

# Life History Relationships

*03 enero, 2018*

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Life history traits include growth rate; age and size at sexual maturity; the temporal pattern or schedule of reproduction; the number, size, and sex ratio of offspring; the distribution of intrinsic or extrinsic mortality rates (e.g., patterns of senescence); and patterns of dormancy and dispersal. These traits contribute directly to age-specific survival and reproductive functions.<sup>1</sup> The **FLife** package has a variety of methods for modelling life history traits and functional forms for processes for use in fish stock assessment and for conducting Management Strategy Evaluation (MSE).

These relationships have many uses, for example in age-structured population models, functional relationships for these processes allow the calculation of the population growth rate and have been used to develop priors in stock assessments and to parameterise ecological models.

The **FLife** package has methods for modelling functional forms, for simulating equilibrium FLBRP and dynamic stock objects FLStock.

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## Quick Start

This section provide a quick way to get running and overview of what functions are available, their potential use, and where to seek help. More details are given in later sections.

The simplest way to obtain **FLife** is to install it from the FLR repository via the R console:

```
install.packages("FLife", repos = "http://flr-project.org/R")
```

See `help(install.packages)` for more details.

After installing the **FLife** package, you need to load it

```
library(FLife)
```

There is an example teleost dataset used for illustration and as a test dataset, alternatively you can load your own data.

```
data(teleost)
```

The dataset contains life history parameters for a range of bony fish species and families, i.e. von Bertalanffy growth parameters ( $L_{\infty}, k, t_0$ ), length at 50% mature ( $L_{50}$ ), and the length weight relationship ( $a, b$ ).

When loading a new dataset it is always a good idea to run a sanity check e.g.

---

<sup>1</sup><http://www.oxfordbibliographies.com/view/document/obo-9780199830060/obo-9780199830060-0016.xml>

```
is(teleost)
```

```
[1] "FLPar"      "array"      "structure" "vector"
```

The `teleost` object can be used to create **vectors** or other ‘objects with values by age using **FLife** methods, e.g. to construct a growth curve for hutchen (*Hucho hucho*)

```
vonB(1:10,teleost[, "Hucho hucho"])
```

```
[1] 29.0 40.8 51.5 61.1 69.9 77.8 84.9 91.4 97.3 102.6
```

## Plotting

Plotting is done using **ggplot2** which provides a powerful alternative paradigm for creating both simple and complex plots in R using the *Grammar of Graphics*<sup>2</sup> The idea of the grammar is to specify the individual building blocks of a plot and then to combine them to create the desired graphic<sup>3</sup>.

The **ggplot** methods expects a `data.frame` for its first argument, `data` (this has been overloaded by **ggplotFL** to also accept FLR objects); then a geometric object `geom` that specifies the actual marks put on to a plot and an aesthetic that is “something you can see” have to be provided. Examples of geometric Objects (`geom`) include points (`geom_point`, for scatter plots, dot plots, etc), lines (`geom_line`, for time series, trend lines, etc) and boxplot (`geom_boxplot`, for, well, boxplots!). Aesthetic mappings are set with the `aes()` function and, examples include, position (i.e., on the x and y axes), color (“outside” color), fill (“inside” color), shape (of points), linetype and size.

```
age=FLQuant(1:20,dimnames=list(age=1:20))
len=vonB(age,teleost)
```

```
ggplot(as.data.frame(len))+
  geom_line(aes(age,data,col=iter))+
  theme(legend.position="none")
```

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## Methods

### Life History Parameters

#### Growth

Consider the von Bertalanffy growth equation

$$L_t = L_\infty (1 - e^{(-kt-t_0)})$$

where  $L_t$  is length at time  $t$ ,  $L_\infty$  the asymptotic maximum length,  $k$  the growth coefficient, and  $t_0$  the time at which an individual would, if it possible, be of zero length.

As  $L_\infty$  increases  $k$  declines. in other words at a given length a large species will grow faster than a small species. for example Gislason, Pope, et al. (2008) proposed the relationship

$$k = 3.15L_\infty^{-0.64}$$

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<sup>2</sup>Wilkinson, L. 1999. *The Grammar of Graphics*, Springer. doi 10.1007/978-3-642-21551-3\_13.

<sup>3</sup><http://tutorials.iq.harvard.edu/R/Rgraphics/Rgraphics.html>

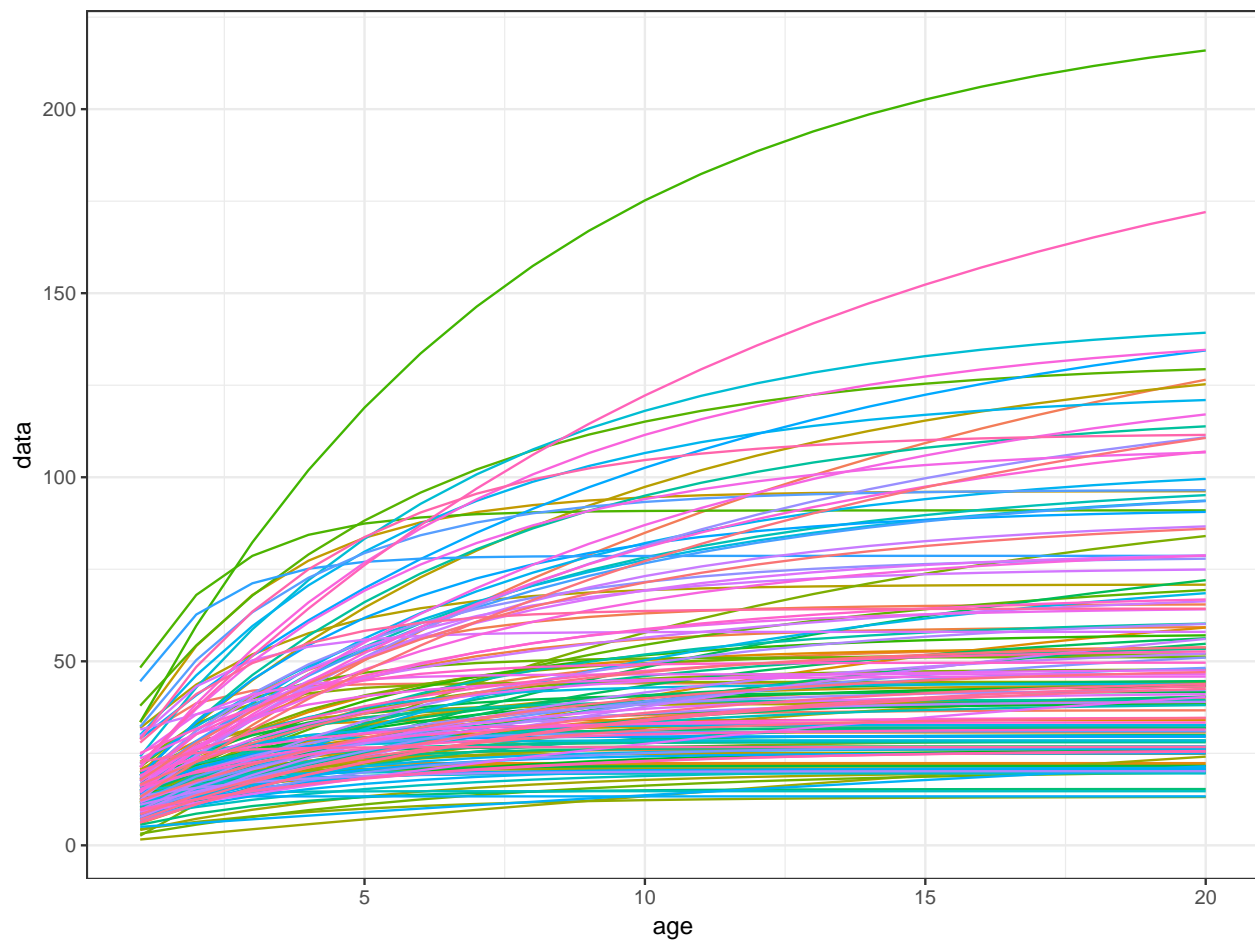


Figure 1: Von Bertalanffy growth curves.

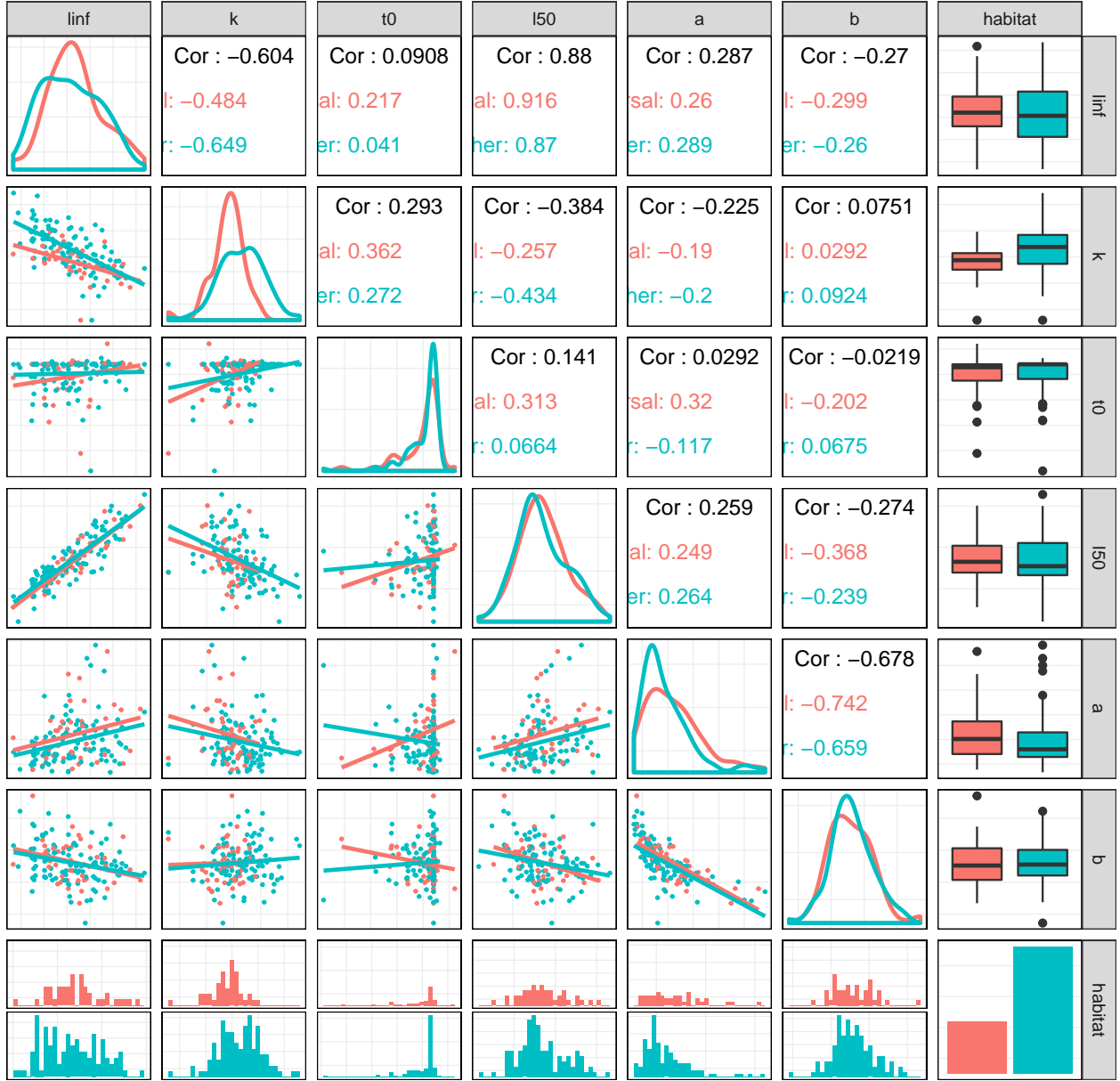


Figure 2: Relationship between life history parameters in the teleost dataset.

There also appears to be empirical relationship between  $t_0$  and  $L_\infty$  and  $k$  i.e.

$$\log(-t_0) = -0.3922 - 0.2752\log(L_\infty) - 1.038\log(k)$$

Therefore for a value of  $L_\infty$  or even  $L_{max}$  the maximum size observed as  $L_\infty = 0.95L_{max}$  then all the growth parameters can be recovered.

## Maturity

There is also a relationship between  $L_{50}$  the length at which 50% of individuals are mature

$$l_{50} = 0.72L_\infty^{0.93}$$

and even between the length weight relationship

$$W = aL^b$$

## Natural Mortality

For larger species securing sufficient food to maintain a fast growth rate may entail exposure to a higher natural mortality Gislason, Daan, et al. (2008). While many small demersal species seem to be partly protected against predation by hiding, cryptic behaviour, being flat or by possessing spines have the lowest rates of natural mortality Griffiths and Harrod (2007). Hence, at a given length individuals belonging to species with a high  $L_\infty$  may generally be exposed to a higher M than individuals belonging to species with a low  $L_\infty$ .

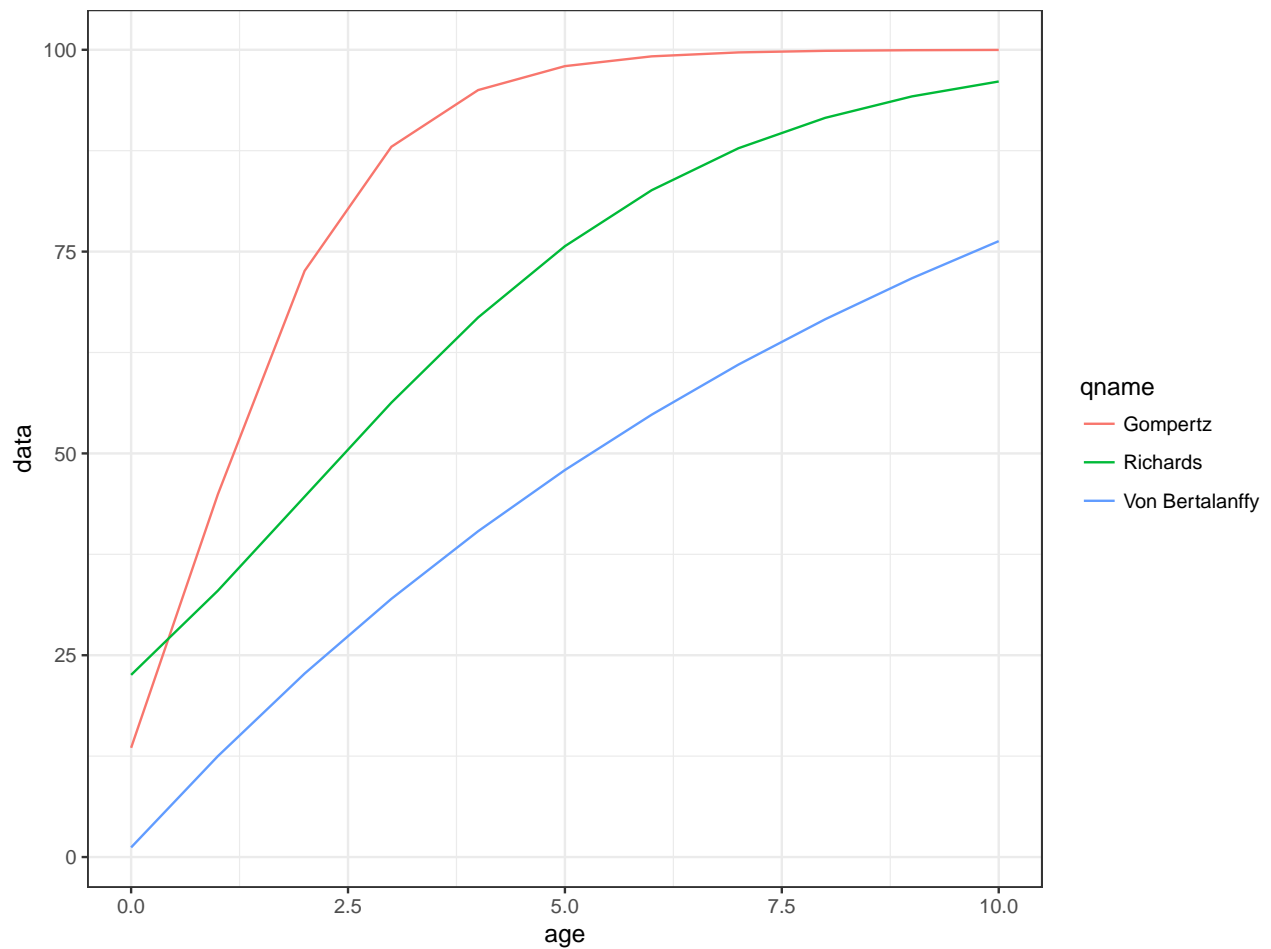
$$\log(M) = 0.55 - 1.61\log(L) + 1.44\log(L_\infty) + \log(k)$$

## Functional forms

In **FLlife** there are methods for creating growth curves, maturity ogives and natural mortality vectors, selection patterns, and other ogives. All these methods are used to create **FLQuant** objects.

## Growth

gompertz, richards, vonB



## Ogives

dnormal, knife, logistic, sigmoid

```
dnormal( age,FLPar(a1=4,sl=2,sr=5000))
knife(   age,FLPar(a1=4))
logistic(age,FLPar(a50=4,ato95=1,asym=1.0))
sigmoid( age,FLPar(a50=4,ato95=1))
```

## Natural Mortality

Many estimators have been propose for M, based on growth and reproduction, see Kenchington (2014).

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## Age at maturity $a_{50}$

Rikhter and Efanov

$$M = \frac{1.521}{a_{50}^{0.72}} - 0.155$$

Jensen

$$M = \frac{1.65}{a_{50}}$$

## Growth

Jensen

$$M = 1.5k$$

Griffiths and Harrod

$$M = 1.406W_{\infty}^{-0.096}k^{0.78}$$

where  $W_{\infty} = \alpha L_{\infty}^{\beta}$

Djabali

$$M = 1.0661L_{\infty}^{-0.1172}k^{0.5092}$$

## Growth and length at maturity $L_{50}$

Roff

$$M = 3kL_{\infty} \frac{(1 - \frac{L_{50}}{L_{\infty}})}{L_{50}}$$

Rikhter and Efanov

$$M = \frac{\beta k}{e^{k(a_{50}-t_0)} - 1}$$

where  $a_{50} = t_0 + \frac{\log(1 - \frac{L_{50}}{L_{\infty}})}{-k}$

## Varing by length

Gislason

$$M_L = 1.73L^{-1.61}L_{\infty}^{1.44}k$$

Charnov

$$M_L = k \frac{L_{\infty}^{1.5}}{L}$$

## Varying by weight

Peterson and Wroblewsk

$$M_W = 1.28W^{-0.25}$$

Lorenzen

$$M_W = 3W^{-0.288}$$

## Senescence

## Conversions

ages, len2wt, wt2len

Generation of missing life history relationships

```
par=lhPar(FLPar(linf=100))
par
```

An object of class "FLPar"

params

linf	k	t0	a	b	ato95	a50
100.0000	0.1653	-0.1000	0.0003	3.0000	1.0000	4.3600
asym	bg	m1	m2	a1	sl	sr
1.0000	3.0000	217.3564	-1.6100	4.3600	2.0000	5000.0000
s	v					
0.9000	1000.0000					

units: cm

There are relationships between the life history parameters and size, growth, maturation, natural mortality and productivity, as seen in the following.

## Simulation

lhPar, lhEq1

## Function Forms

## Population dynamics

## Ecological

leslie, r



## life history traits

An object of class "FLPar"

iters: 145

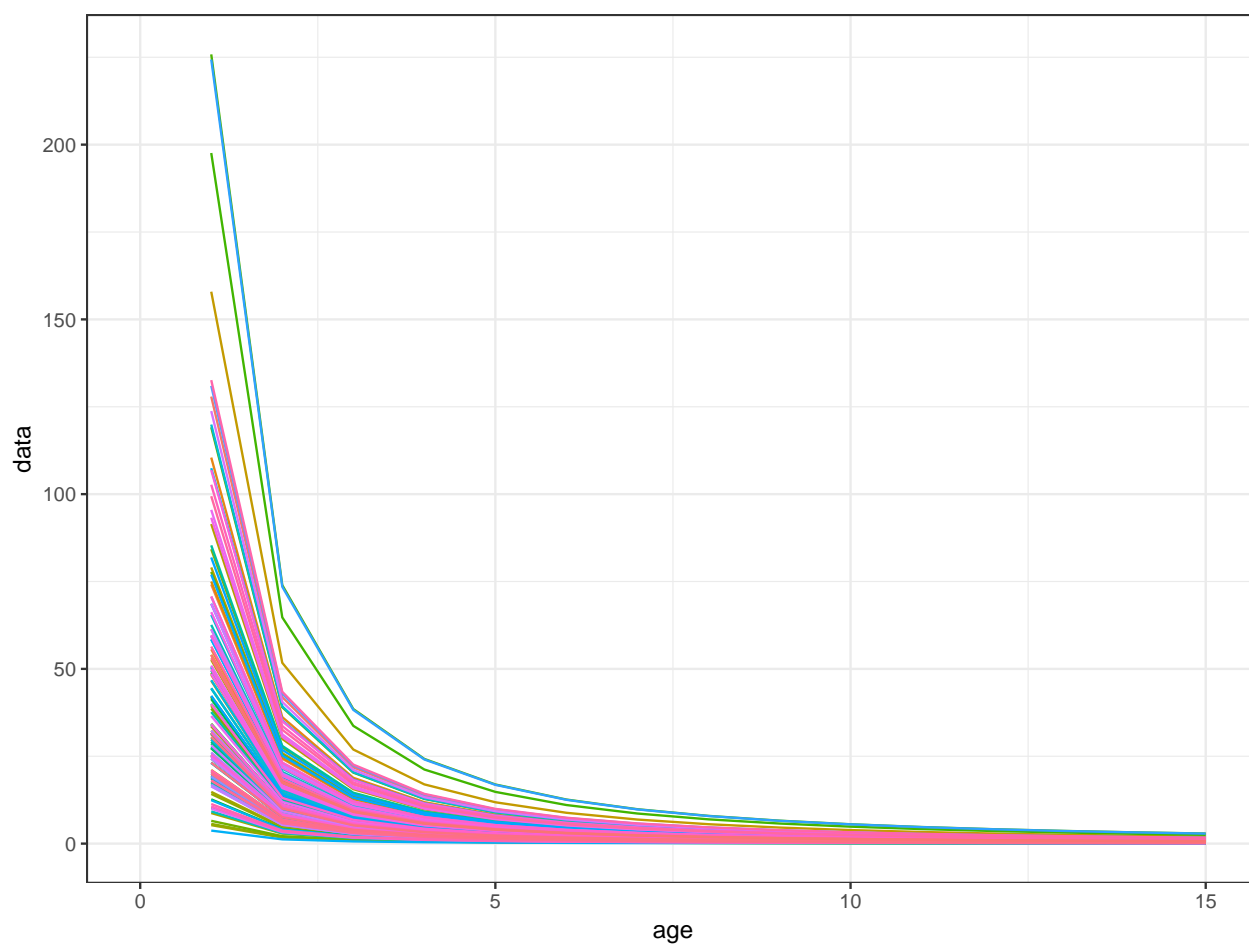
params

	linf		k		t0
	45.100000(28.02114)	0.246667( 0.17297)	-0.143333( 0.13590)		
	l50		a		b
	22.100000(11.71254)	0.011865( 0.00776)	3.010000( 0.15271)		

units: NA

““

## Natural Mortality



## Stock recruitment

## Fishery

## Reference points

lopt, loptAge

## Density Dependence

matdd, mdd

## Parameter estimation

moment, powh

## Stationarity

rod

## Random variables

rnoise

## Refetrence points

```
library(FLBRP)
data(ple4)
refs(ple4)
```

An object of class "FLPar"

params

b.msy	b.virgin	b.f0.1	b.fmax	b.spr.30	b.spr.100
1.76e+06	5.25e+06	2.56e+06	1.85e+06	1.89e+06	2.40e+06
b.f0.1_	b.fmax_	b.spr.30_	b.spr.100_	b.current	s.msy
2.12e+06	1.53e+06	1.56e+06	1.99e+06	3.20e+05	1.58e+06
s.virgin	s.f0.1	s.fmax	s.spr.30	s.spr.100	s.f0.1_
5.04e+06	2.34e+06	1.64e+06	1.68e+06	2.19e+06	1.94e+06
s.fmax_	s.spr.30_	s.spr.100_	s.current	r.msy	r.virgin
1.35e+06	1.39e+06	1.81e+06	2.06e+05	1.05e+06	1.13e+06
r.f0.1	r.fmax	r.spr.30	r.spr.100	r.f0.1_	r.fmax_
1.26e+06	1.26e+06	1.26e+06	1.26e+06	1.04e+06	1.04e+06
r.spr.30_	r.spr.100_	r.current	f.msy	f.crash	f.f0.1
1.04e+06	1.04e+06	8.44e+05	1.15e-01	6.44e-01	8.76e-02
f.fmax	f.spr.30	f.f0.1_	f.fmax_	f.spr.30_	f.current
1.35e-01	1.32e-01	8.76e-02	1.35e-01	1.32e-01	3.56e-01
y.msy	y.f0.1	y.fmax	y.spr.30	y.f0.1_	y.fmax_
1.43e+05	1.63e+05	1.72e+05	1.72e+05	1.35e+05	1.42e+05
y.spr.30_	y.spr.100_	y.current	r	rc	rt
1.42e+05	1.38e+05	9.60e+04	4.42e-01	9.38e-02	3.86e+00

units:

# Simulation

## Simulation of equilibrium values and reference points

```
library(FLBRP)
eq1=1hEq1(par)

ggplot(FLQuants(eq1,"m","catch.sel","mat","catch.wt"))+
  geom_line(aes(age,data))+
  facet_wrap(~qname,scale="free")+
  scale_x_continuous(limits=c(0,15))
```

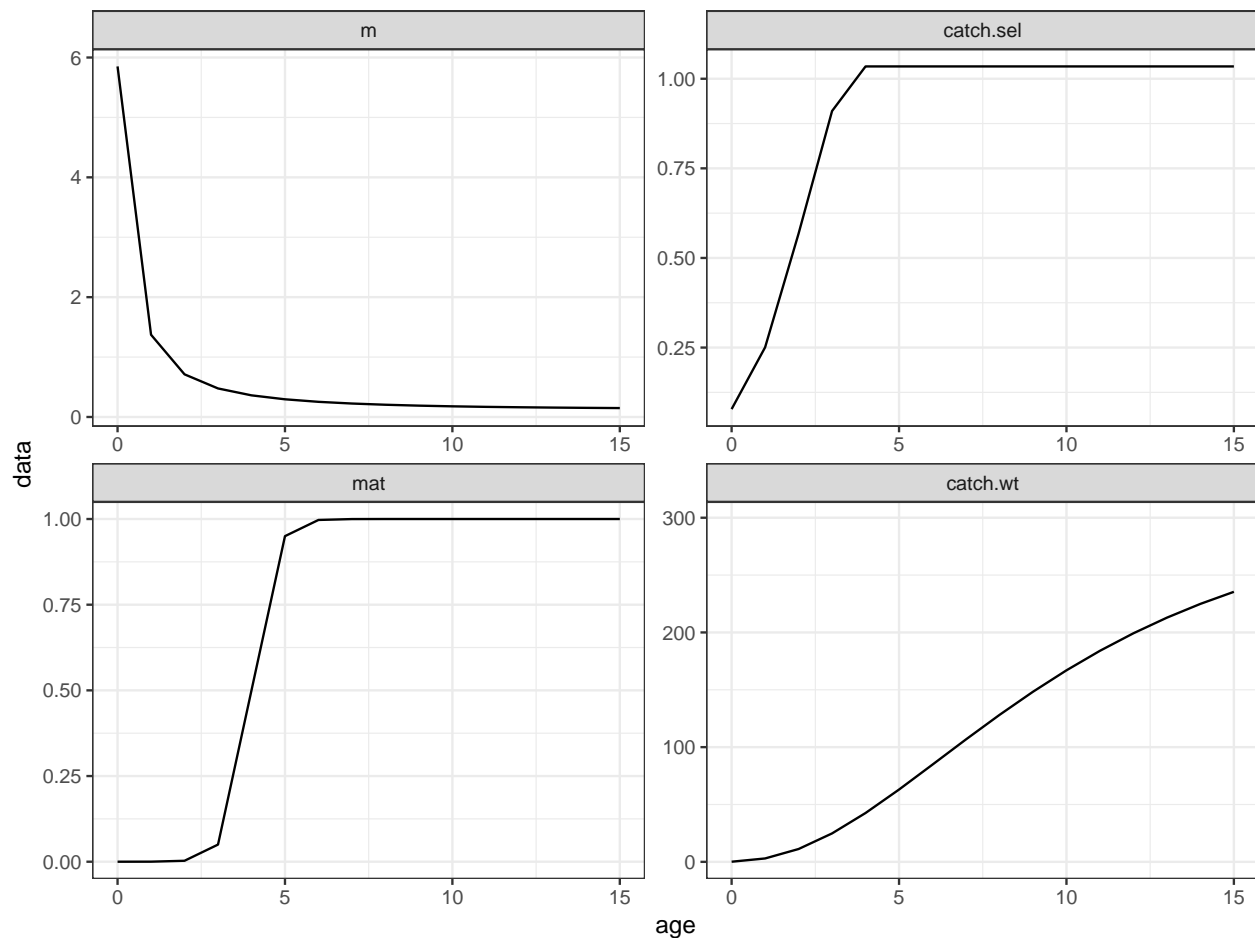


Figure 3: Age-vectors of growthm natural mortality, maturity and selection pattern

An object of class "FLPar"

params

r	rc	msy	lopt	sk	spr0	sprmsy
0.3943	0.1397	53.6441	63.5204	0.1954	0.1208	0.0263
units:	NA	NA	NA	NA	NA	NA

Creation of FLBRP objects

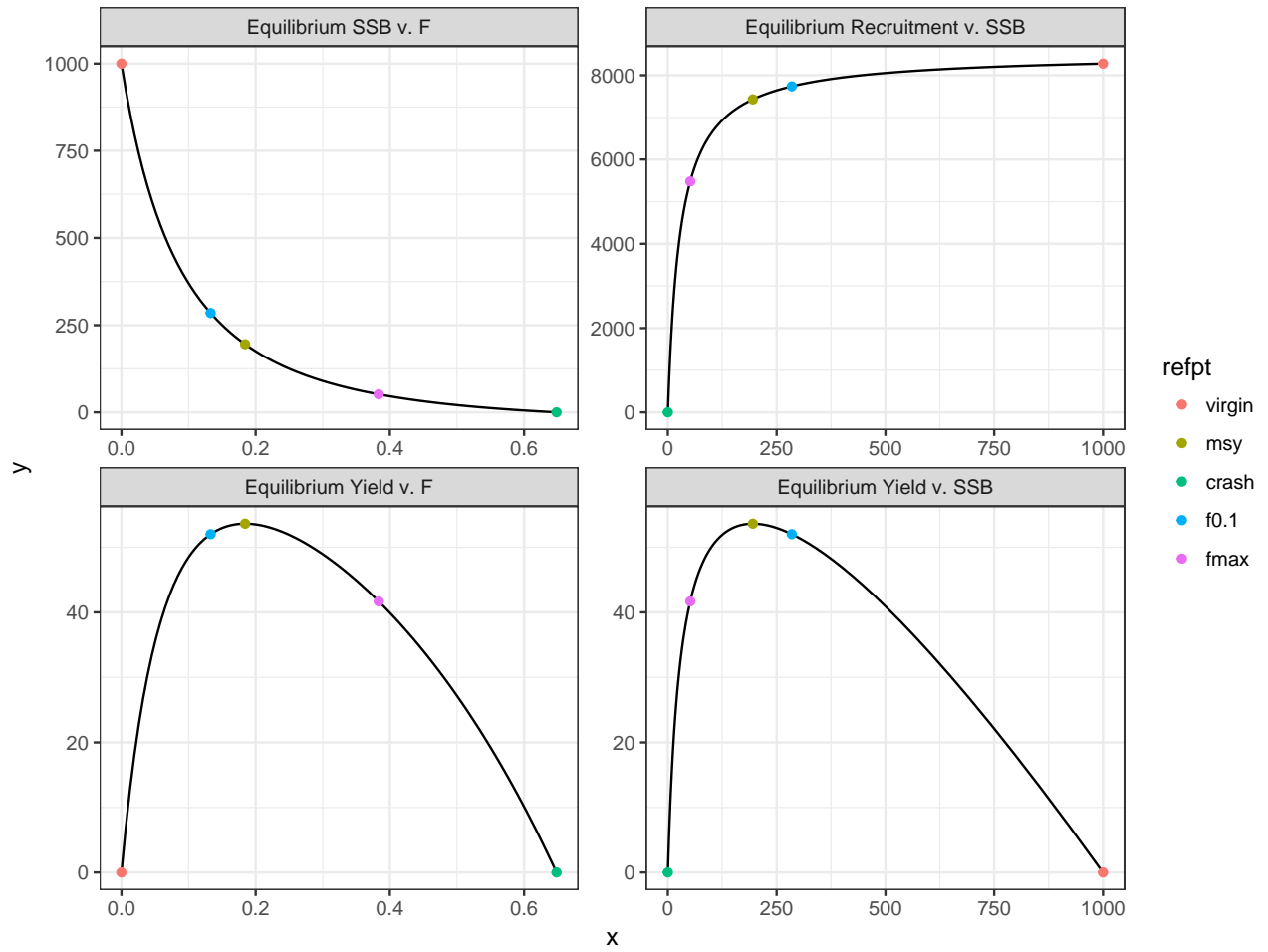


Figure 4: Equilibrium curves and reference points.

## Stock recruitment relationships

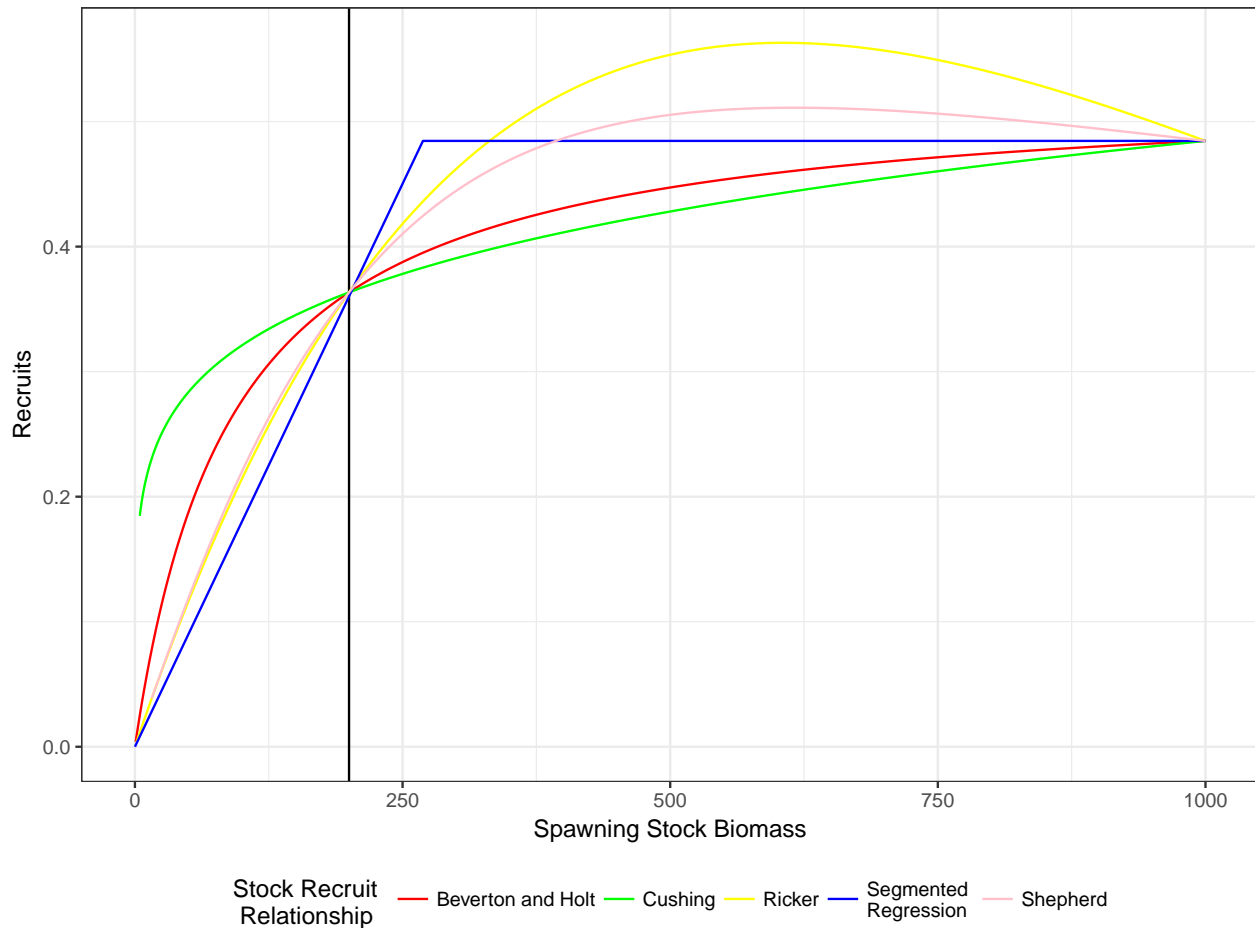


Figure 5: Stock recruitment relationships for a steepness of 0.75 and virgin biomass of 1000

## Density Dependence

Modelling density dependence in natural mortality and fecundity.

```
library(FLBRP)
library(FLife)

data(eleost)
par=eleost[, "Hucho hucho"]
par=1hPar(par)
hutchen=1hEq1(par)

scale=stock.n(hutchen)[,25]*%stock.wt(hutchen)
scale=(stock.n(hutchen)*%stock.wt(hutchen)%-scale)%/scale

m=mdd(stock.wt(hutchen),par=FLPar(m1=.2,m2=-0.288),scale,k=.5)

ggplot(as.data.frame(m))+
  geom_line(aes(age,data,col=factor(year)))+
```

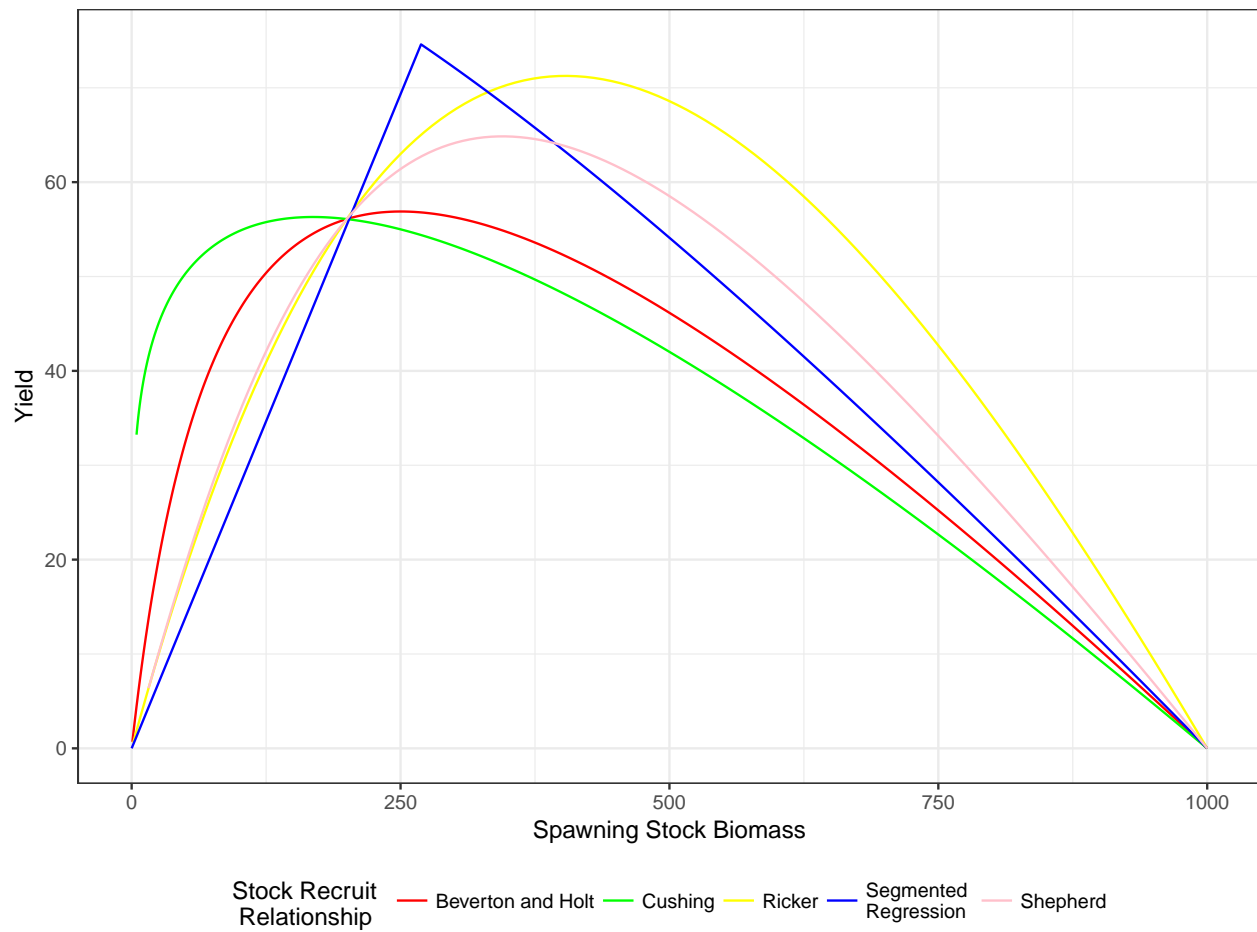


Figure 6: Production curves, Yield v SSB, for a steepness of 0.75 and virgin biomass of 1000.

```
theme(legend.position="none")+
  scale_x_continuous(limits=c(0,15))
```

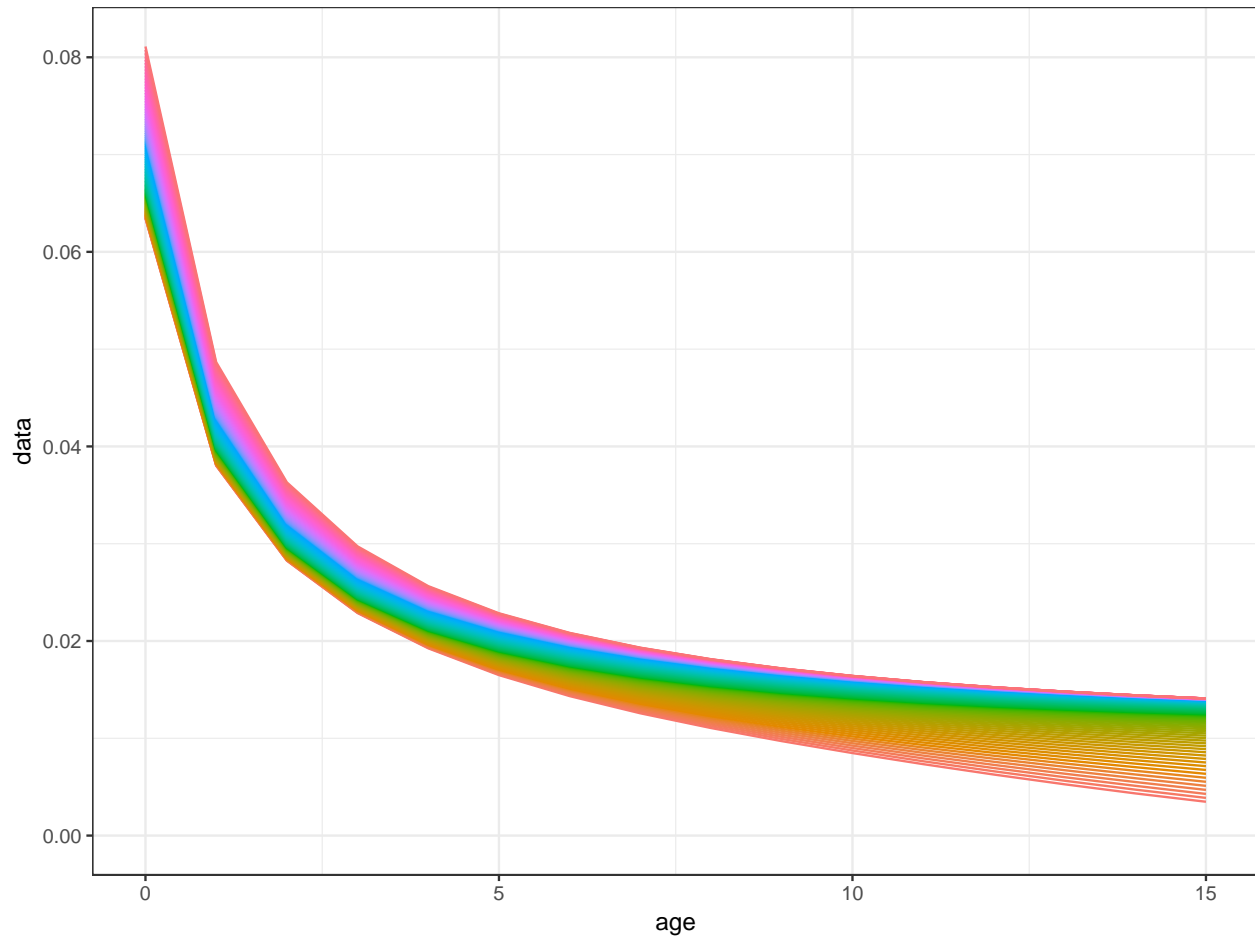


Figure 7: Density Dependence in M

```
scale=stock.n(hutchen)[,25]*%stock.wt(hutchen)
scale=(stock.n(hutchen)*%stock.wt(hutchen)%-scale)%/scale

mat=matdd(ages(scale),par,scale,k=.5)

ggplot(as.data.frame(mat))+
  geom_line(aes(age,data,col=factor(year)))+
  theme(legend.position="none")+
  scale_x_continuous(limits=c(0,15))
```

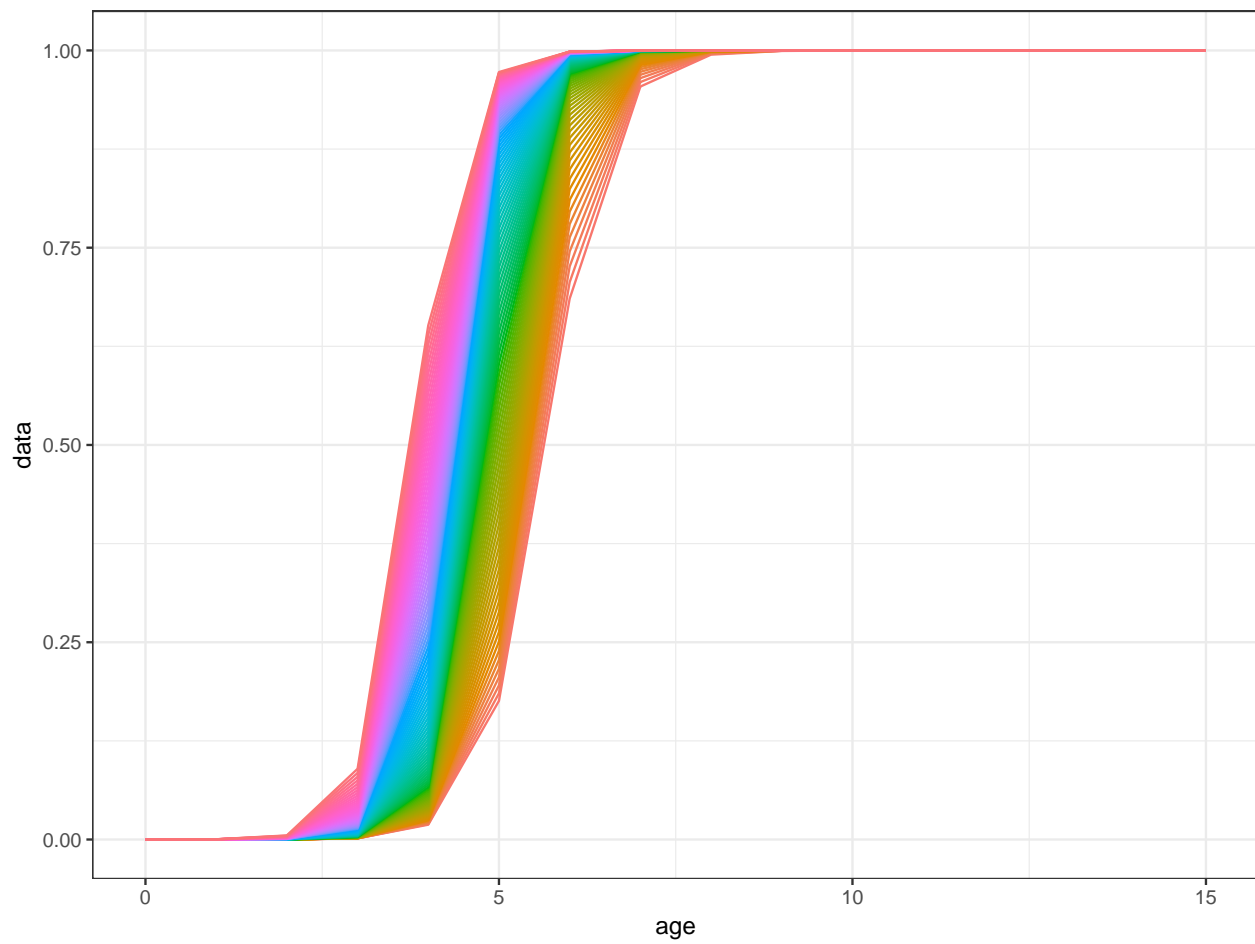
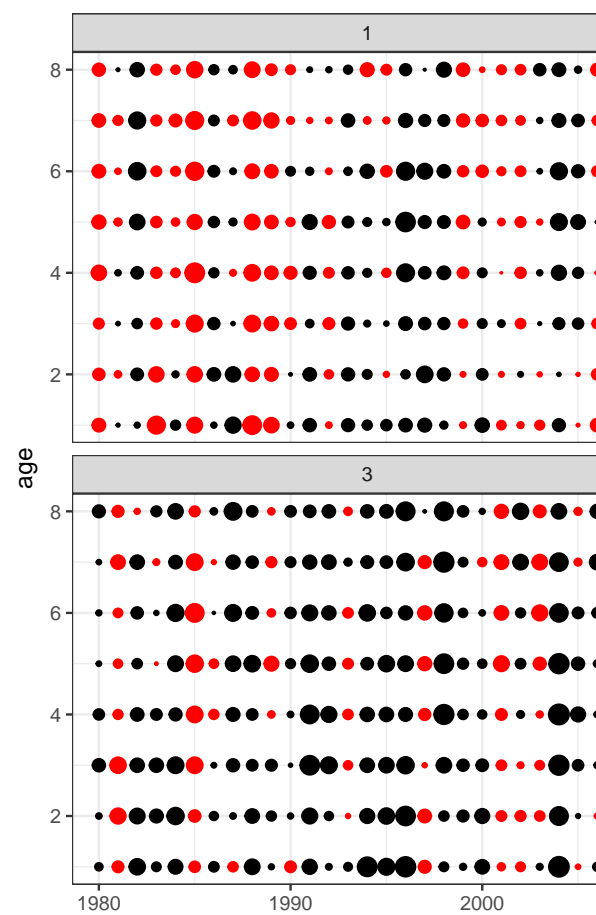


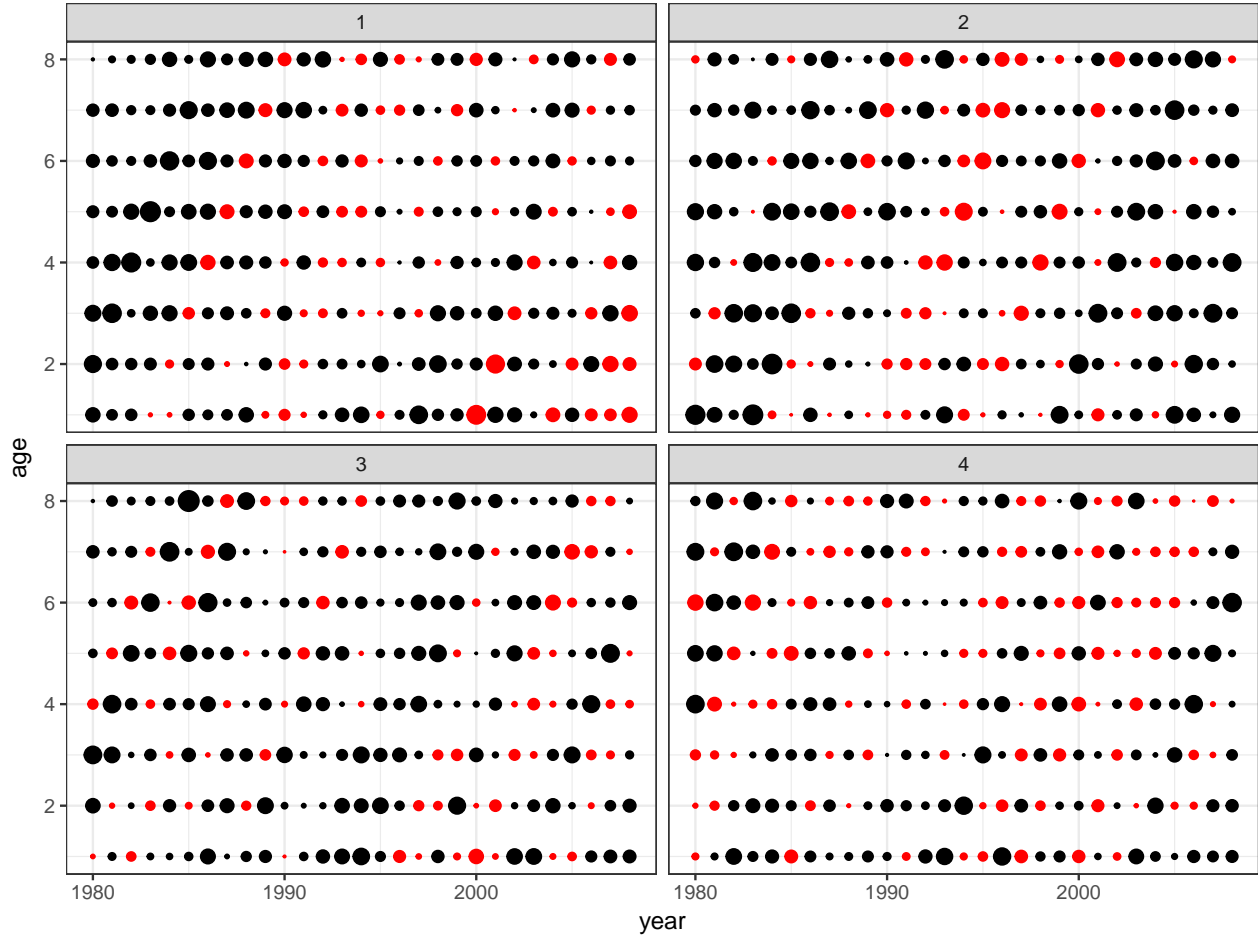
Figure 8: Density Dependence in M



Noise



Methods to simulate random noise with autocorrelation, e.g. by age or cohort



## MSE using empirical HCR

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## Estimation

Life history parameters can also be used to estimate quantities of use in stock assessment

Beverton and Holt (1956) developed a method to estimate life history and population parameters length data. e.g.

$$Z = K \frac{L_{\infty} - \bar{L}}{\bar{L} - L'} \quad (1)$$

Based on which Powell (1979) developed a method, extended by Wetherall, Polovina, and Ralston (1987), to estimate growth and mortality parameters. This assumes that the right hand tail of a length frequency distribution was determined by the asymptotic length  $L_{\infty}$  and the ratio between  $Z$  and the growth rate  $k$ .

The Beverton and Holt methods assumes good estimates for  $K$  and  $L_{\infty}$ , while the Powell-Wetherall method only requires an estimate of  $K$ , since  $L_{\infty}$  is estimated by the method as well as  $Z/K$ . These method therefore provide estimates for each distribution of  $Z/K$ , if  $K$  is unknown and  $Z$  if  $K$  is known.

%As well as assuming that growth follows the von Bertalanffy growth function, it is also assumed that the

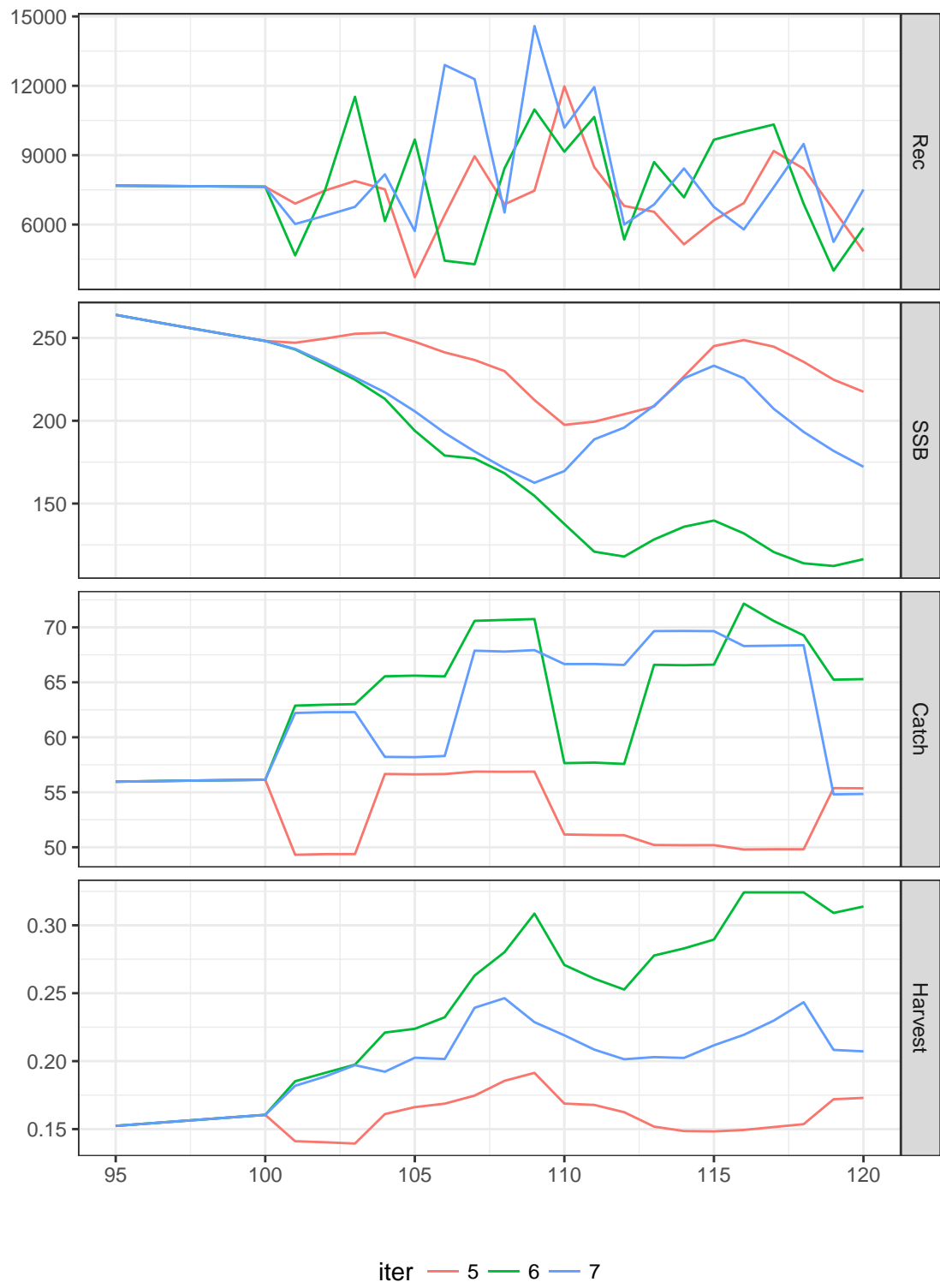


Figure 9: MSE using empirical HCR

population is in a steady state with constant exponential mortality, no changes in selection pattern of the fishery and constant recruitment. In the Powell-Wetherall method  $L'$  can take any value between the smallest and largest sizes. Equation 1 then provides a series of estimates of  $Z$  and since

$$\bar{L} - L' = a + bL' \quad (2)$$

$a$  and  $b$  can be estimated by a regression analysis where

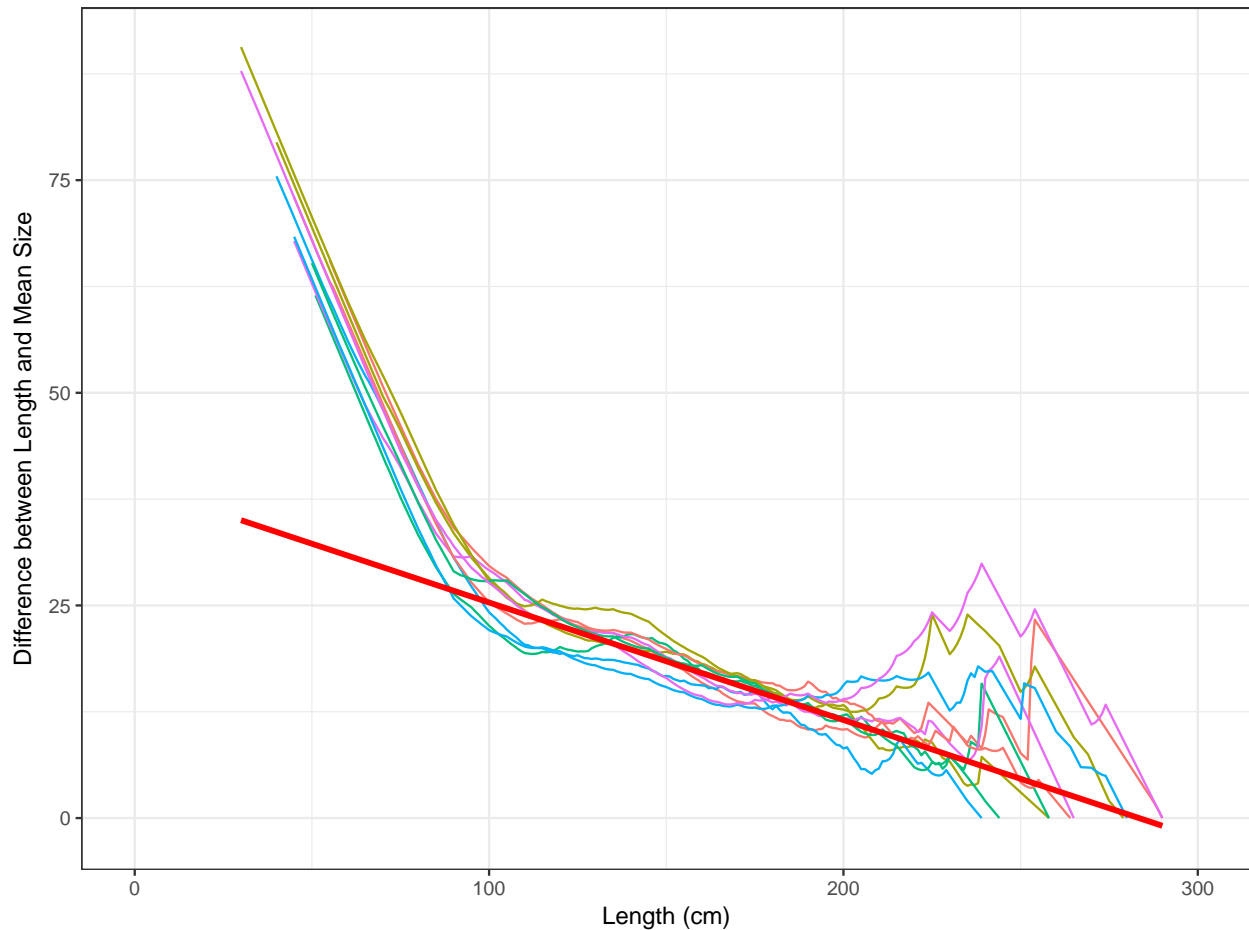
$$b = \frac{-K}{Z + K} \quad (3)$$

$$a = -bL_{\infty} \quad (4)$$

Therefore plotting  $\bar{L} - L'$  against  $L'$  therefore provides an estimate of  $L_{\infty}$  and  $Z/K$

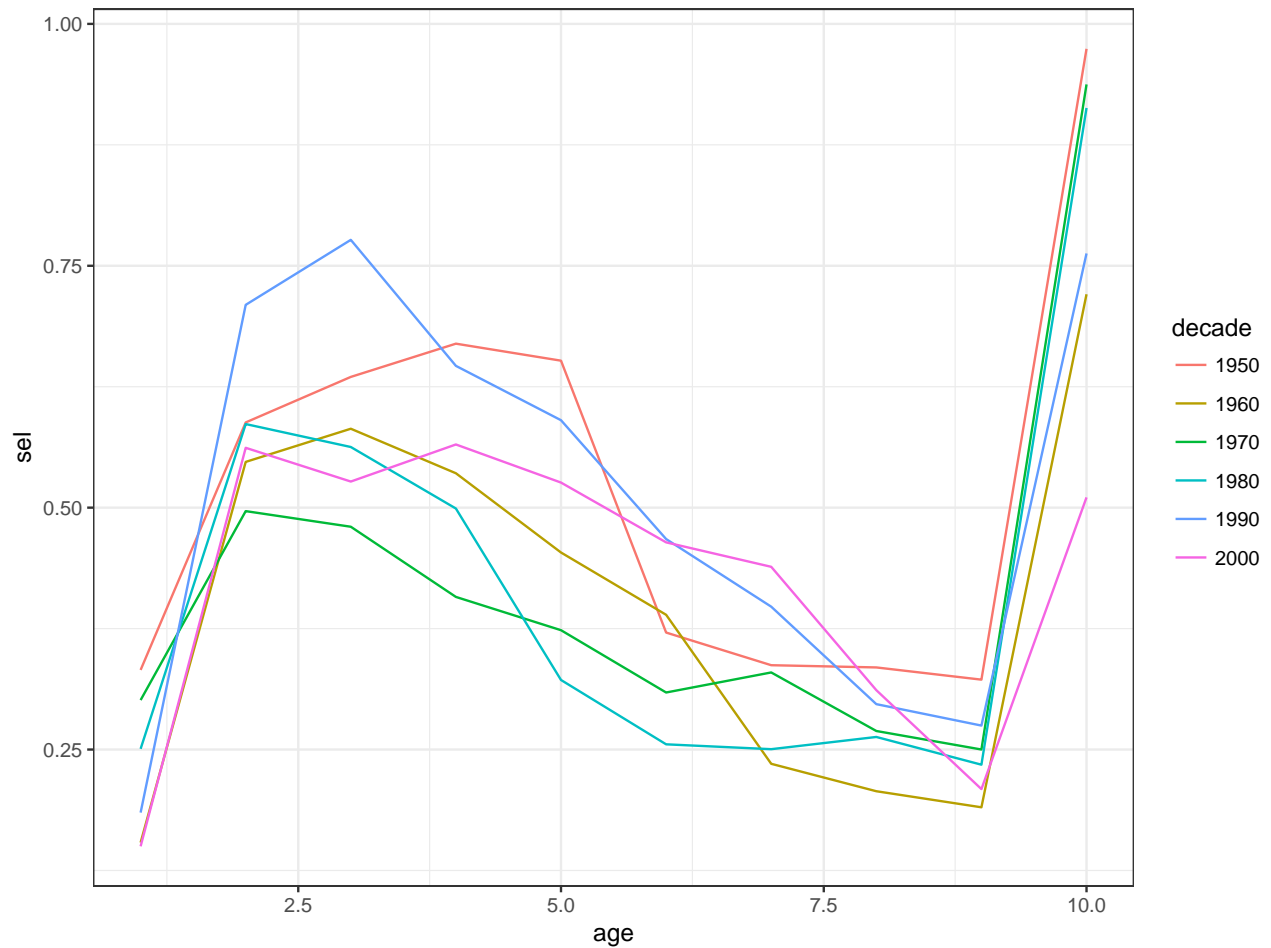
Plotting  $\bar{L} - L'$  against  $L'$  provides an estimate of  $L_{\infty}$  and  $Z/k$ , since  $L_{\infty} = -a/b$  and  $Z/k = \frac{-1-b}{b}$ . If  $k$  is known then it also provides an estimate of  $Z$  (**Figure ??**).

	age	obs	hat	sel
1	1	32356	249252	0.0136
2	2	49911	152624	0.0342
3	3	69038	93457	0.0773
4	4	45627	57226	0.0834
5	5	32732	35041	0.0977
6	6	8910	21457	0.0434



## Catch curve analysis

```
data(ple4)
ctc=as.data.frame(catch.n(ple4))
ctc=ddply(ctc,.(year), with, cc(age=age,n=data))
ctc=ddply(transform(ctc,decade=factor(10*(year%%10))),.(decade,age),with,data.frame(sel=mean(sel)))
ggplot(ctc)+
  geom_line(aes(age,sel,colour=decade))
```



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## More Information

- You can submit bug reports, questions or suggestions on **FLife** at the **FLife** issue page,<sup>4</sup> or on the *FLR* mailing list.
- Or send a pull request to <https://github.com/lauriekell/FLife/>
- For more information on the FLR Project for Quantitative Fisheries Science in R, visit the FLR webpage.<sup>5</sup>
- The latest version of **FLife** can always be installed using the **devtools** package, by calling

<sup>4</sup><https://github.com/lauriekell/FLife/issues>

<sup>5</sup><http://flr-project.org>

```
library(devtools)
install_github("lauriekell/FLife")
```

## Software Versions

- R version 3.4.1 (2017-06-30)
- FLCore: 2.6.5
- FLPKG:
- **Compiled:** Wed Jan 3 11:48:13 2018
- **Git Hash:** e7f290b

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## Acknowledgements

This vignette and many of the methods documented in it were developed under the MyDas project funded by the Irish exchequer and EMFF 2014-2020. The overall aim of MyDas is to develop and test a range of assessment models and methods to establish Maximum Sustainable Yield (MSY) reference points (or proxy MSY reference points) across the spectrum of data-limited stocks.

## References

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