Working Document: Preliminary diagnosis in Northeast Atlantic Cephalopod Stock using Stochastic Surplus Production models

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Abstract

The lack of management leaves fishery resources vulnerable to increases in fishing pressure. In spite of their economic importance, most Northeast Atlantic cephalopod stocks are non-quota species with no catch or effort limits in large-scale fisheries and only some harvest control rules implemented at the local scale in inshore fisheries. Specific life traits and population dynamics in cephalopods are often argued to prevent the use of classical stock assessments methods i.e. cephalopods are short-lived, fast growing species, with highly plastic life history characteristics and wide year to year variation in abundance linked to environmental variation. Monitoring such species is also data-demanding and some of the largest EU cephalopod fisheries are not included in fishery data collection protocols. Over the past two decades, several stock assessment exercises were carried out in European cephalopods but the wide variety of models that were tested to tackle distinctive features of different species makes it difficult to compare results.

Surplus production models are among the oldest assessment tools adapted to data-limited situations. In their basic form, the maximum sustainable yield reference points that they provide (MSY, FMSY, BMSY) correspond to the long term average, which may not be very well adapted to cephalopods. Nevertheless, such preliminary diagnostics can be refined in a second step (for instance taking into account environmental variation).

In the present study, Generalised Surplus Production Models were fitted to abundance time series for several Northeast Atlantic cephalopod stocks, including loliginid and ommastrephid squid and cuttlefish, the distributions of which range from Scottish to Spanish and Portuguese fishing grounds. All models were fitted with the R package SPiCT (Stochastic production model in continuous-time) and the homogeneous protocol allowed comparisons between data sets. In

the nine cases presented, the model converged and the exercise provided useful preliminary diagnostics, allowing long-term trends in productivity to be considered reasonable in eight of them (only the exercise for *Loligo* at Rockall exercise showed unreliable outputs). For several loliginid stocks, results allowed statements to be made about whether biomass and fishing effort were above or below MSY reference values. However, results for Sepiidae and, especially, Ommastrephidae showed very wide confidence intervals, such that it was generally not possible to be sure whether biomass and fishing effort were above or below reference levels. The possible causes for this uncertainty will have to be explored.

The study is a first step to better understand how fishing fleets opportunistically exploit these resources and what aspects of their population dynamics are important to take into account to ensure sustainable fishing. Several refinements to the approach taken are proposed for future work.

Key-words: *Data-limited methods, Pella-Tomlinson model, SPiCT, biological reference points, cephalopods population dynamics, stock assessment.*

I Introduction

Cephalopods are major resource for European fishing fleets with ~ 50 000 t tonnes landed per year (56 500 t on average in 2014-2018). Such commercially exploited stocks lack scientific advice whereas their abundance, productivity and sustainability remained undetermined or highly uncertain regarding the input of solely rare local measures. The need to better understand their stocks dynamics, particularly in North-eastern Atlantic waters, will allow their consideration in Fisheries Policy.

Different assessment tools have been proposed to determine the status of several EU cephalopod stocks during the past two decades. Depletion methods, cohort analysis and a two-stage biomass model were successfully applied to a range of stocks. However, while cohort analysis suggested that growth overfishing (and F_{opt}) might depend on cohort abundance, the two other methods do not include the estimation of Biological Reference Points (BRP) and thus were only used to quantify recruitment variability (Royer et al, 2002; Young et al, 2004; Royer et al, 2006; Gras et al, 2014).

Cephalopods, specifically cuttlefish, loliginid and ommastrephid squids and octopods fall under ICES category 3, which comprises stocks for which relative abundance indices exist, e.g. survey indices or fishery-dependent LPUEs and CPUEs, along with information on the mean length of animals in the catch), that can provide reliable indications of abundance trends. For a variety of reasons, quantitative assessments and forecasts for category 3 stocks are often considered to indicate only trends in fishing mortality, recruitment and biomass (ICES 2012a, b).

Since European fishing fleets are increasingly exploiting cephalopod resources, sustainable exploitation of these stocks is more and more desirable and thus diagnostics of stock status are needed. Instead of testing various tools in different cases the approach agreed was to apply a common assessment method to a series of data sets.

In the present study, we used data for loliginid squid, ommastrephid squid and cuttlefish. The Octopodidae are also important fishery resources. Among the Octopodidae species present in European shelf waters, although *Eledone* spp. are of minor commercial importance, *Octopus vulgaris* is of substantial importance in Spanish and Portuguese fisheries, especially small-scale fisheries. In the Gulf of Cadiz, the influence of environmental variables on the population dynamics of *Octopus vulgaris* has been modelled (Sobrino et al 2020, see also previous WGCEPG reports). We aim to include octopus in the next round of assessment exercises.

Following the recommendations of ICES WKProxy (ICES, 2016) and WKLIFE (ICES, 2012b, 2017), the objective of this work was to apply a Stochastic Surplus Production Model in Continuous Time (SPiCT) (Pedersen & Berg, 2017) to provide a preliminary assessment for a range of cephalopods stocks in the Northeast Atlantic, thus to obtain comparable results and provide a basis for further analysis (ICES, 2016), with the ultimate aim of facilitating routine stock assessment in support of management. In contrast to other production models, SPiCT models both stock dynamics and the dynamics of the fisheries, thus enabling error in the catch process to be reflected in the uncertainty of estimated model parameters and reference points (Pedersen & Berg, 2017).

II Material & Methods

In each of the assessed stocks surplus production models require minimally total catch data and an abundance index (which can be obtained from research surveys or derived from commercial data).

1.1. Stock definition

Reflecting the fact that European cephalopod stocks are not formally assessed there is no current formal definition of stocks. Previous genetic studies have tended to confirm what might be expected based on the mobility of these species: there is less evidence of the existence of separate stocks in those species which routinely undertake longer migrations (Trites, 1983; Sims et al, 2001; Wolfram et al, 2006). Thus we would expect fewest distinct stocks in ommastrephids, followed by loliginids, cuttlefish and octopus. Previous studies on *Loligo forbesii* indicate a single genetic stock throughout European coastal waters, with some evidence of differences in offshore areas (Rockall, Faroe) and only one clearly differentiated stock, in the Azores (Brierley et al. 1995; Shaw et al. 1999). However, the situation is complicated by the presence of multiple species within commercial fishery categories and often also within survey data categories. Thus, the two *Loligo* species are rarely distinguished from each other. Therefore, decisions about stock definition for the purposes of assessment are necessarily pragmatic. The management units (i.e. pragmatic stocks) that are selected in this study are based on groups of ICES divisions that ICES WGCEPH has used since 1992 to monitor trends in Northeast Atlantic Cephalopod fisheries.

1.2. Landings data

Total landings by country and ICES divisions are compiled by calendar year (January-December) by ICES WGCEPH. In recent years this is derived from the ICES data call (see Table 1). Non-reported values were considered as missing (NA) and limited gaps can be taken into account in the fitting procedure. Discards data suggest that discarding occurs only in areas where cephalopod catch is low (ICES, 2019). For example, onboard observations provided by the Ifremer program "OBSMER" and to France's and UK's declarations, there is a low squid discard level in the English Channel, always below 6% (ICES, 2011; 2017). Thus, in this study, discards are considered to be negligible.

Table 1: Cephalopods stocks used for SPiCT assessments in Northeast Atlantic Waters.

ToR A table is the compilation of annual landings statistics carried out by WGCEPH. (in two stocks landings figures preceeded by "<" are overestimates computed for the whole 9.a division). Survey acronyms are as follows: Marine Scotland Science (MSS), Scottish West Coast International Bottom Trawl Survey (SWC-IBTS), Scottish Groundfish Survey (SCOGFS), Irish Groundfish Survey (IGFS), EValuation des ressources Halieutiques de l'Ouest Européen (EVHOE), North West Groundfish Survey (NWGFS), Channel Groundfish Survey (CGFS), Spanish Ground Fish Survey on the Gulf of Cádiz (SP-ARSA), Portuguese International Bottom Trawl Survey (PT-IBTS). Abundance indices derived from commercial fishery statistics: France Otter Bottom Trawl delta-GLM standardized LPUE (FR-OTB std.LPUE), Spain Otter Bottom Trawl LPUE (SP-OTB-LPUE) Landings figures for each group are Average Annual landings (tons) and this figures expressed as a percentage of the total Northeast Atlantic landings. See Appendix A for further details of survey indices.

Group	AREA	Figure	Landings	Data sources and time periods	
				Origin of catch data	Origin of survey abundance indices
Loliginidae	6.a; 7.b,c	1	532 (6%)	ToRA table (1992-2018)	2 MSS (1981 -2012), SWCIBTS + SCOGFS (1997-2018), IGFS (2003 -2018)
	6.b	2	315 (3%)	ToRA table (1992-2018)	MSS (1981 - 2018)
	7.a; 7.f; 7.g,h,j,k	3	996 (10%)	ToRA table (1992-2018)	EVHOE (1997-2018), NWGFS (1988-2018)
	7.d,e	4	3,577 (36%)	ToRA table (1992-2018)	FR-OTB std.LPUE (1989-2018), CGFS (1990-2017)
	8 a,b,d	5	1,856 (19%)	ToRA table (1997-2016)	EVHOE (1992-2016)
	9.a.s	6	<962 (10%)	PT + ES landings (1993-2018)	SP-ARSA (March) + PT-IBTS (Nov.) (1993-2018)
Sepiidae	7.d,e	7	10,495 (57%)	ToRA table (2001-2018)	FR-OTB LPUE (2001-2018)
	8. abd	8	4,695 (19%)	ToRA table (2000-2018)	FR-OTB LPUE (2000-2018)
Ommastre-phidae	8.c; 9.a n	9	<1,073* (31%)	ES landings (2000-2018)	SP-IBTS + SP-OTB-LPUE (2000-2018)

1.3. Abundance indices from surveys

Research trawl surveys are seldom designed specifically to describe cephalopod abundance and the seasonal timing or spatial extent may not always correspond to the species life cycle. Nevertheless, rigorous protocols and species identification make time series of survey indices a major source of time series of abundance indices. All surveys used in the assessments are listed in table 1 (with more details in Appendix A).

1.4. Commercial catch-effort data: standardised landings per unit effort (lpue)

When fishery-independent data is not available commercial catch and effort data can be used to derive abundance indices provided biases related to changes in the fishery are properly taken into account. The standardization procedure is based on the Delta-GLM method (Stefansson, 1996; Gras et al., 2014). This approach is designed to extract the temporal component of the LPUE data while disentangling it from other effects such as changes in the spatial distribution of the fleet or distribution of the animals, changes in the size of the boats, changes in the seasonality of the abundance, giving the best image of inter-annual variation in the whole area.

French commercial landings and effort data were extracted from national databases maintained by the French ministry for fisheries (Direction des Pêches Maritimes et de l'Aquaculture (DPMA)) and Ifremer (Système d'Information Halieutique (SIH)). Commercial squid and cuttlefish landings (kg) and effort (hours of trawling) for French bottom otter trawls (OTB) were collected by fishing sequence (i.e. groups of hauls carried out during the same day and within the same ICES rectangle), year, months, ICES statistical rectangle and engine power class.

In the case of Loliginidae, species are not distinguished in French commercial data. Therefore, the standardized times series describe the abundance of the mix of *Loligo forbesii* and *Loligo vulgaris* in the English Channel (7.d and 7.e).

In the cuttlefish *Sepia officinalis*, the same initial database was used (French OTB detailed catch and effort data) but engine power ship class was missing, so LPUE values are averaged by year (in a shorter period: 2001-2018), accounting for effects of the previously mentioned variables except for power. The assessments based on these "lpue-derived indices" are listed in table 1.

It is worth noting that in spite of the heterogeneous distribution of fishing activities (both in time and space) commercial data is abundant and corresponds to a wider temporal extent than survey data. Besides, cephalopods being no-quota species are less susceptible to misreporting than managed resources. Detailed fishery statistics needed for the standardization procedure are now included in the WGCEPH data call and in the English Channel UK beam trawl data has already been used to model cuttlefish abundance (Gras et al, 2014).

1.5. Model

The population dynamics is described in terms of biomass and the model combines the main biological processes (recruitment, growth, natural mortality) in a single function. Only catches and abundance/biomass indices are required to fit the model. The approach is based on the deterministic state equation of the Pella-Tomlinson model (Pella and Tomlinson, 1969):

$$\frac{dB_t}{dt} = rB_t\left(1 - \left[\frac{B_t}{K}\right]^{n-1}\right) - F_tB_t,$$

Where *r* is the intrinsic growth rate parameter, *k* the carrying capacity and *n* the asymmetry parameter of the production curve. This latter parameter allows the surplus production function to be asymmetric with respect to the biomass and determines the maximum level of productivity.

SPiCT (R package, version 1.2.7) was used to fit a stochastic surplus production model in continuous time to abundance index series for several cephalopods stocks occurring in Northeastern Atlantic waters. The model incorporates both fisheries and biomass dynamics and also observation errors for both catches and biomass indices (Pedersen and Berg, 2017). The package, available on GitHub (https://github.com/DTUAqua/spict), is still under development.

For each stock, the input data applied in SPiCT runs are listed in Table 1.

Default priors were used as follows: *n* around 2; α=β=1. An attempt to impose preliminary estimated priors was carried out for the stock of *Loligo vulgaris* in the Gulf of Biscay (8.abd) (16 runs), see **supplementary** material for details about the different runs for this particular stock.

III Results

Surplus production models were fitted with SPiCT for the nine stocks listed in Table 1. Fisheries characteristics have been described in WGCEPH reports (see for instance ICES 2019) and there is no need to repeat this here. However, it is worth to remind that most stocks are shared resources that can be exploited (at least at some time in the year) by different countries.

III.1 – Loliginidae assessment

West Coast of Ireland and Scotland (6.a and 7.b,c)

For this stock, five abundance indices were included in the assessment: two derived from Marine Scotland Science (MSS) (divisions 6.a and 7.b.c, separately), two from DATRAS (divisions 6.a and 7.b.c, separately) and one from the Irish Groundfish Survey (IGFS) (division 7.b.c only). See Appendix A for description of data and sources. The MSS aggregated dataset may be less reliable than the DATRAS dataset since it is a combination of surveys not all standardised in the same way, using various gears and sampling strategies. Despite this, both data sets showed similar trends for the period in common and model would not converge without the MSS dataset.

This stock probably comprises mainly *L. forbesii* although the two European *Loligo* species are not distinguished in the landings data, as *L.vulgaris* is rare in the area.

The model diagnostics (Fig. 1 and Fig.1.A in Appendix B) were considered satisfactory, except that autocorrelation was evident at lag 1 for the abundance index from the Scottish Surveys (DATRAS) in division 6a. The model also provided a consistent performance until the early 2000s, after which becomes slightly noisy towards the present day (Fig 1.1.B Appendix B). The production curve (Fig. 1) was skewed slightly to the left as might be expected for cephalopod stocks, which are characterised by very high growth rates, particularly at low densities. With increasing densities, the population production might decline not only because of competition for food etc., but due to cannibalism within animals of the same generation – a particular trait of cephalopods (Ibañez & Keyl, 2010) (Fig 1.).

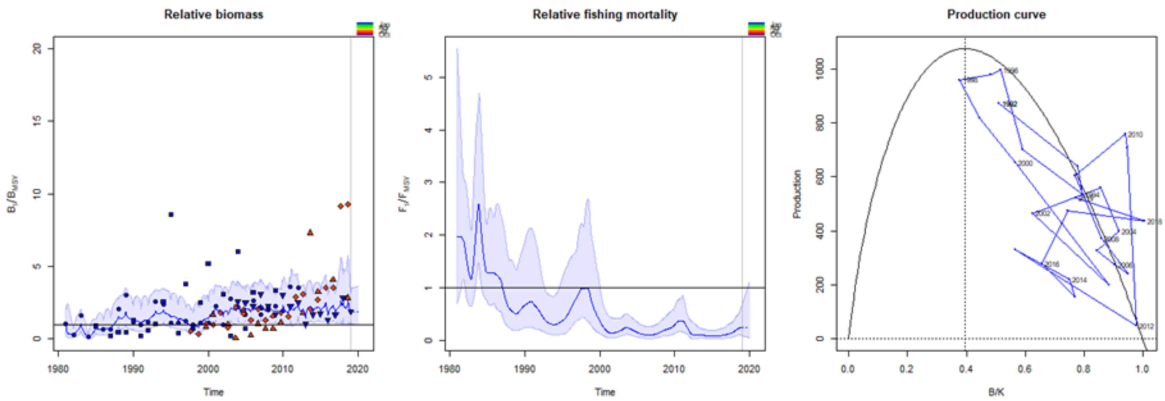

Figure 1. Stock metrics of Loliginidae for West Coast of Ireland and Scotland (6.a and 7.b,c) estimated by SPiCT. Ratios of biomass (B/B_{MSY}) and fishing mortality (F/F_{MSY}) and production curve given. The relative biomass plot axes were adjusted to provide a clear image of the confidence interval widths.

The Irish-Scottish West Coast stock status appears to be fished sustainably with in recent years the biomass above that of optimal exploitation ($B/B_{MSY} > 1$) and fishing mortality below that of optimal exploitation ($F/F_{MSY} < 1$)

Rockall (6.b)

The SPiCT model produced overall unsatisfactory results whereby convergence was achieved but produced very wide confidence intervals. Nevertheless, given the great importance given to Rockall as a squid hotspot (referred to as 'squid alley' by fishers), the results are presented here. The stock of interest was represented by mixture of two European *Loligo* species in the landings data, but the abundance indices effectively consisted of *L. forbesii* using a CPUE index generated by combining Marine Scotland Science (MSS) survey data from 1981 to 2018. The model diagnostics (Fig 2 and Fig 1.2.A in supplementary material) produced otherwise satisfactory results, other than evidence of autocorrelation in the abundance index at Lag 2. The model also provided somewhat consistent but noisy performance in retrospective (Fig 1.2.B in supplementary material) and a bizarre production curve skewed slightly to the left but extending into negative productivity values (Fig 2.).

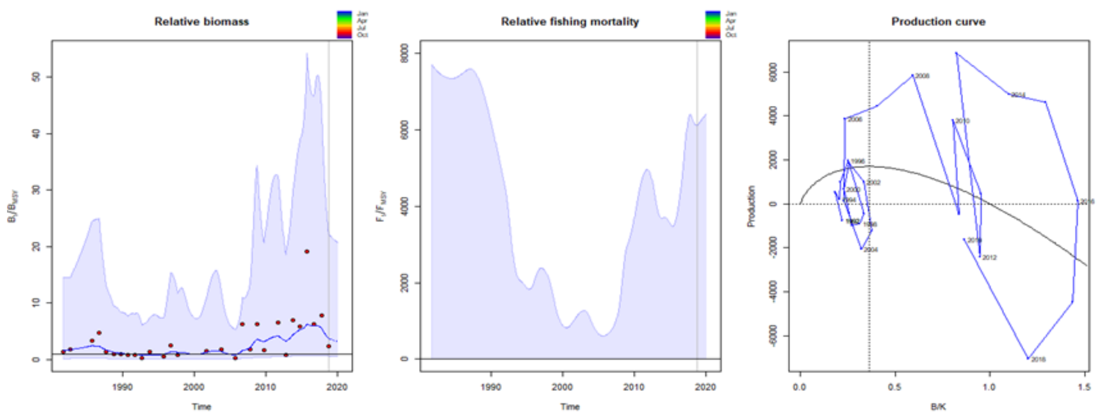

Figure 2. Stock metrics of Loliginidae in Rockall (6.b) estimated by SPiCT. Relative biomass and fishing mortality and production curve given.

Results suggest that B> B_{MSY} but the relation between fishing mortality and F_{MSY} could not be assessed with any confidence. Given the degree of uncertainty, as well as the reliability of the data, it would not be recommended that outputs such as these, be used for management decisions. The lack of reliable data, however, clearly highlights the need to further surveying efforts in this area if reliable stock management advice is to be given.

Irish and Celtic Seas (7.a, 7.f and 7.g,h,j,k)

The stock of interest was represented by mixture of two European *Loligo* species in the landings data, but the abundances effectively consisted of *L. forbesii*. Two abundance indices of CPUE were input from the North West Groundfish Survey (NWGFS) covering areas 7.a,f,g from 1988 to 2018 and the French EVHOE survey covering area 7.g,h,j,k from 1997 to 2018.

The model diagnostics (Fig 1.3.A Appendix B) were considered satisfactory, with Catch data showing several minor issues with autocorrelation and non-normality. The model provided a consistent performance (Fig 1.3.B Appendix B) and production curve skewed slightly to the left as expectable for cephalopod stocks (Fig 3).

The Irish and Celtic Seas stock was assessed to be in a good condition and exploited sustainably as B>B_{MSY} and F<F_{MSY} with favourable forecast (Fig 3.). The SPiCT likely might be applied to its assessment in future.

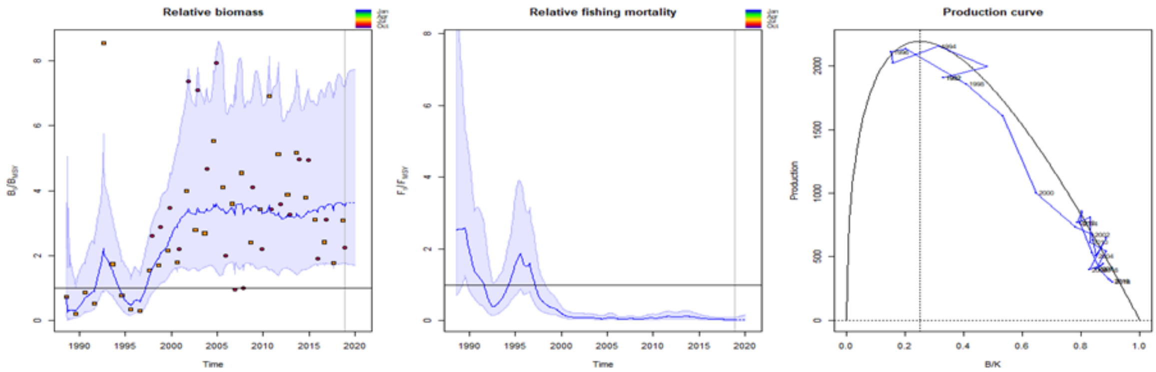

Figure 3. Stock metrics of Loliginidae in Irish and Celtic Seas (7.a, 7.f and 7.g,h,j,k) estimated by SPiCT. Relative biomass and fishing mortality and production curve given.

English Channel (7.d and 7.e)

The stock of interest is regrouping both species of Loligo (*L. vulgaris* and *L. forbesii*. Data landings provided an annual coverage through January-December from 1992 to 2018. Two abundance indices were used: CPUEs from the Channel Ground Fish Survey (CGFS) from 1990 to 2017 (September-October) and standardised French commercial LPUEs (through the all year) for selected region (7.d and 7.e). The distinction between the two *Loligo* species was possible and computed in the LPUE series according to the species proportions sampled at the Port-en-Bessin fish market each month by the University of Caen, France since 1993.

The model diagnostics (Fig. 4 and Fig 1.4.A Appendix B) were considered satisfactory as the result did not point significant bias (mean of the residuals different from zero) or auto-correlation from LPUE index. Both QQ-plot and the Shapiro test shows normality in the residuals. The retrospective pattern (Fig 1.4.B Appendix B), demonstrated reasonably consistent trend in recent biomass being at or slightly below B_{MSY}, and fishing mortality being at or slightly above F_{MSY}. The shape of the production curve seems to indicate a Schaefer model (n = 2) and according to the KOBE-plot (Fig 4. bottom right).

Bay of Biscay (8.a,b,d)

In this area Loliginid resources are most likely dominated by *Loligo vulgaris*. Species-specific EVHOE survey data indicate that in autumn *L. vulgaris* represents on average 83% of biomass indices (ICES, 2019). A series of 16 different initial conditions were tested in order to obtain convergence of the SPiCT fitting procedure (Table 2) and model selection was based on the lowest AIC.

Results of the retained model (alpha=beta=1 and n=2; Schaefer model) are still highly uncertain, with graphs showing huge confidence intervals (Fig. 5). Thus, biological reference points derived from this exercise should be considered as preliminary indications. Fishery diagnostics suggesting $B/B_{MSY} > 1$ and $F/F_{MSY} > 1$ should also be considered as preliminary indications. It is worth noting however that these ratios are similar to those of a surplus production model fitted to the same stock a few years ago with a Bayesian procedure (Ibaibarriaga et al, 2015).

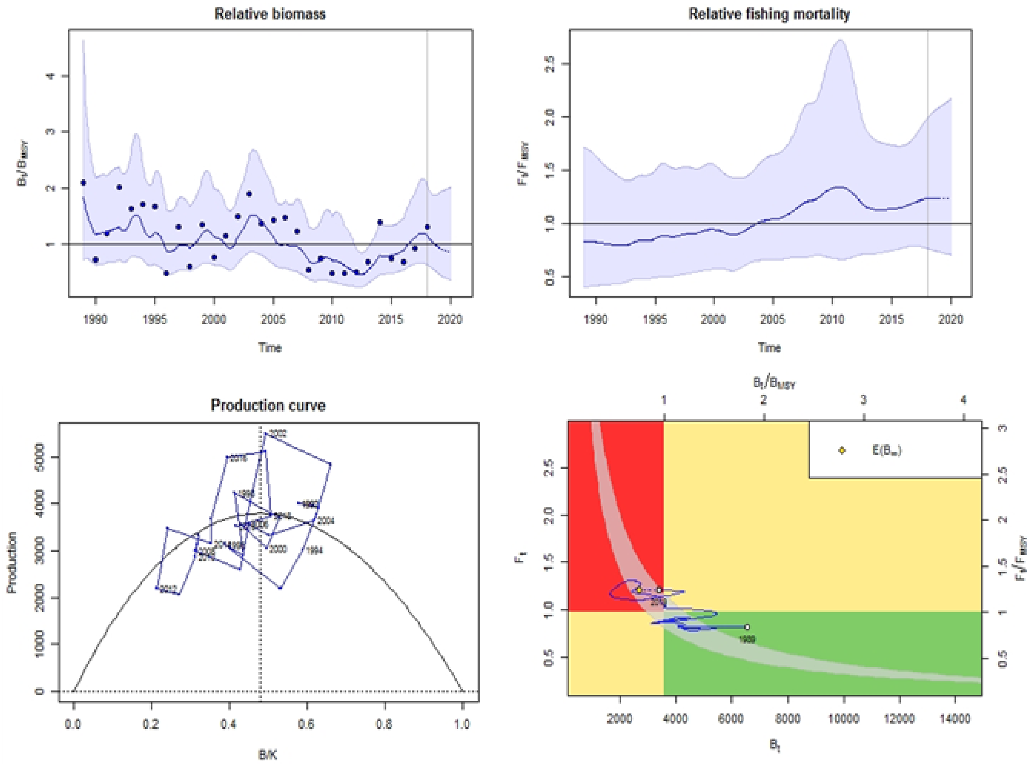

Figure 4. Stock metrics of Loliginidae in the English Channel (7.d and 7.e) estimated by SPiCT. Relative biomass and fishing mortality, production curve and KOBE-plot are given

Table 2. Different cases conducted. trying to fix model priors. Red cases did not converge. green did and Case 6a* is the one retained giving best model fitting (Schaeffer model).

SPICT	n=estimated	n=2	n=estimated Prior r	n=2 Prior r
No priors	Case 0a		Case 0b	
α estimated β estimated	Case 1a Case 2a	Case 5a	Case 1b Case 2b	Case 5b
α=1, β=1	Case 3a	**Case 6a***	Case 3b	Case 6b
α=4, β=1	Case 4	Case 7a	Case 4b	Case 7b

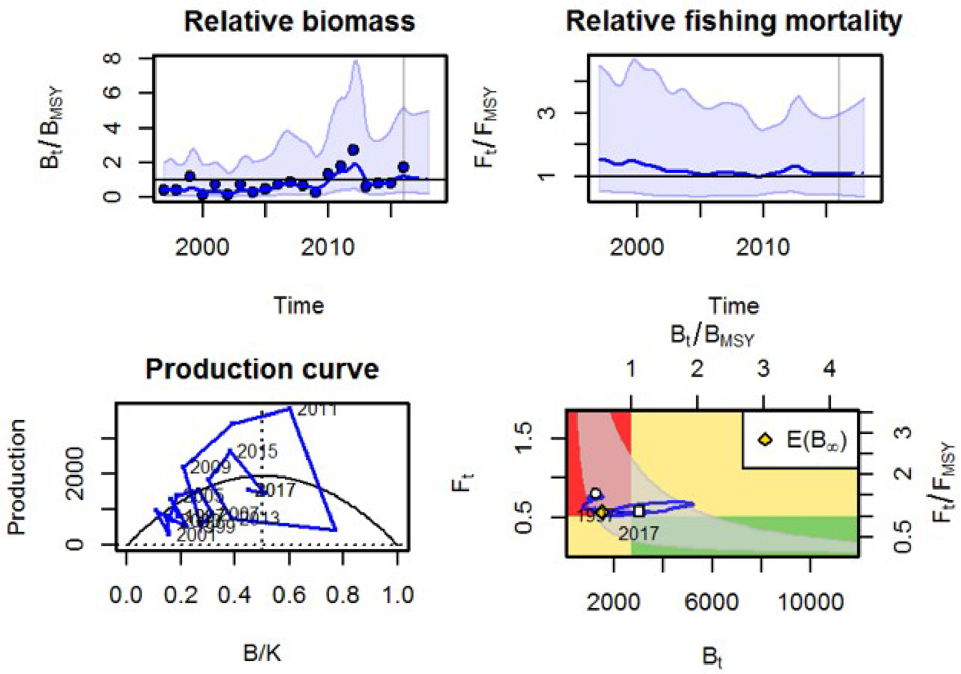

Figure 5. Stock metrics of Loliginidae in the Bay of Biscay (8.a,b,d) estimated by SPiCT. Relative biomass and fishing mortality, production curve and KOBE-plot are given.

Gulf of Cadiz (9.a south)

Combined landings of artisanal and trawl fisheries and CPUEs of 2 research surveys (March for Spain and November for Portugal) for 1993-2018 period were used.

The stock of interest was represented by mixture of two European *Loligo* species, but effectively consisted of *L.vulgaris*, as *L.forbesii* is rare in the south of Iberian Peninsula. The model diagnostics were considered to be satisfactory (Fig 1.5.A Appendix B).

The model also provided a consistent performance in retrospective (Fig 1.5.B Appendix B) and a production curve with the peak shifted left as expectable for cephalopod stocks (Fig 6.). The stock was assessed to be in a good condition and exploited sustainably as $B>B_{MSY}$ and $F<F_{MSY}$ with favourable forecast (**Fig 5.**). The SPiCT likely might be applied to its assessment in future.

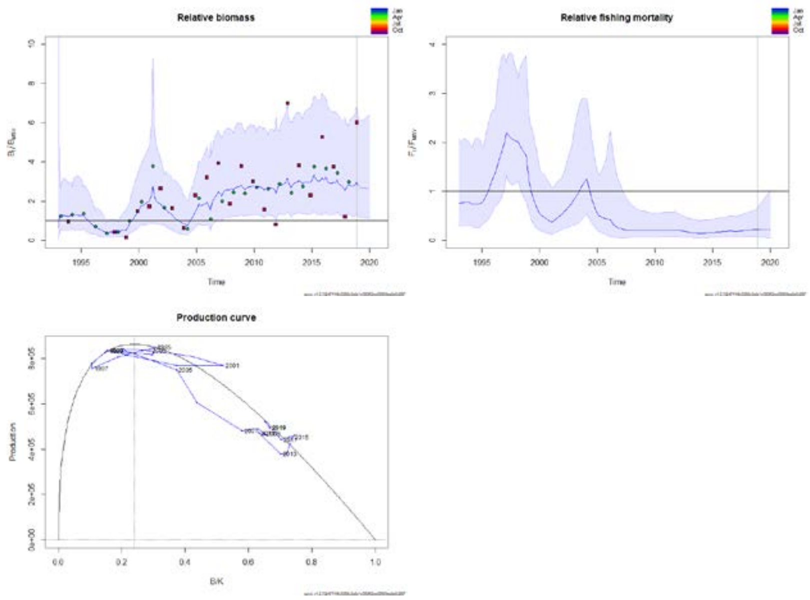

Figure 6. Stock metrics of Loliginidae in Gulf of Cadiz (9.a south) estimated by SPiCT. Relative biomass and fishing mortality and production curve given.

III.2 – Sepiidae assessment

English Channel (7.d and 7.e)

Here we consider *Sepia officinalis* annual landings from 2001 to 2018. French Otter Bottom Trawl catch and effort data were used to compile a time series of annual average abundance index for the period 2001-2018 and for the selected area (ICES divisions 7.d and 7.e).

The SPiCT model seemed to be acceptable for this assessment unit. The model's output shows reasonable confidence intervals. However, although the best estimates of B and F in 2018 suggest overexploitation, confidence intervals are too wide to be certain of this (**Fig. 7**). The model diagnostics (Fig 1.6.A Appendix B) were considered satisfactory as the result did not show significant bias (mean of the residuals different from zero) or auto-correlation from LPUE index. Both the QQ-plot and the Shapiro test showed normality in the residuals.

The stock was assessed to be in a good condition and exploited sustainably between 2001 and 2016 as $B > B_{MSY}$ and $F < F_{MSY}$ with favourable forecast but the possible recent overexploitation needs further investigation (**Fig 7.).**

Following WKLIFE and WKDLSLSS advice about the **1 over 2 rule**, abundance variation was tested for cuttlefish through survey and commercial indices for 2017-2018 and 2018-2019 (Table 3).

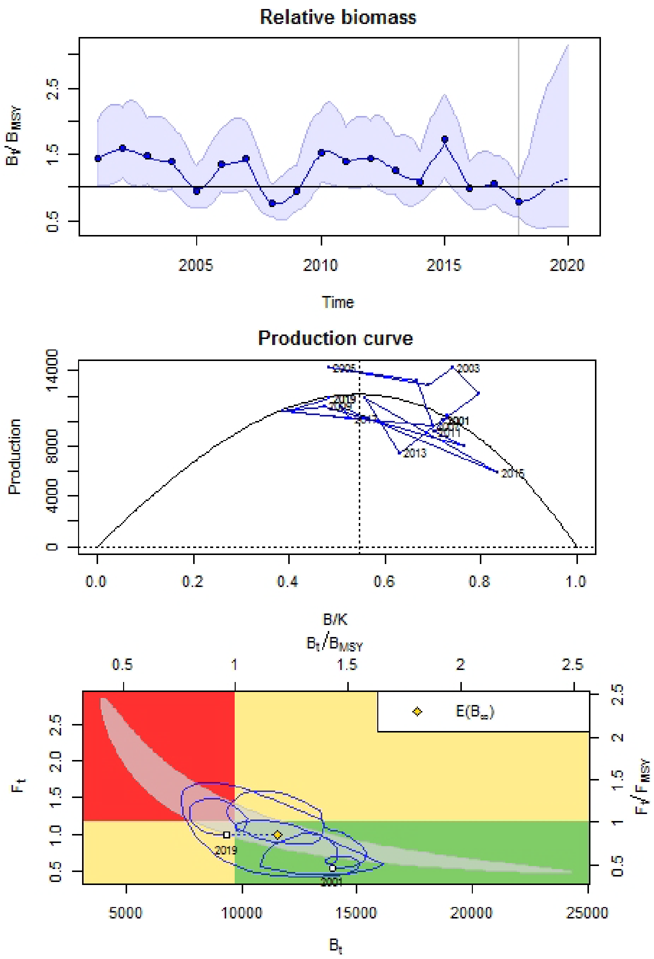

Figure 7. Stock metrics of Sepiidae in English Channel (7.d and 7.e) estimated by SPiCT(1.2.7). Relative biomass and fishing mortality, production curve and KOBE-plot are given.

Table 3. Application of the 1 over 2 rule to trends in catches and in abundance in English Channel cuttlefish (X_t = value of variable X for Year t)

Calculation	Total catch	Abundance Indices							
		st.FR LPUE	CGFS nb	CGFS biomass	BTS 7d	SW BEAM	TBB oct	TBB nov	surveyQ1
X_{2018} / (mean (X_{2016}, X_{2017}))	77.8%	71.1%*				74.6%	53.4%	89.0%	116.6%
X_{2017} / (mean (X_{2015}, X_{2016}))	97.3%	102.5%	44.94%	35.46%	90.08%	115.9%	123.9%	105.9%	91.6%

***Cuttlefish declined by 28.9% in abundance in 2018-2019 according to commercial fisheries data.**

Bay of Biscay (8.abd)

The stock of interest is also mainly considering *S. officinalis* annual coverage landings from 2000 to 2018. French commercial landings were used to compile an abundance index averaged for 2000-2018 period for selected region (8.abd).

The SPiCT model result is uninformativefor this assessment unit as confidence intervals are very wide. Nevertheless, the trend of the model output suggests overexploitation between 2000 and

2010 with F>F_{MSY} and B<B_{MSY}, and since 2010 the exploitation seems stabilised at an underexploited level with F<F_{MSY} and B>B_{MSY}. Biomass was especially high in 2016 (**Fig. 8**). This model could be further investigated using abundance index series from other countries like Portugal or Spain.

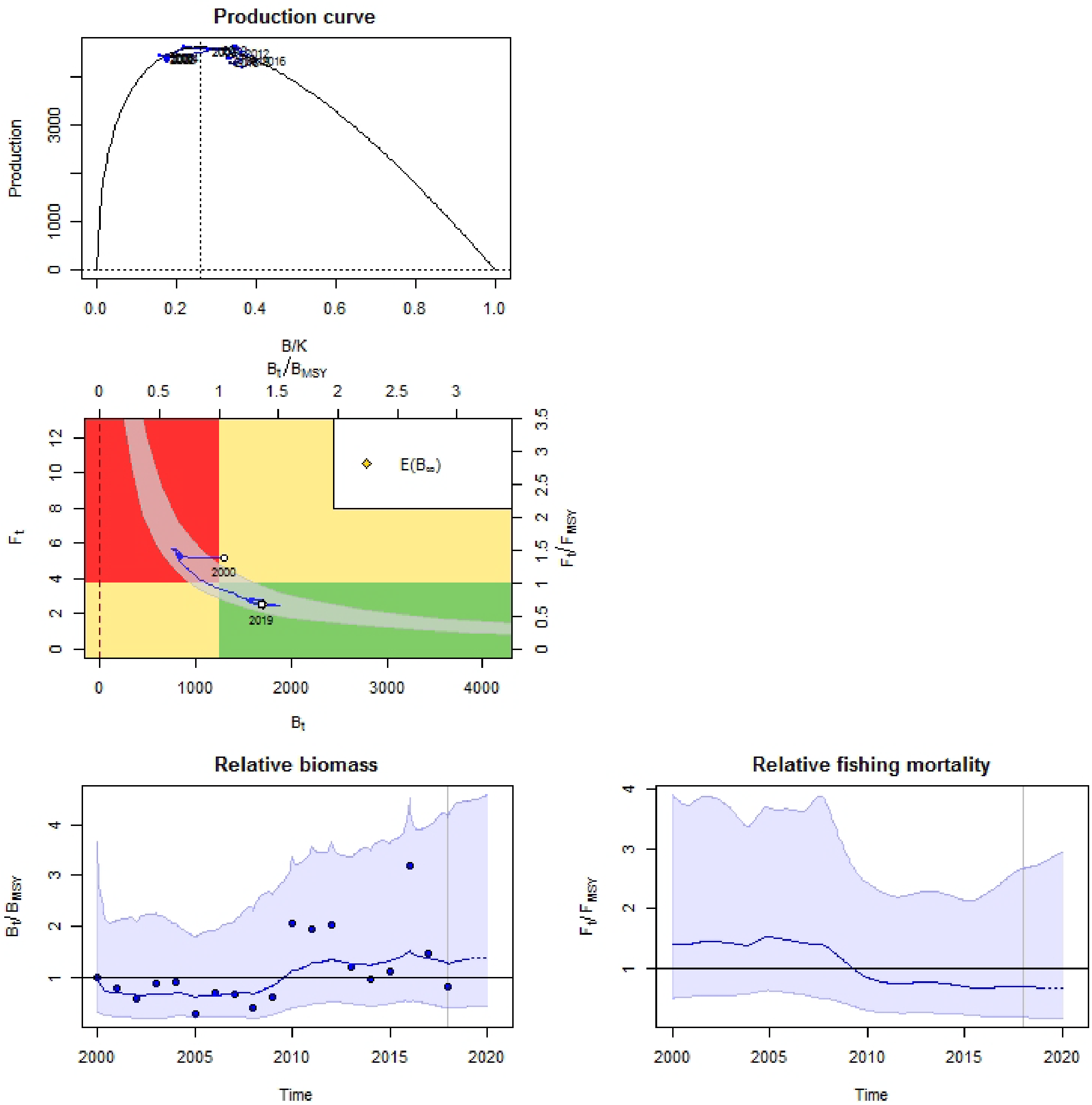

Figure 8. Stock metrics of Sepiidae in Bay of Biscay (8.abd) estimated by SPiCT (1.2.7). Relative biomass and fishing mortality, production curve and KOBE-plot are given.

III.3 – Ommastrephidae assessment

Northwest Iberian Peninsula (8.c. 9.a north)

To assess the Ommastrephid stocks off the Northwest Iberian Peninsula, landings for a period 2000-2018 and two tuning series were used: Spanish IBTS Trawl survey 8c9aN (September – October) and LPUEs of the Spanish Trawlers in the area. The model had satisfactory diagnostics

(**Fig 1.8.A Appendix C**) and suggested that Ommastrephid stocks are below B_{MSY}. and fishing mortality is at or above F_{MSY} suggesting an overexploitation through the time series (**Fig. 9**).

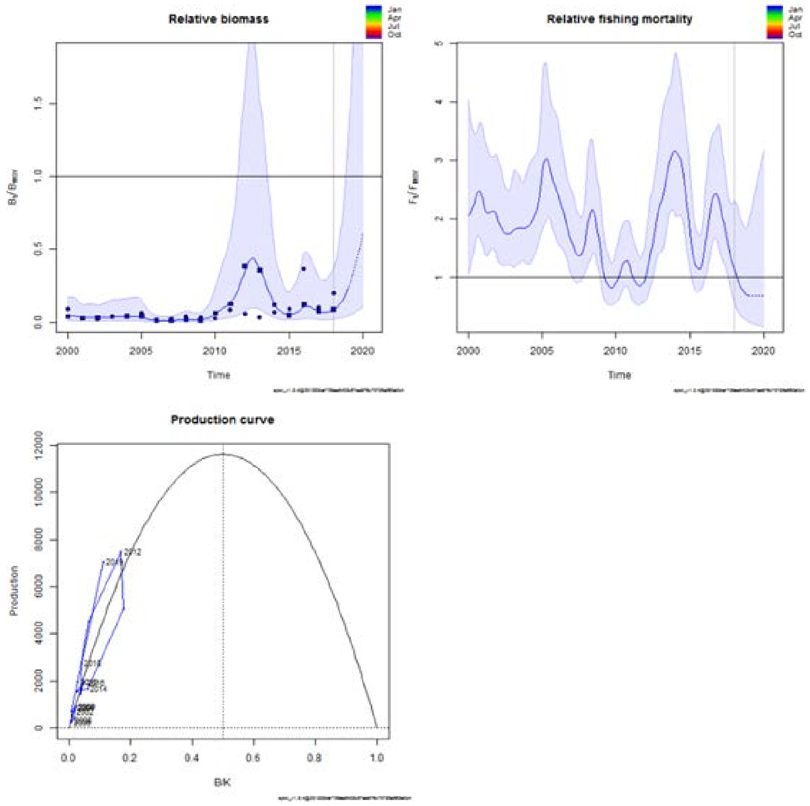

Figure 9. Stock metrics of Ommastrephidae in the Northwest Iberian Peninsula (8.c, 9.a.north) estimated by SPiCT. Relative biomass and fishing mortality and production curve are given.

However, results of such exercise should be treated cautiously as Ommastrephidae in the region comprise a mixture of three species (*Todaropsis eblanae*, *Illex coindetii* and *Todarodes sagittatus*). Although the proportion of each species in the catches is unknown and probably very variable from year to year, *T. eblanae* and *I. coindetii* are thought to be more abundant than *T. sagittatus*. All these squids have wide ranges of distribution and a long pelagic "paralarval" stage when products of the spawning might be transported far away from the spawning area by oceanic currents. The reliability of the model in such a situation is questionable. Also, occasional "explosions" in abundance might lead to overestimation of B_{MSY} and hence to underestimation of B/B_{MSY} and overestimation of F/F_{MSY}.

III.4 Overview of preliminary diagnostics

In the nine studied stocks, fitted models outputs correspond to preliminary diagnostics and candidate biological reference points. With the exception of the Rockall squid fishery (Loliginidae in area 6.b) the models seem to be valid in spite of the large confidence intervals displayed in Fig. 2 to 9. The comparison of average catches in the four last years and MSY, and the ratios B/B_{MSY} and F/F_{MSY}, seem to indicate that large stocks (English Channel Sepiidae, Bay of Biscay Loliginidae) may be more prone to overexploitation (Table 4).

Table 4. Summarised Biological Reference Points (BRP) obtained with SPiCT models (C = catch in tonnes, averaged over the last 4 years with available data; MSY_s = Stochastic Maximum Sustainable Yield (tonnes). Relative estimates of stochastic Biomass (B/B_{MSY}) and Fishing Mortality (F/F_{MSY}) refer to the final year for which data were available (refer to the index time periods in Table 1).

Cephalopod group	Area	C	MSY_s	B/B_{MSY}	F/F_{MSY}
Loliginidae	6.a + 7.bc	360	1095	2.173	0.139
Loliginidae	6.b	873	1129	5.483	0.121
Loliginidae	7.a +7.ghjk	374	2195	3.508	0.050
Loliginidae	7.de	4359	3480	1.158	1.161
Loliginidae	8.abd	1520	1376	1.275	1.113
Loliginidae	9.a all	717	1076	2.796	0.224
S. officinalis	7.de	10920	11336	0.796	1.155
S. officinalis	8.abd	4172	4649	1.261	0.701
Ommastrephidae	8.c.+ 9.a north	1193	11254	0.084	1.153

IV Discussion

Following recommendations of ICES WKProxy (ICES, 2016) and WKLIFE (ICES 2012b, 2017), a Stochastic Surplus Production Model in Continuous Time (SPiCT) was applied by the WGCEPH to data available for several cephalopod stocks. This is a preliminary application and the exercises will continue during future WGCEPH meetings.

Results for Loliginidae from the West Coast of Scotland, Celtic Sea and Gulf of Cadiz were found to be valid in the sense that the final diagnostics were obtained with confidence limits which do not overlap threshold ratios (B/B_{MSY} and F/F_{MSY}). Results for Sepiidae in the English Channel and Ommastrephidae in the Northwest Iberian Peninsula were considered to be satisfactory but estimated values for stock biomass and fishing mortality had wide confidence limits.

The model is applicable only to stocks for which exploitation rate is high enough to drive the stock dynamics and this might not be the case for many cephalopods in the study area. Taking into account the short-lived nature of cephalopods, for future work, the use of seasonally-averaged (i.e. by quarter) values of catches and abundance indices (by month or by quarter) rather than annual values might be recommended for the next trials. Mildenberger *et al.* (2019) underlined that taking into account seasonal changes in stock productivity improved the stock sustainability reference levels. A related possibility, when the seasonality of catches is clearly defined, catches are identified to species and the life cycle is around 1 year in duration (the latter is not always true for cuttlefish), would be to focus on those months during which an annual cohort is fished. Thus for *Loligo forbesii* in Scotland, each year of data might run from August to May. While some animals live longer than 12 months and in some years there has been evidence of a second, summer breeding, cohort, use of July to June to represent a "fishing year" is probably a better option than the calendar year (e.g. Boyle et al., 1995).

Pedersen & Berg (2017) point out that consideration of the shape of the production curve is important in order to obtain unbiased reference points and recommend trying a run without fixing the shape parameter *n*. Nevertheless, previous work by ICES WKLIFE group of ICES suggested that fixing n (except to 1, which refers to the Fox model) could reduce estimation error and generate narrower confidence intervals. It is suggested to try first running models without a prior knowledge of *n* and then redo the models, fixing the *n* parameter based on the previous estimates, possibly also aiming for a production curve tilted to the left.

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Supplementary material

Appendix A – Description of surveys indices:

North West Groundfish Survey (NWGFS) covered ICES Divisions 7a, 7f and 7g combined, from 1988 to 2018. The CPUE was given as an annual average number of individuals per hour of haul. For the years 2014 and 2015, no survey data was available from the NWFS survey. To have a complete time series, 2014 was replaced by the average of 2013 and 2016 and 2015 was given the average of 2014 and 2016. Data was sourced directly from CEFAS.

Irish Groundfish Survey (IGFS) covered ICES Divisions 6a and 7a,b,c,g,j,k separately from 2003 to 2018. The CPUE was given as an annual simple mean weight (kg) per hour of haul for each division for *Loligo forbesii*. Due to the patchiness of the time series, Divisions 7c and 7k were not used. The data for this data was sourced from DATRAS.

South West Beam Trawl Survey Q1 (SWBEAM) data covered ICES Divisions 7.a,f,e combined from 2006 to 2018. The CPUE was given as the annual mean of the number of individuals per hour of haul. Data sourced from CEFAS.

Channel Beam Trawl Survey (BTS) covered ICES Division 7.d from 1989 to 2017. The CPUE was given as the annual mean of the number of individuals per hour of haul, data sourced from CEFAS.

EVHOE data were extracted for the Celtic Sea portion of the Survey covering ICES Division 7.g,h,j,k combined, from 1997 to 2018. The CPUE was provided as an annual stratified mean weight (kg) per swept area of haul for *Loligo forbesii*. Data sourced from IFREMER.

Channel Groundfish Survey (CGFS) data covered ICES divisions 7.d and 7.e of the English Channel from 1990 to 2017. The CPUEs are both available as an annual average number or biomass (kg) of individuals per square kilometre. Data sourced from IFREMER.

Scottish Surveys

Data were sourced from DATRAS for the **Scottish West Coast IBTS (SWC-IBTS)** survey and the **Scottish Groundfish Survey (SCOGFS) (**1997 to 2018) for ICES Division 6.a. The CPUE was given as the annual mean of the number of individuals per hour of haul.

In addition, previously extracted Scottish survey data from **Marine Scotland Science (MSS)** were provided by Graham Pierce which included the SWC-IBTS, SCOGFS, International Young Fish Survey (IYFS), Scottish Monk and Megrim Survey, Mackerel Recruitment Survey, Deepwater surveys, experimental surveys, Pre-recruit surveys and several other trawl surveys. The data was selected for ICES Divisions 6.a and 7.b, from 1981 to 2012 – more recent data has still not been provided. The abundance is expressed as an annual simple mean of the number of individuals per hour haul for each.

Rockall

As for the Scottish surveys, index data for Rockall were derived from **DATRAS Scottish Rockall surveys** from 2001 to 2018, with an abundance index represented as an annual simple mean weight (kg) per hour of haul, and **MSS source**; which included an aggregation of data from the Groundfish, Pre-recruit, Haddock, Demersal and Hydrographic surveys at Rockall, together producing a continuous time series from 1981 to 2012 for ICES Division 6.b. The abundance index was represented as an annual simple mean of the number of individuals per hour of haul. Surveys took place in the 2nd and 3rd Quarters.

The model would not converge using the abovementioned datasets. Several modifications of the CPUE were attempted in order to get convergence, with success. Instead of producing the CPUE as a number per haul, a length-weight relationship formal from Young et al. (2004), given as:

$$W\ (g) = 0.00094 \times L\ (mm)^{2.33295}$$

$$\text{Then, } W\ (\text{per haul}) = W \times \text{No. at Length class}$$

Where the weight was calculated for each length class and multiplied by the number of individuals of that length class in a haul. So CPUE is now measured as the annual average of the calculated weight (kg) per hour of haul.

In both datasets, data were missing from 2002, 2004 and 2010 and an average of the previous and following year was used to replace each missing year. To complete the time series, the DATRAS data series from 2011 was added to the other time series. This approach is not ideal as it collates indices from different surveys, gears and calculated weights but it was considered to be a necessary trade-off so as to have a sufficiently long and complete time-series to allow models to converge.

Appendix B – Diagnostics and retrospective plots for Loliginidae, Sepiidae and Ommastrephidae

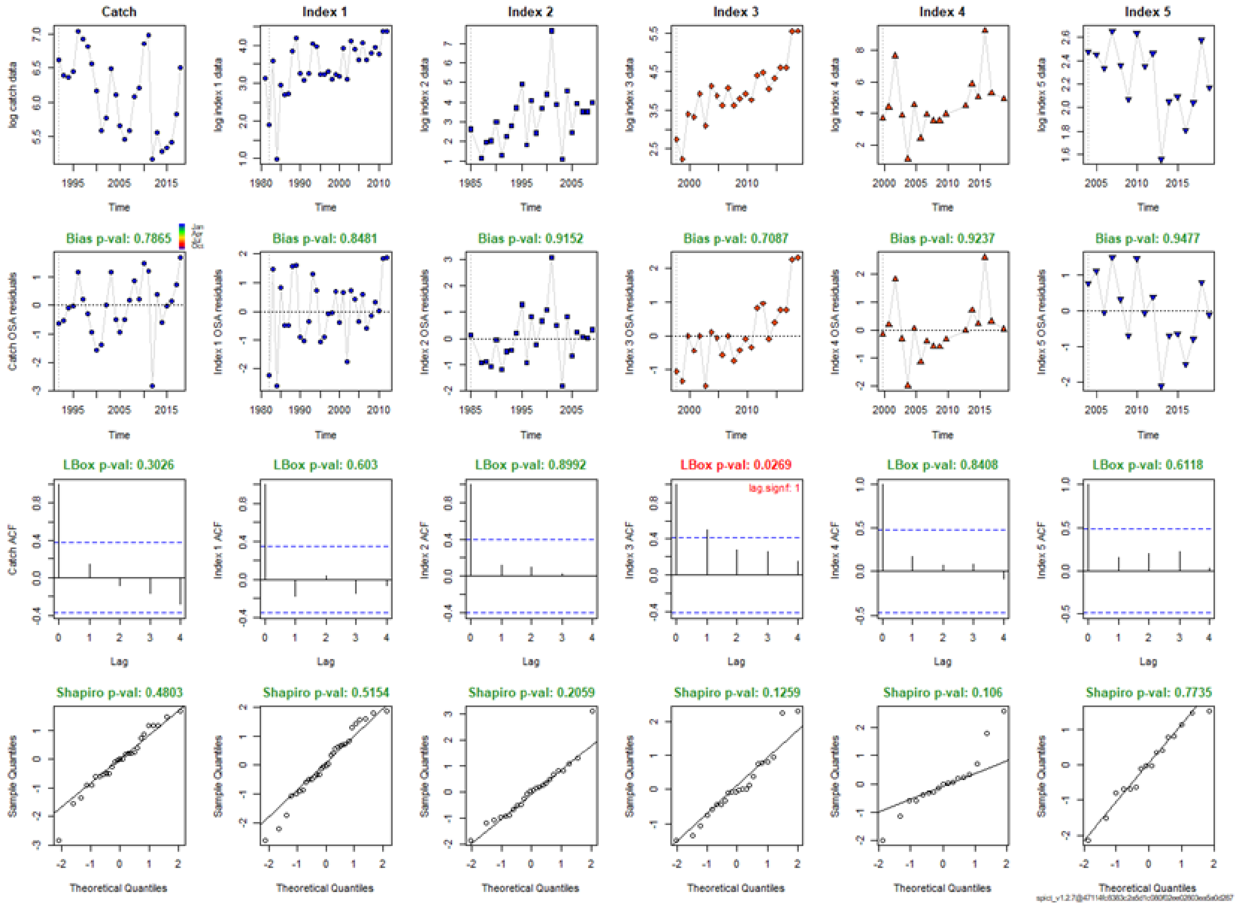


Figure 1.1.A. SPiCT diagnostic for Loliginid squid of West Coast of Ireland and Scotland (6.a and 7.b.c). Row 1 Log of the input dataseries. Row 2 OSA residuals with the p-value of a test for bias. Row 3 Empirical autocorrelation of the residuals with tests for significance. Row 4 Tests for normality of the residuals. QQ-plot and Shapiro test.

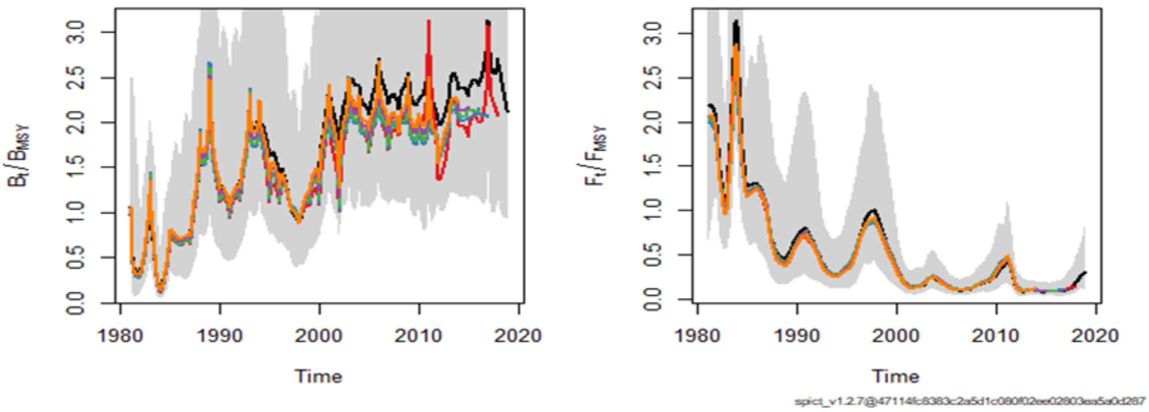


Figure 1.1.B. Loliginid squid of West Coast of Ireland and Scotland (6.a and 7.b.c) - 5 years retrospective analysis. Relative biomass and fishing mortality respectively on left and right.

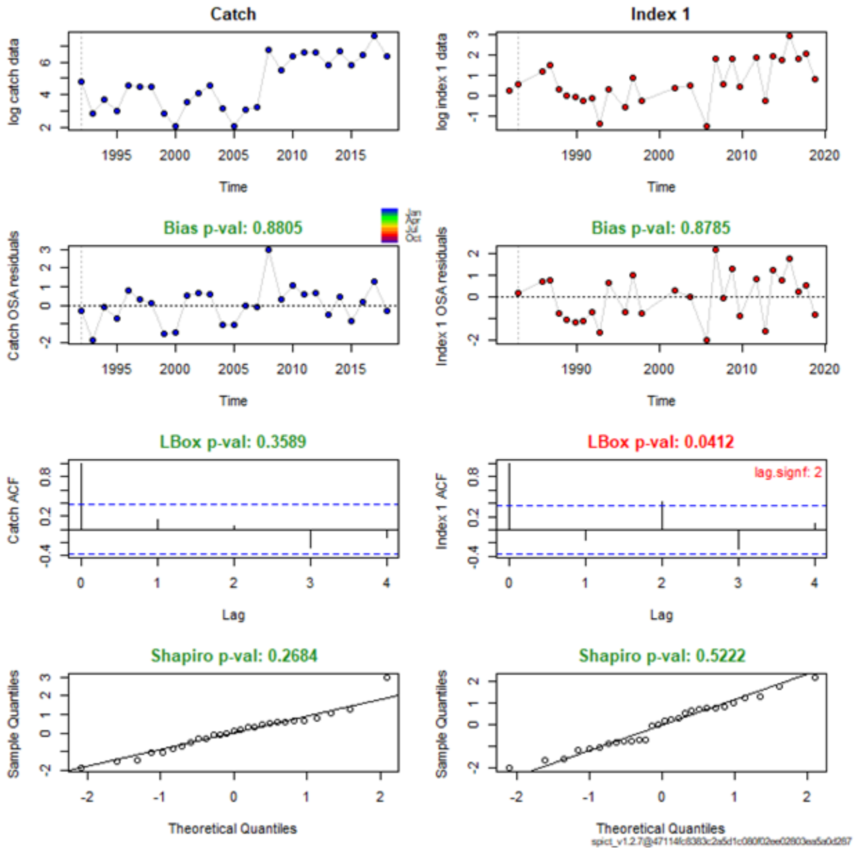


Figure 1.2.A. SPiCT diagnostic for Loliginid squid of Rockall (6.b). Row 1 Log of the input data series. Row 2 OSA residuals with the p-value of a test for bias. Row 3 Empirical autocorrelation of the residuals with tests for significance. Row 4 Tests for normality of the residuals. QQ-plot and Shapiro test.

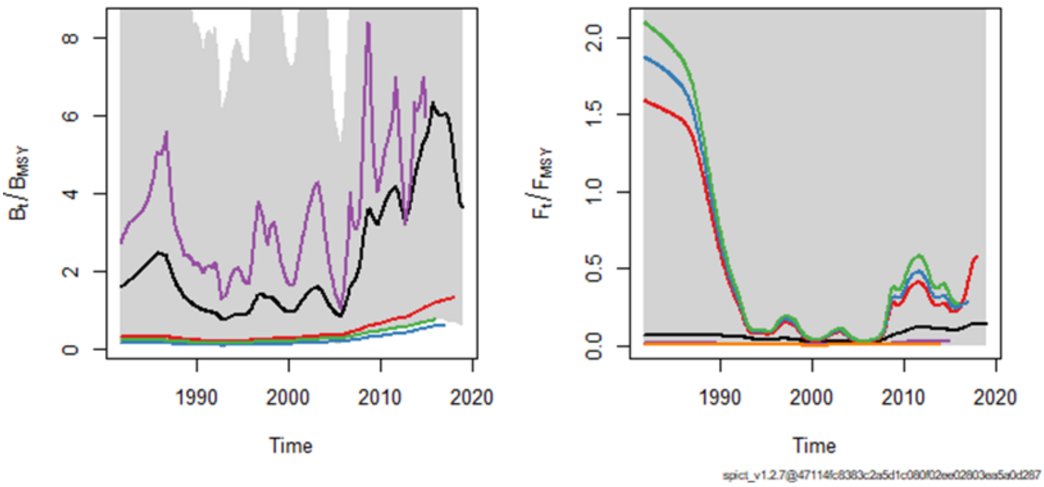


Figure 1.2.B. Loliginid squid of West Coast of Rockall (6.b) - 5 years retrospective analysis. Relative biomass and fishing mortality respectively on left and right.

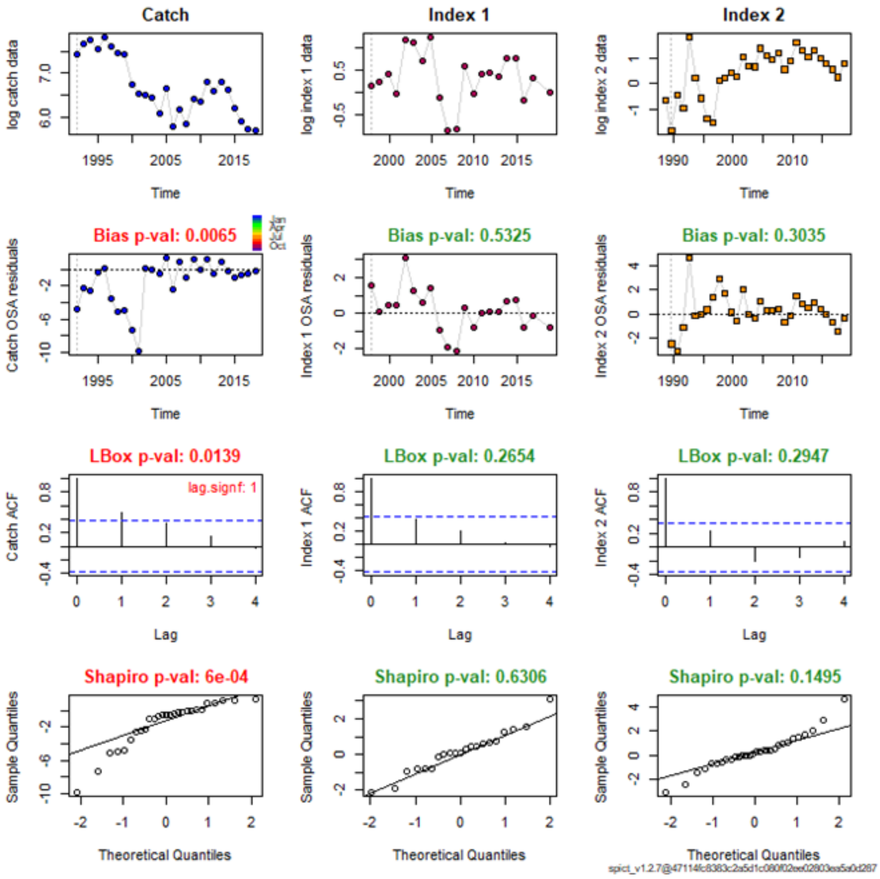


Figure 1.3.A. SPiCT diagnostic for Loliginid squid of Irish Sea and Celtic Sea (7.a. 7.f and 7.g.h.j.k). Row 1 Log of the input datas eries. Row 2 OSA residuals with the p-value of a test for bias. Row 3 Empirical autocorrelation of the residuals with tests for significance. Row 4 Tests for normality of the residuals. QQ-plot and Shapiro test.

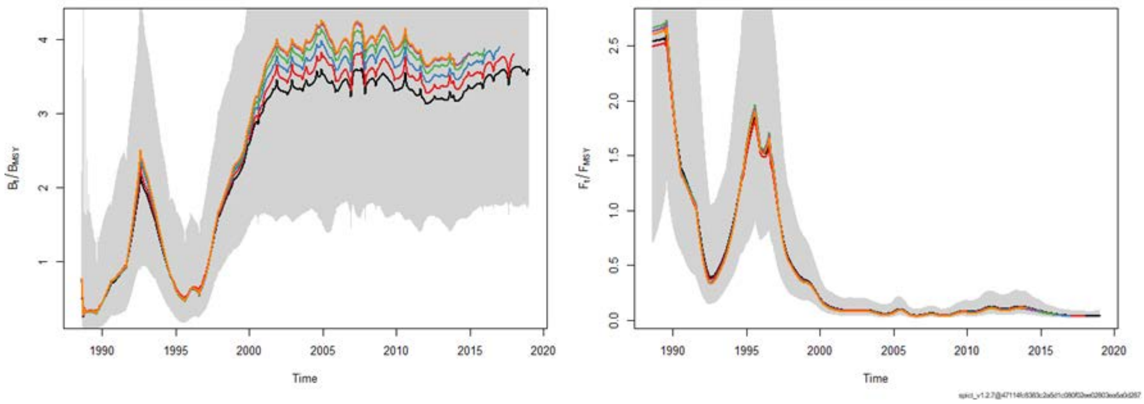


Figure 1.3.B. Loliginid squid of Irish Sea and Celtic Sea (7.a. 7.f and 7.g.h.j.k) - 5 years retrospective analysis. Relative biomass and fishing mortality respectively on left and right.

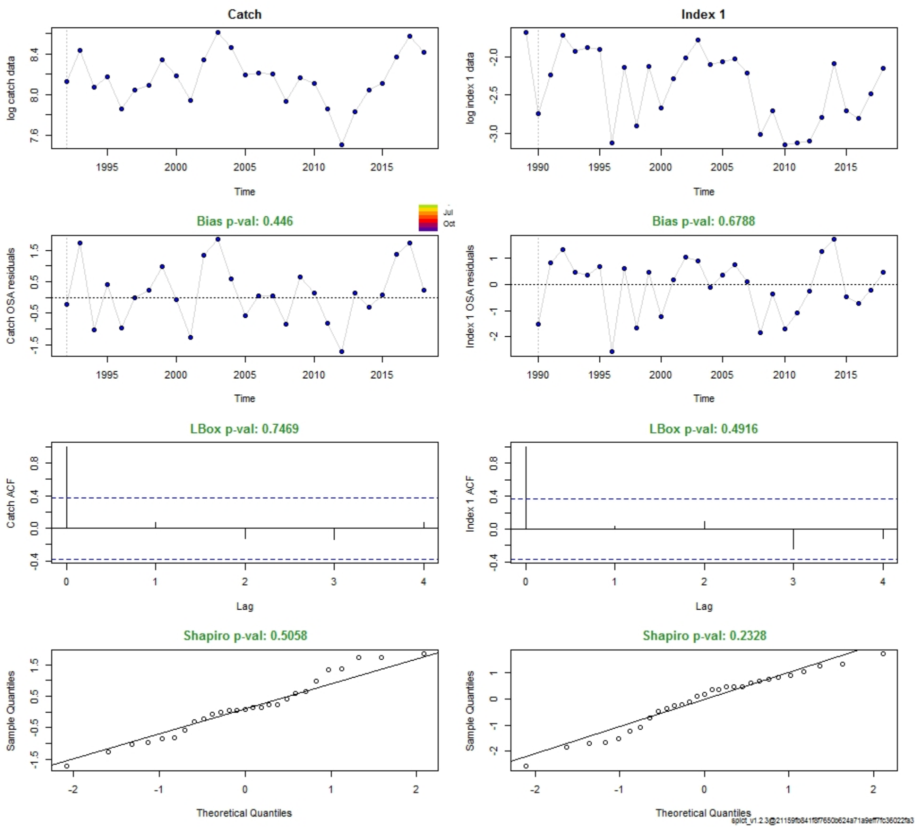


Figure 1.4.A. SPiCT diagnostic for Loliginid squid of English Channel (7.d and 7.e). Row 1 Log of the input data series. Row 2 OSA residuals with the p-value of a test for bias. Row 3 Empirical autocorrelation of the residuals with tests for significance. Row 4 Tests for normality of the residuals. QQ-plot and Shapiro test.

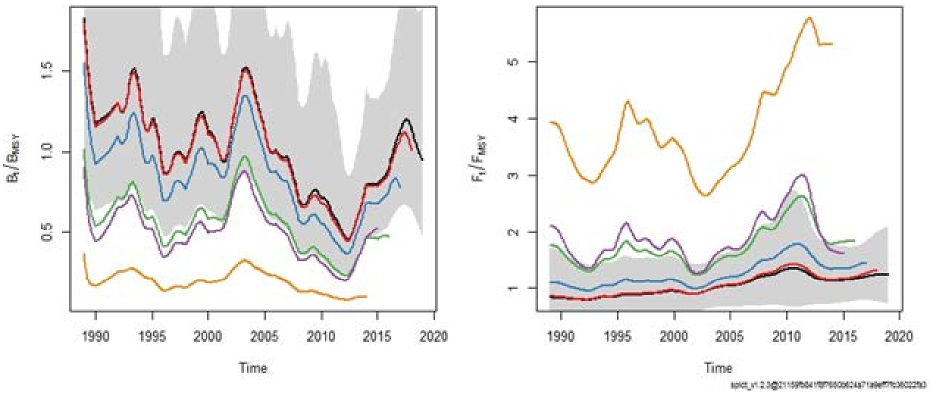


Figure 1.4.B. Loliginid squid of English Channel (7.d and 7.e) - 5 years retrospective analysis. Relative biomass and fishing mortality respectively on left and right.

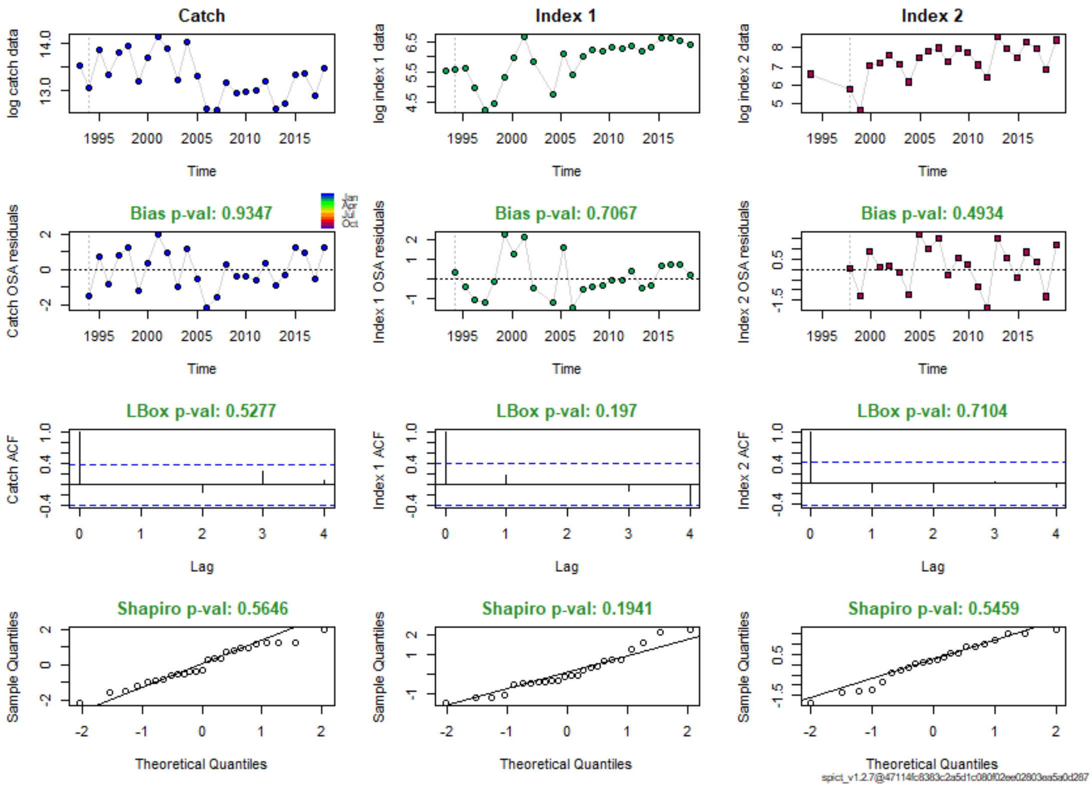


Figure 1.5.A. SPiCT diagnostic for Loliginid squid of Gulf of Cadiz (9.a south). Row 1 Log of the input dataseries. Row 2 OSA residuals with the p-value of a test for bias. Row 3 Empirical autocorrelation of the residuals with tests for significance. Row 4 Tests for normality of the residuals. QQ-plot and Shapiro test.

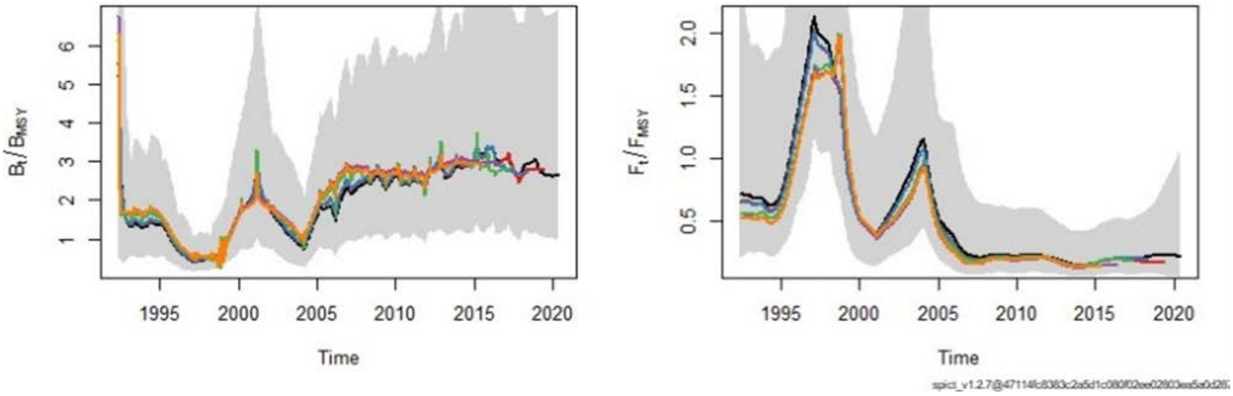


Figure 1.5.B. Loliginid squid of Gulf of Cadiz (9.a south) - 5 years retrospective analysis. Relative biomass and fishing mortality respectively on left and right.

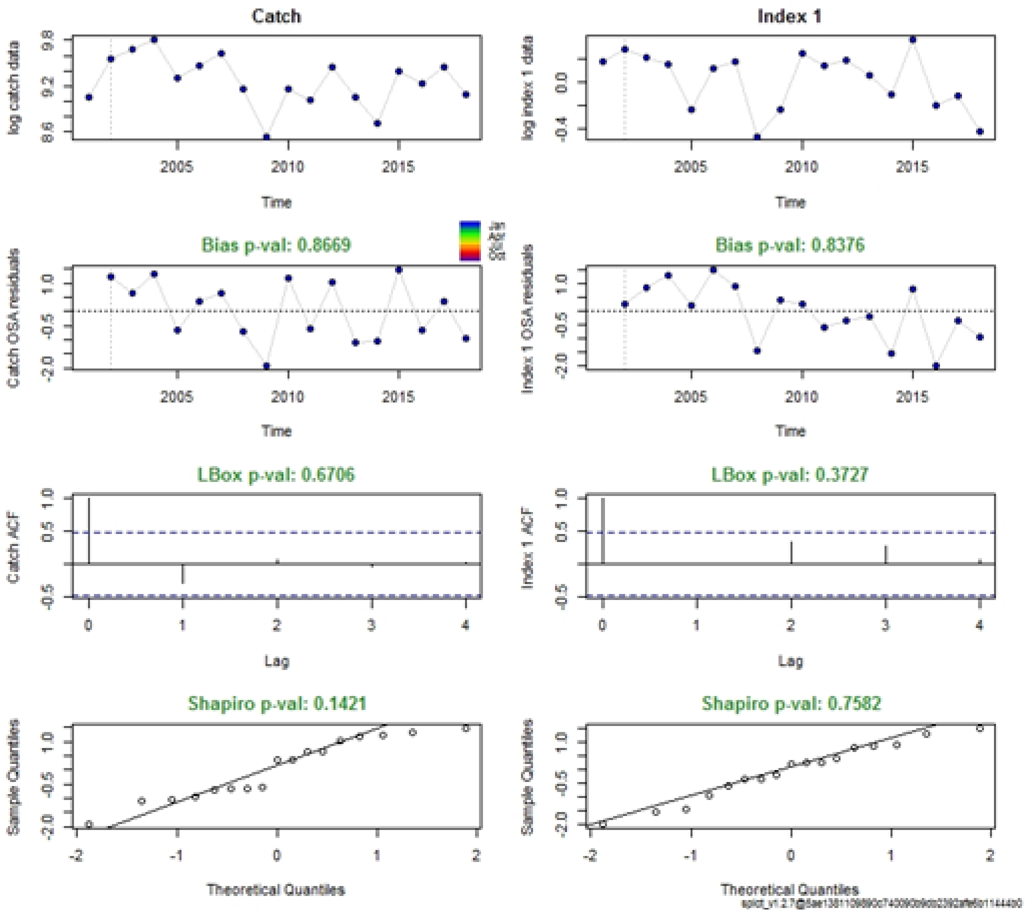


Figure 1.6.A. SPiCT diagnostic for Sepiidae of the English Channel (7.d and 7.e). Row 1 Log of the input data series. Row 2 OSA residuals with the p-value of a test for bias. Row 3 Empirical autocorrelation of the residuals with tests for significance. Row 4 Tests for normality of the residuals. QQ-plot and Shapiro test.

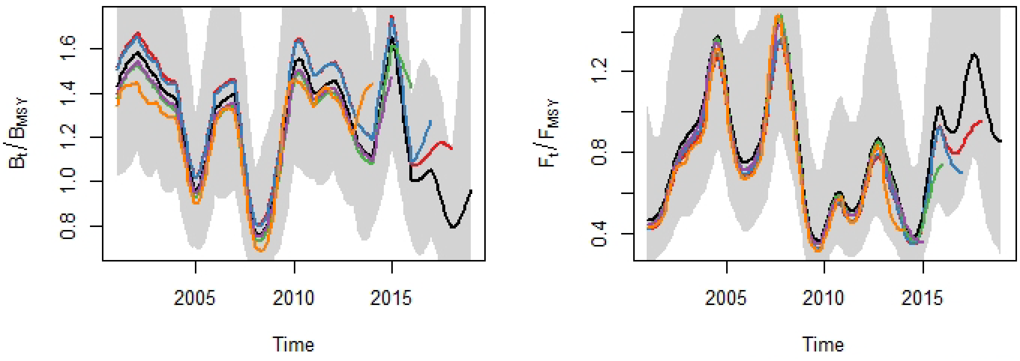


Figure 1.6.B. Sepiidae of the English Channel (7.d and 7.e) - 5 years retrospective analysis. Relative biomass and fishing mortality respectively on left and right.

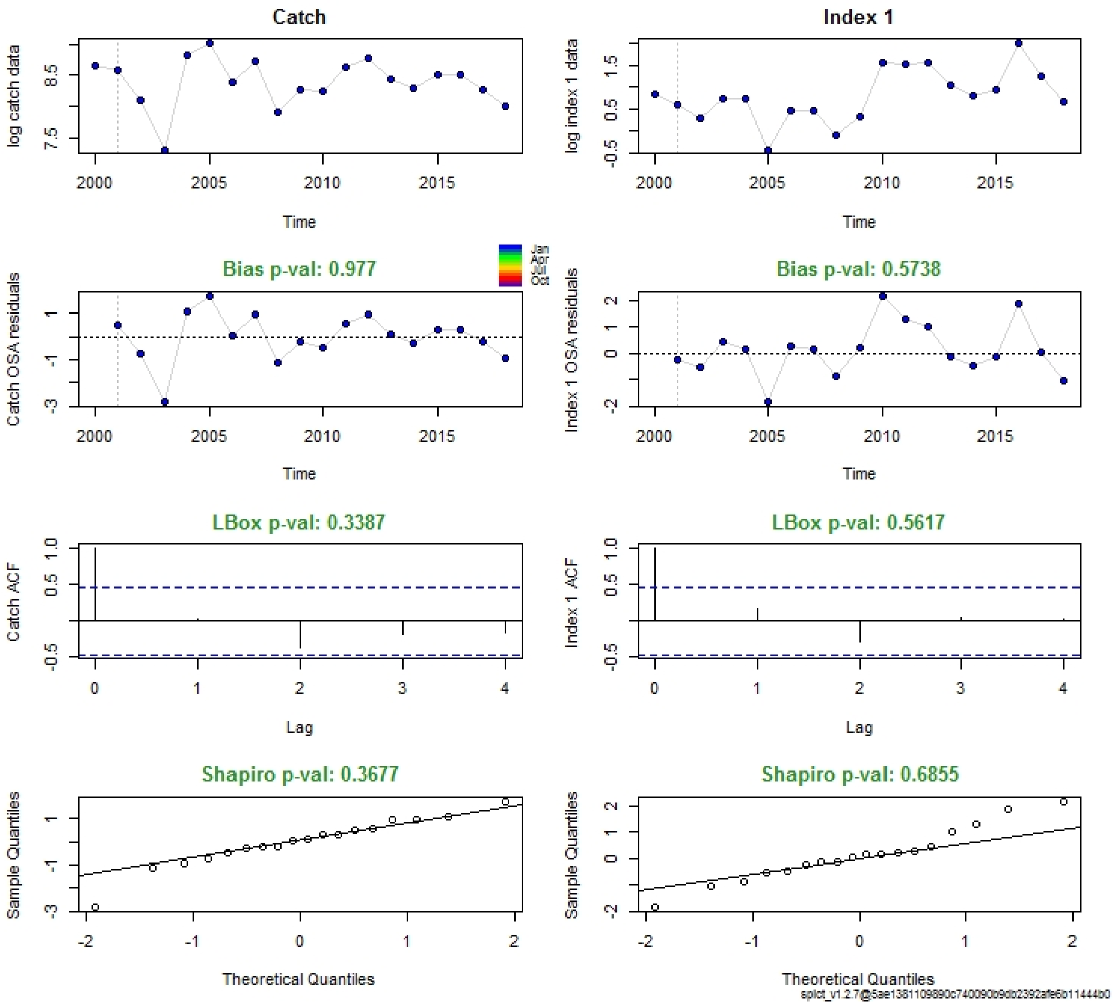


Figure 1.7.A. SPiCT diagnostic for Sepiidae of the Bay of Bisacy (8.a,b, d). Row 1 Log of the input data series. Row 2 OSA residuals with the p-value of a test for bias. Row 3 Empirical autocorrelation of the residuals with tests for significance. Row 4 Tests for normality of the residuals. QQ-plot and Shapiro test.

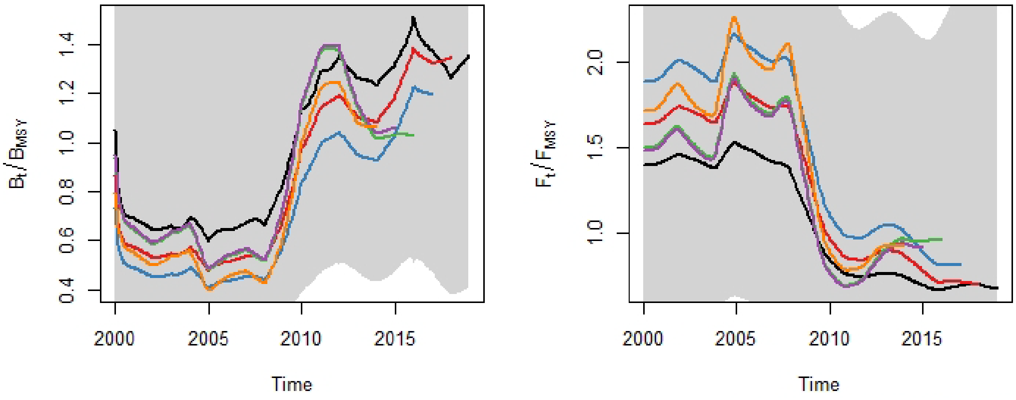


Figure 1.7.B. Sepiidae of the Bay of Bisacy (8.a,b, d) - 5 years retrospective analysis. Relative biomass and fishing mortality respectively on left and right.

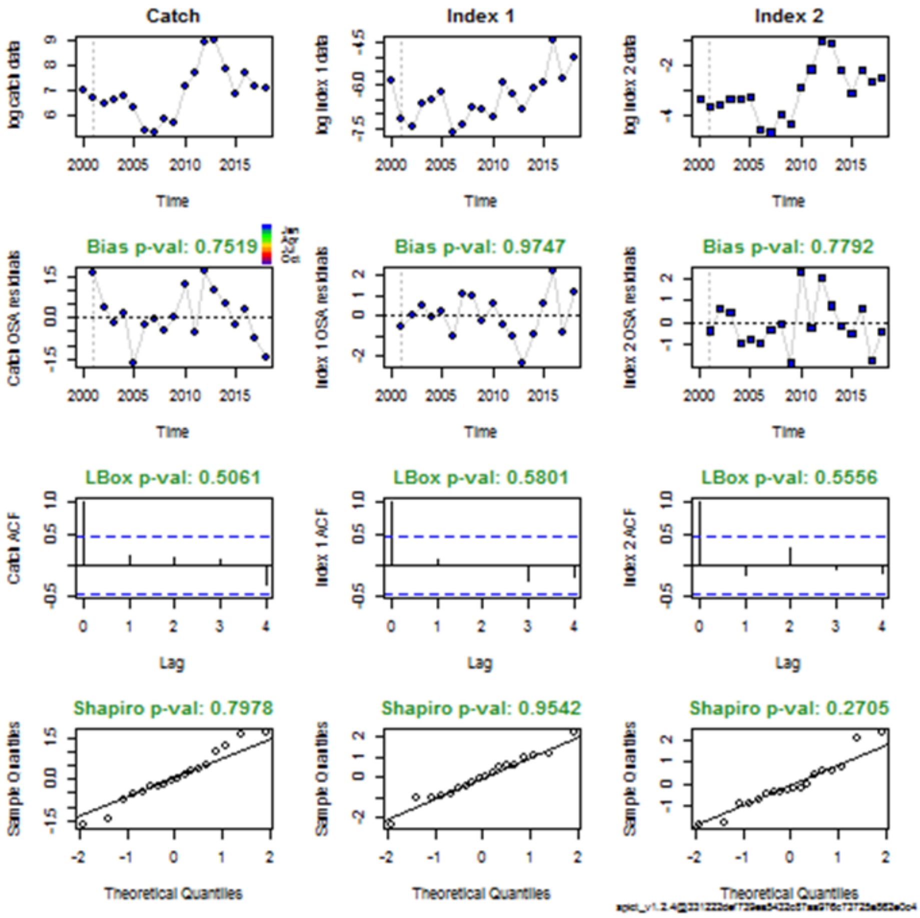


Figure 1.8.A. SPiCT diagnostic for Ommastrephidae of Northwest Iberian Peninsula (8.c. 9.a north). Row 1 Log of the input data series. Row 2 OSA residuals with the p-value of a test for bias. Row 3 Empirical autocorrelation of the residuals with tests for significance. Row 4 Tests for normality of the residuals. QQ-plot and Shapiro test.

Appendix C – Loligo vulgaris exercise in the Bay of Biscay

Model simulations fixing parameters - *Loligo vulgaris* in the Gulf of Biscay

When using the default values the models do not converge and results show wide confidence intervals. Trying to fix the model, some assumptions were made to set parameters values: for example, using Schaeffer model (fixing n=2). In one of the results, convergence was achieved and relatively acceptable results were obtained to estimate relative stock biomass (Table 3.1.).

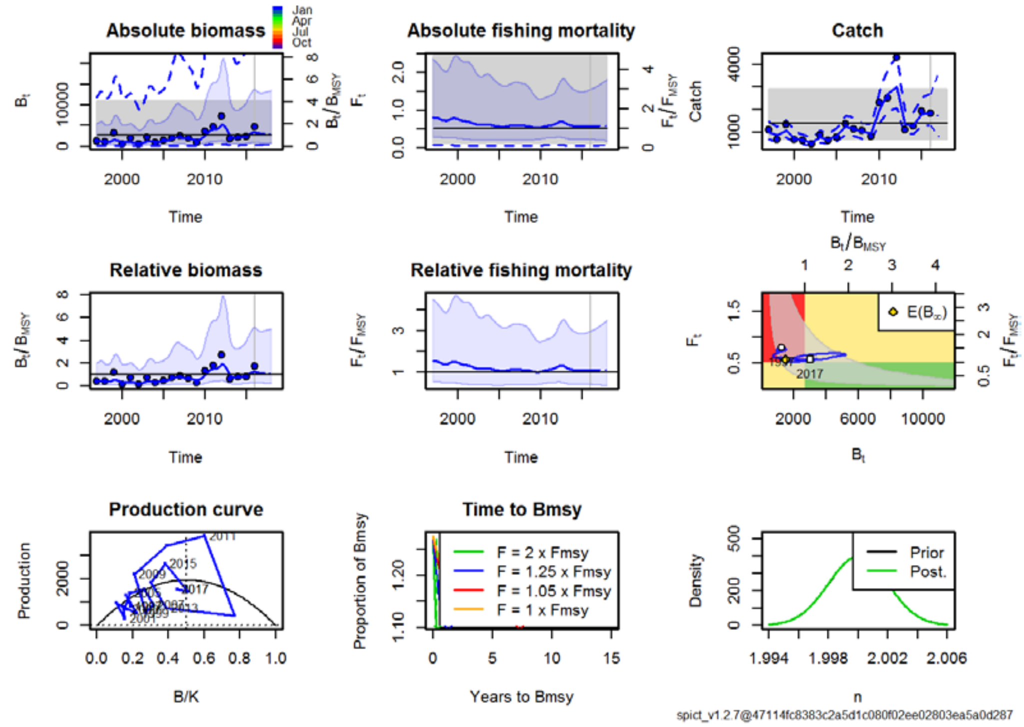
These results are part of an exercise and they will be considered as an example of the possible assumptions that will be done to fix the SPiCT model.

Table 3.1. Different cases conducted. trying to fix model priors. Red cases did not converge. green did and Case 6a* is the one retained giving best model fitting (Schaeffer model).

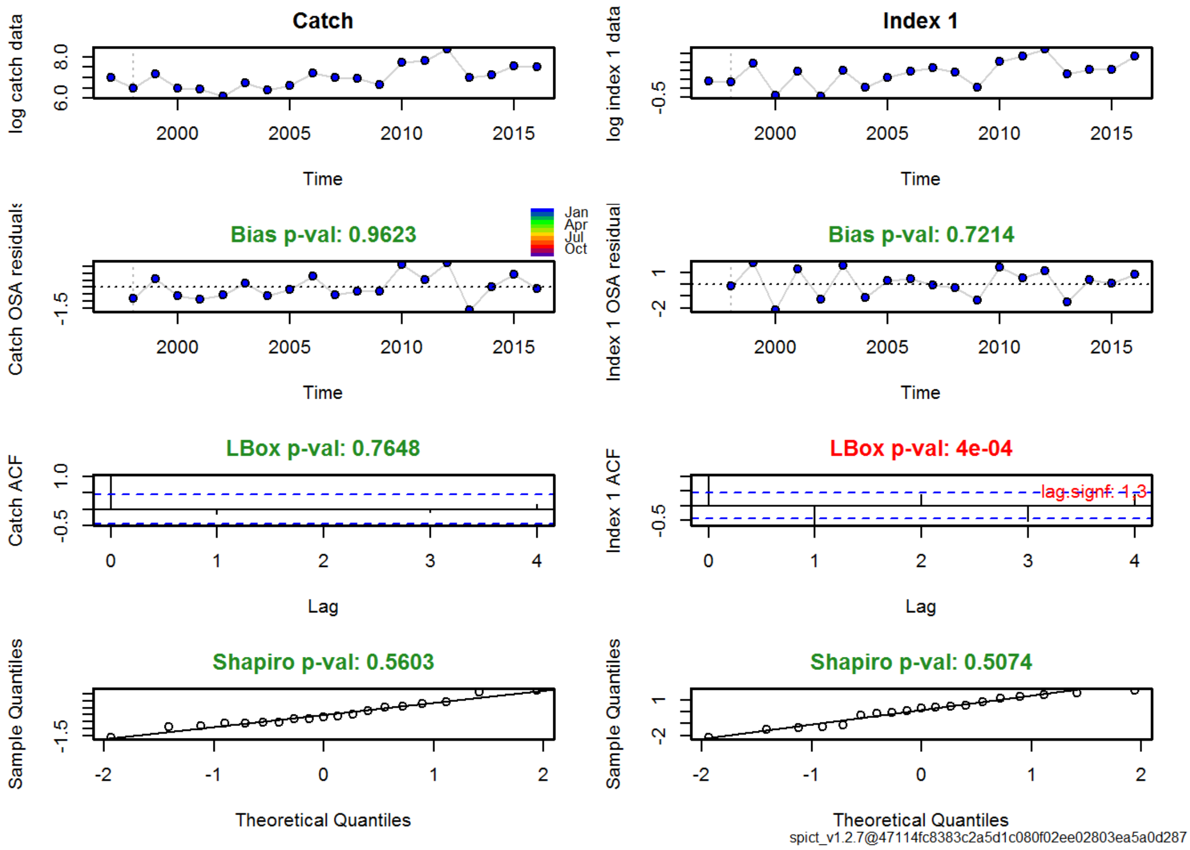
SPICT	n=estimated	n=2	n=estimated Prior r	n=2 Prior r
No priors	Case 0a		Case 0b	
α estimated β estimated	Case 1a Case 2a	Case 5a	Case 1b Case 2b	Case 5b
α=1, β=1	Case 3a	**Case 6a***	Case 3b	Case 6b
α=4, β=1	Case 4	Case 7a	Case 4b	Case 7b

Diagnostics and retrospective plots for Case 6a: α=β=1 and n=2 (Schaefer model)

Assessment results



Residual diagnostics



Model parameters and 95% CI

	estimate	cilow	Ciupp
alpha	1	0.998	1.002
beta	1	0.998	1.002
r	1.145	0.295	4.442
rc			
rold			
M	1938	1075	3494
K	6772	1589	28866
Q	0.001	0	0.012
N	2	1.996	2.004
Sdb	0.487	0.354	0.671
Sdf	0.224	0.135	0.369
Sdi	0.487	0.354	0.671
Sdc	0.224	0.135	0.369

Reference points: (Loliginidae in the Bay of Biscay)

Deterministic reference points

	estimate	ci_{low}	ci_{upp}	log.est
B_{MSY}d	3386	794	14433	8.127
F_{MSY}d	0.572	0.147	2.221	-0.558
MSYd	1938	1075	3494	7.569

Stochastic reference points

	estimate	ci_{low}	ci_{upp}	log.est	rel.diff.Drp
B_{MSY}s	2698	665	10937	7.900	-0.255
F_{MSY}s	0.523	0.110	2.474	-0.649	-0.095
MSYs	1376	656	2883	7.227	-0.409

Stock status

	estimate	ci_{low}	ci_{upp}	log.est
B2016.00	3441	369	32056	8.143
F2016.00	0.582	0.064	5.262	-0.542
B2016/B_{MSY}	1.275	0.316	5.146	0.243
F2016/F_{MSY}	1.113	0.417	2.973	0.107

(Note: Biomass is above B_{MSY} but F is above F_{MSY})

Retrospective plot Case 6a data until 2016