

Integration of environmental processes in MSEs in FLBEIA

With a focus on
reference point
changes under
climate change

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SEAwise has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 101000318



What is

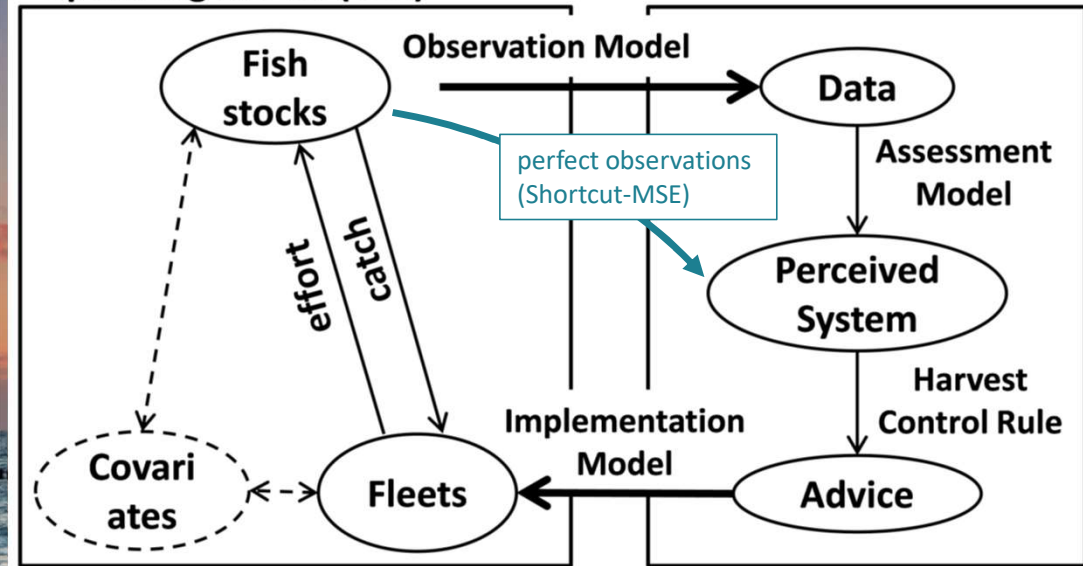


FLBEIA = bioeconomic impact assessment using FLR

- Flexible and generic simulation model to test different management strategies (in the form of harvest control rules) under a MSE-framework with a focus on bioeconomy
- **multi-stock, multi-fleet, multi-métier** capabilities and as such particularly suited for mixed fisheries simulations
- 2 components:
 - **Operating model (OM)** ~ real dynamics of the system
 - **Management procedure (MP)** ~ simulation of the management process
- Builds on the FLR-framework:
 - Incorporates: **FLQuants**, **FLstock**, **FLSRsim** –objects
 - But also new classes: **FLBiols**, **FLFleetExt**, **FLMetiersExt**, ...
- So many familiar things, but also new ones...

FLBEIA

Operating Model (OM)



Garcia et al. 2017

Management Procedure Model (MPM)

Typical FLQuant-obj (6dim array):

```

An object of class "FLQuant"
, , unit = unique, season = all, area = unique

   year
age 2012   2013   2014   2015   2016   2017
  1 0.60352 0.97440 0.99065 1.68515 1.36443 5.05653
  2 1.93833 2.09946 3.13919 0.84972 0.53418 0.69980
  3 0.24826 1.51710 5.28007 0.61229 0.59522 1.19544
  4 3.14748 6.16351 1.06234 0.93561 1.43151 0.81529

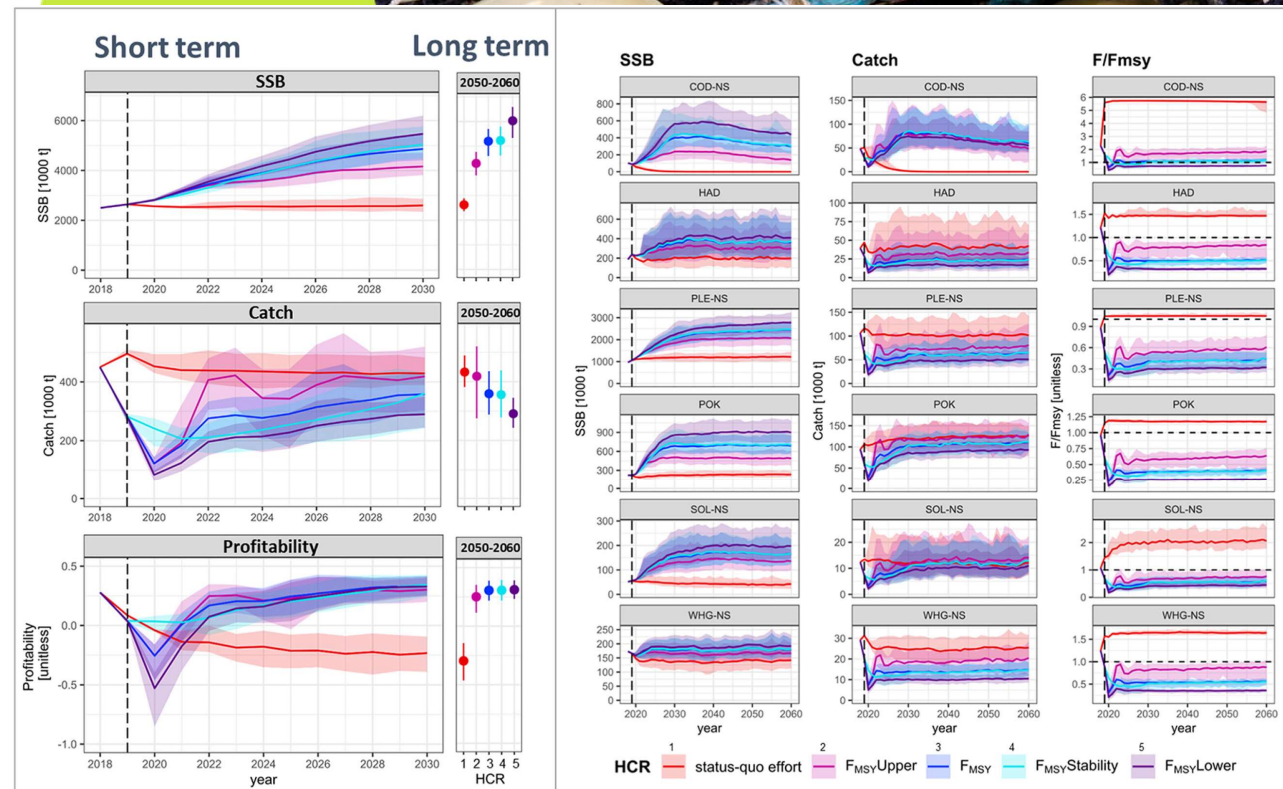
units:  t
    
```

<https://flr-project.org/>

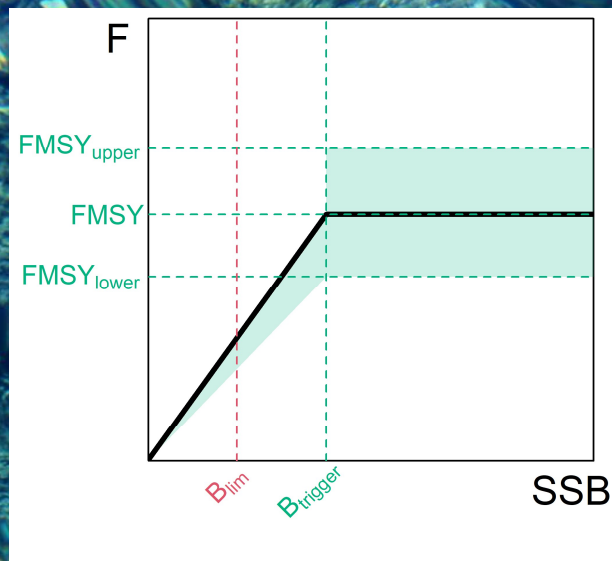
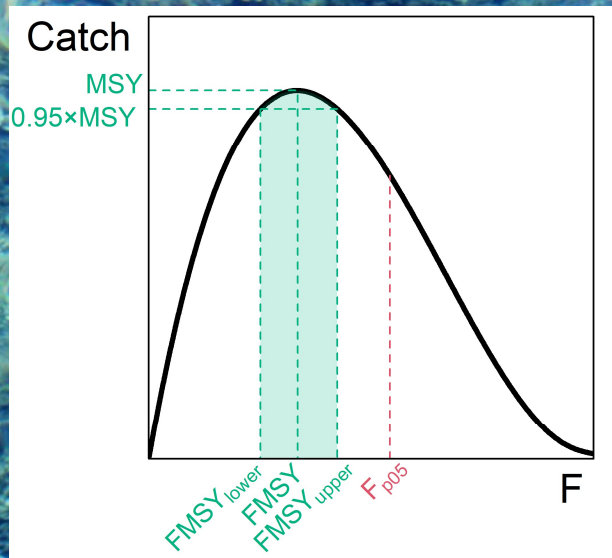
Motivation to assess reference point changes

- Reference points are affected by both changes in productivity and in the fishery
 - Growth, maturity, natural mortality, recruitment
 - Selectivity, catchability
- Interest in describing these changes and potentially use in MSEs to mimic periodic revisions to harvest control rules (HCRs)
 - Potential trade-offs within a mixed fisheries context (stock status, yield, economic aspects)
- Evaluation of HCRs using *adaptive vs static* reference points
 - Potential trade-offs within a mixed fisheries context (stock status, yield, economic aspects)

Motivation



Kühn, B., Kempf, A., Brunel, T., Cole, H., Mathis, M., Sys, K., Trijoulet, V., Vermard, Y., Taylor, M., 2023. Adding to the mix – Challenges of mixed-fisheries management in the North Sea under climate change and technical interactions. *Fisheries Management Eco* 30, 360–377. <https://doi.org/10.1111/fme.12629>



ICES Reference point definitions

- Reference points in ICES are periodically updated (i.e. during a benchmark assessment, every 5-10 years) to reflect current productivity regimes and equilibrium conditions.

Important reference points to remember:

Blim – Spawning stock biomass (SSB) below which recruitment is reduced [can be subjective]

Fmsy – fishing mortality associated with maximum sustainable yield (landings) [calc. without HCR]

MSY Btrigger – 5th percentile of SSB when fishing at Fmsy [calc. without HCR]

Bpa – Provides precautionary buffer above Blim, considering the uncertainty of the SSB estimate from the assessment (95th percentile): $B_{pa} = B_{lim} \times \exp(1.645 \times \sigma)$ [calc. without HCR].

*Trumps MSY Btrigger (choose higher value)

Fpa / Fp05 – Maximum fishing mortality resulting in <5% probability of SSB below Blim [calc. with HCR]. *Trumps Fmsy (choose lower value)

ICES Ref. pts definitions

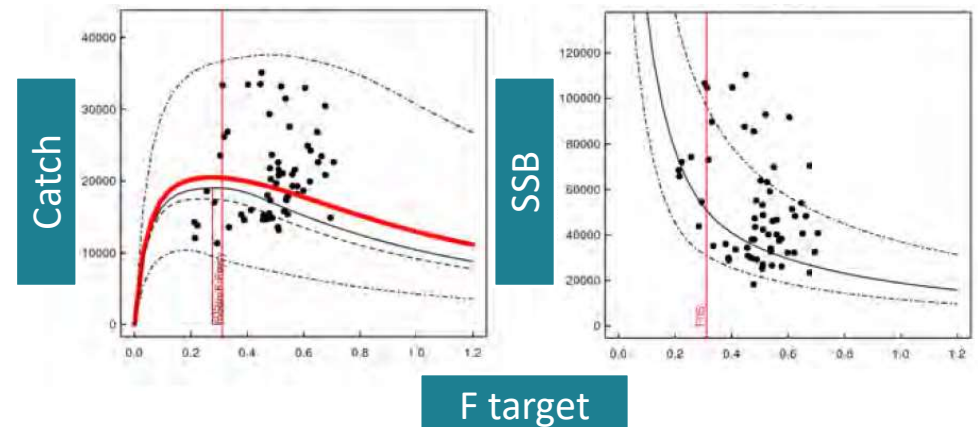
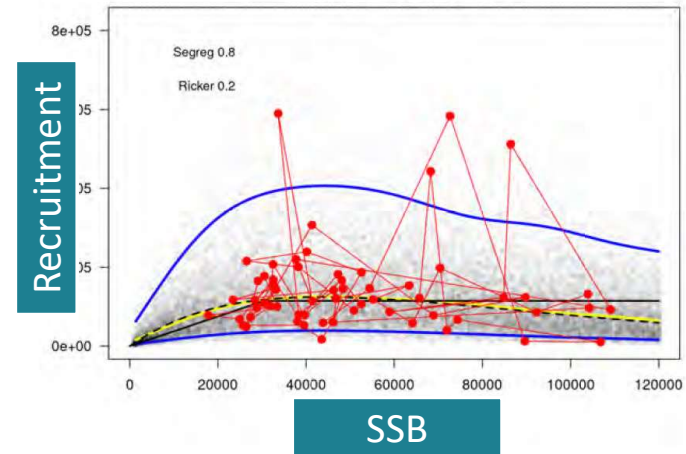
Incorporating variability / uncertainty

- **Eqsim** (Simmonds et al. 2022) is typically used to evaluate reference points.
- **Variability** - resampling of historical data (assessment outputs)
- Stock-recruitment pairs are resampled and SRR(s) refit (Bevholt, Ricker, Segreg)
- Biological parameter resampling (weights, maturity, M)
- Selectivity resampling
- **Uncertainty** – implementation/obs. error in the assessment (F_{cv} , SSB_{cv}) and autocorrelation and (F_{phi})
- **Reference points at equilibrium** - Typical to simulate 200 years and evaluate the final 50 years (e.g. median yield, SSB).

Simmonds, J., Hjorleifsson, E., Millar, C., 2022. msy: Estimation of Equilibrium Reference Points for Fisheries. R package, <https://github.com/ices-tools-prod/msy>

Incorporating variability/uncertainty

ex. Eqsim for North Sea sole



ICES, 2020. Benchmark Workshop for Flatfish stocks in the North Sea and Celtic Sea (WKFlatNSCS). ICES Scientific Reports 2, 975. <https://doi.org/10.17895/ICES.PUB.5976>

Testing Consistency with FLBEIA

- - **Why FLBEIA?** - Used as multi-spp, multi-fleet MSE in SEAwis, and thus integration of env.-mediated processes for later scenarios was important
- - **Main difference** - Different catch equations: FLBEIA (Cobb-Douglas), Eqsim (Baranov)
- - **Fewer simulation years (100) and iterations** than Eqsim due primarily to computational speed
- - **Largely consistent** reference points between the two models (Savina-Rolland et al. 2024, Annex 2).

Savina-Rolland et al. (2024). SEAwis Report on effects of environmental and ecological factors on stock productivity for online tool. Technical University of Denmark. <https://doi.org/10.11583/DTU.25610955>

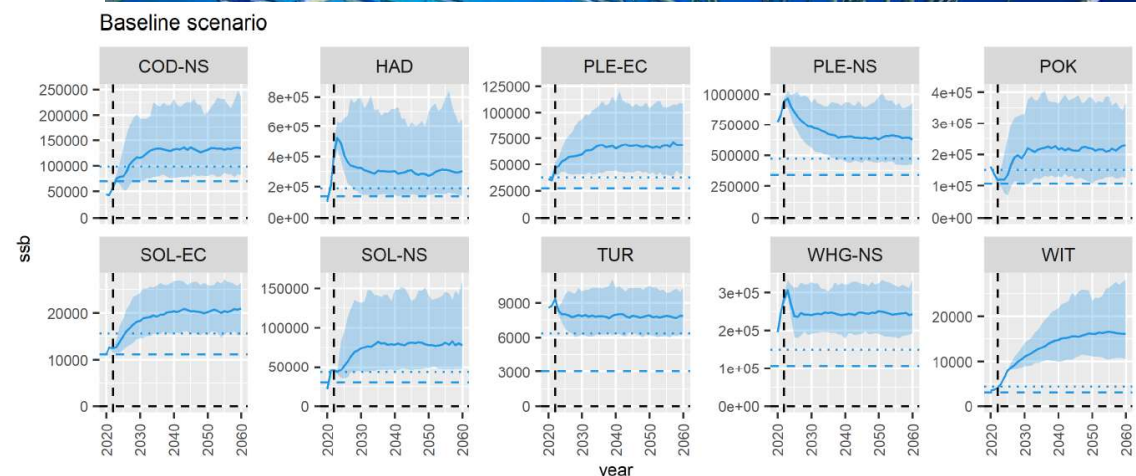


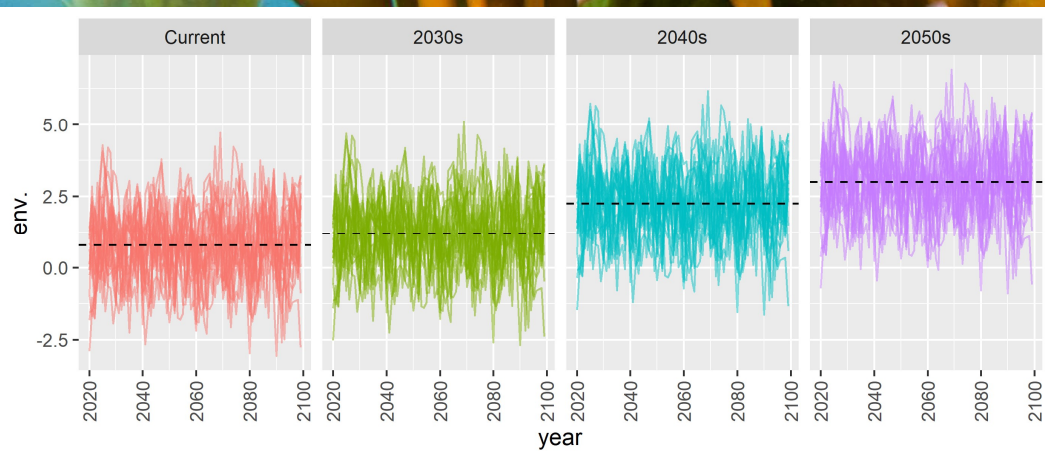
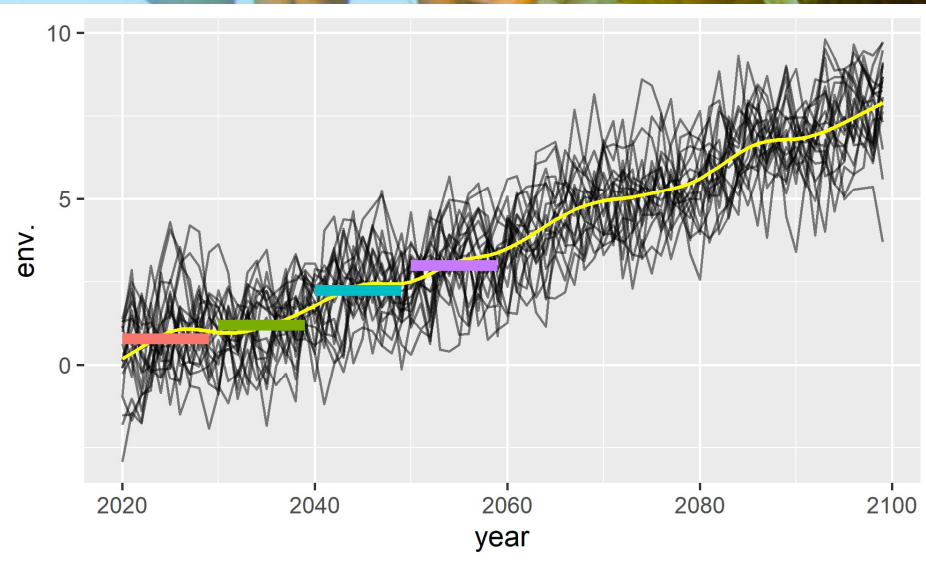
Figure A2. SSB trajectories by stock showing median (solid blue line) and quantile distributions (5%, 95%, shaded blue area). Btrigger and Blim reference values are denoted by blue dotted and dashed horizontal lines, respectively.

FLBEIA as
MSE tool

Periodic
Updating of
Ref-pts.

Preparation of environmental time series

- In order to mimic the updating of reference points in MSEs, we used detrended environmental time series, offset by mean values over discrete periods
- Creates comparable time series (e.g. noise structure)
- Predictions among coupled GCMs show divergence further into the future. Thus, SEAwisE scenarios have been limited to ~40 years (up to 2060)



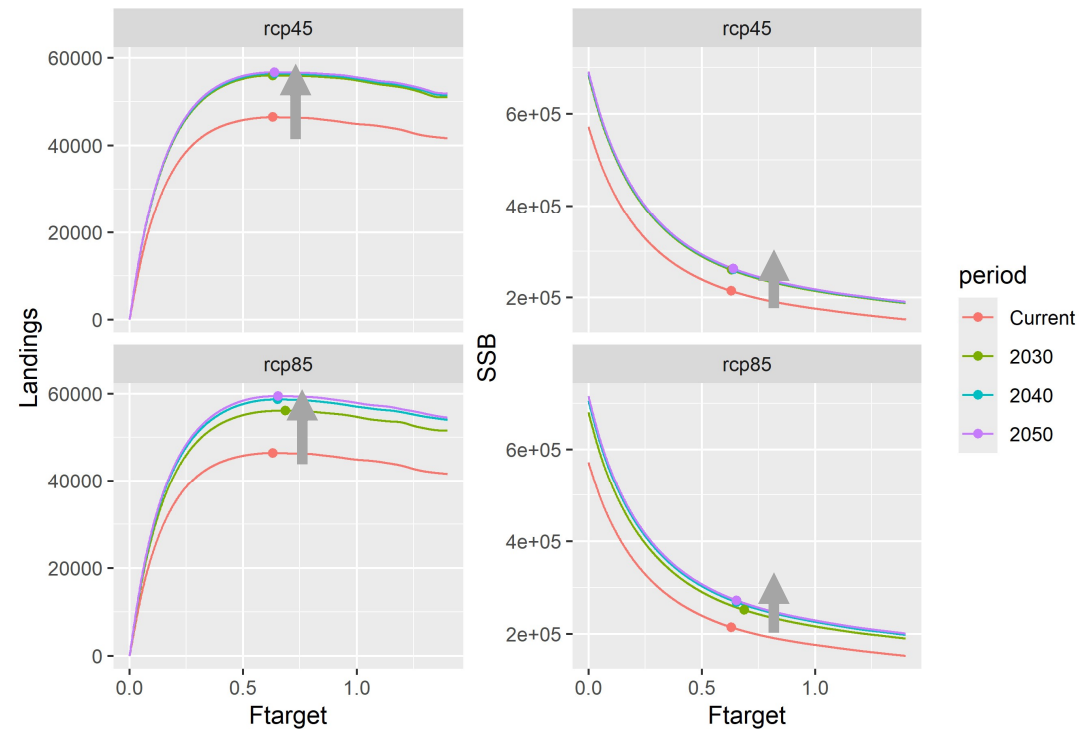
Example Output: Whiting with EMSRR

- Whiting recruitment is driven by other covariates (currents, salinity) resulting in somewhat positive trends to MSY and biomass reference points, while F_{msy} is affected to lesser degree
- Relatively flat yield curve is due to a low degree of recruitment / growth overfishing, as the fishery targets mainly mature ages (high F_{msy} consistent with recent benchmark)

Ref. Pts
changes Whiting

WHG-NS, all regimes, without HCR

WHG-NS



Example Output: Cod with EMSRR

- Also for Cod they are strong changes visible resulting in clear trends in Fmsy, MSY, and biomass reference points (Bmsy, Btrigger).
- More extreme changes in RCP8.5 scenarios
- But I don't want to spoil too much!

Ref-pts
changes
cod

COD-NS, all regimes, without HCR

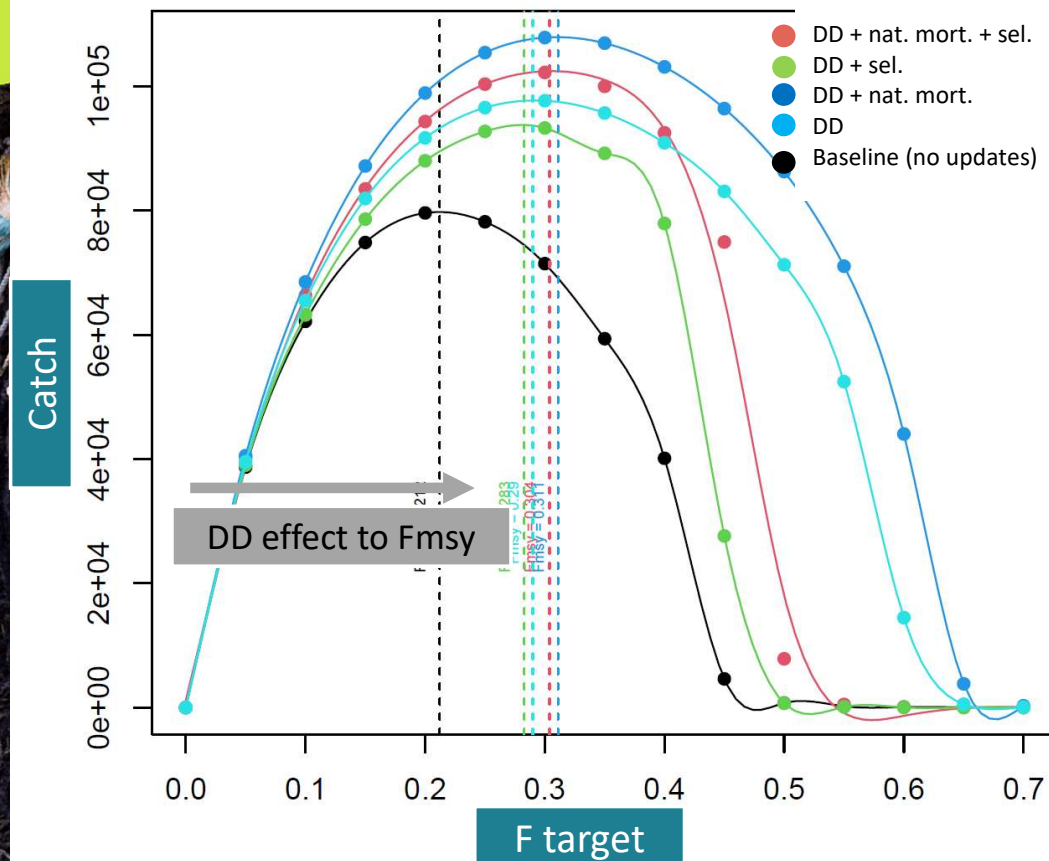
Part of the practical!

To do'S and open questions

- Should reference point updates to the Management Procedure (MP) be those defined by the previous climate regime?
 - Climate predictions are unlikely to be used to setting future reference points – Rather reflect recent past
 - Will create a bias due to lagged implementation (but more realistic given the current management approach?)
- Incorporate mediated growth models
 - Update parameters that might be influenced by weight-at-age (**M**, **q**, **mat**)?
- **Note:** We have not implemented a benchmark-like procedure in our MPs, but rather provided the "true" reference points (short-cut MSE). Would be interesting to see how reference points derived without knowledge of the env.-mediation might be biased (e.g. using truncated time series)

Open questions

Ex. North Sea plaice with density-dependent (DD) growth ($L_{inf} \sim SSB$)



Aims of the following practical:

- Get a glimpse of the **main functionalities of FLBEIA** and how those can be extended to **include EMSRRs and dynamic growth**
- Provide you with some **food for thought on how reference points change** with a changing stock productivity
- How **reference point changes can be integrated into MSE simulations using FLBEIA**



Summary