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Recruitment-based dynamic harvest control rules to manage stocks of uncertain productivity: Application to Iberian sardine

A. Uriarte (AZTI), L. Citores (AZTI), ***L. Ibaibarriaga*** *(AZTI), Isabel Riveiro (IEO), Sonia Sánchez-Maroño (AZTI), Laura Wise (IPMA), Alexandra Silva (IPMA)*

PLAN DE RECUPERACIÓN, TRANSFORMACIÓN Y RESILIENCIA
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EU Project NEXT GENERATION

GOBIERNO DE ESPAÑA · MINISTERIO DE AGRICULTURA, PESCA Y ALIMENTACIÓN · ESPAÑA PUEDE.

EUSKO JAURLARITZA
GOBIERNO VASCO

Introduction

Most management strategies **rely on the notion of steady-state** productivity of stocks, however most of the stocks are not in such stationary productivity.

There is **growing demand to formulate adaptative harvest control rules** robust to uncertainties in the carrying capacity of the ecosystems and productivity of stocks (Deroba and Bence 2007; Silvar-Viladomiu et al. 2022).

Changes in stock productivity tend to happen **quite often**, either as shifts on the ecosystem structure or as result of environmental drivers (Vert-Pre et al. 2013; Perälä et al. 2017).

It is assumed that **recruitment production is probably the key component** of stock productivity (Collie et al. 2021; Silvar-Viladomiu et al. 2022; Quinn and Collie 2005) (in addition to growth and natural mortality).

Objective

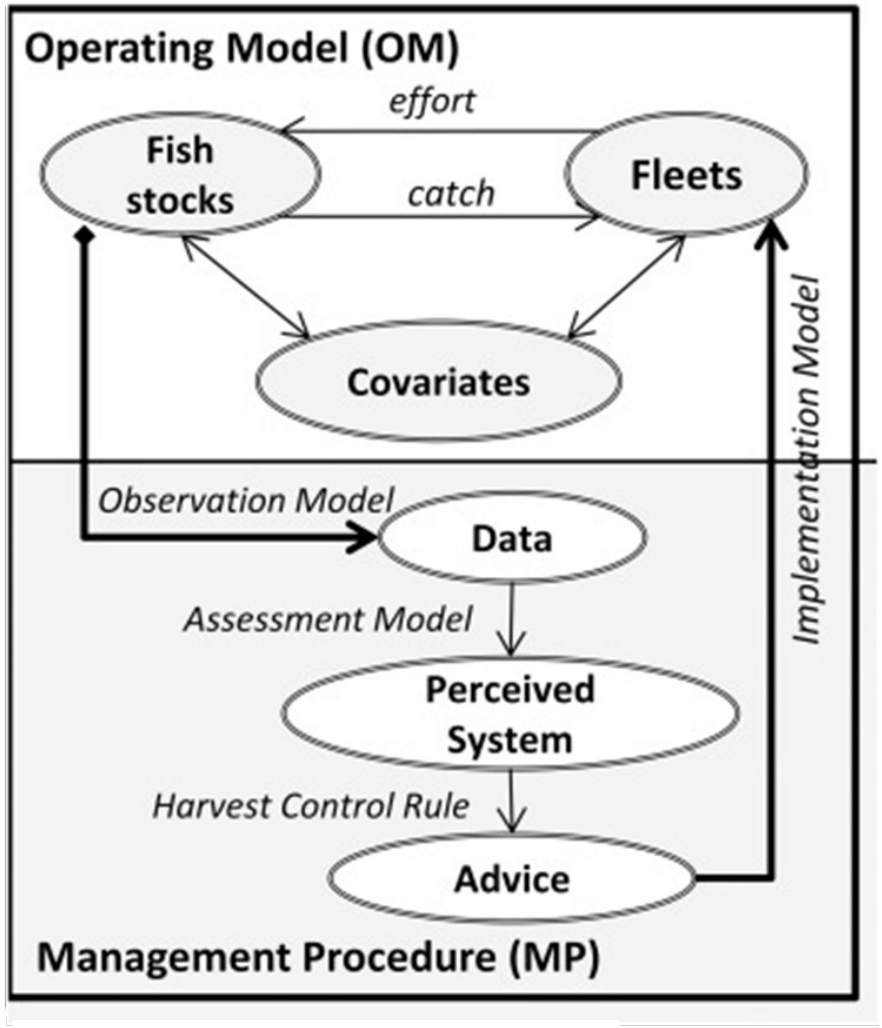
To propose harvest control rules (HCR), adaptative to changes in productivity, so that risks to (absolute or relative) threshold levels of Biomass can remain rather constant across productivity states.

These rules are based on a continuous accommodation of management fishing targets to the recent levels of recruitments assessed through the monitoring of the fishery. They rely on the assumption that the changes in productivity are mostly reflected in the average levels of recruitments per spawning stock productivity (Collie et al. 2021; Silvar-Viladomiu et al. 2022).

For that we:

- Identify potential adaptative rules
- Test rules in a management strategy evaluation (MSE) framework
- Test rules under a range of operating models (OM)
- Compare proposed rules to already existing/used rules.

MSE framework to test HCRs

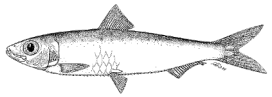


Source: Garcia et al., 2017

- Historical period: 1978-2019
- Projection period: 2020-2069 (50 years)
- 1000 iterations
- OMs: Implementation of different types of models
- Assessment model: stock synthesis model fit is included in the loop.
- HCRs: Implementation of several types of rules
- Performance indicators: Median SSB, Median catches, Fishing Mortality F, probability of being below Blim, Median interannual catch variations.
- Tool: FLBEIA (https://flr-project.org/FLBEIA/)

Case study: Iberian sardine

- Crisis perceived in 2011-2012
- Benchmark in 2012 (for the advices from 2013 to 2017)
- New Benchmark in 2018 (for the advices from 2018 onwards)
- Workshops for testing of Harvest Control Rules for a Management Plan between Portugal & Spain
  - in 2019 (ICES WKSARMP)
  - In 2021 (ICES WKSARHCR)

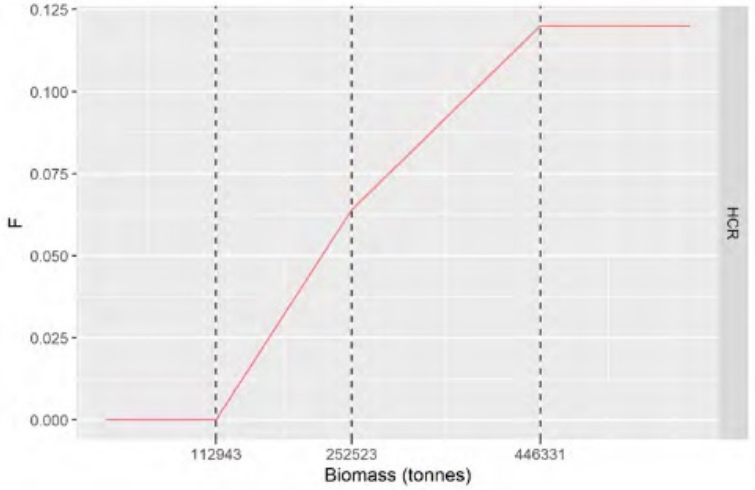


Sardina pilchardus

Stock distributed along ICES divisions 8c9a

Current rule:
Threshold Biomass based HCR

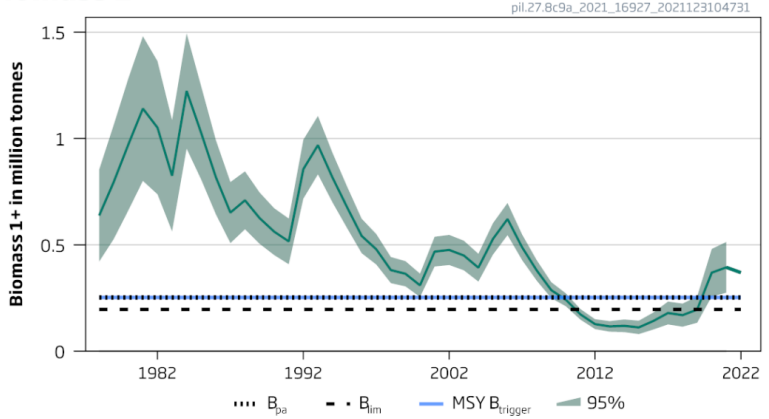
i. If B1+ ≤ 112 943 t, then F = 0;
ii. If 112 943 t < B1+ ≤ 252 523 t, then F increases linearly from 0 to 0.064;
iii. If 252 523 t < B1+ ≤ 446 331 t, then F increases linearly from 0.064 to 0.12;
iv. If B1+ > 446 331 t, then F = 0.12.



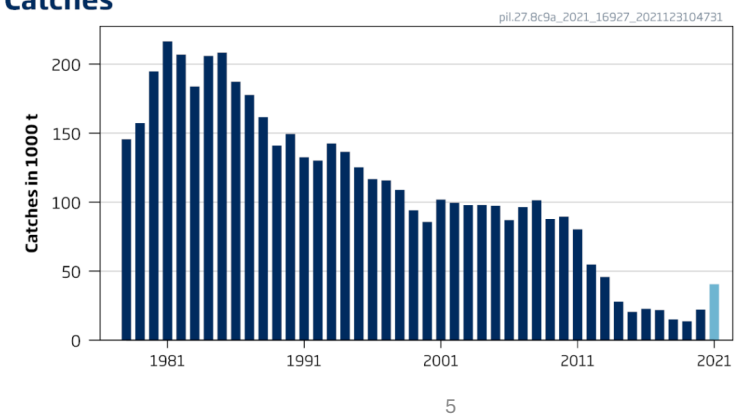
This rule was tested with different maximum catch limits of 30kt, 40kt and 50kt.

Source: WORKSHOP FOR THE EVALUATION OF THE IBERIAN SARDINE HCR (WKSARHCR) 2021

Biomass 1+

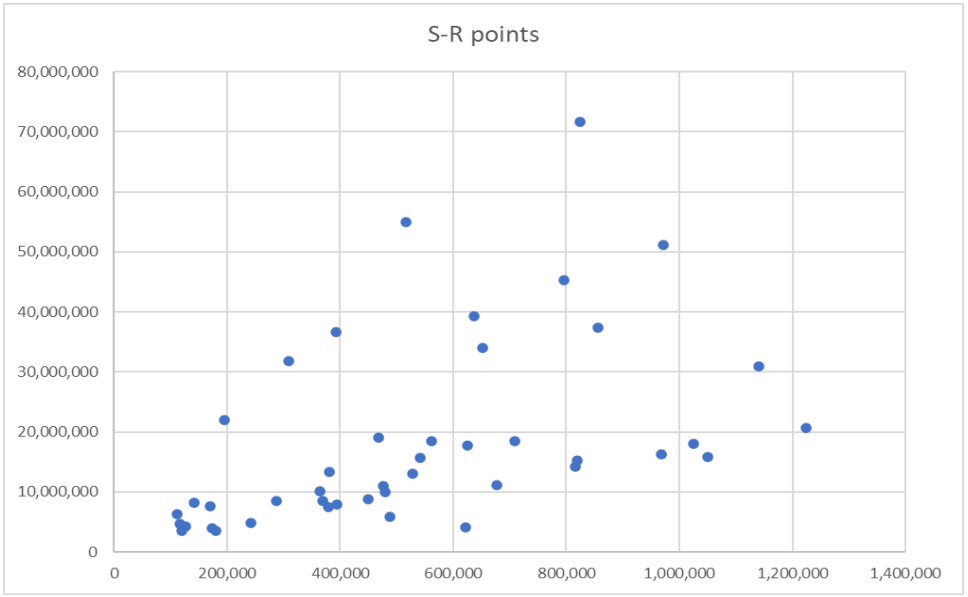


Catches



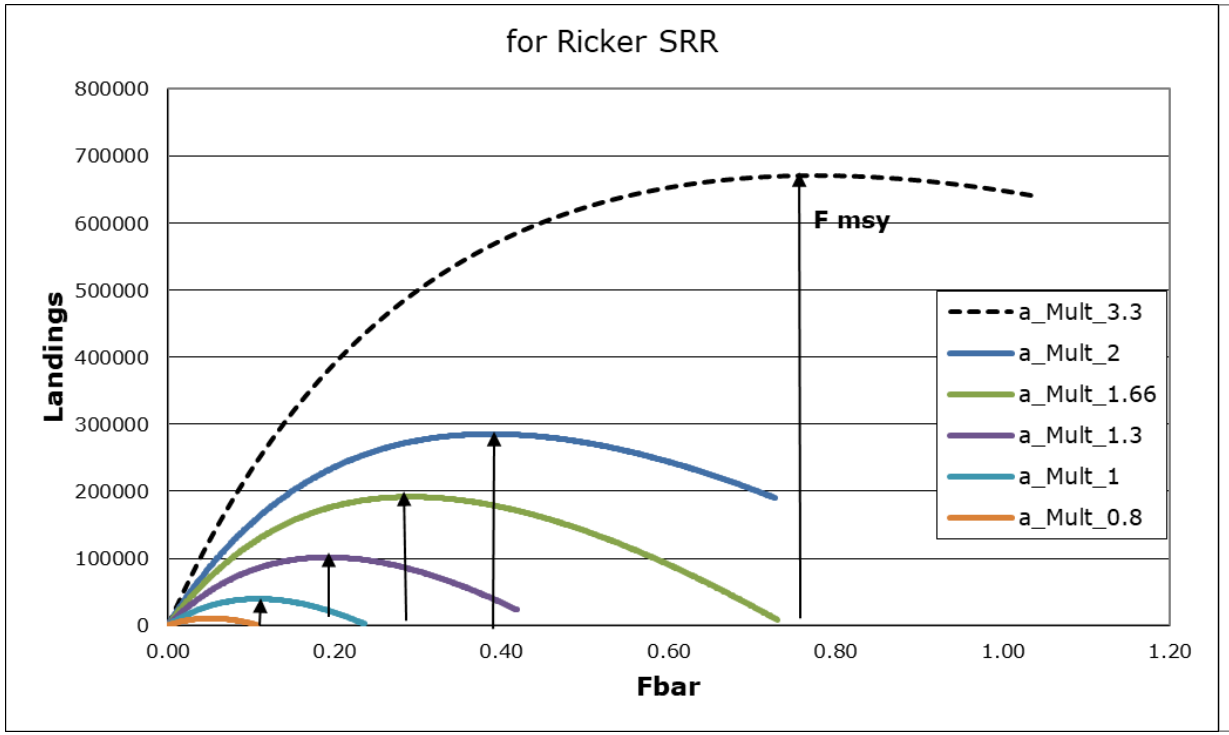
Case study: Iberian sardine

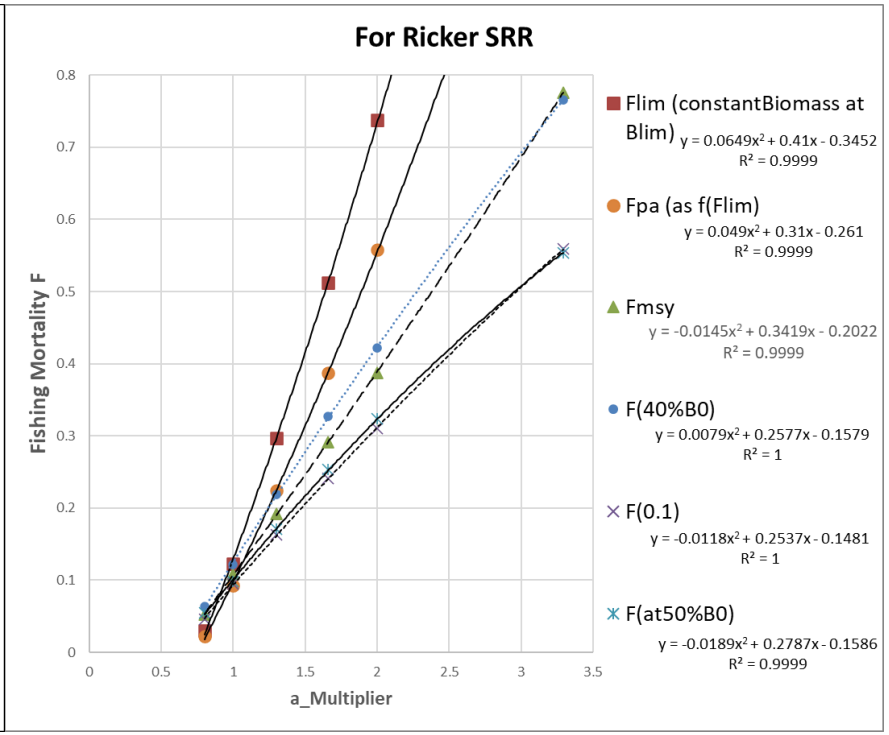
Recruitment (age 0)



It is considered that this stock is in a low productivity regime since 2006

SRR parameters and reference points



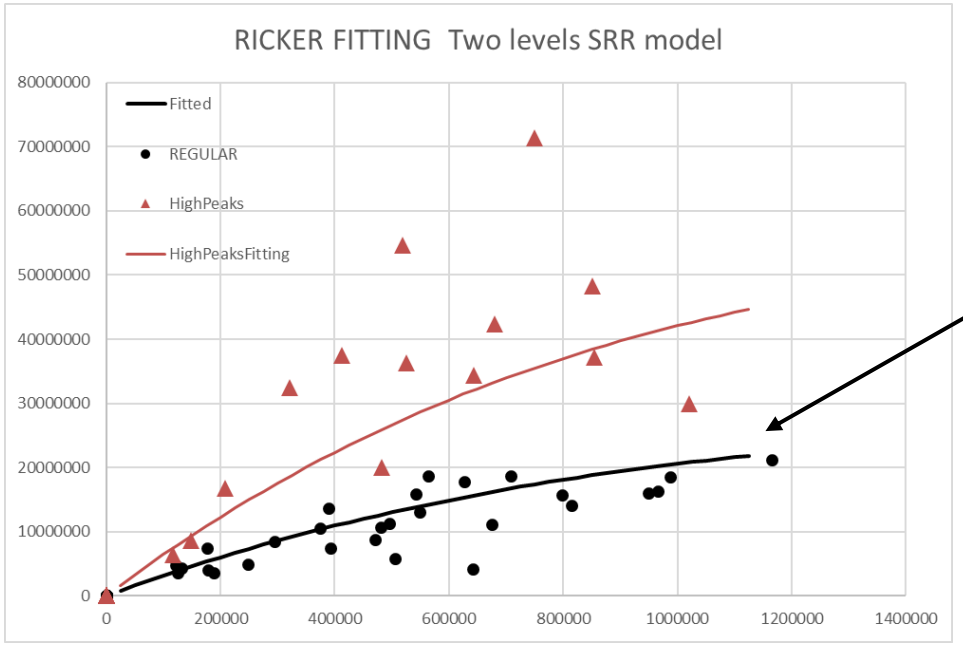


For every year class we will get an $Fmsy.proxy_{a(Yc)}$ according to *My*

$$M_y = \exp(\epsilon_y) = \frac{R_y}{a \cdot S_y \cdot \exp(-b \cdot S_y))}$$

Ricker SRR: 2 levels fitting

In a single fit, a regular regime and a high regime are estimated, as well as the probabilities of switching from one to the other.



Random switching model (Munch and Kottas, 2009)

There are two unobserved environmental regimes characterized by different productivities. The regime state is a two-state Markov chain with unknown transition probabilities.

Estimated model parameters:

- Regime1 (regular) $\boldsymbol{a} \cdot S_y \cdot \exp(-\boldsymbol{b} \cdot S_y))$
- Regime2 (high) $\mathbf{M} \cdot \boldsymbol{a} \cdot S_y \cdot \exp(-\boldsymbol{b} \cdot S_y))$

- Probability of changing from Regime1 to Regime2
- Probability of changing from Regime2 to Regime1

Derived quantities:

- Fmsy1 and Fmsy2
- SSBmsy1 and SSBmsy2

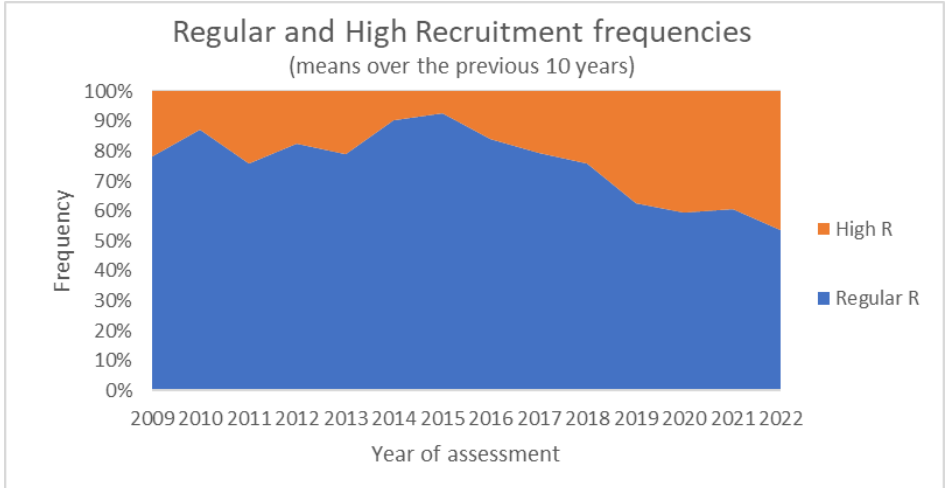
Proposed HCR: Two level Recruitment based F rule (2LRb)

$$F_{y+1} = \exp\left[f_1 \cdot ln\left(Fmsy_1 \cdot Min\left(1; \frac{B_y}{Bthresh.1}\right)\right) + (1 - f_1) \cdot ln\left(Fmsy_2 \cdot Min\left(1; \frac{B_y}{Bthresh.2}\right)\right)\right]$$

$Bthresh = SSBmsy$

f_1 =Mean likelihood(R1) / [likelihood(R1)+ likelihood(R2)] over last 10 years and ***f_2*** = 1-f_1

The likelihood of a certain recruitment is computed as the probability associated to the two-side t-distribution respective to each expected recruitment level (R1 or R2)



Proposed HCR: Multi level Recruitment based F rule (MLRb)

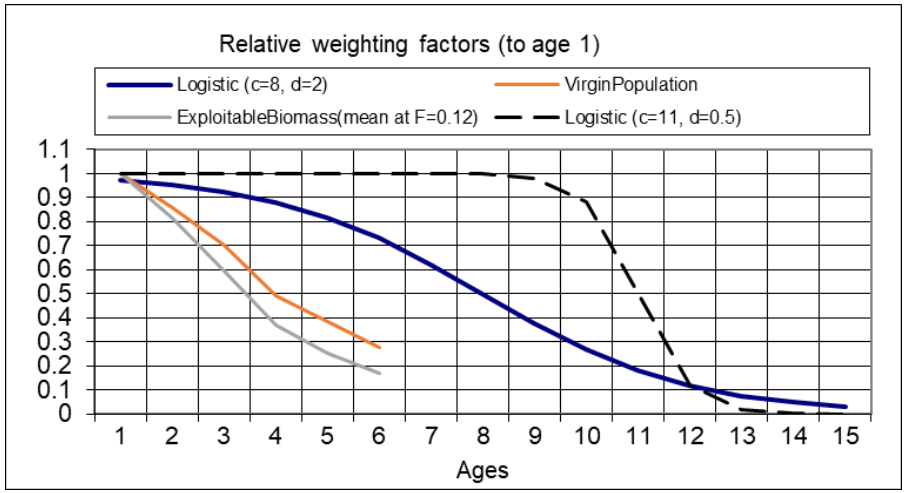
$$F_{y+1} = Fmsy.proxy\left(\overline{M_y}\right) * Min\left(1; \frac{SSBt}{Bthreshold}\right)$$

With mean My ($\overline{M_y}$) over the N recent years (Nry) defined as the geometric mean of My:

$$\overline{M_y} = \frac{\sum_{Yc=y}^{Yc=y-Nry}[Ln(My) \cdot W_{Yc}]}{\sum_{Yc=Iy}^{Yc=Iy-Nry}[W_{Yc}]}$$

Logistic mean weighting factors:

$$W_{Yc} = \frac{1}{1 + \exp([(Iy - Yc) - c]/d)}$$



Tested HCRs

16 rules tested

Parameters for these rules are based on Munch and Kottas (MK) *Random switching model* fittings until 2019.

- **2-Level Recruitment based Harvest Control Rule (2LRbMK)**
  - With maximum catch limits from 50 to 100 kt
  - Without catch limits
- **Multi-Level Recruitment based Harvest Control Rule (MLRbMK)**
  - With maximum catch limits from 50 to 100 kt
  - Without catch limits

New rules, same as the current rule, include a fishery closure when the biomass is below a fixed limit

- **Current rule (from WKSARHCR 2021)**
  - With maximum catch limits from 30 to 100 kt
  - Without catch limits
- **ICES HCR**
  - Target and trigger points in the rule derived from the low regime **(F=0.03)**
  - Target and trigger points in the rule derived from the medium regime (**F=0.11**)

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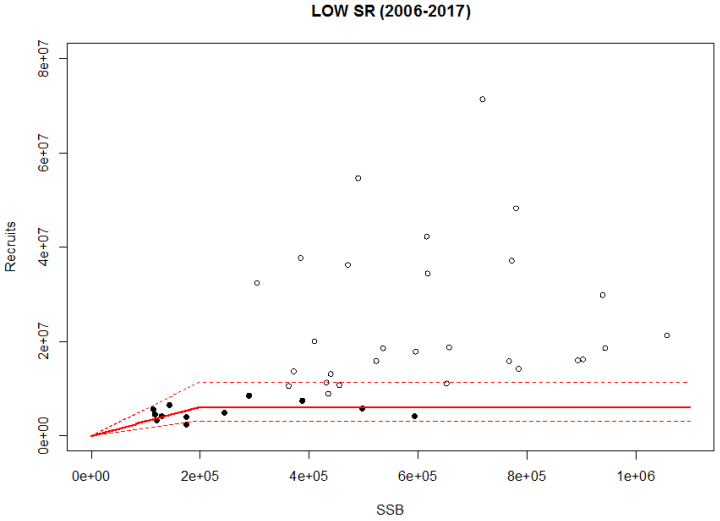
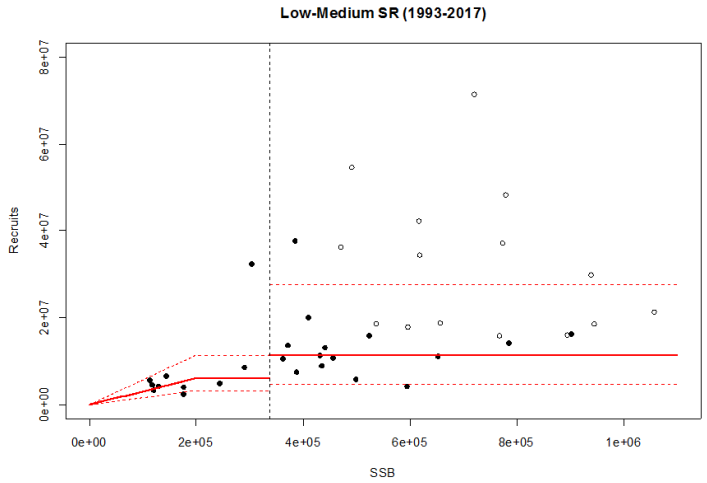
Operating models (OMs)

7 OMs implemented

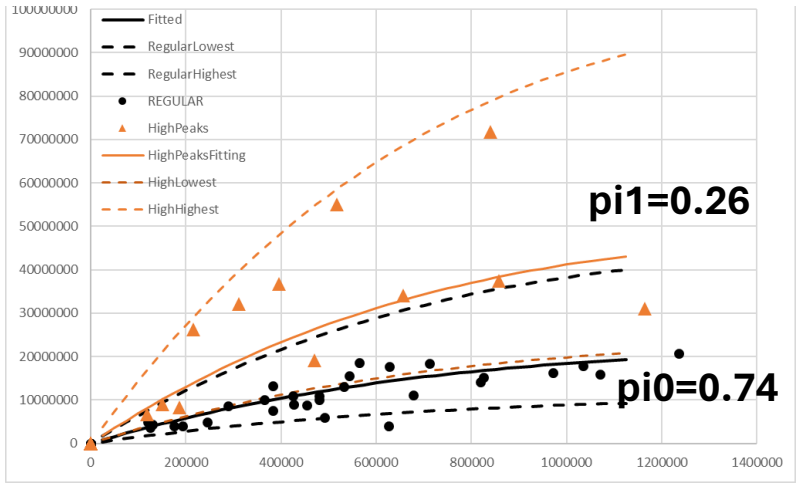
- LOW Hockey-stick



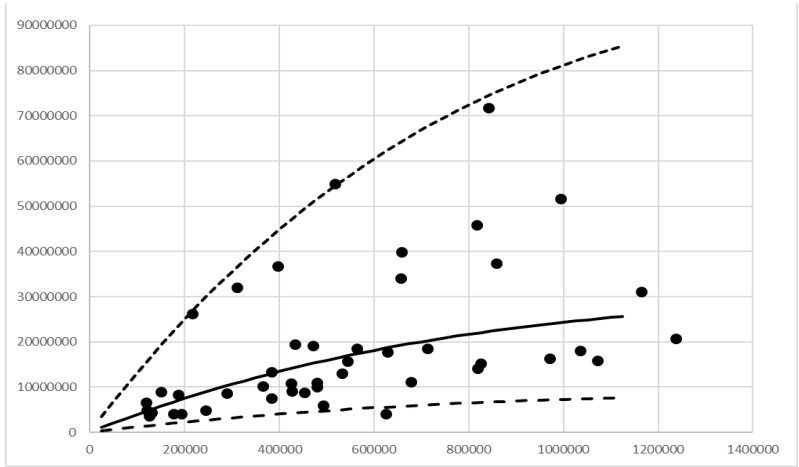
- LOW to MEDIUM Hockey-stick



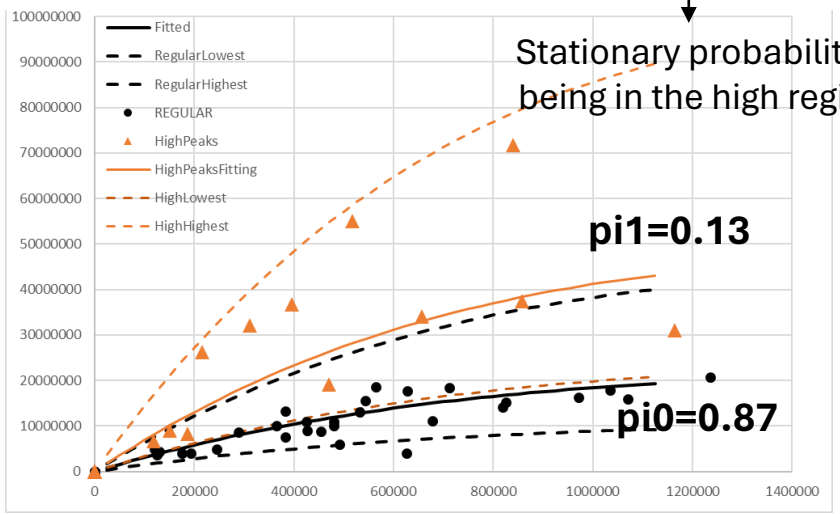
- 2levels Ricker



- 1level Ricker



- 2levels Ricker 1981-2021, lower pi1



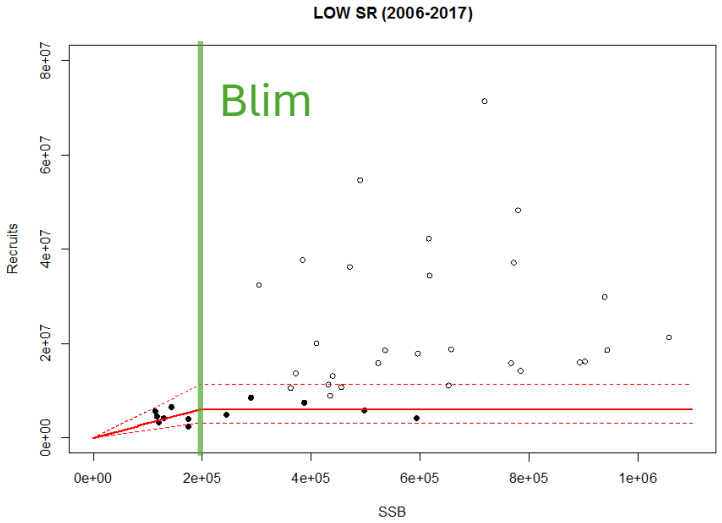
Additional OMs:

Changing productivity in time

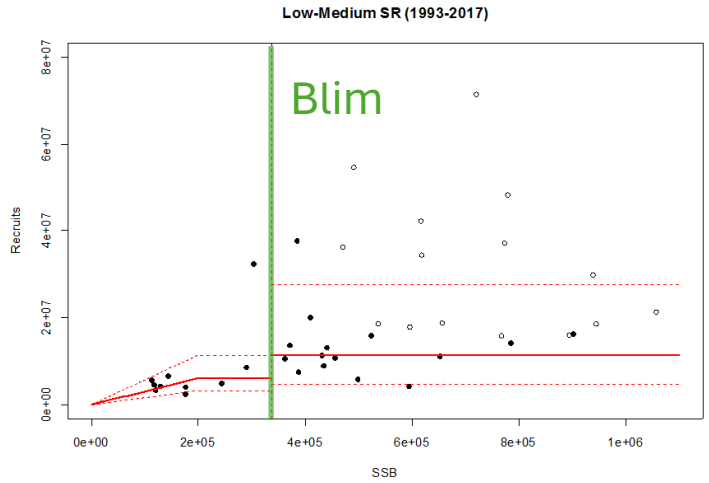
- 2levelsLOWtoHIGHpi1: halve pi1 after 25 years of projections
- 2levelsHIGHtoLOWpi1: start with halved pi1 and recover to original pi1 after 25 years of projections

Blim for performance indicators

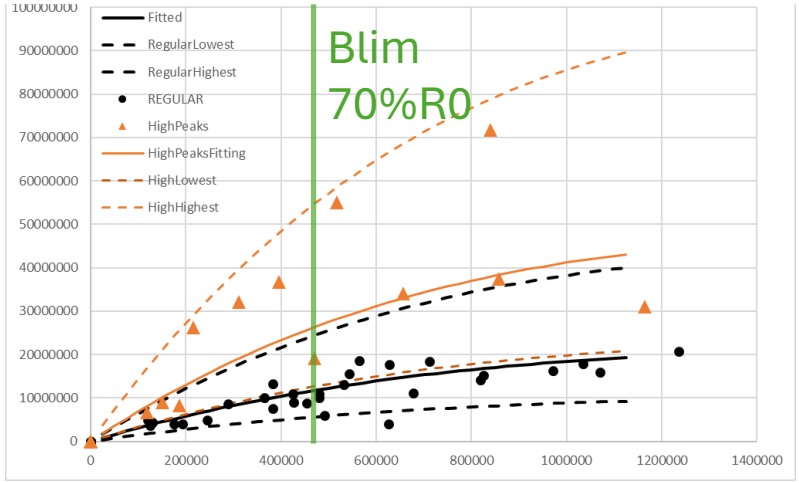
- LOW Hockey-stick



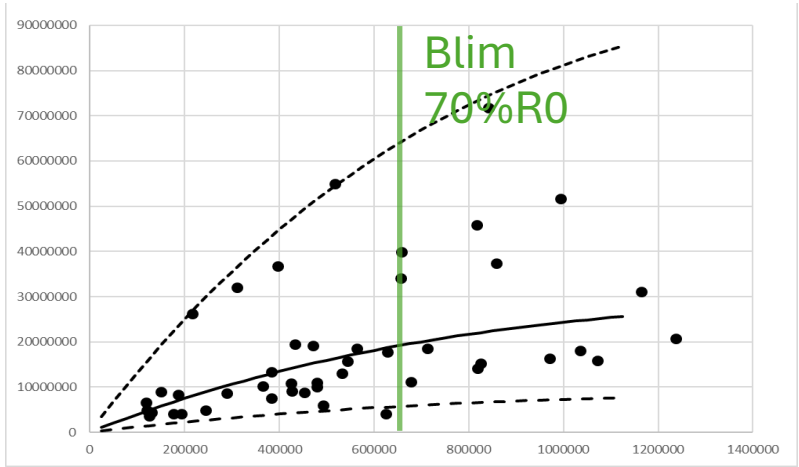
- LOW to MEDIUM Hockey-stick



- 2levels Ricker



- 1level Ricker



All rules have been tested for all implemented OMs.

Risk performance indicators are computed based on a **different Blim for each OM**.

Risk3 = maximum probability of SSB being below Blim in the projection period (ICES considers that a rule is precautionary if risk3<%5)

Blim values for the new operating models based on ricker SRR, have been computed as the biomass resulting from a 70% of R0 (for the regular regime).

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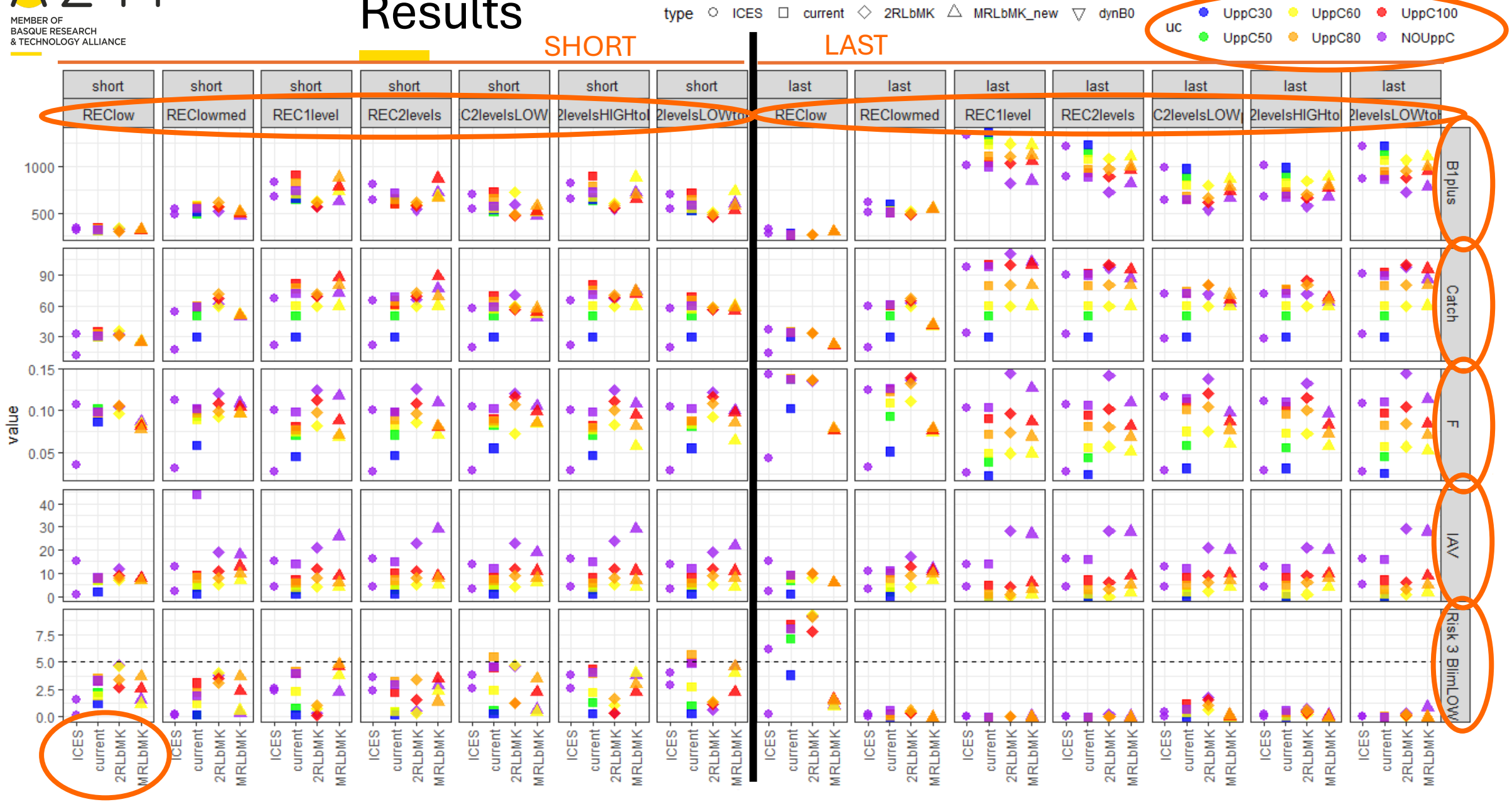
Results

Short: 2021-2030
Last: 2061-2070



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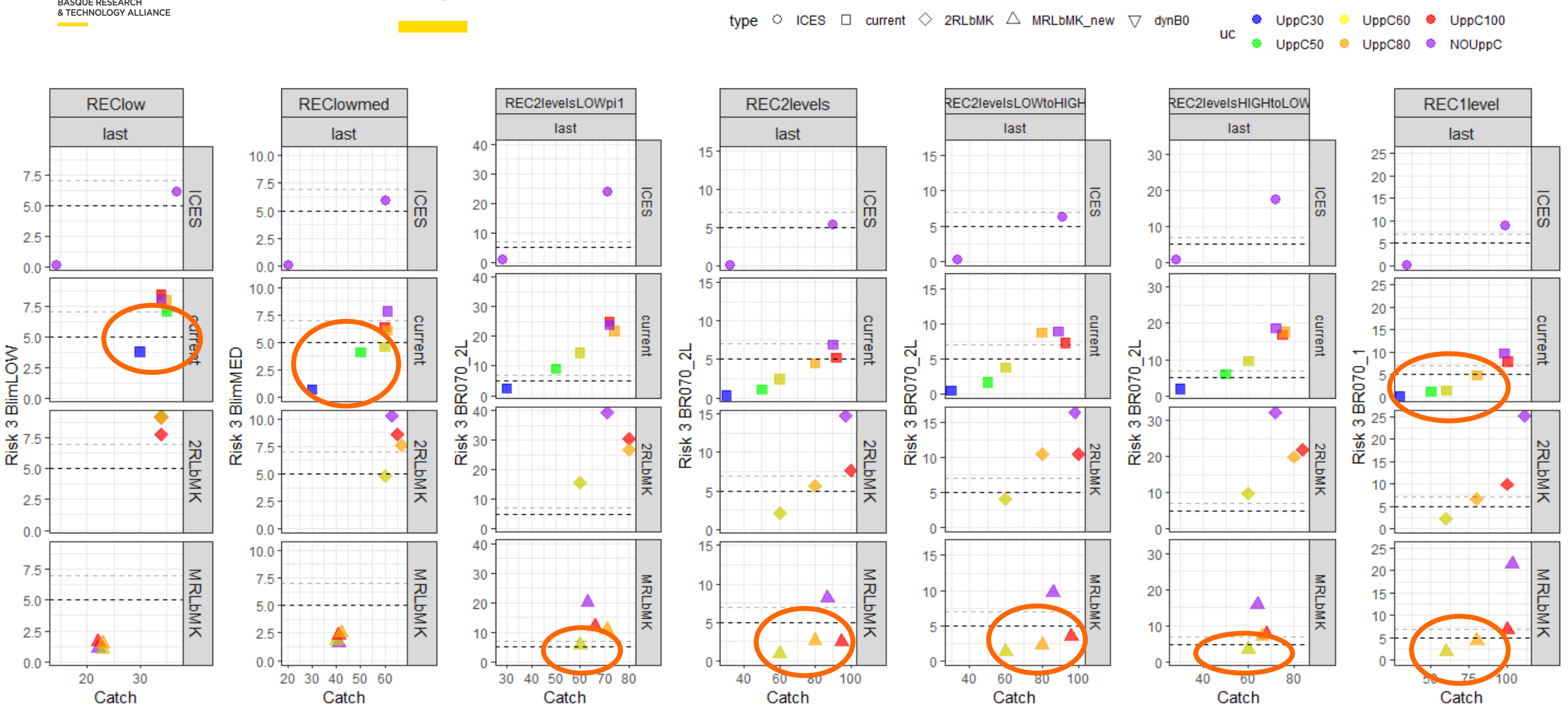
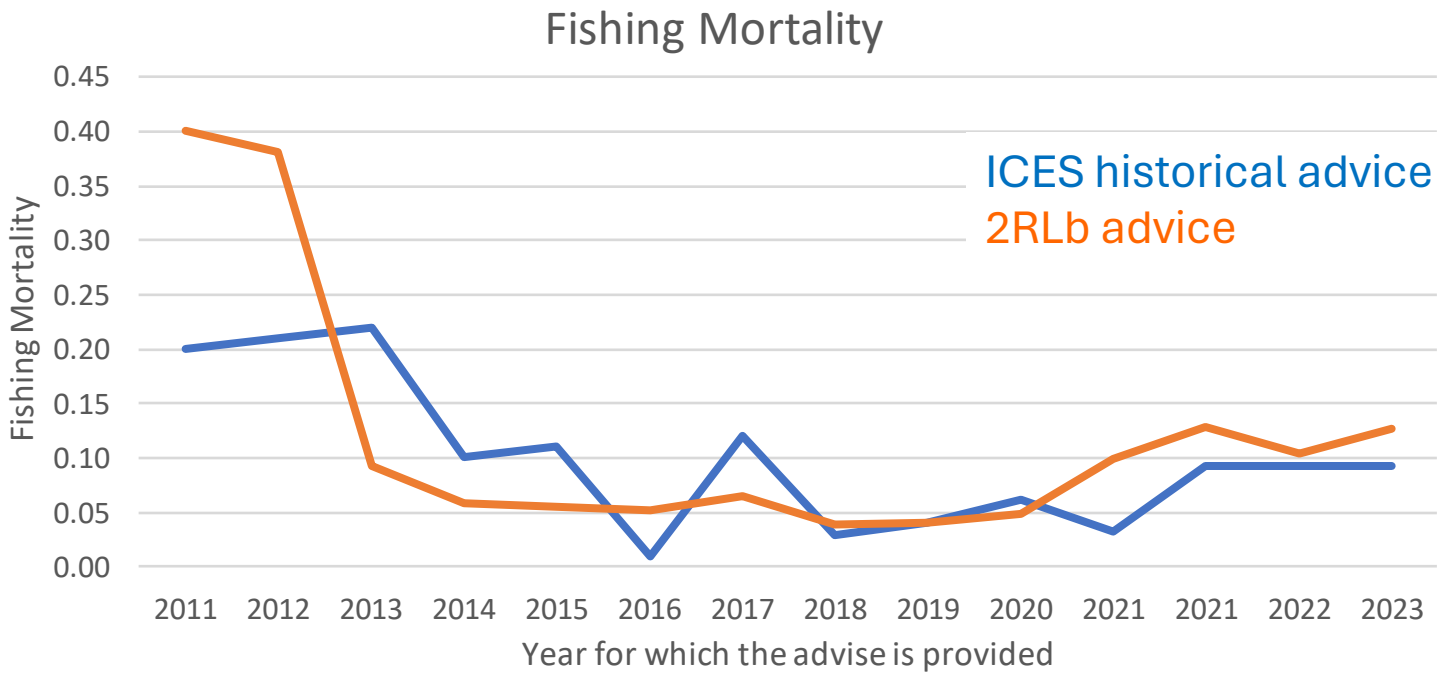
Results



What would have been the advice in the last years if the two-level rule would have been applied?



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Conclusions

- The dynamic HCRs can accommodate fishing mortality to the changes in productivity of the resources.

- The current rule is the best performing rule for the previously tested OMs
- The current rule has been now tested under new OMs and has shown to be robust to most of the them. However, for the less productive OMs the maximum catch limit to be sustainable is low (~30kt) at Blim 70%R0

- The Multi-Level Recruitment based rules outperform the 2-Level Recruitment based and the current rule for most of the new OMs resulting in higher catches for sustainable risk levels.
- The Multi-Level Recruitment based is also sustainable for the previously tested OMs, however, resulting catches are lower in comparison with the other type of rules.
- The Multi-Level Recruitment based with max catch limit of 60kt had shown to be precautionary for all implemented OMs.

- The performance of all HCRs depend on selected maximum catch limits.
- Including maximum catch limits reduces the interannual variability in catches and risk to Blim.

- Definition of Blim may be open to debate, nearly all rules are sustainable when taking an alternative Blim at 50%R0 for example.

- Retrospective application of 2-Level Recruitment based HCRs would have produced consistent or lower advices of F than those given by ICES from 2014 to 2020, but they would have advised higher F values from 2021 to 2023.

- Recruitment-based dynamic harvest control rules are generic and easily implementable rules at any fishery, which may speed up the definition of HCRs (i.e. in comparison with the several years that took the elaboration of a sustainable HCR for the sardine fishery).

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Thank you

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lcitores@azti.es; libaibarriaga@azti.es

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