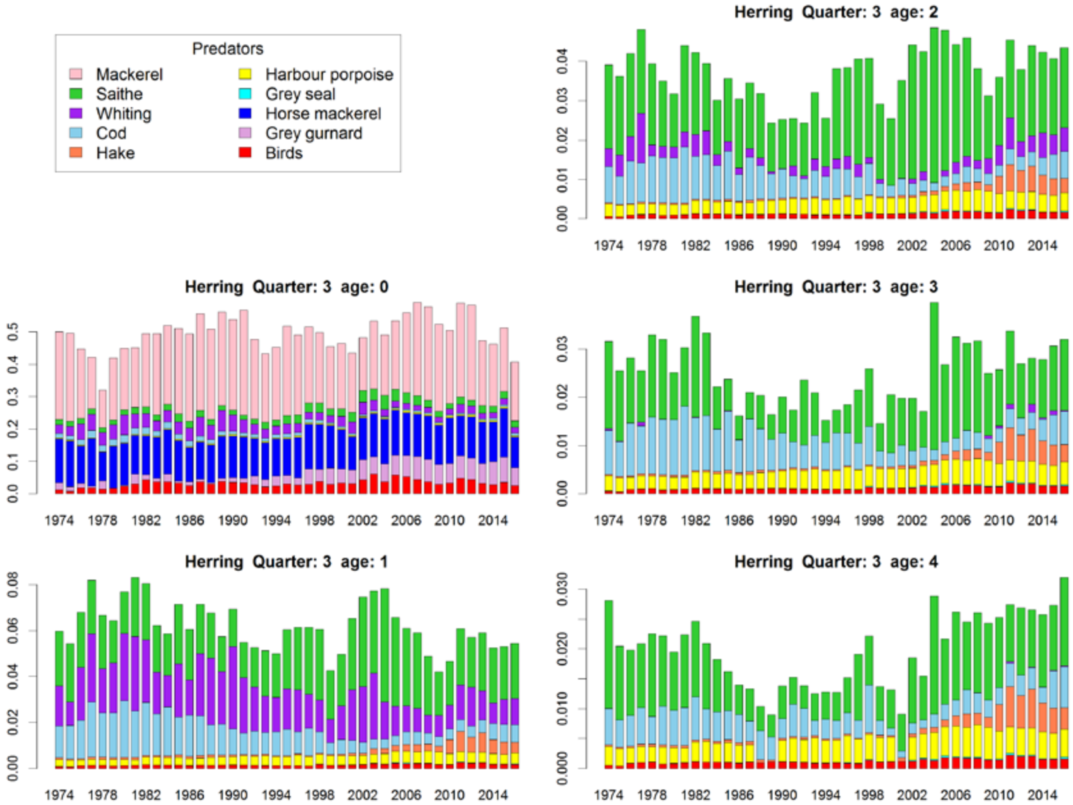


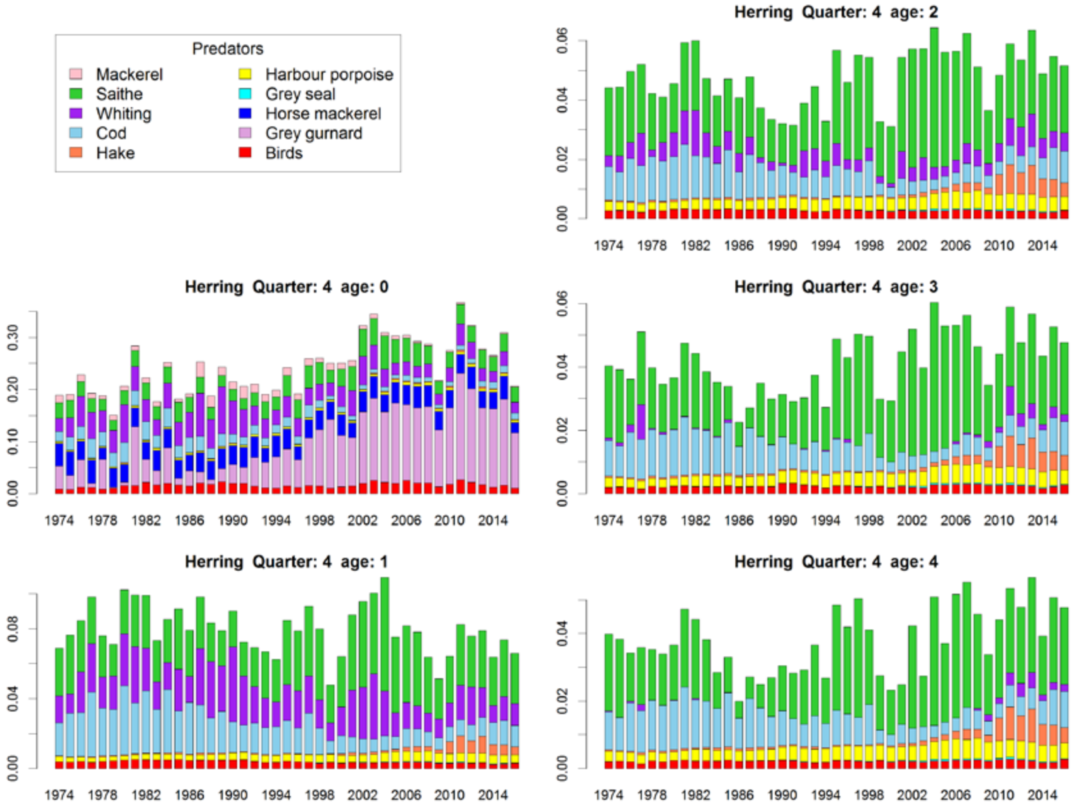

Predators
Saithe
Whiting
Cod
Grey seal
Grey gurnard
Birds
Haddock Quarter: 3 age: 2
Haddock Quarter: 3 age: 0
Haddock Quarter: 3 age: 3
Haddock Quarter: 3 age: 1
Haddock Quarter: 3 age: 4


Predators
Saithe
Whiting
Cod
Grey seal
Birds
Haddock Quarter: 4 age: 2
Haddock Quarter: 4 age: 0
Haddock Quarter: 4 age: 3
Haddock Quarter: 4 age: 1
Haddock Quarter: 4 age: 4

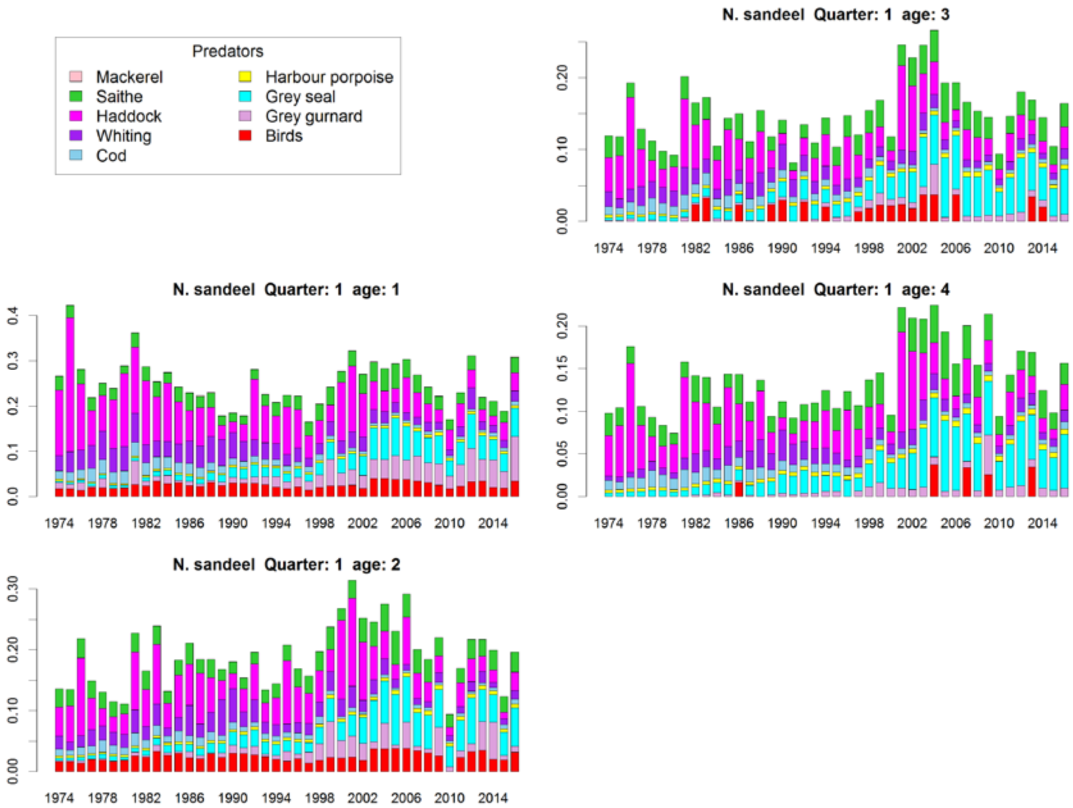
Predation mortality for Herring

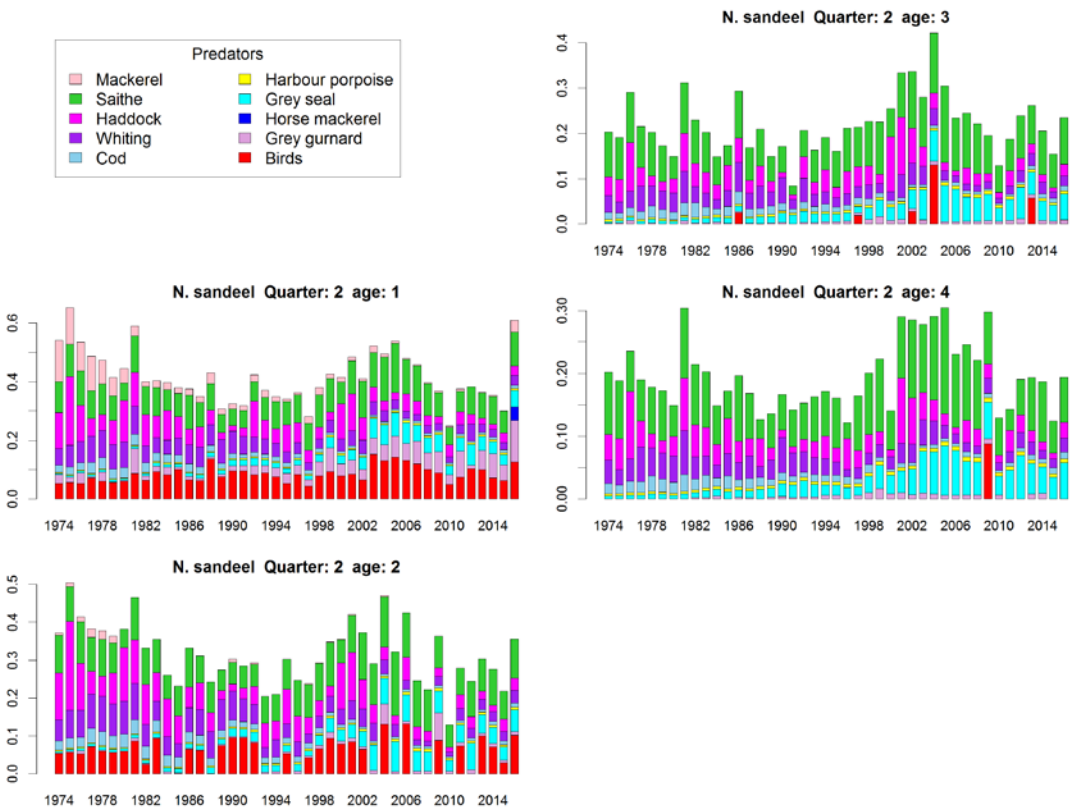


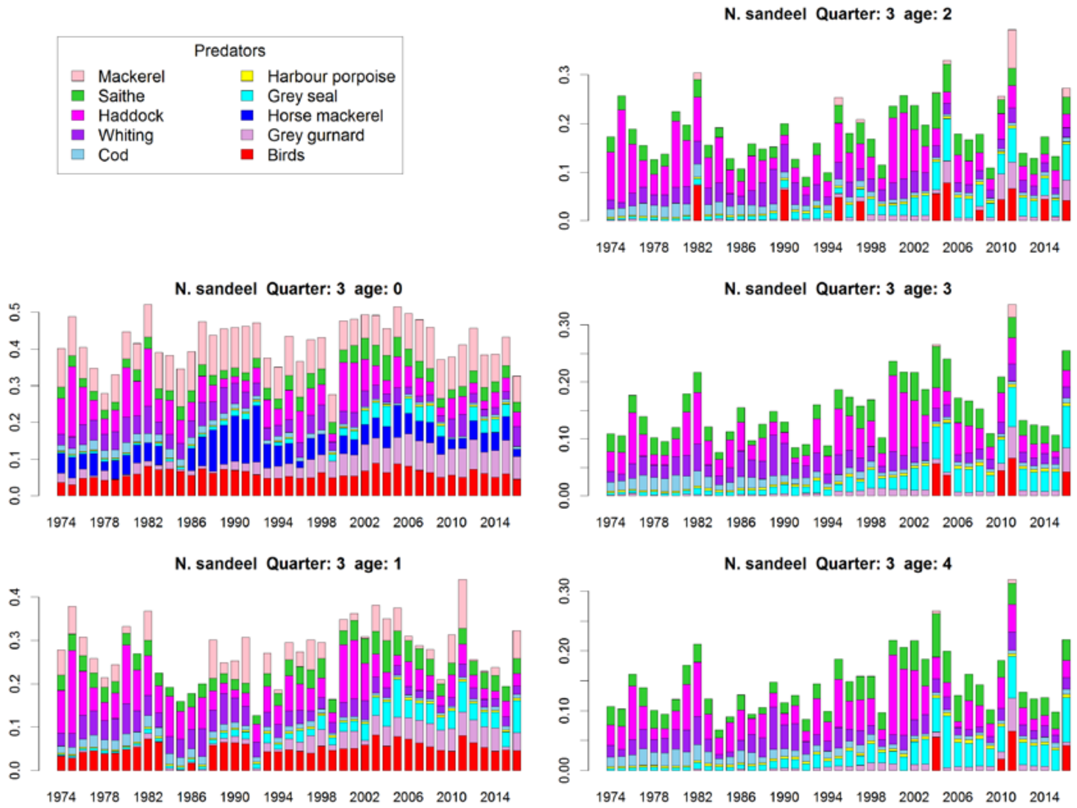

Predators
Mackerel
Saithe
Whiting
Cod
Hake
Harbour porpoise
Grey seal
Horse mackerel
Grey gurnard
Birds
Herring Quarter: 3 age: 0
Herring Quarter: 3 age: 1
Herring Quarter: 3 age: 2
Herring Quarter: 3 age: 3
Herring Quarter: 3 age: 4
1974 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014

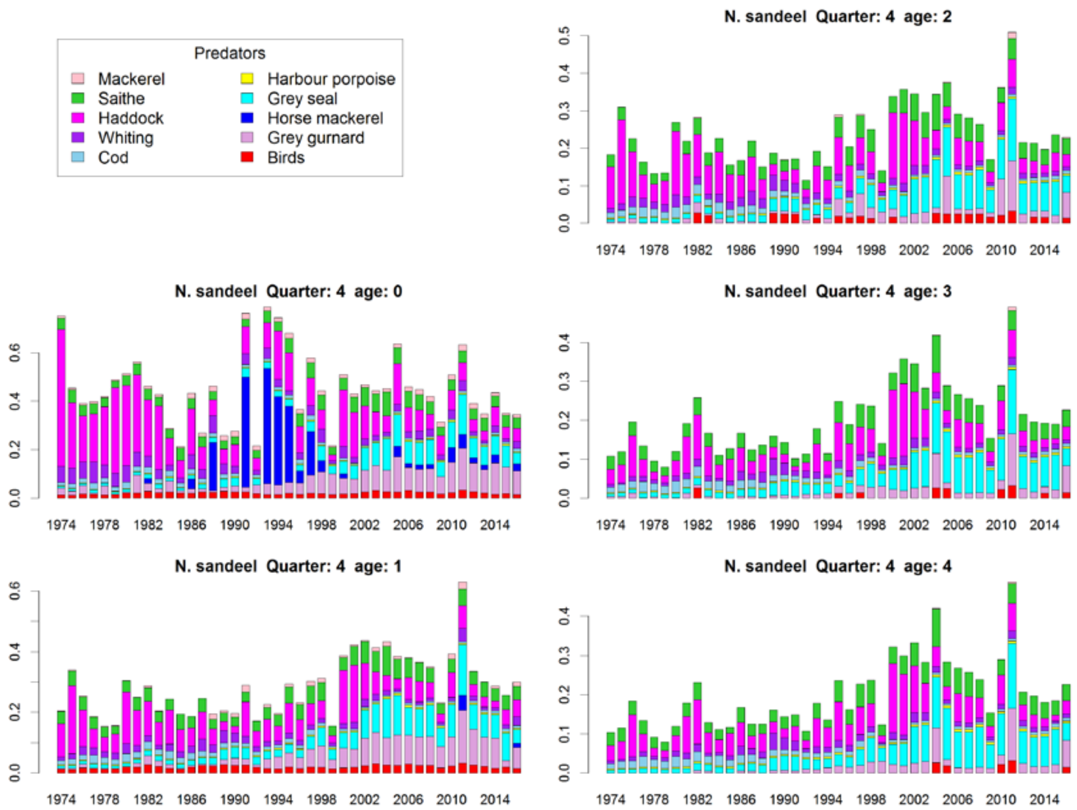

Predators
Mackerel
Saithe
Whiting
Cod
Hake
Harbour porpoise
Grey seal
Horse mackerel
Grey gurnard
Birds
Herring Quarter: 4 age: 0
Herring Quarter: 4 age: 1
Herring Quarter: 4 age: 2
Herring Quarter: 4 age: 3
Herring Quarter: 4 age: 4
1974 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014

Predation mortality for northern Sandeel

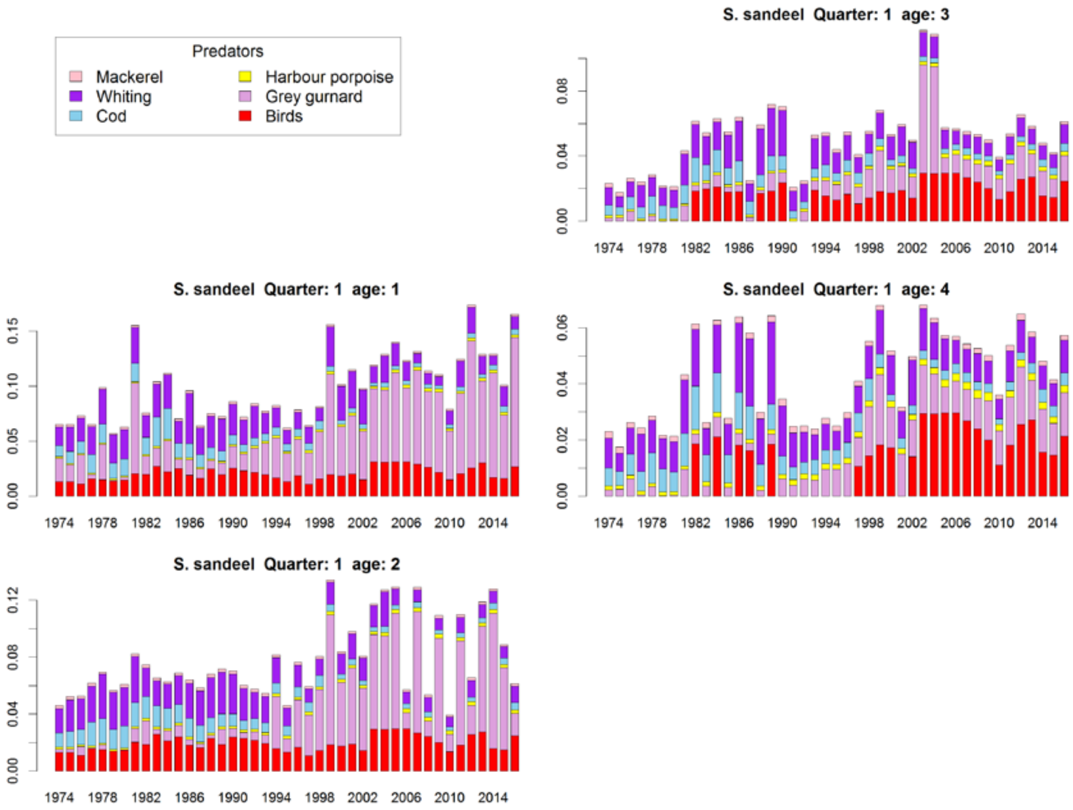


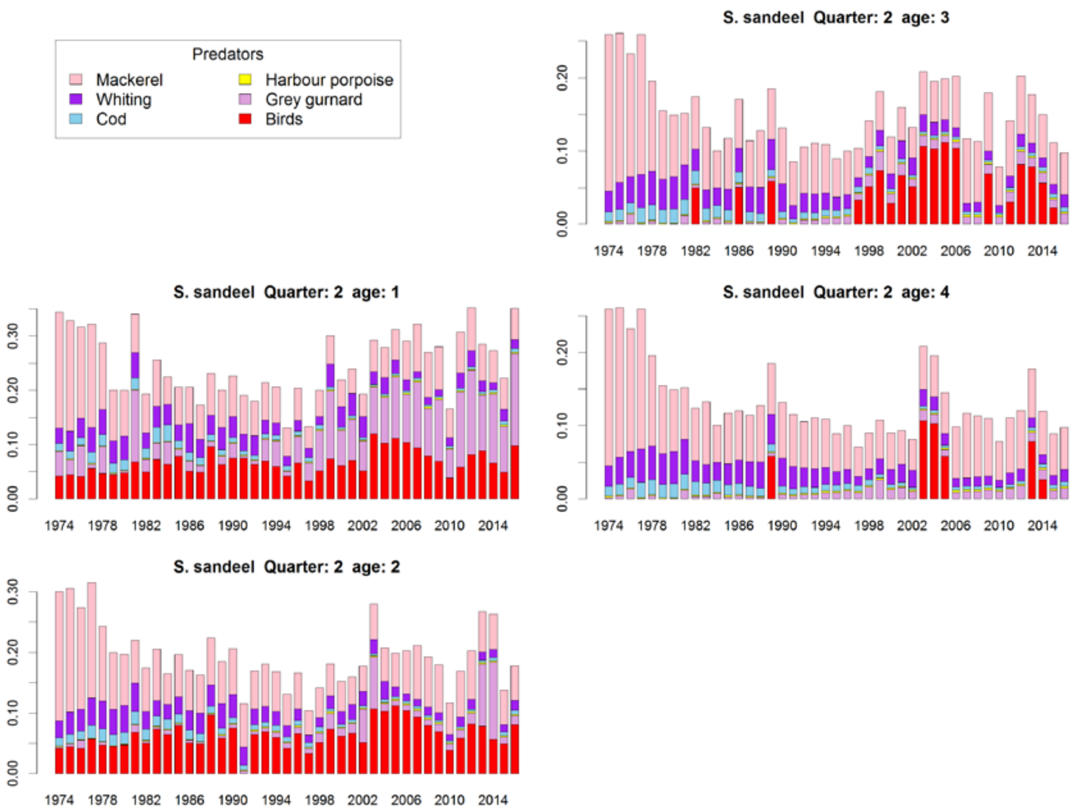


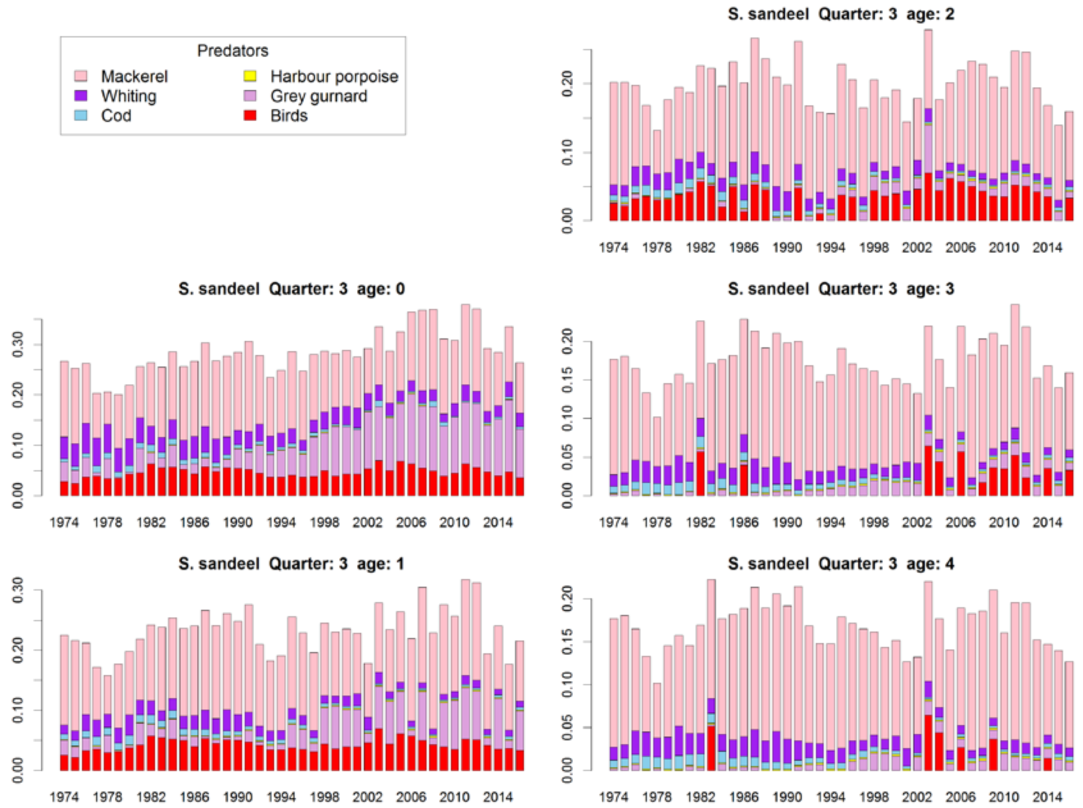

Predators
Mackerel
Saithe
Haddock
Whiting
Cod
Harbour porpoise
Grey seal
Horse mackerel
Grey gurnard
Birds
N. sandeel Quarter: 3 age: 2
N. sandeel Quarter: 3 age: 0
N. sandeel Quarter: 3 age: 3
N. sandeel Quarter: 3 age: 1
N. sandeel Quarter: 3 age: 4
1974 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014

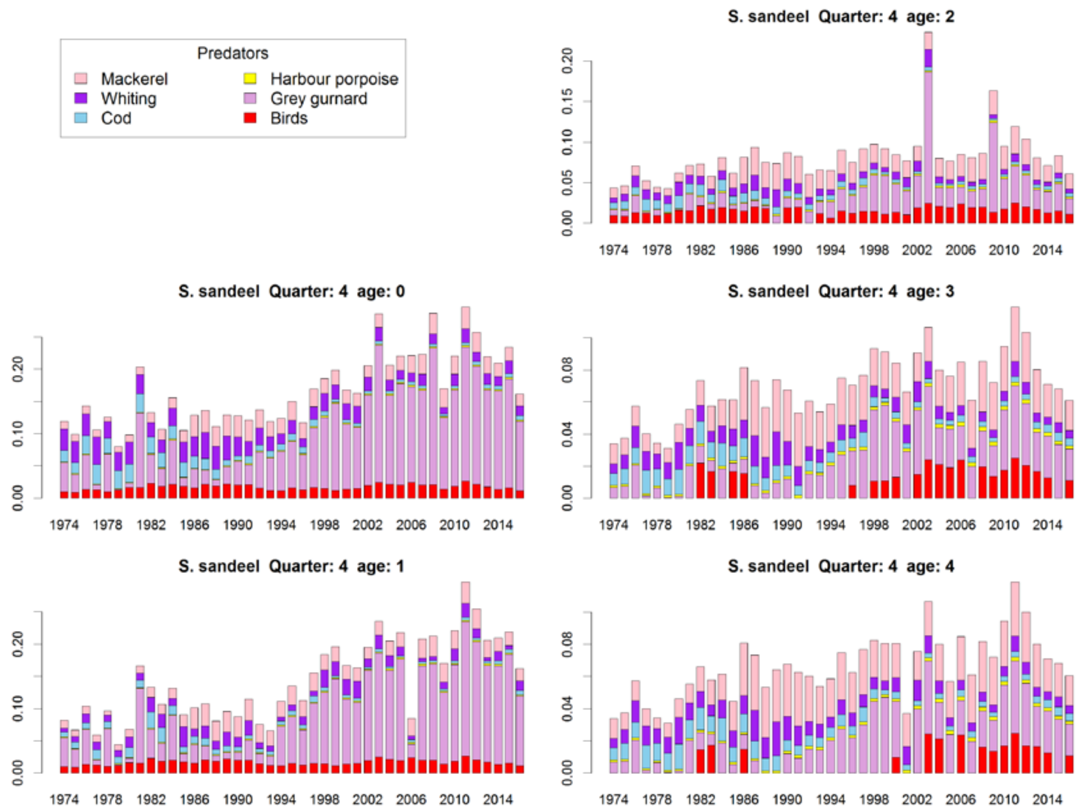

Predators
Mackerel
Saithe
Haddock
Whiting
Cod
Harbour porpoise
Grey seal
Horse mackerel
Grey gurnard
Birds
N. sandeel Quarter: 4 age: 2
N. sandeel Quarter: 4 age: 0
N. sandeel Quarter: 4 age: 3
N. sandeel Quarter: 4 age: 1
N. sandeel Quarter: 4 age: 4
1974 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014

Predation mortality for Southern Sandeel

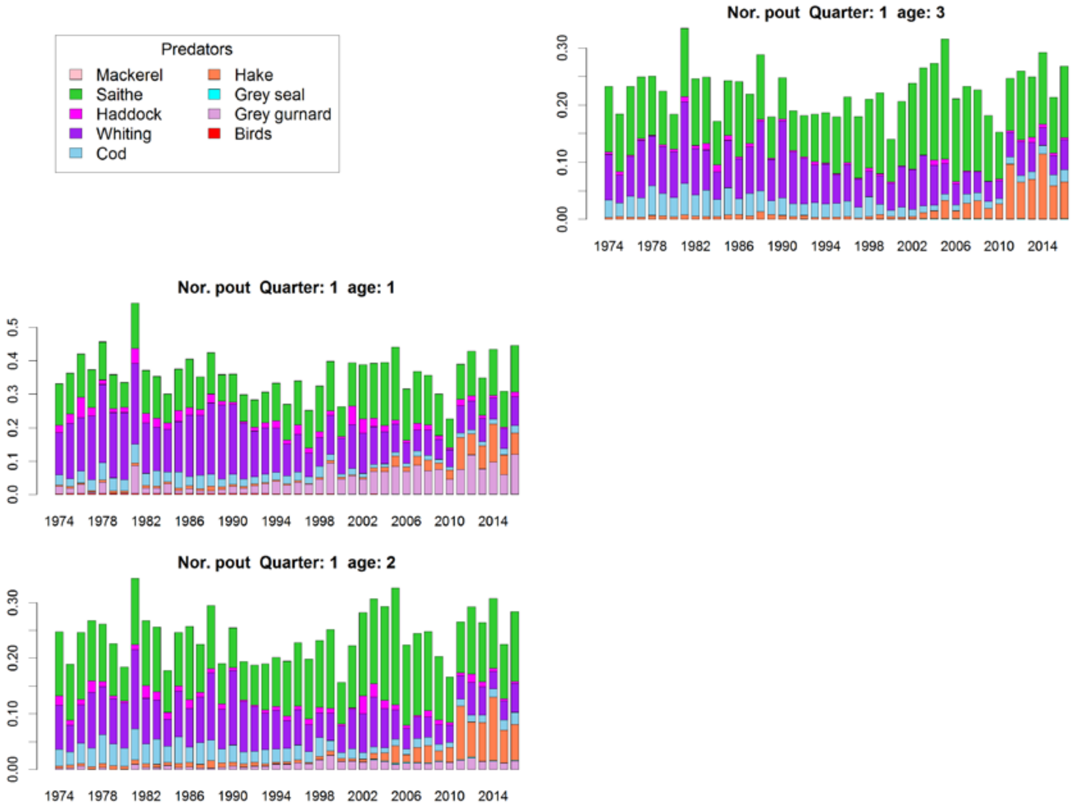


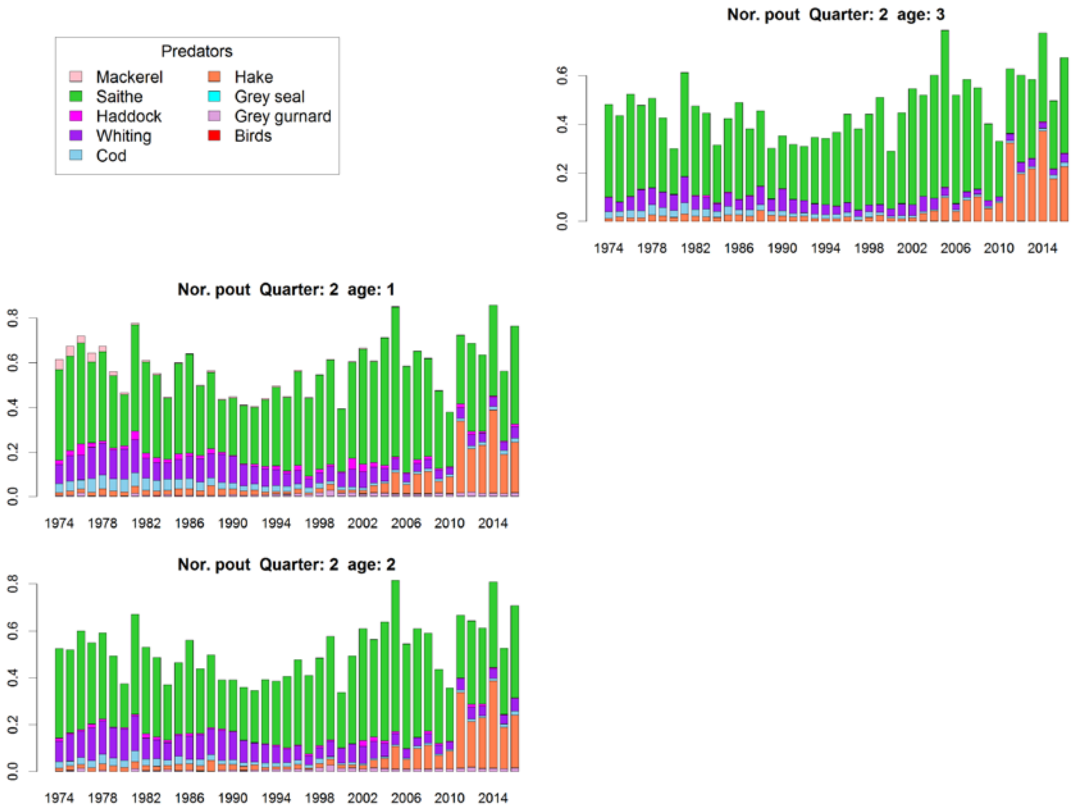


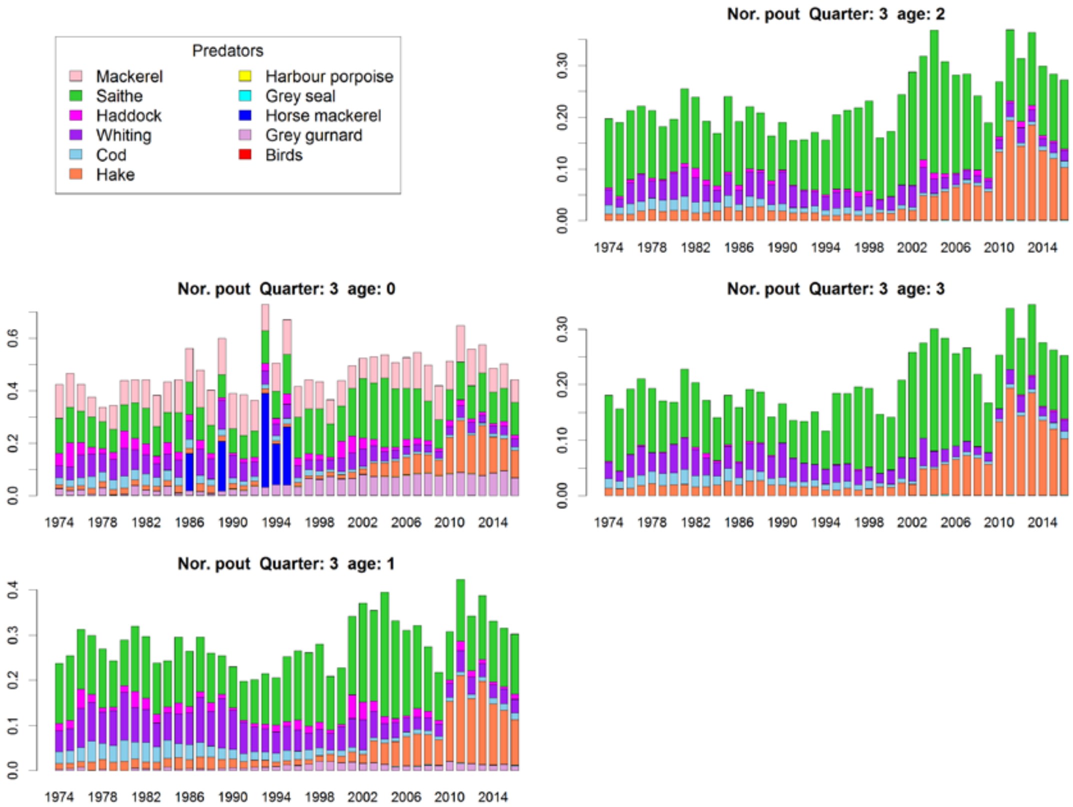

Predators
Mackerel
Whiting
Cod
Harbour porpoise
Grey gurnard
Birds
S. sandeel Quarter: 3 age: 2
S. sandeel Quarter: 3 age: 0
S. sandeel Quarter: 3 age: 3
S. sandeel Quarter: 3 age: 1
S. sandeel Quarter: 3 age: 4
1974 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014

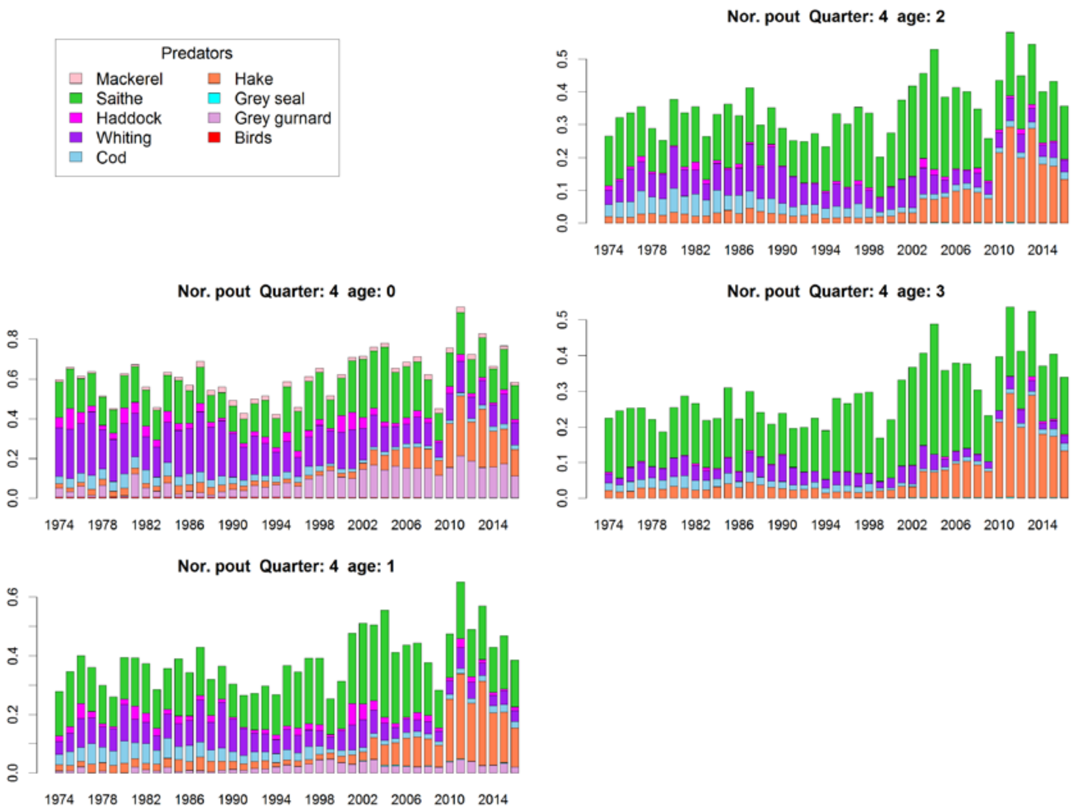

Predators
Mackerel
Whiting
Cod
Harbour porpoise
Grey gurnard
Birds
S. sandeel Quarter: 4 age: 2
S. sandeel Quarter: 4 age: 0
S. sandeel Quarter: 4 age: 3
S. sandeel Quarter: 4 age: 1
S. sandeel Quarter: 4 age: 4
1974 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014

Predation mortality for Norway pout

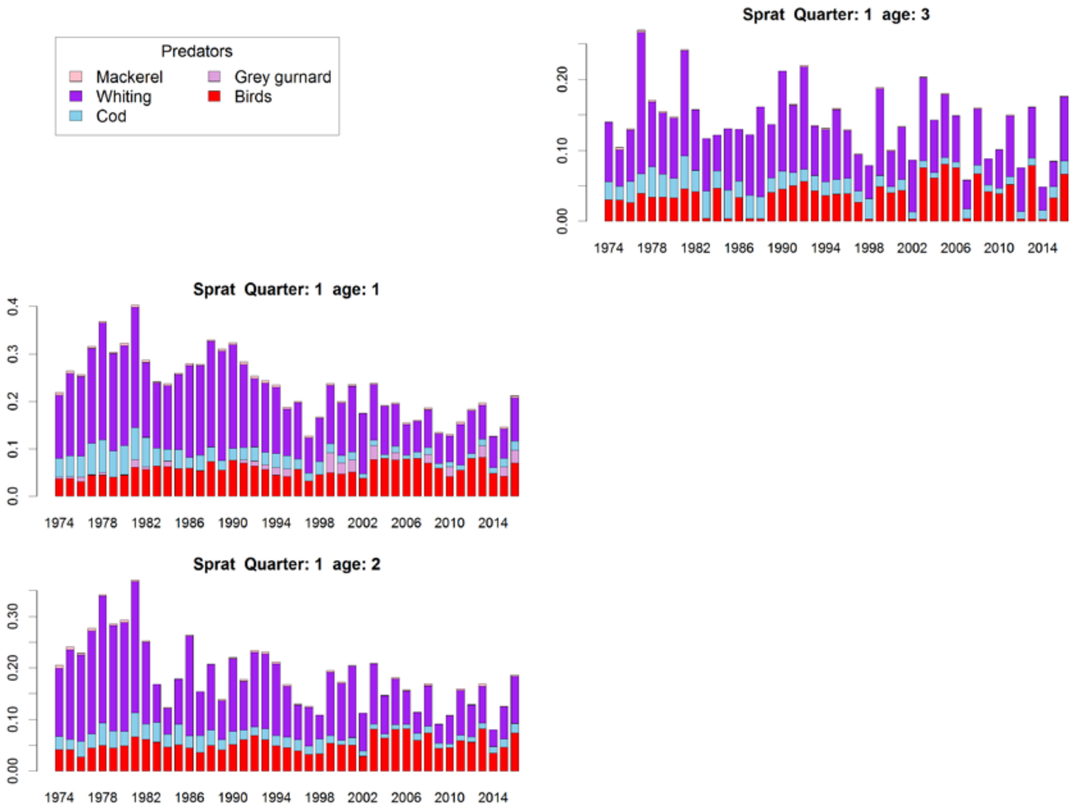


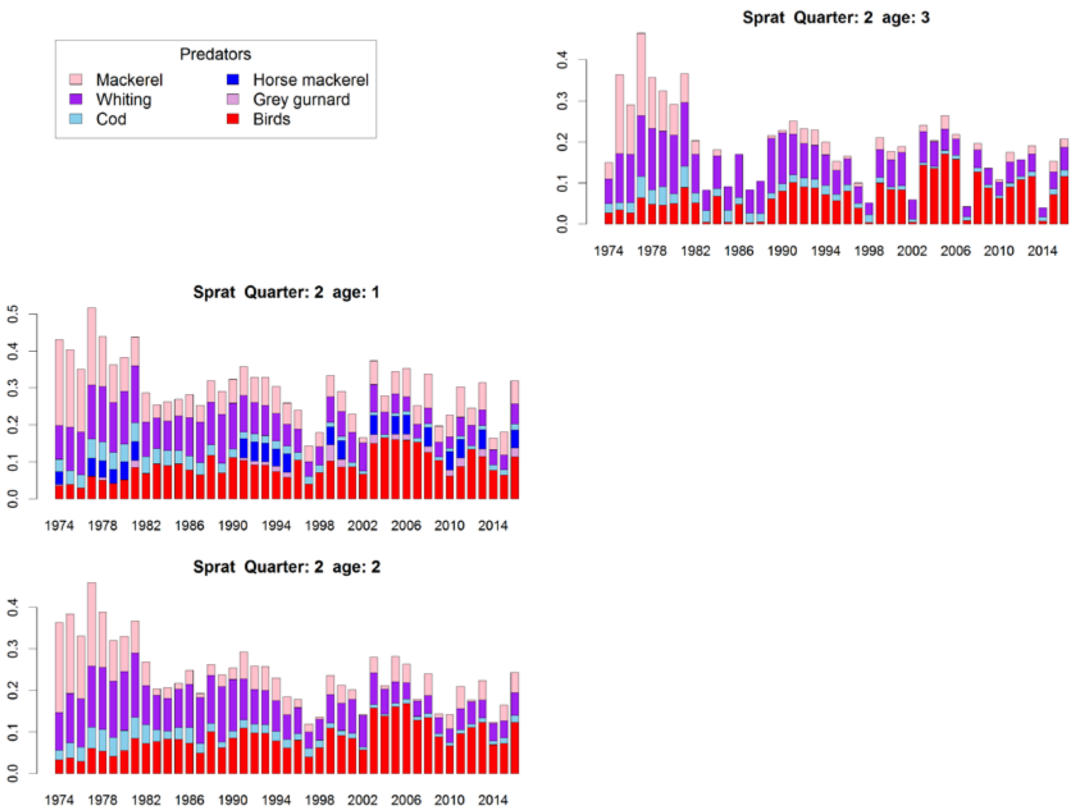


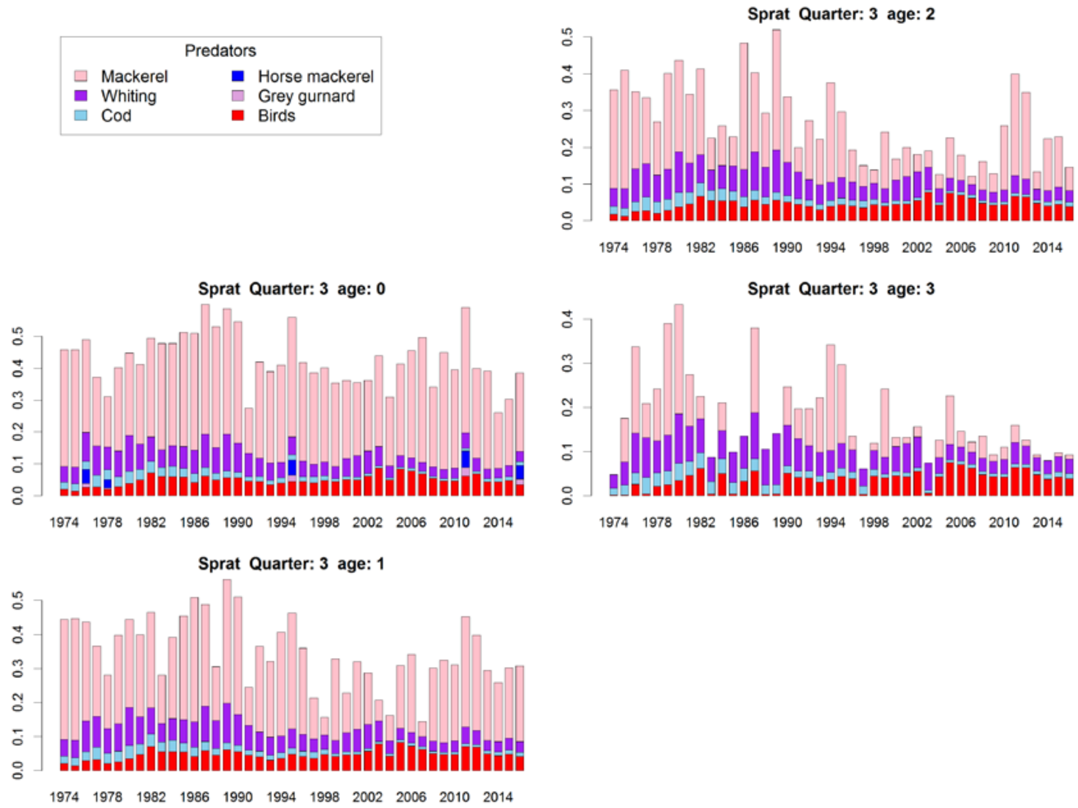

Predators
Mackerel
Saithe
Haddock
Whiting
Cod
Hake
Harbour porpoise
Grey seal
Horse mackerel
Grey gurnard
Birds
Nor. pout Quarter: 3 age: 2
Nor. pout Quarter: 3 age: 0
Nor. pout Quarter: 3 age: 3
Nor. pout Quarter: 3 age: 1

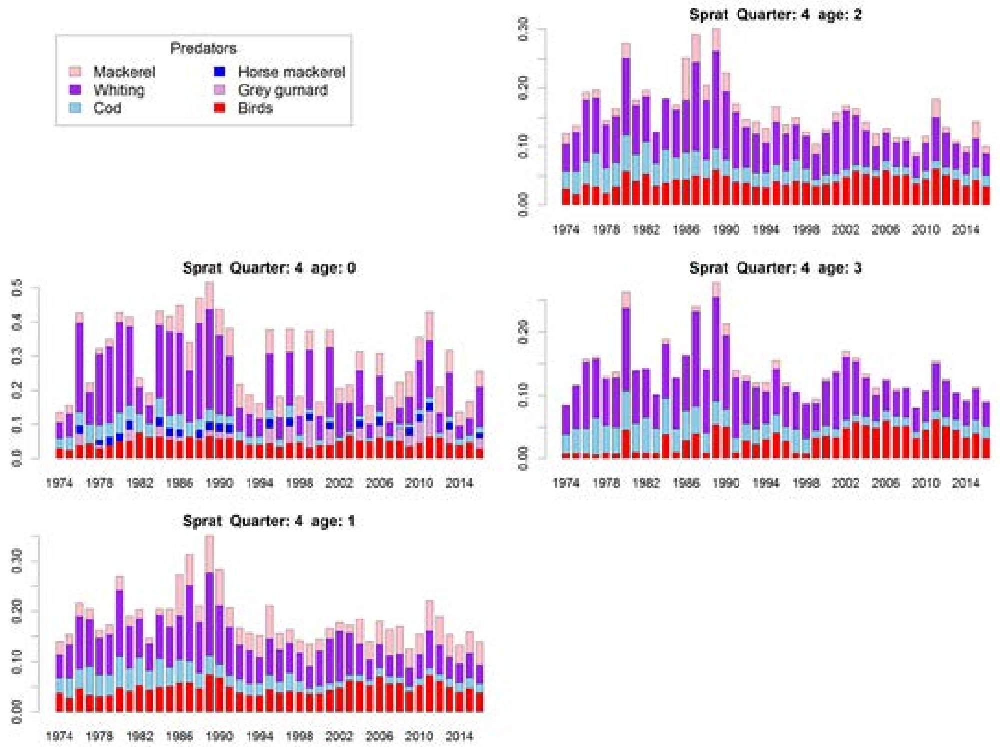

Predators
Mackerel
Saithe
Haddock
Whiting
Cod
Hake
Grey seal
Grey gurnard
Birds
Nor. pout Quarter: 4 age: 2
Nor. pout Quarter: 4 age: 0
Nor. pout Quarter: 4 age: 3
Nor. pout Quarter: 4 age: 1

Predation mortality for Sprat






Predators
Mackerel
Whiting
Cod
Horse mackerel
Grey gurnard
Birds
Sprat Quarter: 3 age: 2
Sprat Quarter: 3 age: 0
Sprat Quarter: 3 age: 3
Sprat Quarter: 3 age: 1
1974 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014


Predators
Mackerel
Whiting
Cod
Horse mackerel
Grey gurnard
Birds
Sprat Quarter: 4 age: 2
Sprat Quarter: 4 age: 0
Sprat Quarter: 4 age: 3
Sprat Quarter: 4 age: 1
1974 1978 1982 1986 1990 1994 1998 2002 2006 2010 2014