Stock assessment on fishery-dependent data: effect of data quality and parametrisation for red snapper fishery

Running title: Stock assessment on fishery-dependent data

Morgana Tagliarolo[a], Jason Cope[b], Fabian Blanchard[a]

a. Ifremer, UMSR LEEISA (CNRS, UG, Ifremer), 275 Route de Montabo, BP477, 97323 Cayenne Cedex, French Guiana, France.

b. Fisheries Resource Assessment and Monitoring Division, Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA, Seattle, WA, USA

*Corresponding author:

Morgana.tagliarolo@ifremer.fr

Postal address: 275 Route de Montabo, BP477, 97323 Cayenne Cedex, French Guiana, France

Acknowledgments

We would like to tanks all the SIH team (E. Mansuy and all the VSC) for collecting the data. We would also like to acknowledge the fisherman committee (CPMEM) and all fishermen for their willingness to share information with us. This work has been initiated by the IFREMER/WECAFC/CRFM Working Group on Shrimp and Groundfish of the North Brazil-Guiana Shelf allowing, funding, the collaboration with NOAA (J. Cope).

DR MORGANA TAGLIAROLO (Orcid ID : 0000-0002-9659-4565)

Article type : Article

Stock assessment on fishery-dependent data: effect of data quality and parametrisation for a red snapper fishery

Abstract

Data availability, unreported and unregulated fishing are significant obstacles to evaluating stock status, especially in tropical areas. Limitations in data quantity and quality can lead to model misspecification and erroneous data treatments, potentially causing important changes in model outputs and subsequent management implications. Red snapper *Lutjanus purpureus* (Poey) in French Guiana provides an example of a stock with a long-time series of fishery-dependent data subject to large uncertainty. A flexible catch-at-age model (Stock Synthesis) was applied to the available data and compared to an historically applied assessment approach. Inter-model variability based on different model specifications and data treatments were compared to identify better the status of the resource. Results showed that a major source of uncertainty in the model was the inclusion of a catch-per-unit-effort abundance index with questionable ability to track abundance. The Stock Synthesis model provided a more flexible and viable method than the virtual population analysis approach. Despite large uncertainty, models depicted a similar trend with a notable stock depletion in the late 1990s but with two distinct biomass trends in more recent years depending on the treatment. To reduce uncertainty and preserve this important economic resource, new data collection programmes and management policies are needed.

Keywords

Lutjanus purpureus, French Guiana, data-limited, Stock Synthesis

Introduction

Quantitative fishery stock assessments look to produce data-driven estimates of population abundance and dynamics to inform management decisions (Hilborn & Walters, 2013). Measurement error associated with a variety of data types and parameters, and natural process variability in population dynamics all lead to uncertainty in analytical outputs (Francis & Shotton, 2011). This uncertainty can hinge greatly on the quality and availability of the data (Chen, Chen, & Stergiou, 2003). Despite the potential for data-derived biases in assessments that could lead to management failures, improvements in quality and data availability are often limited by resources like money, time and available expertise (Chen et al., 2003). Developing harvest strategies based on limited data without waiting for extensive data sets that my never materialize is critical to responsive and responsible natural resource management (Dowling et al., 2015).

Data limitation is a global problem, particularly in tropical regions (Amorim, Sousa, Jardim, & Menezes, 2019). In addition to the challenges of monitoring legal activities, unreported and unregulated fishing presents an additional significant challenge to informing stock assessments (Cawthorn & Mariani, 2017). For example, unreported catches and effort can lead to severely biased estimates of biomass and other model outputs (Omori, Hoenig, Luehring, & Baier-Lockhart, 2016). This creates a mixed situation of partial coverage in data streams resulting in uncertainty that deserves respect and acknowledgement, but such uncertainty is an insufficient reason to avoid using science to inform management (Dowling et al., 2016). Unfortunately, numerous valuable fishery resources, especially in tropical areas, remain unevaluated.

The red snapper *Lutjanus purpureus* (Poey) fishery in French Guiana constitutes a good example of a data-limited fishery where, despite the availability of long time series of fishery-dependent data, information on the ecology of the species is still poorly understood and data gaps remain. The commercial handline red snapper fishery in French Guiana is predominantly performed by Venezuelan boats under a licensing system introduced in the 1980s by the French government and now under EU authority. The licence agreement requires boats to sell 75% of their catch to a processing factory in French Guiana, while the other 25% can be sold abroad. Controls at sea and at landing sites exist, but no information is available on the catch sold beyond French Guiana borders. Moreover, this fishing activity is mostly focused on smaller fish since the international market demands plate-sized fish typically below the size of maturity. This type of size-selective fishery can lead to age truncation if fishing mortality is high (Brunel & Piet, 2013; Reddy et al., 2013). Even if the catch of large fish declines, high fishing intensity on small individuals can threaten population sustainability (Reddy et al., 2013).

Lutjanus purpureus is particularly vulnerable to fishing pressure due to its behaviour and general life history characteristics (slow-growth, late maturity and seasonal spawning aggregations (Manickchand-Heileman & Phillip, 1996). Red snapper is known to aggregate for spawning, a behaviour that can lead to hyperstable signals of population density and overestimation of the stock size if not accounted for in stock assessments (Erisman, Apel, MacCall, Román, & Fujita, 2014). Additionally, the specific life history of *L. purpureus* is not well understood, creating significant uncertainty in the use of biological parameters (e.g. growth, natural mortally and reproduction) in French Guiana waters (Rivot, Charuau, Rose, & Achoun, 2000).

Red snapper in French Guiana provides an example of a stock with multiple data sources (e.g. catch, fishery-dependent index and biological compositions) of limited quality and uncertain life history values. Consequently, it is critical to compare several possible model specifications and data treatments to account for uncertainty in the estimation of management quantities in any stock assessment. This work takes up the challenge of assessing *L. purpureus* by: 1) investigating stock assessment uncertainty based on limitations in the fishery-dependent data and life history inputs using a flexible statistical catch at age approach (i.e. the Stock Synthesis (SS) modelling framework) and 2) comparing results from the SS model to that of a Virtual Population Analysis (VPA) approach that has historically been used to assess the stock. By accounting for the uncertainty in sources of data and inputs, the major sources of model output uncertainty are identified and quantified for management consideration, while using the flexible SS framework may provide a more advantageous modelling environment compared to the more rigid VPA approach.

Material and methods

Fishery catch data

In French Guiana, red snapper is mostly fished by Venezuelan hand-liners between 30 and 200 m depth. The hand-line fishery is estimated to have started around 1960, with some information on landings beginning in 1976, with the most reliably data recorded from 1985 onward when Ifremer (Institut Français de Recherche pour l'Exploitation de la Mer) started a fisheries information database (Tous, 1988). Before 1988, other fishing activities such as trawling were also targeting red snapper, but catches were not monitored (Prevost, 1989; Tous, 1988).

In 1984 a licencing system was implemented requiring Venezuelan boats to sell a fixed percentage of their catch in French Guiana (50% for 1984 and 75% from 1985 to present). In addition to the main hand-line fishery, a few boats coming from the French Antilles islands occasionally fished French Guiana waters with fish traps (e.g. in 2019, less than 70 t or 2.6% of total yearly catches). Additionally, bycatch in shrimp trawlers takes small (between 8 and 30 cm) red snapper (i.e. in 2007 about 100 t, or 6% of total catches for 23 trawlers), but little information on the historical time series of these catches is available (Caro & Lampert, 2011). Currently, only 10 shrimp trawlers remain, likely reducing the amount of red snapper bycatch. Considering the high uncertainty of the landings data, especially at the beginning of the time-series, and the need to correct for these missing catches, landings data were expanded by 25% for all years to estimate total removals from the red snapper population (Fig. 1). No information was available to hypothesise any temporal changes in the expansion value.

Abundance data

Fishery-dependent catch per unit effort (CPUE) indices were available from 1986 to 2018 (Fig. 1). CPUE was calculated by dividing the total annual catches by the total annual number of days at sea estimated from logbooks and/or vessel monitoring systems (VMS) data (t catch / days at sea). CPUE were not standardised since no historical information in changes of the fishing techniques or other factors were available. This lack of standardisation adds uncertainty in the application of this index, but it is the only index available.

Biological data

Length composition (fork length in cm) data were available from 1986 to 2019. Length is routinely measured by observers at landing sites in Cayenne according to the framework of the fisheries information system (SIH) implemented by Ifremer. The available data set is obtained from a monthly sampling plan that subsamples boats landing red snapper. The sample size has changed over the years following changes in the fishery and improvement in the statistical analysis to try and optimise the sample size. The length frequency of the subsample was therefore expanded to match the 25% expansion in landings (to account for the animals fished in French Guiana waters but landed abroad).

Life history relationships and values

Natural mortality was assumed constant across ages and time. Individual growth was modelled as a von Bertalanffy function, fecundity was modelled as proportional to weight, and a Beverton-Holt stock-recruit relationship was assumed. Life history values were fixed in the reference model and were obtained from literature sources (Table 1). Exploration of uncertainty in natural mortality (M) and the Beverton-Holt steepness parameters (h;

recruitment compensation, or average recruitment of a population reduced to 20% of unfished levels relative to average recruitment of the unfished population) are described in the next section on sensitivity analysis.

Model description and specification

The assessment was conducted using the Stock Synthesis (SS version 3.30.13.02) framework that uses maximum likelihood estimation (MLE) to obtain values and calculate asymptotic uncertainty for estimated parameters and model outputs (Methot Jr & Wetzel, 2013). The model is configured as one sex as females and males were assumed to have the same life history parameters. Fishery-dependent data (catch, CPUE and length compositions) were specified as one fleet with dome-shape selectivity as the largest individuals are not taken in the fishery, a parameterization choice confirmed by fishermen. A selectivity time block was applied with a break implemented after 1996 and 2018 to account for a possible change in fishing practice (targeting smaller individuals to adapt to market demand) as suggested by local fishermen that changed the size composition of the fish landed. The model with a time block in selectivity improved model fit to the length compositions (see Appendix B and C). Catch in metric tonnes was assumed known while the CPUE index assumed a lognormal error with a standard deviation of 0.3 for all years. Length composition data were modelled with 2-cm length bins between 15 and 85 cm, and relative sample sizes among years were determined by the samples by trip weighted by catch. The list of the parameters used in the reference model is provided in Appendix A. The data and model outputs were summarised using the r4SS package (https://github.com/r4ss/r4ss). Additional data weighting for lengths and CPUE were unnecessary given the model fit (see Appendix C).

Sensitivity analysis and likelihood profiles

Model sensitivity to parameter uncertainty was explored via likelihood profiles—the fixing of the model to various values of a specific parameter to see how model fit and derived outputs change. Likelihood profiles demonstrate the amount of information (measured by the changing likelihood metric) contained in the data for the featured parameter. Using the negative log likelihood metric, any value outside of 1.96 units from the maximum likelihood estimate (MLE) is considered significantly less supported by the data. The spread of model outputs within the interval of significant data support therefore provides a measure of uncertainty in model output based on parameter input. To demonstrate how model output changes across profiled parameter values, three model outputs were considered: 1) initial spawning output (SO_0); 2) terminal year spawning output (SO_{2018}); 3) the stock status in the terminal year (SO_{2018}/SO_0). Comparing the information content of a particular parameter value to the associated model output allows a mapping of model information (i.e. data) to sensitivity in the model output (i.e. results). Likelihood profiles were conducted for the following two parameters:

Natural mortality

Natural mortality is one of the most influential and difficult parameters to estimate in fisheries stock assessment (Lee, Maunder, Piner, & Methot, 2011). Stock assessments often use an external estimate of *M* as a fixed value, but may also estimate *M* within the model. Estimating *M* depends on other model specifications (e.g. having at least one fishery with asymptotic selectivity) and necessitates an exploration of model performance (Brodziak, Ianelli, Lorenzen, & Methot Jr, 2011; Lee et al., 2011).

The range of *M* values used in the likelihood profile were defined by first estimating M indirectly using meta-analytical and empirical methods based on life history parameters. “The Natural Mortality Tool” (http://barefootecologist.com.au/shiny_m) application was used to access to many different empirical *M* estimators. The methods based on maximum age (Hamel et al., 2015; Then, Hoenig, Hall, & Hewitt, 2015) and on the von Bertalanffy K parameter (Alverson & Carney, 1975; Jensen, 1996, 1997; Zhang & Megrey, 2006) and FishLife (Thorson, Munch, Cope, & Gao, 2017) estimates were selected. *M* estimates varied between 0.09 and 0.46 per year with a median value of 0.39 per year. These values were also compared to that of Rivot et al. (2000) who compared three different estimation methods for French Guiana red snappers suggesting that *M* ranged from 0.18 to 0.61 per year (Pauly & Moreau, 1997; Ralston & Polovina, 1987; Rikhter & Efanov, 1976), with 0.29 per year considered the most plausible. A likelihood profile range of *M* from 0.10 to 0.60 per year at an interval of 0.05 was defined using both of the above sources (The Natural Mortality Tool and Rivot et al. 2000).

Steepness

It is common in stock assessments to define the functional relationship between spawners and recruits using the reparameterized Beverton-Holt function (Mace & Doonan, 1988) where steepness (*h)* is a key parameter. Steepness technically ranges from 0.2 to 1 in the Beverton-Holt model, though values below 0.3 are often deemed unsustainable (He, Mangel, & MacCall, 2006). A higher *h* value loosens the relationship between stock and recruits, producing higher productivity at smaller stock sizes. A value of *h*=1 essentially decouples the stock-recruit relationship (Mangel et al., 2013; Shertzer & Conn, 2012). Steepness defines some management quantities (e.g. MSY and F_{MSY}), but direct estimation requires contrast in the data at low and high population sizes.

Externally-derived steepness values are much more commonly used, and come from life history parameters and meta-analyses on ecologically similar species (Shertzer & Conn, 2012). The R package "FishLife" (https://github.com/James-Thorson-NOAA/FishLife; Thorson (2020)) was used to specify *h* (0.7) for *L. purpureus*, and the subsequent likelihood profile range of *h* was 0.40 to 1 with an interval of 0.05.

Uncertainty in length data

The impact of bias in unsampled lengths was explored from the unreported international fishery. Unfortunately, no data were available on the proportion of fish sold abroad, but local fisherman indicate bigger fish are typically landed for markets outside French Guiana. To test this hypothesis, length compositions of the non-monitored landings (assumed to represent 25% of the total catch) from 1991 to present were modified to include individuals larger than 40 cm following the average length distribution composition for years 1986-1991 (period when larger individuals were fished). This model was then compared to the reference model using only sampled lengths.

Uncertainty in CPUE

The available raw CPUE data used in this study were exclusively derived from fishery-dependent time series and were non standardised since little information are available on sampling conditions, fish biology and movement patterns, or on changes in fishing behaviour. To understand the influence of the CPUE index on model outputs better, the reference SS model was compared to a model with no CPUE index, thus relying only on catches and lengths as inputs. The assumption of linearity between CPUE and abundance was investigated by estimating the exponent of a power function relationship between the CPUE index and the catchability (Hilborn & Walters, 2013; Methot, 2009).

Comparison to VPA

The *L. purpureus* stock was first assessed in 2012 by applying a VPA on commercial length frequency data from 1986 following a von Bertalanffy growth relationship and assuming a maximum age of 13 years (Lampert, 2012). VPA uses a backward projection to estimate recruits with no stock recruit relationship, while SS assumes the Beverton-Holt stock-recruitment relationship. The SS model also assumes length variability at age, whereas the length-age relationship in the VPA was taken straight from the von Bertalanffy curve. The VPA model was constructed following the equations in example 18 of Sparre and Venema (1998). A plus-group was employed for the last age group. F (and Z) are age-specific with the plus group applying a constant average F value. The VPA model does not explicitly specify selectivity. The VPA model did not consider the CPUE data and applied a constant fishing mortality by cohorts (averaged over the most recent 5 years) to estimate stock biomass. Natural mortality in the VPA model was fixed at 0.29. The VPA model was run again with the most recent data and main outputs (total biomass, recruitment, spawning biomass and relative spawning biomass relative to the first year of the model) were compared to the SS model.

RESULTS

Reference model

The reference SS model of the red snapper shows a stock in initial decline, but in recent years increases in biomass despite increasing catches (Fig. 2). Recruitment is at its highest post-2000, when the CPUE time series shows a steady increase. Current relative stock status is very high and well above what would be considered maximum sustainable biomass (Fig. 2).

Likelihood profiles

<u>Natural mortality</u>

The model tends to support higher values of natural mortality (Fig. 3, likelihood panel), but the amount of information in the model on natural mortality is very limited. Most of the information comes from the assumed prior on *M* when looking at the likelihood components in the profile (Appendix C). Initial and final spawning output are very sensitive to the assumption of lower *M* values (Fig. 3). Despite the sensitivity in the absolute biomass measures, the relative biomass was similar across the full profile (Fig. 3). This illustrates a situation where the model is poorly informed on the absolute biomass of the stock, but the current stock status is robust to changes in perception of *M* and indicative of a high stock status.

The SS-estimated *M* value was particularly high (0.46 per year) and probably unrealistic for *L. purpureus* given the life history and lack of information on *M* contained in the data (Fig. 3). For this reason, the median value of 0.39 per year from the nine empirical estimation methods was fixed and assumed for both sexes in the reference assessment model.

<u>Steepness</u>

The steepness likelihood profile showed the available data had no information on the steepness value (Fig. 4). Biomass changed non-linearly to steepness, with higher biomass at lower steepness values, a typical result when looking across steepness values. Relative stock status, while somewhat sensitive to the value of *h*, was consistently high across all steepness values given the other data and parameter specifications in the reference model.

Uncertainty in length data

The inclusion of larger individuals on the length compositions resulted in slightly different estimated selectivity parameters in the two-time periods (Appendix E) that result in large overlap in biomass estimates between the length composition treatments (Fig. 6). The small differences between models are highlighted by slightly larger biomass estimates, higher relative stock sizes and lower fishing pressure in the model including larger individuals, although well within the bounds of uncertainty of the reference model.

Uncertainty in CPUE

Removing the CPUE index strongly affected model output, resulting in a more pessimistic situation for both ending biomass and subsequent stock status (Fig. 7 and Appendix D). The scale of the initial population biomass was not sensitive to inclusion of the CPUE index, but the final biomass was sensitive, pointing to the importance of the CPUE index as a source of current stock status information. Whether this data sets contains an unbiased signal relative to noise regarding the trend in the population is a critical assumption when interpreting these results.

The SS model using a power relationship between the CPUE index and the catchability suggests hyperdepletion in the raw CPUE (estimated catchability power value of 2.62). The model outputs also incorporated more uncertainty relative to the reference model but the trends were similar (Appendix F). Any interpretation using the raw CPUE index should be considered with enormous caution.

Comparison to VPA

SS outputs for the reference model and the model without CPUE were compared to the results from the VPA model (Fig. 2). As previously demonstrated, these two specifications of the SS models differ mostly in years after 2001. Before 2001, the VPA model showed relatively lower biomass levels compared to the SS outputs, though both models suggest the lowest biomass was in the early 2000s (Fig. 2). From about 2010, the outputs of SS model without CPUE (recruitments, SSB and total biomass) resulted closer to the VPA estimation. On the other hand, the relative stock status as defined by the first year of the time series ($SSB_{current}/SSB_{1986}$) indicates a larger decline for SS model without CPUE compared with the VPA. Note, the VPA uses only the length data, not the CPUE, yet still shows recovery, whereas the SS with no CPUE scenario shows a persistent decline.

Given the historical VPA assumes a lower *M* value than the SS models, an additional VPA model with the same *M* value used in the SS model was performed. This sensitivity did not result in enough change in the VPA model to account for the different biomass scales between the VPA and SS models.

Discussion

When applying complex stock assessment models in data-limited situations, it is important to have the flexibility to explore major axes of uncertainty and alternative model specifications, and not rely on the output of just one model. SS is a powerful and flexible modelling framework accommodating many ways of exploring uncertainty, including data inputs and major life history parameter exploration. Sensitivity analysis can be performed on several assumptions (e.g. growth parameters or selectivity shape), but results can be difficult to interpret if the probabilistic statements for the different values are unknown (Maunder & Piner, 2015). Natural mortality and particularly steepness can be difficult to estimate in stock assessments, as both benefit from contrast in the data. Although empirical estimators for *M* are available, their imprecision (Kenchington, 2014) requires further characterisation of uncertainty outside one model specification (i.e. using only one value of *M*). Sensitivity analyses are recommended to test for the robustness of model outputs to parameter and data choices and offer a fuller representation of uncertainty and effects of model misspecifications (Brooks & Deroba, 2015). Erroneous estimation of *M* can lead to over- or underestimates of stock biomass and status, poorly informing management of the resource (Kenchington, 2014). Mortality rates for *Lutjanus* species reported in literature from Florida to Brazil range widely from 0.11 to 0.49 per year (Arreguín-Sánchez, Munro, Balgos, & Pauly, 1996; Burton, 2002; Rivot et al., 2000; Topping & Szedlmayer, 2013). Our likelihood profile and sensitivity analysis showed the largest changes in model output with low *M* values. Given the prior constructed here (based on life history values via empirical *M* estimators) drove the estimation of *M* and profiling showed no information to delineated M values >0.4, fixing *M* to 0.39 per year seemed a very reasonable decision when determining a reference model.

This model also showed sensitivity to steepness for several model derived quantities, a common result as changes in the steepness value usually causes major uncertainty in the estimation of management quantities (Zhou, 2007). But the model also was unable to estimate steepness given the lack of strong contrast in population biomass and recruitment, despite the u-shaped population dynamics in the model using CPUE (Lee, Maunder, Piner, & Methot, 2012; Magnusson & Hilborn, 2007).

Length composition data are one of the easier data sources to collect for many species, although non-representative sampling can potentially cause bias in interpreting sampled lengths. Length data are a central component for age-structured models, especially when aging data are typically not available (Heery & Berkson, 2009), providing information on gear selectivity, recruitment pulses, and stock status (as well as life history parameter information in some situations). Length data can suffer from systematic errors during the sampling of catch that make it unrepresentative of the true catch. While the causes of bias in sampling fishery-dependent length composition data are recognised (e.g. non-random sample collection, limited access to fishery catch or poor sampling design), the effect of it on stock assessment is always not straightforward (Gerritsen & McGrath, 2007; Heery & Berkson, 2009). Here it was demonstrated that correcting for the main source of sampling error (no sampling of the exported portion of catch) for *L. purpureus* had little effect on model outputs. While this lack of model sensitivity points to model robustness to this particular data scenario, representativeness in the length data should always either be ensured through proper sampling design or evaluated in the model with the exploration of data scenarios.

One of the biggest sources of uncertainty in the red snapper model was the inclusion of the CPUE-based abundance index. CPUE misspecification can cause a significant weakness in the model performance when linking the population trend to the abundance index (Methot Jr & Wetzel, 2013; Wiedenmann & Jensen, 2017). In the case of this model, the final trend in the population dynamics demonstrated a major dichotomy in results depending on the treatment of the CPUE index. Removing it caused the population to continue to decline (as the catch continued to increase) instead of rebound. This also demonstrates how the signal in the index was different to that of the length composition data. Competing signals in data sources are very common in integrated stock assessments, and must be resolved using data weighting or, ideally, alternative model specification (Maunder and Piner, 2017). Such data weighting choices are a major consideration when model building and defining appropriate sensitivity analyses.

Fishery-dependent CPUE is known to vary over time violating the assumption of being proportional to abundance. Several methods have been employed to incorporate time-varying catchability into stock assessments (e. g. random walk) but fishery-dependent CPUE generally need standardisation (Wilberg, Thorson, Linton, & Berkson, 2009). CPUE data series can be standardised to account for a variety of factors, however standardisation can only correct for measured factors and require available data for each factor (Wilberg et al., 2009). Information on stock spatial and temporal variability and technological changes in the French Guiana red snapper fishery is fragmentary and incomplete, thus, CPUE standardisation for this red snapper model is currently not possible. The incorporation of a non-linear power function between the CPUE index and the catchability suggests possible hyperdepletion that added more uncertainty to the model outputs. One possible mechanism explaining this result is that the grouping behaviour of snappers can lead to localised depletions as already showed for *Lutjanus* spp. In the Gulf of Mexico (Saul, Brooks, & Die, 2020). Nevertheless, those results should be interpreted with caution since the CPUE integrated in the model were not standardised. Future use of CPUE as an index in this assessment should consider the possibility of incorporating time-varying or non-proportional catchability if additional data could be collected to improve CPUE standardisation and application.

The VPA approach has a long history of application to major fished stocks in French Guiana and several European regions, but this methods requires a relatively complete data set and can often accommodate only the most recent period of the fishery since age composition data are rarely available for the beginning of the fishery (Stewart & Martell, 2015). The VPA approach requires a complete catch-at-age time series that is often estimated from cohort slicing of length data (Ailloud et al., 2015). This type of procedures can introduce a large and unpredictable uncertainty that can influence VPA assessments (Carruthers, Kell, & Palma, 2017). The SS model does not need catches-at age and can directly integrate length datasets using growth parameters and uncertainty in length at age, thus integrating this uncertainty in the assessment (Methot Jr & Wetzel, 2013). SS and VPA follow a similar process but in opposite directions (VPA is a backward projection model while SS is a forward projection model) and adopt a different selectivity approach (Punt, Hurtado-Ferro, & Whitten, 2014) and treatment of recruitment. In the recent years, French Guiana stock assessments has been performed with both methods to compare the results. The possibility to use SS exclusively for future assessments is now a consideration. The differences result in a notable difference in absolute biomass estimation among the approaches. Stewart and Martell (2015) also found a biomass difference comparing VPA and SS models. The catch and length version of the SS model, which is the most similar SS model to the data used in the VPA model, was also different in both population trend and biomass size. These models all give very different measures of absolute and/or relative stocks size, and thus management should consider the most appropriate way to weight these different model specifications to inform management (Stewart & Martell, 2015). The SS model allows for flexibility and uncertainty specification and should be preferred over VPA for further management scenarios.

Conclusion

Dealing with data-limited fisheries and unreported times series can be particularly challenging, and model misspecification and data treatments can cause important changes in the model outputs and management suggestions. Prioritising some of the data and down-weighting others can be a solution to reduce conflicts but it can be difficult to choosing these weightings (Ichinokawa, Okamura, & Takeuchi, 2014). These conflicts instead should be confronted with model exploration to avoid model mis-specification (Wang & Maunder, 2017) or re-evaluation of the representativeness of the data in question. Thorough sensitivity analysis and even simulation analysis may be needed to identify potential bias and misspecifications.

The present results showed that for French Guiana *L. purpureus* the SS model provided a flexible and viable method to assess the exploitation status of the stock and the uncertainty to model specification and data set choices given the limitations in available data and life history inputs. The available data were insufficient for the estimation of natural mortality and steepness, necessitating a sensitivity exploration through a likelihood profile to understand how model outputs were affected by the values of these parameters. This model also showed sensitivity to data inputs, as the CPUE index seems to contrast with the length composition data-set. Whether this is due to truly different signals in the data, lack of proper standardization in the CPUE, or unrepresentativeness of the data is not known at this time, but it does pinpoint a critical research topic to improve future stock assessments of red snapper. Despite the above uncertainties, all models were depicting a similar trend with notable stock depletion in the late 1990s. Biomass is recovering in recent years when using the CPUE abundance index (~60% of the unfished spawning biomass) despite stable fishing mortality. To preserve this important economic resource, new data collections (e.g. measuring lengths of all catches; improving the quality of the CPUE time series with electronic monitoring; development of a fishery-independent survey; collecting ageing structures) can be added directly to the SS model configured here, while enforceable management measures (e.g. hook size regulations; developing spatial and temporal restrictions; limit illegal activities; catch limits) should be explored.

Acknowledgments

We would like to tanks all the SIH team (E. Mansuy and all the VSC) for collecting the data. We would also like to acknowledge the fisherman committee (CPMEM) and all fishermen for their willingness to share information with us. This work has been initiated in the the IFREMER/WECAFC/CRFM Working Group on Shrimp and Groundfish of the North Brazil-Guiana Shelf allowing, funding, the collaboration with NOAA (J. Cope).

References

Ailloud, L. E., Smith, M. W., Then, A. Y., Omori, K. L., Ralph, G. M., & Hoenig, J. M. (2015). Properties of age compositions and mortality estimates derived from cohort slicing of length data. *ICES Journal of Marine Science*, *72*(1), 44-53. doi: 10.1093/icesjms/fsu088

Alverson, D. L., & Carney, M. J. (1975). A graphic review of the growth and decay of population cohorts. *ICES Journal of Marine Science*, *36*(2), 133-143. doi: 10.1093/icesjms/36.2.133

Amorim, P., Sousa, P., Jardim, E., & Menezes, G. M. (2019). Sustainability Status of Data-Limited Fisheries : Global Challenges for Snapper and Grouper. *Frontiers in Marine Science*, *6*. doi: 10.3389/fmars.2019.00654

Arreguín-Sánchez, F., Munro, J. L., Balgos, M. C., & Pauly, D. (1996). *Biology, Fisheries, and Culture of Tropical Groupers and Snappers : Proceedings of an EPOMEX/ICLARM International Workshop on Tropical Snappers and Groupers, Held at the University of Campeche, Campeche, Mexico, 26-29 October 1993*. WorldFish.

Brodziak, J., Ianelli, J., Lorenzen, K., & Methot Jr, R. D. (2011). Estimating natural mortality in stock assessment applications. *NOAA Technical Memorandum NMFS-F/SPO*, *119*, 38.

Brooks, E. N., & Deroba, J. J. (2015). When “data” are not data : The pitfalls of post hoc analyses that use stock assessment model output. *Canadian Journal of Fisheries and Aquatic Sciences*, *72*(4), 634-641. doi: 10.1139/cjfas-2014-0231

Brunel, T., & Piet, G. J. (2013). Is age structure a relevant criterion for the health of fish stocks? *ICES Journal of Marine Science*, *70*(2), 270-283. doi: 10.1093/icesjms/fss184

Burton, M. L. (2002). Age, growth and mortality of mutton snapper, Lutjanus analis, from the east coast of Florida, with a brief discussion of management implications. *Fisheries Research*, *59*(1), 31-41. doi: 10.1016/S0165-7836(02)00007-3

Caro, A., & Lampert, L. (2011). *Description de la pêcherie vénézuélienne de vivaneaux dans la ZEE de Guyane et évaluation du stock de vivaneau rouge (L. purpureus) en 2010* (N° RBE/BIODIVHAL 2011-02). Ifremer. Consulté à l’adresse Ifremer website: https://archimer.ifremer.fr/doc/00075/18580/

Carruthers, T., Kell, L., & Palma, C. (2017). Accounting for uncertainty due to data processing in virtual population analysis using Bayesian multiple imputation. *Canadian Journal of Fisheries and Aquatic Sciences*, *75*(6), 883-896. doi: 10.1139/cjfas-2017-0165

Cawthorn, D.-M., & Mariani, S. (2017). Global trade statistics lack granularity to inform traceability and management of diverse and high-value fishes. *Scientific Reports*, *7*(1), 1-11. doi: 10.1038/s41598-017-12301-x

Chen, Y., Chen, L., & Stergiou, K. I. (2003). Impacts of data quantity on fisheries stock assessment. *Aquatic Sciences*, *65*(1), 92-98. doi: 10.1007/s000270300008

Dowling, N. A., Dichmont, C. M., Haddon, M., Smith, D. C., Smith, A. D. M., & Sainsbury, K. (2015). Empirical harvest strategies for data-poor fisheries : A review of the literature. *Fisheries Research*, *171*, 141-153. doi: 10.1016/j.fishres.2014.11.005

Dowling, N. A., Wilson, J., Rudd, M., Babcock, E., Caillaux, M., Cope, J., … Victor, S. (2016). *FishPath : A Decision Support System for Assessing and Managing Data- and Capacity- Limited Fisheries*. doi: 10.4027/amdlfs.2016.03

Erisman, B. E., Apel, A. M., MacCall, A. D., Román, M. J., & Fujita, R. (2014). The influence of gear selectivity and spawning behavior on a data-poor assessment of a spawning aggregation fishery. *Fisheries Research*, *159*, 75-87. doi: 10.1016/j.fishres.2014.05.013

Francis, R., & Shotton, R. (2011). "Risk" in fisheries management : A review. *Canadian Journal of Fisheries and Aquatic Sciences*. (Ottawa, Canada). doi: 10.1139/f97-100

Gerritsen, H. D., & McGrath, D. (2007). Precision estimates and suggested sample sizes for length-frequency data. *Fishery Bulletin*, *105*(1), 116-120.

Hamel, M. J., Pegg, M. A., Goforth, R. R., Phelps, Q. E., Steffensen, K. D., Hammen, J. J., & Rugg, M. L. (2015). Range-wide age and growth characteristics of shovelnose sturgeon from mark–recapture data : Implications for conservation and management. *Canadian Journal of Fisheries and Aquatic Sciences*, *72*(1), 71-82.

He, X., Mangel, M., & MacCall, A. (2006). A prior for steepness in stock-recruitment relationships, based on an evolutionary persistence principle. *Fishery Bulletin*, *104*(3), 428-433.

Heery, E. C., & Berkson, J. (2009). Systematic Errors in Length Frequency Data and their Effect on Age-Structured Stock Assessment Models and Management. *Transactions of the American Fisheries Society*, *138*(1), 218-232. doi: 10.1577/T07-226.1

Hilborn, R., & Walters, C. J. (2013). *Quantitative Fisheries Stock Assessment : Choice, Dynamics and Uncertainty*. Springer Science & Business Media.

Ichinokawa, M., Okamura, H., & Takeuchi, Y. (2014). Data conflict caused by model mis-specification of selectivity in an integrated stock assessment model and its potential effects on stock status estimation. *Fisheries Research*, *158*, 147-157. doi: 10.1016/j.fishres.2014.02.003

Jensen, A. L. (1996). Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Canadian Journal of Fisheries and Aquatic Sciences*, *53*(4), 820-822.

Jensen, A. L. (1997). Origin of relation between K and L inf and synthesis of relations among life history parameters. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*(5), 987-989.

Kenchington, T. J. (2014). Natural mortality estimators for information-limited fisheries. *Fish and Fisheries*, *15*(4), 533-562. doi: 10.1111/faf.12027

Lampert, L. (2012). *Manuel de procédures et méthodes pour le suivi de la pêche au vivaneau en Guyane* (Report (Technical document (specification, manual)) N° RBE/BIODIVHAL 2012-02). Ifremer.

Lampert, L., Achoun, J., & Levrel, A. (2013). *Actualisation des relations Taille-Poids pour le vivaneau Lutjanus purpureus en Guyane.* [Report (Normative document (norm, referencial, protocol))]. FRANCE. Consulté à l'adresse https://archimer.ifremer.fr/doc/00126/23726/

Lee, H.-H., Maunder, M. N., Piner, K. R., & Methot, R. D. (2011). Estimating natural mortality within a fisheries stock assessment model : An evaluation using simulation analysis based on twelve stock assessments. *Fisheries Research*, *109*(1), 89-94. doi: 10.1016/j.fishres.2011.01.021

Lee, H.-H., Maunder, M. N., Piner, K. R., & Methot, R. D. (2012). Can steepness of the stock–recruitment relationship be estimated in fishery stock assessment models? *Fisheries Research*, *125-126*, 254-261. doi: 10.1016/j.fishres.2012.03.001

Mace, P. M., & Doonan, I. J. (1988). *A generalised bioeconomic simulation model for fish population dynamics*. MAFFish, NZ Ministry of Agriculture and Fisheries.

Magnusson, A., & Hilborn, R. (2007). What makes fisheries data informative? *Fish and Fisheries*, *8*(4), 337-358. doi: 10.1111/j.1467-2979.2007.00258.x

Mangel, M., MacCall, A. D., Brodziak, J., Dick, E. j., Forrest, R. E., Pourzand, R., & Ralston, S. (2013). A perspective on steepness, reference points, and stock assessment. *Canadian Journal of Fisheries and Aquatic Sciences*, *70*(6), 930-940. doi: 10.1139/cjfas-2012-0372

Manickchand-Heileman, S. C., & Phillip, D. A. T. (1996). Reproduction, Age and Growth of the Caribbean Red Snapper (Lutjanus purpureus) In Waters off Trinidad and Tobago. In *ICLARM Conf.*: *Vol. 48*. *Biology, fisheries and culture of tropical groupers and snappers.* (p. 137-149).

Maunder, M. N., & Piner, K. R. (2015). Contemporary fisheries stock assessment : Many issues still remain. *ICES Journal of Marine Science*, *72*(1), 7-18. doi: 10.1093/icesjms/fsu015

Methot Jr, R. D., & Wetzel, C. R. (2013). Stock synthesis : A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research*, *142*, 86-99.

Methot, R. D. (2009). User manual for stock synthesis. *NOAA Fisheries, Seattle, USA*.

Omori, K. L., Hoenig, J. M., Luehring, M. A., & Baier-Lockhart, K. (2016). Effects of underestimating catch and effort on surplus production models. *Fisheries Research*, *183*, 138-145. doi: 10.1016/j.fishres.2016.05.021

Pauly, D., & Moreau, J. (1997). *Méthodes pour l'évaluation des ressources halieutiques*. Toulouse: Editions Cépaduès.

Prevost, E. (1989). *La pêche au vivaneau en Guyane Française : Etude comparative et évaluation des trois techniques : (Ligne à main, nasse, chalut)* [Report]. FRANCE. Consulté à l'adresse https://archimer.ifremer.fr/doc/00429/54014/

Punt, A. E., Hurtado-Ferro, F., & Whitten, A. R. (2014). Model selection for selectivity in fisheries stock assessments. *Fisheries Research*, *158*, 124-134. doi: 10.1016/j.fishres.2013.06.003

Ralston, S., & Polovina, J. J. (1987). *Tropical snappers and groupers : Biology and fisheries management*. Westview.

Reddy, S. M. W., Wentz, A., Aburto-Oropeza, O., Maxey, M., Nagavarapu, S., & Leslie, H. M. (2013). Evidence of market-driven size-selective fishing and the mediating effects of biological and institutional factors. *Ecological applications : a publication of the Ecological Society of America*, *23*(4), 726-741.

Rikhter, V. A., & Efanov, V. N. (1976). *On one of the approaches to estimation of natural mortality of fish populations*. International Commission for the Northwest Atlantic Fisheries.

Rivot, E., Charuau, A., Rose, J., & Achoun, J. (2000). *La pêche du vivaneau rouge en Guyane. Un bilan de l'exploitation sous le régime vénézuélien, des techniques de capture à adapter et à développer*. Consulté à l'adresse https://archimer.ifremer.fr/doc/00075/18614/

Saul, S., Brooks, E. N., & Die, D. (2020). How fisher behavior can bias stock assessment : Insights from an agent-based modeling approach. *Canadian Journal of Fisheries and Aquatic Sciences*, *77*(11), 1794-1809.

Shertzer, K. W., & Conn, P. B. (2012). Spawner-Recruit Relationships of Demersal Marine Fishes : Prior Distribution of Steepness. *Bulletin of Marine Science*, *88*(1), 39-50. doi: 10.5343/bms.2011.1019

Sparre, P., & Venema, S. C. (1998). *Introduction to tropical fish stock assessment - Part 1 : Manual (French version not published)*. Rome, Italy: FAO. Consulté à l'adresse http://www.fao.org/documents/card/en/c/9bb12a06-2f05-5dcb-a6ca-2d6dd3080f65/

Stewart, I. J., & Martell, S. J. D. (2015). Reconciling stock assessment paradigms to better inform fisheries management. *ICES Journal of Marine Science*, *72*(8), 2187-2196. doi: 10.1093/icesjms/fsv061

Then, A. Y., Hoenig, J. M., Hall, N. G., & Hewitt, D. A. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science*, *72*(1), 82-92. doi: 10.1093/icesjms/fsu136

Thorson, J. T. (2020). Predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide using a data-integrated life-history model. *Fish and Fisheries*, *21*(2), 237-251. doi: 10.1111/faf.12427

Thorson, J. T., Munch, S. B., Cope, J. M., & Gao, J. (2017). Predicting life history parameters for all fishes worldwide. *Ecological Applications*, *27*(8), 2262-2276. doi: 10.1002/eap.1606

Topping, D. T., & Szedlmayer, S. T. (2013). Use of ultrasonic telemetry to estimate natural and fishing mortality of red snapper. *Transactions of the American Fisheries Society*, *142*(4), 1090-1100.

Tous, PH. (1988). *Perspectives d'exploitation d'espèces nouvelles : La pêche au vivaneau* [Report]. Consulté à l'adresse https://archimer.ifremer.fr/doc/00087/19811/

Wang, S.-P., & Maunder, M. N. (2017). Is down-weighting composition data adequate for dealing with model misspecification, or do we need to fix the model? *Fisheries Research*, *192*, 41-51. doi: 10.1016/j.fishres.2016.12.005

Wiedenmann, J., & Jensen, O. P. (2017). Uncertainty in stock assessment estimates for New England groundfish and its impact on achieving target harvest rates. *Canadian Journal of Fisheries and Aquatic Sciences*, *75*(3), 342-356. doi: 10.1139/cjfas-2016-0484

Wilberg, M. J., Thorson, J. T., Linton, B. C., & Berkson, J. (2009). Incorporating time-varying catchability into population dynamic stock assessment models. *Reviews in Fisheries Science*, *18*(1), 7-24.

Zhang, C.-I., & Megrey, B. A. (2006). A revised Alverson and Carney model for estimating the instantaneous rate of natural mortality. *Transactions of the American Fisheries Society*, *135*(3), 620-633.

Zhou, S. (2007). Discriminating alternative stock–recruitment models and evaluating uncertainty in model structure. *Fisheries Research*, *86*(2), 268-279. doi: 10.1016/j.fishres.2007.06.026

Tables

Table 1: Life history parameters employed in this study

von Bertalanffy growth coefficient (k)	0.12 year-1	(Rivot et al., 2000)
von Bertalanffy asymptotic length (Linf)	105 cm	(Rivot et al., 2000)
length-weight allometric parameter (b)	2.95455	(Lampert, Achoun, & Levrel, 2013)
length-weight scaling parameter (a)	1.97E-05	(Lampert et al., 2013)
maximum age	13 year	(Rivot et al., 2000)
maximum length	88 cm	(Rivot et al., 2000)
Length at 50% maturity	32 cm	

Figure legends

Fig. 1: Catches and catch per unit effort (CPUE) data employed in red snapper SS model.

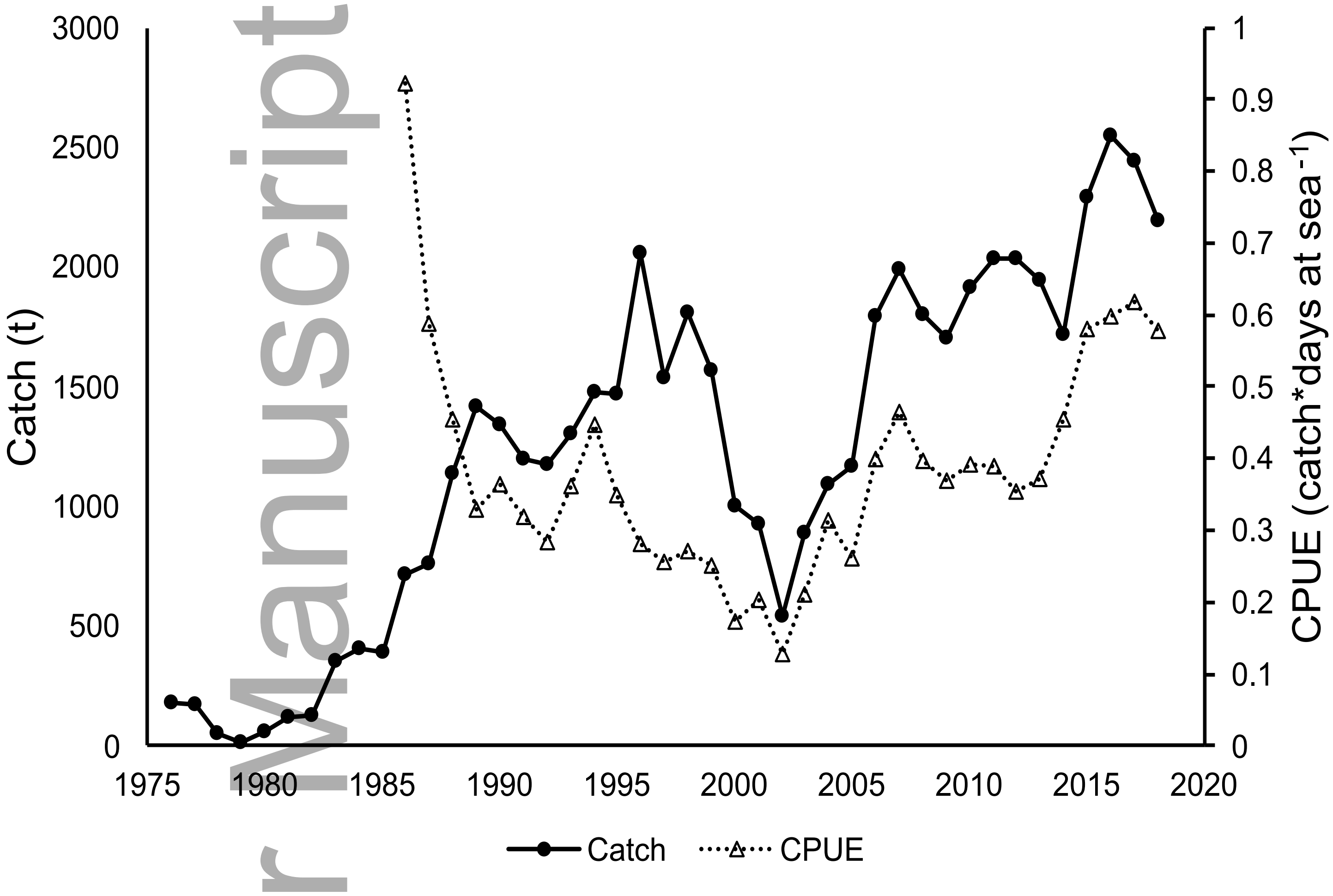
Fig. 2: Comparison of the main model outputs for the reference SS model, the SS model without catch per unit effort (CPUE) and the virtual population analysis (VPA).

Fig. 3: Likelihood profile for natural mortality and derived quantities (initial spawning output (SO_0); spawning output in 2018 (SO_{2018}), stock status (SO_{2018}/SO_0) in the French Guiana red snapper SS model. The natural mortality of 0.39 estimated by "The Natural Mortality tool" is showed by a grey dot.

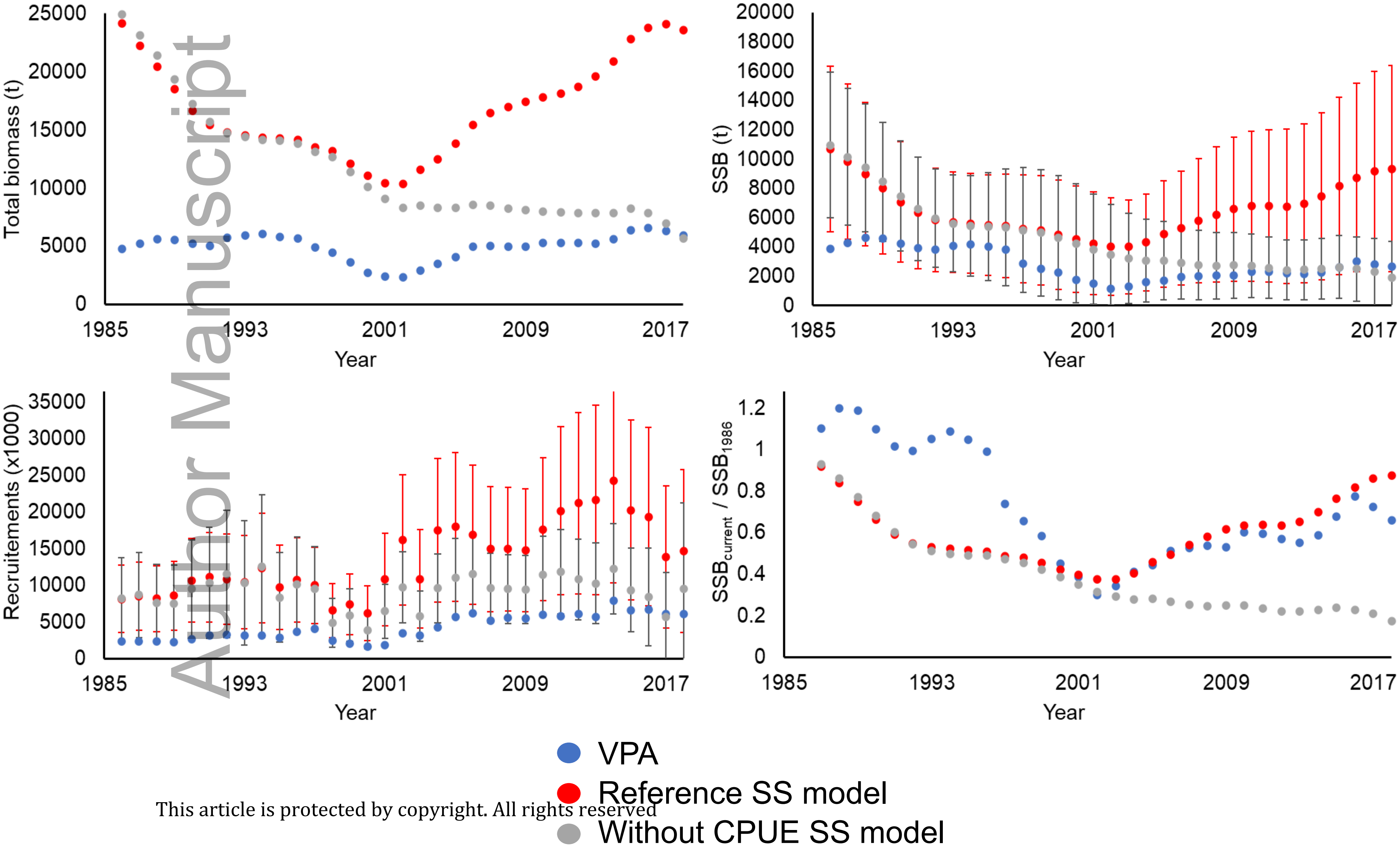
Fig. 4: Likelihood profile for steepness (h) and derived quantities (initial spawning output (SO_0); spawning output in 2018 (SO_{2018}), stock status (SO_{2018}/SO_0) in the French Guiana red snapper SS model. The steepness value of 0.7 estimated by Fishlife is showed by a grey dot.

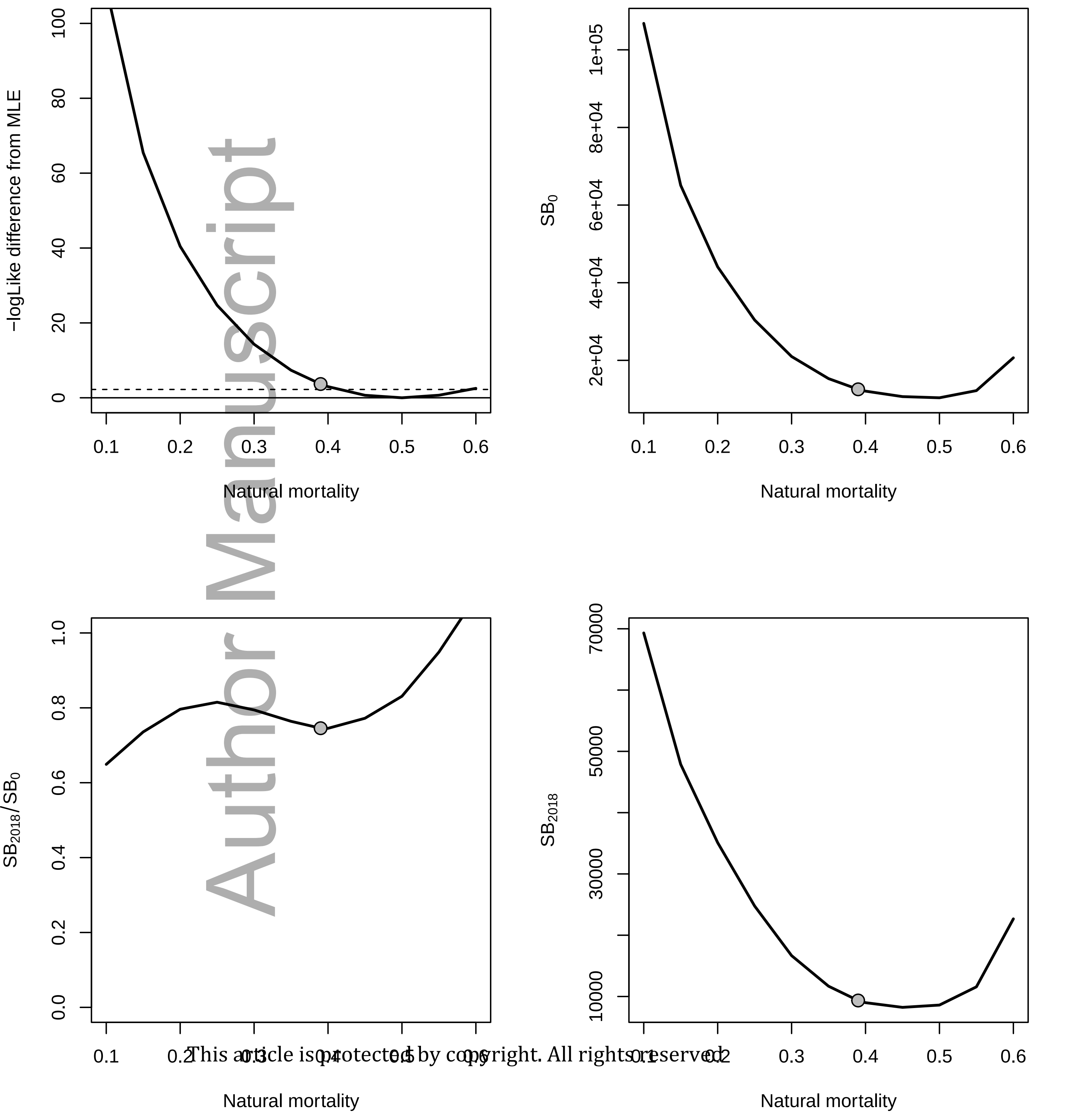
Fig. 5: Comparison of the main model outputs and index fit for the reference model and the model using the modified length composition dataset.

Fig. 6: Comparison of the main model outputs and index fit for the reference model and the model without catch per unit effort (CPUE).



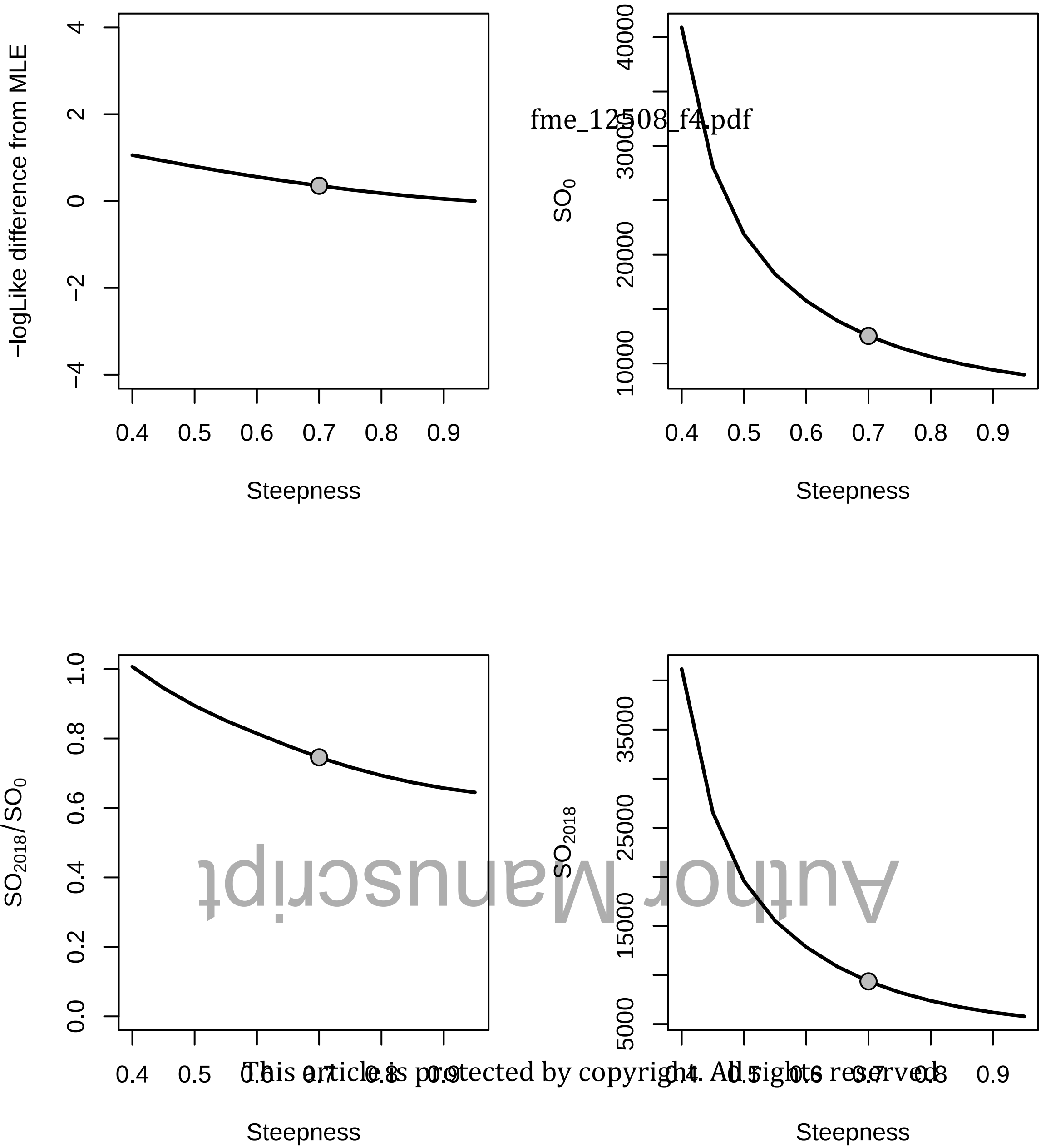
Catch (t)
3000
2500
2000
1500
1000
500
0
CPUE (catch*days at sea^{-1})
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Catch
CPUE

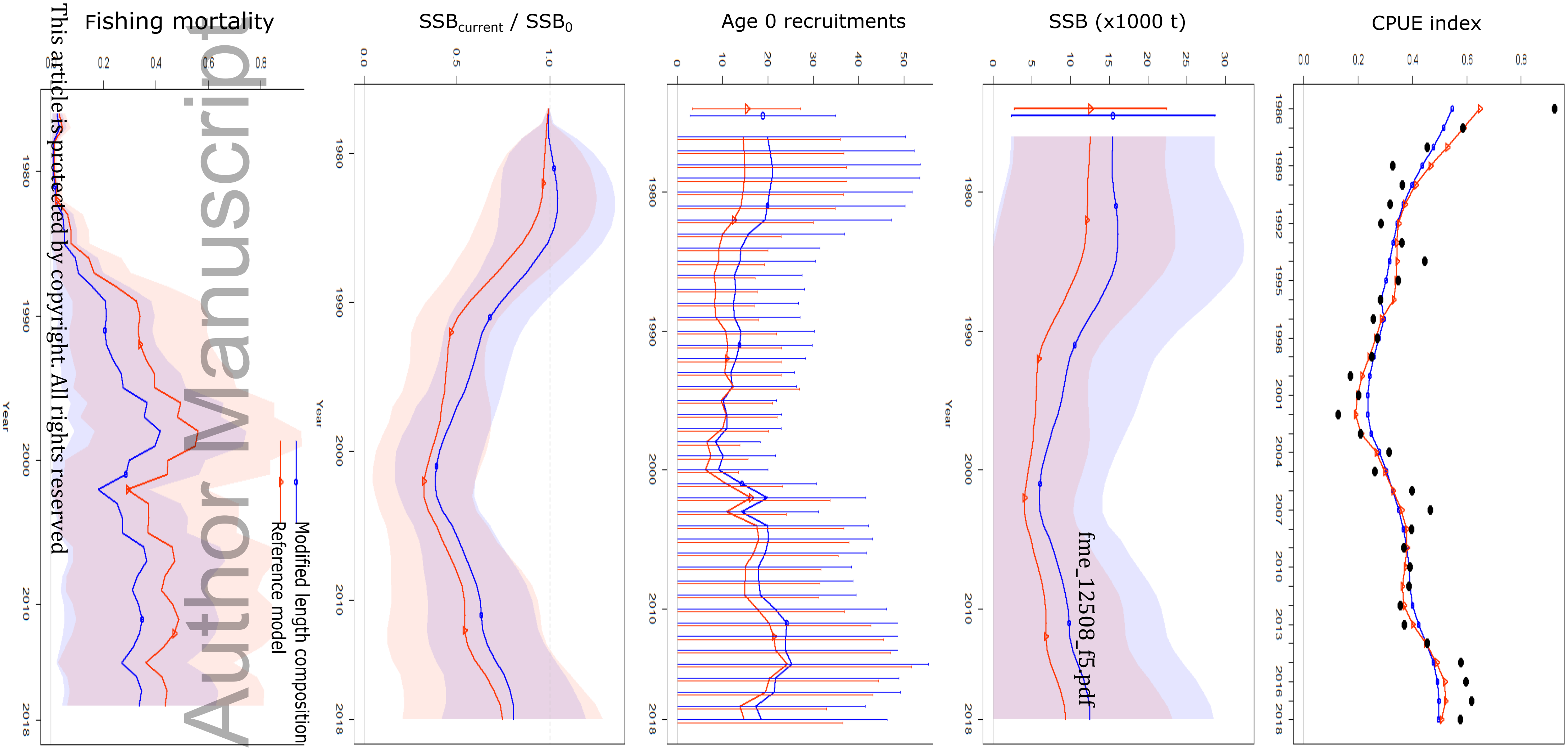

25000
20000
15000
10000
5000
0
Total biomass (t)
1985
1993
2001
2009
2017
Year
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
SSB (t)
1985
1993
2001
2009
2017
Year
35000
30000
25000
20000
15000
10000
5000
0
Recruitements (x1000)
1985
1993
2001
2009
2017
Year
1.2
1
0.8
0.6
0.4
0.2
0
SSBcurrent / SSB1986
1985
1993
2001
2009
2017
Year
VPA
Reference SS model
Without CPUE SS model

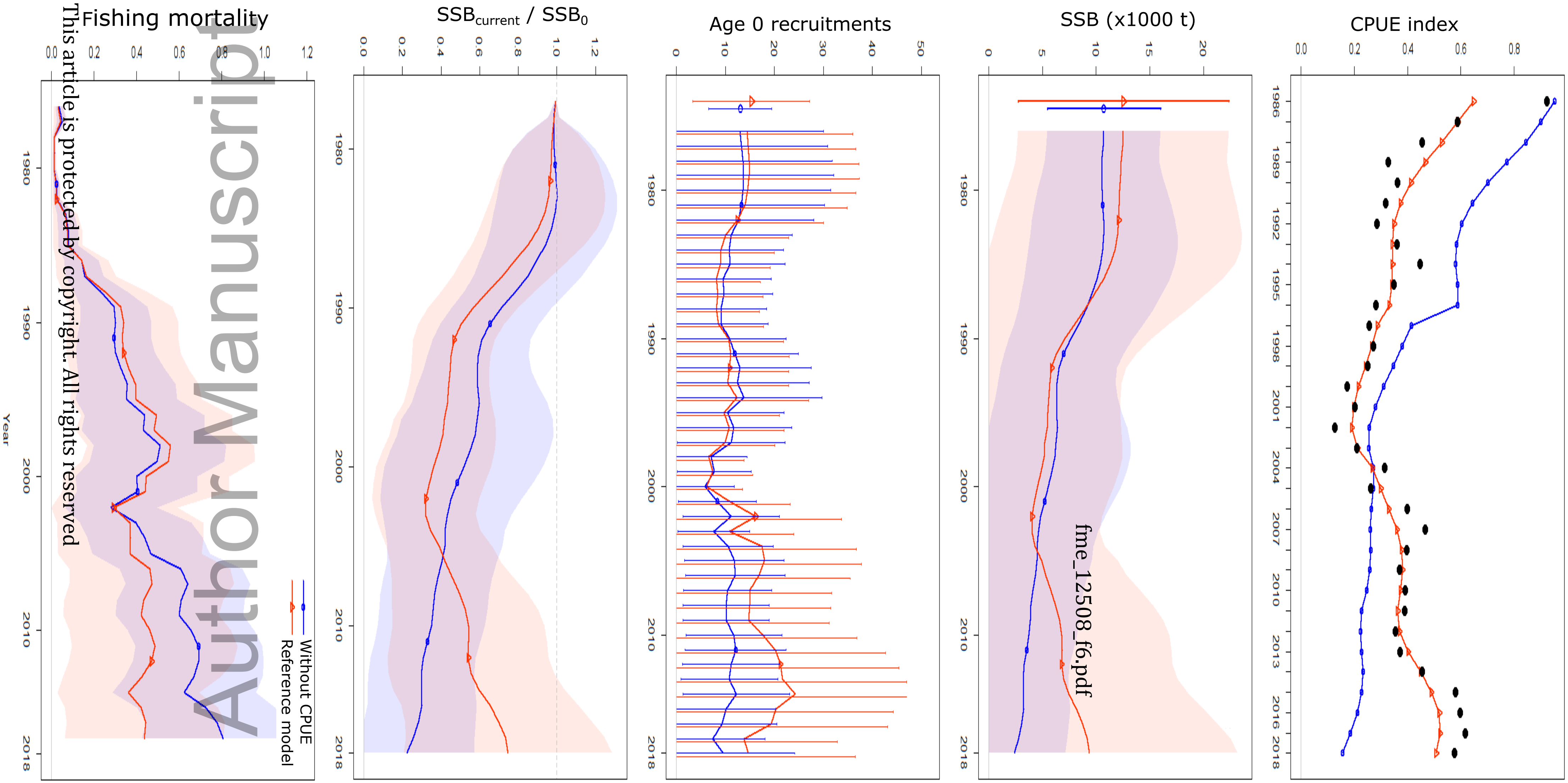


−logLike difference from MLE
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
Natural mortality
SB0
1e+05
8e+04
6e+04
4e+04
2e+04
Natural mortality
SB2018/SB0
1.0
0.8
0.6
0.4
0.2
0.0
Natural mortality
SB2018
70000
50000
30000
10000
Natural mortality

fme_12508_f4.pdf




CPUE index
SSB (x1000 t)
Age 0 recruitments
SSB$_{current}$ / SSB$_0$
Fishing mortality
Modified length composition
Reference model
Year
fme_12508_f5.pdf


CPUE index
SSB (x1000 t)
Age 0 recruitments
SSB$_{current}$ / SSB$_0$
Fishing mortality
Without CPUE
Reference model
Year
fme_12508_f6.pdf