`knobi`: an R package for estimating effects of environmental variability on the fish stocks production

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Abstract

In order to understand the population dynamics of marine resources, science had to come up with large collection of statistical and mathematical models, known as stock assessment models, however, most of them ignore the possible environmental effects and biological interactions on the stocks dynamics. Known biomass production models (KBPMs), implemented in the `knobi` R package, provide a useful and simple tool to model overall productivity considering that it responds in a non-linear way to multiple drivers related to climatic, anthropogenic and ecological factors.

Keywords: Stock assessment model, R package, non-linear models.

1. Introduction

Living marine resources inhabit complex ecosystems, influenced by multiple drivers that operate and interact at multiple scales that can result in non-linear or abrupt responses to disturbances. Mathematical and statistical techniques (called assessment methods) can be applied to understand the impact of fishing and environmental effects on fish stocks. Depending on the available data the options goes from simple data-limited methods to more complex age or length-structured methods. However, the majority of models ignore the different environmental effects and biological interactions, hence stock assessment models that can address this issue in a simple way are needed.

The known-biomass production models (KBPMs), introduced by MacCall in 2002 ([1]) are addressed in this study as a useful and simple tool to model overall productivity considering that it responds in a non-linear way to multiple drivers related to climatic, anthropogenic and ecological factors. In particular, KBPMs can identify possible changes in fish stock production caused by different reason as, for example, the environmental variability.

For this reason, we have developed `knobi` package, which implements KBPMs in a simple and intuitive way allowing to assess the stock productivity of relevant fishery resources.

2. Methods

In fisheries research, surplus production (SP) is defined as the change in stock size that would have taken place if there had been no exploitation. KBPMs are based on the idea that the annual surplus production, in an unfished stock, is equal to the difference in biomass for two consecutive years, and that, for a fished stock, the calculation of surplus production depends on catch.

$$SP_t = \overline{B}_{t+1} - \overline{B}_t + C_t \tag{1}$$

where SP_t is the SP in the year t, $\overline{B}_t$ is the average spawning stock biomass (SSB) in year t, i.e. $\overline{B}_t = (B_t + B_{t+1})/2$, being B_t is the stock SSB at the beginning of the year t, and C_t represent the catch in year t.

KBPMs use as input data a SSB time series produced by other more complex stock assessment model. Then, surplus production is calculated from the known average biomass (of two consecutive years) and the observed catch using equation 1. The KBPMs fit the observed data, SSB and SP, to the production curve in (refec:3) using the quasi-Newton optimization method L-BFGS-B. The formulation in (refec:3) is derived from the model defined by Pella and Tomlinson in 1969 ([2]),

$$SP_t = \frac{r}{p}\overline{B}_t \left(1 - \left(\frac{\overline{B}_t}{K}\right)^p\right) \tag{2}$$

where r is the intrinsic population grown rate, K is the virgin biomass and p is the asymmetry parameter, used so that the production curve is not always symmetrical.

As mentioned above, KBPMs offer the possibility of considering environmental variability. In `knobi` these effects are included as additive and multiplicative effects in the base formulation 2. Then, the additive and multiplicative models are, respectively,

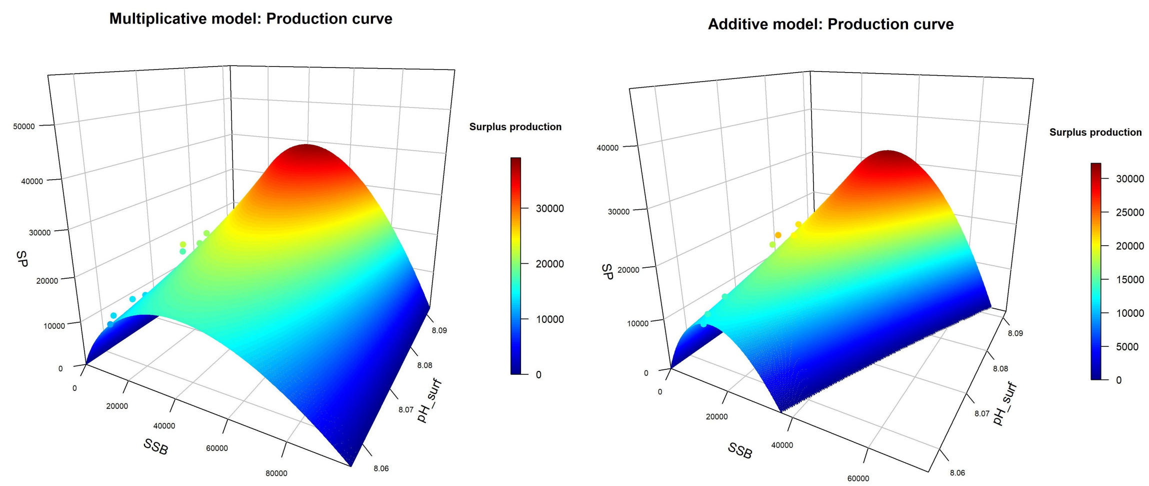
$$SP_t = \frac{r}{p}\overline{B}_t \left(1 - \left(\frac{\overline{B}_t}{K}\right)^p\right) + cX_t\overline{B}_t; \qquad SP_t = \frac{r}{p}\overline{B}_t \left(1 - \left(\frac{\overline{B}_t}{K}\right)^p\right) exp^{cX_t} \tag{3}$$

being c the parameter that represents the effect of the environmental variable X_t, where t represents time (years).

From the equations 2 and 3, the so-called reference points can be obtained, which are informative quantities on the state of exploitation of the different stocks, such as the maximum sustainable yield (MSY) or its associated biomass and fishing mortality.

3. `knobi` package

In this section, `knobi` use and abilities are illustrated through the case study of the European hake (*Merluccius merluccius*) southern stock, which is a demersal species found in the southern Bay of Biscay



(a) Multiplicative environmental KBPM (b) Additive environmental KBPM

Figure 1: knobi_env example. Production curves according to the environmental variable values for (a) multiplicative model and (b) additive model in the European hake (southern stock) case study. The environmental variable is *pH_surf* (surface pH).

and Atlantic Iberian waters.

The first step is the model fit through the knobi_fit function using the spawning stock biomass (SSB) time series, the catch time series and the corresponding years. Once the KBPM fit is carried out, the knobi_retro function tests its robustness to the deletion of data. After that, the environmental effects over the surplus production can be addressed through the knobi_env function. More precisely, the function analyse and model the relationships between the surplus production and the environmental variables (Figure 1), implementing a variable selection process based on their correlation with the residuals of a KBPM model that only considers the SSB of the stock as a covariable. Alternatively, the entire set of environmental variables can also be considered in the adjustment instead of carrying out the variable selection process.

Finally, knobi_proj function allows us to check the future evolution of the biomass and production of the stock depending on the environmental scenario and the assumed fishing pressure (Figure 2). Then, it allows us to analyze the future status of the stock under different possible settings of fishing pressure or, for example, under the Representative Concentration Pathway (RCP) scenarios defined by the Intergovernmental Panel on Climate Change (IPCC).

4. Conclusions

knobi package implements for the first time the known biomass production models, providing a powerful tool for analyzing the stock status from a surplus production point of view. Additionally, the package illustrates KBPMs potential and use, and highlights their advantages. In particular, KBPMs simplicity facilitates the consideration of important drivers that influence the stocks dynamics as the

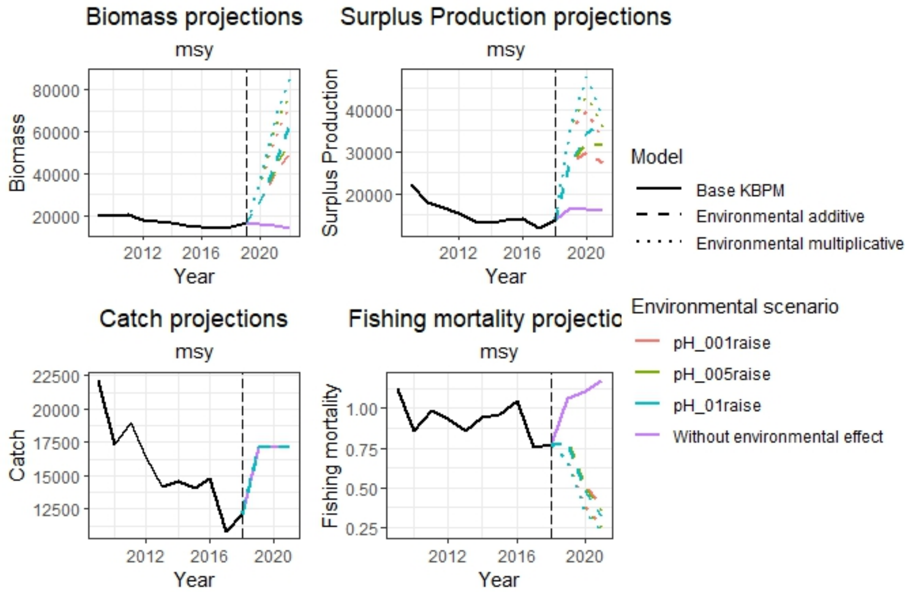


Figure 2: `knobi_proj` example. Each model projections for different future values of the environmental variable surface pH when catches are equal to the Maximum Sustainable Yield (MSY) obtained from the KBPM fit considering only the biomass covariable.

climate change.

For the correct understanding of the package use, `vignettes` in the package help at `https://github.com/MERVEX-group/knobi` are available including illustrative examples.

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