A quick introduction to FLR

15 September, 2017

The Fisheries Library in R (FLR) is a collection of tools for quantitative fisheries science, developed in the R language, that facilitates the construction of bio-economic simulation models of fisheries systems as well as the application of a wide range of quantitative analysis.

FLR builds on the powerful R environment and syntax to create a domain-specific language for the quantitative analysis of the expected risks and impacts of fisheries management decisions. The classes and methods in FLR consider uncertainty an integral part of our knowledge of fisheries systems.

Required packages

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

- CRAN: latticeExtra, gridExtra, ggplot2
- FLR: FLCore, FLa4a, ggplotFL, FLBRP, FLash

You can do so as follows:

```
install.packages(c("latticeExtra", "gridExtra", "ggplot2", "triangle", "copula", "coda", "mgcv"))
install.packages(c("FLCore", "ggplotFL", "FLa4a", "FLBRP", "FLash"), repos="http://flr-project.org/R")
```

Classes and methods

The *FLCore* package defines a series of data structures that represent different elements of the fishery system. These structures are defined using R's S4 class system, while functions to operate on those classes are defined as methods. In this way function call (e.g. `plot()`) can be used on different classes and their behaviour is consistent with the class structure and content. For further information on the S4 class system, please look at the introductory text on the **methods** package.

FLQuant

The FLQuant class is the basic data structure for **FLR**, and it is in essence a 6D array on which data and outputs can be stored, structured along dimensions related to time, space, age or length, etc. It is also able to keep track of the units of measurement employed, as a simple character vector, although various operations on these objects are aware of the units of measurements contained in them.

We will be creating an altering *FLQuant* objects as we go along, but we can long briefly at some basic operations, as the syntax will then be used in other classes in *FLR*.

Let's first load the necessary packages in our session. The **FLCore** paxckage

```
library(FLCore)
library(ggplotFL)
```

As it is the case for R classes, for example *data.frame*, classes in *FLR* can be constructed using a constructor method with the same name as the class, in this case `FLQuant()`.

```
FLQuant(1:10)
```

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

     year
quant 1  2  3  4  5  6  7  8  9  10
  all  1  2  3  4  5  6  7  8  9 10

units:  NA
```

The *FLQuant* constructor can take a variety of inputs, like a vector, a matrix or an array, and also allows you to specify a nuber of arguments. We will only look now at three of them, `units` for the units of measurement, `quant` for the name of the first dimension, and `dimnames` for the dimension names of the object. For example, to construct an object holding (random) data in tonnes on catches for ages 1 to 4, over a period of 6 years, one could call

```
flq <- FLQuant(rlnorm(60), dimnames=list(age=1:4, year=2012:2017), units="t")

flq
```

```
An object of class "FLQuant"
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
```

The object has six dimensions, although some of them (`unit`, `season`, `area` and `iter`) ar not used in this case. We can inspect the object in various ways

```
# A summary of structure and data
summary(flq)
```

```
An object of class "FLQuant" with:
dim  :  4 6 1 1 1 1
quant:  age
units:  t

Min    :  0.2483
1st Qu.:  0.7864
Mean   :  1.789
Median :  1.129
3rd Qu.:  1.979
Max    :  6.164
NAs    :  0 %
```

```
# dimnames
dimnames(flq)
```

```
$age
[1] "1" "2" "3" "4"
```

```
$year
[1] "2012" "2013" "2014" "2015" "2016" "2017"

$unit
[1] "unique"

$season
[1] "all"

$area
[1] "unique"

$iter
[1] "1"
```

```r
# dims
dim(flq)
```

```
[1] 4 6 1 1 1 1
```

```r
# units
units(flq)
```

```
[1] "t"
```

It can be also subset and modified

```r
# Extract first year
flq[, 1]
```

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

   year
age 2012
  1 0.60352
  2 1.93833
  3 0.24826
  4 3.14748

units:  t
```

```r
# Extract year 2013
flq[, "2013"]
```

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

   year
age 2013
  1 0.9744
  2 2.0995
  3 1.5171
  4 6.1635
```

```
units:  t
```

```
# Set catches on age 1 to zero
flq[1,] <- 0
flq
```

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

   year
age 2012    2013    2014    2015    2016    2017
  1 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
  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
```

as it can be used in many operations

```
# Product with scalar
flq * 10
```

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

   year
age 2012    2013    2014    2015    2016    2017
  1  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  2 19.3833 20.9946 31.3919  8.4972  5.3418  6.9980
  3  2.4826 15.1710 52.8007  6.1229  5.9522 11.9544
  4 31.4748 61.6351 10.6234  9.3561 14.3151  8.1529

units:  t
```

```
# Addition with another FLQuant
flq + (flq * 0.20)
```

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

   year
age 2012    2013    2014    2015    2016    2017
  1 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
  2 2.32600 2.51935 3.76703 1.01966 0.64102 0.83976
  3 0.29791 1.82052 6.33608 0.73475 0.71427 1.43453
  4 3.77698 7.39621 1.27480 1.12273 1.71781 0.97834

units:  t
```

```
# Sum along years
yearSums(flq)
```

```
An object of class "FLQuant"
An object of class "FLQuant"
```

```
, , unit = unique, season = all, area = unique

   year
age 1
  1  0.0000
  2  9.2607
  3  9.4484
  4 13.5557

units:  t
```

More information

To learn more about the class, check the FLQuant help page.

Loading your data

The first step in an analysis is to get the relevant data into the system. We will need to construct objects of certain **FLR** classes, but first data is loaded into the R session using any of the tools available in the language: `read.csv` for CSV files, `readVPA` and others for fisheries legacy file formats, …

In this example we will create an object of class *FLStock*, a representation of both inputs and outputs involved in fitting a stock assessment model, from a CSV file containing a table with five columns:

- *slot*, the name of the input quantity, in this case either landings at age, *landings.n*, weight-at-age in the landings, *landings.wt*, and the same quantitieds for discards, *discards.n* and *discards.wt*.
- *age* and *year*
- *data*, the numeric values themselves.
- *units*, a character string for the units of measurement employed: *kg* and *1000* in this case for kilograms and thousands.

The file is downloaded into a temporary folder, and uncompressed. Simply change the value of `dir` to save the file in another folder.

```
dir <- tempdir()
download.file("http://www.flr-project.org/doc/src/ple4.csv.zip", file.path(dir, "ple4.csv.zip"))
unzip(file.path(dir, "ple4.csv.zip"), exdir=dir)
```

The CSV file can now be loaded as a `data.frame` using `read.csv` and inspected

```
dat <- read.csv(file.path(dir, "ple4.csv"))
head(dat)
```

slot	age	year	data	units
discards.n	1	1957	32356	1000
discards.n	2	1957	45596	1000
discards.n	3	1957	9220	1000
discards.n	4	1957	909	1000
discards.n	5	1957	961	1000
discards.n	6	1957	25	1000

This data.frame contains the time series of landings and discards at age, in thousands, and the corresponding mean weights-at-age, in kg, for North Sea plaice (*Pleuronectes platessa*, ICES ple.27.420).

We can create an object to store the landings-at-age data by subsetting it from the *data.frame*

```
landn <- subset(dat, slot=="landings.n", select=-slot)
```

and then convert into an *FLQuant* using

```
landsn <- as.FLQuant(landn)
```

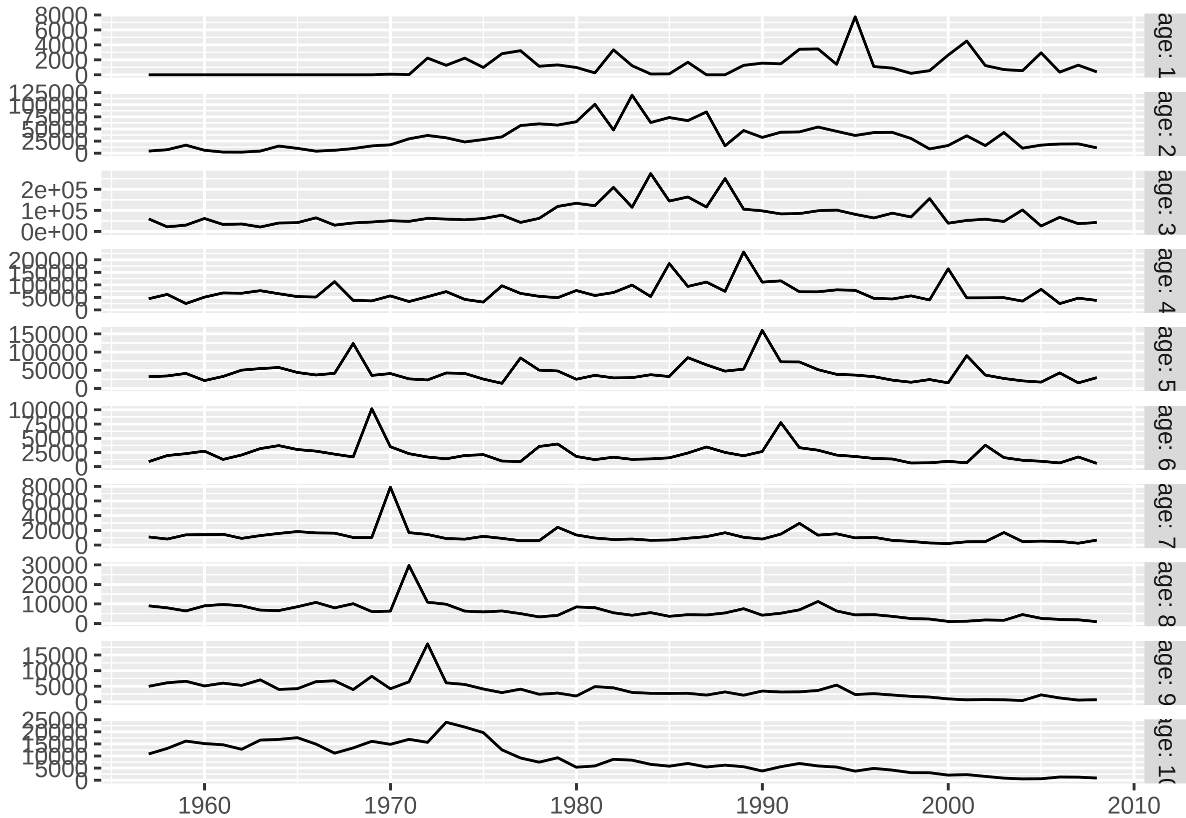
The object can now be inspected and plotted using the FLR-defined methods

```
summary(landsn)
```

```
An object of class "FLQuant" with:
dim  :  10 52 1 1 1 1
quant:  age
units:  1000

Min    :  0
1st Qu.:  4548
Mean   :  28141
Median :  14030
3rd Qu.:  40536
Max    :  274209
NAs    :  0 %
```

```
plot(landsn)
```



In a similar way, we can now convert the input *data.frame*, containing data for four data elements, as specified in the `slots` column, into an *FLStock* object, `ple4`

```r
ple4 <- as.FLStock(dat)

summary(ple4)
```

```
An object of class "FLStock"

Name:
Description:
Quant: age
Dims:  age 	year	unit	season	area 	iter
	10	52	1	1	1	1	

Range:  min	max	pgroup	minyear	maxyear	minfbar	maxfbar 
	1	10	10	1957	2008	1	10	

catch         : [ 1 52 1 1 1 1 ], units =  NA 
catch.n       : [ 10 52 1 1 1 1 ], units =  NA 
catch.wt      : [ 10 52 1 1 1 1 ], units =  NA 
discards      : [ 1 52 1 1 1 1 ], units =  NA 
discards.n    : [ 10 52 1 1 1 1 ], units =  1000 
discards.wt   : [ 10 52 1 1 1 1 ], units =  kg 
landings      : [ 1 52 1 1 1 1 ], units =  NA 
landings.n    : [ 10 52 1 1 1 1 ], units =  1000 
landings.wt   : [ 10 52 1 1 1 1 ], units =  kg 
stock         : [ 1 52 1 1 1 1 ], units =  NA 
stock.n       : [ 10 52 1 1 1 1 ], units =  NA 
stock.wt      : [ 10 52 1 1 1 1 ], units =  NA 
m             : [ 10 52 1 1 1 1 ], units =  m 
mat           : [ 10 52 1 1 1 1 ], units =   
harvest       : [ 10 52 1 1 1 1 ], units =  NA 
harvest.spwn  : [ 10 52 1 1 1 1 ], units =   
m.spwn        : [ 10 52 1 1 1 1 ], units =   
```

To complete this *FLStock* object we will need to specify the natural mortality, *m*, in this case as a constant value of 0.1 for all ages and years,

```r
m(ple4) <- 0.1
```

the proportion of natural and fishing mortality that takes place before spawning, assumed to be zero in both cases,

```r
m.spwn(ple4) <- harvest.spwn(ple4) <- 0
```

and the maturity at age, as the proportion mature, as a vector repeated for all years.

```r
mat(ple4) <- c(0, 0.5, 0.5, rep(1, 7))
```

We now must compute the overall landings and discards, in biomass, from the age-disaggregated values,

```r
landings(ple4) <- computeLandings(ple4)
discards(ple4) <- computeDiscards(ple4)
```

and then the catch slots from both landings and discards

```r
catch(ple4) <- computeCatch(ple4, slot="all")
```

The mean weigth-at-age in the stock needs to be provided. In this case we will assume it is the same as the one computed from the catch sampling programme

```
stock.wt(ple4) <- catch.wt(ple4)
```

We finalize by specifying the fully selected age range, used in the calculation of an overall index of fishing mortality, for example as the mean, using `fbar()`, or as the maximum value, using `fapex()` across those ages. This information is part of the object's *range*.

```
range(ple4, c("minfbar", "maxfbar")) <- c(2, 6)
```

If we now inspect the resulting object we can see that all calculated slots have been assigned the corresponding *units* of measurement, except for those that will hold the estimates coming from a stock assessment model: *stock*, *stock.n* and *stock.wt* for the estimates of abundance, and *harvest* for the estimates of fishing mortality at age.

```
summary(ple4)
```

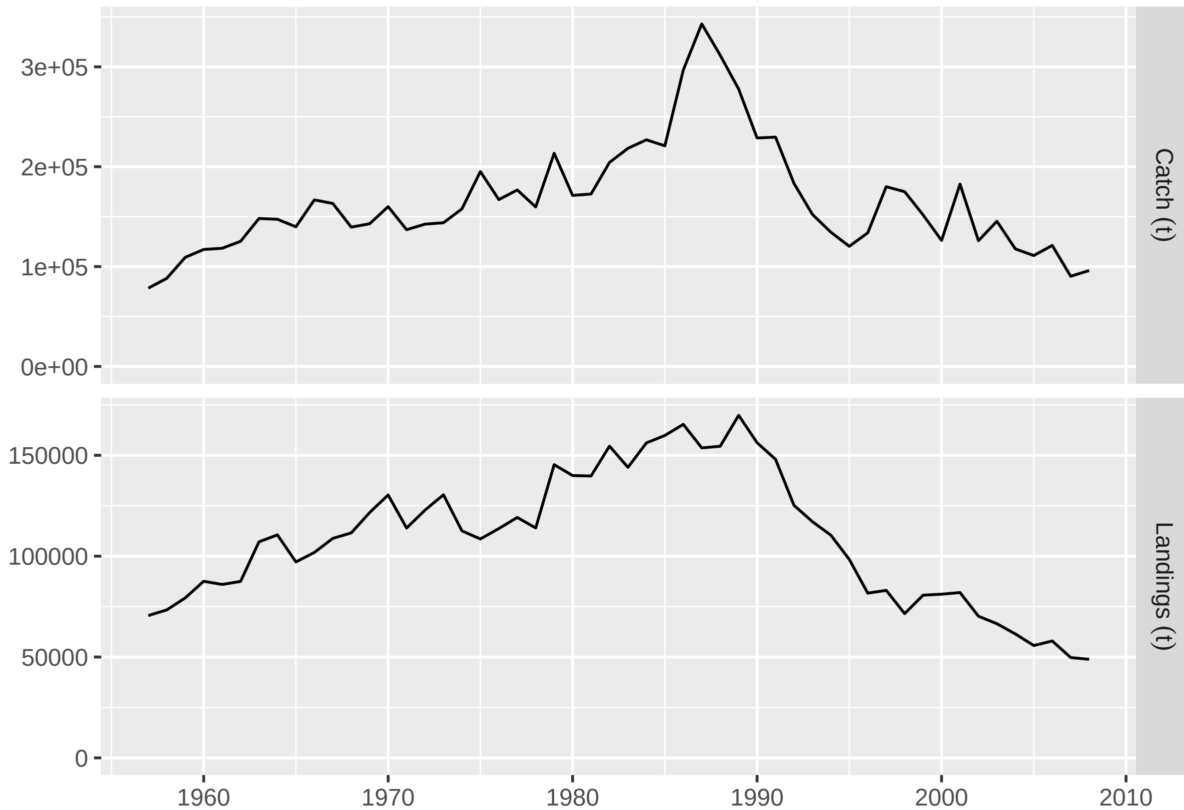
```
An object of class "FLStock"

Name:
Description:
Quant: age
Dims:  age  year    unit    season  area    iter
    10  52  1   1   1   1

Range:  min max pgroup  minyear maxyear minfbar maxfbar
    1   10  10  1957    2008    2   6

catch         : [ 1 52 1 1 1 1 ], units =  t
catch.n       : [ 10 52 1 1 1 1 ], units =  1000
catch.wt      : [ 10 52 1 1 1 1 ], units =  kg
discards      : [ 1 52 1 1 1 1 ], units =  t
discards.n    : [ 10 52 1 1 1 1 ], units =  1000
discards.wt   : [ 10 52 1 1 1 1 ], units =  kg
landings      : [ 1 52 1 1 1 1 ], units =  t
landings.n    : [ 10 52 1 1 1 1 ], units =  1000
landings.wt   : [ 10 52 1 1 1 1 ], units =  kg
stock         : [ 1 52 1 1 1 1 ], units =  NA
stock.n       : [ 10 52 1 1 1 1 ], units =  NA
stock.wt      : [ 10 52 1 1 1 1 ], units =  kg
m             : [ 10 52 1 1 1 1 ], units =  m
mat           : [ 10 52 1 1 1 1 ], units =
harvest       : [ 10 52 1 1 1 1 ], units =  NA
harvest.spwn  : [ 10 52 1 1 1 1 ], units =
m.spwn        : [ 10 52 1 1 1 1 ], units =
```

```
plot(metrics(ple4, Catch=catch, Landings=landings))
```



More information

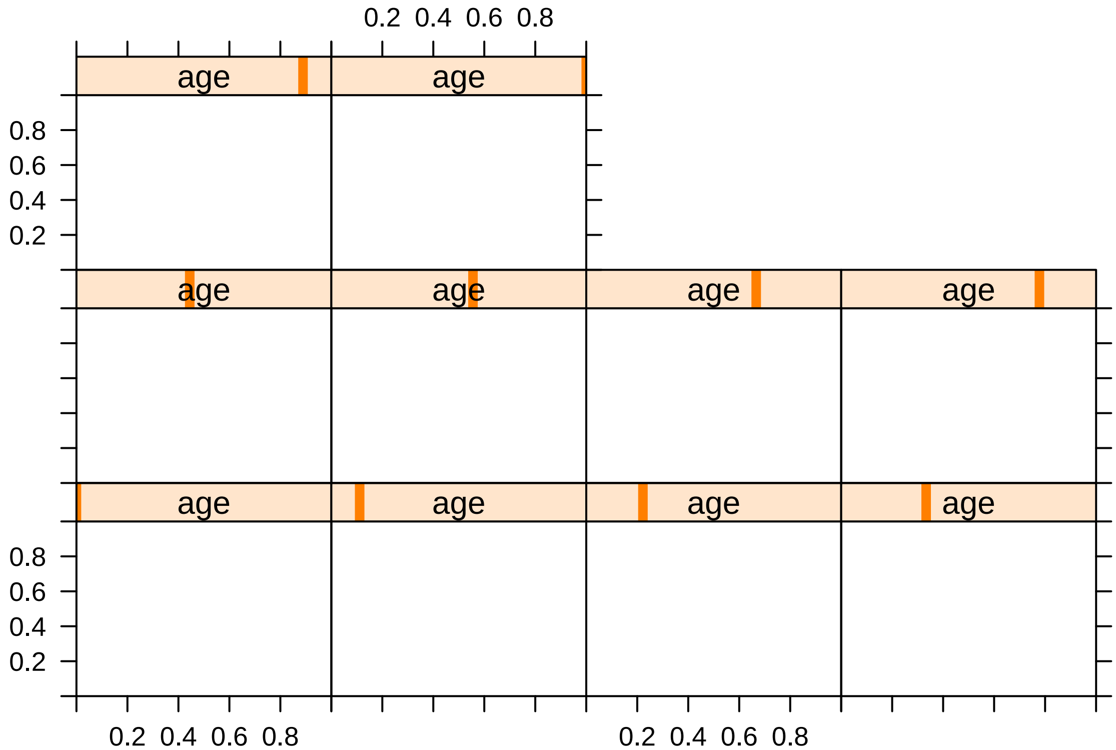
Please see the Reading data into FLR tutorial for more examples on how to get your data into into **FLR**.

Visualizing and plotting

As already shown, **FLR** classes have always a `plot` methods defined that provide a basic visual exploration of the object contents. But you are not limited to those plots, and other methods are available to allow you to build the plots you need.

The *FLCore* package provides a set of those plot methods based on R's lattice package, as well as versions of lattice's methods that work directly on **FLR** objects, for example `xyplot`

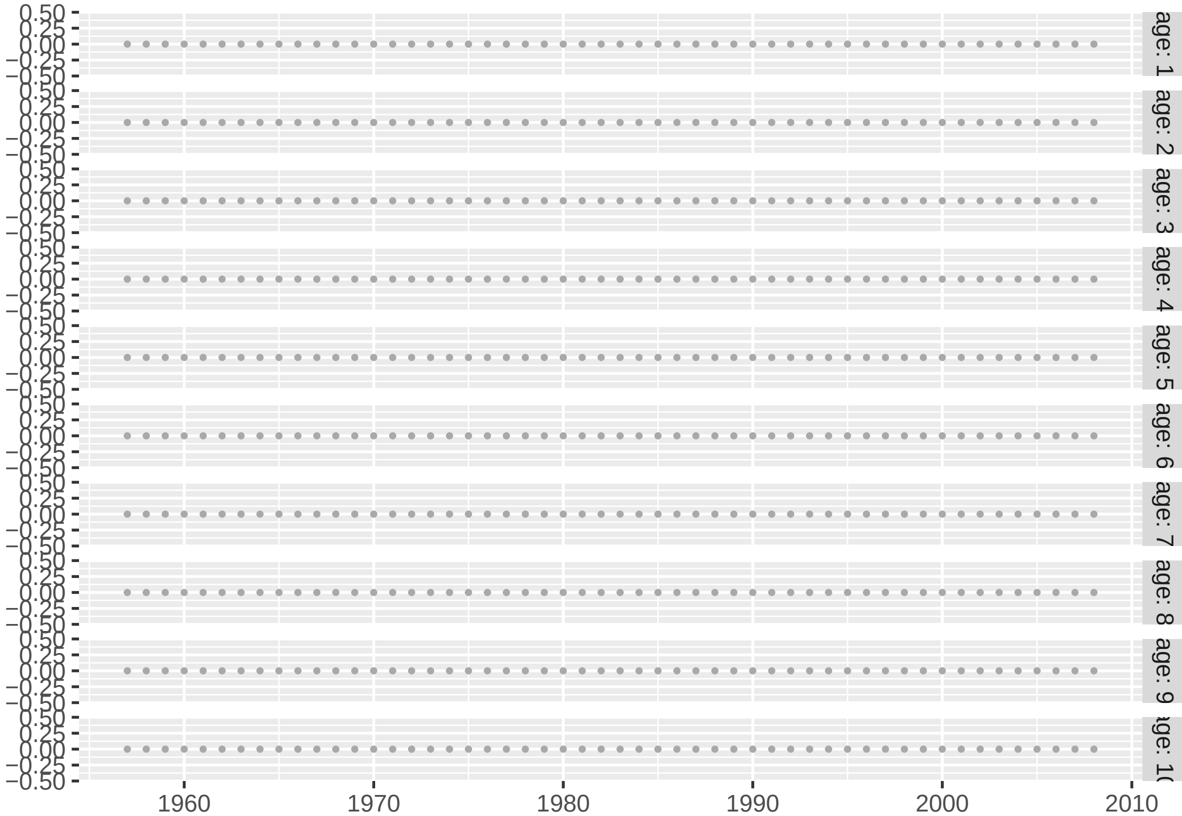
```
xyplot(data~year|age, harvest(ple4), xlab="", ylab="", type="b", cex=0.5, pch=19)
```



But the *ggplotFL* package, which we have already loaded, provides a new set of plot methods based on ggplot2, from which all the plots shown so far in this tutorial have been generated.

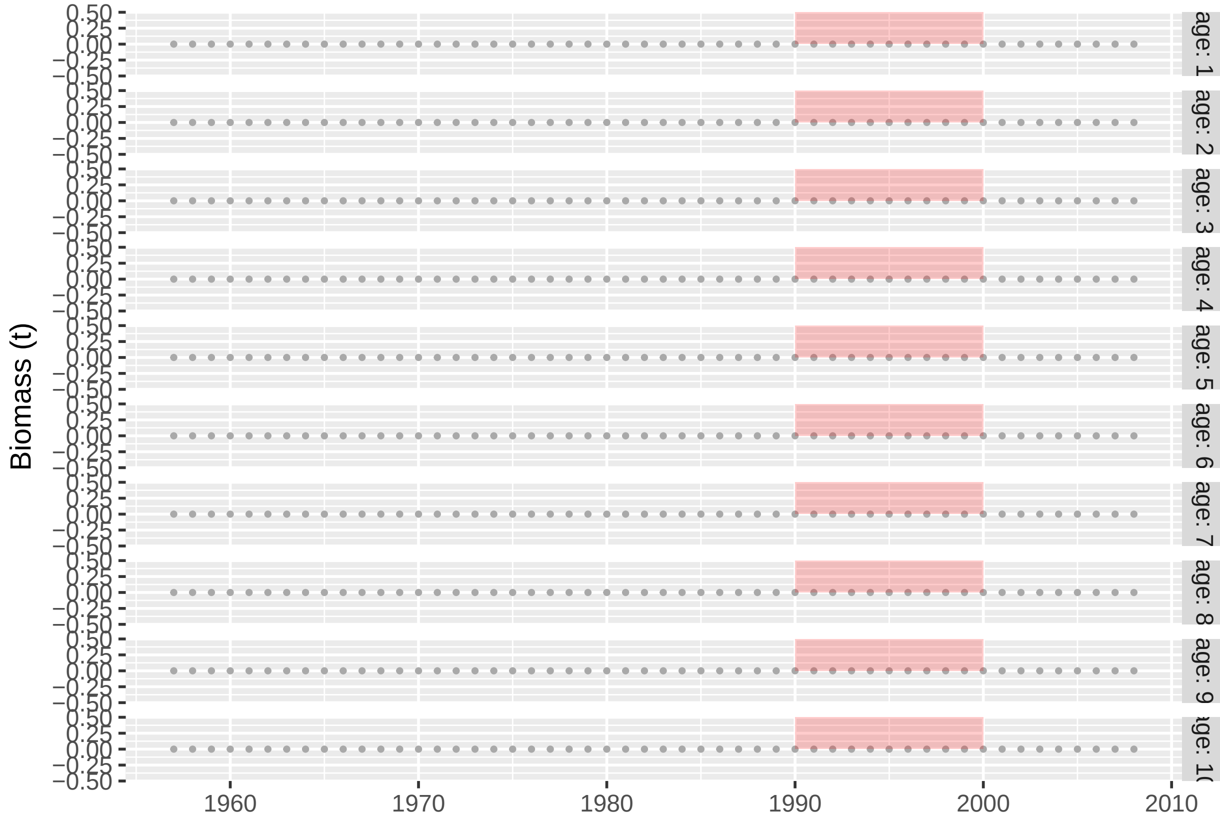
One important advantage of *ggplot2* is that plots are returned as objects that can be modified and extended. For example, the basic plot for the abundances at age *FLQuant* using *ggplotFL* would be this one

```
plot(stock.n(ple4))
```



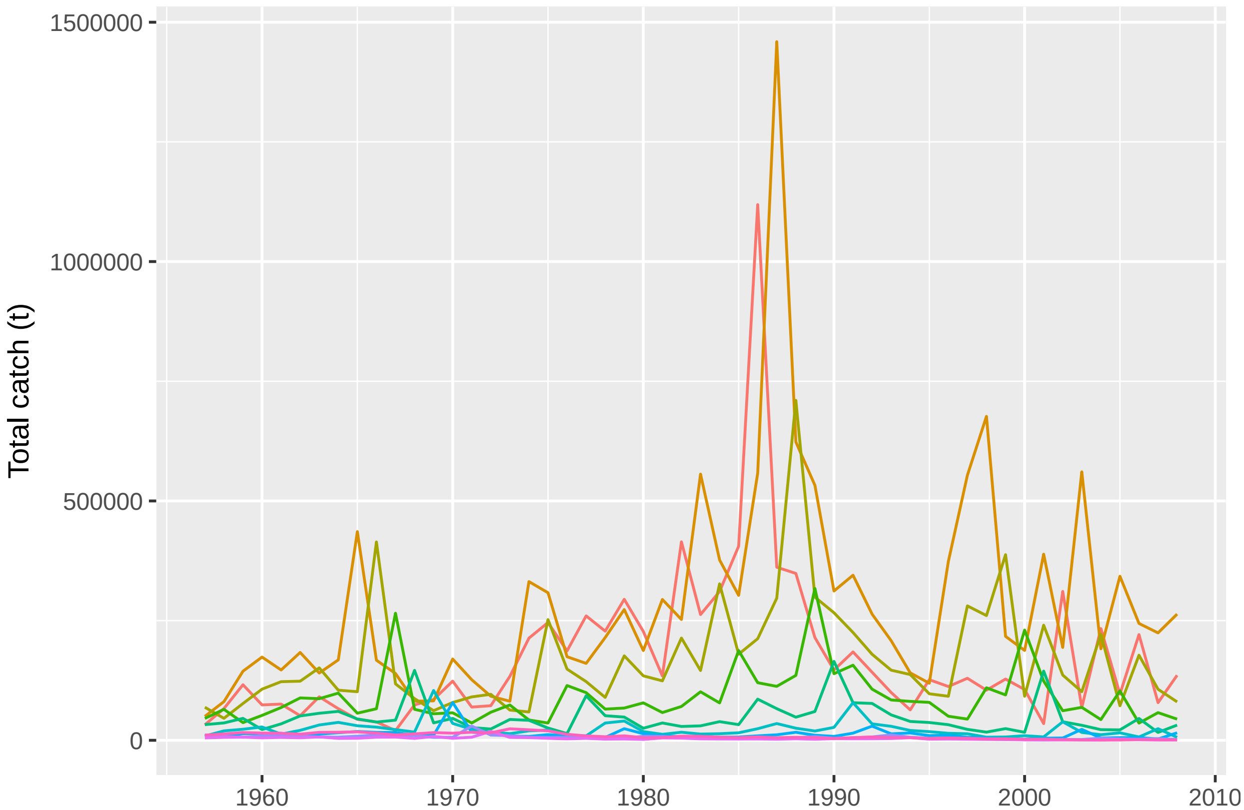
in which each age is shown in a different horizontal panel (*facet*). Now we can modify this plot in various ways by adding extra *ggplot2* commands to it, for example by adding a label to the `y` axis, shading a certain period of interest

```
plot(stock.n(ple4)) +
  # Add y label
  ylab("Biomass (t)") +
  # Draw rectangle between years 1990 and 2000
  annotate("rect", xmin = 1990, xmax = 2000, ymin = 0, ymax = Inf,
    # in semi-transparent red
    alpha = .2, fill='red')
```



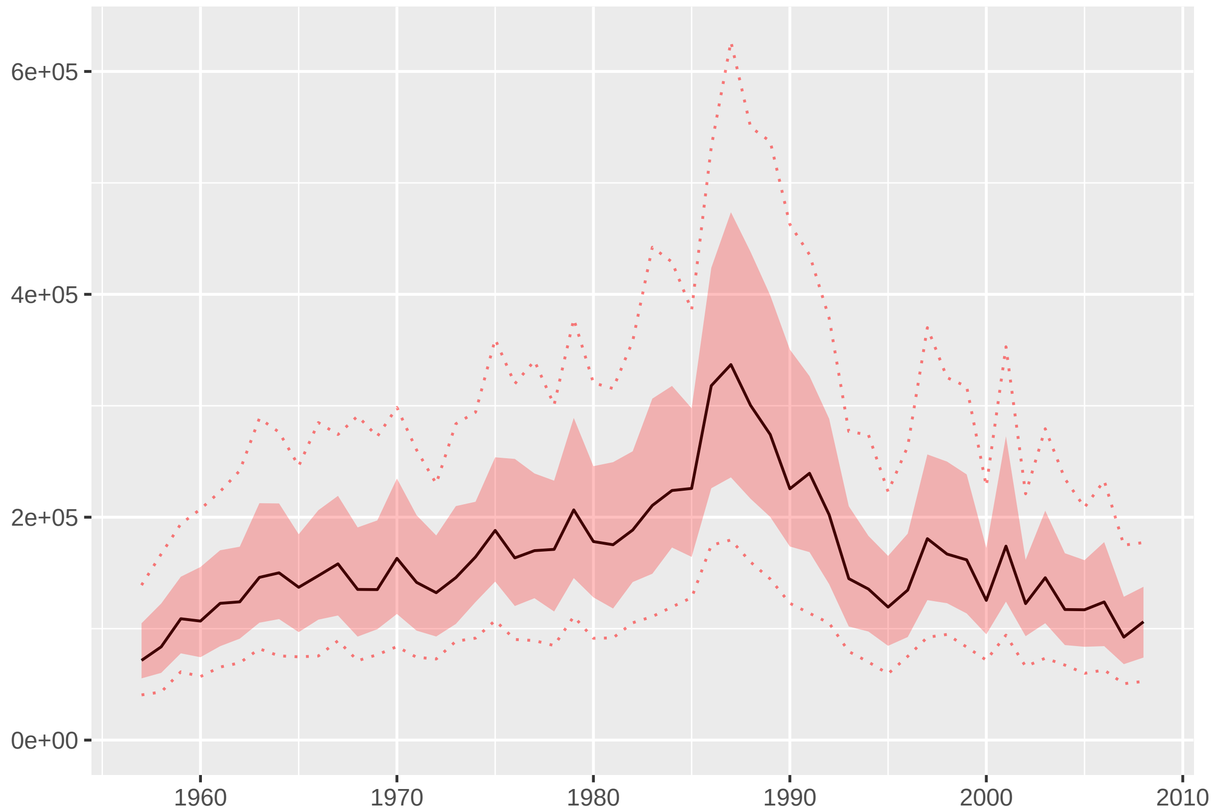
The basic method in *ggplot2* taking a data input, `ggplot`, has also been defined for some *FLCore* class, which simpliefies constructing plots based on objects of those classes from scratch. For example, we can plot our catch-at-age matrix from *ple4* to show the signal of strong cohorts in the data using

```
ggplot(data=catch.n(ple4), aes(x=year, y=data, group=age)) +
  geom_line(aes(colour=as.factor(age))) +
  ylab("Total catch (t)") + xlab("") + theme(legend.position="none")
```



ggplotFL deals with multiple iterations in **FLR** objects by calculating quantiles along the *iter* dimension and plotting them as areas and lines. For example, an object with random lognormal noise around the catch time series would look like this

```
plot(rlnorm(250, log(catch(ple4)), 0.5))
```



where the 50% and 95% intervals are shown as a red region and a dotted line respectively, while the median value is shown as a black line.

Note that plot methods on both *FLCore* and *ggplotFL* work by converting various **FLR** objects to a class that *lattice* and **gplot2** can understand, *data.frame*s. Coercing a 6D array like an *FLQuant* to a 2D *data.frame* requires generating one column per dimension, named as those, plus an extra column for the values stored in the object. This column is named `data`, thus the use of `data` in various plot formulas above. For classes with multiple slots, like *FLStock*, an extra column is necessary, which will be called `slots`. Please check this help page to know more about the coertion methods for **FLR** objects.

More information

For further explanations on the use of the two plotting platforms available for **FLR** classes, please refer to the ggplotFL plotting FLR objects with ggplot2 and Plotting FLR objects using lattice tutorials.

Running a stock assessment

An important step in providing management advice for a fish stock is the estimation of current status, past history and stock productivity through an stock assessment (SA) model. The *FLStock* object we have created contains some of the inputs required for most SA models: catches, natural mortality, and maturity. What is now needed is some indication of changes in abundance over the period of exploitation, an index of abundance, derived from either research surveys or catch-per-unit-effort of commercial fleets.

Index of abundance

An index of abundance for the North Sea plaice stock, as an object of class FLIndex, is available as an example dataset in *FLCore*, and can be loaded using the *data* command

```
data(ple4.index)
```

This time series of abundances at age, covering from 1985 to 2008, was obtained during the ICES International Bottom Trawl Survey, as is one of the indices used by the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK).

The *FLIndex* class is able to contain not only the index of abundance, in this case as an age-structured *FLQuant*, but also other information on variance, associated catches, effort, selectivity and catchability, which might be used by certain methods.

```
summary(ple4.index)
```

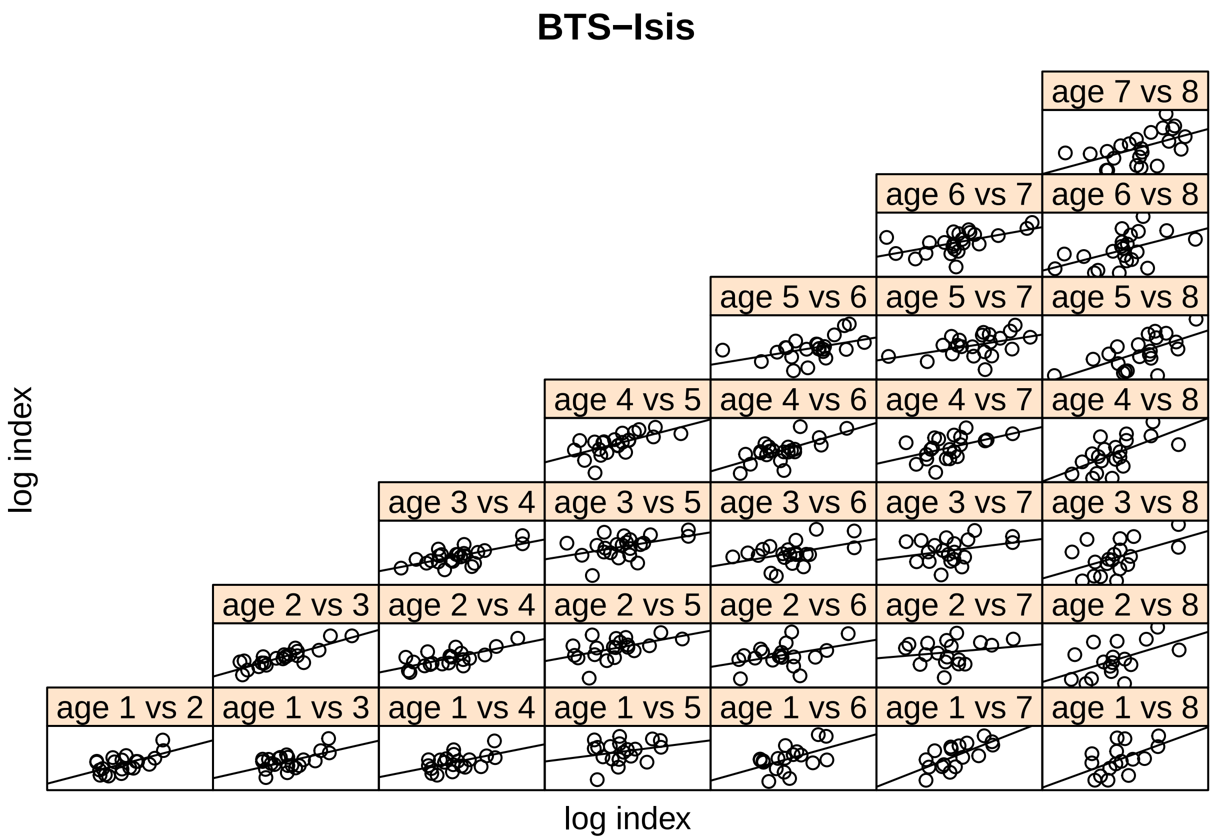
```
An object of class "FLIndex"

Name: BTS-Isis
Description: Plaice in IV . Imported from VPA file.
Type :
Distribution :
Quant: age
Dims:  age  year    unit    season  area    iter
    8   24  1   1   1   1

Range:  min max pgroup  minyear maxyear startf  endf
    1   8   NA  1985    2008    0.66    0.75

index         : [ 8 24 1 1 1 1 ], units =  NA
index.var     : [ 8 24 1 1 1 1 ], units =  NA
catch.n       : [ 8 24 1 1 1 1 ], units =  NA
catch.wt      : [ 8 24 1 1 1 1 ], units =  NA
effort        : [ 1 24 1 1 1 1 ], units =  NA
sel.pattern   : [ 8 24 1 1 1 1 ], units =  NA
index.q       : [ 8 24 1 1 1 1 ], units =  NA
```

```
plot(ple4.index)
```



The *range* slot in this class contains information about the time period over which the survey takes place, as proportions of the year, in this case from the beginning of August to the end of September.

```
range(ple4.index)[c("startf", "endf")]
```

```
startf   endf
  0.66   0.75
```

a4a statistical catch-at-age

The FLa4a package provides an **FLR** implementation of the *a4a* model, an statistical catch-at-age model of medium complexity that has been designed to make use of the power and flexibility of R's formula-based model notation (as used for example in lm), while giving access to a solid and fast minimization algorithm implemented using AD Model Builder.

```
library(FLa4a)
```

A first go at fitting this model to the *ple4* and *ple4.index* datasets requires a single line of code

```
fit <- sca(ple4, FLIndices(BTS=ple4.index))
```

This returns an object of class a4aFit that contains the results fo the model fit, including the estimated catch-at-age, and the derived abundances and fishing mortality at age

```
summary(fit)
```

```
An object of class "a4aFit"

Name:
```

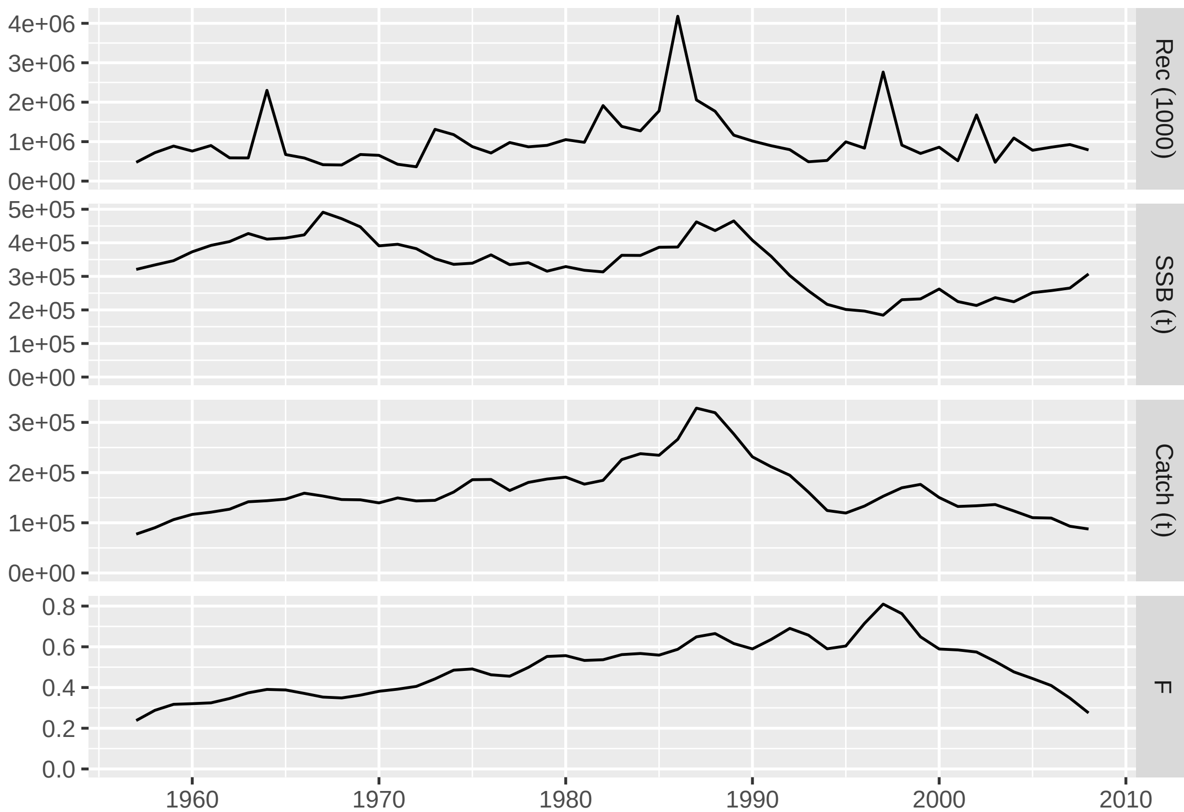
```
Description:
Quant: age
Dims:  age  year    unit    season  area    iter
    10  52  1   1   1   1

Range:  min max pgroup  minyear maxyear minfbar maxfbar
    1   10  10  1957    2008    2   6

stock.n       : [ 10 52 1 1 1 1 ], units =  1000
harvest       : [ 10 52 1 1 1 1 ], units =  f
catch.n       : [ 10 52 1 1 1 1 ], units =  1000
```

which we can use to update the *FLStock* object

```
stk <- ple4 + fit
plot(stk)
```



Among other methods, *FLa4a* provides a range of tools for inspecting the quality of the model fit. For example, a set of residuals, for the fits to both the index olf abundance and

More information

Please see the tutorial for more examples on how to .

Exploring the stock-recruitment relationship

Fitting a model for the relationship between stock abundance and expected recruitment is necessary for forecasting the future dynamics of the stock under various levels of fishing mortality, the central element of fisheries management advice. Certain stock assessment models, for example most statistical catch-at-age models, include the stock-recruitment model in the estimated parameters, but for others, like Virtual Population Analysis, this is a setup carried out once the stock of population abundace have been obtained.

Both inputs and outputs for stock-recruitment models are stored in an object of the FLSR class which we can create directly from the SA results by coertion using

```
plsr <- as.FLSR(stk)
```

The resulting *FLSR* object contains the series of recruitment `rec`, the abundance of the first age, and the stock reproductive potential, in this case the spawning stock biomass `ssb`. Both series are already displaced as corresponds by the age of recruitment, 1 in this case.

```
summary(plsr)
```

```
An object of class "FLSR"

Name:
Description: 'rec' and 'ssb' slots obtained from a 'FLStock' object
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 =  1000
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 =  1000

Model:  list()
Parameters:
    params
iter
   1
Log-likelihood:  NA(NA)
Variance-covariance: <0 x 0 matrix>
```

We now need to choose a model to fit, and *FLCore* provides a number of them already defined in terms of:

- the model formula, kept in the `model` slot
- a function returning the log-likelihood, to be used for minimization, in the `logl` slot
- a function to obtain initial values for the minimization procedure, in the `initial` slot

See the SR Models help page for further details of the available models.

We can now assign the output of the chosen model function, in this case `ricker()` to the existing object using

```
model(plsr) <- ricker()
```

The model object is ready to fit, through Maximum Likelihood Estimation (MLE), using the `fmle` method defined in *FLCore*. This makes use of R's `optim`, but defaults to the Melder-Mead algorithm.

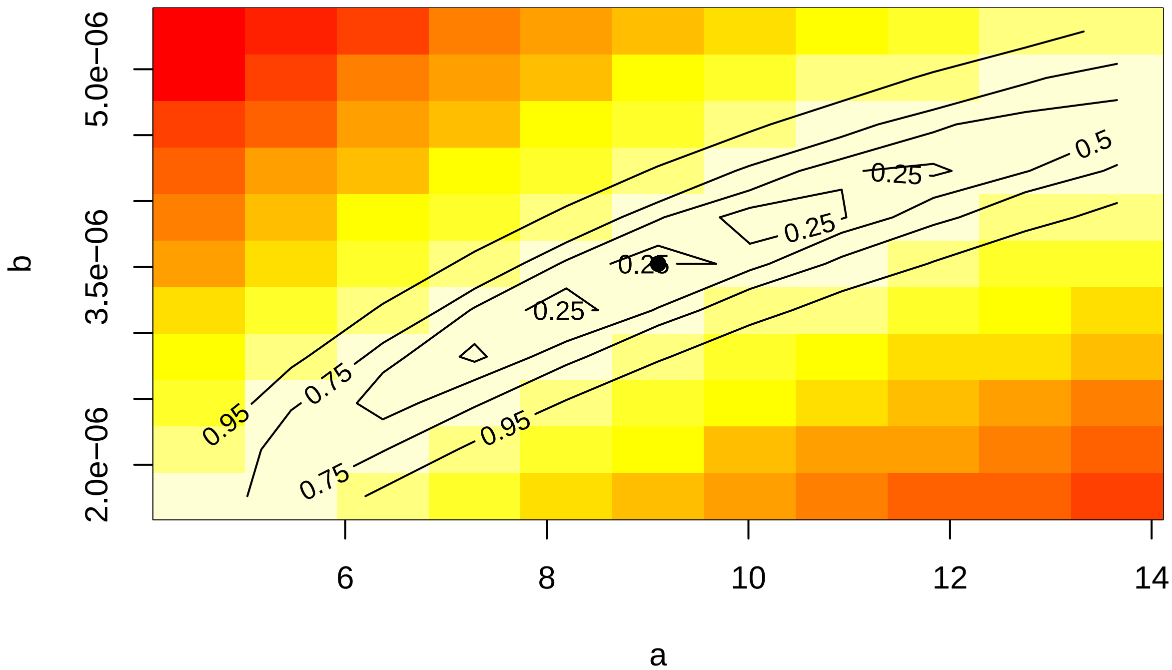
```r
plsr <- fmle(plsr)
```

Another look at the object ill show us that a number of slots now contain the results of the model fit, among them:

- `fitted` for the estimated recruitment, as an *FLQuant*
- `residuals` for the residuals in log space, *FLQuant*
- `params` for the estimated parameters, as an object of class *FLPar*
- `vcov` for the variance-covariance matrix, as an *array*

The standard plot for the class shows the model fit and a series of useful diagnostics that will help us evaluating the its quality and usefulness for future projections. This can be further explored by likelihood profiling over a range of values of the estimated parameters, simply calling the `profile` method of the object

```r
profile(plsr)
```



Finally, the model can be used to predict future recruitments if provided with a set of new of values of SSB, as in

```r
predict(plsr, ssb=FLQuant(rnorm(10, 25e4, sd(ssb(plsr))), dimnames=list(age=1, year=2008:2017)))
```

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

   year
age 2008   2009   2010   2011   2012   2013   2014   2015   2016   2017
  1 949982 918951 943288 932477 918357 946336 894682 940465 920933 948483

units:  NA
```

More information

Please see the Modelling stock recruitment with FLSR tutorial for more examples and information on the stock-recruitment model fitting capabilities of **FLR**.

Estimating reference points

To assess current and future status of a stock we need reference points which he hold to represent desirable states for the stock, usually either in terms of stock abundance, like B_{MSY}, the biomass expected to produce, on average and under the current exploitation pattern, the Maximum Sustainable Yield (MSY), or of fishing mortality, such as the fishing mortality expected to produce MSY, F_{MSY}.

We can use the FLBRP package to calculate a large set of reference points, once we have an estimate of stock status, our *FLStock* object, and of the stock-recruitment relationship, *FLSR*. We can use them both to create the necessary object, of class FLBRP, after loading the package

```
library(FLBRP)
plrp <- FLBRP(stk, sr=plsr)
summary(plrp)
```

```
An object of class "FLBRP"

Name:
Description:
Quant: age
Dims:  age  year    unit    season  area    iter
    10  101 1   1   1   1

Range:  min max pgroup  minfbar maxfbar
    1   10  10  2   6

fbar           : [ 1 101 1 1 1 1 ], units =  f
fbar.obs       : [ 1 52 1 1 1 1 ], units =  f
landings.obs   : [ 1 52 1 1 1 1 ], units =  t
discards.obs   : [ 1 52 1 1 1 1 ], units =  t
rec.obs        : [ 1 52 1 1 1 1 ], units =  1000
ssb.obs        : [ 1 52 1 1 1 1 ], units =  t
stock.obs      : [ 1 52 1 1 1 1 ], units =  t
profit.obs     : [ 1 52 1 1 1 1 ], units =  NA
landings.sel   : [ 10 1 1 1 1 1 ], units =  f
discards.sel   : [ 10 1 1 1 1 1 ], units =  f
bycatch.harv   : [ 10 1 1 1 1 1 ], units =  f
stock.wt       : [ 10 1 1 1 1 1 ], units =  kg
landings.wt    : [ 10 1 1 1 1 1 ], units =  kg
discards.wt    : [ 10 1 1 1 1 1 ], units =  kg
bycatch.wt     : [ 10 1 1 1 1 1 ], units =  NA
m              : [ 10 1 1 1 1 1 ], units =  m
mat            : [ 10 1 1 1 1 1 ], units =
harvest.spwn   : [ 10 1 1 1 1 1 ], units =
m.spwn         : [ 10 1 1 1 1 1 ], units =
availability   : [ 10 1 1 1 1 1 ], units =  NA
price          : [ 10 1 1 1 1 1 ], units =  NA
vcost          : [ 1 1 1 1 1 1 ], units =  NA
fcost          : [ 1 1 1 1 1 1 ], units =  NA
```

An object of the *FLBRP* class contains a series of times series of observations on dynamics of both stock and fishery, as well as average quantities computed along an specified time period. A series of slot are designed to contain economic variables, such as `price`, variable costs (`vcost`) and fixed costs (`fcost`), which will need to be provided. When those data are available, economic reference points can also be calculated. Finally, a vector of fishing mortality values, `fbar`, has been created, by default to be of length 101 and with values going from $F = 0$ to $F = 4$, to be used in the calculation procedure.

We can now proceed with the calculation of reference points, through the `brp` method

```
plrp <- brp(plrp)
```

and the extraction of the values obtained, stored in the `refpts` slot of the object

```
refpts(plrp)
```

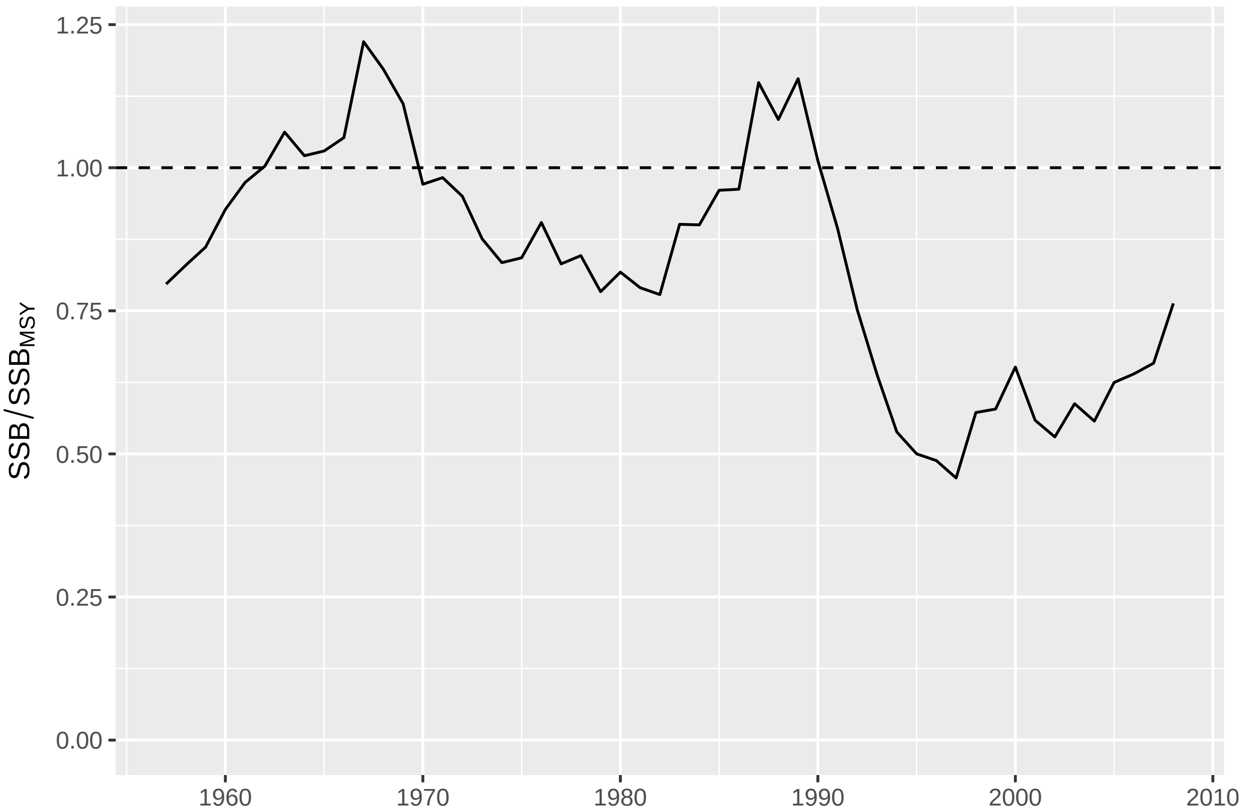
```
An object of class "FLPar"
        quantity
refpt    harvest  yield    rec      ssb      biomass  revenue  cost
  virgin 0.00e+00 0.00e+00 2.36e+05 1.05e+06 1.10e+06       NA       NA
  msy    4.05e-01 6.78e+04 8.87e+05 4.03e+05 5.34e+05       NA       NA
  crash  7.95e-01 1.67e-06 4.15e-05 4.56e-06 9.41e-06       NA       NA
  f0.1   1.72e-01 4.15e+04 4.84e+05 7.51e+05 8.38e+05       NA       NA
  fmax   2.31e-01 5.25e+04 5.92e+05 6.56e+05 7.56e+05       NA       NA
  spr.30 1.98e-01 4.66e+04 5.31e+05 7.09e+05 8.01e+05       NA       NA
  mey          NA       NA       NA       NA       NA       NA       NA
        quantity
refpt    profit
  virgin       NA
  msy          NA
  crash        NA
  f0.1         NA
  fmax         NA
  spr.30       NA
  mey          NA
units:  NA
```

This slot contains the estimates for a series of reference points and for a number of quantities. For example, the value stored at the intersection of `msy` and `harvest` corresponds to F_{MSY}, while that of `virgin` and `ssb` is the estimate of virgin stock biomass. We can, for example, extract the two standard MSY-related reference points as a named vector using

```
pmsy <- refpts(plrp)["msy", c("harvest", "ssb"), drop=TRUE]
```

to then use them to visualize the status of the stock in relation to these points, for example

```
plot(ssb(stk) / pmsy["ssb"]) + geom_hline(aes(yintercept=1), linetype=2) +
  ylab(expression(SSB / SSB[MSY]))
```



More information

For more information on *FLBRP*, please see the Reference points for fisheries management with FLBRP tutorial.

Forecasting under different scenarios

Our final step in this quick tour takes us to the tools in *FLR* for forecasting the future responses of the stock to alternative management decisions. This example concerns a Short Term Forecast, in which the effect of the current management, for example a maximum catch limit or TAC, on the present year is forecasted, and then a series of alternative increases or decreases in catch are applied to the object representing our current understanding of the stock status and dynamics.

The FLash package contains the current implementation of the forecasting mechanism in *FLR*. Please note that FLash is currently only working on 32 bit R if using Windows. A new forecasting package, called *FLasher* is about to be released and will only work on 64 bit R.

```
library(FLash)
```

The key element in the *FLash* interface is the *fwdControl* class, which allows us to specify the targets and limits that we want the stock to achieve or remain within. But first we need to make some assumptions about the future values of certain quantities, both on the biology (natural mortality, maturity) and the fishery (selectivity, proportion of discards). A common approach for this kind of forecast is to use averages over the last few years (tipycally three) for certain quantities. This can be done in *FLR* using the `stf` method in the *FLBRP* package.

```
proj <- FLBRP:::stf(stk)
```

Our new object extends up to 2011, and the values for certain stocks have been extended using the mean of the last three years, for example for the weight-at-age in the stock

```
stock.wt(proj)[, ac(2006:2011)]
```

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

    year
age  2006     2007     2008     2009     2010     2011    
  1  0.062313 0.060347 0.058530 0.060397 0.060397 0.060397
  2  0.139194 0.111512 0.122204 0.124303 0.124303 0.124303
  3  0.210275 0.221105 0.240195 0.223858 0.223858 0.223858
  4  0.294857 0.314374 0.320583 0.309938 0.309938 0.309938
  5  0.385415 0.361766 0.387632 0.378271 0.378271 0.378271
  6  0.396499 0.377003 0.434290 0.402598 0.402598 0.402598
  7  0.439897 0.514525 0.357386 0.437270 0.437270 0.437270
  8  0.464998 0.347238 0.460998 0.424411 0.424411 0.424411
  9  0.532624 0.590289 0.640373 0.587762 0.587762 0.587762
  10 0.755080 0.618717 0.636754 0.670183 0.670183 0.670183

units:  kg
```

We can now construct a `fwdControl` object that projects the stock as if catches in the current year, 2009 in this case, were those of the agreed TAC, 85,000 t, and F was then kept in 2010 and 2011 at the same levels as in 2008. The main component of a *fwdControl* object is a *data.frame* that must at least contains columns for

- *year*
- *quantity*, the quantity to be projected, for example `ssb`, `f` or `catch`
- *val*, the actual value to be obtained

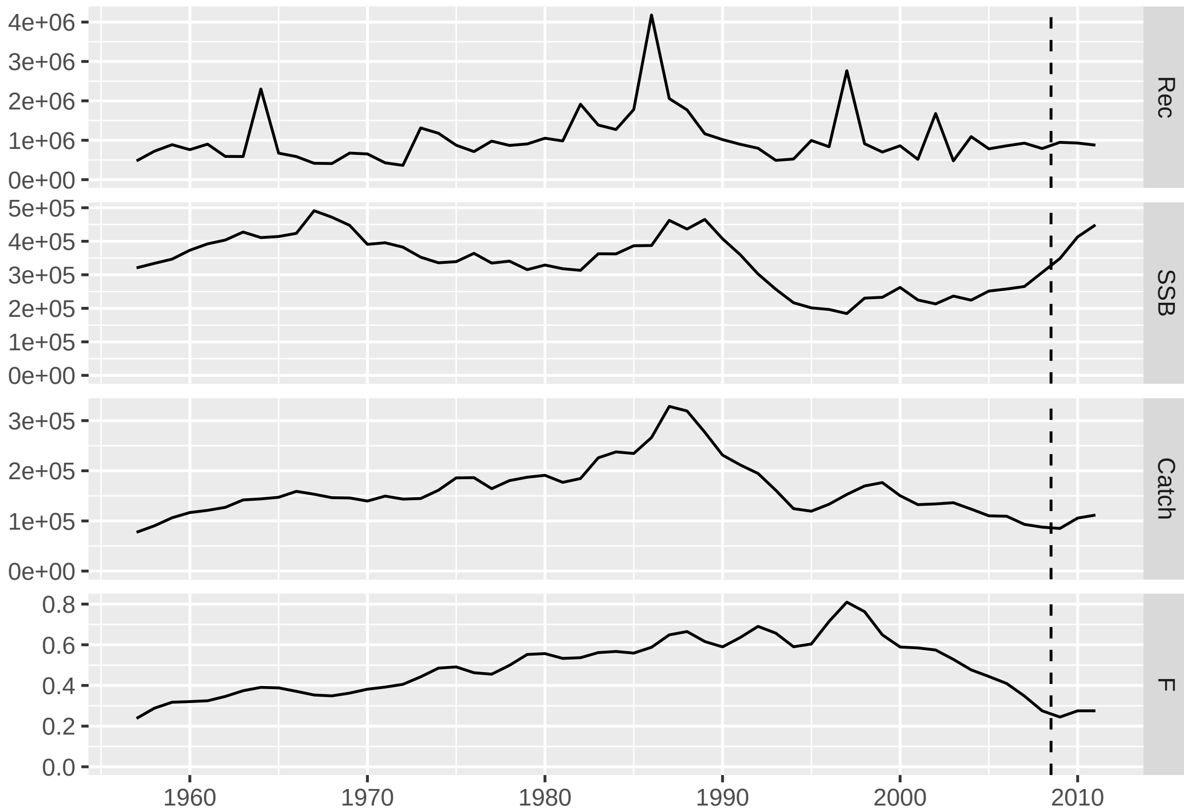
```
TAC <- 85000
Flevel <- fbar(stk)[,"2008"]
ctrl <- fwdControl(data.frame(year=2009:2011, quantity=c("catch", "f", "f"), val=c(TAC, Flevel, Flevel)
```

Now the `fwd` method will carry ou the projection using those three object: stock, stock-recruitment and control

```
proj <- fwd(proj, control=ctrl, sr=plsr)
```

and the results can be visualized

```
plot(proj) + geom_vline(aes(xintercept=2008.5), linetype=2)
```



More information

Please see the Short Term Forecasting for advice using FLash and Short Term Forecasting for advice using FLash tutorials for more examples on how to use the capabilitis of *FLash* to forecast population dynamics under various scenarios.

More on FLR

Please visit our website for more information on the FLR packages, tutorials and examples of use, and instructions for getting in touch if you want to report a bug, ask a question or get involved in the development of the **FLR** toolset. The project is run by a team of fisheries scientists that decided to share the R code they were writing and using so a common platform for Quantitative Fisheries Science in R could break the Babel tower spell that J. Schnute first identified

"The cosmic plan for confounding software languages seems to be working remarkably well among the community of quantitative fishery scientists!"

Schnute et al. 2007

References

L. T. Kell, I. Mosqueira, P. Grosjean, J-M. Fromentin, D. Garcia, R. Hillary, E. Jardim, S. Mardle, M. A. Pastoors, J. J. Poos, F. Scott, R. D. Scott; FLR: an open-source framework for the evaluation and development of management strategies. *ICES J Mar Sci* 2007; 64 (4): 640-646. doi: 10.1093/icesjms/fsm012.

More information

- You can submit bug reports, questions or suggestions on this tutorial at https://github.com/flr/doc/issues.
- Alternatively, 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 3.4.1 (2017-06-30)
- FLCore: 2.6.5
- ggplotFL: 2.6.1
- FLa4a: 1.1.3
- FLBRP: 2.5.2
- FLash: 2.5.8
- **Compiled**: Fri Sep 15 14:48:02 2017

License

Author information

Iago MOSQUEIRA. European Commission, DG Joint Research Centre, Directorate D - Sustainable Resources, Unit D.02 Water and Marine Resources, Via E. Fermi 2749, 21027 Ispra VA, Italy. https://ec.europa.eu/jrc/.