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Stock Annex: White anglerfish (*Lophius piscatorius*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)

Stock specific documentation of standard assessment procedures used by ICES

Stock	White anglerfish_mon.27.8c9a
Working Group	Working Group for the Bay of Biscay and Iberian Waters Ecoregion (WGBIE)
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A. General

A.1 Stock definition

The two species of anglerfish (the white, *Lophius piscatorius,* and the black, *L. budegassa*) are Northeastern Atlantic species; however black anglerfish has a more southerly distribution. White anglerfish is distributed from Norway (Barents Sea) to the Strait of Gibraltar (and including the Mediterranean and the Black Sea) and black anglerfish from the British Isles to Senegal (including the Mediterranean and the Black Sea). Anglerfish occur in a wide range of depths, from shallow waters to at least 1000 m. Information about spawning areas and seasonality is scarce, therefore the stock structure remains unclear. This lack of information is due to their particular spawning behaviour. Anglerfish eggs and larvae are rarely caught in scientific surveys.

ICES gives advice for the management of several anglerfish spp. stocks in European waters: one stock on the Northern Shelf area, that includes anglerfish from the Northern Shelf, Division 3.a, subareas 4 and 6, and the stocks on the Southern Shelf area, one in divisions 7.b–k and 8.a,b and d and the Southern stocks in divisions 8.c and 9.a. The stock under this Annex is called Southern White Anglerfish and is defined as white anglerfish in divisions 8.c and 9.a. The boundaries of anglerfish in divisions 7.b–k and 8.a,b and d and Southern Anglerfish stocks were established for management purposes and they are not based on biological or genetic evidences (GESSAN, 2002; Duarte *et al.*, 2004; Fariña *et al.*, 2004; Cañás, 2012).

Although the stock assessment is carried out separately for each species, white and black anglerfish are caught and landed together, due to that, the advice is given for individual and the combined species. There is a unique TAC for both species.

A.2 Fishery

Anglerfish in ICES divisions 8.c and 9.a is mainly exploited by Spanish and Portuguese vessels, since 2000 the Spanish landings being more than 81% for both anglerfish total reported landings. France have reported catches of this stock for the period 2002–2017, that represent an average of 2% of total landings. International catches for these two stocks have increased since the beginning of the 1980s, until a maximum was reached in 1988 (10 021 t). They have decreased to 1801 t–1900 t in 2001–2002. In the 2005–2011 period the catches were between 2179 t and 4757 t. Both species are caught on the same grounds by the same fleets and are marked together.

White and black anglerfish are caught together by Spanish and Portuguese bottom trawlers and gillnet fisheries. Spanish and Portuguese bottom trawlers are mixed fisheries. The Spanish bottom-trawl fleet predominantly targets hake, megrim, Norway lobster and anglerfish. Since 2003 the alternative use of a trawl gear with High Vertical Opening (HVO) has taken place in larger proportion relative to previous years. This gear targets horse mackerel and mackerel with very few anglerfish catches. Since 2003, the Spanish landings were on average 53% from the trawl fleet and 47% from the gillnet fishery. The Spanish gillnet fishery can use different artisanal gears, but most catches come from "Rasco" that is a specific gear targeting anglerfish.

Anglerfish are caught by Portuguese fleets in trawl and artisanal mixed fisheries. Portuguese landings were on average, from 2002, 11% from trawlers and 89% from artisanal fisheries. The trawl fleet has two components, the trawl fleet targeting demersal fish and trawl fleet targeting crustaceans. Since 2005, Portuguese combined species landings were TAC constrained and very low landings were registered during the 4th quarter since then.

Discarding in white anglerfish is considered low for the trawl fishery, based on estimated data for Spanish trawl fleet (ICES, 2011) and information from Portuguese trawl fleet (ICES, 2012a).

Each year, the European Union sets a combined TAC and quota for white and black anglerfish. There is no minimum landing size for anglerfish, but in order to ensure marketing standards a minimum landing weight of 500 g was fixed in 1996 by the Council Regulation (EC) No.2406/96.

As part of the Recovery Plan for the Southern hake and Iberian *Nephrops* stocks (Council Regulation (EC) No.2166/2005), in force since January of 2006, the fishing effort regulations are affecting the Spanish and Portuguese mixed trawl fisheries. As anglerfish are taken in these mixed trawl fisheries, these stocks are also affected by the recovery plan effort limitation.

A.3 Ecosystem aspects

White anglerfish is a benthic species that occur on muddy to gravelly bottoms. It attains a maximum size of around 175 cm corresponding to a weight of approximately 63 kg. Historically white anglerfish has been considered a slow growing species, with a late maturation (Duarte *et al.*, 2001). Nevertheless, new evidences from mark–recapture experiments indicate that the anglerfish growth could be faster (Landa *et al.*, 2008).

The ovarian structure of anglerfish differs from most other teleosts. It consists of very long ribbons of a gelatinous matrix, within individual mature eggs floating in separate chambers (Afonso-Dias and Hislop, 1996). The spawning of the *Lophius* species is very particular, with eggs extruded in a buoyant, gelatinous ribbon that may measure more than 10 m and contain more than a million eggs (Afonso-Dias and Hislop, 1996; Hislop *et al.*, 2001; Quincoces, 2002). Eggs and larvae drift with ocean currents and juveniles settle on the seabed when they reach a length of 5–12 cm. This particular spawning leads to highly clumped distributions of eggs and newly emerged larvae (Hislop *et al.*, 2001) and favourable or unfavourable ecosystem conditions can therefore have major impacts on recruitment.

Due to their particular reproduction aspects (that shows a high parental investment in the offspring) the population dynamics of these species is expected to be highly sensitive to external biological/ecosystem factors.

Vertical displacements of immature and mature white anglerfish from the seabed to the near surface have been recorded in the Northeast Atlantic (Hislop *et al*., 2001) and are suggested to be related to spawning or feeding.

Improvement of knowledge regarding growth, spawning behaviour, migratory behaviour and juvenile drift are essential to present and future assessment and management of both Southern Anglerfish stocks.

B. Data

B.1 Commercial catch

Landings data are provided by National Government and research institutions of Spain, Portugal and France. Quarterly landings by country, gear and ICES division are available from 1978. There were unrecorded landings in Division 8.c between 1978 and 1979, and it was not possible to obtain the total landings in those years. Portuguese landings were TAC constrained since 2005. Very low landings have been registered during the 4th quarters since then. The Portuguese landings were relatively stable during the first two years, but have decreased substantially from 2004 to 2010. In 2010 Portuguese landings were at its minimum value of the series. France landings are only available for the period 2002–2017.

The two species are not usually landed separately, for the majority of the commercial categories, and they are recorded together in the ports' statistics. Therefore, estimates of each species in Spanish landings from divisions 8.c and 9.a and Portuguese landings of Division 9.a are derived from their relative proportions in market samples.

For white anglerfish the maximum landing of the available series was recorded in 1986 at 6870 t. After that, a general decline to 788 t in 2001 was observed, reaching the minimum of the available series. From 2002–2005 landings increased reaching 3824 t. Since 2005 landings have slowly decreased to 1157 t in 2011.

Discards

Since 1994 a Spanish Discard Sampling Programme is being carried out for trawl fleets operating in the ICES divisions 8.c and 9.a. However, the time-series is not complete and years with discard data are 1994, 1997, 1999, 2000 and from 2003–2017. The raising procedure used to estimate discards was based on effort. A short time-series, 2013–2017, of discards estimates is available for the Spanish gillnet fleets. The Portuguese Discard Sampling Programme recorded anglerfish data from 2004. The frequency of occurrence of white anglerfish in discard samples is very low and its discard is considered negligible.

B.2 Biological

Landing numbers-at-length

Since 2009 the quarterly Spanish and Portuguese sampling for length compositions is by métier and ICES division. Length data from sampled vessels are summed and the resulting length composition is applied to the quarterly landings of the corresponding métier and ICES division. The sampled length compositions were raised for each country and SOP corrected to total landings on a quarterly or half yearly basis (when the sampling levels by quarter were low). The average lengths of trawl caught anglerfish are lower compared to the artisanal fleets.

Catch numbers-at-age

No catch numbers-at-age are provided to the Working Group. At the WGHMM 2007 meeting (ICES, 2007), age–length keys, based on *illicia* readings, were used to obtain catch number-at-age for each species. The exploratory analysis of estimates indicated that the biased age-reading criterion does not allow following cohorts along years in either of the two species. The last research about white anglerfish ageing, *White Anglerfish Illicia and Otoliths Exchange 2011* (ICES, 2012b), highlighted that neither *illicia* nor otolith age readings have been validated and, in the case of *illicia* studies, the agreement among readers and the precision were not acceptable. Therefore, it was concluded that the available age-reading criteria for white anglerfish southern stock is not valid to build an ALK.

Growth curve

The most recent study about white anglerfish growth in Atlantic integrates results for different growth researches (tag–recapture study, length–frequency of catches, and microstructure analysis of hard parts) (Landa *et al.*, 2008). A von Bertalanffy growth curve fitted to all data provided the parameter values L*inf* = 140 cm and K = 0.11. This growth rate is faster than estimated recently using *illicia* for age estimation.

Maturity-at-length

Different estimates of maturity ogive based on macroscopic maturity staging are available for white anglerfish (Duarte *et al*., 2001; Landa *et al*., 2012). In these studies the difficulty of finding mature females in the field resulted in samplings with low coverage of mature individuals. Besides, the inadequacy in same instances of the macroscopic examination to determine maturity stage, let it to consider a maturity ogive of white anglerfish from other areas. The available study was carried out in ICES divisions 8abd and determined microscopically the maturity stage (Quincoces, 2002). The parameters of maturity ogive are 50% maturity at 61.84 cm and a slope at 0.1001.

Natural mortality

No specific studies about natural mortality of white anglerfish were available. However, taking into consideration its growth rate and the high size that can attain, a constant annual instantaneous natural mortality rate (M) of 0.2 yr^{-1}, for all ages and years, is assumed.

Length-weight relationship

The weight–length relationship was calculated using data from an international project that spatially covered a large proportion of the stock and which a large number of samples and from samples collected through years 2002–2016 (Landa and Antolínez, 2017):

$$W = 2.5 \times 10^{-5} \cdot L^{2.853}$$

where W = weight in kilograms and L = length in centimetres.

B.3 Surveys

SpGFS-WIBTS-Q4

The Spanish Groundfish Survey aims to collect data on the distribution and relative abundance, and biological information of commercial fish in ICES divisions 8.c and Northern 9.a. Since 1983 it is annually carried out in the fourth quarter (September/October) of the years, except for 1987. Time-series of abundance indices, in weight and in number, and correspondent length composition are available for both anglerfish species. The full time-series of this survey is used in the assessment of white anglerfish since 2012.

SP-ARSA-Q1,4

The Southern Spanish Groundfish Survey on the Gulf of Cádiz (SP-ARSA) is conducted in the southern part of ICES Division 9a, the Gulf of Cádiz. The covered area extends from 15 m to 800 m depth, during spring and autumn. This survey was identified during the WKAngler DataEvaluation meeting as a potential abundance index for anglerfish in divisions 8c9a. The time-series data were requested to Spain. The series covers the period 1993–2017, two surveys by year, and the abundance index (in number and in weight) and their associated variance, and length compositions are available. The abundance values of *L. piscatorius* in this survey are very low, being zero in some cases. This survey index is not used in the assessment.

PtGFS-WIBTS-Q4

Portuguese Autumn Groundfish Survey has been carried out in Portuguese continental waters since 1979 in the fourth quarter of the years. Abundance indices for both anglerfish species are available from 1989–2011. The abundance values detected by this survey are very low for the whole time-series, being insignificant for some years.

This survey is not used in the assessment of white anglerfish.

B.4 Commercial cpue

Six commercial series of landing effort are available to the WG. Four of them are Spanish fleets in the ICES Division 8c and two Portuguese fleets in the ICES Division 9a. The Portuguese trawl fleet was split into fish trawlers and crustacean trawlers (WD12, Duarte *et al.*, 2007 in ICES, 2007) according to the fleet segmentation proposed by the IBERMIX project (WD06, Castro *et al.*, 2007 in ICES, 2007).

SP-CORTR8C

A Coruña trawl fleet fishing in Division 8c is available for years 1982–2012. Data provided for A Coruña trawlers comprise quarterly effort (fishing days per 100 horse power), landings and length composition of landings. This fleet represents an average of 15% of international catches of white anglerfishalong the time-series. A standardized series from 1994 to 2006 is also available for this fleet with annual effort data (in fishing days) and annual lpue.

Data from this commercial lpue series have been used in the white anglerfish assessment since 2007.

SP-CEDGNS8C

Cedeira gillnet fleet fishing in Division 8.c is available for years 1999–2011. Data provided for Cedeira gillnets comprise quarterly standardized effort (in soaking days), landings and length composition of landings. This fleet represents an average of 11% of international catches of white anglerfish since 1999. Due to the reduction in the number of vessels of Cedeira fleet, this tuning series could not be considered as a representative abundance index of the stock and since 2012 it is no longer recorded.

Data from this commercial lpue series have been used in the white anglerfish assessment since 2007.

Other available commercial series of lpues that have never been employed in the assessment are:

PT-TRF9A

Portuguese trawlers targeting fish: years 1989–2017. Data provided for Portuguese trawlers targeting fish comprise quarterly effort (1000 hours trawling with occurrence of anglerfish), landings and length composition of landings. This fleet represents an average of 1% of international catches of white anglerfish along the time-series. A standardized series from 1989 to 2008 is also available for this fleet with annual effort data (in 1000 hauls) and annual lpue.

PT-TRC9A

Portuguese trawlers targeting crustacean: years 1989–2017. Data provided for Portuguese trawlers targeting fish comprise quarterly effort (1000 hours trawling with occurrence of anglerfish), landings and length composition of landings. This fleet represents an average of 1% of international catches of white anglerfish along the time-series. A standardized series from 1989 to 2008 is also available for this fleet with annual effort data (in 1000 hauls) and annual lpue.

SP-AVITR8C

Avilés trawl fleet fishing in Division 8.c is available for years 1986–2003. Data provided for Avilés trawlers comprise quarterly effort (fishing days per 100 horse power), landings and length composition of landings. This fleet represents an average of 6% of international catches of white anglerfish along the time-series. The effortseries was interrupted in 2003.

SP-SANTR8C

Santander trawl fleet fishing in Division 8.c is available for years: years 1986–2010. Data provided for Santander trawlers comprise quarterly effort (fishing days per 100 horse power), landings and length composition of landings. This fleet represents an average of 7% of international catches of white anglerfish along the time-series. Effort data for 2008 were not provided to the WG.

C. Assessment: data and method

Until 2011 white anglerfish stock was assessed with a non-equilibrium production model (ASPIC software). Results from growth studies provide a growth pattern for this stock allowing the application of a length-based assessment model. Stock Synthesis (SS) was considered a suitable model to assess this stock by WKFLAT (ICES, 2012a). During the WKAngler 2018, some settings and input data of SS assessment model for white anglerfish were modified.

The assessment method:

Model

Model used: Stock Synthesis (SS) (Methot, 2000)

Software used: Stock Synthesis v3.30.10(Methot *et al.*, 2018)

Stock Synthesis is an integrated assessment model. SS has been used for stock assessment all around the world. The area of highest used is on the US Pacific Coast. SS is coded in C++ using Auto-Differentiation Model Builder (http://www.admb-project.org) and available at the NOAA Virtual Laboratory (https://vlab.ncep.noaa.gov/). SS has three main characteristics that differentiate it from classical assessment models:

- SS model structure allows for building of simple to complex models depending upon the data available. It is capable to build models with age and/or length structure and spatial structure.
- It is capable to use different sources of information.
- All parameters have a set of controls to allow prior constraints, time-varying flexibility, and linkages to environmental data.

The overall SS model is subdivided into 3 submodels. The first submodel simulates the population dynamics, where the basic abundance, mortality and growth functions create a synthetic representation of the true population. The second submodel is the observation submodel. This contains the processes and filters designed to derive expected values for the various types of data. The last submodel is the statistical that quantifies the magnitude of the difference between observed and expected data and employs an algorithm to find the set of parameters that maximizes the goodness-of-fit.

The SS model developed for white anglerfish during the WKAngler 2018 has been designed for a particular set of data and specifications. White anglerfish is harvested by four fleets, and two commercial lpue series and one fishery-independent survey provide information about relative abundance. No discard information is considered. Length composition data are available from both the fisheries and surveys. No age information is available for this stock.

Input data

Years: 1980–2017.

Model structure:

- Temporal unit: quarterly based data (landings, lpue and length–frequency) were used in SS calculations.
- Spatial structure: One area.
- Sex: Both sexes combined.

Fleet definition:

Four *fleets* were defined attending to the gear type and country:

- Spanish trawlers in ICES divisions8.c–9.a (SPTR8C9A)
- Spanish artisanal in ICES Division 8.c (SPART8C)
- Portuguese trawlers in ICES Division 9.a (PTTR9A)
- Portuguese artisanal in ICES Division 9.a (PTART9A)

Landed catches:

Quarterly landings entered the model as biomass (in weight) for the four fleets. Landings data for January 1980 to December 2017 were used to conduct the stock assessment of white anglerfish.

From 1980 to 1988 quarterly landings were estimated using the average proportion for the further five years (1989–1993) by fleet. In the case of SPART8C quarterly landings were estimated from 1980 to 1993 using the average proportion for the further five years (1994–1998).

Abundance indices:

- A Coruña trawlers (SPCORTR8C): Quarterly lpue in weight from 1982 to 2012. It is entered as four separate indices, one index per quarter.
- Cedeira gillnetters (SPCEDGN8C): Quarterly lpue in weight from 1999 to 2011. It is entered as four separate indices, one index per quarter.
- Spanish Groundfish Survey (SPGFS): Abundance index in numbers from 1983 to 2017, except for 1987.

Length composition of data:

The length bin was set by 2 cm, from 4 to 100 cm, by 10 cm from 100 to 160 cm and by 40 cm from 160 to 200 cm. Length composition for the four fishing fleets and the three abundance indices were used. The available length data and their disaggregated level differ among fleets:

Length composition of Fleets:

- SPTR8C9A: 1986–2017, quarterly basis. From 1986 to 1988 quarterly length proportions were estimated from an annual proportion using the Data Super-Period approach available in SS.
- SPART8C: 1986–2017, quarterly basis. From 1986 to 1994 quarterly length proportions were estimated from an annual proportion using the Data Super-Period approach available in SS.
- PTTR9A: 1986–2009, quarterly basis. From 1986 to 1988 quarterly length proportions were estimated from an annual proportion using the Data Super-Period approach presented in SS.
- PTART9A: 1986–2009, quarterly basis. From 1986 to 1988 quarterly length proportions were estimated from an annual proportion using the Data Super-Period approach present in SS.

Length composition of Abundance Indices:

- SPCORTR8C: 1982–2012, quarterly basis. Gaps are presented in years 1982, 1984, 1985 and 1986.
- SPCEDGN8C: 1999–2011, quarterly basis.
- SPGFS: length composition for fourth quarter, from 1983–2017. 1987 length composition is missing.

Model assumptions and parameters

- Natural mortality: M=0.2 for all ages and years.
- Growth: vonBertalanffy function: K=0.11 fixed, L_{max} and mean length-at-age 0.75 are estimated.
- Maturity ogive: length-based logistic, L_{50}=61.84 and slope=-0.1001, constant over time.
- Weight-at-length: a=2.5×10-5 b=2.853, not estimated.
- Recruitment allocation in Quarter 3.
- Stock–recruitment relationship: Beverton–Holt model: steepness h=0.999, sigmaR=0.4, R0 estimated.
- Selectivity: For all fleets selectivity was only length-based and was modelled as a double normal function. Selectivity for fishery PTART9A was set to be flattop. Selectivity varies among fleets, but is assumed to be time-invariant.

D. Short-term projection

Model used: Stock Synthesis.

Software used: *ad hoc* R code.

Initial stock size: SS outputs in the last assessment year.

Natural mortality: Set to 0.2 for all ages in all years.

Growth model: von Bertalanffy function, with parameters estimated in the assessment model.

Maturity-at-length: The same ogive as in the assessment is used for all years.

Weight-at-length in the stock and in the catch: The same length–weight relationship as in the assessment model.

Exploitation pattern: Average of the final three assessment years (with the possibility of scaling to final year F).

Intermediate year assumptions: *status quo* F.

Recruitment: geometric mean of estimated recruitment from 1980 until the final assessment year. If trends in recruitment become evident a shorter range of years could be selected.

E. Medium-term projections

No medium-term projections are conducted for white anglerfish stock.

F. Yield and biomass per recruit/long-term projections

Yield-per-recruit calculations are conducted using the same input values as those used for the short-term forecasts.

Model used: yield and biomass-per-recruit over a range of F values.

Software used: *ad hoc* R code.

G. Biological reference points

In the WKAngler 2018 (ICES, 2018) biological reference points were revised for this stock. The following table shows the estimates that were obtained:

	Type	**Value**	**Technical basis**
MSY approach	MSY Btrigger	6283 t	5th percentile of SSB when fishing at F_{MSY}
	F_{MSY}	0.24	F that maximises median equilibrium yield
	F_{MSY} ranges [Flower, Fupper]	0.16, 0.33	5% reduction in long-term yield compared with MSY
Precautionary approach	Blim	1993 t	Bloss (lowest observed SSB)
	Bpa	2769 t	Blim * exp(1.645 * σ), where σ = 0.2
	Flim	0.56	Segmented regression with Blim as breakpoint
	Fpa	0.40	Flim *exp (-σ*1.645), where σ=0.2

H. Other issues

H.1 Historical development of assessment

Southern Anglerfish stocks were assessed for the first time in the 1990 ICES WG meeting. Different assessment trials were performed during the subsequent eight years, but analytical assessments indicated unrealistic results. The database (both biological and fisheries data) was improved along these years trying to apply an analytical assessment model. Since 1998, a non-equilibrium surplus production model ASPIC (Prager, 1994) was applied to each stock or to the combined stock data. These stock assessments were accepted by the ACFM and used to provide management advice. The assessment of white anglerfish as a separate stock has been carried out continuously from 2007. The history of white anglerfish assessment from 2007 to 2018 is presented in Table 1.

Table 1. History of southern white anglerfish assessment from 2007–2018.

WG	2007	2008	2009	2010	2011		2012	2013
Assessment Model	Non-equilibrium Surplus production model (Prager, 2004)	No updated	Non-equilibrium Surplus production model (Prager, 2004)	Non-equilibrium Surplus production model (Prager, 2004)	Non-equilibrium Surplus production model (Prager, 2004)	Assessment Model Model Structure	Stock Synthesis 3 (Methot, 2000) Length-based Quarterly based data	Stock Synthesis 3 (Methot, 2000) Length-based Quarterly based data
Software	ASPIC (v. 5.16)	No updated	ASPIC (v. 5.16)	ASPIC (v. 5.34)	ASPIC (v. 5.34.9)	Software	SS3v23b	SS3v23b
Catch data range	1980–2006		1980–2008	1980–2009	1980–2010	Catch data range Fleets	1980–2010 SPTR8C9A SPART8C PTTR9A PTART9A	1980–2012 SPTR8C9A SPART8C PTTR9A PTART9A
Cpue Series 1 (years)	SP-CORUTR8c (1986–2006)		SP-CORUTR8c (1986–2008)	SP-CORUTR8c (1986–2009)	SP-CORUTR8c (1986–2010)	Abundance Index 1 (by quarter)	SPCORUTR8c (1982–2010)	SPCORUTR8c (1982–2012)
Index of Biomass (years)	SP-CEDGNS8c (1999–2006)		SP-CEDGNS8c (1999–2008)	SP-CEDGNS8c (1999–2009)	SP-CEDGNS8c (1999–2010)	Abundance Index 2 (by quarter)	SPCEDGN8C (1999–2010)	SPCEDGN8C (1999–2011)
Error Type	Condition on yield		Condition on yield	Condition on yield	Condition on yield	Abundance Index 3 (4rd quarter)	SPGFS (1983–2010)	SPGFS (1983–2012)

WG	2007	2008	2009	2010	2011		2012	2013
Number of bootstrap	500		500	1000	1000	Natural mortality	M=0.2 for all ages and years	M=0.2 for all ages and years
Maximum F	8.0 (y-1)		8.0 (y-1)	8.0 (y-1)	8.0 (y-1)	Growth	von Bertalanffy K=0.11 fixed Lmax estimated	von Bertalanffy K=0.11 fixed Lmax estimated
Statistical weight B1/K	1		1	1	1	Maturity ogive	length-based logistic L50=61.84 slope=-0.1001	length-based logistic L50=61.84 slope=-0.1001
Statistical weight for fisheries	1,1		1,1	1,1	1,1	Weight-at-length	a=2.70×10-5 b=2.839	a=2.70×10-5 b=2.839
B1-ratio (starting guess)	0.5		0.5	0.5	0.5	Recruitment allocation	Quarter 3	Quarter 3
MSY (starting guess)	5000 t		5000 t	5000 t	5000 t	Stock–Recruitment	Beverton–Holt model h=0.999 sigmaR=0.4 R0 estimated	Beverton–Holt model h=0.999 sigmaR=0.4 R0 estimated
K (starting guess)	50 000 t		50 000 t	50 000 t	50 000 t	Selectivity	All fleets: length-based double normal function Varies among fleets Time-invariant	All fleets: length-based double normal function Varies among fleets Time-invariant
q1 (starting guess)	1d-5		1d-5	1d-5	1d-5			
q2 (starting guess)	1d-6		1d-6	1d-6	1d-6			

WG	2007	2008	2009	2010	2011		2012	2013
Estimated parameter	All		All	All	All			
Min and Max allowable MSY	2000 (t)–10 000 (t)		2000 (t)–10 000 (t)	2000 (t)–11 500 (t)	2000 (t)–11 500 (t)			
Min and Max K	5000 (t)–500 000 (t)		5000 (t)–100 000 (t)	5000 (t)–112 000 (t)	5000 (t)–112 000 (t)			
Random Number Seed	1 964 185		1 964 185	1 964 185	1 964 185			

WG	2014	2015	2016	2018 (WGBIE)
Assessment Model Model Structure	Stock Synthesis 3 (Methot, 2000) Length-based Quarterly based data	Stock Synthesis 3 (Methot, 2000) Length-based Quarterly based data	Stock Synthesis 3 (Methot, 2000) Length-based Quarterly based data	Stock Synthesis (Methot, 2018) Length-based Quarterly based data
Software	SS3v23b	SS3v23b	SS3v23b	SS v30.10
Catch data range Fleets	1980–2013 SPTR8C9A SPART8C PTTR9A PTART9A	1980–2014 SPTR8C9A SPART8C PTTR9A PTART9A	1980–2015 SPTR8C9A SPART8C PTTR9A PTART9A	1980–2017 SPTR8C9A SPART8C PTTR9A PTART9A
Abundance Index 1 (by quarter)	SPCORUTR8c (1982–2012)	SPCORUTR8c (1982–2012)	SPCORUTR8c (1982–2012)	SPCORUTR8c (1982–2012)

WG	2007 2008 2009	2010 2011		2012 2013
Abundance Index 2 (by quarter)	SPCEDGN8C (1999–2011)	SPCEDGN8C (1999–2011)	SPCEDGN8C (1999–2011)	SPCEDGN8C (1999–2011)
Abundance Index 3 (4rd quarter)	SPGFS (1983–2013)	SPGFS (1983–2014)	SPGFS (1983–2015)	SPGFS (1983–2017)
Natural mortality	M=0.2 for all ages and years	M=0.2 for all ages and years	M=0.2 for all ages and years	M=0.2 for all ages and years
Growth	von Bertalanffy K=0.11 fixed Lmax estimated	von Bertalanffy K=0.11 fixed Lmax estimated	von Bertalanffy K=0.11 fixed Lmax estimated	von Bertalanffy K=0.11 fixed Lmax estimated
Maturity ogive	length-based logistic L50=61.84 slope=-0.1001	length-based logistic L50=61.84 slope=-0.1001	length-based logistic L50=61.84 slope=-0.1001	length-based logistic L50=61.84 slope=-0.1001
Weight-at-length	a=2.70×10-5 b=2.839	a=2.70×10-5 b=2.839	a=2.70×10-5 b=2.839	a=2.50×10-5 b=2.853
Recruitment allocation	Quarter 3	Quarter 3	Quarter 3	Quarter 3
Stock–recruitment	Beverton–Holt model h=0.999 sigmaR=0.4 R0 estimated	Beverton–Holt model h=0.999 sigmaR=0.4 R0 estimated	Beverton–Holt model h=0.999 sigmaR=0.4 R0 estimated	Beverton–Holt model h=0.999 sigmaR=0.4 R0 estimated
Selectivity	All fleets: length-based double normal function Varies among fleets Time-invariant	All fleets: length-based double normal function Varies among fleets Time-invariant	All fleets: length-based double normal function Varies among fleets Time-invariant	All fleets: length-based double normal function PTART9A flat top Varies among fleets Time-invariant

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