

User Guide: Selectivity Analysis with FLSelex in FLR

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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 github 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 as 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 2.6.16.9002, packaged: 2021-08-13 11:49:48 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: Can save you from what has begun!
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
  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

```

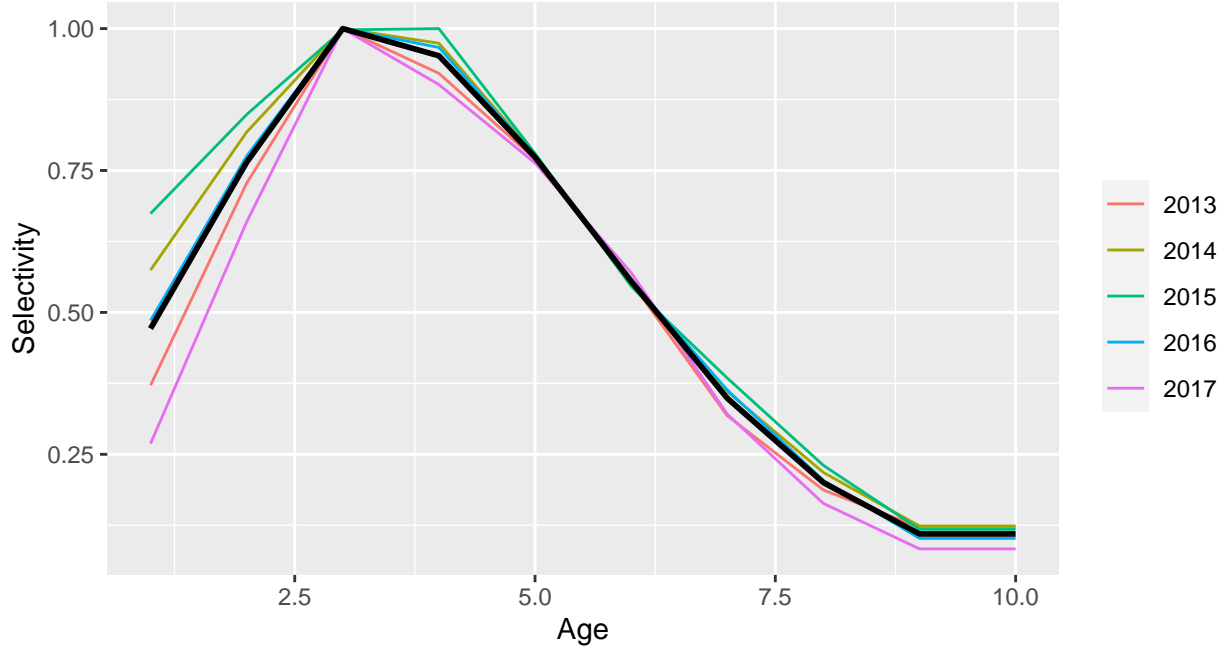


Figure 1: Observed $S_a = F_a/F_{max}$ for North Sea place over the recent 5 years

1.3 The Selex function

A variety 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 variety of selectivity curves, **FLSelex** provides a flexible 5-parameter parametric **selex()** function, which comprises the following three compouds:

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 minimum 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 S_a is done optim optimization with `fitselex()`

```
Sa = selage(ple4, nyears = 3)
fit = fitselex(Sa)
plotselex(pars = fit, Sa = Sa)
```

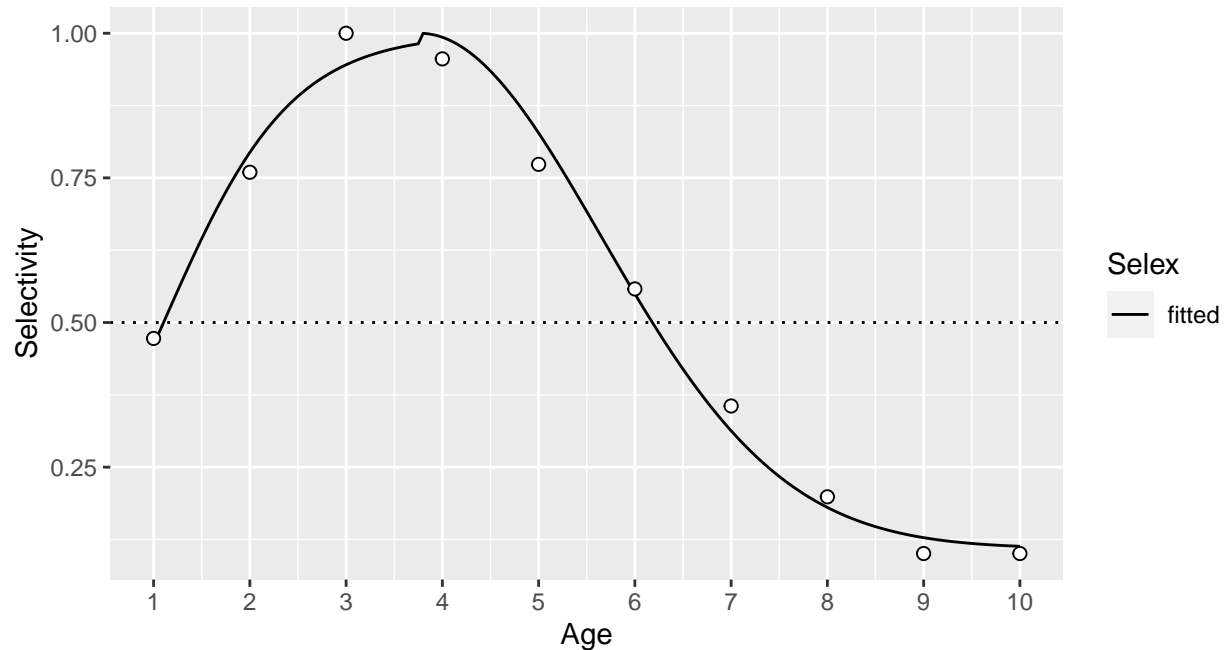


Figure 2: Observed S_a and fitted S_a for North Sea plaice using ‘`fitselex()`’

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

```
plotselex(pars = fit, Sa = Sa, compounds = TRUE)
```

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(pars = ogivefit, Sa = Sa)
```

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.

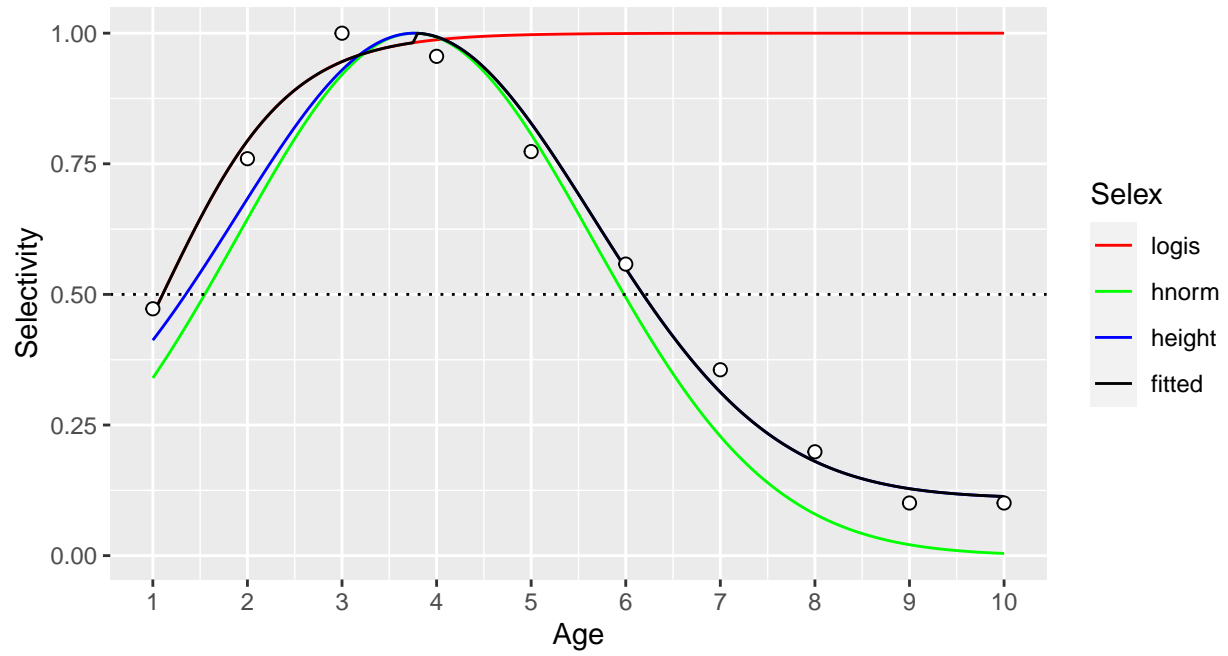


Figure 3: Observed S_a and fitted S_a for North Sea plaice illustrating the compounds of the piece-wise 'selex' function. logis: logistic of ascending curve (S_{50} , S_{95}), hnrm: unadjusted halfnormal (S_{max} , D_{cv}) for the descending curve, height: adjusted height of the halfnormal (D_{min})

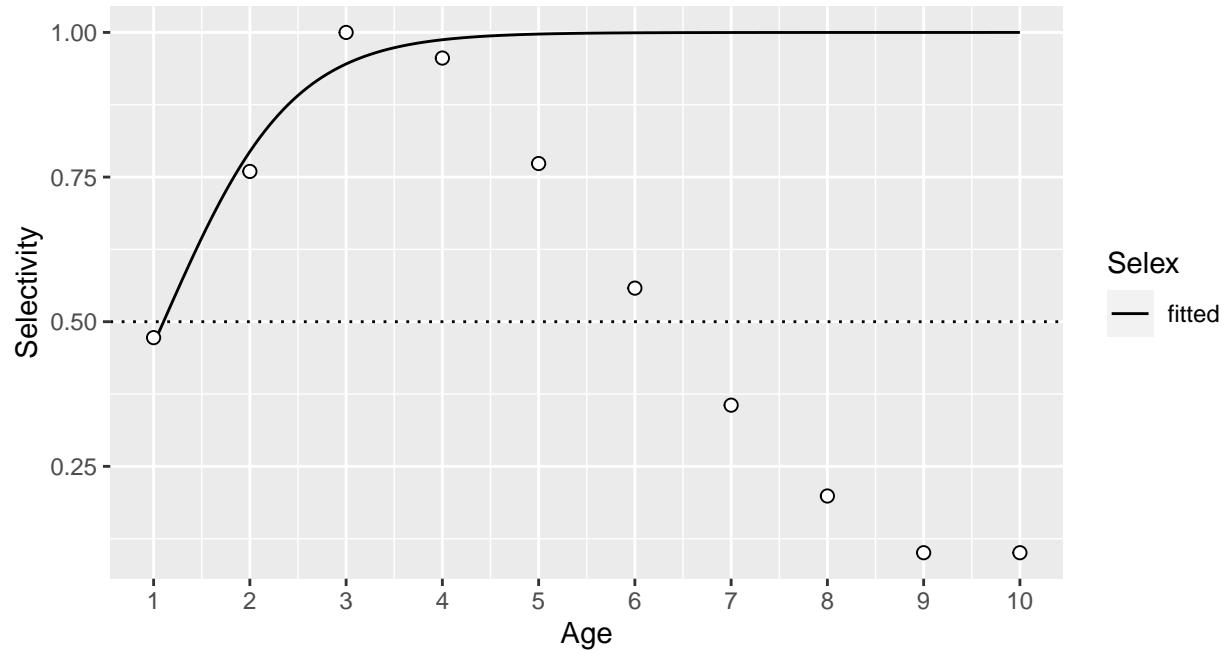


Figure 4: Observed S_a and fitted S_a for North Sea plaice, assuming a simplified logistic selectivity

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(pars = crank, Sa = Sa)
```

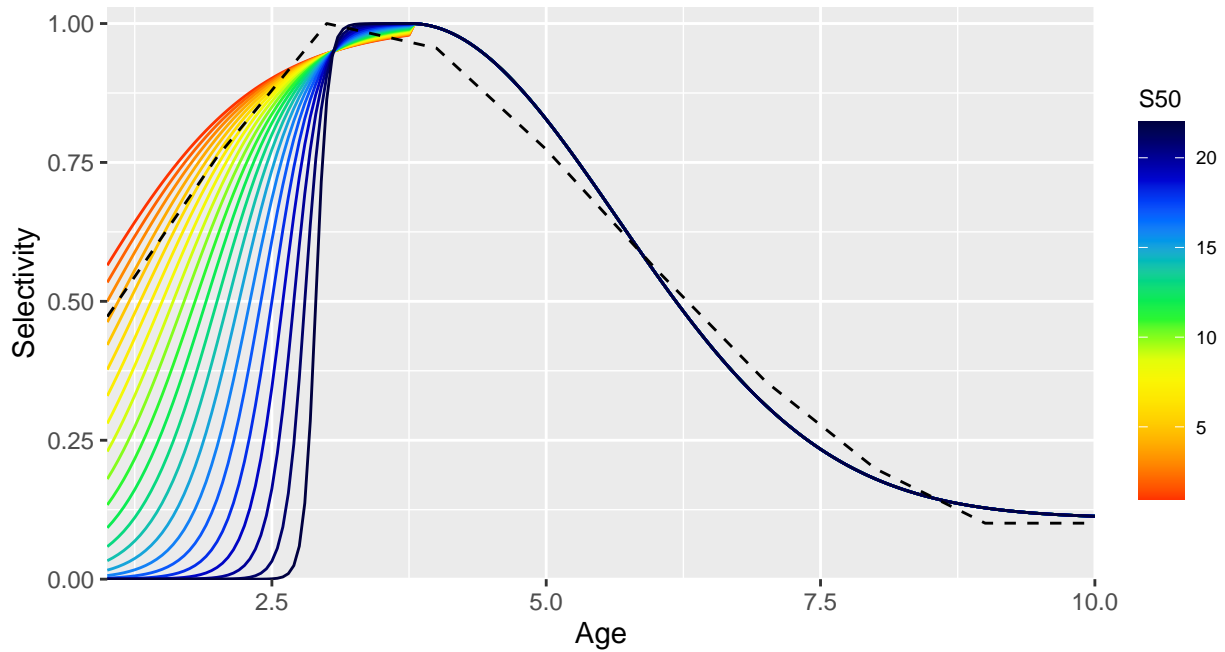


Figure 5: Cranking the ascending slope of the estimated selectivity curve by varying S_{50}

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(pars = shift, Sa = Sa)
```

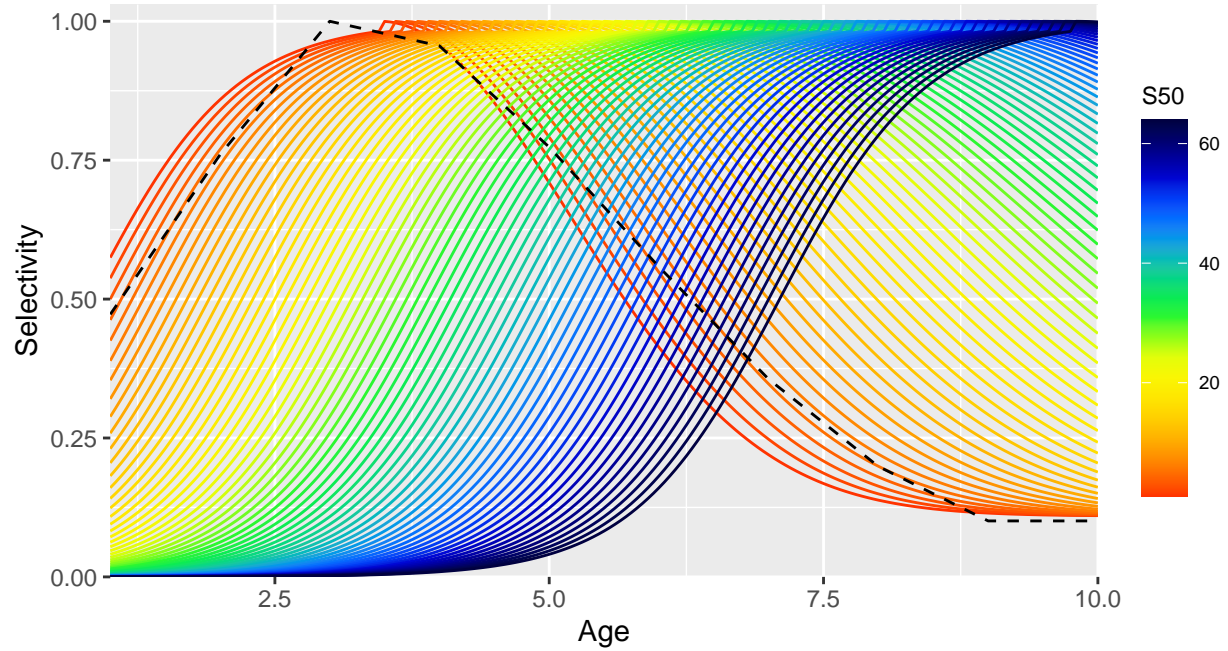


Figure 6: Shifting the estimated selectivity curve in its unchanged shape by varying S_{50} , S_{95} and S_{max}

3. The option *dynamic* dynamically combines *crank* and *shift* by first cranking 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 density of older fish or (3) some combination of (1) and (2).

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

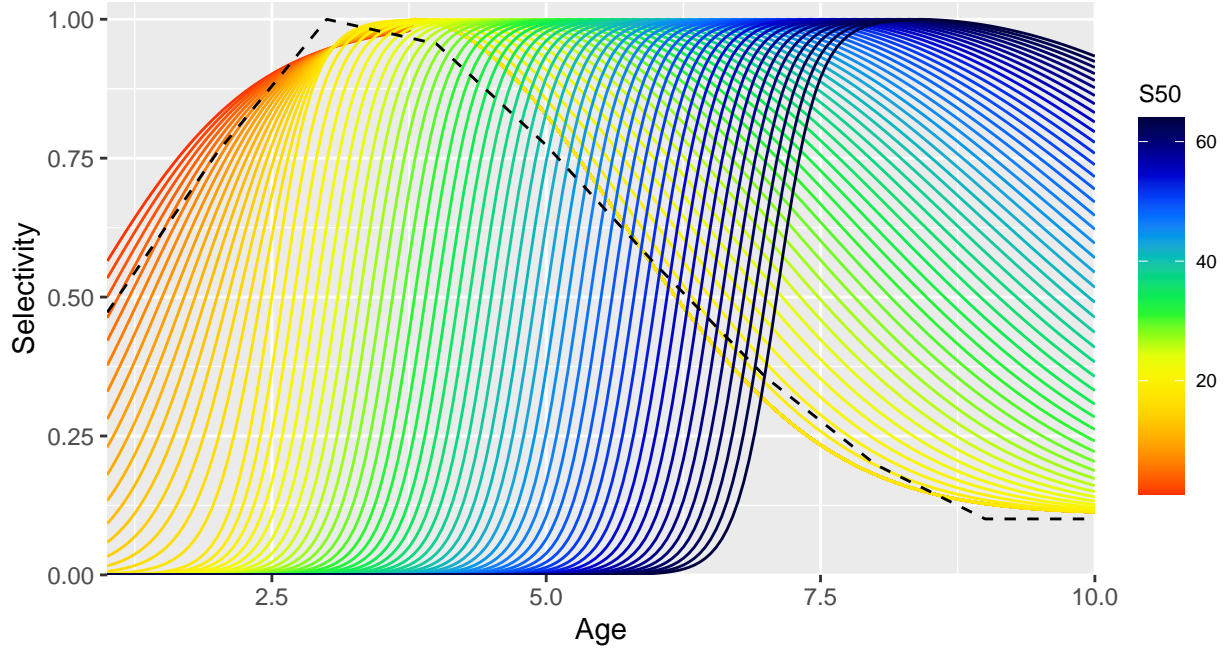


Figure 7: Shifting the estimated selectivity curve in its unchanged shape by varying S_{50} , S_{95} and S_{max}

1.5 Using apical F as a standardized metric for evaluating selectivity

Comparing the impacts of alternative selectivity pattern requires setting the instantaneous rate of fishing mortality 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.

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()`

```
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"
```

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

The results can then be visualized using `ploteqselex` and

```
ploteqselex(brps)
```

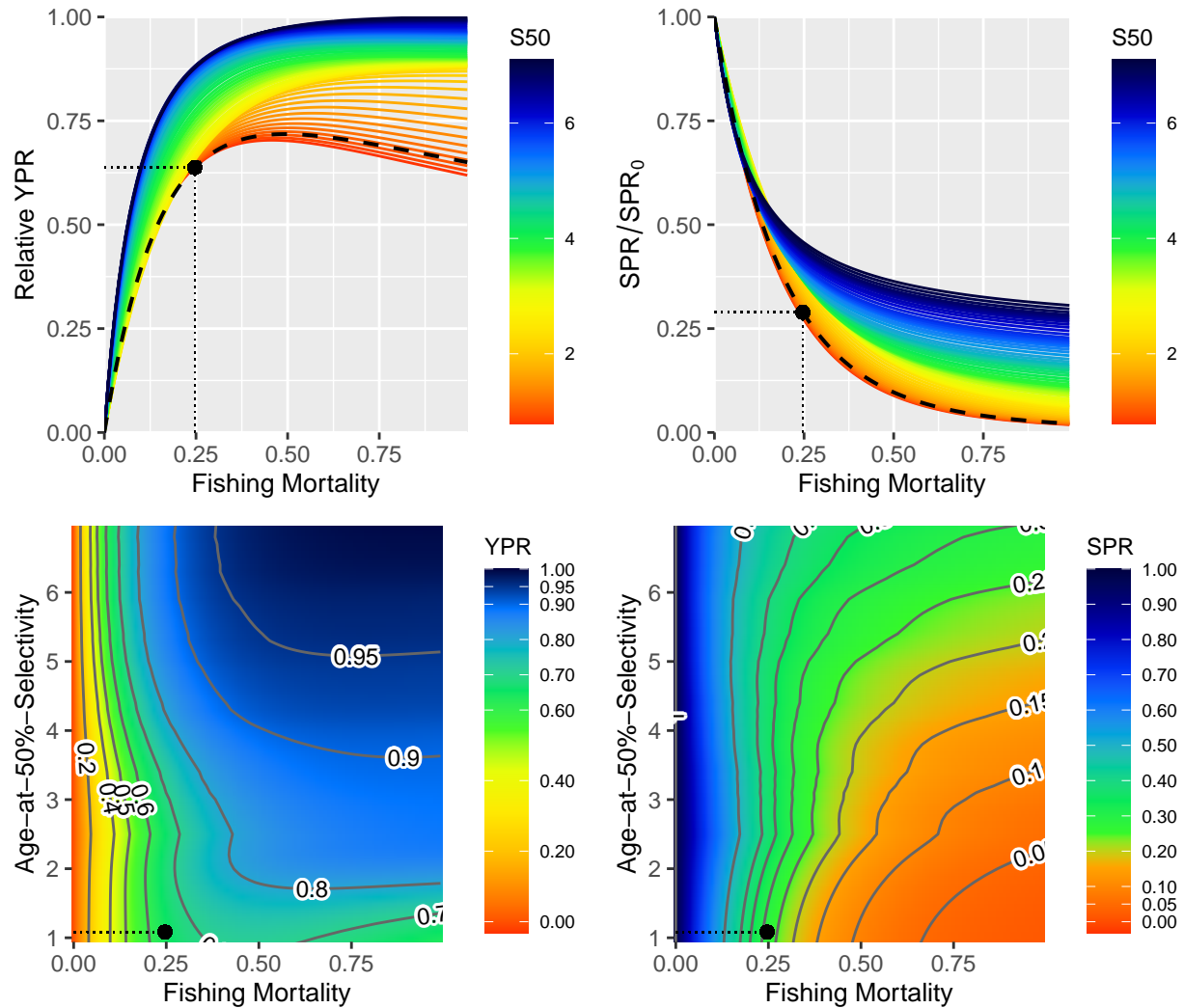


Figure 8: Plots showing the trade-offs between S_{50} and F with respect to relative yield-per-recruit and the spawning ratio potential (SPR, or spawning biomass per recruit). Dashed lines connecting at solid black dots denote the expected outcome of current F and S_a at equilibrium

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")
```

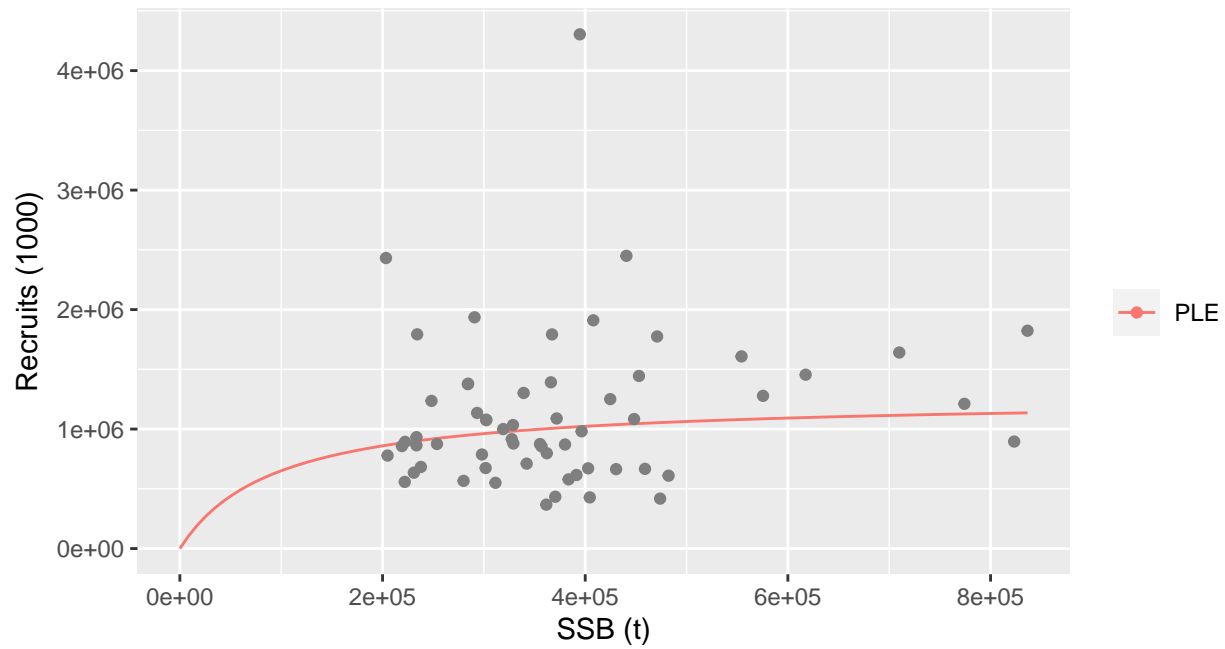


Figure 9: Fit of a Beverholt Model to the spawning stock biomass and recruitment estimates for North Sea plaice

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)
```

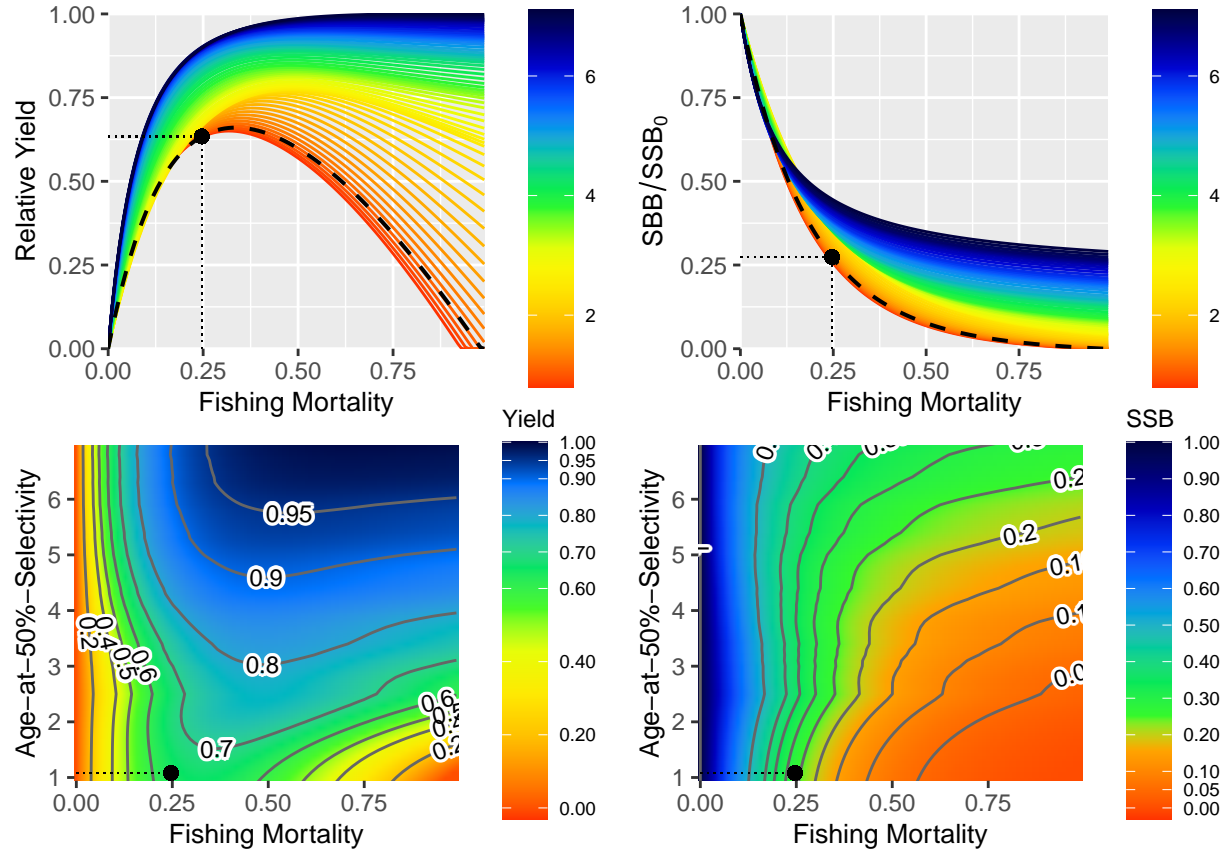


Figure 10: Plots showing the trade-offs between S_{50} and F with respect to relative yield and and SSB based on a Beverton-Holt SSR. Dashed lines connecting at solid black dots denote the expected outcome of current F and S_a at equilibrium

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 F_{ref} , which is by default the average F over the three years. If a SRR 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)
```

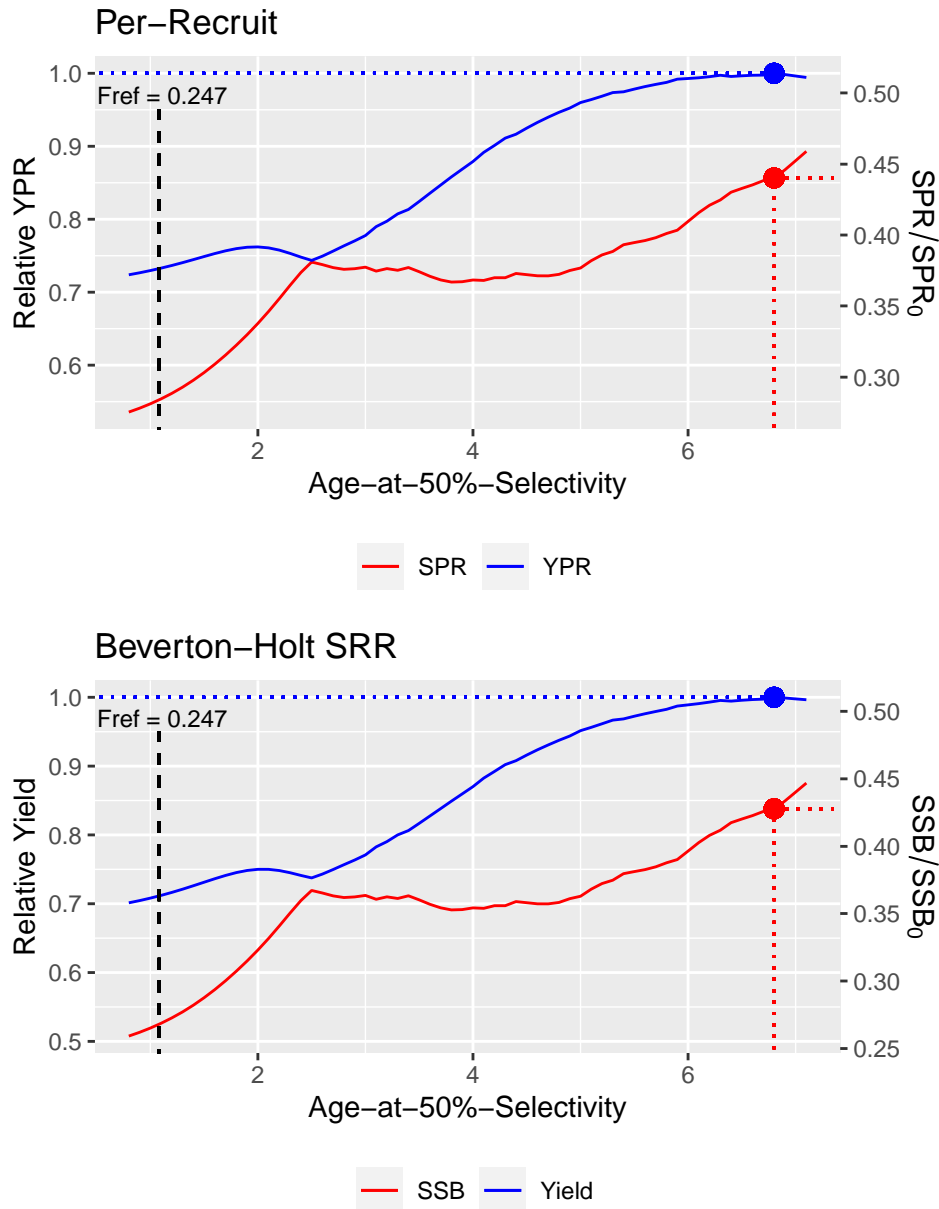


Figure 11: Plots showing relative changes in (top) YPR and SPR and (bottom) yield and SSB over range of S_{50} values under the current F

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 prescribed 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)
```

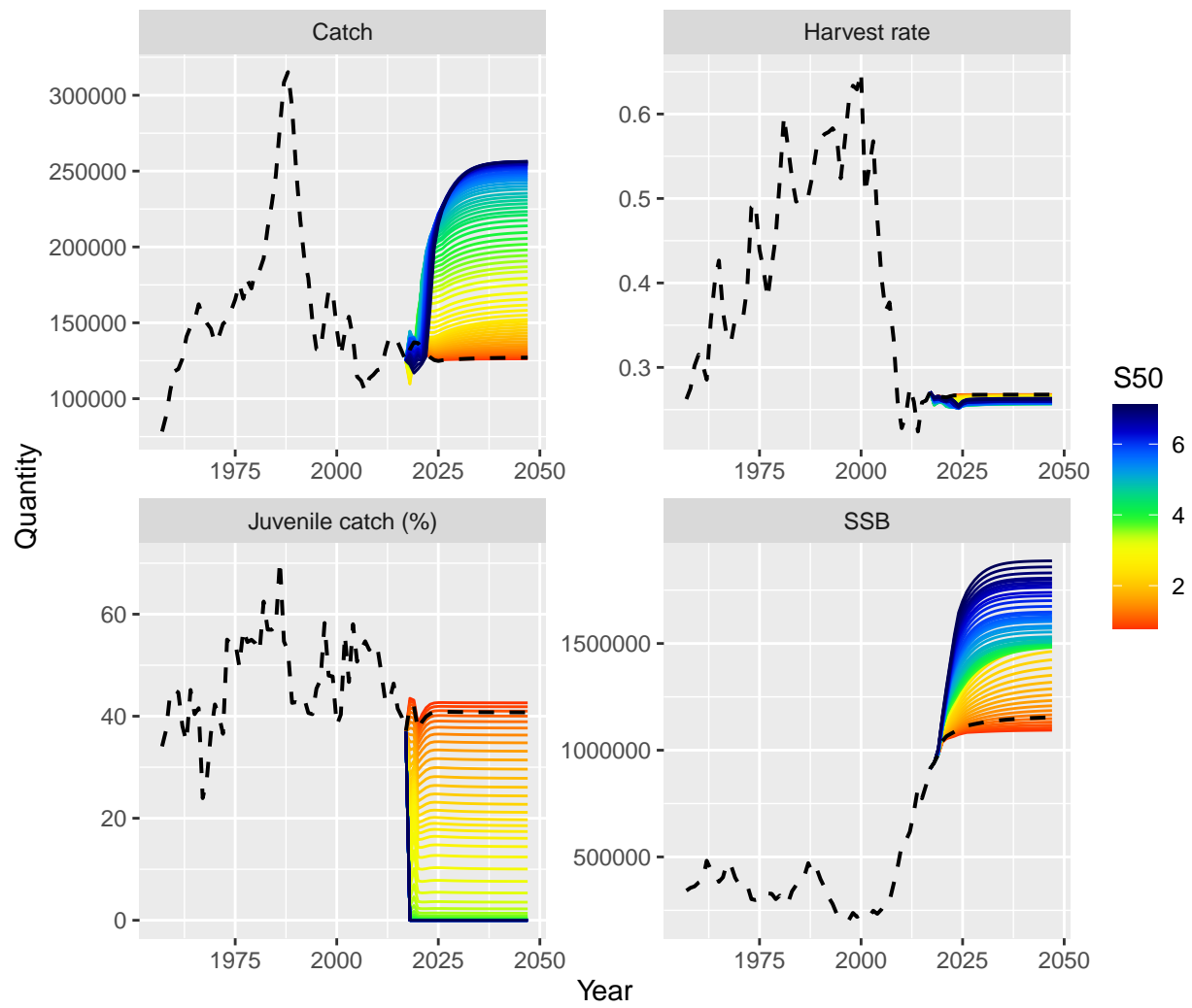


Figure 12: Plots showing the responses of Catch, Harvest Rate, Percentage of juveniles in the catch and SSB to changes in selectivity for deterministic future forecasts over 30 years

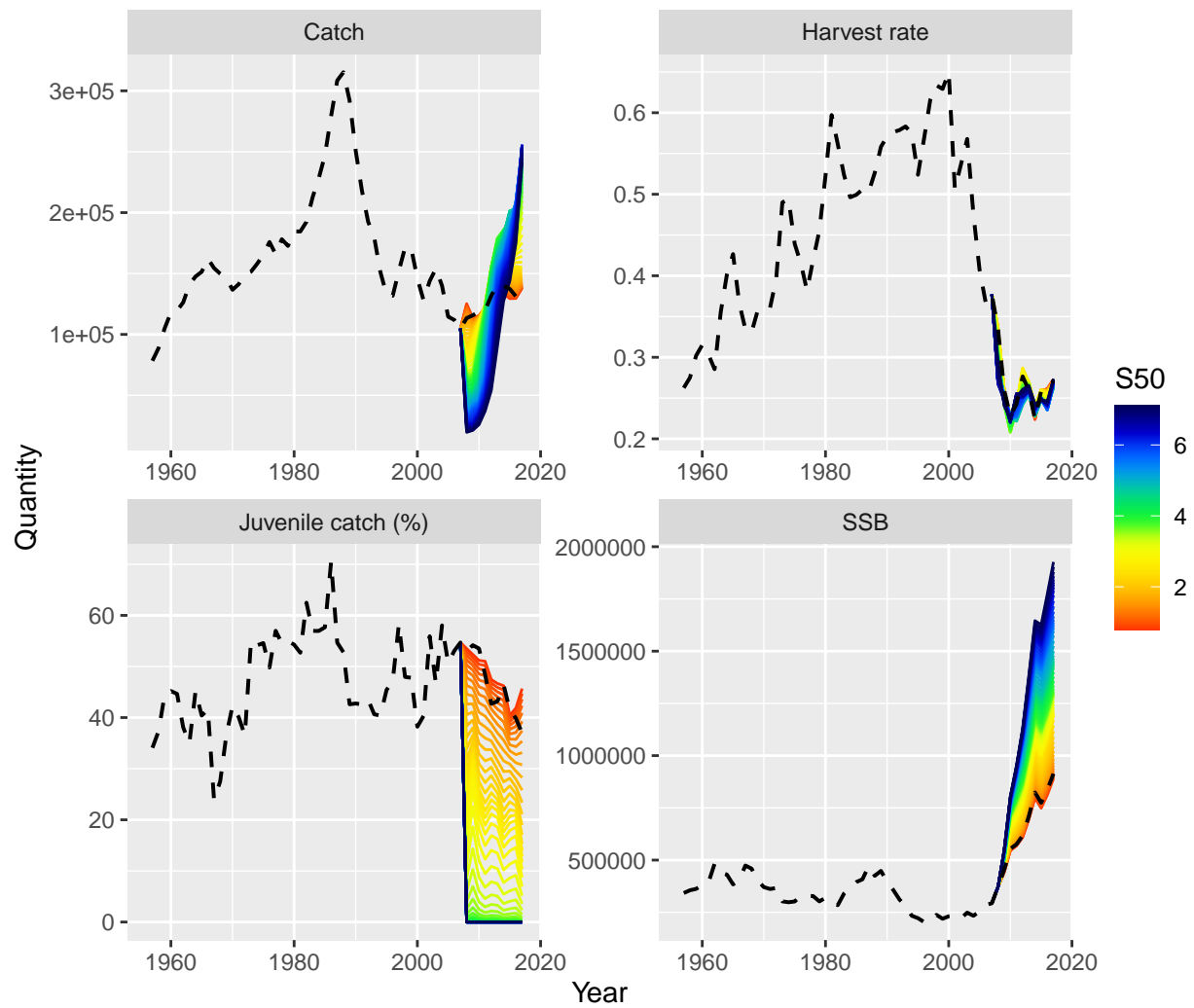


Figure 13: Plots showing the responses of Catch, Harvest Rate, Percentage of juveniles in the catch and SSB to changes in selectivity if they had actually been implemented in 2009

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.