An introduction to MSE with FLR

11 August, 2017

Management Strategy Evaluation (MSE) is a framework for evaluating the performance of Harvest Control Rules (HCRs) against prevailing uncertainties (Punt et al. 2016). This tutorial introduces the basic steps for building a single-species MSE: conditioning the operating model, setting up the observation error model, constructing a simple model-based HCR (based on the ICES MSY approach), performing the MSE simulations (including feedback), and producing performance statistics.

Required packages

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

- CRAN: ggplot2
- FLR: FLCore, FLash,FLXSA,FLBRP, ggplotFL

You can do so as follows,

```
install.packages(c("ggplot2"))
install.packages(c("FLa4a", "FLash", "FLXSA",
    "FLBRP", "ggplotFL"), repos = "http://flr-project.org/R")
```

```
# This chunk loads all necessary packages,
# trims pkg messages
library(FLa4a)
library(FLash)
library(FLXSA)
library(FLBRP)
library(ggplotFL)
```

CONDITIONING THE OPERATING MODEL

Conditioning the operating model is a key step in building an MSE analysis, as it allows operating models to be considered "plausible" in the sense that they are consistent with observed data. In this tutorial, the a4a assessment model is fitted to the data within the `ple4` `FLStock` and `ple4.index` `FLIndex` objects to produce `stk`, the operating model `FLStock` object. An mcmc method withing the a4a assessment is used to obtain parameter uncertainty, reflected in the `iter` dimension of `stk`.

Read in stock assessment data

```
data(ple4)
data(ple4.index)
stk <- ple4
rm("ple4")
idx <- FLIndices(idx = ple4.index)
rm("ple4.index")
```

Set up the iteration and projection window parameters
In this tutorial, 20 iterations are used along with a 12-year projection window. A 3-year period is used for to calculate averages needed for projections (e.g. mean weights, etc.).

```
it <- 20  # iterations
y0 <- range(stk)["minyear"]  # initial data year
dy <- range(stk)["maxyear"]  # final data year
iy <- dy + 1  # initial year of projection (also intermediate year)
fy <- dy + 12  # final year
ny <- fy - iy + 1  # number of years to project from intial year
nsqy <- 3  # number of years to compute status quo metrics
```

Fit stock assessment model a4a
Set up the operating model (including parameter uncertainty) based on fitting the a4a assessment model to data. Reference points are obtained for a "median" `stk` (`stk0`) to mimic best estimates of reference points used in the ICES MSY approach.

```
qmod <- list(~s(age, k = 6))
fmod <- ~te(replace(age, age > 9, 9), year, k = c(6,
    8))
mcsave <- 100  #this needs to be an integer value
mcmc <- it * mcsave
fit <- a4aSCA(stk, idx, fmodel = fmod, qmodel = qmod,
    fit = "MCMC", mcmc = SCAMCMC(mcmc = mcmc,
        mcsave = mcsave, mcprobe = 0.4))
stk <- stk + fit
stk0 <- qapply(stk, iterMedians)  #reduce to keep one iteration only for reference points
```

Fit stock-recruit model
A Beverton-Holt stock-recruit model is fitted for each iteration, with residuals generated for the projection window based on the residuals from the historic period. A stock-recruit model is also fitted to the "median" stk for reference points.

```
srbh <- fmle(as.FLSR(stk, model = "bevholt"),
    method = "L-BFGS-B", lower = c(1e-06, 1e-06),
    upper = c(max(rec(stk)) * 3, Inf))
```

```
srbh0 <- fmle(as.FLSR(stk0, model = "bevholt"),
    method = "L-BFGS-B", lower = c(1e-06, 1e-06),
    upper = c(max(rec(stk)) * 3, Inf))
srbh.res <- rnorm(it, FLQuant(0, dimnames = list(year = iy:fy)),
    mean(c(apply(residuals(srbh), 6, sd))))
```

Calculate reference points and set up the operating model for the projection window

Reference points based on the "median" stk, assuming (for illustrative purposes only) that Bpa=0.5Bmsy and Blim=Bpa/1.4. The stf method is applied to the operating model stk object in order to have the necessary data (mean weights, etc.) for the projection window.

```
brp <- brp(FLBRP(stk0, srbh0))
Fmsy <- c(refpts(brp)["msy", "harvest"])
msy <- c(refpts(brp)["msy", "yield"])
Bmsy <- c(refpts(brp)["msy", "ssb"])
Bpa <- 0.5 * Bmsy
Blim <- Bpa/1.4
stk <- stf(stk, fy - dy, nsqy, nsqy)
```

SET UP OBSERVATION ERROR MODEL ELEMENTS

Estimate the index catchabilities from the a4a fit (without simulation)

Observation error is introduced through the index catchability-at-age

```
idcs <- FLIndices()
for (i in 1:length(idx)) {
    lst <- mcf(list(idx[[i]]@index, stock.n(stk0)))  #make FLQuants same dimensions
    idx.lq <- log(lst[[1]]/lst[[2]])  # log catchability of index
    idx.qmu <- idx.qsig <- stock.n(iter(stk, 1))  # create quants
    idx.qmu[] <- yearMeans(idx.lq)  # allocate same mean-at-age to very year
    idx.qsig[] <- sqrt(yearVars(idx.lq))  # allocate same sd-at-age to very year
    idx.q <- rlnorm(it, idx.qmu, idx.qsig)  # Build index catchability based on lognormal distribution wit
    idx_temp <- idx.q * stock.n(stk)
    idx_temp <- FLIndex(index = idx_temp, index.q = idx.q)  # generate initial index
    range(idx_temp)[c("startf", "endf")] <- c(0,
        0)
    idcs[[i]] <- idx_temp
}
names(idcs) <- names(idx)
idx <- idcs[1]
```

SET UP MSE LOOP

Needed Functions

Observation error model

In this tutorial, observation error is applied to the operating model population numbers to obtain an index of abundance. This is implemented through the index catchability-at-age. Observation error is added during each year of the projection window, and is therefore dealt with more easily in a function.

```
o <- function(stk, idx, assessmentYear, dataYears) {
    # dataYears is a position vector, not the
    # years themselves
    stk0 <- stk[, dataYears]
    # add small amount to avoid zeros
    catch.n(stk0) <- catch.n(stk0) + 0.1
    # Generate the indices - just data years
    idx0 <- lapply(idx, function(x) x[, dataYears])
    # Generate observed index
    for (i in 1:length(idx)) index(idx[[i]])[,
        assessmentYear] <- stock.n(stk)[, assessmentYear] *
        index.q(idx[[i]])[, assessmentYear]
    list(stk = stk0, idx = idx0, idx.om = idx)
}
```

XSA assessment model

The assessment model used to parameterise the HCR is XSA, through `FLXSA`. This function sets the control parameters for `FLXSA` and fits the assessment.

```
xsa <- function(stk0, idx0) {
    # Use default XSA settings
    control <- FLXSA.control(tol = 1e-09, maxit = 99,
        min.nse = 0.3, fse = 2, rage = -1, qage = stk0@range["max"] -
            1, shk.n = TRUE, shk.f = TRUE, shk.yrs = 5,
        shk.ages = 5, window = 100, tsrange = 99,
        tspower = 0)
    # Fit XSA
    fit0 <- FLXSA(stk0, idx0, control)
    # convergence diagnostic (quick and dirty)
    maxit <- c(maxit = fit0@control@maxit)
    # Update stk0
    stk0 <- transform(stk0, harvest = fit0@harvest,
        stock.n = fit0@stock.n)
```

```
    return(list(stk0 = stk0, converge = maxit))
}
```

Control object for projections

The fwd method from FLash needs a control object, which is set by this function.

```
getCtrl <- function(values, quantity, years, it) {
    dnms <- list(iter = 1:it, year = years, c("min",
        "val", "max"))
    arr0 <- array(NA, dimnames = dnms, dim = unlist(lapply(dnms,
        length)))
    arr0[, , "val"] <- unlist(values)
    arr0 <- aperm(arr0, c(2, 3, 1))
    ctrl <- fwdControl(data.frame(year = years,
        quantity = quantity, val = NA))
    ctrl@trgtArray <- arr0
    ctrl
}
```

MSE initialisation

The first year of the projection window is the intermediate year, for which, following the ICES WG timeline, already has a TAC. For this tutorial, the TAC in the final year of data is assumed to be the realised catch in stk for the same year, while the TAC in the intermediate year is set equal to the TAC in the final year of data. The stk object then needs to be projected through the intermediate year by applying the TAC in the intermediate year with fwd.

```
vy <- ac(iy:fy)
TAC <- FLQuant(NA, dimnames = list(TAC = "all",
    year = c(dy, vy), iter = 1:it))
TAC[, ac(dy)] <- catch(stk)[, ac(dy)]
TAC[, ac(iy)] <- TAC[, ac(dy)]  #assume same TAC in the first intermediate year
ctrl <- getCtrl(c(TAC[, ac(iy)]), "catch", iy,
    it)
stk.om <- fwd(stk, control = ctrl, sr = srbh,
    sr.residuals = exp(srbh.res), sr.residuals.mult = TRUE)
```

Start the MSE loop

The MSE loop requires the observation error model to be applied to generate the index of abundance, the stock assessment (XSA) to be appled using this index to generate the management procedure stock object stk.mp, the resultant SSB estimate to be used in the HCR, along with the reference points obtained earlier, to derive target Fs for the TAC year (the year after the intermediate year), and the TAC associated with the target F to be calculated by applying `fwd` to the `stk.mp`. The final step of the MSE loop is to apply the TAC to the operating model stock object, `stk.om`, by using `fwd`.

```
for (i in vy[-length(vy)]) {
    # set up simulations parameters
    ay <- an(i)
    cat(i, " > ")
    vy0 <- 1:(ay - y0)  # data years (positions vector) - one less than current year
    sqy <- (ay - y0 - nsqy + 1):(ay - y0)  # status quo years (positions vector) - one less than current y

    # apply observation error
    oem <- o(stk.om, idx, i, vy0)
    stk.mp <- oem$stk
    idx.mp <- oem$idx
    idx <- oem$idx.om

    # perform assessment
    out.assess <- eval(call("xsa", stk.mp, idx.mp))
    stk.mp <- out.assess$stk0

    # apply ICES MSY-like Rule to obtain Ftrgt
    # (note this is not the ICES MSY rule, but is
    # similar)
    flag <- ssb(stk.mp)[, ac(ay - 1)] < Bpa
    Ftrgt <- ifelse(flag, ssb(stk.mp)[, ac(ay -
        1)] * Fmsy/Bpa, Fmsy)

    # project the perceived stock to get the TAC
    # for ay+1
    fsq.mp <- yearMeans(fbar(stk.mp)[, sqy])  # Use status quo years defined above
    ctrl <- getCtrl(c(fsq.mp, Ftrgt), "f", c(ay,
        ay + 1), it)
    stk.mp <- stf(stk.mp, 2)
    gmean_rec <- c(exp(yearMeans(log(rec(stk.mp)))))
    stk.mp <- fwd(stk.mp, control = ctrl, sr = list(model = "mean",
        params = FLPar(gmean_rec, iter = it)))
    TAC[, ac(ay + 1)] <- catch(stk.mp)[, ac(ay +
        1)]

    # apply the TAC to the operating model stock
    ctrl <- getCtrl(c(TAC[, ac(ay + 1)]), "catch",
```

```
        ay + 1, it)
    stk.om <- fwd(stk.om, control = ctrl, sr = srbh,
        sr.residuals = exp(srbh.res), sr.residuals.mult = TRUE)
}
```

PERFORMANCE STATISTICS

```
# Some example performance statstics, but
# first isolate the projection period
stk.tmp <- window(stk.om, start = iy)
# annual probability of being below Blim
(risky <- iterSums(ssb(stk.tmp)/Blim < 1)/it)
```

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

     year
age   2009 2010 2011 2012 2013
  all 1.00 1.00 0.90 0.50 0.05

      [ ...  2 years]

     year
age   2016 2017 2018 2019 2020
  all 0    0    0    0    0
```

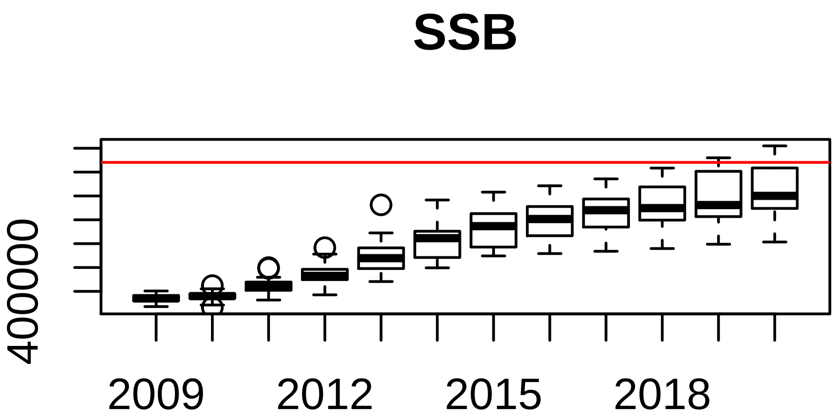
```
# mean probabiity of being below Blim in the
# first half of the projection period
mean(risky[, 1:trunc(length(risky)/2)])
```

```
[1] 0.575
```

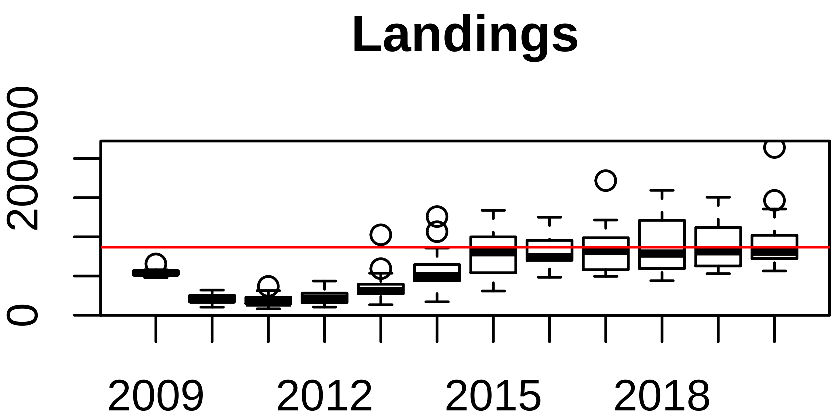
```
# ...and second half
mean(risky[, (trunc(length(risky)/2) + 1):length(risky)])
```

```
[1] 0
```

```
# plot of SSB relative to Bmsy
boxplot(data ~ year, data = as.data.frame(ssb(stk.tmp)),
    main = "SSB")
abline(h = Bmsy, col = "red")
```




```
# plot of landings relative to MSY yield
boxplot(data ~ year, data = as.data.frame(landings(stk.tmp)),
    main = "Landings")
abline(h = msy, col = "red")
```




```
plot(FLStocks(stk.om = stk.om, stk.mp = stk.mp)) +
    theme(legend.position = "top") + geom_vline(aes(xintercept = as.numeric(ISOdate(iy,
    1, 1))))
```

References

Punt, A.E., Butterworth, D.S., de Moor, C.L., De Oliveira, J.A.A. and M. Haddon (2016). Management Strategy Evaluation: Best Practices. Fish and Fisheries, 17(2): 303-334. DOI: 10.1111/faf.12104.

More information

- You can submit bug reports, questions or suggestions on this tutorial at `https://github.com/flr/doc/issues`.

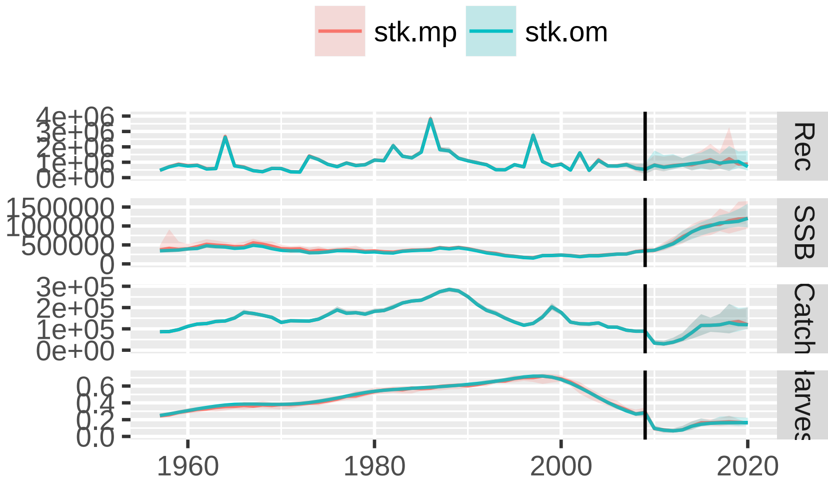


Figure 1: Results for applying an ICES MSY-like rule, comparing the operating model to the management procedure

- 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 3.4.1 (2017-06-30)
- FLCore: 2.6.3.9006
- ggplotFL: 2.6.0
- ggplot2: 2.2.1.9000
- **Compiled**: Fri Aug 11 14:53:48 2017

License

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