User Guide: Selectivity Analysis with FLSelex in FLR

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Contents

1 Getting started

This vignette introduces the `FLSelex` R package available on https://github.com/Henning-Winker/FLSelex, as a support tool for analysing the impact of varying fisheries selectivity pattern in `FLR`.

1.1 Installation

`FLSelex` requires very recent versions of `FLR` libraries `FLCore`, `FLBRP`, `FLasher` and `ggplotFL`. This can be installed together with `FLSelex` from gihtub using library(devtools):

```
installed.packages("devtools")

devtools::install_github("flr/FLCore")

devtools::install_github("flr/FLBRP")

devtools::install_github("flr/FLasher")

devtools::install_github("flr/ggplotFL")

devtools::install_github("henning-winker/FLSelex")
```

However, due to increasing difficulties of compiling C++ code with Rtools for Windows systems, these are also provided a binary package zip files here. Not a dependency, but a very useful to explore selectivity pattern under alternative stock recruitment relationships is the new `FLSRTMBbeta` (Winker and Mosqueira, 2021), for which the latest binary package zip for Windows can be found here.

```
library(FLCore)
   Loading required package: lattice
   Loading required package: iterators
   FLCore (Version 2.6.16.9004, packaged: 2021-09-29 21:38:55 UTC)
library(FLBRP)
   Loading required package: ggplotFL
   Loading required package: ggplot2

   Attaching package: 'ggplot2'
   The following object is masked from 'package:FLCore':

       %+%
library(FLasher)
   Loading required package: FLFishery
   FLasher: The rats and the suckers, the strong and the lame
library(FLSelex)
library(ggplotFL)
```

1.2 Selectivity-at-age

The starting point for an `FLSelex` analysis is a `FLStock` generated from an age-structured assessment (e.g. a4a, SAM, SS3) or simulation. Therefore, selectivity is expressed as selectivity-at-age (`Sa`), such that:

$$S_a = \frac{F_a}{max(F_a)}$$

where F_a is the instantaneous rate of fishing mortality at age (e.g. Sampson and Scott 2011).

A common assumption is that S_a follows a logistic curve in the form of an ogive. However, initial exploration of `FLStock` objects based on recent ICES benchmark assessments indicate the a logistic is the exception than the norm (c.f. Scott and Davies 2011). The North Sea plaice `FLStock` example `data(ple4)` from `FLCore` therefore provides a somewhat typical example for observed fishery selectivity F_a pattern estimates.

```
data(ple4)

plotselage(ple4,nyears=5)
```

The average S_a over `nyears` is made easy to extract as an `FLQuant` using `selage()`

```
Sa = selage(ple4,nyears=3)
Sa
   An object of class "FLQuant"
   , , unit = unique, season = all, area = unique

       year
   age  1
     1  0.47249
     2  0.75974
```

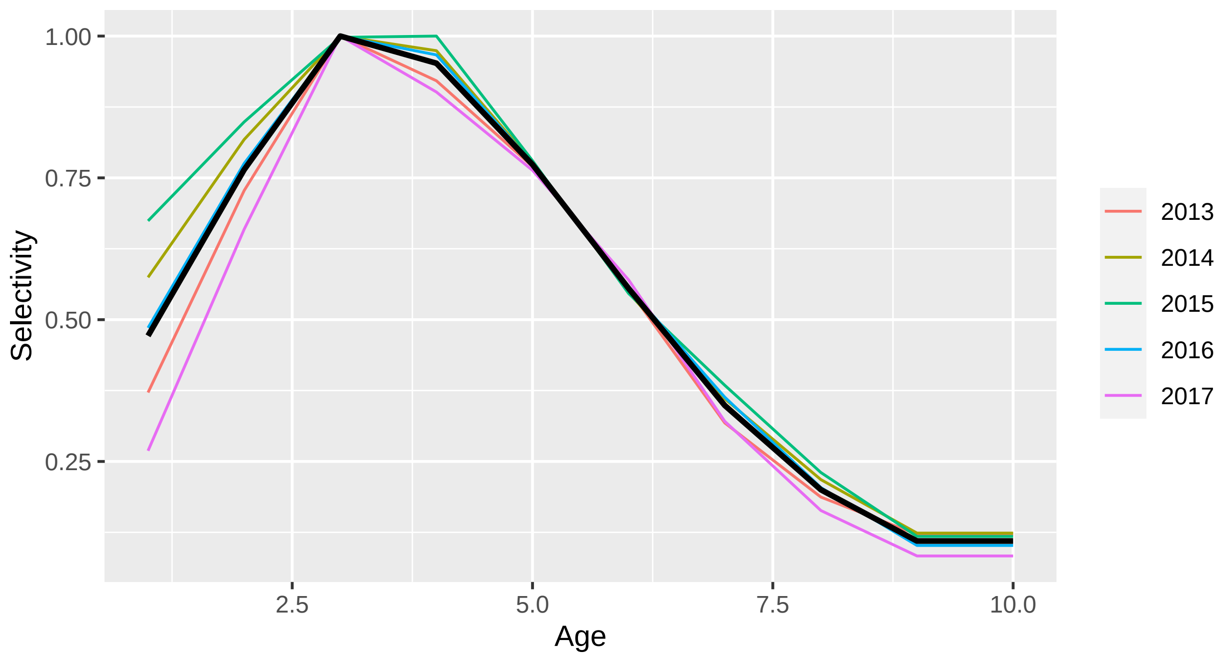

Figure 1: Observed $S_a = F_a/F_{max}$ for North Sea place over the recent 5 years

```
    3  1.00000
    4  0.95572
    5  0.77341
    6  0.55804
    7  0.35577
    8  0.19876
    9  0.10074
    10 0.10074

 units:  NA
```

1.3 The Selex function

A variaty of dome-shaped selectivity can arise because F_a and thus S_a is estimated on combined fleet level, combining multiple fleet (gear) segments that fish over a wide range of different areas. In fact, Sampson and Davies (2011) demonstrated that a logistic selectivity pattern would require that all age-classes would be equally distributed in space and time and harvested with the gear that is associated with a logistic selectivity.

To accomodate a wide variaty of selectivity curves, `FLSelex` provides a flexible 5-parameter parameteric `selex()` function, which comprises the following three compounds:

1. A *logistic* describing the ascending limb of the selectivity curve

$$S_a = \frac{1}{1 + exp(-log(19)\frac{a-S_{50}}{S_{95}-S_{50}})}$$

where S_{50} and S_{95} are the ages where S_a corresponds to 0.5 and 0.95.

2. An adjustable $halfnormal$ decribing the descending

$$S_a = -(D_{min} - 1)\frac{dnorm(age, S_{max}, S_{max}D_{cv})}{max(dnorm(S_{max}, S_{max}D_{cv}))} + 1$$

where $dnorm$ denotes a normal probability density distribution, S_{max} corresponds to the mean of the normal distribution where S_a peaks, D_{cv} determines the slope of the descending limb with the standardeviation of the normal give by the product $S_{max}D_{cv}$, and D_{min} determines the mimimum the descending slope (height).

The expected S_a is then defined as a peace-wise function of the form:

$$S_a = \begin{cases} g(logistic) & \text{if } age < S_a \\ g(halfnormal) & \text{if } age \geq S_a \end{cases}$$

Fitting `selex()` to any `Sa` is done `optim` optimization with `fitselex()`

```
Sa = selage(ple4,nyears=3)

fit = fitselex(Sa)

plotselex(sel=fit,Sa=Sa)
   Scale for 'x' is already present. Adding another scale for 'x', which will
   replace the existing scale.
   Scale for 'y' is already present. Adding another scale for 'y', which will
   replace the existing scale.
```

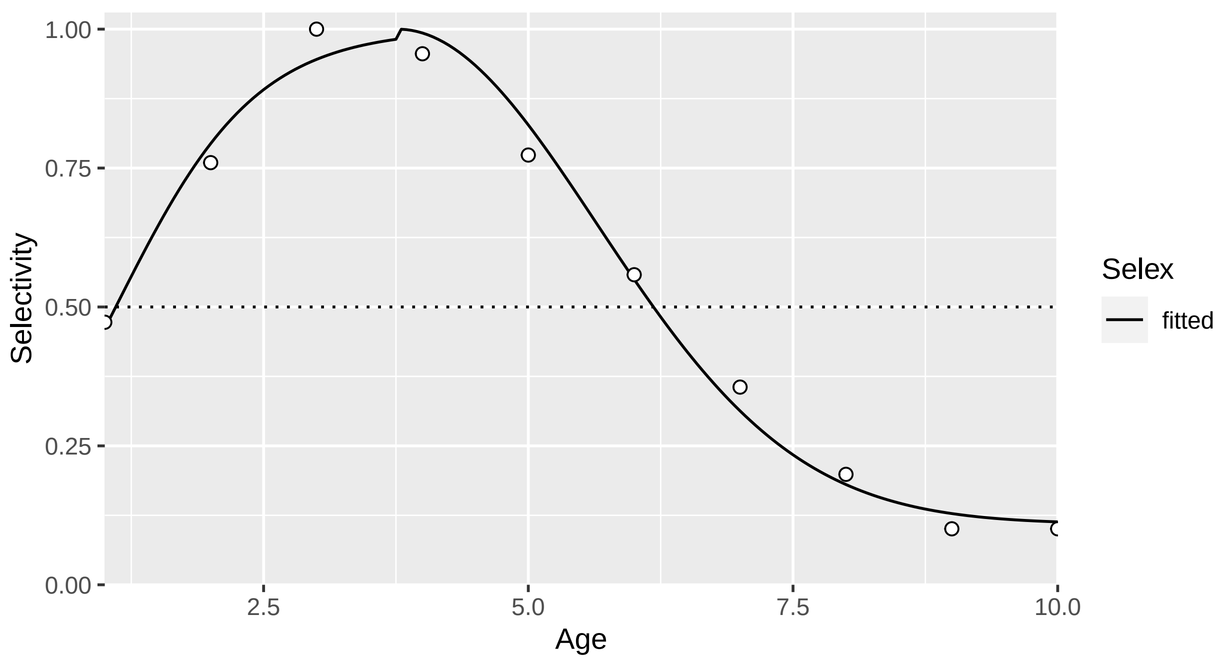

Figure 2: Observed S_a and fitted S_a for North Sea place using ‘fitselex()‘

Plotting with `plotselex()` also provides option `compounds=TRUE` to visualize the different compounds of `selex` fit.

```
plotselex(sel=fit,Sa=Sa,compounds=TRUE)
   Scale for 'x' is already present. Adding another scale for 'x', which will
   replace the existing scale.
   Scale for 'y' is already present. Adding another scale for 'y', which will
   replace the existing scale.
```

In some cases a simplification of the fitted selectivity to an ogive may be desired. `FLSelex` provides this option via the function `as.ogive()`.

```
ogivefit = as.ogive(fit)

plotselex(sel=ogivefit,Sa=Sa)
```

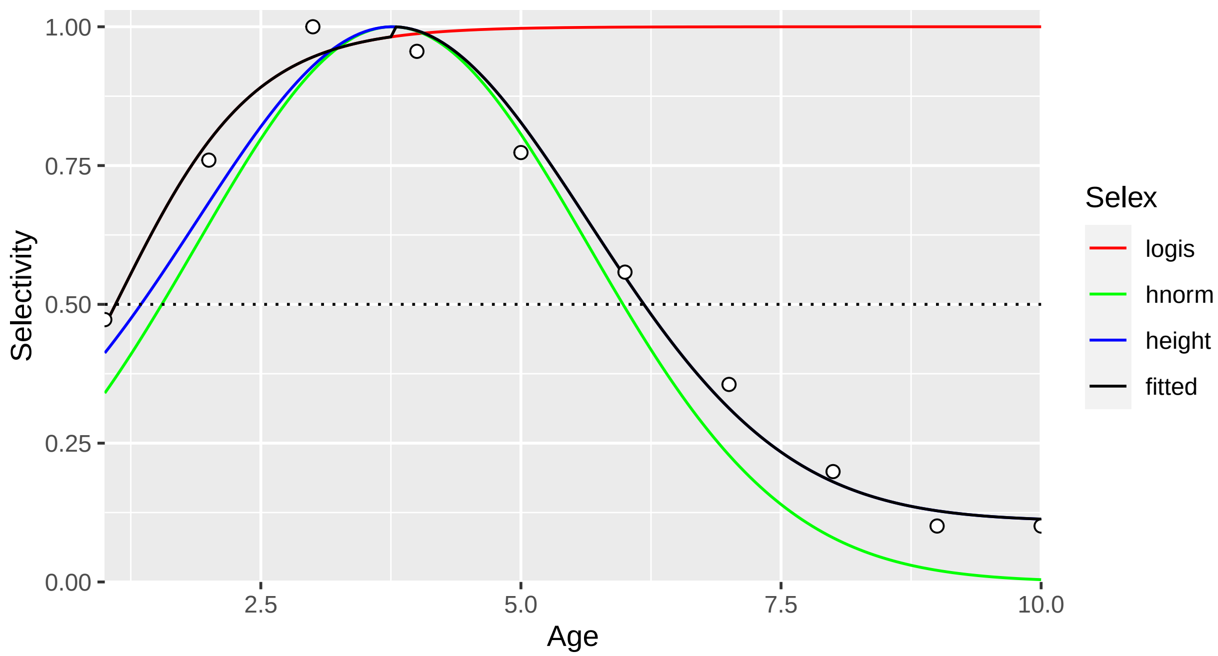

Figure 3: Observed S_a and fitted S_a for North Sea plaice illustrating the compounds of the piece-wise 'selex' function. logis: logistic of acending curve (S_{50}, S_{95}), hnorm: unadjusted halfnormal (S_{max}, D_{cv}) for the descending curve, height: adjusted height of the halfnormal (D_{min})

```
Scale for 'x' is already present. Adding another scale for 'x', which will
replace the existing scale.
Scale for 'y' is already present. Adding another scale for 'y', which will
replace the existing scale.
```

It should be noted, however, that such simplification may drastically change the underlying stock dynamics and is unlikely compatible with expected dynamics from the original assessment and associated advice.

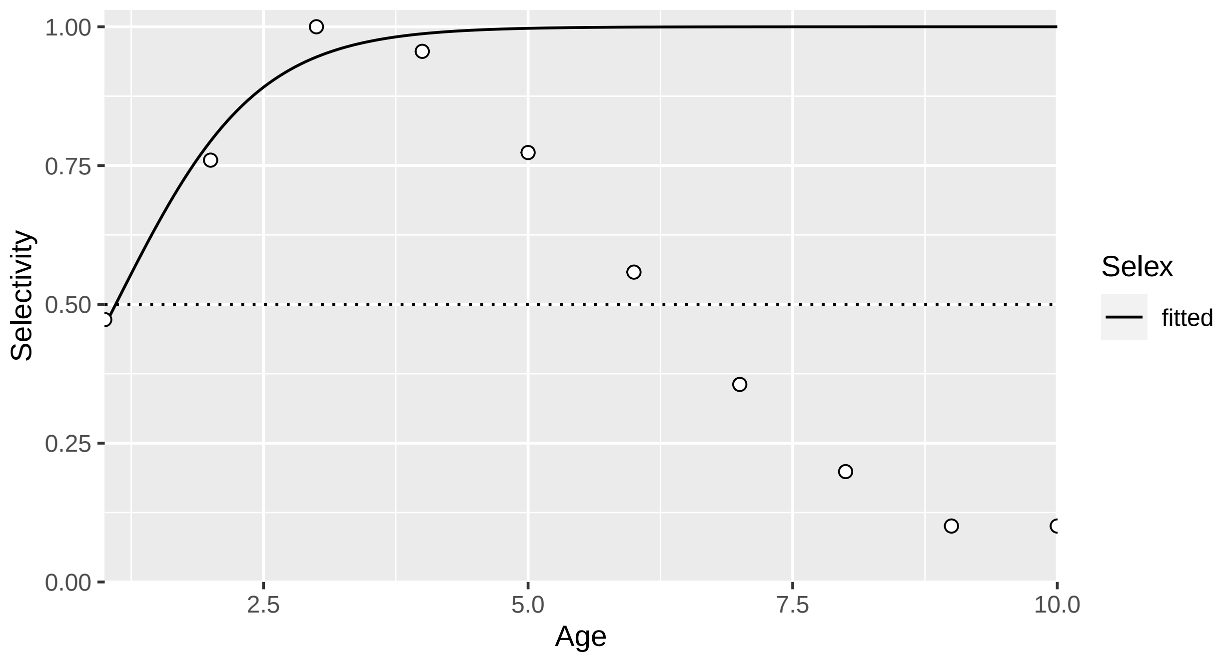

Figure 4: Observed S_a and fitted S_a for North Sea place, assuming a simplified logistic selectivity

1.4 Varying selectivity-at-age

Currently `FLSelex` provides three inbuilt option to vary the estimated `selex` parameters via the function `varselex()`:

1. The option *crank* sequentially changes S_{50}, thereby changing ascending slope of the curve, given an upper bound at S_{95}. This change in selectivity pattern is intended to represent a situation where targeting of young fish can be minimized, e.g. through spatial-temporal closure of nursery grounds or gear through exclusion.

```
crank = varselex(pars=fit$par,stock=ple4,step=0.1,type="crank")

plotselex(sel=crank,Sa=Sa)
```

2. The option *shift* sequentially changes S_{50}, S_{95} and S_{max} thereby shifting the selectivity curve, while retaining the shape unchanged. The default upper bound is to theoretical age at A_{opt} where an unfished cohort attains its maximum biomass (Froese et al. 2008; Froese et al. 2016), which is computed internally by the function `aopt()`. Alternatively, the user has the option to customize the range by specifying `amin` and `amax`.

```
shift = varselex(pars=fit$par,stock=ple4,step=0.1,type="shift")

plotselex(sel=shift,Sa=Sa)
```

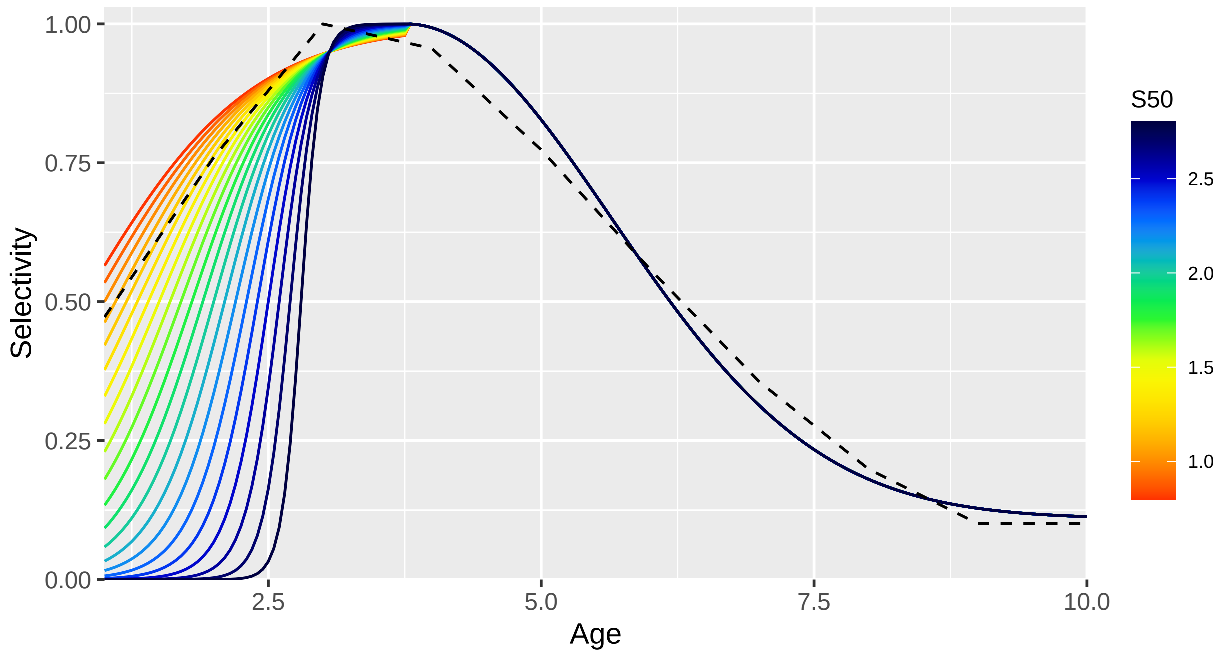

Figure 5: Cranking the ascending slope of the estimated selectivity curve by varying S_{50}

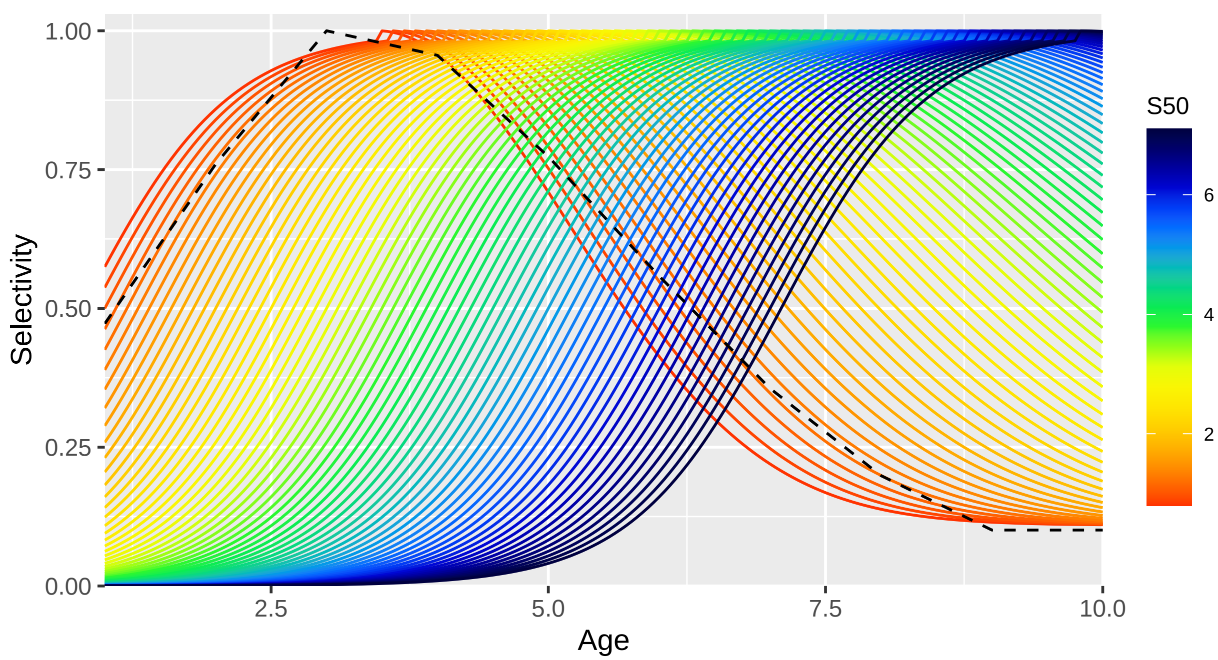

Figure 6: Shifting the estimated selectivity curve in its unchanged shape by varying S_{50}, S_{95} and S_{max}

3. The option *dynamic* dynamically combines *crank* and *shift* by first craking the ascending limb close to S_{95} and shifting the resulting curve towards larger ages. This dynamic change in the selectivity pattern is intended to approximate situations where (1) reduction small specimens in the catch is achieved through larger mesh sizes of active gears, thereby reducing drag associated with higher catchability of larger and faster fish, (2) reduction small specimens in the catch is achieved through a spatial shift in fishing effort to areas with higher densitiy of older fish or (3) some combination of (1) and (2).

```
dyn = varselex(pars=fit$par,stock=ple4,step=0.1,type="dynamic")

plotselex(sel=dyn,Sa=Sa)
```

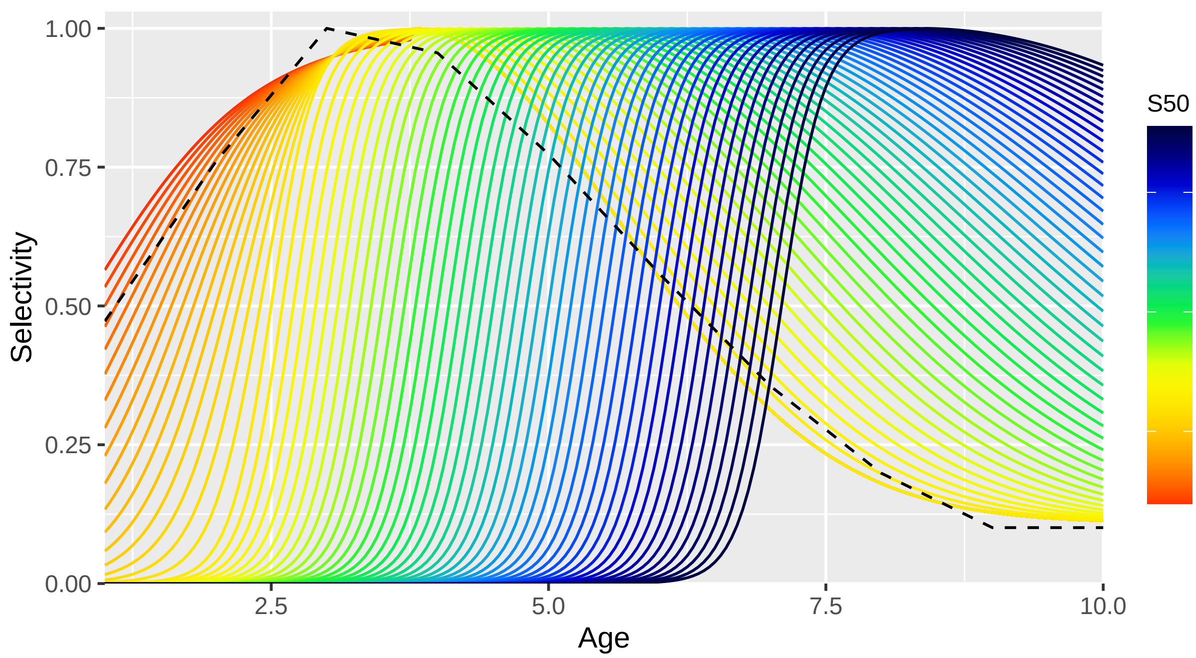

Figure 7: Shifting the estimated selectivity curve in its unchanged shape by varying S_{50}, S_{95} and S_{max}

1.5 Using apical F as a standardized metric for evaluating selectivy

Comparing the impacts of alternative selectivity pattern requires setting the instantaneous rate of fishing mortaly F at comparable constant levels. For this purpose, it is important to consider that the definition of selectivity differs across regions. In Europe, it common to use $\bar{F_y}$ as a measure of annual F, whereas in many other regions (e.g. US West Coast, South Africa, Austrial and New Zealand) the so called apical $F_{apical} = max(F_a)$ is used as a standard metric.

With regards to isolating the selectivity effect, $\bar{F_y}$ has the undesirable property that its scale depends on the pre-specified age range across which F_a is averaged. For example, if $\bar{F_y}$ is set to ages 2-4 to represent the dominant age classes under the current selectivity regime, but the goal is to evaluate the effect of selecting fish only at age-5, a common $\bar{F_y}$ would result in disproportionately high F_a on ages 5+. This is because $\bar{F_y}$ is computed for age ranges that are hardly selected for the definition $S_a = F_a/max(F_a)$ as is used in `FLR`. For this reason, and consistent with previous studies (e.g. Samson and Davies 2011), the F_{apical} is used as F as the standardized quantity to compare stock responses across selectivity pattern in `FLSelex`. To implement this in `FLR`, the $\bar{F_y}$ range determined by `fbarmin` and `fbarmax` is dynamically adjusted in the `FLStock` object to the $max(F_a)$ under each selectivity scenario under equilibrium conditions.

The conversion from the original $\bar{F_y}$ to the age where $F_{apical} = max(F_a)$ is automatically done internally for each selectivity pattern, but can also be called manually:

```
range(ple4)[c("minfbar","maxfbar")]
   minfbar maxfbar
         2       6
test = fbar2f(ple4)
range(test)[c("minfbar","maxfbar")]
   minfbar maxfbar
         3       3
```

1.6 Estimating selectivty effects at equilibrium

The function `brp.selex()` computes reference points and values of SSB, recruitment, yield and catch at equilibrium over a range of F_{apical} for the selectivity parameter output from `varselex()` using the `FLBRP` package.

```
pars = varselex(fit$par,ple4,type="dynamic")

brps = brp.selex(pars,ple4)
   initial  value -28.279390
   final  value -28.279390
   converged

class(brps)
   [1] "FLBRPs"
   attr(,"package")
   [1] "FLBRP"
```

An important to note feature of `FLBRP` is that it currently bases yield estimates on landings only and not on the total catch including discards. To include discards in the equilibrium computation `brp.selex()` therefore internally set `landings` = `catch` and `discards` to 0 using the function `allcatch()`.

As a default option a the stock recruitment function is fitted with `model="geomean` and therefore effectively produces relative per-recruit results that acount for growth over-fishing but ignore recruitment over-fishing.

The results can then be visualized using `ploteqselex` and

```
ploteqselex(brps)
```

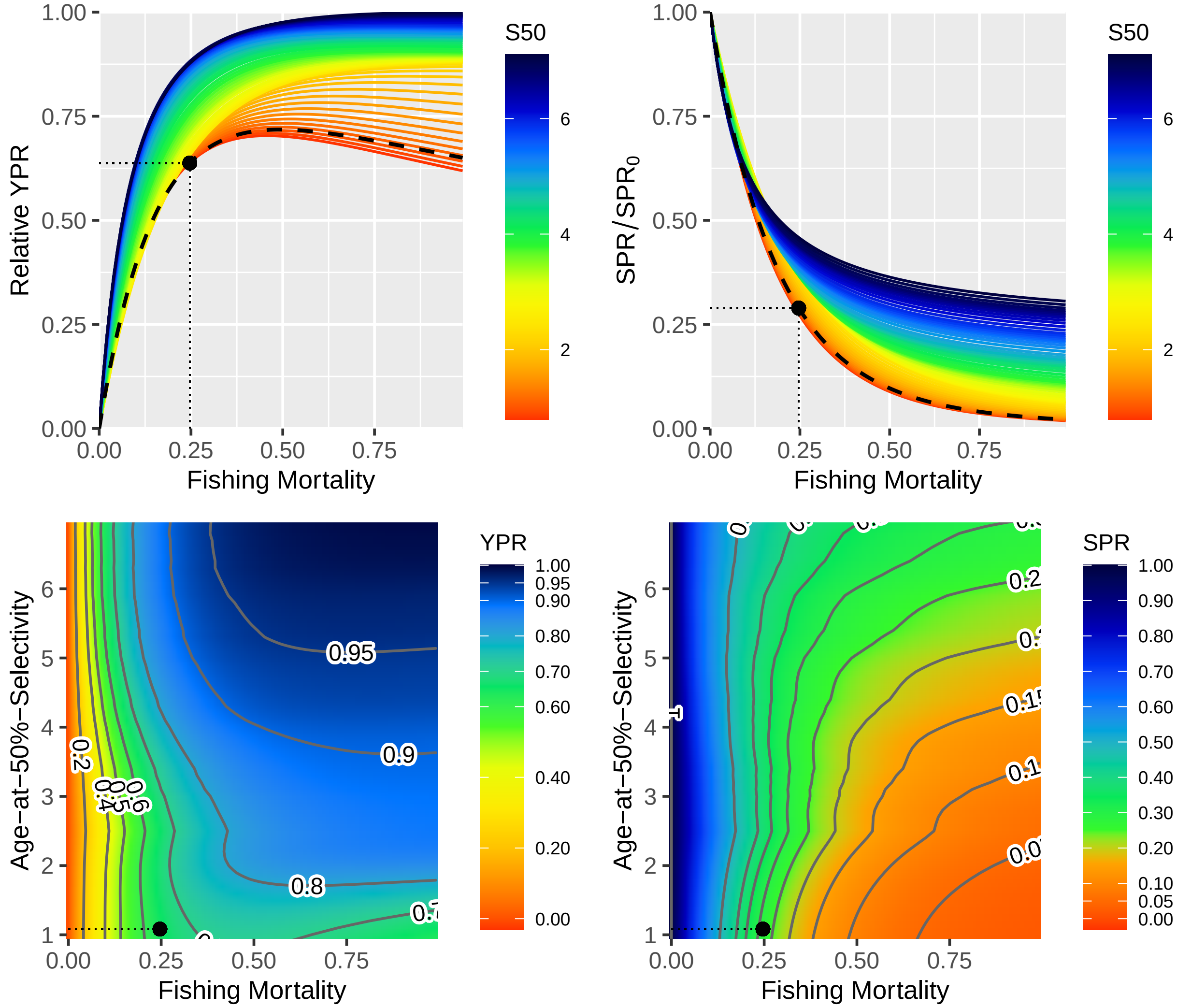

Figure 8: Plots showing the trade-offs between S_50 and F with respect to relative yield-per-recruit and the spawning ratio potential (SPR, or spawning biomass per recruit). Dashed lines connecting at solid black dots denote the expected outcome of current F and S_a at equilibrium

In addition, `brp.selex` provides the option to evaluate potential recruitment overfishing by incorporating a stock-recruitment relationship (SRR). For this example, a simple Beverton-Holt model is fitted using `fmle()` in from `FLR`

```
sr = as.FLSR(ple4,model=bevholt)
bh = fmle(sr)
     Nelder-Mead direct search function minimizer
   function value for initial parameters = -20.097169
     Scaled convergence tolerance is 2.99471e-07
   Stepsize computed as 137684.750000
   BUILD              3 -8.128215 -24.570205
   REFLECTION         5 -20.097169 -28.014520
   LO-REDUCTION       7 -24.570205 -28.280012
   HI-REDUCTION       9 -27.975891 -28.280012
   HI-REDUCTION      11 -28.014520 -28.575314
   LO-REDUCTION      13 -28.280012 -28.575314
   HI-REDUCTION      15 -28.497149 -28.575314
   HI-REDUCTION      17 -28.516345 -28.575314
   EXTENSION         19 -28.542557 -28.640725
   EXTENSION         21 -28.575314 -28.712927
   EXTENSION         23 -28.640725 -28.787001
   LO-REDUCTION      25 -28.712927 -28.809723
   HI-REDUCTION      27 -28.786104 -28.809723
   HI-REDUCTION      29 -28.787001 -28.809723
   HI-REDUCTION      31 -28.805559 -28.809723
   REFLECTION        33 -28.807849 -28.811169
   HI-REDUCTION      35 -28.809723 -28.812621
   HI-REDUCTION      37 -28.811169 -28.812735
   HI-REDUCTION      39 -28.812621 -28.812756
   HI-REDUCTION      41 -28.812735 -28.813113
   HI-REDUCTION      43 -28.812756 -28.813113
   LO-REDUCTION      45 -28.813080 -28.813124
   HI-REDUCTION      47 -28.813113 -28.813152
   HI-REDUCTION      49 -28.813124 -28.813156
   HI-REDUCTION      51 -28.813152 -28.813156
   HI-REDUCTION      53 -28.813152 -28.813159
   LO-REDUCTION      55 -28.813156 -28.813159
   HI-REDUCTION      57 -28.813159 -28.813160
   HI-REDUCTION      59 -28.813159 -28.813160
   HI-REDUCTION      61 -28.813160 -28.813161
   LO-REDUCTION      63 -28.813160 -28.813161
   Exiting from Nelder Mead minimizer
       65 function evaluations used
plot(FLSRs(bh))+theme(legend.position = "right")
```

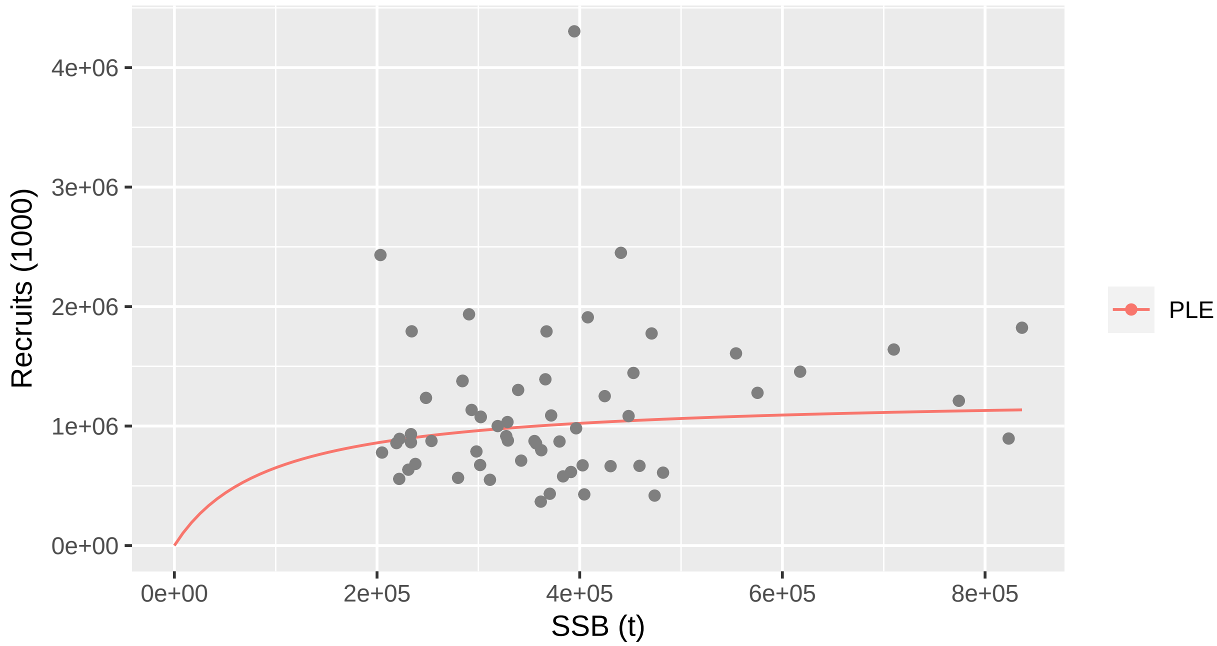

Figure 9: Fit of a Beverholt Model to the spawing stock biomass and recruitment estimates for North Sea plaice

The function `brp.selex()` can now be updated with the SRR and the effect visualized with `ploteqselex()`

```
brps.sr = brp.selex(pars,ple4,sr=bh)
ploteqselex(brps.sr)
```

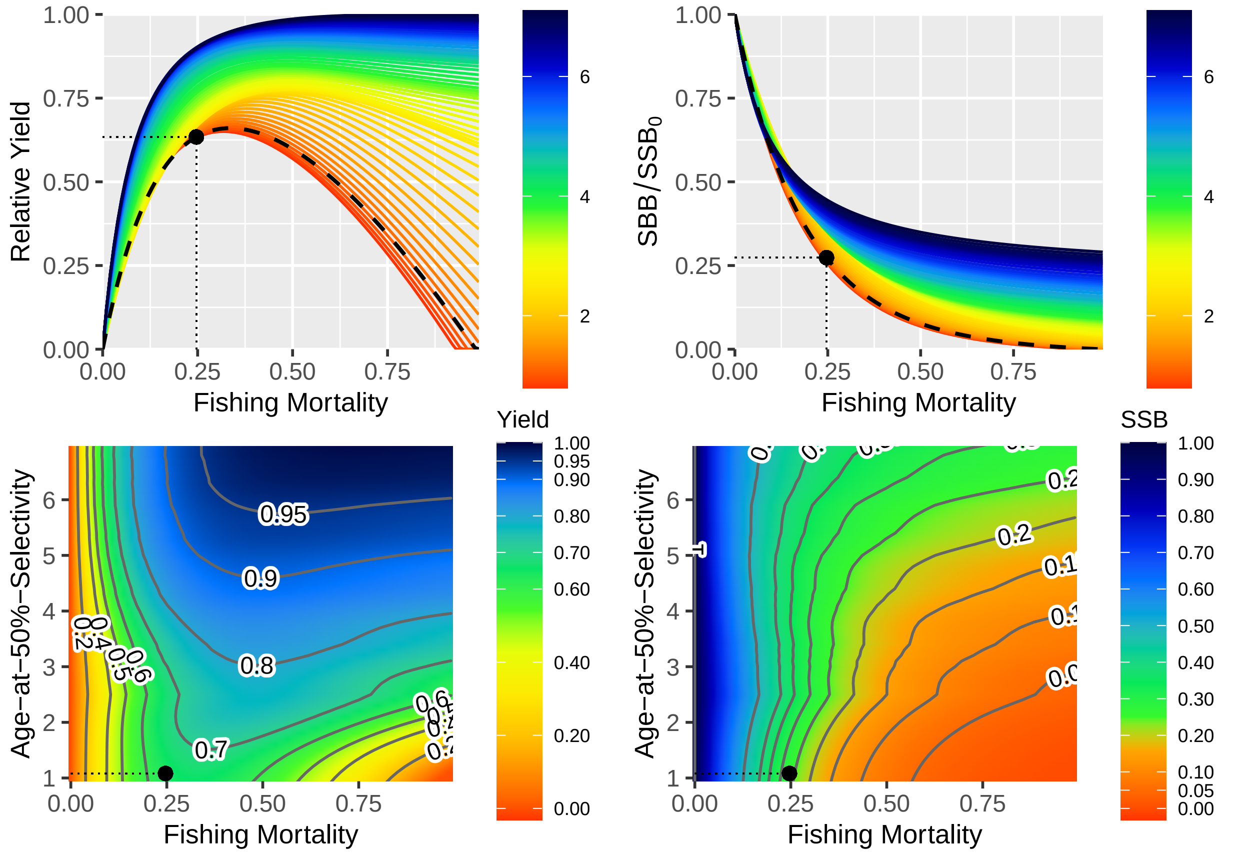

Figure 10: Plots showing the trade-offs between S_50 and F with respect to relative yield and and SSB based on a Beverton-Holt SSR. Dashed lines connecting at solid black dots denote the expected outcome of current F and S_a at equilibrium

An additional plotting function is `plotFselex()`. In the absence of a SRR, `plotFselex()` illustrates relative changes in YPR and SPR as function of a selected `Fref`, which is by default the average F over the three years. If a SSR is provided relative changes are representative of total yield and SSB

```
p1=plotFselex(brps,what="Fref")+ggtitle("Per-Recruit")
p2=plotFselex(brps.sr,what="Fref")+ggtitle("Beverton-Holt SRR")
gridExtra::grid.arrange(p1,p2,ncol=1)
```

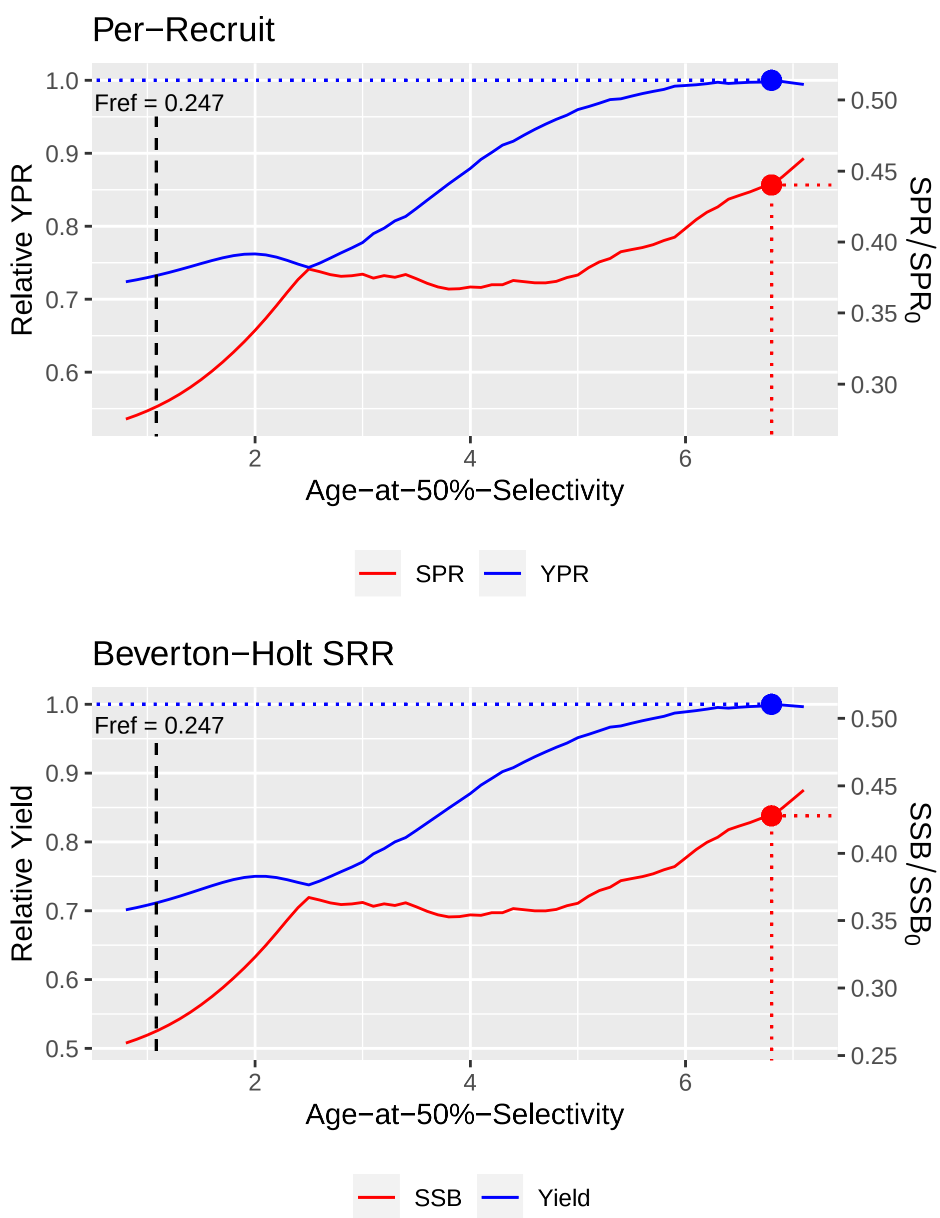

Figure 11: Plots showing relative changes in (top) YPR and SPR and (bottom) yield and SSB over range of $S50$ values under the current F

1.7 Forecasting with FLSelex

Forecasting over a range of selectivity pattern is conducted with `FLasher` using the function `selex.fwd()`. All forecasts assume deterministic recruitment, so at long-term forecasts are equivalent to the equilibrium estimates from `selex.brp`. While forecasting is computational more demanding as thus limited to a specified F value (default F_{cur}), it provides the increased flexible for computing additional quantities of interest from the output in the form of a `FLStocks` objects. Currently, two additional quantities are computed routinely: (1) Harvest rate as a direct indicator for relative fishing effort and (2) percentage juveniles in the catches.

For the relationship between fishing effort and harvest rate consider the central relationship between catch (C), effort (E), the biomass that vulnerable to the fishery (V_B) and catchability (q):

$$C = qEV_B$$

with harvest rate is defined as

$$H = C/V_B$$

Substituting H, it follows that

$$H = qE$$

If q is assumed constant, then H is linear proportional to E.

The percentage of juveniles in the catches is computed as ratio of the number immature to the total number of fish in the catch.

Like `brp.select`, `selex.fwd()` enables the inclusion of a SRR. In the following example the projection horizon is set to 30 years, and the projection are conducted with default option for F_{cur} (mean average apical F across the 3 most recent years).

```
bt = selex.fwd(pars,ple4,sr=bh,fyears=30)
plotprjselex(bt)
```

1.8 Backtesting with FLSelex

A backtest is a form of hindcasting and allows the impact of a management strategy to be evaluated as if it had actually been used in the past. In contrast to forecasting, backtests require no assumptions about stochasticity in the population as variations in, e.g. recruitment, M_a or W_a prescriped as estimated from the data. Like `selex.fwd`, `selex.backtest` is implemented with `FLasher` and produces an `FLStocks` object as output. In the following example, the backtest is conducted without specifying a SSR.

```
bt = selex.backtest(pars,ple4,byears=10)
   initial  value -28.279390
   final  value -28.279390
   converged
plotprjselex(bt)
```

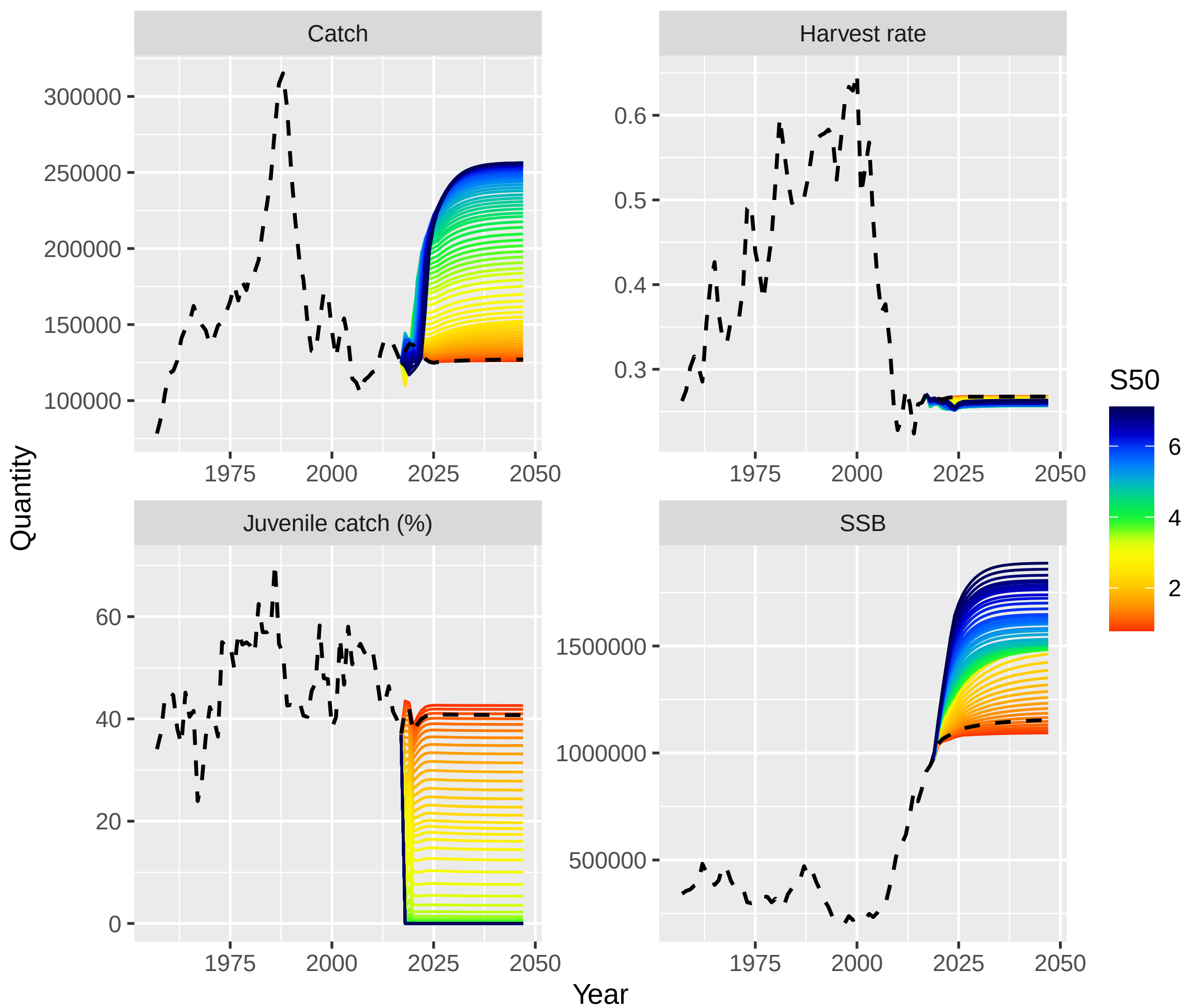

Figure 12: Plots showing the responses of Catch, Harvest Rate, Percentage of juveniles in the catch and SSB to changes in selectivity for determistic future forecasts over 30 years

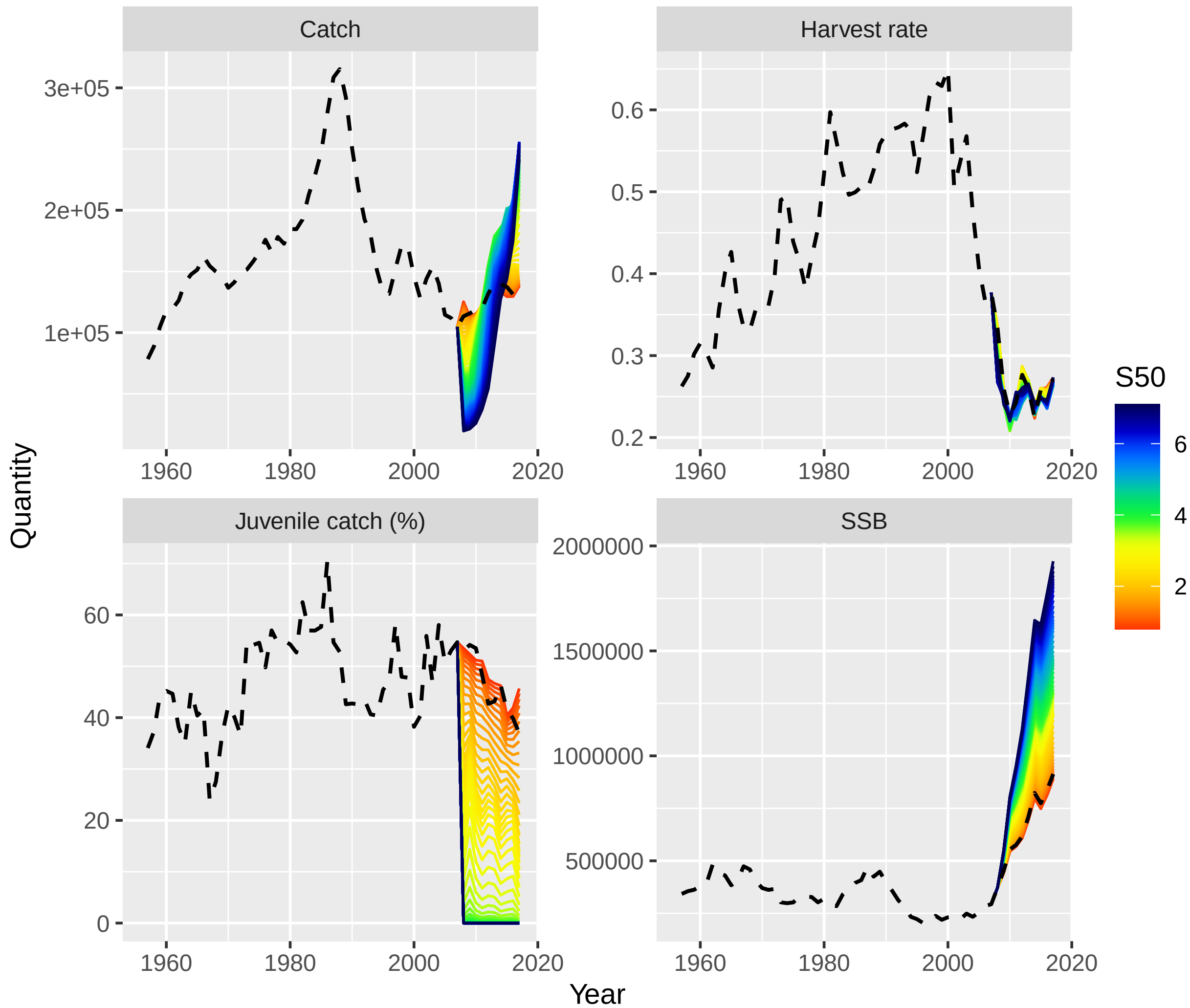

Figure 13: Plots showing the responses of Catch, Harvest Rate, Percentage of juveniles in the catch and SSB to changes in selectivity if they had actually been implemeted in 2009

1.9 References

- Froese, R., Stern-Pirlot, A., Winker, H., and Gascuel, D. 2008. Size matters: How single-species management can contribute to ecosystem-based fisheries management. Fisheries Research, 92: 231–241.
- Froese, R., Winker, H., Gascuel, D., Sumaila, U. R., and Pauly, D. 2016. Minimizing the impact of fishing. Fish and Fisheries, 17.
- Sampson, D. B., and Scott, R. D. 2011. A spatial model for fishery age-selection at the population level. Canadian Journal of Fisheries and Aquatic Sciences, 68: 1077–1086.