Modelling Stock-Recruitment with FLSR

08 March, 2017

FLSR is a S4 class for Stock-Recruitment (SR) models, an extension of *FLModel* , and part of the *FLCore* package. Commonly used or custom-tailored SR models can be fitted directly on *FLStock* objects and provide estimates of uncertainty. *FLSR* class objects can be then used to visualize the fitted models, in calculations of biological reference points using *FLBPR* or when performing stock projections.

Required packages

To follow this tutorial you should have installed the following packages:

- CRAN: ggplot2
- FLR: FLCore, ggplotFL

You can do so as follows,

```
install.packages(c("ggplot2"))
install.packages(c("FLCore"), repos = "http://flr-project.org/R")
install.packages(c("ggplotFL"), repos = "http://flr-project.org/R")
```

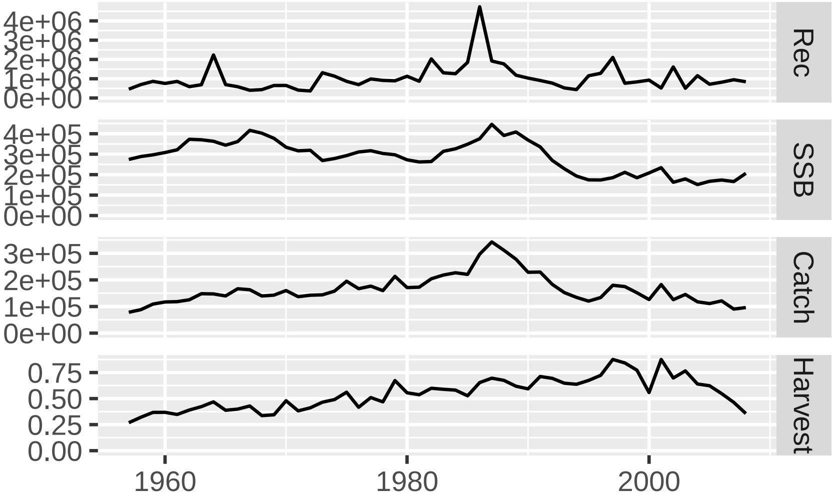
Initially, the libraries need to be called.

```
# This chunk loads all necessary packages,
# trims pkg messages
library(FLCore)
library(ggplotFL)
```

And then the user can load and visualize the results of an assessment (VPA) already performed and stored in the ple4 *FLStock* object.

```
# This chunk loads the ple4 FLStock object
data(ple4)
```

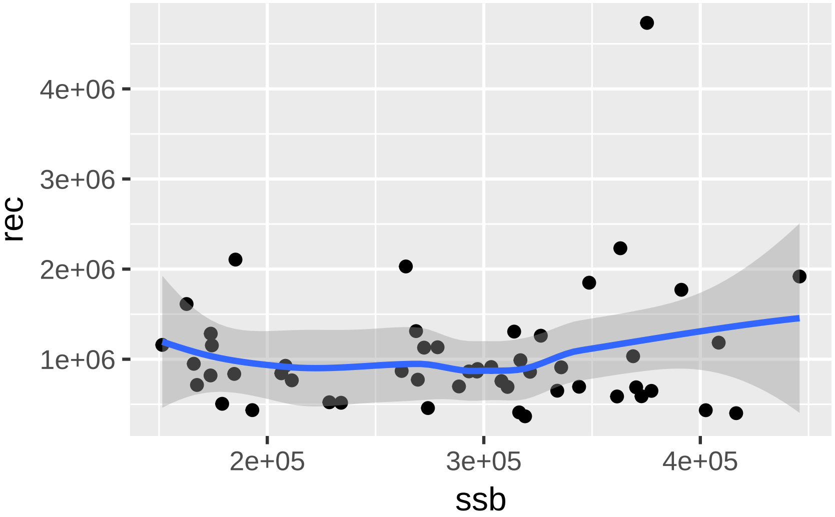
```
# This chunk plots the assesment output
plot(ple4)
```



The Stock-Recruitment (SR) relationship

Given that recruitment and spawning stock biomass (SSB) are provided as an output of the assessment, their relationship can be visualized simply by ploting the recruits against the SSB.

```
# This chunk plots the SSB-Recruits graph
# plot(FLQuants(ple4, 'ssb', 'rec'))
ggplot(aes(ssb, rec), data = model.frame(FLQuants(ple4,
    "ssb", "rec"))) + geom_point() + geom_smooth()
```



Working with FLSR objects

An empty *FLSR* object can be directly created simply by:

```
# This chunk creates an empty FLSR object
sr1 <- FLSR()
```

An *FLSR* object can be also be created from converting directly an *FLStock* object:

```
# This chunk converts an FLStock object into
# an FLSR object
p4sr <- as.FLSR(ple4)
```

The contents of the *FLSR* object are the following:

```
# This chunk outputs the summary of the FLSR
# object
summary(p4sr)
```

```
An object of class "FLSR"

Name: Plaice in IV
Description: 'rec' and 'ssb' slots obtained from a ' [...]
Quant: age
Dims:  age  year    unit    season  area    iter
    1   51  1   1   1   1

Range:  min minyear max maxyear
    1   1958    1   2008

rec           : [ 1 51 1 1 1 1 ], units =  10^3
ssb           : [ 1 51 1 1 1 1 ], units =  kg
residuals     : [ 1 51 1 1 1 1 ], units =  NA
fitted        : [ 1 51 1 1 1 1 ], units =  10^3

Model:  list()
<environment: 0xa7c9130>
Parameters:
    params
iter
   1

Log-likelihood:  NA(NA)
Variance-covariance: <0 x 0 matrix>
```

In the case of ple4 data, recruits are fish of age=1. Hence, the lag between ssb and rec is also 1 year. The starting year for SSB is 1957, whereas for recruits it is 1958.

```
# This chunk outputs the contents of the rec
# and ssb slots of the FLSR object
ssb(p4sr)[, 1]
```

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

     year
age   1957
  all 274205

units:  kg
```

```
rec(p4sr)[, 1]
```

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

   year
age 1958
  1 698110

units:  10^3
```

The default recruitment age in FLSR is age=1. However, the user can change this by triming the *FLStock* object while converting it into an *FLSR* object:

```
# This chunk shows how to set a different
# recruitment age than the default, e.g. set
# the recruitment age at age=2 this can be
# done by trimming the FLStock object as
# follows
p4sr2 <- as.FLSR(ple4[-1])
```

In this case, the lag between ssb and rec is 2 years. The starting year for SSB is 1957, whereas for recruits it is 1959.

```
# Note the shift in years, reflecting that
# recruitment is now at age 2
ssb(p4sr2)[, 1]
```

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

```
     year
age   1957
  all 274205

units:  kg
```

```
rec(p4sr2)[, 1]
```

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

   year
age 1959
  2 568706

units:  10^3
```

Fitting a SR model

To fit a SR model a series of commonly-used stock-recruitment models are already available, including the corresponding likelihood functions and calculation of initial values. See SRModels for more details and the exact formulation implemented for each of them. Each method is defined as a function returning a list with one or more elements as follows:

- modelFormula for the model, using the slot names (rec and ssb) to refer to the usual inputs.
- loglFunction to calculate the loglikelihood of the given model when estimated through Maximum Likelihood Estimation (MLE, see fmle).
- initialFunction to provide initial values for all parameters to be minimization algorithms called by fmle or nls. If required, this function also have two attributes, lower and upper, that give lower and upper limits for the parameter values, respectively. This is used by some of the methods defined in optim, like “L-BFGS-B”. The *model* <– method for *FLModel* can then be called with *value* being a list thus described, the name of the function returning such a list, or the function itself.

The available SR models are: bevholt(), bevholt.ar1(), bevholt.c.a(), bevholt.c.b(), bevholt.d(), bevholt.ndc(), bevholt.sv(), geomean(), logl.ar1(rho, sigma2, obs, hat), ricker(), ricker.ar1(), ricker.c.a(), ricker.c.b(), ricker.d(), ricker.sv(), segreg(), shepherd(), shepherd.ar1(), shepherd.d(), shepherd.d.ar1(), shepherd.ndc(), shepherd.ndc.ar1(), sv2ab(steepness, vbiomass, spro, model).

The user can assign a Ricker SR model to the *FLStock* object. The user can also obtain the model formula of the fitted model, as well as the log-likelihood. The fmle method fits the model specified in an *FLModel* object using R's optim function to minimize the negative of the log-likelihood function, in the logl slot, through calls to the minimizaton routine. The default algorithm for optim is Nelder-Mead, however other options are available (e.g. "L-BFGS-B", see ?optim).

```
# This chunk assigns a Ricker SR model and
# fits it
model(p4sr) <- ricker()
model(p4sr)
```

```
rec ~ a * ssb * exp(-b * ssb)
<environment: 0x4a26ac0>
```

```
# the fmle method then fits the SR model using
# logl and R's optim model fitting through MLE
p4sr <- fmle(p4sr)
```

```
  Nelder-Mead direct search function minimizer
function value for initial parameters = -21.363701
  Scaled convergence tolerance is 3.18344e-07
Stepsize computed as 0.916257
BUILD              3 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK             7 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            11 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            15 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            19 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            23 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            27 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            31 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            35 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            39 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
HI-REDUCTION      41 298.701908 -21.363701
HI-REDUCTION      43 263.351655 -21.363701
HI-REDUCTION      45 228.002195 -21.363701
HI-REDUCTION      47 192.655949 -21.363701
HI-REDUCTION      49 157.322617 -21.363701
HI-REDUCTION      51 122.040982 -21.363701
HI-REDUCTION      53 86.964680 -21.363701
HI-REDUCTION      55 52.683513 -21.363701
```

```
HI-REDUCTION      57 21.213301 -21.363701
HI-REDUCTION      59 -2.719834 -21.363701
HI-REDUCTION      61 -15.283622 -21.363701
HI-REDUCTION      63 -19.703632 -21.363701
HI-REDUCTION      65 -20.939051 -21.363701
HI-REDUCTION      67 -21.257181 -21.363701
HI-REDUCTION      69 -21.337183 -21.363701
HI-REDUCTION      71 -21.357145 -21.363701
HI-REDUCTION      73 -21.362100 -21.363701
HI-REDUCTION      75 -21.363319 -21.363701
HI-REDUCTION      77 -21.363614 -21.363701
HI-REDUCTION      79 -21.363683 -21.363701
HI-REDUCTION      81 -21.363697 -21.363701
HI-REDUCTION      83 -21.363698 -21.363701
HI-REDUCTION      85 -21.363700 -21.363701
HI-REDUCTION      87 -21.363700 -21.363701
Exiting from Nelder Mead minimizer
    89 function evaluations used
```

```
# log-likelihood logl(p4sr)
```

The user can extract the initial parameters used by the optimiser, as well as the lower and upper limits of these parameters.

```
# initial values for the optimiser
initial(p4sr)
```

```
function (rec, ssb)
{
    res <- coefficients(lm(log(c(rec)/c(ssb)) ~ c(ssb)))
    return(FLPar(a = max(exp(res[1])), b = -max(res[2])))
}
<environment: 0x4a26ac0>
attr(,"lower")
[1] -Inf -Inf
attr(,"upper")
[1] Inf Inf
```

```
# lower and upper limits for the parameters
lower(p4sr)
```

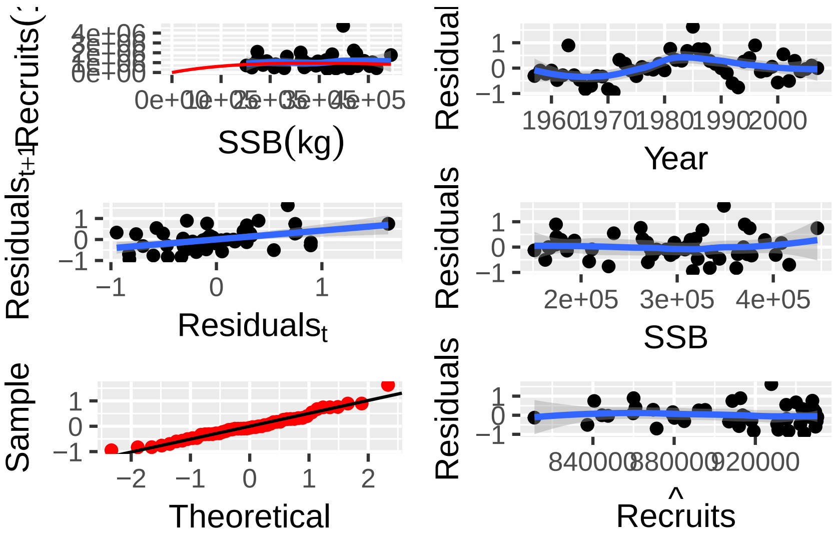
```
[1] -Inf -Inf
```

```
upper(p4sr)
```

```
[1] Inf Inf
```

Diagnostic plots can be produced by simply calling the /plot/ function on the *FLSR* object.

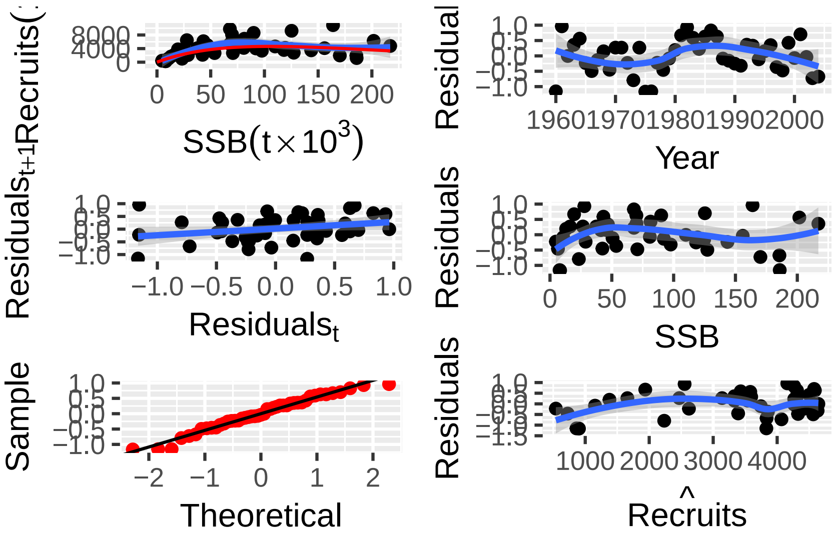
```
# Diagnostics plots of the fitted SR model
plot(p4sr)
```



NS Herring stock-recruitment dataset example

The user can experiment with North Sea herring data where a Ricker model has already been fitted.

```
# This chunk loads, plots and prints a summary
# of the nsher FLSR object (a ricker SR model
# has already been fitted)
data(nsher)
plot(nsher)
```



```
summary(nsher)
```

```
An object of class "FLSR"

Name:
Description:
Quant: age
Dims:  age  year    unit    season  area    iter
    1   45  1   1   1   1

Range:  min minyear max maxyear
    0   1960    0   2004

rec           : [ 1 45 1 1 1 1 ], units =  10^3
ssb           : [ 1 45 1 1 1 1 ], units =  t*10^3
residuals     : [ 1 45 1 1 1 1 ], units =  NA
fitted        : [ 1 45 1 1 1 1 ], units =  10^3

Model:  rec ~ a * ssb * exp(-b * ssb)
<environment: 0x7b30748>
Parameters:
    params
iter     a        b
   1 119.4 0.009451

Log-likelihood:  15.862(0)
Variance-covariance:
            a         b
  a 255.33882 1.809e-02
  b   0.01809 1.993e-06
```

The user can change the fitted SR model if so desired. Below bevholt() and cushing() models are used.

```
# This chunk fits and plots a bevholt SR model
# and a cushing SR model on nsher data assign
# nsher with ricker model to a new object
nsher_ri <- nsher
# change model to bevholt
model(nsher) <- bevholt()
# fit through MLE
nsher_bh <- fmle(nsher)
```

```
  Nelder-Mead direct search function minimizer
function value for initial parameters = -10.336211
  Scaled convergence tolerance is 1.54022e-07
Stepsize computed as 501.110000
BUILD              3 44.842344 -11.603908
HI-REDUCTION       5 31.685209 -11.603908
HI-REDUCTION       7 17.913114 -11.603908
HI-REDUCTION       9 5.415279 -11.603908
HI-REDUCTION      11 -3.412974 -11.603908
HI-REDUCTION      13 -8.018030 -11.603908
LO-REDUCTION      15 -10.336211 -11.603908
LO-REDUCTION      17 -11.081040 -11.603908
EXTENSION         19 -11.295930 -12.061705
LO-REDUCTION      21 -11.603908 -12.061705
REFLECTION        23 -11.813826 -12.087620
REFLECTION        25 -12.061705 -12.199591
LO-REDUCTION      27 -12.087620 -12.199591
LO-REDUCTION      29 -12.158184 -12.199591
LO-REDUCTION      31 -12.191726 -12.199591
HI-REDUCTION      33 -12.192269 -12.199591
HI-REDUCTION      35 -12.197784 -12.199591
LO-REDUCTION      37 -12.198015 -12.199591
HI-REDUCTION      39 -12.199555 -12.199776
REFLECTION        41 -12.199591 -12.200058
HI-REDUCTION      43 -12.199776 -12.200092
HI-REDUCTION      45 -12.200058 -12.200142
HI-REDUCTION      47 -12.200092 -12.200155
HI-REDUCTION      49 -12.200142 -12.200160
HI-REDUCTION      51 -12.200155 -12.200177
HI-REDUCTION      53 -12.200160 -12.200177
LO-REDUCTION      55 -12.200171 -12.200179
```

```
HI-REDUCTION      57 -12.200177 -12.200179
HI-REDUCTION      59 -12.200178 -12.200179
HI-REDUCTION      61 -12.200179 -12.200179
HI-REDUCTION      63 -12.200179 -12.200179
HI-REDUCTION      65 -12.200179 -12.200179
Exiting from Nelder Mead minimizer
    67 function evaluations used
```

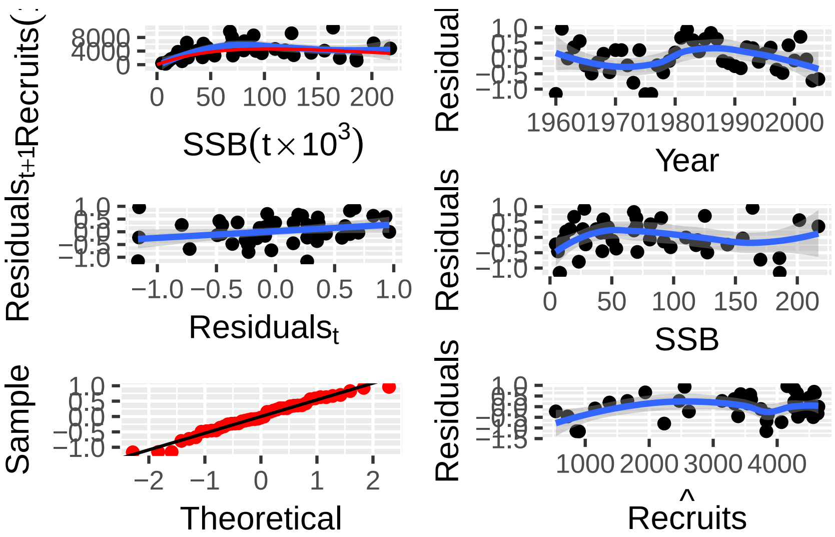
```
# change model to cushing
model(nsher) <- cushing()
# fit through MLE
nsher_cs <- fmle(nsher)
```

```
  Nelder-Mead direct search function minimizer
function value for initial parameters = 2.643728
  Scaled convergence tolerance is 3.93946e-08
Stepsize computed as 7.305886
BUILD              3 165.749466 2.643728
LO-REDUCTION       5 132.833288 2.643728
HI-REDUCTION       7 100.600604 2.643728
HI-REDUCTION       9 67.664549 2.643728
HI-REDUCTION      11 34.733185 2.643728
HI-REDUCTION      13 7.911548 2.643728
HI-REDUCTION      15 4.521431 -1.878950
LO-REDUCTION      17 2.643728 -1.878950
HI-REDUCTION      19 -0.979191 -1.878950
HI-REDUCTION      21 -1.703436 -1.878950
EXTENSION         23 -1.799779 -2.563273
LO-REDUCTION      25 -1.878950 -2.563273
EXTENSION         27 -2.224734 -3.314794
LO-REDUCTION      29 -2.563273 -3.314794
EXTENSION         31 -3.066239 -4.172130
EXTENSION         33 -3.314794 -4.839079
EXTENSION         35 -4.172130 -5.749640
LO-REDUCTION      37 -4.839079 -5.749640
HI-REDUCTION      39 -5.330663 -5.749640
LO-REDUCTION      41 -5.399427 -5.749640
EXTENSION         43 -5.660976 -6.024063
HI-REDUCTION      45 -5.749640 -6.024063
EXTENSION         47 -5.858861 -6.325684
LO-REDUCTION      49 -6.024063 -6.325684
EXTENSION         51 -6.188183 -6.571603
EXTENSION         53 -6.325684 -6.841173
EXTENSION         55 -6.571603 -7.008862
REFLECTION        57 -6.841173 -7.107980
```

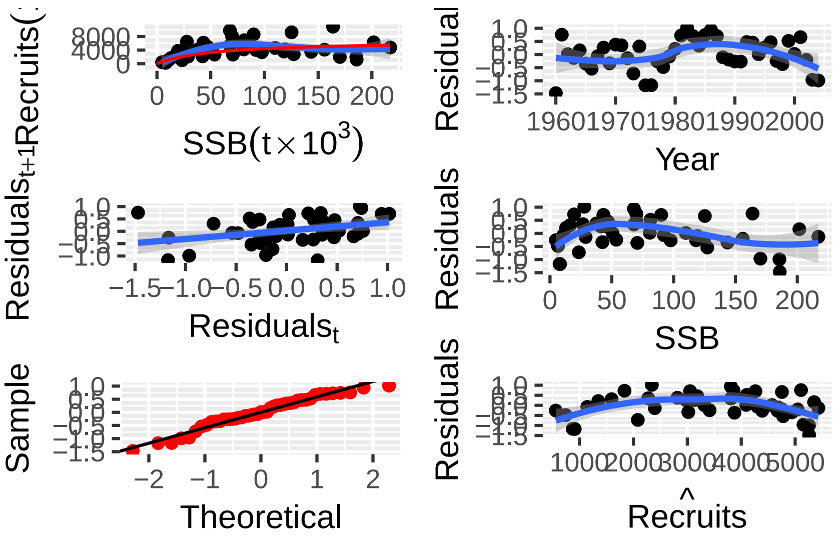
```
LO-REDUCTION      59 -7.008862 -7.107980
LO-REDUCTION      61 -7.093943 -7.133055
HI-REDUCTION      63 -7.107980 -7.141163
LO-REDUCTION      65 -7.133055 -7.142445
HI-REDUCTION      67 -7.141163 -7.143281
HI-REDUCTION      69 -7.142445 -7.143809
HI-REDUCTION      71 -7.143281 -7.144162
HI-REDUCTION      73 -7.143809 -7.144383
LO-REDUCTION      75 -7.144162 -7.144383
HI-REDUCTION      77 -7.144314 -7.144404
LO-REDUCTION      79 -7.144383 -7.144447
HI-REDUCTION      81 -7.144404 -7.144447
HI-REDUCTION      83 -7.144447 -7.144452
HI-REDUCTION      85 -7.144447 -7.144455
HI-REDUCTION      87 -7.144452 -7.144455
HI-REDUCTION      89 -7.144455 -7.144457
HI-REDUCTION      91 -7.144455 -7.144457
LO-REDUCTION      93 -7.144457 -7.144457
HI-REDUCTION      95 -7.144457 -7.144457
LO-REDUCTION      97 -7.144457 -7.144457
HI-REDUCTION      99 -7.144457 -7.144457
Exiting from Nelder Mead minimizer
    101 function evaluations used
```

One can inspect the fits visually,

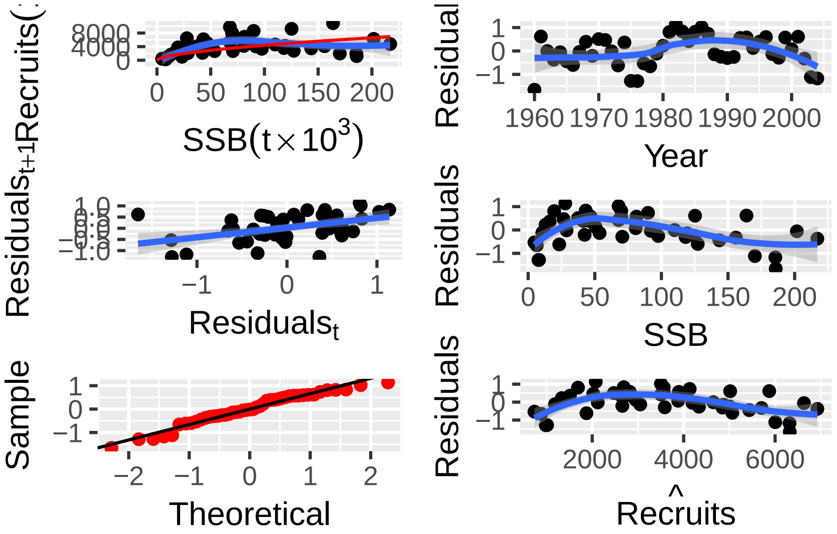
```
# this chunk plots the fits from the 3
# different SR models
plot(nsher_ri)
```



```
plot(nsher_bh)
```



```
plot(nsher_cs)
```



by using the AIC,

```
# this chunk plots the fits from the 3
# different SR models
print(paste0("Ricker: ", round(AIC(nsher_ri),
    4), " ", "Beverton-Holt: ", round(AIC(nsher_bh),
    4), " ", "Cushing: ", round(AIC(nsher_cs),
    4)))
```

```
[1] "Ricker: -27.7245 Beverton-Holt: -20.4004 Cushing: -10.2889"
```

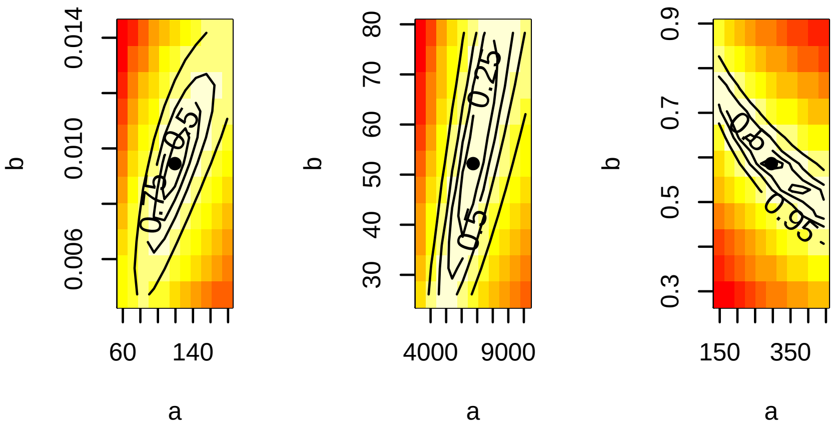
or Schwarz's Bayesian Information Criterion

```
# this chunk plots the fits from the 3
# different SR models
print(paste0("Ricker: ", round(BIC(nsher_ri),
    4), " ", "Beverton-Holt: ", round(BIC(nsher_bh),
    4), " ", "Cushing: ", round(BIC(nsher_cs),
    4)))
```

```
[1] "Ricker: -24.1112 Beverton-Holt: -16.787 Cushing: -6.6756"
```

Additionally, a profiling of the model parameters can be visualized for each fitted model.

```
# Profile the likelihood to check the fit
par(mfrow = c(1, 3))
profile(nsher_ri)
profile(nsher_bh)
profile(nsher_cs)
```



SR model parameters can also be fixed. In this case, *steepness* is fixed to a value of 0.8. Details on the model parameterization can be found in SRmodels.

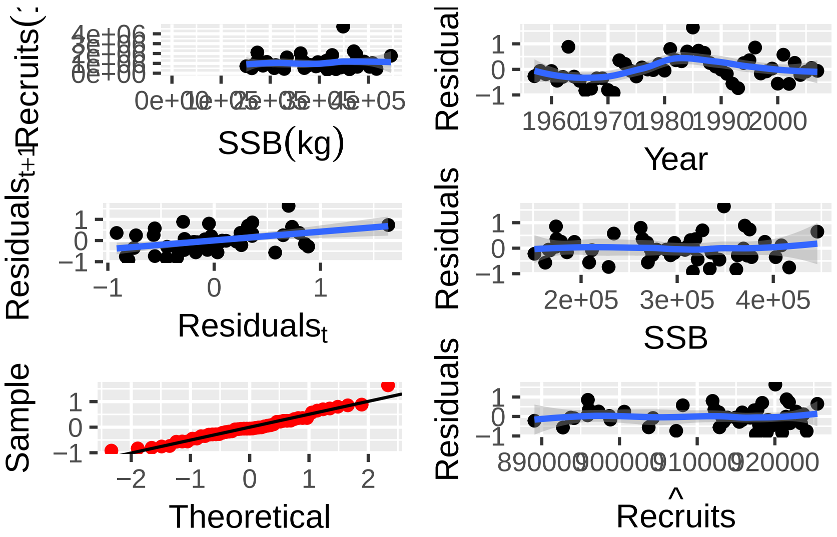
```
# Fit a bevholtSV model with fixed steepness
# at 0.8
par(mfrow = c(1, 1))
model(p4sr) <- bevholtSV
p4sr <- fmle(p4sr, fixed = list(s = 0.8))
```

```
  Nelder-Mead direct search function minimizer
function value for initial parameters = -21.555680
  Scaled convergence tolerance is 3.21205e-07
Stepsize computed as 57698.729975
```

```
BUILD              3 138.239783 -21.555680
HI-REDUCTION       5 134.971658 -21.555680
HI-REDUCTION       7 131.535838 -21.555680
HI-REDUCTION       9 127.881431 -21.555680
HI-REDUCTION      11 123.961309 -21.555680
HI-REDUCTION      13 119.724583 -21.555680
HI-REDUCTION      15 115.111062 -21.555680
HI-REDUCTION      17 110.045701 -21.555680
HI-REDUCTION      19 104.431766 -21.555680
HI-REDUCTION      21 98.141556 -21.555680
HI-REDUCTION      23 91.003478 -21.555680
HI-REDUCTION      25 82.784736 -21.555680
HI-REDUCTION      27 73.171495 -21.555680
HI-REDUCTION      29 61.758606 -21.555680
HI-REDUCTION      31 48.093801 -21.555680
HI-REDUCTION      33 31.909759 -21.555680
HI-REDUCTION      35 13.835912 -21.555680
HI-REDUCTION      37 -3.319845 -21.555680
HI-REDUCTION      39 -15.017575 -21.555680
HI-REDUCTION      41 -20.031655 -21.555680
HI-REDUCTION      43 -20.760888 -21.555680
HI-REDUCTION      45 -21.372072 -21.555680
HI-REDUCTION      47 -21.422166 -21.555680
HI-REDUCTION      49 -21.523998 -21.555680
HI-REDUCTION      51 -21.537566 -21.555680
HI-REDUCTION      53 -21.548170 -21.555680
REFLECTION        55 -21.552329 -21.557356
EXTENSION         57 -21.555680 -21.564655
EXTENSION         59 -21.557356 -21.569964
EXTENSION         61 -21.564655 -21.594889
LO-REDUCTION      63 -21.569964 -21.594889
EXTENSION         65 -21.590236 -21.626546
LO-REDUCTION      67 -21.594889 -21.626546
LO-REDUCTION      69 -21.605773 -21.633123
HI-REDUCTION      71 -21.620052 -21.633123
LO-REDUCTION      73 -21.626546 -21.633123
LO-REDUCTION      75 -21.631055 -21.633123
EXTENSION         77 -21.632799 -21.636830
LO-REDUCTION      79 -21.633123 -21.636830
REFLECTION        81 -21.635481 -21.637874
HI-REDUCTION      83 -21.636830 -21.637874
EXTENSION         85 -21.637041 -21.639180
HI-REDUCTION      87 -21.637874 -21.639180
LO-REDUCTION      89 -21.638130 -21.639180
```

```
EXTENSION         91 -21.638504 -21.639587
REFLECTION        93 -21.639180 -21.639887
LO-REDUCTION      95 -21.639587 -21.640005
HI-REDUCTION      97 -21.639887 -21.640005
HI-REDUCTION      99 -21.639933 -21.640005
HI-REDUCTION     101 -21.639993 -21.640005
LO-REDUCTION     103 -21.640003 -21.640015
HI-REDUCTION     105 -21.640005 -21.640017
HI-REDUCTION     107 -21.640015 -21.640017
LO-REDUCTION     109 -21.640017 -21.640018
HI-REDUCTION     111 -21.640017 -21.640019
Exiting from Nelder Mead minimizer
    113 function evaluations used
```

```
plot(p4sr)
```



```
params(p4sr)
```

```
An object of class "FLPar"
params
         s          v       spr0
8.0000e-01 1.4400e+05 1.6247e-01
units:  NA
```

Custom SR models can be implemented. To define a new model requires the specification of it´s i) functional form, ii) likelihood iii) bounds and iv) starting values. For example, the user can fit the Deriso-Schnute model below.

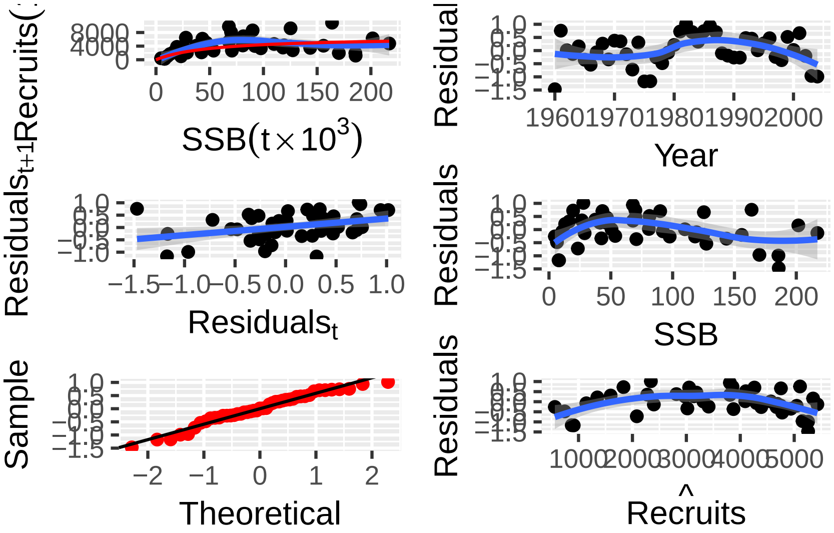
```
# Fit a custom SR model (Deriso Schnute)
```

```
dersch<-function(){
  logl <- function(a,b,c,rec,ssb) {
          res<-loglAR1(log(rec), log(a*ssb*(1-b*c*ssb)^(1/c)))
          return(res)
          }

  ## initial parameter values
  initial <- structure(function(rec, ssb){
     slopeAt0 <- max(quantile(c(rec)/c(ssb), 0.9, na.rm = TRUE))
     maxRec   <- max(quantile(c(rec), 0.75, na.rm = TRUE))

     ## Bevholt by default c=-1
     return(FLPar(a=slopeAt0, b=1/maxRec, c=-1))},

  lower=rep(-Inf, 3),
    upper=rep( Inf, 3))

  model  <- rec~a*ssb*(1-b*c*ssb)^(1/c)

  return(list(logl = logl, model = model, initial = initial))}

model(nsher)<-dersch()
nsher_dersch<-fmle(nsher,fixed=list(c=-1))
```

```
  Nelder-Mead direct search function minimizer
function value for initial parameters = 17.333408
  Scaled convergence tolerance is 2.58288e-07
Stepsize computed as 13.153756
BUILD              3 91.201914 17.333408
HI-REDUCTION       5 85.346515 17.333408
HI-REDUCTION       7 78.788974 17.333408
HI-REDUCTION       9 71.274855 17.333408
HI-REDUCTION      11 62.476925 17.333408
HI-REDUCTION      13 51.941338 17.333408
HI-REDUCTION      15 39.022910 17.333408
HI-REDUCTION      17 22.906931 17.333408
HI-REDUCTION      19 20.124271 3.640675
LO-REDUCTION      21 17.333408 -2.032233
HI-REDUCTION      23 3.640675 -11.842531
LO-REDUCTION      25 -2.032233 -12.091641
HI-REDUCTION      27 -7.857027 -12.091641
LO-REDUCTION      29 -11.842531 -12.091641
HI-REDUCTION      31 -11.864288 -12.133957
HI-REDUCTION      33 -12.091641 -12.181781
```

```
LO-REDUCTION      35 -12.133957 -12.190420
HI-REDUCTION      37 -12.181781 -12.191712
HI-REDUCTION      39 -12.190420 -12.194357
LO-REDUCTION      41 -12.191712 -12.196973
HI-REDUCTION      43 -12.194357 -12.197107
HI-REDUCTION      45 -12.196973 -12.198455
LO-REDUCTION      47 -12.197107 -12.198455
HI-REDUCTION      49 -12.198049 -12.198455
EXTENSION         51 -12.198157 -12.198929
REFLECTION        53 -12.198455 -12.199181
REFLECTION        55 -12.198929 -12.199488
REFLECTION        57 -12.199181 -12.199694
REFLECTION        59 -12.199488 -12.199833
REFLECTION        61 -12.199694 -12.199991
LO-REDUCTION      63 -12.199833 -12.200077
LO-REDUCTION      65 -12.199991 -12.200077
LO-REDUCTION      67 -12.200074 -12.200142
HI-REDUCTION      69 -12.200077 -12.200154
LO-REDUCTION      71 -12.200142 -12.200165
HI-REDUCTION      73 -12.200154 -12.200165
REFLECTION        75 -12.200161 -12.200170
REFLECTION        77 -12.200165 -12.200172
REFLECTION        79 -12.200170 -12.200176
LO-REDUCTION      81 -12.200172 -12.200177
LO-REDUCTION      83 -12.200176 -12.200178
LO-REDUCTION      85 -12.200177 -12.200178
LO-REDUCTION      87 -12.200178 -12.200178
LO-REDUCTION      89 -12.200178 -12.200178
HI-REDUCTION      91 -12.200178 -12.200178
Exiting from Nelder Mead minimizer
    93 function evaluations used
```

```
plot(nsher_dersch)
```



A SR model with AR1 autocorrelation can be also be fitted.

```
# Fit a custom SR AR1 model
rickerAR1 <- function()
  {
  ## log likelihood, assuming normal log.
  logl <- function(a, b, rho, rec, ssb)
      loglAR1(log(rec), log(a*ssb*exp(-b*ssb)), rho=rho)

  ## initial parameter values
  initial <- structure(function(rec, ssb) {
        # The function to provide initial values
    res  <-coefficients(lm(c(log(rec/ssb))~c(ssb)))
    return(FLPar(a=max(exp(res[1])), b=-max(res[2]), rho=0))
    },
  # lower and upper limits for optim()
    lower=rep(-Inf, 3),
    upper=rep( Inf, 3)
    )

  ## model to be fitted
    model  <- rec~a*ssb*exp(-b*ssb)

    return(list(logl=logl, model=model, initial=initial))}

#### Fit
model(nsher)<-rickerAR1()
nsherAR1 <-fmle(nsher)
```

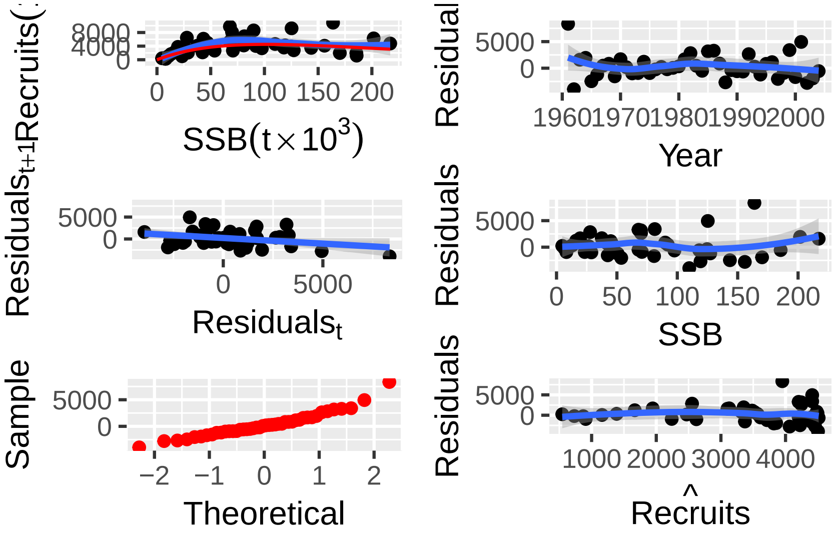
```
  Nelder-Mead direct search function minimizer
```

```
function value for initial parameters = -15.862252
  Scaled convergence tolerance is 2.36366e-07
Stepsize computed as 11.939303
BUILD              4 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK             9 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
HI-REDUCTION      11 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            16 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
SHRINK            21 1000000000000000015902891109759918046836080856394528138978132755774783877217038106081
HI-REDUCTION      23 199.932706 -15.862252
LO-REDUCTION      25 160.064215 -15.862252
HI-REDUCTION      27 122.575917 -15.862252
HI-REDUCTION      29 95.910817 -15.862252
HI-REDUCTION      31 77.059487 -15.862252
HI-REDUCTION      33 75.271871 -15.862252
HI-REDUCTION      35 40.926789 -15.862252
HI-REDUCTION      37 37.197738 -15.862252
HI-REDUCTION      39 9.160356 -15.862252
HI-REDUCTION      41 3.525050 -15.862252
HI-REDUCTION      43 -10.621462 -15.862252
HI-REDUCTION      45 -10.875514 -15.862252
HI-REDUCTION      47 -14.927859 -15.862252
HI-REDUCTION      49 -15.479386 -15.883057
HI-REDUCTION      51 -15.850187 -15.953467
EXTENSION         53 -15.862252 -16.277050
EXTENSION         55 -15.883057 -16.742508
LO-REDUCTION      57 -15.953467 -16.742508
EXTENSION         59 -16.277050 -17.411690
EXTENSION         61 -16.326258 -18.207461
EXTENSION         63 -16.742508 -18.726139
REFLECTION        65 -17.411690 -18.873183
HI-REDUCTION      67 -18.207461 -18.873183
HI-REDUCTION      69 -18.253126 -18.873183
HI-REDUCTION      71 -18.669816 -18.873183
HI-REDUCTION      73 -18.676157 -18.873183
HI-REDUCTION      75 -18.726139 -18.873183
EXTENSION         77 -18.855372 -19.146764
LO-REDUCTION      79 -18.857423 -19.146764
HI-REDUCTION      81 -18.873183 -19.146764
LO-REDUCTION      83 -19.074175 -19.146764
LO-REDUCTION      85 -19.108674 -19.177667
REFLECTION        87 -19.138719 -19.177986
HI-REDUCTION      89 -19.146764 -19.194019
HI-REDUCTION      91 -19.177667 -19.194019
HI-REDUCTION      93 -19.177986 -19.200472
```

```
HI-REDUCTION      95 -19.191663 -19.201744
HI-REDUCTION      97 -19.194019 -19.201785
LO-REDUCTION      99 -19.200472 -19.202304
REFLECTION       101 -19.201744 -19.204887
HI-REDUCTION     103 -19.201785 -19.205193
LO-REDUCTION     105 -19.202304 -19.205564
HI-REDUCTION     107 -19.204887 -19.205598
LO-REDUCTION     109 -19.205193 -19.205708
LO-REDUCTION     111 -19.205564 -19.205748
HI-REDUCTION     113 -19.205598 -19.205919
LO-REDUCTION     115 -19.205708 -19.205919
LO-REDUCTION     117 -19.205748 -19.205919
HI-REDUCTION     119 -19.205796 -19.205919
EXTENSION        121 -19.205860 -19.206121
LO-REDUCTION     123 -19.205890 -19.206121
EXTENSION        125 -19.205919 -19.206200
EXTENSION        127 -19.206074 -19.206664
LO-REDUCTION     129 -19.206121 -19.206664
LO-REDUCTION     131 -19.206200 -19.206664
EXTENSION        133 -19.206530 -19.207296
EXTENSION        135 -19.206623 -19.207714
EXTENSION        137 -19.206664 -19.207966
EXTENSION        139 -19.207296 -19.209082
EXTENSION        141 -19.207714 -19.210731
LO-REDUCTION     143 -19.207966 -19.210731
EXTENSION        145 -19.209082 -19.211281
EXTENSION        147 -19.209579 -19.213590
EXTENSION        149 -19.210731 -19.215430
LO-REDUCTION     151 -19.211281 -19.215430
EXTENSION        153 -19.213493 -19.218586
EXTENSION        155 -19.213590 -19.221266
EXTENSION        157 -19.215430 -19.224034
REFLECTION       159 -19.218586 -19.225505
EXTENSION        161 -19.221266 -19.235535
LO-REDUCTION     163 -19.224034 -19.235535
LO-REDUCTION     165 -19.225505 -19.235535
EXTENSION        167 -19.228750 -19.241904
EXTENSION        169 -19.232759 -19.243345
EXTENSION        171 -19.235535 -19.257402
LO-REDUCTION     173 -19.241904 -19.257402
LO-REDUCTION     175 -19.243345 -19.257402
EXTENSION        177 -19.249895 -19.259607
EXTENSION        179 -19.250691 -19.267125
LO-REDUCTION     181 -19.257402 -19.267125
```

```
HI-REDUCTION     183 -19.259607 -19.267125
REFLECTION       185 -19.263335 -19.269115
LO-REDUCTION     187 -19.265866 -19.269115
LO-REDUCTION     189 -19.267125 -19.269115
REFLECTION       191 -19.268636 -19.269944
LO-REDUCTION     193 -19.269093 -19.270003
HI-REDUCTION     195 -19.269115 -19.270003
REFLECTION       197 -19.269777 -19.270375
LO-REDUCTION     199 -19.269944 -19.270375
LO-REDUCTION     201 -19.270003 -19.270375
LO-REDUCTION     203 -19.270290 -19.270408
HI-REDUCTION     205 -19.270328 -19.270408
HI-REDUCTION     207 -19.270375 -19.270408
LO-REDUCTION     209 -19.270394 -19.270416
LO-REDUCTION     211 -19.270397 -19.270423
HI-REDUCTION     213 -19.270408 -19.270423
HI-REDUCTION     215 -19.270416 -19.270423
HI-REDUCTION     217 -19.270419 -19.270423
LO-REDUCTION     219 -19.270421 -19.270424
REFLECTION       221 -19.270423 -19.270426
HI-REDUCTION     223 -19.270423 -19.270426
HI-REDUCTION     225 -19.270424 -19.270426
HI-REDUCTION     227 -19.270425 -19.270426
LO-REDUCTION     229 -19.270425 -19.270426
EXTENSION        231 -19.270426 -19.270427
HI-REDUCTION     233 -19.270426 -19.270427
LO-REDUCTION     235 -19.270426 -19.270427
LO-REDUCTION     237 -19.270426 -19.270427
REFLECTION       239 -19.270427 -19.270427
EXTENSION        241 -19.270427 -19.270428
HI-REDUCTION     243 -19.270427 -19.270428
EXTENSION        245 -19.270427 -19.270428
LO-REDUCTION     247 -19.270427 -19.270428
EXTENSION        249 -19.270428 -19.270428
LO-REDUCTION     251 -19.270428 -19.270428
EXTENSION        253 -19.270428 -19.270429
LO-REDUCTION     255 -19.270428 -19.270429
LO-REDUCTION     257 -19.270428 -19.270429
Exiting from Nelder Mead minimizer
    259 function evaluations used
```

```
plot(nsherAR1)
```



The code is provided for demonstration purposes only as the used dataset is not adequate for all 3 parameters of the SR model to be estimated.

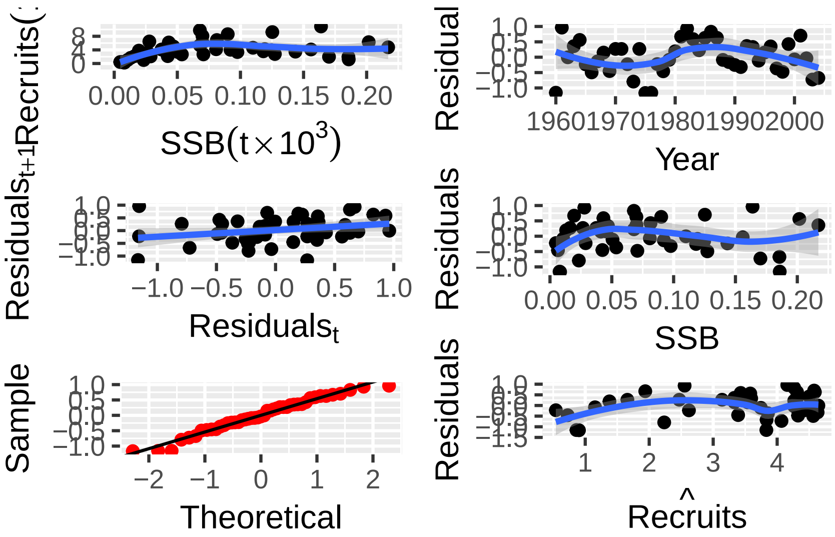
Finally, a SR model where covariates (e.g. NAO index), can be used to model environmental effects on the stock recruitment relationship.

```
# Fit a custom SR model with covariates
nao     <-read.table(url("https://www.esrl.noaa.gov/psd/data/correlation/nao.data"),
  skip=1, nrow=62, na.strings="-99.90")
dnms    <-list(quant="nao", year=1948:2009, unit="unique", season=1:12, area="unique")
nao     <-FLQuant(unlist(nao[,-1]), dimnames=dnms, units="nao")

# include NAO as covar (note that it must be a FLQuants with a single component
# called “covar” that matches the year span of the data) and adjust the model.

nsherCovA <- nsher
nsherCovA <- transform(nsherCovA,ssb=ssb/1000,rec=rec/1000)

#### Modified so temperature affects larval survival
rickerCovA <- function(){
  logl <- function(a, b, c, rec, ssb, covar){
            loglAR1(log(rec), log(a*(1+c*covar[[1]])*ssb*exp(-b*ssb)))}

  initial <- structure(function(rec, ssb, covar) {
        # The function to provide initial values
    res  <-coefficients(lm(c(log(rec/ssb))~c(ssb)))
    return(FLPar(a=max(exp(res[1])), b=-max(res[2]), c=0.0))},
  # lower and upper limits for optim()
    lower=rep(-Inf, 3),
    upper=rep( Inf, 3))

    model  <- rec~a*(1+c*covar[[1]])*ssb*exp(-b*ssb)

    return(list(logl=logl, model=model, initial=initial))}


model(nsherCovA)<-rickerCovA()
covar(nsherCovA)<-FLQuants(covar=seasonMeans(trim(nao, year=dimnames(ssb(nsherCovA))$year)))
nsherCovA       <-fmle(nsherCovA,fixed=list(c=0))
```

```
  Nelder-Mead direct search function minimizer
function value for initial parameters = -15.862252
  Scaled convergence tolerance is 2.36366e-07
Stepsize computed as 11.939303
BUILD              3 23.472050 -15.862252
HI-REDUCTION       5 0.913325 -15.862252
HI-REDUCTION       7 -11.000265 -15.862252
HI-REDUCTION       9 -14.858951 -15.862252
HI-REDUCTION      11 -15.162812 -15.862252
HI-REDUCTION      13 -15.693611 -15.862252
HI-REDUCTION      15 -15.701787 -15.862252
LO-REDUCTION      17 -15.811080 -15.862252
HI-REDUCTION      19 -15.819773 -15.862252
LO-REDUCTION      21 -15.841204 -15.862252
LO-REDUCTION      23 -15.855707 -15.862252
HI-REDUCTION      25 -15.857190 -15.862252
LO-REDUCTION      27 -15.859739 -15.862252
LO-REDUCTION      29 -15.861361 -15.862252
LO-REDUCTION      31 -15.861642 -15.862252
LO-REDUCTION      33 -15.861929 -15.862252
LO-REDUCTION      35 -15.862139 -15.862252
LO-REDUCTION      37 -15.862179 -15.862252
LO-REDUCTION      39 -15.862211 -15.862252
LO-REDUCTION      41 -15.862238 -15.862252
HI-REDUCTION      43 -15.862244 -15.862252
LO-REDUCTION      45 -15.862247 -15.862252
LO-REDUCTION      47 -15.862251 -15.862252
LO-REDUCTION      49 -15.862251 -15.862252
LO-REDUCTION      51 -15.862252 -15.862252
LO-REDUCTION      53 -15.862252 -15.862252
Exiting from Nelder Mead minimizer
```

```
    55 function evaluations used
```

```
plot(nsherCovA)
```



References

Beverton, R.J.H. and Holt, S.J. (1957) On the dynamics of exploited fish populations. MAFF Fish. Invest., Ser: II 19, 533. ISBN: 1930665946

Needle, C.L. Recruitment models: diagnosis and prognosis. Reviews in Fish Biology and Fisheries 11: 95-111, 2002. DOI: `https://doi.org/10.1023/A:1015208017674`

Ricker, W.E. (1954) Stock and recruitment. J. Fish. Res. Bd Can. 11, 559-623. DOI: `https://doi.org/10.1139/f54-039`

Shepherd, J.G. (1982) A versatile new stock-recruitment relationship for fisheries and the construction of sustainable yield curves. J. Cons. Int. Explor. Mer 40, 67-75. DOI: `https://doi.org/10.1093/icesjms/40.1.7`

More information

- You can submit bug reports, questions or suggestions on this tutorial at `https://github.com/flr/doc/issues`.
- Or send a pull request to `https://github.com/flr/doc/`
- For more information on the FLR Project for Quantitative Fisheries Science in R, visit the FLR webpage, `http://flr-project.org`.

Software Versions

- R version 3.3.2 (2016-10-31)

- FLCore: 2.6.0.20170228
- ggplotFL: 2.5.9.9000
- ggplot2: 2.2.1
- **Compiled**: Wed Mar 8 13:53:24 2017

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