Annex1 to WP.4.2 deliverable

North Eastern Atlantic cephalopods stock assessment in a data limited framework

Surplus Production in a Continuous Time (SPiCT)

Angela Larivain[1], Michael Petroni[2], Ane Iriondo[3], Esther Abad[4], Julio Valeiras[4], Ana Moreno[5], David Dinis[5], Alberto Rocha[5], Vladimir Laptikovsky[6], Jean-Paul Robin[1], Anne Marie Power[2]

[1] UNICAEN, Normandie Univ., Biologie des ORganismes et Ecosystèmes Aquatiques BOREA (MNHN, UPMC, UCBN, CNRS-7208, IRD-207) CS 14032, 14032 Caen, France,
[2] NUI, National University of Ireland Galway, Ryan Institute, School of Natural Sciences, Galway, Ireland,
[3] AZTI Sustainable fisheries management, Txatxarramendi Ugartea z/g. E-48395 Sukarrieta - Bizkaia, Spain,
[4] Centro Oceanográfico de Vigo, Instituto Español de Oceanografía, Subida a Radio Faro 50, 36390 Vigo, Spain,
[5] IPMA Instituto Português do Mar e da Atmosfera, Divisão de Modelação e Gestão dos Recursos da Pesca, Departamento do Mar e dos Recursos Marinhos, Rua Alfredo Magalhães Ramalho nº 6, 1495-006 Lisboa, Portugal,
[6] CEFAS Group of Fisheries and Ecosystems Management Advice, Fisheries Division, Pakefield Rd. Lowestoft, Suffolk, NR33 0HT, U.K.

Abstract

The lack of management leaves fishery resources vulnerable to increases in fishing pressure. Although some cephalopods are of commercial importance, most of Northeast Atlantic stocks are non-quota species (no catch or effort limits in large-scale fisheries and only some harvest control rules at the local scale in inshore fisheries). 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. This had contributed to prevent the use of classical stock assessments methods and monitoring such species is also data-demanding with some of the largest EU cephalopod fisheries being not include in fishery data collection protocols. These factors have led the cephalopods to be classified under the ICES category 3 data limited stocks.
Several stock assessment exercises were already carried out in European cephalopods but the wide variety of models tested to tackle distinctive features of different species makes it difficult to compare results. The progress on assessment methods for short-lived data limited stocks that are cephalopods and estimation of biological and MSY proxy reference points, focused on the application of the model SPiCT for stochastic production in continuous time (Pedersen and Berg, 2017).
This model allowed the abundance time series for several Northeast Atlantic cephalopod stocks to be fit, including cuttlefish and squids (Loliginidae and Ommastrephidae) and octopuses (Octopodidae). The different assessed stocks were distributed from Scottish to Spanish and Portuguese fishing grounds. All models have been fitted with the R package SPiCT, the homogeneous protocol allowing comparisons between outputs. In the presented cases, the model converged and the exercise provided useful preliminary diagnostics, allowing long-term trends in productivity to be considered reasonable (only the Rockall 6.b exercise for *Loligo spp.* showed unreliable outputs). Results for the cuttlefish indicated a rather good condition of the stock since 2008, relative fishing mortality interestingly following the fishing efforts trends on the available time-series. For several Loliginid stocks, results allowed statements to be made about whether biomass and fishing effort were above or below MSY reference values. However, especially for Ommastrephidae and Octopodidae, confidence intervals were still huge and it was generally not possible to be sure whether biomass and fishing effort were above or below reference levels. Also the convergence was sometimes obtained after a set of input parametrization on the priors. The possible causes for this uncertainty are discussed and will have to be further explored even if some refinements to the approach taken are already proposed for future work.

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

Table des matières

INTRODUCTION

Cephalopods are major resource for European fishing fleets with ~ 50,000 t tonnes landed per year (56,500 t on average for the 2014-2018 period). 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.

Cephalopods are data-limited species and 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).

Different assessment tools have been proposed to determine the status of several European 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 (Alemany et al., 2017; Gras et al., 2014). However, while cohort analysis suggested that growth overfishing (and optimal fishing mortality 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). 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. The common cuttlefish (*Sepia officinalis*) is an important resource mostly shared by French and English fishers in the English Channel and the common octopus (*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 *O. vulgaris* has been modelled (Sobrino et al., 2020, see also previous WGCEPH reports). Instead of testing various tools in different cases, it was agreed to apply a common assessment method to a series of data sets by the use of Stochastic Surplus Production model in Continuous Time (SPiCT) (Pedersen & Berg, 2017). Good results were obtained when assessing data on the limited South Pacific albacore tuna resources, and the also data-limited stock of anchovy in the 9.a has been subject to the SPiCT assessment under the WKDLSSLS, ICES workshop of the WKLIFE group. Some other species, like the Brill (*Scophthalmus rhombus*) in subarea 4 and ICES divisions 3.a and 7.de, have been validated as SPiCT assessment with application of precautionary buffer. However, only one published example was found abroad about the application of the SPiCT model to cephalopod stock, it concerns the Argentine squid (*Illex argentinus*) in a data-limited situation in Southwest Atlantic (Han et al., 2018). In contrast to other production models, this one models both stock dynamics and the dynamics of the fisheries, enabling error in the catch process to be reflected in the uncertainty of estimated model parameters and reference points (Pedersen & Berg, 2017).

In the present study, we used limited data available for sepiidae, loliginidae, ommastrephidae and octopodidae, all being (or becoming) important fishery resources. Although *Eledone spp.* is of less commercial importance in European shelf waters it was also included in assessment exercises.

Following the recommendations of ICES WKProxy (ICES, 2016) and WKLIFE (ICES, 2012b, 2017, 2019), the objective of this work was to apply SPiCT to provide a preliminary assessment for a range of cephalopods stocks in the Northeast Atlantic waters. It allows the comparison of the results and provide a basis for further analysis (ICES, 2016), with the ultimate aim of facilitating routine stock assessment in support of management.

MATERIAL AND 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).

General characteristics of cephalopods

Cephalopods are short-lived species, meaning they are characterized by short life span (two-year lifespan being the highest record), high variable growth, suffer a high natural mortality, mostly linked to the environmental conditions, and have a high recruitment variability (Pierce *et al.*, 2008). Because of the nature of their life-cycle, cephalopods have been described to require specific models development (Alemany *et al.*, 2017). Given the population dynamics characterized by large (multi-) inter-annual fluctuations in landings, and regular annual migration cycle for certain like the cuttlefish, they are difficult to assess, especially in a need to compare the status among the stocks.

Available data

Total landings by country and ICES divisions are available by calendar year (January-December), provided in the ToRA tables by ICES WGCEPH. Landings of all Loliginidae stocks but the 7.de and 8.abd were previewed to identify any potential fishing season pattern as opposed to annual. Fishing season in the English Channel (7.de) were already describe to be from June year y to May of the following year y+1 (Royer *et al.*, 2002). Thus, the fishing season for the other Loliginidae stocks was determined by visually inspecting monthly landings data for seasonal breaks in landings for each area. The estimated fishing season landings was derived by calculating the proportion landings for each month across all the available years of the monthly *Loligo spp.* landings data. The monthly proportion was applied to the annual Loliginidae landings data between 1992 and 2019 (sourced from WGCEPH ToR A) to get a broken down estimate of each month to obtain an estimated monthly landings time-series from all fleets. Fishing season was then calculated as described before from this new estimate Loliginidae time-series.

When monthly landings were available and relevant for the stock unit of concern, landings were also compiled quarterly (see Table 1).

Discards data suggested that discarding occurs only in areas where cephalopods catch is low (ICES, 2019) – for example, on board observation provided by "OBSMER" IFREMER program reported squid discards < 6% in the English Channel (ICES, 2017) – Thus, in the study, discards are considered negligible.

Data extraction for the compilation of abundance indices originated from both commercial fisheries - which allowed the derived standardization of abundance indices - and from research surveys for the concerned regions (detailed in **Appendix 1**).

The use of SPiCT (Surplus Production in Continuous Time)

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, F_{MSY}, B_{MSY}) 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).

SPiCT allowed the use of the Pella-Tomlinson (1969) surplus production formulation with the parameter *n* controlling the shape of the production curve (equation 1), allowing it to be asymmetric with respect to the biomass and with the determination of the maximum level of productivity. When *n* equals two, the equation refers to a Schaeffer model (Pedersen & Berg, 2017).

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

Equation 1. General formulation of the surplus production

Where r is the intrinsic growth rate parameter, K the carrying capacity and n the asymmetry parameter of the production curve.

Group	AREA	Landings (tons)	**Data sources and time periods**	
			Origin of catch data	Origin of survey abundance indices
Sepiidae	7.de	10,670	FR-OTB + UK-TBB quaterly landings [2000-2019]	* FR-OTB LPUE yearly [2000-2019] * UK-TBB LPUE November [2000-2019]
	8. abd	4,695	ToRA table [2000-2019]	* FR-OTB LPUE [2000-2019] * EVHOE_CPUE [Q4 1997-2019]
Loliginidae	6.a; 7.bc	439	Fishing season landings (July-June) [1995-2019]	* 2 MSS [1995-2018] * SCOGFS [Q4 1995-2018] * IGFS_CPUE [Q4 2003 -2019] * SWCIBTS [1995-2018]
	6.b	673	Fishing season landings (May-April) [2000-2019]	* Rockall survey *Lfor* [2001-2019] * IR_LPUE [2001-2018]
	7.a	5	Irish Sea (7.a) annual landings [1996-2019]	* IGFS_CPUE [Q4 2003-2019] * NWGFS [Q3 1988-2019]
	7.ghjk	228	Celtic Sea (7.ghjk) annual landings [2000-2019]	* IGFS_CPUE [Q4 2003-2019] * EVHOE_CPUE *Lfor* [Q4 1992-2019] * IR_LPUE (7.g) [2000-2019] * IR-LPUE (7.j) [2000-2019]
	7.de	4,512	ToRA landings (mix) [1992-2019]	* FR-OTB LPUE (mix) yearly [1992-2019] * UK-TBB LPUE November [2000-2019]
	8 abd	1,492	ToRA table [1997-2019]	* FR-OTB LPUE [2000-2019] * EVHOE_CPUE *Lvul* [Q4 1997-2019]
	9.a.s	<962	PT + ES landings]1993-2018]	* SP-ARSA (March) + PT-IBTS (Nov.) [1993-2018]
Octopodidae	9.a.S	3,354	PT landings RFOTBW [2003-2019]	* LPUE_RFMISS [2003-2019]
	8.c; 9.a N		ES landings [2000-2019]	* Survey demersal Sept.-Oct. [2000-2019] * ES_OTB_LPUE [2009-2019]
Ommastrephidae	8.c; 9.a N	<1,073	ES landings [2000-2019]	* Survey demersal Sept.-Oct. [2000-2019] * ES_OTB_LPUE [2009-2019]

Table 1. Cephalopods stocks and inputs data used for SPiCT assessment in Northeast Atlantic waters

ToR A table is the compilation of annual landings statistics carried out by WGCEPH. (in stocks landings figures preceded by "<" are overestimates computed for the whole 9.a division). Survey acronyms are described in **Appendix 1.** Abundance indices derived from commercial fishery statistics: France Otter Bottom Trawl delta-GLM standardized LPUE (FR-OTB LPUE), United Kingdom Beam Bottom Trawl LPUE (UK_TBB_LPUE), Spanish Otter Bottom Trawl LPUE (ES_OTB_LPUE), LPUE_RFMISS Landings figures for each group are the average landings of the Fourth last years (2016-2019) (in tons).

SPiCT (version 1.2.8) was used to fit a stochastic surplus production model in continuous time to abundance index series for several cephalopods stocks occurring in North-eastern Atlantic waters. The model incorporates both fisheries and biomass dynamics (the model combining the main biological processes *e.g.* recruitment, growth, natural mortality in a single function) 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 actively under development, and guidelines for its use is also available for the check of main assumptions, acceptance of SPiCT assessment and management part (Mildenberger et al., 2020; https://raw.githubusercontent.com/DTUAqua/spict/master/spict/inst/doc/spict_guidelines.pdf).

Autocorrelation and normality of the catch and abundance indices residuals were tested using Ljung-Box and Shapiro tests.

Several models trials were run in all the exercises, using different set of catch data (annual, seasonal or quarterly landings compilation), allowing SPiCT to estimate the seasonal pattern of the fishing mortality when quaterly data were available. For each stock, different scenarios were run according to the available datasets and settings (default or some fixed parameters) are described in each section.

When a fix parametrization of the n prior (shape of the production curve) was not changing the model performance, the default setting was kept in order to follow the SPiCT recommendations (Alexandros Kokkalis saying during WKDLSSLS2).

In all the cases using any priors in order to obtain at least the convergence, a sensitivity analysis was applied to check how much it affected the outputs estimates. When the outputs relied on the guidelines and Mildenberger (2019), the best models were selected and presented in this work.

RESULTS

Surplus production models were fitted with SPiCT for the ten stocks listed in Table 1.

Fisheries characteristics have been described in WGCEPH reports (see for instance ICES, 2019), however, when needed, some valuable information that help inputs or outputs comprehension are presented. 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.

Sepiidae assessment

The common cuttlefish (*Sepia officinalis*) in the English Channel (ICES divisions 7.de)

In the English Channel (ICES divisions 7.de), the cuttlefish is mainly exploited by France and U.K. countries (England, Wales and North Ireland), being of an important commercial interest (WGCEPH, 2020). In this region, the stock consists mostly of the cuttlefish *Sepia officinalis*, the species having a 2 years old life cycle with a fishing season assumed to start in July the year y until June the year y+1, with seasonal migrations (offshore, in the central western channel part in the winter/coastal areas during spring-summer) (Alemany *et al.*, 2017).

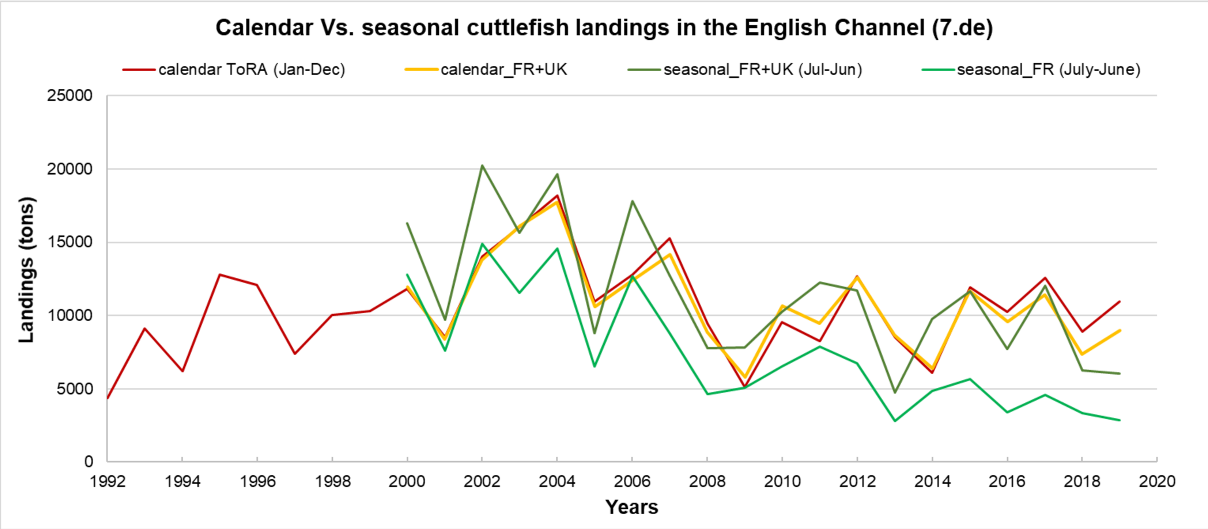


Figure 1: Comparison of English Channel cuttlefish *Sepia officinalis* landings inter-annual trends computed using calendar years (Jan-Dec) or fishing seasons (July-June).

Following last year SPiCT stock assessment exercises (WGCEPH, 2020 & WKDLSSLS1 in July), models and data have been updated, running a permutation of trials testing different versions of landings: (1) calendar year (Jan-Dec) [1992-2019], (2) seasonal year (July-June) (Figure 1) - according to the fishing season of the species - and (3) quarterly, both (2) and (3) available for a shorter period [2000-2019]; all with default priors and different model settings.

5 index (2 from commercial fisheries/3 from surveys) were initially available for this stock unit: the standardized FR-OTB LPUE (kg/h) [1992-2019]; the mean November LPUE from UK-TBB [2000-2019]; the biomass index from the Channel Ground Fish Survey (CGFS) collected in September-October [1990-2019]; abundance index from the Bottom Trawl Survey (BTS7d) collected in July [1989-2017] and the abundance index from the South Western Beam Trawl Survey collected in Quarter 1 each year (Q1SWBEAM) [2007-2018].

The index time-series were cut to cover the landings time-series as recommended (WKDLSSLS). The performance was tested using different data sets (combination of catch/index) and various model settings (no priors, default, fixed prior on n) and models allowing seasonal fishing mortality (fixed pattern over time) were also tested. These were considered reasonable given historical data and knowledge on the species. Although survey indices are available, they appeared to widen the confidence intervals or restricted the convergence of the model (Q1SWBEAM, was evicted because of its covering). Two indices are available in nearly the same time, the UK-TBB (November) and the CGFS (September-October), showing conflicting signals. It was then decided to remove one of the two, the CGFS survey index as it covers only the 7.d part of the channel (and also the new standardization process shown residuals autocorrelation in the diagnostics checking). The four tested scenarios are presented in the WD of the WKDLSSLS (2020), with different inputs and settings.

The best model performing was concluded to consider *Sepia officinalis* quarterly FR+UK landings from July 2000 to June 2019 with the 2 commercial LPUE - yearly standardized FR-OTB LPUE [2000-2019] and November UK-TBB LPUE [2000-2019] -, with default priors (estimated by the model). The quarterly landings allowed the representation of the fishing mortality pattern, with higher mortality pointed around May-June and November-December each year (Fig. 2 bottom center).

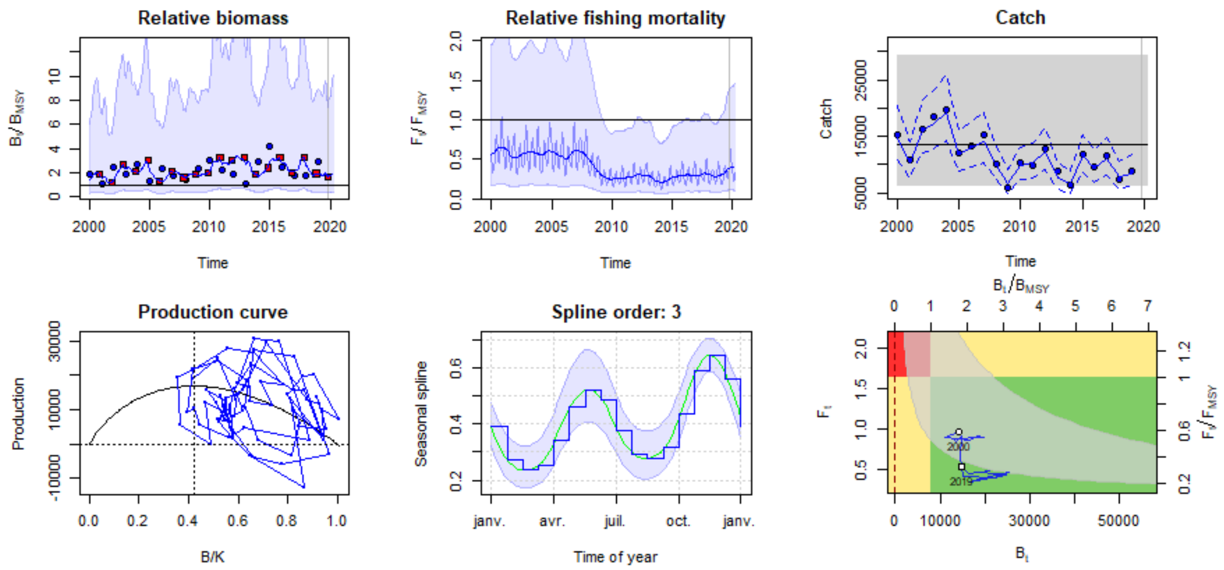


Figure 2: Main outputs of the best model fitted for English Channel cuttlefish

Residuals appeared randomly and independent distributed and the 5 years retrospective plots showed consistent performance (Appendix 3.A1.). The confidence intervals of both relative biomass and fishing mortality (B/B_{MSY} and F/F_{MSY} respectively) are still high, even reasonable, with B/B_{MSY} spanned the 2 orders of magnitude required in the Guidelines (which could be revised for species like cephalopods in further exploration as the assessment could not be benchmarked at this stage).

B_{2020}/B_{MSY} was estimated at 1.77 and F_{2020}/F_{MSY} at 0.39 (Table 6) which, despite the still large confidence intervals, indicate that the cuttlefish stock of English Channel is reasonably exploited, even in a better condition since 2008. However, fishing effort in some fishing grounds can change very suddenly (as observed in September 2017, off Devon and Dorset) and the consequences of such changes still needs investigations.

The cuttlefish in the Bay of Biscay (ICES divisions 8.abd)

The stock of interest is also mainly considering *S. officinalis*, fished almost exclusively by French and by OTB as in the Channel. Landings were at the lowest in 2003 (1,500 T in average) and at the highest 2 years later in 2005 with about 8,000 tons. Since 2015, landings have decreased in the Bay of Biscay, averaging 4,000 tons (WGCEPH, 2020).

Models tested were considering the annual coverage for the total 8.abd from the ToRA (Table 1; ICES, 2020) and two indices available (one from the FR-OTB commercial fishery of the 8.abd and one from the EVHOE survey). The FR-OTB commercial landings were used to compile the abundance index averaged for 2000-2019 period in the selected region (8.abd) following the same procedure applied through the delta-GLM method (Appendix 2.).

FR abundance index from 2000 to 2019 period and the biomass index (CPUE) from the EVHOE survey available from 1997 to 2019.

The best model is considering the annual coverage landings cut according to the index used (FR-OTB_LPUE) from 2000 to 2019 (Figure 3).

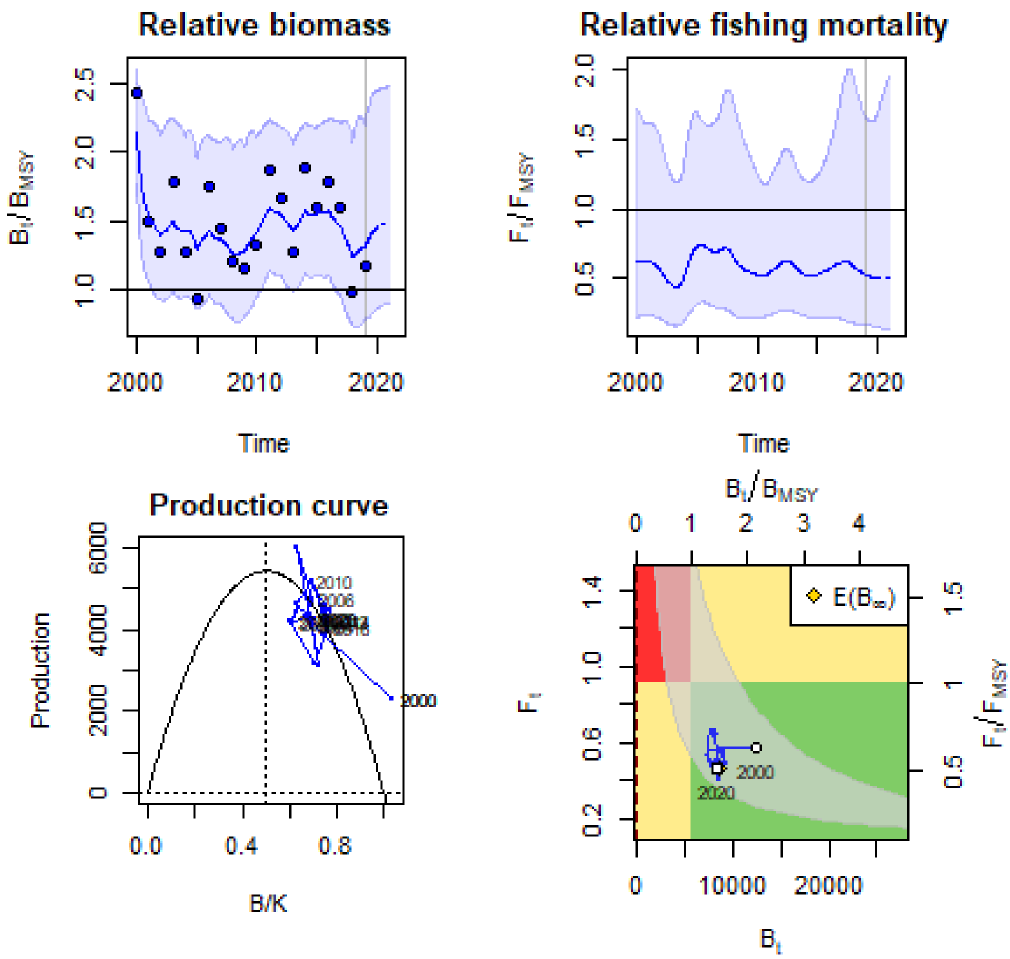


Figure 3: Main outputs for the best model fitted in the Bay of Biscay cuttlefish

The SPiCT model result is uninformative for 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.

Table 2. Summary of the outputs parameters with corresponding confidence intervals [CI] for the best models fitting using SPiCT on Sepiidae. α the process errors of the inputed indices; β the observation error (difference between the measured biomass and the real biomass); n the shape of the production curve; r the intrinsic growth

Outputs parameters	**α**	**β**	**N**	**r**	**K**	**sdb**
CTC.7de	0.93 [0.56-1.55] 0.15 [0.02-0.97]	0.85 [0.36-2.05]	1.32 [0.24-7.15]	1.97 [0.59-6.62]	26,915 [10,206-70,984]	0.47 [0.32-0.70]
CTL.8abd	1 (fixed)	1 (fixed)	2 (fixed)	1.82 [0.41-8.12]	11,925 [2,479-57,365]	0.18 [0.12-0.26]

rate; K the carrying capacity of the stock and sdb the standard deviation of the biomass.

CTC.7de the FAO code for *Sepia officinalis* in the English Channel; CTL.8abd for the Sepiidae in the Bay of Biscay

Loliginidae assessments

Several stock assessments were run for the Loliginidae, from North (Irish/Celtic seas) to South (Gulf of Cadiz) of the Northeastern Atlantic waters. Following last year exercises, SPiCT models have been updated, which include using updated, sometimes corrected input datasets (time-series/calculation).

Results in Northern areas:
-Rockall 6b no convergence with default. Horrible models when using bkfrac settings.
-Area 6a7bc again were confusing with the best model using bfrac of 0.5 - this model is not the most reliable (among Northern trials).
-the best stocks were 7a using default but also bkfrac was good.
-the 7ghjk worked best with bkfrac =0.5 but the default model showed similar results just with wider confidence intervals.

Loliginids in the west coast of Ireland and Scotland (6.a and 7.bc)

The stock of interest consists mostly of *L. forbesii*, with the occasional *L.vulgaris* and a small portion of *Alloteuthis spp*. Convergence was obtained using the fishing season landings data [July to June y+1] between 2000 and 2019 (Table 1), for different models setting scenarios tested. The two abundance indices used were IGFS and SCOGFS CPUE putting in the corresponding time of the year (quarter 4).

The best model outputs were obtained setting bkfrac prior at 0.5, even with still high CI in the relative fishing mortality obtained (Fig.4).

The production curve shifted slightly to the left, which is expected in cephalopods, however, negative production was still observed for certain years. The default model scenario settings produced results with similar trends but having unacceptably large confidence intervals and unsatisfactory production curve. All model scenarios produced a consistent output of relative biomass > 1 and relative fishing mortality < 1 (Table 6) suggesting that the stock would be in good condition. For both default and bkfrac setting models, an increasing trend in both relative fishing mortality and relative biomass appears from 2015 to present day. Since fishing season landings were used, projections for 2020 were not possible. Given these signals it is difficult to reconcile the assessment of the loliginid stock within ICES divisions 6.a and 7.bc and so this stock cannot be assessed accurately.

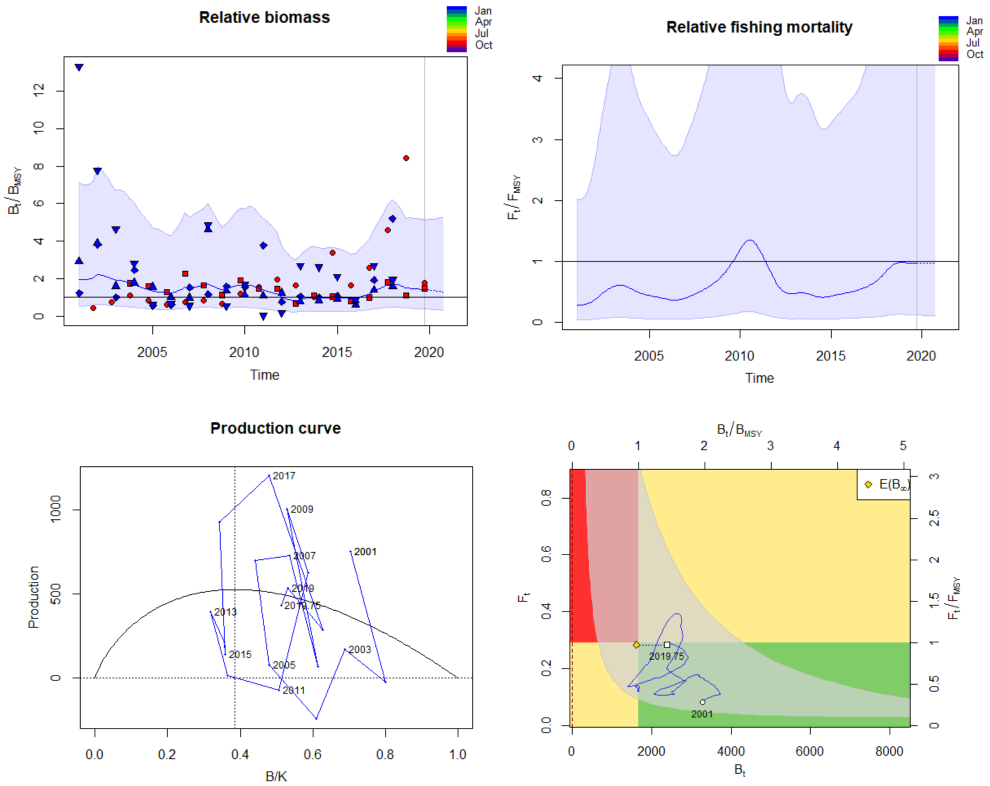


Figure 4: Main outputs of the best model fitted in Loliginids in the west coast of Ireland and Scotland (6.a and 7.bc)

The average catch from the prior four years (2016-2019) was 439 tonnes (Table 1), falling below the stochastic MSY_s estimated to be 488 tonnes (Table 6). Retrospective plots showed the model provided consistent performance in the relative biomass but was slightly variable with relative fishing mortality (Appendix 3.B1). Model diagnostics indicated that autocorrelation was evident in the SCOGFS CPUE index and catch data series and possible normality issues were observed with the Irish LPUE dataseries from areas 7b and 7c (Appendix 3.B1).

Loliginids in Rockall (6.b)

The stock of interest was represented by mixture of loliginid but effectively dominantly consists of *L. forbesii* in the landings, which is reflected by the CPUE index from the Rockall survey by Marine Scotland Science (MSS). Given the great importance given to Rockall as a squid hotspot (referred to as 'squid alley' by fishers), the stock assessment results would be of interest in informing management decisions.

Model convergence was obtained using estimated fishing season landings [May_y to $April_{y+1}$] data only for the trials with the two abundance indices available and described in Table 1. Convergence was not obtained with the default setting, so the presented model, accepted so far, used a bkfrac prior set to 0.5. However, the outputs from the model showed $B_{2020}>B_{MSY}$ and $F_{2020}<F_{MSY}$ (Table 6) suggesting the stock being in a good condition and currently exploited at sustainable levels. Unfortunately, the model still produced unsatisfactory results characterised by extremely wide confidence intervals (Figure 5). Retrospective plots showed the model provided consistent performance in the relative biomass but was slightly variable with relative fishing mortality (Appendix 3.B2). The model diagnostics (Appendix 3.B2) produced otherwise satisfactory results, with only a slightly violation in Lag.1 residuals autocorrelation for one of both indices.

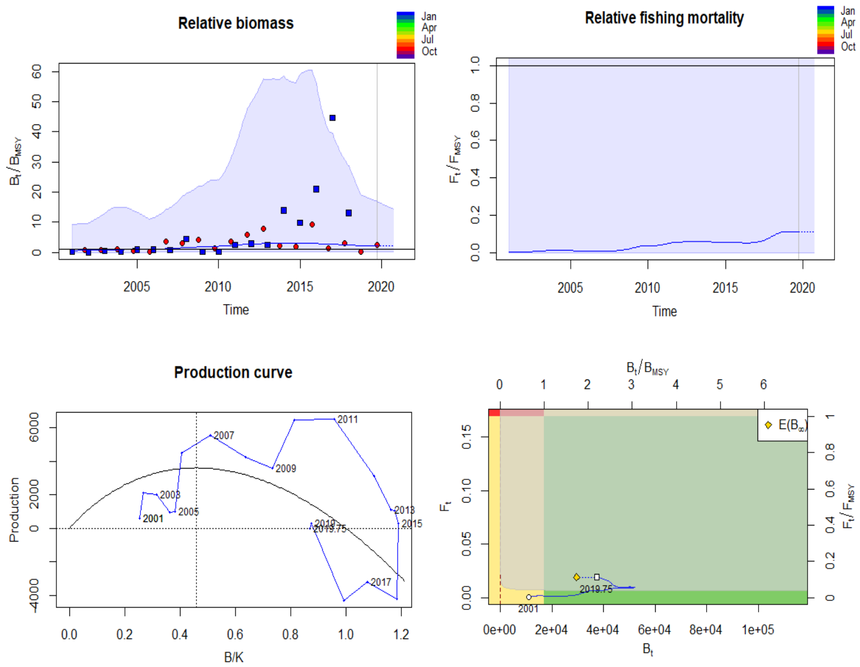


Figure 5: Main outputs of the model fitted in Loliginids in Rockall (6.b)

Since the model performed poorly and the default model trial could not converge, the stock could not be confidently assessed. Reasons for this could be attributed to possible lack of sufficient data abundance and quality, given the difficulty in surveying the area.

Since fishing season landings were used, projections for 2020 were not possible. The average catch from the previous four years (2016-2019: 673 tonnes) was calculated to be smaller than the estimated stochastic MSYs (2,848 tonnes) (Table 6) suggesting that the stock might be underexploited. These figures however would not be suitable for management advice give the unreliability of this model.

Loliginids in the Irish Seas (7.a)

Models run were using annual landings data available for the division 7.a from the ToRA (Table 1), subset between 1996 and 2019 with both abundance indices available with corresponding season of the year.

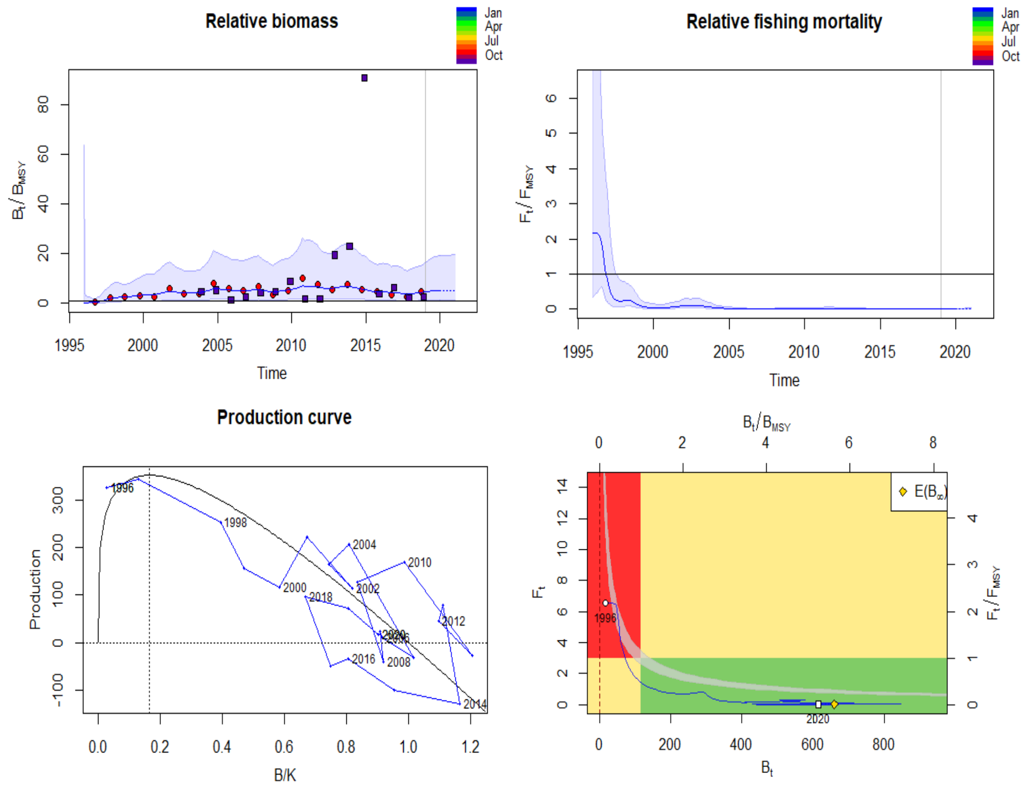


Figure 6: Main outputs of the model fitted in Loliginids in the Irish Seas (7.a)

Confidence intervals of relative biomass and fishing mortality were narrow but the production curve shifted strongly to the left (Figure 6). The results for the bkfrac = 0.5, 0.8 models produced similarly good results with the same trends, however different estimates (Table 3, Appendix C, Figure 2).

The assessment suggest that the stock is in good condition (Figure 6), as relative biomass > 1 and relative fishing mortality < 1 (Figure 3; Table 3) and this was replicated when using the bkfrac = 0.5, 0.8 model settings (Table 3). Given the agreement between the different model specification scenarios, it can be said that this stock is being exploited at sustainable levels. Using the default model settings suggests higher relative biomass and MSY compared to trials using bkfrac priors (under which previous exploitation is assumed).

The average catch from the prior four years was 5.03 tonnes, falling well below the estimated stochastic MSY_s of 352.824tonnes (Table 1). It should be noted that the NWGFS index, which represents a larger area than the IGFS index and catch data, might have an effect on the model, however, convergence could not be achieved without the addition of the NWGFS dataset. Retrospective plots showed the model provided consistent performance (Figure 3.A in Appendix B). The model diagnostics (Figure 3.B in Appendix B) produced satisfactory results with no evidence of autocorrelation or non-normality in the data.

Loliginids in the Celtic Seas (7.ghjk)

The stock of interest in the Celtic Sea consists of L.forbesii and L.vulgaris; however, the only suitable biomass indices available included only L.forbesii as the L. vulgaris CPUE index values were low (i.e. negligible biomass). Convergence was obtained using a subset of the annual Loliginidae landings dataseries between 2000 and 2019. Despite having slightly wide confidence intervals, the selected model specifications with bkfrac = 0.5, produced the best results, however the default priors model produced similar results but with wider confidence intervals (Appendix C, Figure 3). The production curve followed a somewhat chaotic path but was shifted slightly to the left, which is expected in cephalopods.

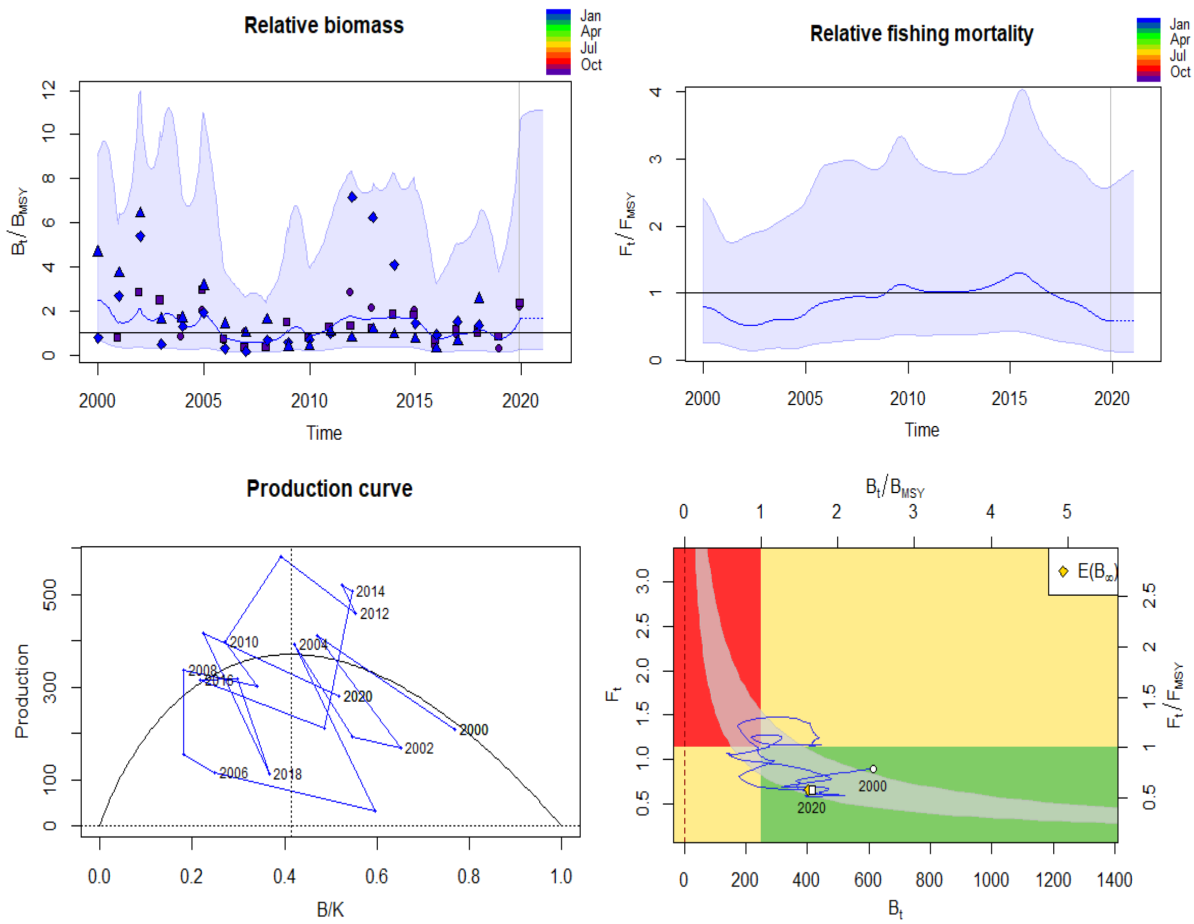


Figure 7: Main outputs of the model fitted in Loliginids in the Celtic Seas (7.ghjk)

The assessment suggest that the stock is in good condition (Figure 7), as relative biomass > 1 and relative fishing mortality < 1 (Figure 4; Table 4) and this was replicated when using the default model settings (Table 4). Given the agreement between the different model specification trials it can be said that this stock being exploited at sustainable levels and that using the bkfrac = 0.5 offers a more conservative estimate of MSY with reduced uncertainty compared to using the default settings.

The average catch from the previous four years (227.5 tonnes) was calculated to be smaller than the estimated stochastic MSYs (283.8 tonnes) (Table 1). A potential caveat of this model is the lack of representation of L. vulgaris indices, which could have a potential effect on the outcome.

Retrospective plots showed the model provided consistent performance (Figure 4.A in Appendix B). The model diagnostics (Figure 4.B in Appendix B) produced satisfactory results with no evidence of autocorrelation or non-normality in the data.

Loliginids in the English Channel (7.de)

Like for the cuttlefish in this region, *Loligo spp.* are mainly exploited by French and English fishers with trawlers (respectively OTB and TBB). 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 2019.

The distinction between the two *Loligo* species was possible in this area 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 1992.

The best model considered the mix of the Loliginidae, yearly calendar (Jan-Dec) landings from the ToRA [1992-2019] with 2 LPUEs index: - yearly FR-OTB standardized LPUE for the mix [1992-2019] and the November UK-TBB LPUE [2000-2019], with the default priors (Fig. 8).

Like for the cuttlefish unit, CGFS time-series was removed of the assessment as it showed conflicting signals with the UK-TBB LPUE. It was decided to remove as CGFS is not covering the whole channel and gave same signal outputs but wider CI. Also BTS7d index was removed as it was not considered a relevant time-series for this assessment: as a beam trawl it just catches no squids with in 2019 and 2019, only *Alloteuthis spp.* records.

The SPiCT model appeared acceptable for this assessment unit in a complex of a multiple species basis (considering the mix of the two Loligo species). The species-specific models showed conflicting results outputs as the only availability for the distinction of the species came from one side of the Channel (French proportions in one harbour market).

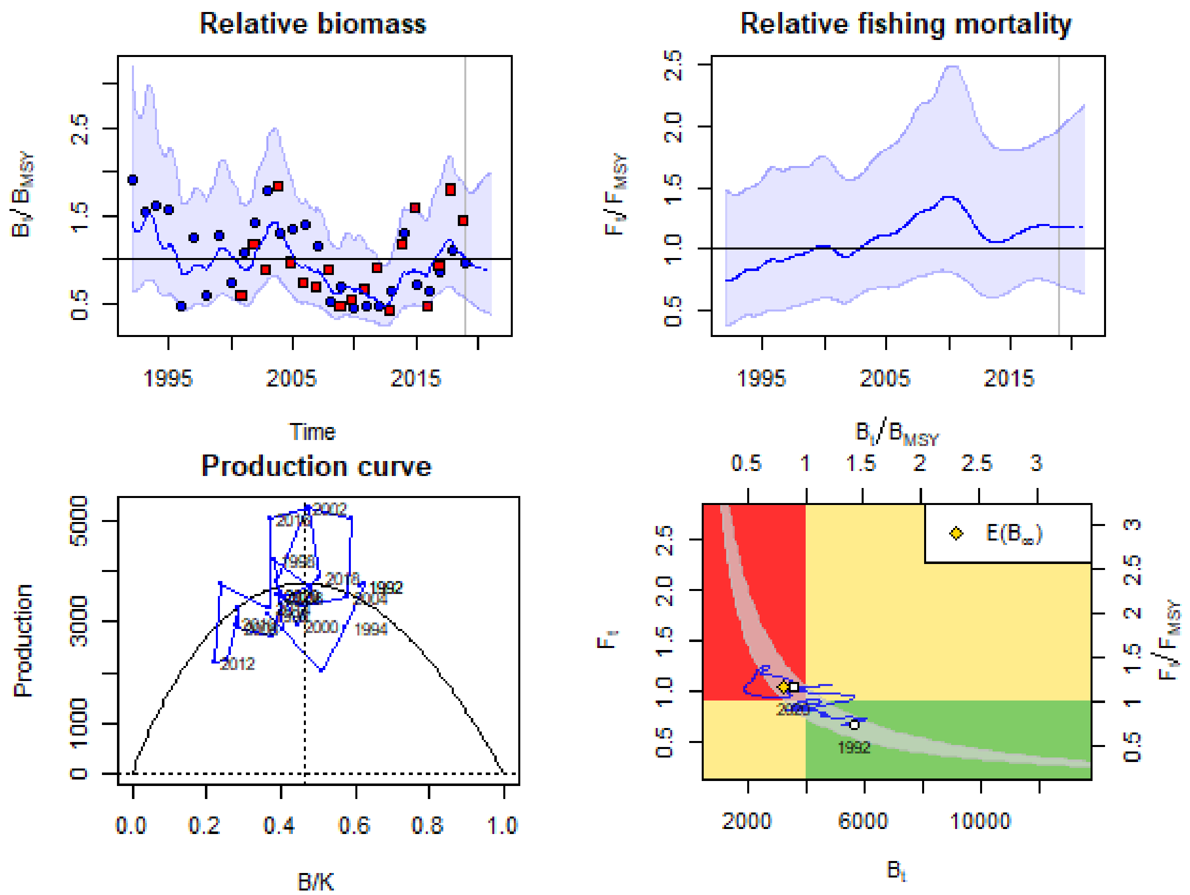


Figure 8 : Main outputs of the best model fitted in English Channel Loliginidae

The model diagnostics (Fig. 8) 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 (Appendix 3.B4.), 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 8**.** bottom right).

Loliginids in the Bay of Biscay (8.abd)

Squid in the Bay of Biscay (ICES divisions 8.abd) are mostly assumed to be the *Loligo vulgaris*, became in the last years a species of increased interest for the Basque fleet. Cephalopod catches were in the past by-catch of other demersal fisheries that target hake, anglerfish or megrim among others. However, in the last years, cephalopods in general and squid in particular obtained in mixed fisheries (mainly “Baka” otter trawls) are becoming more important in relation to the species composition of the catch and are even the target species for some trips. The fact that this stock has no TAC (Total Allowable Catch) and the good price they get make it an appealing alternative for the Basque fleet.

In this region (8.abd), landings are mainly dominated by French (95%) with contribution of the Spanish fleets for the rest (WGCEPH, 2020).

Species-specific EVHOE survey data indicate that in autumn *L. vulgaris* represents on average 83% of biomass indices (ICES, 2019). Previously (WGCEPH, 2019) a series of 16 different initial conditions were tested in order to obtain convergence of the SPiCT fitting procedure and model selection was based on the lowest AIC. Results of the retained model (alpha=beta=1 and n=2; Schaefer model) were still highly uncertain, with graphs showing wide confidence intervals. Data were also incomplete, with EVHOE time-series no longer than 2017 record. The updated run was considering the complete EVHOE time-series until 2019 and like it is available for the Loliginid stock in the English Channel, an abundance index was derived from FR-OTB commercial fisheries with the delta-GLM method - in order to add potential information while assessing the stock with SPiCT.

Convergence succeeded either with or without the FR-OTB LPUE but ‘smoothing’ the contrast of the inputs data (so the CI were wider and only a flat line was shown below the F/FMSY overall the period).

The best model performing was concluded to include the ToRA table landings [1997-2019] for this area (mostly France and Spain, Fig. xxx) with the EVHOE CPUE of *L. vulgaris* [1997-2019].

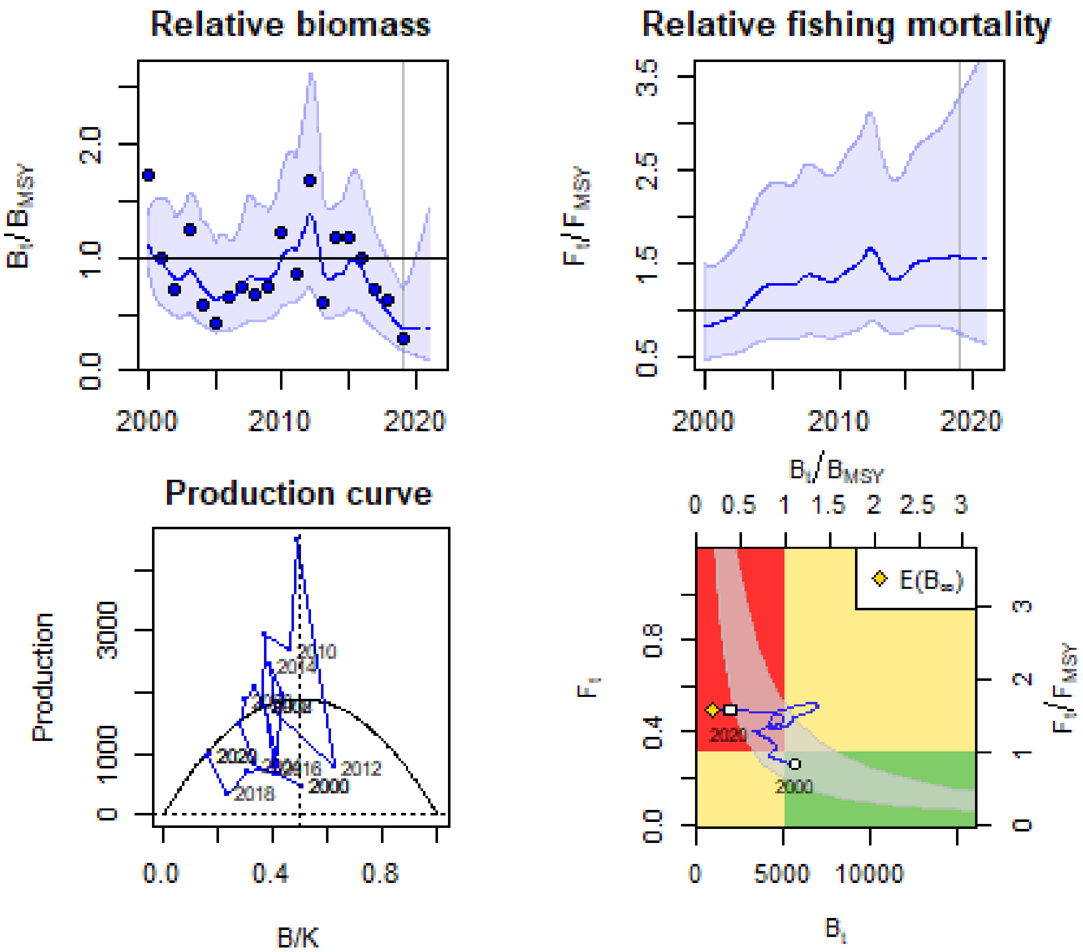


Figure 9: Main outputs of the best model fitted in Loliginids in the Bay of Biscay (8.abd)

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).

Loliginids in the Gulf of Cadiz (9.a South)

The Loliginid stock unit of the Gulf of Cadiz (9.a South) was run in 2019 with outputs results available in the Working Document of the WGCEPH 2020. No data were requested for the year 2020, reason for which the SPiCT was not updated this year. However, previous results were using combination of artisanal and trawl fisheries landings [1993-2018] available for Spain and Portugal countries sharing the resource, and 2 CPUE consisting of both surveys described in **Appendix 1.**: SP-ARSA (March) + PT-IBTS (Nov.) [1993-2018].

The stock of interest is representing a mixture of the two European *Loligo* species, but was agreed to consist on *L. vulgaris* as *L. forbesii* is rare in the south of the Iberian Peninsula. Model Diagnostics were considered satisfactory and provided a consistent retrospective pattern plots of both relative biomass and fishing mortality. Relative biomass was above the B_{MSY} (2.80) and relative fishing mortality below the F_{MSY} (0.24) since 2005, indicated the stock to be in a good condition and sustainably exploited.

Table 3. Summary of the outputs parameters with corresponding confidence intervals [CI] for the best models fitting using SPiCT on Loliginidae. α the process errors of the inputed indices; β the observation error (difference between the measured biomass and the real biomass); n the shape of the production curve; r the intrinsic growth rate; K the carrying capacity of the stock and sdb the standard deviation of the biomass.

Outputs parameters	**α**	**β**	**n**	**r**	**K**	**sdb**
SQZ.6a7bc	3.22	0.16	1.10	0.32	4,658	0.26
SQZ.6b	3.29	1.12	1.62	0.30	42,974	0.29
SQZ.7a	0.73	0.21	0.27	0.84	681	0.32
SQZ.7ghjk	0.69	0.47	1.28	1.44	801	0.60
SQZ.7de	1.11 [0.48-2.55] 1.25 [0.53-2.93]	0.79 [0.15-4.32]	1.64 [0.43-6.27]	1.45 [0.26-8.02]	9,206 [2,888-29,349]	0.28 [0.14-0.57]
SQZ.8abd	1 (fixed)	1 (fixed)	2 (fixed)	0.67 [0.10-4.36]	11,245 [1,721-73,482]	0.29 [0.20-0.43]

SQZ the FAO code for the Loliginidae and the ICES divisions for the region of interest following (*e.g.* 7de for the English Channel).

Octopodidae assessment

The octopod *Octopus vulgaris* in the Gulf of Cadiz (9.a South) (

- Data between 2003 and 2019 for the 27.9.a.s.a + 27.a.s.c subdivisions
- Portuguese + Spanish total landings (tonnes)
- Portuguese LPUE for the polyvalent fleet (kg/fd) -RFMISS
- Spanish LPUE for the trawling fleet (kg/fd)
- Spanish CPUE for the November **IBTM - GFS** surveys (g/h)

Figure 10 shows the main outputs of the model fitted in this area

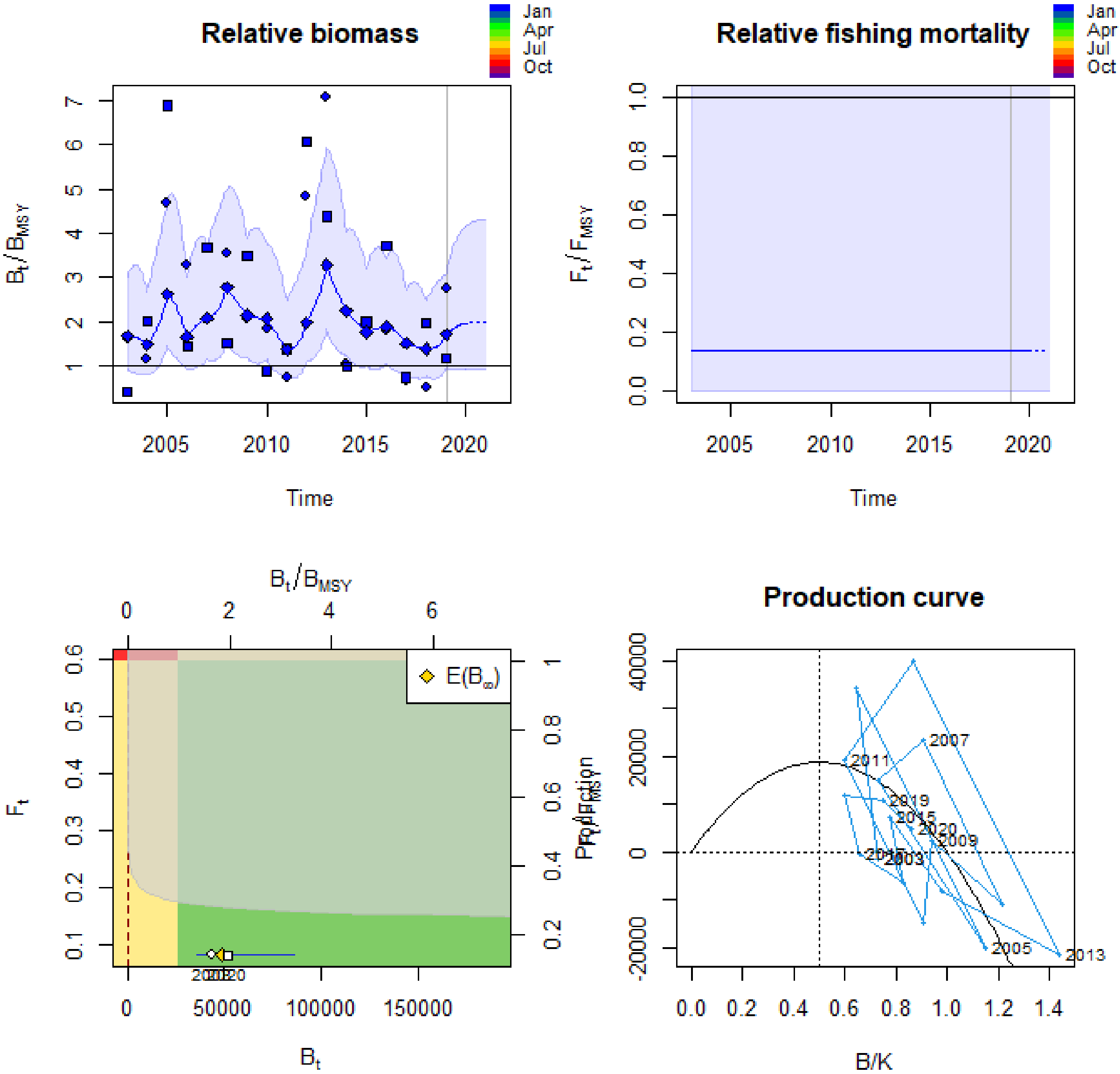


Figure 10: Main outputs of the model fitted in Octous vulgaris in the Gulf of Cadiz (ICES div. 9.a.South)

The octopod *Eledone spp.* in the Northwest Iberian Peninsula (8.c, 9.a North)

The horned octopus *Eledone cirrhosa* is a common demersal species in the North Iberian Peninsula (ICES divisions 8.c and 9.a North). The species is mostly caught in bottom trawlers as a secondary species, as commercially important although *Eledone* is one of the most commonly discard species by trawlers in the area (23.2% discarded in trawls fisheries). The horned octopus is commercially important for the Asturias (western Cantabrian), and increasing towards Galicia and southern latitudes. There are not defined stock units either a management advise by ICES. In this exercise we chose the same ICES divisions (8c9a) of other assessed stocks in the area that are caught by the same fleets.

Models tested were considering the annual Spanish coverage for the 8.c; 9.aN ICES divisions (Table 1; ICES, 2020) from 2000 to 2019 period, including landings from all gears and metiers of the Peninsula region. Two indices were available: the 'Spanish GroundFish Research Survey' index (kg/hauls) operating in the region from 2000 to 2019 in September-October and the Spanish LPUE (tons/fishing sequence) derived from the commercial bottom trawlers > 55 m, operating in the 8.c solely from 2009 to 2019 (Table 1).

The chosen model (Fig. 11) converged with the settings of symmetric productive curve (BMSY/K=0.5) and set priors for the ratio between biomass in the initial year relative to K, mean of log(0.5) and sd of 0.2. The confidence intervals are wide for relative biomass and huge for fishing mortality. The production curve is fixed in a Schaeffer type by the model settings. Kobe plot shows that the stock is in the area of harvest state where the biomass is low but the fishing level is good.

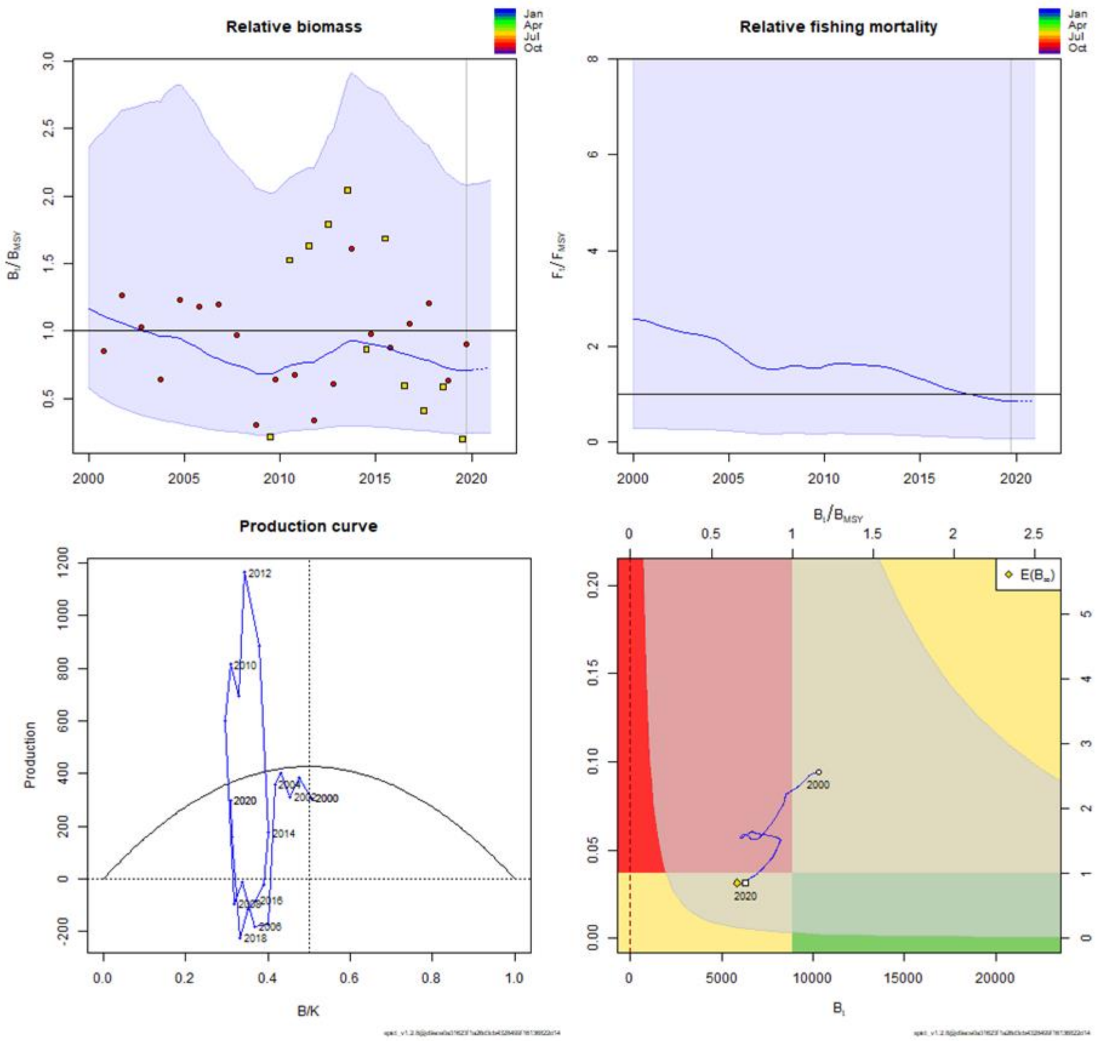


Figure 11: Main outputs of the model fitted in Eledone cirrhosa in the Northwest of the Iberian Peninsula (ICES Div. 8.c and 9.a. North)

Table 4. Summary of the outputs parameters with corresponding confidence intervals [CI] for the best models fitting using SPiCT on Octopodidae. α the process errors of the inputed indices; β the observation error (difference between the measured biomass and the real biomass); n the shape of the production curve; r the

Outputs parameters	α	β	n	r	K	sdb
OCC.9aS	1.47 […]	1.80 […]	6.00^{+04} […]	0.04 […]	1.25 !!! […]	0.00 […]
EOI.8c9aN	2.78 [0.69-11.25]	2.03 [0.53-7.76]	2 (fixed)	0.08 [0.00-8.84]	20,353 [483-858,096]	0.15 [0.04-0.53]

intrinsic growth rate; K the carrying capacity of the stock and sdb the standard deviation of the biomass.

OCC and EOI the respective FAO code for the *Octopus vulgaris* and the *Eledone spp.* with the corresponding ICES divisions of interest

Ommastrephidae assessment

Ommastrephid squids in the Northwest Iberian Peninsula (8.c, 9.a North)

The Ommastrephidae resource of the Northwest Iberian Peninsula is mostly dominated by shortfin squids *Illex coindetii* and *Todaropsis eblanae*, common benthopelagic species, found in soft-bottom fishing grounds. The shortfin squids are also mainly discard species (12.5% discarded in trawls fisheries). In the Cantabrian Sea the most exploited and commercially valued species are members of the Loliginidae (long-finned squid) whereas the importance of the Ommastrephid (short-finned squid) family increases westwards towards Galicia, decreasing to the southern latitudes.. Although they are caught as bycatch, their commercial interest increased the last years and some fishing trips have been show to target the Ommastrephidae species when their abundance are high (season?).

Inputs data for the model were total landings data in period 2000-2019, Spanish groundfish Research Survey, operating in div 8c9aN, period 2000-2019 and assigned to September/October and Spanish LPUE Coruña (Spanish fishing port) bottom trawlers > 55 mm, operating in division 8c, period 2009-2019 and assigned to the middle of the year.

The accepted model converged with the settings of symmetric productive curve (BMSY/K=0.5) and set priors for the ratio between biomass in the initial year relative to K, mean of log(0.5) and sd of 0.2, although is sensitive to initial values and the confidence intervals are quite wide. Kobe plot shows that the stock is sustainable and the fishery has potential to produce more (Fig. 12).

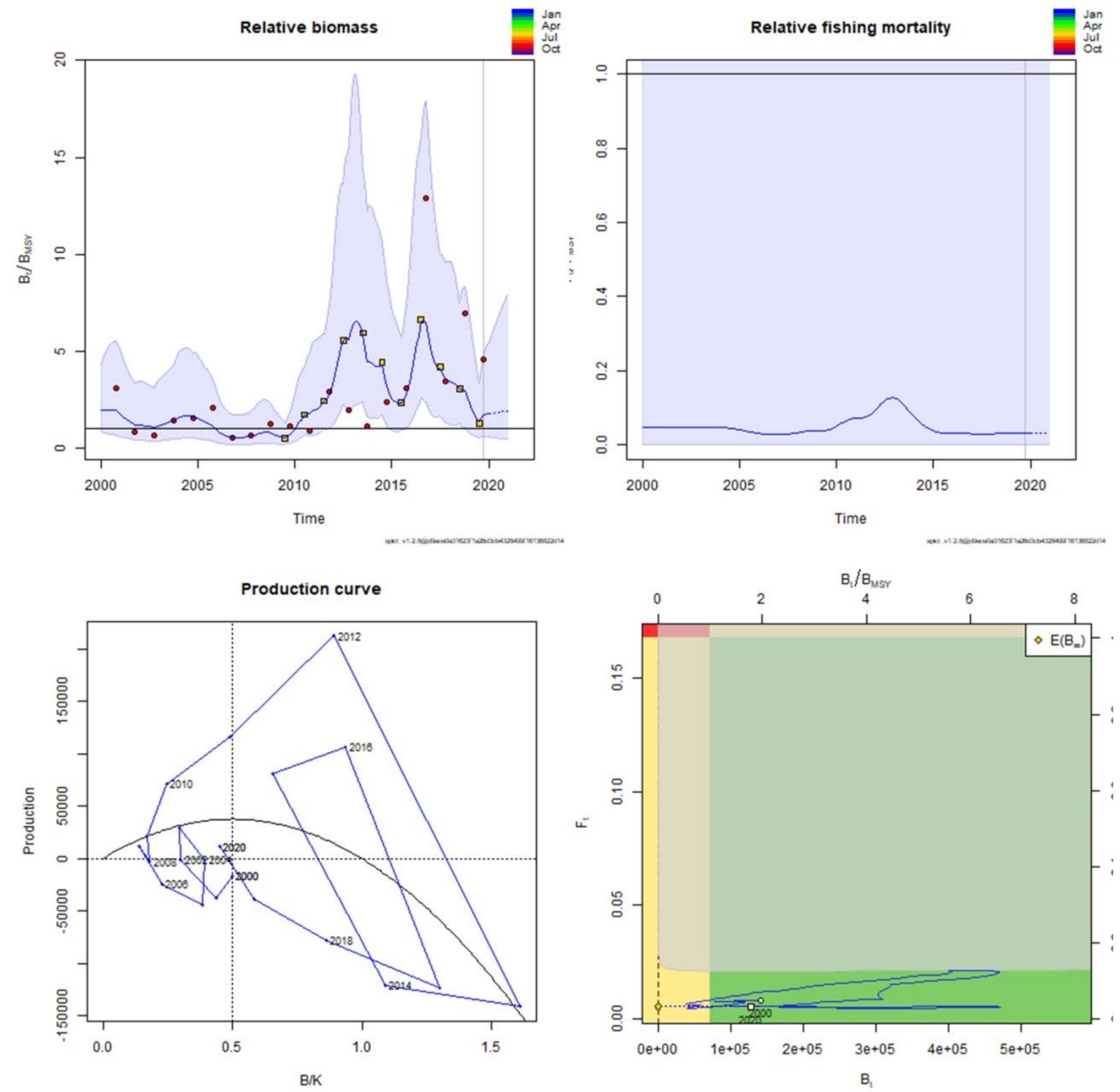


Figure 12: Main outputs of the model fitted in Ommastrephid squids in the Northwest of the Iberian Peninsula (ICES Div. 8.c and 9.a. North)

Table 5. Summary of the outputs parameters with corresponding confidence intervals [CI] for the best models fitting using SPiCT on Ommastrephidae. α the process errors of the inputed indices; β the observation error (difference between the measured biomass and the real biomass); n the shape of the production curve; r the

Outputs parameters	**α**	**β**	**n**	**r**	**K**	**sdb**
OMZ.8c9aN	1.06 [0.60-1.88]	0.31 [0.05-1.78]	2 (fixed)	0.53 [0.16-1.71]	285,364 [87.36-932,198^{+03}]	0.63 [0.43-0.92]

intrinsic growth rate; K the carrying capacity of the stock and sdb the standard deviation of the biomass.

OMZ the FAO code for the Ommastrephidae with the ICES division 8.c 9.aN for the NorthWest Iberian Peninsula

Overview of the different stock assessment

Preliminary results were obtained for ten cephalopods stocks unit in the North-eastern Atlantic waters using SPiCT (Table 6). Only the 'best' models over a range of different parametrization settings were presented for each unit, considering the respect of the Guidelines established by Mildenberger *et al.* (2020).

Over the 10 stock units assessed with the SPiCT model, outputs results were satisfying enough to provide first estimation of the biological reference points (BRP). Table 6 is summarizing the estimates with lower and upper CI of the BRP. The current (2020) median biomass and fishing mortality of *Sepia officinalis* in the English Channel, Loliginidae in Rockall (6.b), Irish (7.a) and Celtic (7.ghjk) seas, and Ommastrephidae in the Northwest Iberian Peninsula (8.c 9.aN) is above the B_{MSY} and below the F_{MSY}, suggesting the stocks to be in a rather good condition (Table 6.)

The relatives values for English Channel (7.de) and Scotland (6.a 7.bc) Loliginidae stocks are for both above the B_{MSY} and F_{MSY} limits, suggesting an overfishing state of the stocks, already described as the northern most exploited stocks of species by Royer *et al.* (2002).

The model never converged for the xxx xxxx xxxx when taking the less informative prior (default) parameter setting. Convergence was obtained (in these cases) while dealing with prior information on n (forced to be equal to 2 as a Schaeffer model), and prior information on the bkfrac which is the fraction of the biomass over the carrying capacity for the stock consideration. A high value of the bkfrac prior was applied when assuming the stock was poorly exploited at the beginning of the time-series; a mean of 0.5 for the parameter correspond to the B_{MSY} (for models that are close to Schaefer, n=2) and so a low value for the more exploited.

The presented SPiCT model outputs of the selected ICES Areas are representative of the best model performances from a series of trials of different model specification scenarios. Model assessments ideally used default settings. In this exercise, the use of adjusted bkfrac parameters of 0.5 and 0.8 were interpreted alongside the results of the default models of each stock exercise. The exercise was shown to produce relatively satisfactory results for the Loligindae stocks of the Irish Sea (Area 7a) and the Celtic Sea (7ghjk), with mixed outputs from the models assessing the West coast of Scotland and Ireland stock (Area 6a and 7bc) and failed results from the Rockall (Area 6b) stock.

It should be noted that changing the n prior was attempted but it did not change model performance and so it was decided to run the default n for all scenarios. When setting bkfrac to 0.8, model performance did not change from bkfrac of 0.5 but numerical outputs were affected, which is a reflection on setting different prior exploitation assumptions in the model.

Furthermore, shortening the length of catch data time series was a factor in trying to get model convergence or improvement, however, this could not solve for the large confidence intervals associated with relative fishing mortality in most models. Tables 5 and 6 below summarises the average catch over the past four years, compared with the estimated stochastic MSYs and the estimate relative biomass and fishing mortality.

Table 6. Estimates with low and upp confidence intervals (CI) and log estimate of the main Biological Reference Points (BRP) obtained from the best SPiCT models outputs: both relative biomass and fishing mortality for the year 2020 (respectively B_{2020}/B_{MSY} and F_{2020}/F_{MSY}) and the stochastic maximum sustainable yield (MSY_S).

	estimate	cilow	ciupp	log.est
CTC.7de				
B_2020/B_{MSY}	1.77	0.37	8.35	0.57
F_2020/F_{MSY}	0.39	0.11	1.42	-0.94
MSY_s	13,573	6,262	29,420	9.52
CTL.8abd				
B_2020/B_{MSY}	1.45	0.87	2.44	0.37
F_2020/F_{MSY}	0.51	0.15	1.69	-0.67
MSY_s	5,255	3,231	8,546	8.57
SQZ.6a7bc				
B_2020/B_{MSY}	1.43	0.40	5.14	-
F_2020/F_{MSY}	0.97	0.12	7.87	-
MSY_s	488	193	1,234	-
SQZ.6b				
B_2020/B_{MSY}	2.20	0.28	16.94	-
F_2020/F_{MSY}	0.11	0.00	345.38	-
MSY_s	2,848	3.28	25^{e+05}	-
SQZ.7a				
B_2020/B_{MSY}	5.24	1.43	19.27	-
F_2020/F_{MSY}	0.004	0.00	0.02	-
MSY_s	353	169	735	-
SQZ. 7ghjk				
B_2020/B_{MSY}	1.67	0.26	10.76	-
F_2020/F_{MSY}	0.58	0.13	2.61	-
MSY_s	284	149	540	-
SQZ.7de				
B_2020/B_{MSY}	1.01	0.56	1.81	-0.10
F_2020/F_{MSY}	1.18	0.71	1.98	0.16
MSY_s	3,518	3,035	4,078	8.17
SQZ.8abd				
B_2020/B_{MSY}	0.37	0.14	0.99	-0.99
F_2020/F_{MSY}	1.56	0.69	3.54	0.45
MSY_s	1,603	1,042	2,468	7.38
OCC.9a				
B_2020/B_{MSY}	1.96			
F_2020/F_{MSY}	0.14			
MSY_s	15,644			
EOI.8c9aN				
B_2020/B_{MSY}	0.71	0.24	2.09	-0.34
F_2020/F_{MSY}	0.85	0.07	9.71	-0.16
MSY_s	318	21	4,699	5.76
OMZ.8c9aN				
B_2020/B_{MSY}	1.78	0.57	5.50	0.58
F_2020/F_{MSY}	0.03	0.00	121	-3.42
MSY_s	5,204	0.38	$71,933^{+03}$	8 .55

DISCUSSION/PERSPECTIVES

The SPiCT model is based on population productive characteristics and is a simplification of the dynamic process of populations, allowing the simple requirement of time-series catches and biomass indicators (LPUE/CPUE) as input data. The objective of this work was to update the preliminary assessment of cephalopods in the Northeast Atlantic waters initiated in 2019, in order to provide estimates and comparable BRP.

Management perspectives

This starting point to obtain preliminary biological reference points will allow to improve assumptions and may lead to apply Harvest Control Rules (HCR) and/or Management Strategy Evaluation (MSE), now available in the SPiCT package. Cuttlefish stock in the 7.de appeared to be a good candidate to try the use of this component available in SPiCT (Tobias saying).

Potential data improvement

DataCall

Species identification in a complex of species (like ommastrephidae or loliginidae – distinction between vulgaris and forbesii)

Recent studies on cuttlefish (Gras *et al.*, 2014; Laptikhovsky *et al.*, 2019) suggested the life-cycle began to switch to an annual life style somewhere between 1999 and 2010, rather than a two year previously described. Also, considering the accuracy of reporting, mostly thought to be incomplete before 2006 in U.K. cause of the no specific statutory for fishers to declare their catches (fishing fleet being 80% < 10 m vessels), information for this sector should be considering time-series cut at 2005 at least (MMO, 2019, available at https://www.gov.uk/guidance/fishing-activity-and-landings-data-collection-and-processing#data-collection-for-vessels-10-metres-and-under-in-length). It could be interesting to try also to consider, rather than the LPUE, an index of the U.K. effort – possible to incorporate as inputs in the model – by dividing the monthly catch by mean monthly LPUE (Vladimir, pers. com.).

Future directions

During the second ICES workshop for the data-limited stocks of short-lived species (WKDLSSLS2), some conclusions were draw, considering the cuttlefish SPiCT models and the depletion method coupled with a Pella-Tomlinson formulation model on the *Octopus vulgaris* in the Asturias, as cephalopods examples.

It was concluded that the seasonal data (e.g. quarterly catch input) could be too noisy when used in a mixed recorded species as it was the case in this study for the Loliginidae in 7.de (both *L. forbesii* and *L. vulgaris*) with the overlapping of different life cycle (in the breeding season, different recruitment time), or also for the Ommastrephidae which consist of mostly two (even three) different short-fined squid's species. Thus, the aggregation of the catch input in a yearly basis would be better to use in this case.

In other cases, when possible and as shown by the *Octopus* case in Asturias (Ruben), short time-steps (daily or weekly) analysis might be more relevant for such short-lived species as to improve population and fishery dynamics assessment. This is valuable for both the catch and efforts input data, as it may bring additional information about population parameters when run in a depletion model, which then can help improve the prior information when running population dynamics models at annual time-steps. Depletion method could be implemented on SPiCT by setting a prior on the bkfrac – B/K which is the ratio between biomass in the initial year of the catch time-series relative to the carrying capacity – as to inform about the exploitation status at the beginning of the considered stock.

was helpingmany cephalopods stocks to converge (from Loliginidae in Northern regions to Octo-podidae in the South). This is somehow difficult to understand.

• •Review the order of magnitude accepted in the relative abundance values resulting from the fitted model for short-lived species.

Among the recent improvement in SPiCT, the assumption of a regime shift in productivity may be worth exploring in the future (with the application of the seasonal productivity parameter) in the cephalopods assessments. Also the implementation of environmental variables, known to be of a great influence on short-lived species like cephalopod should be of future interest.

Following the application of SPiCT on *Illex argentinus* by Han et al. (2019), it would be interesting to improve knowledge about the parameters *r* and *K* (respectively the intrinsic growth rate and carrying capacity) as well as the initialization of the catchability coefficient *q*.

The SPiCT model is a simplification of the dynamic process of populations. Although the residuals in this study passed all tests (Tables 3 and 4), the predictions are uncertain and should not be relied upon to produce long-term predictions (>2 years). Therefore, this study did not perform long-term predictive analysis of resources under different management scenarios. The uncertainty of the long-term prediction of the SPiCT model requires further study on its impact on the assessment of the limited and short-lived Argentinian squid resources and the reduction of uncertainty.

APPENDICES

Appendix 1 Description and acronyms of surveys indices

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 useful for the assessment in this document are listed below.

North West Groundfish Survey (NWGFS) covered ICES Divisions 7a, 7f and 7g combined, from 1988 to 2019. 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 2019. 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 2019. 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.

EValuation des ressources Halieutiques de l'Ouest Européen (EVHOE) data were extracted for the Celtic Sea portion of the Survey covering ICES Division 7.g,h,j,k combined, from 1997 to 2019. 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 2019) 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, Deep-water 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 2019, 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:

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

Then, W (per haul) = W x 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 2 Description of abundance indices from commercial fisheries

2.1 French bottom otter trawls (OTB) 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 that are properly taken into account. The standardization procedure of FR-OTB LPUE 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.

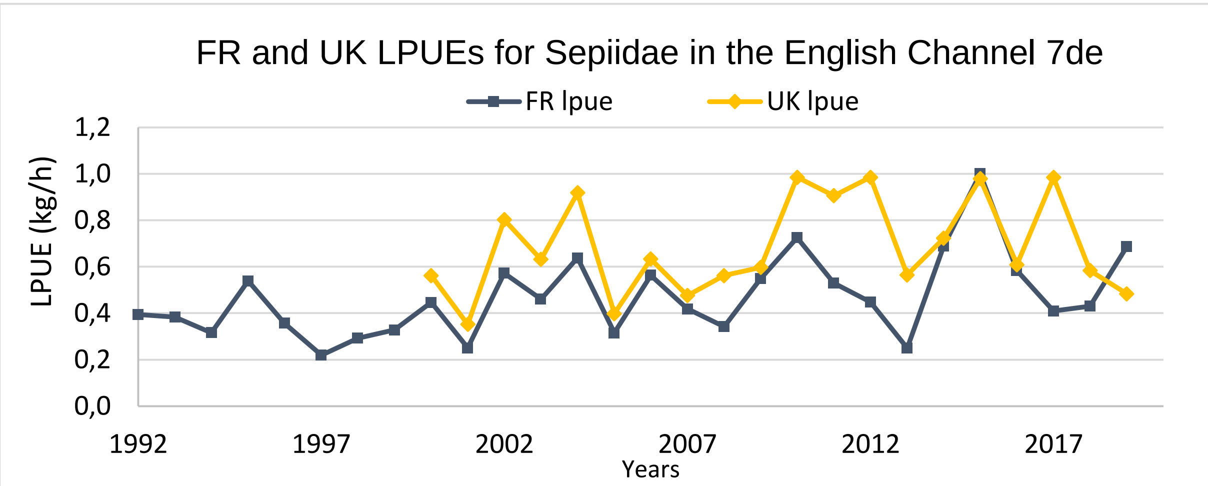
French commercial landings and effort data were extracted from national databases maintained by the French ministry for fisheries (Direction des Pêches Maritimes et de l'Aquaculture (DPMA)) and Ifremer (Système d'Information Halieutique (SIH)). Commercial squid and cuttlefish landings (kg) and effort (hours of trawling) for French OTB were collected by fishing sequence (*e.g.* 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: 2001-2019), accounting for effects of the previously mentioned variables except for power. The assessments based on these "LPUE-derived indices" are listed in table 1.

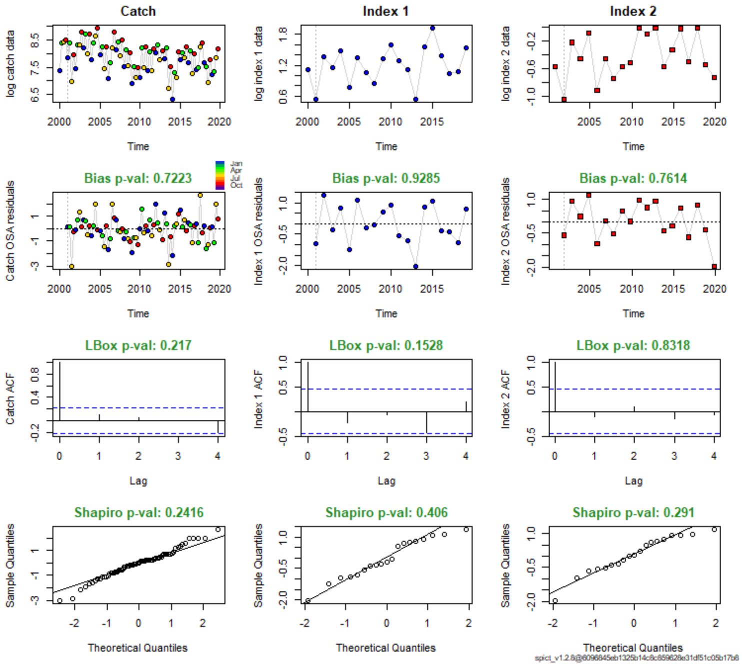
It is worth noting that in spite of the heterogeneous distribution of fishing activities (both in time and space) commercial data is abundant and corresponds to a wider temporal extent than survey data. Besides, cephalopods being no-quota species are less susceptible to misreporting than managed resources. 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).

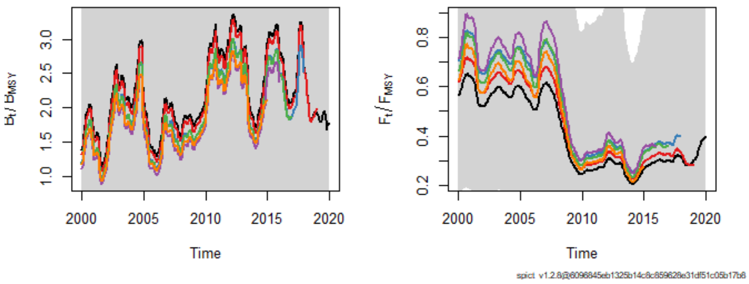
2.2 U.K. bottom beam trawls (TBB) LPUE



Appendix 3 Residuals and retrospective plots of the best models

3.A1. *Sepia officinalis* in the English Channel 7.de





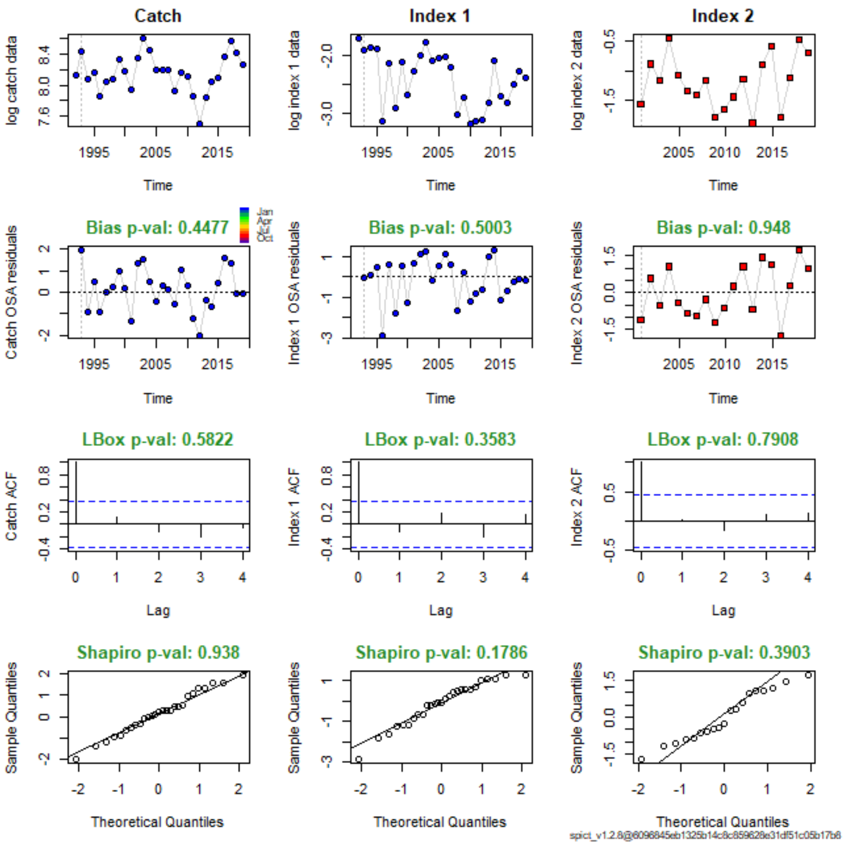
3.A2. Sepiidae in the Bay of Biscay 8.abd

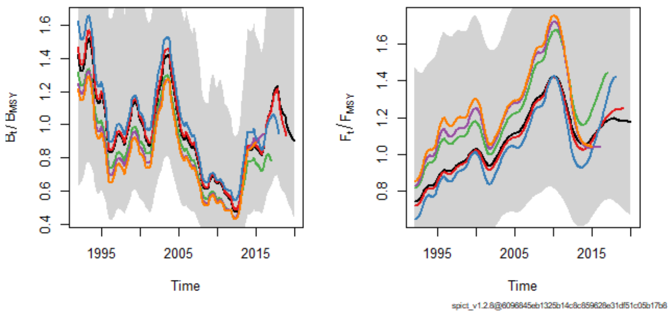
3.B1. The Loliginidae in the West Coast of Ireland and Scotland 6.a 7.bc

3.B2. The Loliginidae in Rockall 6.b

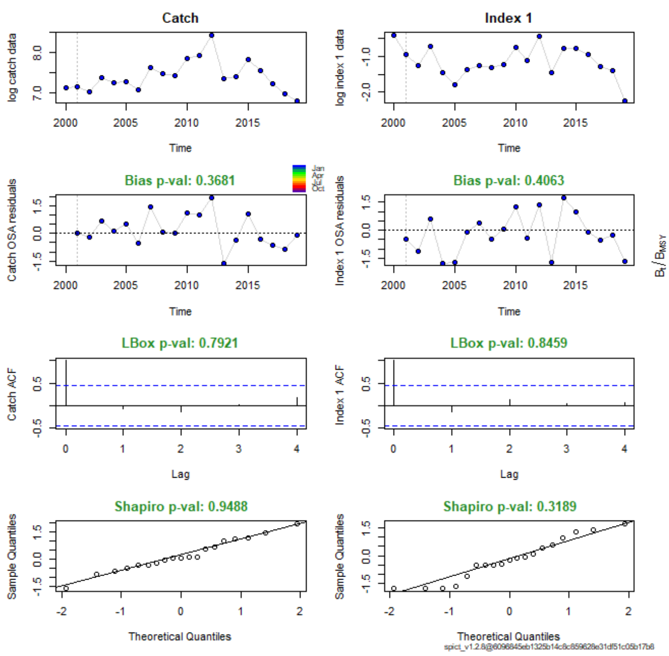
3.B3. The Loliginidae in Irish and Celtic seas 7.a 7.f 7.ghjk

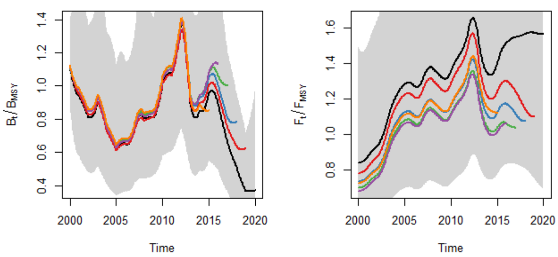
3.B4. The Loliginidae in the English Channel 7.de





3.B5. The Loliginidae in the Bay of Biscay 8.abd





3.C1. The Octopodidae Octopus vulgaris in the Gulf of Cadiz 9.a South

3.C2. The Octopodidae Eledone spp. in the Northwest Iberian Peninsula 8.c 9.a North

3.D. The ommastrephidae in the Northwest Iberian Peninsula 8.c 9.a North