GMSE: an R package for generalised management strategy evaluation

Supporting Information 5

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Integration and simulation with fisheries

Early development of management strategy evaluation (MSE) models originated in fisheries (Polacheck et al., 1999; Smith et al., 1999; Sainsbury et al., 2000). Consequently, fisheries-focused software for MSE has been extensively developed, including R libraries that focus on the management of species of exceptional interest, such as the Atlantic Bluefin Tuna (*Thunnus thynnus*) (ABFTMSE; Carruthers and Butterworth, 2018b,a), and Indian Ocean Bigeye (*T. obesus*) and Yellowfin (*T. albacares*) Tuna (MSE-IO-BET-YFT; Kolody and Jumppanen, 2016). The largest of all such libraries is the Fisheries Library in R (FLR), which includes an extensive collection of tools targeted for fisheries science. The FLR library has been used in over a hundred publications (recent publications include Jardim et al., 2018; Mackinson et al., 2018; Utizi et al., 2018), and includes an MSE framework for evaluating different harvest control rules.

As part of the ConFooBio project, a central focus of GMSE is on simulating the management of populations of conservation interest, with a particular emphasis on understanding conservation conflict; further development of GMSE is expected to continue with this as a priority, further building upon the decision-making algorithms of managers and users to better understand how conflict arises and can potentially be resolved. Hence, GMSE is not intended as a substitute for packages such as FLR, but the integration of these packages with GMSE could make use of GSME's current and future simulation capabilities, and particularly the genetic algorithm. Such integration might be possible using the `gmse_apply` function, which allows for custom defined submodels to be used within the GMSE framework, and with default GMSE submodels. Hence, GMSE might be especially useful for modelling the management of fisheries under conditions of increasing harvesting demands and stakeholder conflict. We do not attempt such an ambitious project here, but instead show how such a project could be developed through integration of FLR and `gmse_apply`.

Here we follow a Modelling Stock-Recruitment with FLSR example, then integrate this example with `gmse_apply` to explore the behaviour of simulated fishers who are goal-driven to maximise their own harvest. We emphasise that this example is provided only as demonstration of how GMSE can potentially be integrated with already developed fisheries models, and is not intended to make recommendations for management in any population.

Integrating with the Fisheries Library in R (FLR)

The FLR toolset includes a series of pacakges, with several tutorials for using them. For simplicity, we focus here on a model of stock recruitment to be used as the population model in `gmse_apply`. This population model will use sample data and one of the many available stock-recruitment models available in FLR, and a custom function will be written to return a single value for stock recruitment. Currently, `gmse_apply` requires that submodels return subfunction results either as scalar values or data frames that are structured in the same way as GMSE submodels. But interpretation of scalar values is left up to the user (e.g., population model results could be interpreted as abundance or biomass; manager policy could be interpreted as cost of harvesting or as total allowable catch). For simplicity, the observation (i.e., estimation) model will simply be the stock reported from the population model with error, and the manager model will be a total allowable catch calculated from the stock-recruitment relationship that accounts for the number of fishers in the system. The user model, however, will employ the full power of the default GMSE user function to simulate user actions. We first show how a custom function can be made that applies the FLR toolset to a population model.

Modelling stock-recruitment for the population model

Here we closely follow a tutorial from the FLR project. To build the stock-recruitment model, the `FLCore` package is needed (Kell et al., 2007).

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

To start, we need to read in the `FLCore` library.

```
library(FLCore);
```

```
## Loading required package: lattice
```

```
## FLCore (Version 2.6.7, packaged: 2018-04-17 09:12:42 UTC)
```

For a simplified example in GMSE, we will simulate the process of stock recruitment over multiple time steps using an example stock-recruitment model. The stock-recruitment model describes the relationship between stock-recruitment and spawning stock biomass. The sample that we will work from is a recreation of the North Sea Herring (`nsher`) dataset available in the `FLCore` package (Kell et al., 2007). This data set includes recruitment and spawning stock biomass data between 1960 and 2004. First, we initialise an empty `FLSR` object and read in the recreated CSV data files.

```
newFL        <- FLSR(); # Initialises the empty FLSR object
rec.n        <- read.csv("data/SI5/nsher_rec.csv");
ssb.n        <- read.csv("data/SI5/nsher_ssb.csv");
```

The recruitment (`rec.n`) and spawning stock biomass (`ssb.n`) data need to be in the form of a vector, array, matrix to use them with `FLQuant`. We will convert `rec.n` and `ssb.n` into matrices.

```
rec.m        <- as.matrix(rec.n);
ssb.m        <- as.matrix(ssb.n);
```

We can then construct two `FLQuant` objects, specifying the relevant years and units.

```
Frec.m       <- FLQuant(rec.m, dimnames=list(age=1, year = 1960:2004));
Fssb.m       <- FLQuant(ssb.m, dimnames=list(age=1, year = 1960:2004));
Frec.m@units <- "10^3";
Fssb.m@units <- "t*10^3";
```

We then place the recruitment and spawning stock biomass data into the `FLSR` object that we created.

```
rec(newFL)    <- Frec.m;
ssb(newFL)    <- Fssb.m;
range(newFL)  <- c(0, 1960, 0, 2004);
```

The `FLCore` package offers several stock-recruitment models. Here we use a Ricker model of stock recruitment (Ricker, 1954), and insert this model into the `FLSR` object below.

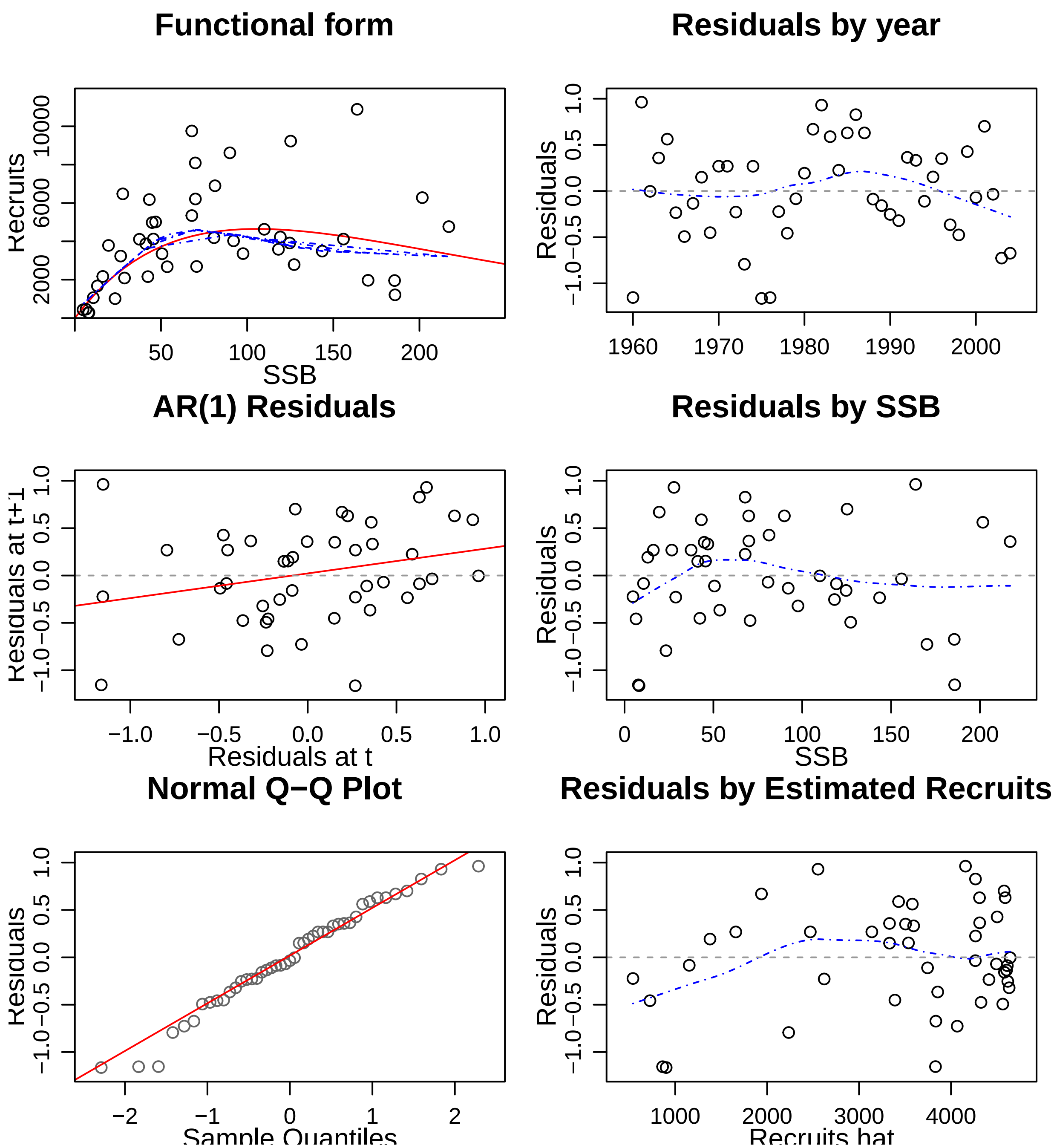
```
model(newFL) <- ricker();
```

Parameters for the Ricker stock-recruitment model can be estimated with maximum likelihood.

```r
newFL <- fmle(newFL);
```

Diagnostic plots, identical to those of the modelling stock-recruitment tutorial for the `nsher_ri` example, are shown below.

```r
plot(newFL);
```



We now have a working example of a stock-recruitment model, but for our integration with `gmse_apply`, we will want a function that automates the above to simulate the process of updating the stock-recruitment model. We do this using the custom function created below.

```r
update_SR_model <- function(rec_m, ssb_m, years){
    Frec_m       <- FLQuant(rec.m, dimnames=list(age=1, year = years));
    Fssb_m       <- FLQuant(ssb.m, dimnames=list(age=1, year = years));
    Frec_m@units <- "10^3";
    Fssb_m@units <- "t*10^3";
    rec(newFL)   <- Frec.m;
    ssb(newFL)   <- Fssb.m;
    range(newFL) <- c(0, years[1], 0, years[length(years)]);
    model(newFL) <- ricker();
    newFL        <- fmle(newFL);
    return(newFL);
}
```

The above function will be used within another custom function to predict the next time step of recruitment.

```r
predict_recruitment <- function(rec_m, ssb_m, years, new_ssb){
    newFL <- update_SR_model(rec_m, ssb_m, years);
    a     <- params(newFL)[[1]] # Extract 'a' parameter of the Ricker model
    b     <- params(newFL)[[2]] # Extract 'b' parameter of the Ricker model
    rec   <- a * new_ssb * exp(-b * new_ssb); # Predict the new recruitment
    return(recruitment)
}
```

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