knobi: an R package implementing Known-Biomass Production Models

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Introduction

- Understanding the <u>assessment of fish stocks</u> to make recommendations for their <u>sustainable exploitation</u> has become an essential part of the management of fisheries resources.

- For this, there are different **assessment methods** which can be applied, from simple data-limited methods to more complex age or length-structured methods.

- In recent years, there has been an increasing research effort on developing methods that can generally improve the reliability of stock assessments in <u>data-limited situations</u>.

- **Surplus production models (SPMs)** are among the assessment methodologies recommended for this purpose. Derived from this, another type of methods, the **Known-Biomass Production Models (KBPMs)** are being developed to improve fisheries management.

Surplus Production Models

Surplus production models (SPMs) have the general structure
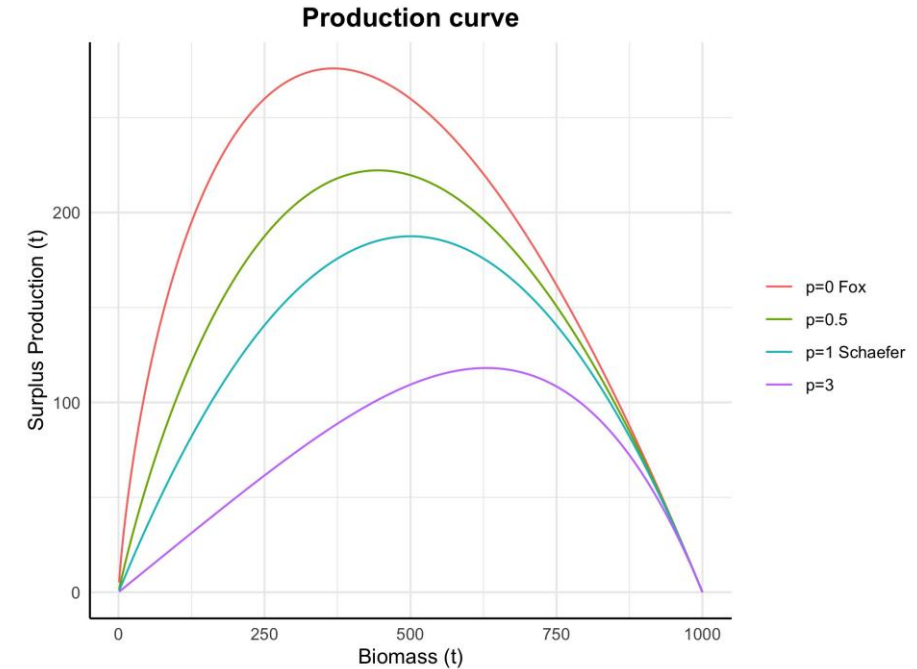
$$B_{t+1} = B_t + f(B_t) - C_t$$

where
B_{t+1} is the exploitable biomass at the beginning of the year *t+1*,
B_t is the exploitable biomass at the beginning of the year *t*,
$f(B_t)$ is the biomass production, as a function of the biomass at *t*,
C_t is the catch during the year *t*.

There are different formulations of the function that describe the biomass production, generalized by Pella-Tomlinson in 1969:

$$f(B_t) = \frac{r}{p} B_t \left(1 - \left(\frac{B_t}{K} \right)^p \right)$$

where *r* is the natural growth rate, *K* is the maximum population size and *p* is the asymmetry parameter.

Production curve

Legend:
p=0 Fox
p=0.5
p=1 Schaefer
p=3

Pella, J. J. and Tomlinson, P. K. (1969). A generalized stock-production model. Bulletin of the Inter-American Tropical Tuna Commission, 13:421-458.

Known-Biomass Production Models

These SPMs relates historical series of catch to <u>historical fishing effort or indexes of relative biomass</u> such as CPUE (catch-per-unit-effort).

$$\hat{I}_t = qB_t = C_t/E_t$$

An alternative line of research based on surplus production models named **known-biomass production models (KBPMs)** was introduced by MacCall (2002), based on the idea that the annual surplus production in an unfished stock is equal to $B_{t+1} - B_t$, and that, for a fished stock, the <u>calculation of surplus production depends on catch</u>.

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

where SP_t is the surplus production, $\bar{B}_t$ is the average biomass or spawn stock biomass (SSB), $\bar{B}_t = (B_{t+1} + B_t)/2$, and C_t represent the catch. The subscript t denotes time (years).

MacCall, A. (2002). Use of Known-Biomass Production Models to Determine Productivity of West Coast Groundfish Stocks. North American Journal of Fisheries Management, 22:272-279.

In contrast to the traditional SPMs, KBPMs use as input data a <u>biomass time series produced by other stock assessment model</u> instead of a biomass index. Then, **surplus production (SP)** is calculated from the known average biomass (of two consecutive years) and the observed catch using the previous equation. Then, for the KBPM fit,

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

where r is the natural growth rate, K is the maximum population size and p is the asymmetry parameter.

KBPMs simplicity facilitates the consideration of crucial aspects of fisheries management as the environmental variability or the multispecific approach.

Environmental effects, for example, can be are included as additive and multiplicative effects in the general KBPM formulation.

- Additive model

$$SP_t = \frac{r}{p}\bar{B}_t\left(1 - \left(\frac{\bar{B}_t}{K}\right)^p\right) + cX_t\,\bar{B}_t$$

- Multiplicative model

$$SP_t = \frac{r}{p}\bar{B}_t\left(1 - \left(\frac{\bar{B}_t}{K}\right)^p\right)exp^{cX_t}$$

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

knobi **package**

We implement KBPMs in the R package `knobi`, available at https://github.com/MERVEX-group/knobi, highlighting their advantages and illustrating their use.

This package allows:

- `knobi_fit`: the KBPM fit to the stock.

- `knobi_retro`: the retrospective analysis.

- `knobi_env`: the estimation of the effects of environmental variability.

- `knobi_proj`: the estimation of future projections for the stock.

Known-Biomass Production Model (KBPM)

Documentation for package 'knobi' version 0.1.0

- DESCRIPTION file.
- User guides, package vignettes and other documentation.

Help Pages

knobi_env	KBPM environmental analysis
knobi_fit	Known biomass Production Model (KBPM) fit
knobi_proj	KBPM projections
knobi_retro	KBPM retrospective analysis
print.knobi	Print a knobi object

Therefore, `knobi` package implements for the first time the KBPMs including tools for the environmental effect analysis and the projections. The package is user-friendly and it is hoped that it will serve the scientific community by providing a simple and powerful tool for the KBPM analysis.

Its use and habilities are illustrated through the case study of northern hake (*Merluccius merluccius*) in the International Council for the Exploration of the Sea (ICES).

knobi_fit

## Known biomass Production Model (KBPM) fit

Description

This function, that is the main function of the knobi package, fits a type of surplus production models named known-biomass production models (KBPM) (MacCall, 2002). The surplus production curve is fitting using the the catch time series and the biomass or SSB (Spawning Stock Biomass) derived from the fit of other stock assessment model.

Usage

```
knobi_fit(
    data,
    control = NULL,
    plot_out = F,
    plot_filename = NULL,
    plot_dir = NULL
)
```
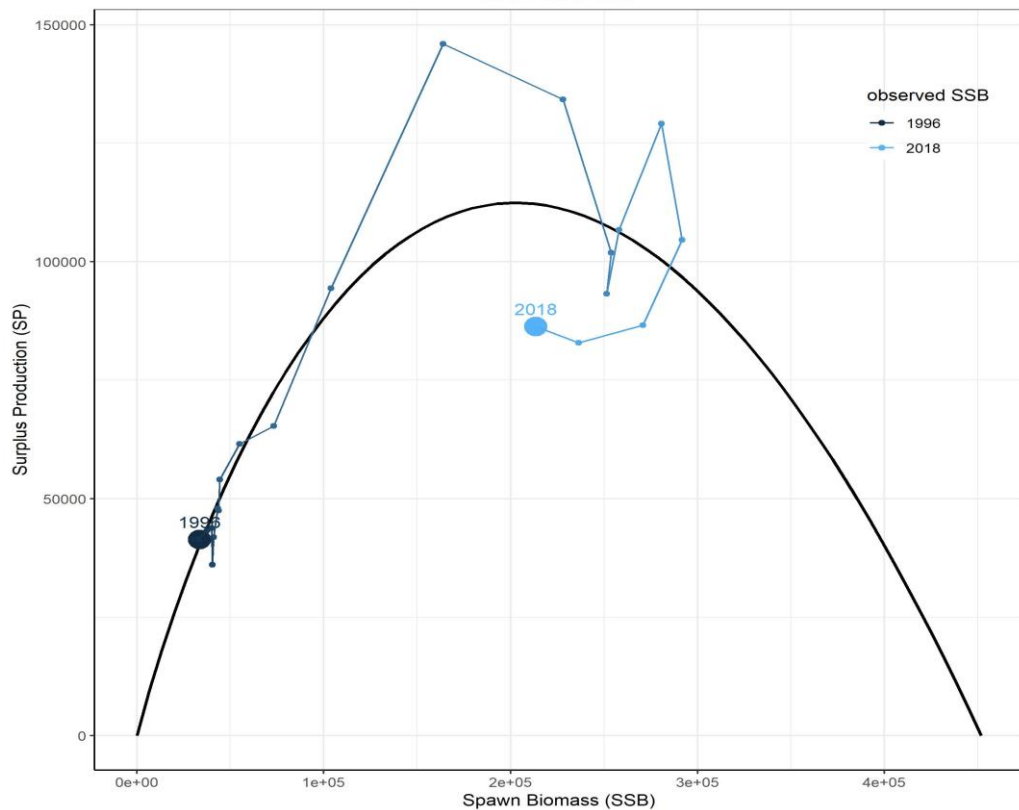
$$SP_t = \frac{r}{p}\bar{B}_t\left(1 - \left(\frac{\bar{B}_t}{K}\right)^p\right)$$

Northern hake example
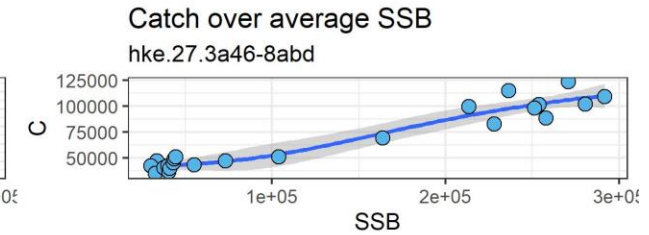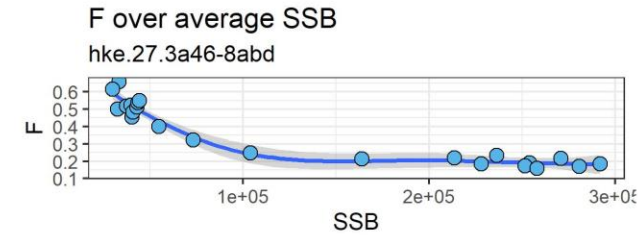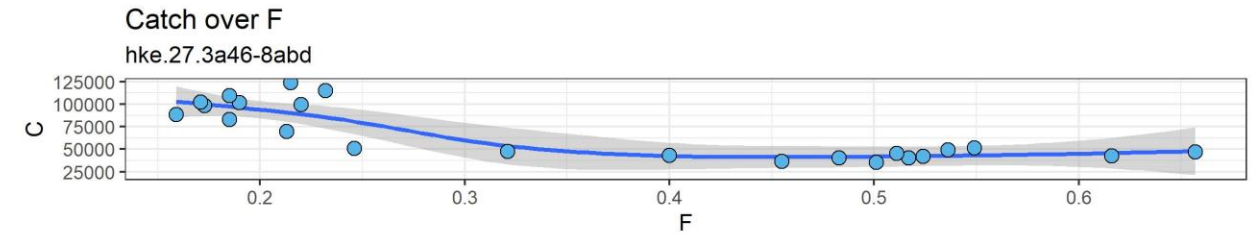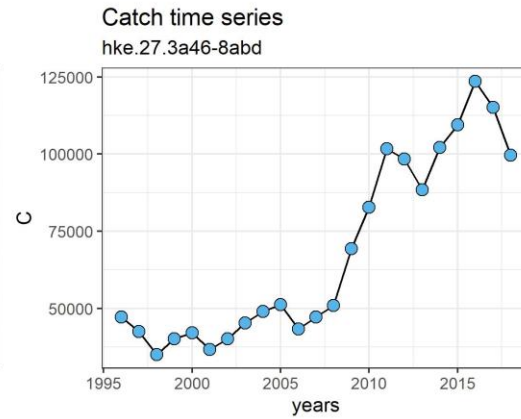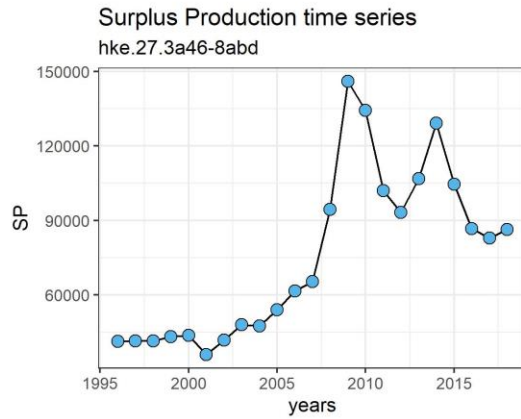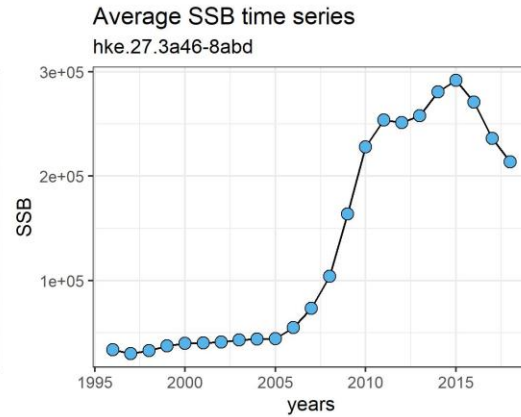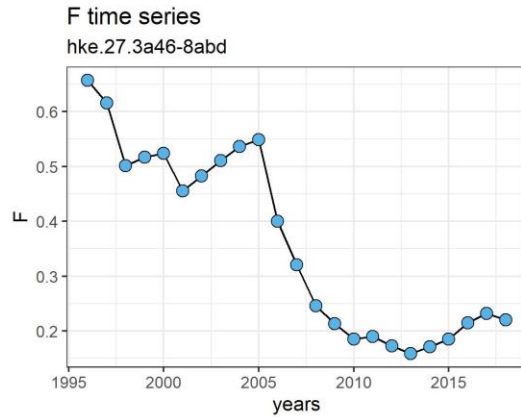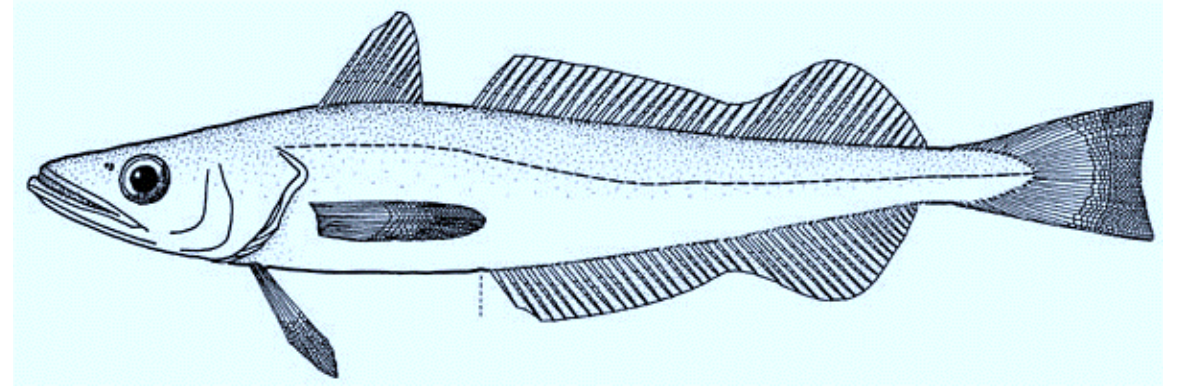
knobi_fit results


```
> hke_3a46_8abd_results

  Formula:
  SP_t = (r/p)*B_t*(1-(B_t/K)^p)

  Parameter estimates:
  r    0.8498313
  K    451824.1
  p    0.531402
```

```
> hke_3a46_8abd_results$fit$RP
$K
[1] 451824.1

$B_MSY
[1] 202612.3

$F_MSY
[1] 0.5549368

$MSY
[1] 112437

$MSYoverK
[1] 0.2488513
```
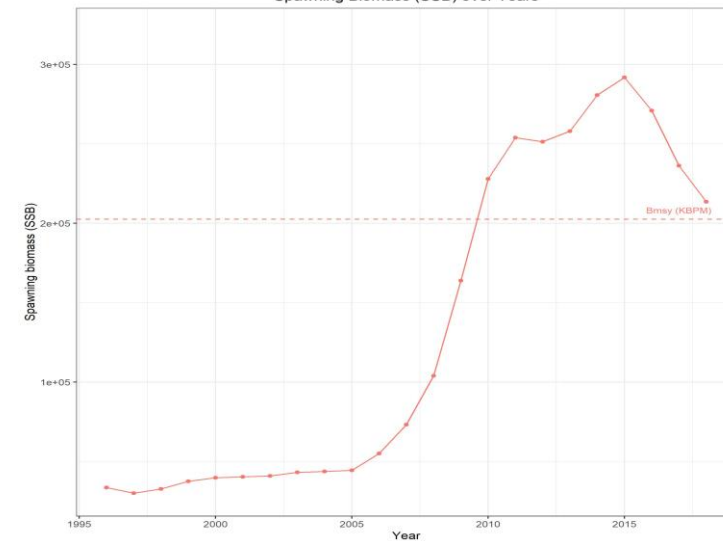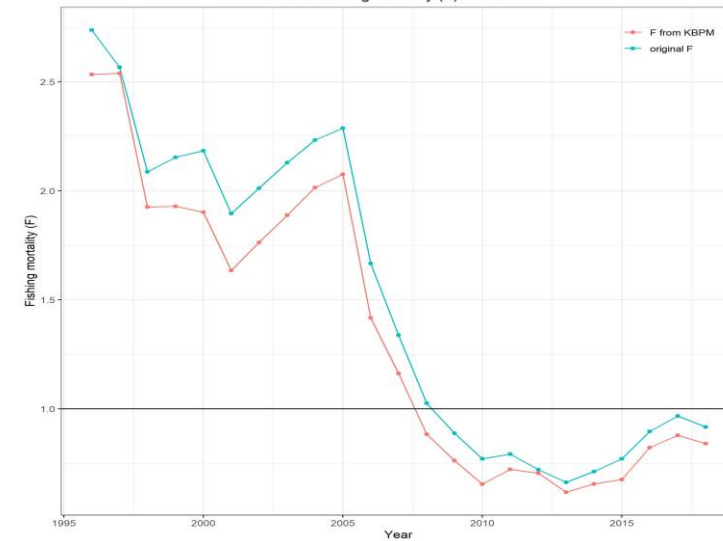
knobi_retro

KBPM retrospective analysis

Description

This function carries out the retrospective analysis evaluating the robustness of the KBPM fit when systematically last years of data are removed.

Usage

```
knobi_retro(
  knobi_results,
  yR = NULL,
  yR0 = NULL,
  nR = NULL,
  plot_out = F,
  plot_filename = NULL,
  plot_dir = NULL
)
```

Arguments

knobi_results	A list containing the results of the KBPM fit. Object provided by knobi_fit function (main function).
yR	Vector containing the years in which the catch time series ends in each of the retrospective analysis settings.
yR0	Optional argument. Vector containing the years in which the catch time series starts in each of the retrospective analysis settings. Equal length of yR vector is required. By default it is assumed that the catch time series starts in the same year as in the original fit.
nR	Number of retrospective patterns. Only required when yR is not provided (if both earguments are included and error message is reported). See details.

knobi_retro results


```
> hke_3a46_8abd_retro <- knobi_retro(hke_3a46_8abd_results,yR=2019,yR0=1996)
> hke_3a46_8abd_retro
$`1996 - 2019`
[[1]]
            r            K            p
6.676944e-01 5.061110e+05 3.173717e-01

attr(,"class")
[1] "Pella"

$RP
                   K     B_MSY     F_MSY       MSY  MSYoverK
1996 - 2019 506111 212353.4 0.5068383 107628.9 0.2126586
```
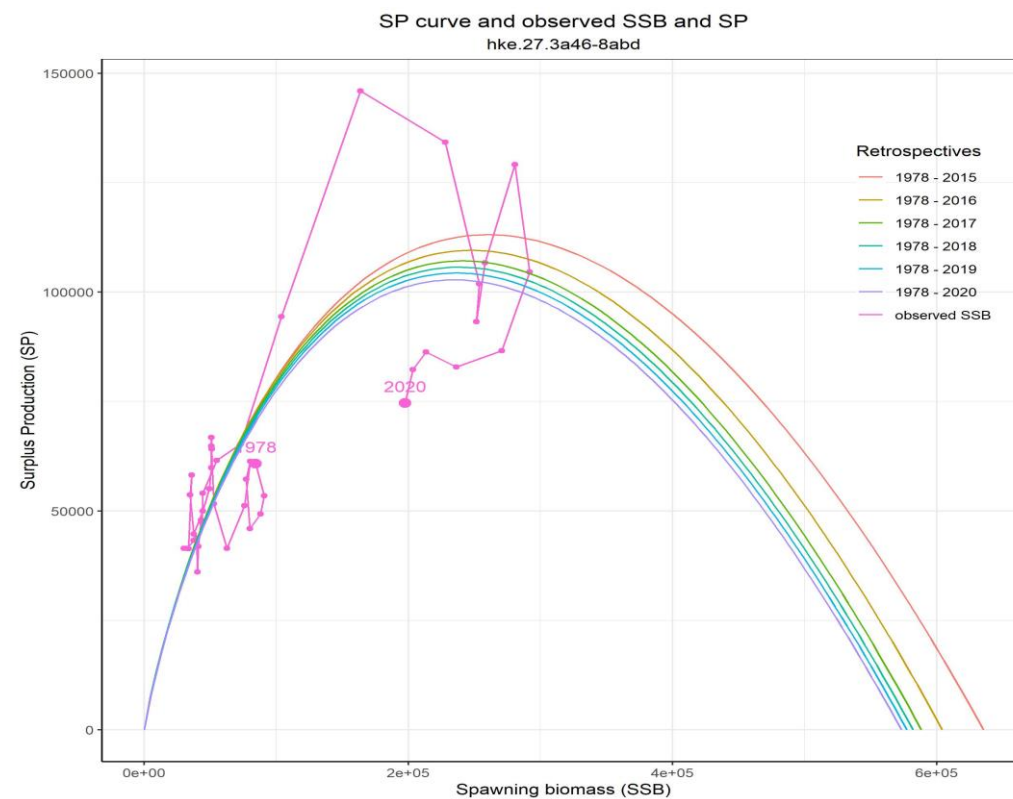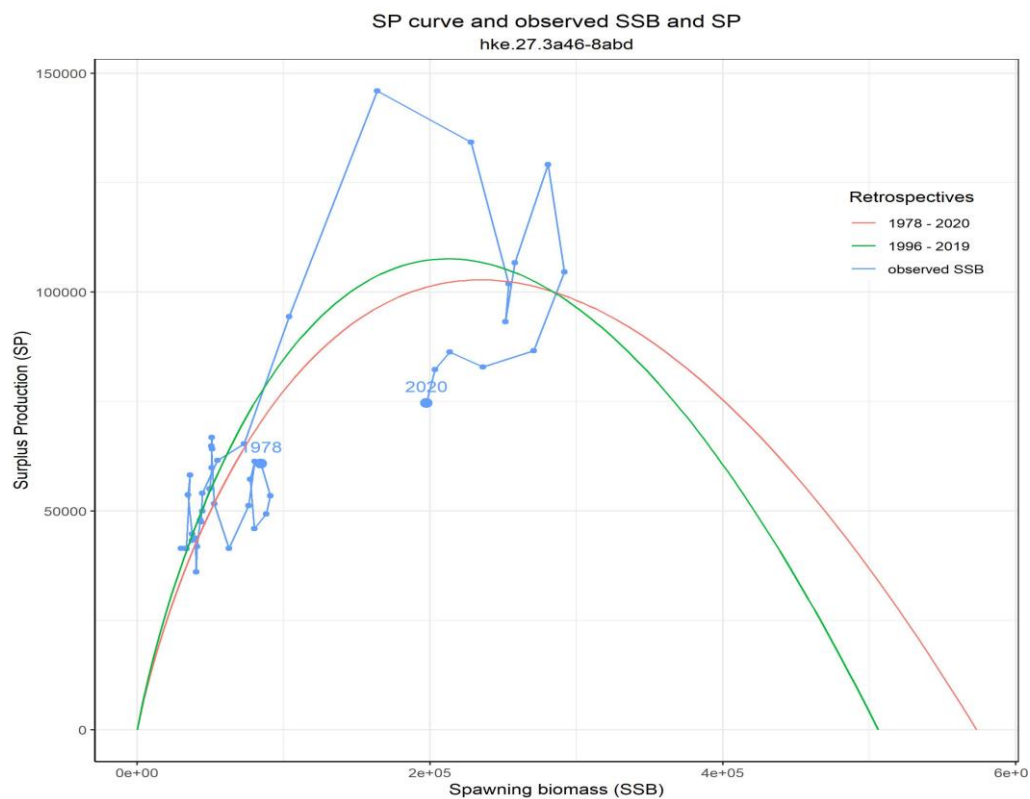
```
> knobi_retro(hke_3a46_8abd_results,nR=5)
$ 1978 - 2015
[[1]]
            r            K            p
5.433165e-01 6.354964e+05 2.500000e-01

attr(,"class")
[1] "Pella"

$RP
                      K     B_MSY     F_MSY       MSY  MSYoverK
1978 - 2019 577421.1 236511.7 0.4412850 104369.1 0.1807503
1978 - 2018 582002.3 238388.2 0.4434978 105724.6 0.1816567
1978 - 2017 588377.2 240999.3 0.4445837 107144.4 0.1821015
1978 - 2016 604269.9 247509.0 0.4427077 109574.1 0.1813331
```

SP curve and observed SSB and SP
hke.27.3a46-8abd

SP curve and observed SSB and SP
hke.27.3a46-8abd

knobi_env

KBPM environmental analysis

Description

Analyse and model the relationships between surplus production and environmental covariables to test whether productivity changes in response to environmental fluctuations. Environmental effects are included as additive and multiplicative effects in the general KBPM formulation (see details).

Usage

```
knobi_env(
  knobi_results,
  environmental,
  plot_out = F,
  plot_filename = NULL,
  plot_dir = NULL
)
```

`environmental` A list containing the following data and settings:

- data: data frame containing the values of each one of the environmental variable(s) in one column. Each row represents a year.

- years: time series of years corresponding to the environmental variable(s).

- lag: optional numerical vector providing the used lag value(s) in the relation among the base KBPM surplus production residuals and the environmental variable(s). This means that the residuals_t is related to X_t-lag being X the environmental variable. The length of this argument must be equal to the number of environmental variables included.

- nlag: if lag value is not provided, this argument is used to test all the lags smaller or equal to nlag (numeric) through cor.test function. The lag corresponding to the highest pearson correlation among the base KBPM surplus production residuals and the lagged environmental covariable values is considered in the environmental model.

- start_c: optional numerical vector providing the start values of the environmental c parameter for the optimization of the additive and multiplicative models, respectively. By default, start_c=c(1,1). See details.

- selected_var: optional character. By default, the fit is done using the environmental values according to the lag derived from the previous arguments. However, if this argument is equal to the name of the environmental variable no lag is applied to its values.

- multicovar: optional logical. TRUE if you want to fit the environmental model including all the input environmental covariables, up to a maximum of 5. By default this argument is FALSE, which means that only the environmental covariable reporting the highest pearson correlation is included (after lagging it if corresponds).

knobi_env results

Multiplicative model: Production curve
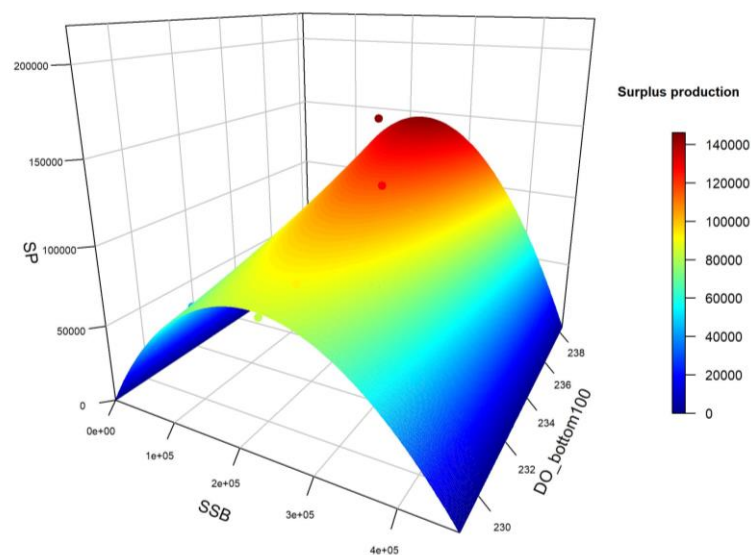
```
> hke_3a46_8abd_env

Multiplicative model:
SP_t = (r/p)*B_t*(1-(B_t/K)^p)*exp(c%*%X_t)

Parameter estimates:
r    0.9490354
K    467168.4
c    0.1547193
p    0.7786324


Additive model:
SP_t = (r/p)*B_t*(1-(B_t/K)^p)+c%*%X_tB_t

Parameter estimates:
r    1.017281
K    451824.9
c    0.07600536
p    0.7991508
```
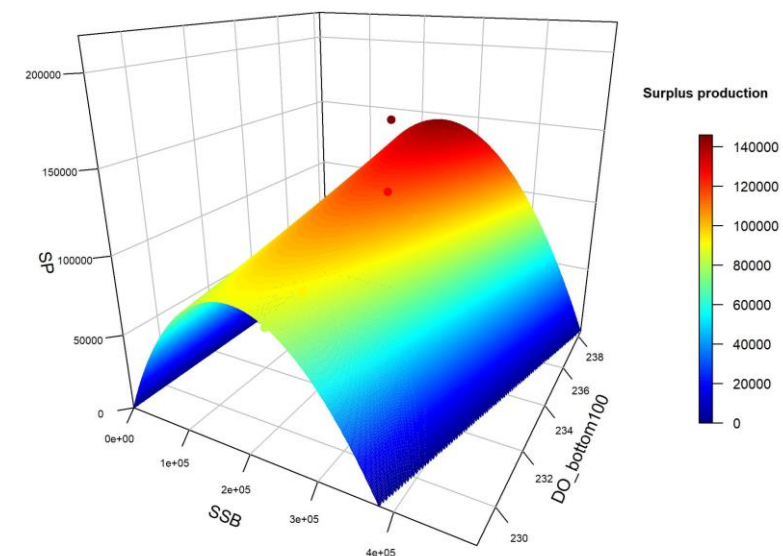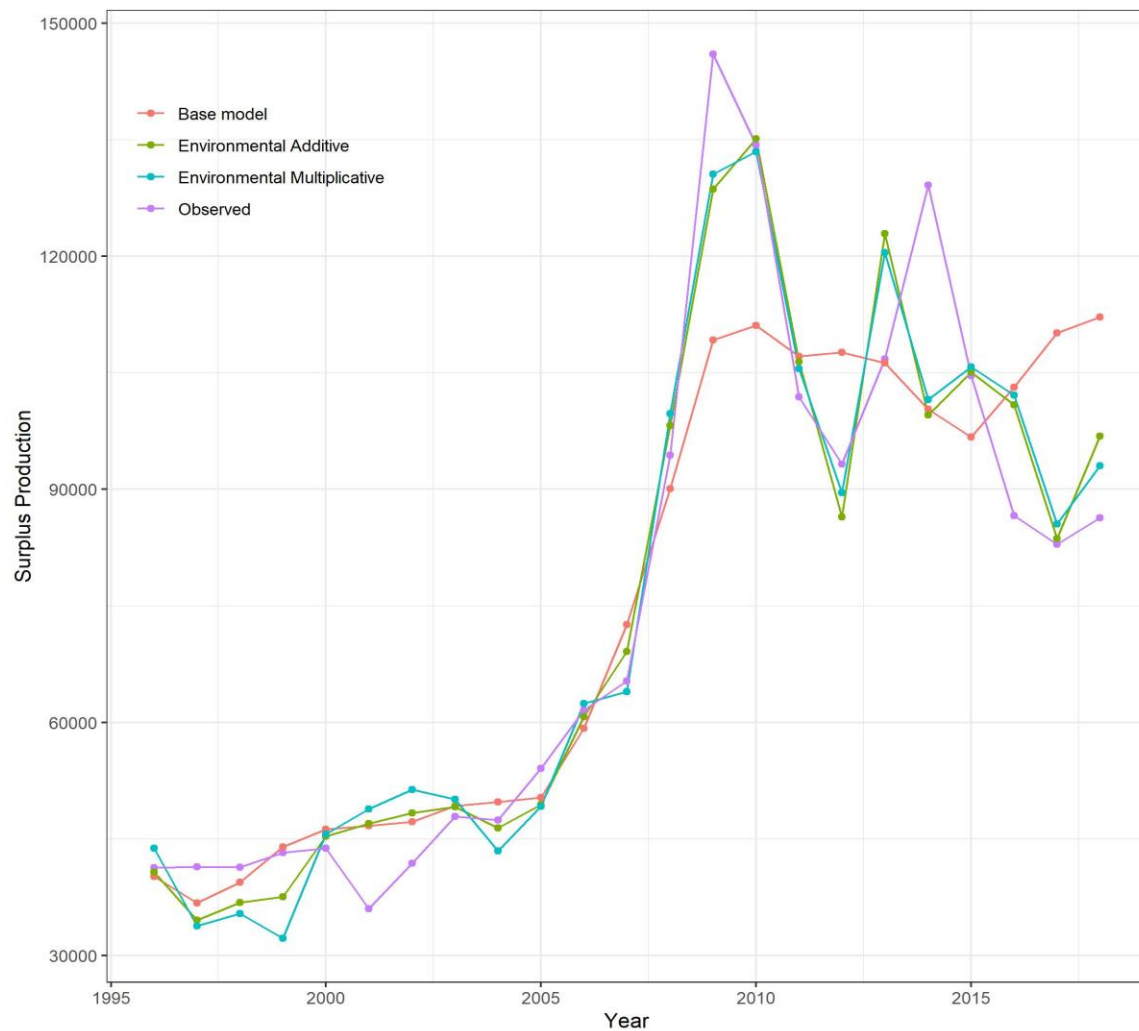

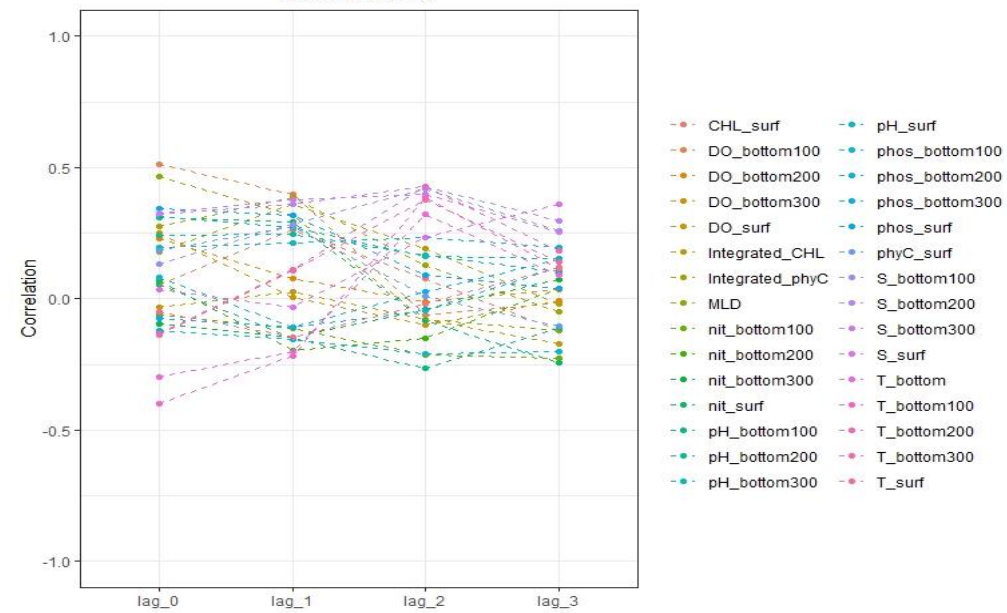Additive model: Production curve

Environmental fits
hke.27.3a46-8abd

Environmental correlation with base KBPM SP residuals
hke.27.3a46-8abd

```
> head(hke_3a46_8abd_env$lag_cor,n=15L)
                 lag_0   lag_1   lag_2   lag_3
CHL_surf        0.0520  0.2650  0.0773 -0.1213
DO_bottom100    0.5117  0.3992 -0.0637 -0.0172
DO_bottom200    0.2281  0.0781 -0.0128  0.0359
DO_bottom300    0.2487  0.0066 -0.1004 -0.0072
DO_surf        -0.0311  0.0286 -0.0798 -0.1708
Integrated_CHL  0.1792  0.3605  0.1899 -0.0207
Integrated_phyC 0.2776  0.3842  0.1295 -0.0499
MLD             0.4665  0.3171 -0.0804 -0.1204
```

knobi_proj

KBPM projections

Description

This function projects the stock biomass (or stock spawning biomass) time series and then the surplus production based on the selected catch or fishing mortality values for the projected years.

Usage

```
knobi_proj(
  knobi_results,
  env_results = NULL,
  Ct = NULL,
  f = NULL,
  env = NULL,
  end_y = NULL,
  n_y = NULL,
  plot_out = F,
  plot_filename = NULL,
  plot_dir = NULL
)
```

knobi_proj results
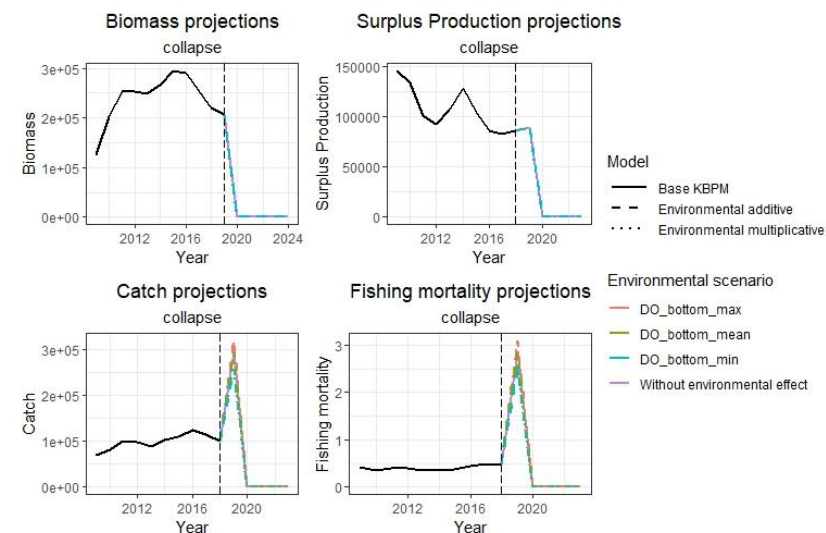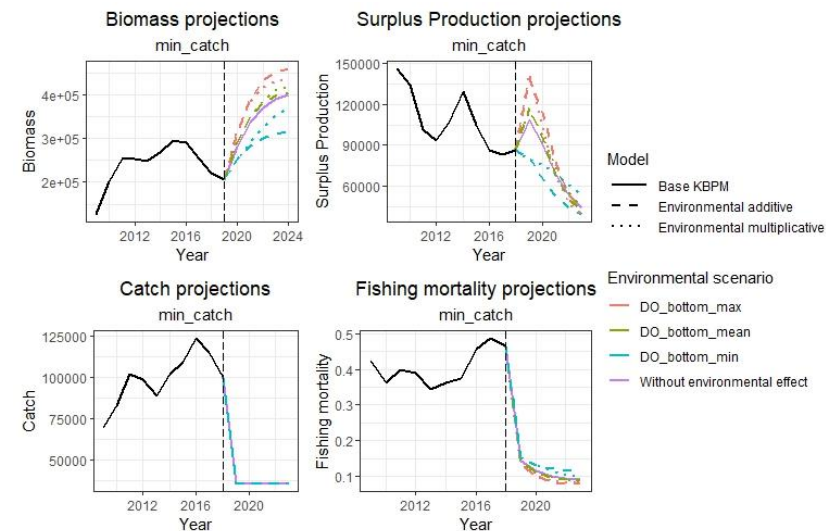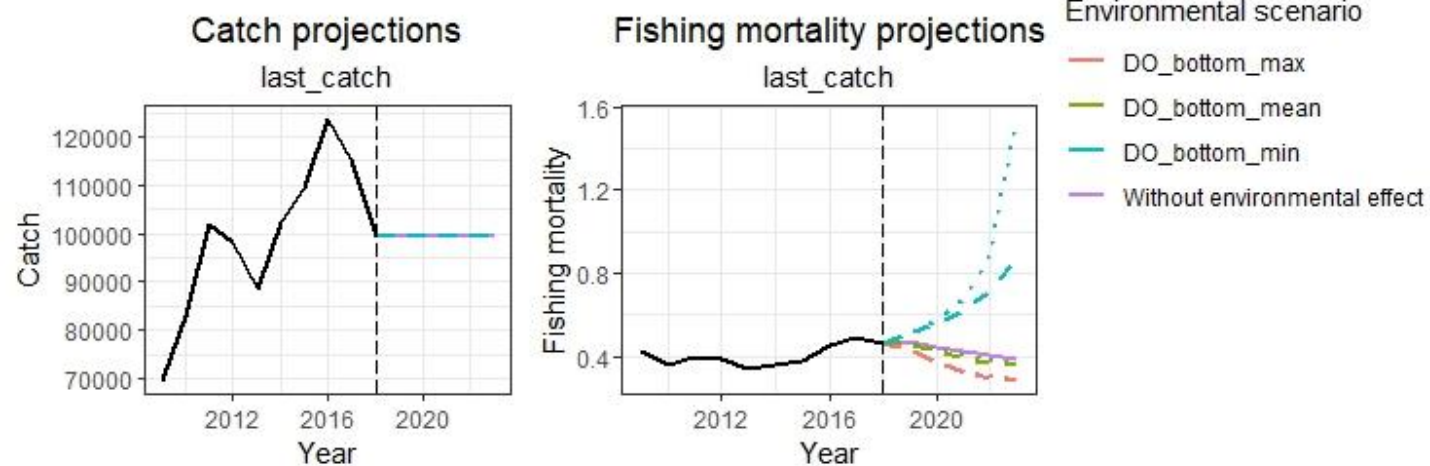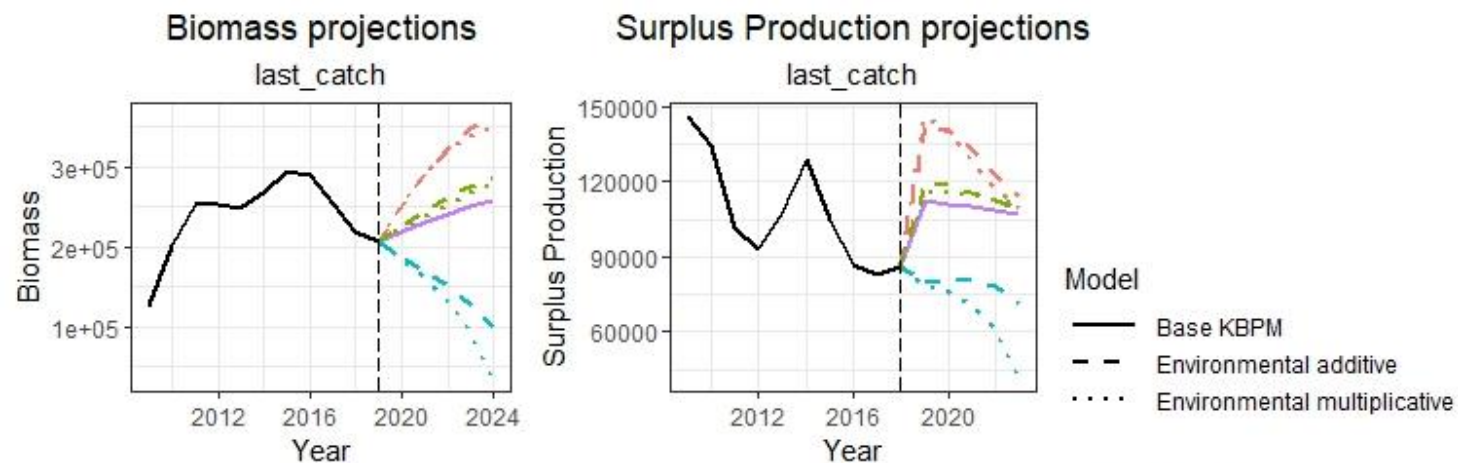
Conclusions

- R has become an essential tool in fisheries science, in particular, for evaluation of fisheries resources.

- `knobi` package implements for the first time KBPMs using available knowledge of these models derived from the combination of information from differences sources. Additionally, we include tools for the environmental effect analysis and future projections.

- The package is user-friendly and it is hoped that it will serve the scientific community by providing a simple and powerful tool for the KBPM analysis.

- The package is available at https://github.com/MERVEX-group/knobi and open to collaboration. It's a work in progress!

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twitter: @FishClim

Thank you for your attention

#PlanDeRecuperacion
#NextGenerationEU