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Stock assessment of the English Channel stock of cuttlefish with a two-stage biomass model

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ABSTRACT

Among the English Channel fishery, the importance of cuttlefish stock has increased, following the cephalopods global landings and market trend. The stock is currently managed at regional scale but not by European regulations, although it is a shared species targeted by French and British fishing fleets at several stages of its life-cycle and across much of its distributional range.

An assessment of this stock was conducted in June 2014 by fitting a two-stage biomass model on a 22 years' time-series (1992-2013). We present the last update of cuttlefish stock assessment using the same model on years 1992-2014. As the outputs of the model are sensitive to a fix growth parameter, we explore possibilities to improve the model.

The use of a Bayesian framework is particularly adapted for decision making, allowing the propagation of uncertainty in the model and the use of prior knowledge on some parameter distributions. Therefore, we implemented the two-stage biomass model into a Bayesian framework and compared the results with the outputs of the initial fit. We found similar trends of biomass estimates for both models. The Bayesian model outputs showed a smaller range of variation than the initial fit.

These results are only a first step toward an improvement of the two-stage biomass model currently used for cuttlefish stock assessment in the English Channel. The Bayesian model could indeed be improved and particular attention should be paid to the growth parameter g because of the high sensitivity of model outputs to its value. We discuss future directions of this work.

Keywords: *stock assessment, short-lived species, data-limited, cuttlefish, Sepia officinalis, English Channel, two-stage biomass model, Bayesian methods*

INTRODUCTION

Stock assessment for short-lived species is a delicate matter because of the difficulty of swift data collection as well as the challenge of modelling population dynamics. Cephalopod populations are fast growing short-lived ecological opportunists. Age based methods in these species are hampered by time consuming age determination with statoliths. In spite of trials with a wide range of models

(Pierce and Guerra 1994) there is no routine stock assessment in most of cephalopods fisheries, although a precautionary approach is often advocated (Rodhouse *et al.* 2014).

The English Channel cuttlefish stock is one of the most important resource for the Channel fisheries and is exploited by French and English fishermen (Engelhard *et al.* 2012). Inshore exploitation is managed by local rules, but no EU regulation apply to the whole stock. It experiences a short life-span (considered of 2 years in the English Channel) and performs seasonal migrations. Cuttlefish concentrates in the central western Channel during winter and in coastal areas during spring and summer (Boucaud-Camou and Boismery 1991). One argument for an English Channel stock unit was that migration takes place almost entirely within the English Channel. Boundaries of the stock were set as ICES division VIIId and VIIe, which was also coherent with the concentration of high Catch Per Unit Effort (CPUE) inside these boundaries (Wang 2003).

Analytical methods have been used to occasionally assess the stock (Royer *et al.* 2006), but because of the difficulty to correctly describe catch structure, less data-demanding models were sought (Gras *et al.* 2014), which could be used routinely (Duhem *et al.* in WGCEPH 2014). The two-stage biomass model (Roel and Butterworth 2000) is not too much data-demanding and is therefore well suited for data-limited stocks. It assumes that the exploited population can be observed at two different stages: recruitment and full exploitation. It has been adapted to the English Channel cuttlefish stock (Gras *et al.* 2014), based on a simplification of cuttlefish life-cycle, and with bootstrap estimated uncertainties. Ibaibarriaga *et al.* (2008) highlights the advantage of using Bayesian methods for estimating uncertainties in these models and to face the lack of data. The main idea of Bayesian inference is to use the initial knowledge (prior distribution), update it with the most recent information (observed data, interpreted via the likelihood function) and form the posterior distribution, which is the new understanding about the studied phenomenon (Pulkkinen 2015).

This study presents the update of cuttlefish stock assessment using the two-stage biomass model from Gras *et al.* (2014). The evolution of biomass estimates from 1992 to 2012 using a Bayesian implementation of this model is also presented. Outputs are compared with the initial fit. This study is a first step in the improvement of the two stag-biomass model currently used for the English Channel stock of cuttlefish, and further work will be done as explained in the discussion part.

MATERIALS AND METHODS

Data used in the model

The implementation of the two-stage biomass model required abundance indices from the Bottom Trawl Survey (BTS) and the Channel Ground Fish Survey (CGFS), as well as landings and effort from French and UK trawlers, and total catch of cuttlefish among the English Channel (C_{1+y}). BTS abundance indices and data from UK trawlers were extracted from the Centre for Environment, Fisheries and Aquaculture Science (Cefas), and data from CGFS and French trawlers were extracted from the French Research Institute for Exploitation of the Sea (Ifremer).

The BTS is carried out each year in July (when cuttlefish recruitment occurs), and the CGFS is carried out in the eastern English Channel one quarter later, in October. Trawling lasts

approximately 30 minutes at each station for both surveys (Carpentier *et al.* 2009). Effort data consist on hours of trawling for the trip considered and engine power of the vessel considered. The weight of specimens of one year old and more caught in the English Channel was also required. This last information could be estimated from sale data, by calculating the percentage of cuttlefish belonging to commercial categories 1 or 2 (i.e. animals above 300g).

Two-stage biomass model

A package with the version of a two-stage biomass model adapted to cuttlefish was coded in R (Gras and Robin 2014). The model (Gras *et al.*, 2014) assumes a simplified life cycle of cuttlefish. It assumes that the exploited population can be observed at two different stages: recruitment and full exploitation. Recruited biomass (B_1) is estimated with abundance indices from BTS and CGFS surveys. Spawning stock biomass (B_2) is estimated with Landings Per Unit Effort (LPUE) from French and UK bottom trawl fisheries. A biomass growth parameter g is fixed externally. It is composed by the natural mortality rate, assumed to be equal to 1.2 (Royer *et al.* 2006, Gras *et al.* 2014) and the growth rate, derived from mean weight at age using historical data collected by the University of Caen.

A first step is to calculate standardized LPUE, using the delta-glm function of the cuttlefish.model package. LPUE variability is explained by 4 variables: year, month, ICES rectangle and engine power of the vessel.

Total catch of one year old cuttlefish (C_{1+y}) is assumed to happen as a pulse in the middle of the fishing season (on 1st January Y). Spawning stock biomass $B_{2,y}$ of the year y at the end of the life cycle is therefore expressed as:

$$B_{2,y} = [B_{1,y}e^{-\frac{g}{2}} - C_{1+y}]e^{-\frac{g}{2}}$$

Abundance $B_{1,y}$ at the beginning of the fishing season can be estimated with BTS and CGFS survey index:

$$S_y^1 = k_1 B_{1,y} e^{\epsilon_y} ; S_y^2 = k_2 B_{1,y} e^{-\frac{g}{4}} e^{\delta_y}$$

Where S_y^1 is the BTS survey index for year y , k_1 is the BTS survey catchability, ϵ_y is the observation error for year y , S_y^2 is the CGFS survey index, k_2 the CGFS survey catchability, and δ_y is the observation error.

LPUE are modelled based on the mean biomass in the fishing season. UK standardized LPUE (U_y^{uk}) and French standardized LPUE (U_y^{fr}) can be expressed as:

$$U_y^{uk} = \frac{1}{2} q_{uk} [B_{1,y}e^{-\frac{g}{4}} + (B_{1,y}e^{-\frac{g}{2}} - C_{1+y})e^{-\frac{g}{4}}]$$

$$U_y^{fr} = \frac{1}{2} q_{fr} [B_{1,y} + (B_{1,y}e^{-\frac{g}{2}} - C_{1+y})e^{-\frac{g}{2}}]$$

Where q_{uk} is the catchability of UK trawlers, q_{fr} the catchability of French trawlers, and C'_{1+y} the landings from July, year y to April, year $y+1$, considering that UK trawlers exploit cuttlefish only in autumn and winter. The model is finally fitted by minimizing the sum of squares residuals.

The exploitation rate can be expressed as the total landings of year y divided by the biomass estimated on 1st January ($B_{1,jan}$), year y :

$$E_y = C_{1+y} / (B_{1,y} e^{-\frac{g}{2}})$$

In a first step, we updated the stock assessment of the English Channel stock of cuttlefish. Then, we implemented the model used by Gras *et al.* (2014) into a Bayesian framework and coded it with Openbugs. The Bayesian fit required prior distributions for B_1 and catchability rates. Priors were the same for each year. We chose normal distributions, with a mean of 15000 and a CV of 2.5 for B_1 , and a mean of 0.0001 and a CV of 0.0067 for catchability rates to stay close to the work of Gras *et al.* (2014). We also used the same value for g as in Gras *et al.* (2014): $g=-1.01$. Posterior distribution of B_1 was obtained by combining the likelihood function with the prior distribution.

Chain convergence was checked with the BGR diagnostic suggested by Brooks and Gelman (1998) and a sensitivity analysis was conducted on B_1 prior distribution and g value. A 20% variation was applied on the mean of B_1 prior distribution, and values of $g=-0.5$ and -1.5 were tested in order to compare results with the sensitivity analysis conducted in Gras *et al.* (2014). Initial and Bayesian fit of the two-stage biomass model were applied on years 1992-2013. 1000 iterations were conducted for the initial model with bootstrap methods, and 100 000 iterations for the Bayesian model using Markov chain Monte Carlo (MCMC) methods. Update took longer for the initial fit than for the Bayesian fit.

RESULTS

Stock assessment update

Total landings of cuttlefish in the English Channel have increased between 1992 and 2004 (Figure 1), mostly because of the French landings evolution. Between 2004 and 2009, French landings have decreased, leading in 2009 to the smallest value of total landings among the entire time-series. Since 2009, French and UK landings are of the same order of magnitude, with no clear trend in total landings evolution.

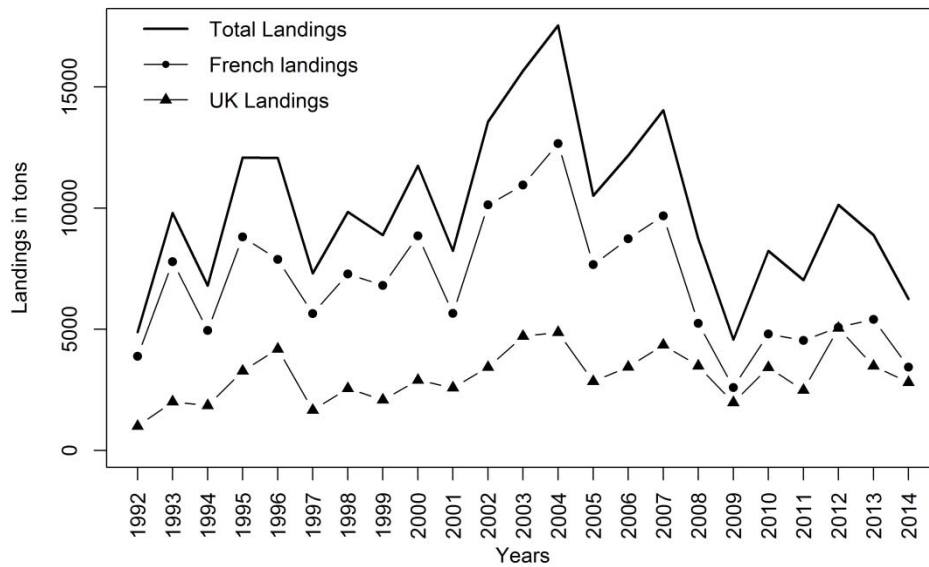


Figure 1: Evolution of cuttlefish landings in the English Channel from 1992 to 2014

Comparison of predicted and observed abundance indices (Figure 2) permits the evaluation of the model fit. In general, observed abundance indices are within the confidence intervals of the model prediction. However, this is not true for years 2000 and 2011. It is interesting to notice that BTS and CGFS survey observed abundance indices seem to follow a same trend, slightly different from the trend of UK and French LPUE. The 95% confidence intervals for years 2001 and 2013 are small, with low abundance indices observed for all data sources.

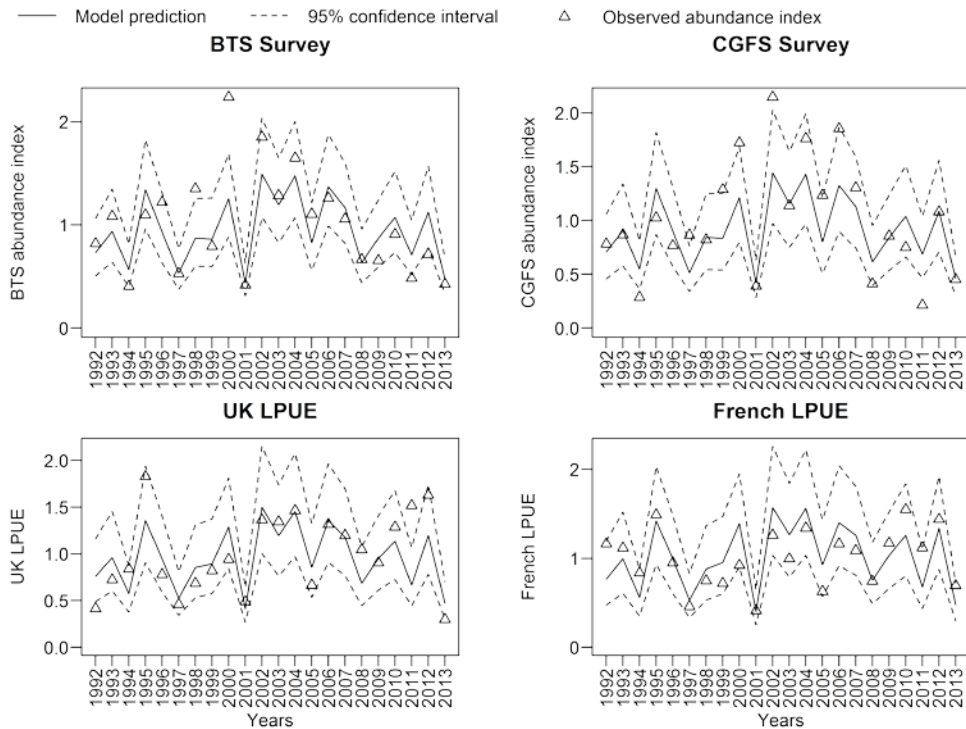


Figure 2: Time-series of the observed and predicted abundance indices for the two-stage biomass model fit with 95% confidence interval from fishing season 1992 (July 1992 to June 1993) to 2013 (July 2013 to June 2014).

As expected in the light of Figure 2 observations, predicted recruited and spawning stock biomass have decreased between 2012 and 2013 (Figure 3), whereas exploitation rate has increased (Figure 4). Although no clear trend of B_1 and B_2 evolution is observed between 1992 and 2002, there seem to be a slight decreasing trend of biomass since 2002. However, no stock-recruitment relationship was observed between spawning stock biomass and recruited biomass (Figure 5). In Gras *et al.* (2014), the minimum estimated B_2 (11 000 tons) was proposed as B_{lim} for English Channel cuttlefish, based on the precautionary principle. As the stock assessment update didn't produce any B_{lim} value smaller than Gras *et al.* (2014) result, conclusions remain unchanged.

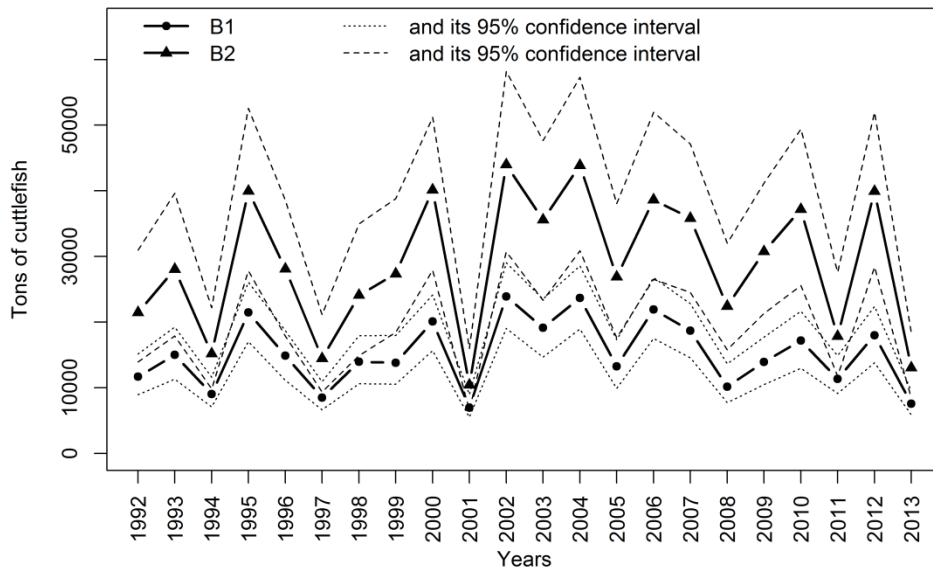


Figure 3: Evolution of cuttlefish recruited biomass (B_1) and spawning stock biomass (B_2) from fishing season 1992 (July 1992 to June 1993) to 2013 (July 2013 to June 2014).

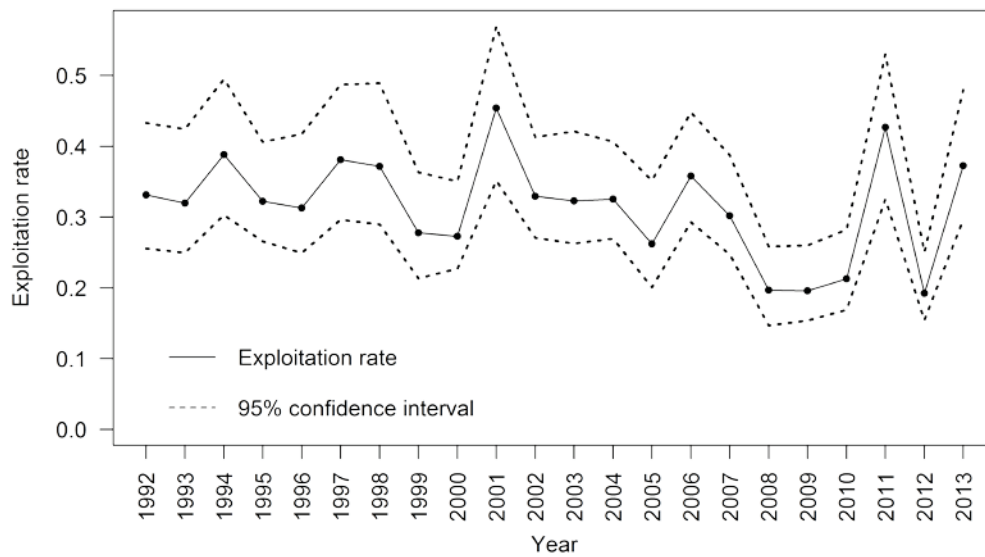


Figure 4: Evolution of cuttlefish exploitation rate from fishing season 1992 (July 1992 to June 1993) to 2013 (July 2013 to June 2014).

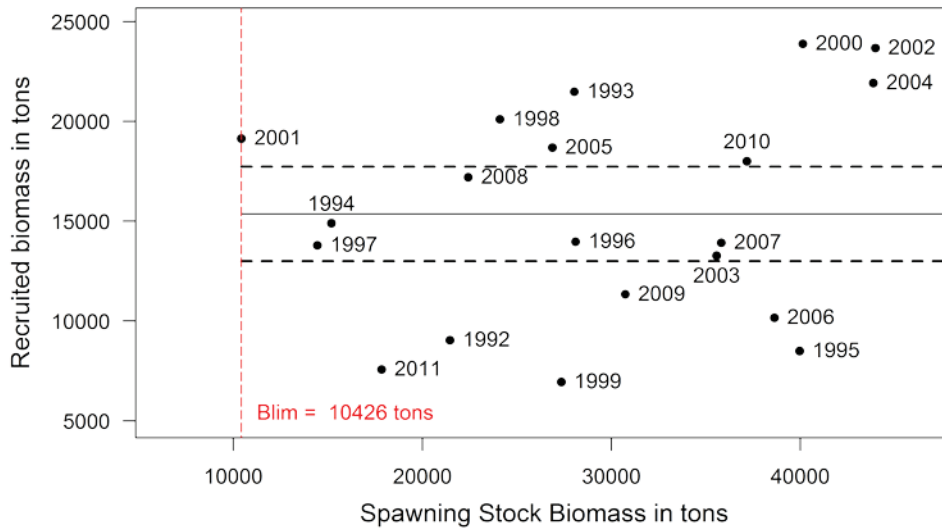


Figure 5: Stock-recruitment relationship with the average annual recruitment (solid line) and its 95% confidence interval (horizontal dashed lines). Years plotted are the years of spawning stock biomass estimates (year Y), which are linked to the recruited biomass (year Y+2).

Comparison of initial and Bayesian fit of the two-stage biomass model

The evolution of estimated abundance indices (Figure 6) shows a better fit of the initial model for BTS and CGFS surveys, but a better fit of the Bayesian model for French and UK LPUE. The models do not succeed in estimating high values of BTS and CGFS abundance indices (e.g. 2000, 2002 for both surveys, and 2006 for CGFS survey). Survey abundance indices in 2012 pull model fit downward, whereas LPUE abundance indices pull it upward.

Evolution of recruited biomass estimates (Figure 7a) and spawning stock biomass estimates (Figure 7b) are similar between initial fit and Bayesian fit of the two-stage biomass model. But outputs from Bayesian fit show a smaller range of variation than the initial fit. Confidence intervals are smaller for Bayesian fit, except during years of small biomass estimate (i.e. 1994, 1997 and 2001).

Similar trends of exploitation rate are observed for both fit of the two-stage biomass model (Figure 8). An important decrease in exploitation rate is observed between 2006 and 2008 for both fit, but the following 2011 spike predicted by the Bayesian fit is not as high as the one predicted by the initial fit.

Catchability rates estimated by Bayesian model are higher than estimations from initial fit (Table 1), from +3.3% to +12.6%. Biggest differences between the two fit are observed for CGFS catchability rate (k_2). Table 3 shows the percentage of variation between outputs from Bayesian and initial fit of the two-stage biomass model. In average, biggest differences between both fits are observed for the exploitation rate.

Results of the sensitivity analysis conducted on the Bayesian two-stage model (Table 2) show that B_2 estimates are very sensitive to variation of g . A change of 20% in the mean value of B_1 prior distribution leads to 30% variation of B_2 estimates. Estimates of exploitation rates are most sensitive to underestimation of B_1 prior distribution and overestimation of g . Survey catchability

estimates are most sensitive to variation of B_1 prior distribution, whereas UK and French fleet catchability estimates are most sensitive to variation of g .

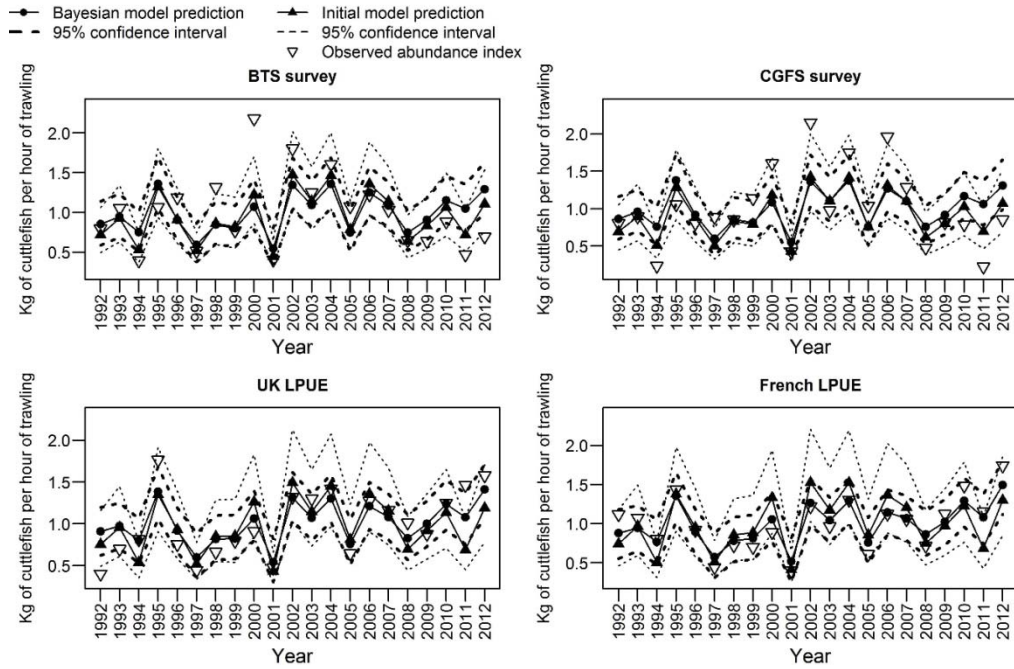


Figure 6: Time-series of the observed and predicted abundance indices for initial model and Bayesian model fit with 95% confidence interval from fishing season 1992 (July 1992 to June 1993) to 2012 (July 2012 to June 2013).

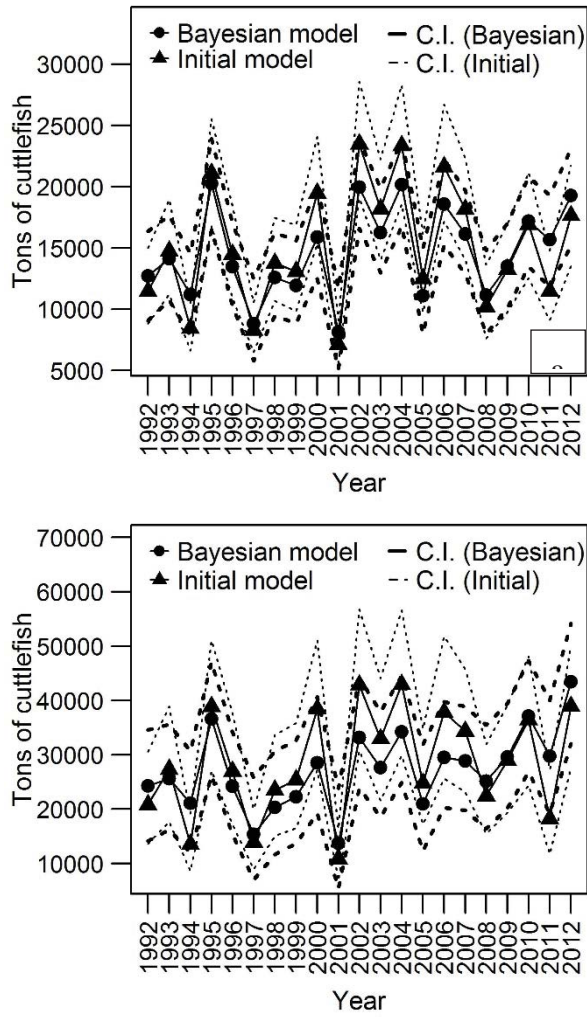


Figure 7: Comparison of the evolution of a) recruited biomass B_1 and b) spawning stock biomass B_2 for initial and Bayesian fit of the two-stage biomass model.

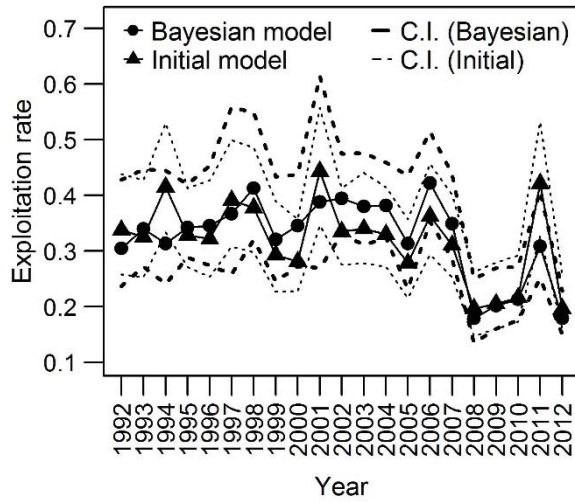


Figure 8: Comparison of the evolution of exploitation rate for initial and Bayesian fit of the two-stage biomass model.

Table 1: Variability between initial model and Bayesian model estimates of catchability rates (in percentage).

k ₁	k ₂	q _{uk}	q _{fr}
7.258	12.64	7.197	3.253

k₁ = catchability rate of BTS survey, k₂ = catchability rate of CGFS survey, q_{uk} = catchability rate of French trawlers, q_{fr} = catchability rate of UK trawlers.

Table 2: Sensitivity analysis of the Bayesian two-stage biomass model

	B1_mean = 12000	B1_mean = 18000	g = -0.5	g = -1.5
B ₁	-19.96	20.06	-2.657 × 10 ⁻²	2.249 × 10 ⁻³
B ₂	-29.72	29.87	-48.56	80.64
B _{1,Jan}	-19.96	20.06	-22.53	27.77
Exp	24.95	-16.71	29.09	-21.73
k ₁	-25.02	16.67	0.0742	0.0297
k ₂	-24.98	16.71	13.7	-11.5
q _{uk}	-30.44	20.69	35.9	-34.2
q _{fr}	-35.03	18.95	45.6	-26.4

B1_mean = value of the mean for B₁ normal prior distribution

Table 3: Percentage of variation between Bayesian model outputs and initial model outputs.

year	B ₁	B ₂	B _{1,Jan}	Exp
1992	10.89	10.84	16.45	-9.802

1993	-4.283	-4.311	-6.332	4.513
1994	32.43	32.42	55.59	-24.49
1995	-3.977	-3.959	-5.866	4.138
1996	-6.940	-6.925	-10.14	7.444
1997	6.548	6.576	10.91	-6.136
1998	-8.488	-8.494	-13.57	9.289
1999	-8.695	-8.669	-12.20	9.491
2000	-18.56	-18.55	-25.77	22.77
2001	14.25	14.27	25.79	-12.46
2002	-15.04	-15.04	-22.58	17.69
2003	-10.62	-10.64	-16.05	11.88
2004	-13.64	-13.66	-20.31	15.81
2005	-11.14	-11.11	-15.34	12.52
2006	-14.07	-14.06	-22.06	16.38
2007	-11.00	-11.00	-15.93	12.38
2008	9.677	9.725	12.16	-8.846
2009	1.698	1.686	2.176	-1.639
2010	1.504	1.515	1.938	-1.476
2011	36.43	36.46	63.07	-26.73
2012	9.375	9.364	11.67	-8.558
Mean variation	-0.1742	-0.1695	0.6482	2.103
SD	14.95	14.59	24.22	13.67

B_1 = Recruited biomass, B_2 = spawning stock biomass, $B_{1, \text{jan}}$ = biomass estimated on 1st January in the middle of the fishing season, Exp = exploitation rate, SD = standard deviation.

DISCUSSION

This work presents the stock assessment update of the English Channel stock of cuttlefish. The R package used for the assessment (Gras and Robin 2014) has proven itself effective as a tool to assess the stock routinely. From next year on, the French scientific survey CGFS will be carried out with a new scientific vessel. This raises the issue of the abundance index time-series future. Some inter-calibration exercises have been carried out, showing that time-series can't be continued for some species. Fortunately, the inter-calibration worked well for cuttlefish, as both scientific vessels exhibited similar catchability rates and selectivity.

In this work, we also wanted to implement the two stage biomass model in a Bayesian framework and check if results were similar. Estimates obtained from the initial fit (Duhem *et al.* in WGCEPH 2014) and from the Bayesian fit of the two-stage biomass model showed similar trends. But the model still doesn't succeed in estimating some values of abundance indices (Figure 6). Outputs from Bayesian fit showed high sensitivity to prior distribution of B_1 and to g value. The need to give good prior estimations is a common issue of Bayesian methods. Gras *et al.* (2014) identified a significant positive correlation between the sea surface temperature during the third quarter (summer) of the year before recruitment and B_1 . This result could be a starting point to

investigate a Bayesian model including environmental factors, in order to give better prior distributions for B_1 .

High sensitivity to g was already highlighted by Gras *et al.* (2014) and further work also needs to be done on this particular point. Growth used for the two-stage biomass model is assumed to be the same for each year, which is a strong assumption for cephalopod species. One possibility would be to build an informative prior for g , using meta-analysis on other cephalopod stocks. Ideally, variations of g in other stocks could be used to infer g annual variations of the English Channel cuttlefish stock in the Bayesian fit. But this information might be hard to obtain, as no regular evaluation of growth seem to be conducted for cephalopods stocks in the English Channel.

Parameter g could also vary with season, as suggested in Dunn (1999). He found that fastest growth in length took place between July and October in males, and between August and October in females. The slowest growth rates were recorded from the winter before spawning in the spawning period. If we could for example find a relationship between sea surface temperature and cuttlefish growth, we could use this link to infer information on annual growth variation. Finally, size frequency data could be an additional source of information on growth variation. To better model reality, the Bayesian two-stage biomass model could also be improved by integrating migration. Massiot-Granier *et al.* (2014) developed an integrated hierarchical Bayesian life cycle modeling framework which could be a starting point to build such a model adapted to cuttlefish.

Another idea is to use the Stock Synthesis (SS) framework (Methot and Wetzel 2013) to compute an adapted model, using all available information, including data used by the two-stage biomass model, as well as mean individual weight by month and length composition data. This framework offers many possibilities to use different sources of data and can be adapted to complex life histories. The model can account for time-varying growth, as well as cohort specific growth rate, environmental factors, and could also include migration. An SS model has for example been adapted for bigeye tuna *Thunnus obesus*, using five areas (Aires-da-Silva and Maunder 2012).

In Gras *et al.* (2014), an exploitation rate below 40% is recommended, and a threshold of 11 000 tons is proposed for the spawning stock biomass. Setting quotas to manage the English Channel cuttlefish stock is unlikely to be efficient because of the high variability in cephalopod stock sizes (Caddy 1983, Beddington *et al.* 1990). Currently, the stock is managed at regional scale. In Normandy, fishing of cuttlefish is forbidden within the 3-miles inshore zone, except during 2 weeks at the end of August, and during another 6 weeks in spring. In order to better manage the stock, a management strategy evaluation could be conducted. Reduction of effort at particular times or in particular areas could be tested. Best management rules could thus be predicted, with good uncertainty estimates, thanks to the Bayesian framework.

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