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P491-BioMod Deliverable 4913 Management Strategy Evaluation Error Model

Bioeconomic Modelling for Fisheries and Aquaculture.

Finlay Scott
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Abstract

In terms of analysing and simulating fisheries management systems, implementation error can be considered to be the difference between management decisions (for example, the TAC or effort limits set for the following year) and what the fishing fleets actually do (for example, the actual catch taken or fishing effort applied that year). It is thought that implementation error can have a strong impact on the potential success of a management plan, but the precise level of impact and the effect of implementation error combined with other sources of uncertainty requires further study.

This document describes the application of a simple Management Strategy Evaluation simulation to investigate the potential impacts of management plan implementation error on the sustainability of a stock. The simulation is based on the cod stock in the Eastern English Channel and Southern Celtic Seas. The results are illustrative only and are not meant to provide advice for the stock.

It was found that including implementation error in the projections (i.e. the realised catch being greater than the desired TAC) not only led to the stock being more exploited (lower SSB, higher fishing mortality) but also increased the uncertainty in the stock status. This will be of particular interest when a risk-based approach to fisheries management is being considered.

The implementation of a management plan is strongly in influenced by a range of economic factors that drive the dynamics of the fishing fleet. The simulations here do not make a full economic analysis and focus on the sustainabilty of the stock rather than the economic viability of the fishing fleet. Future work will include more economic modelling to improve the implementation error model.

Note that this report was not prepared using MS Word. It was prepared using Latex / KnitR and R. This allows the computer code that was used to generate the results to be embedded in the report and executed during the report compilation, including the plotting of figures. This is preferable for scientific report writing as it ensures that the results presented here are ‘live’. Consequently, the following report may not strictly adhere to the JRC template.

Bioeconomic Modelling for Fisheries and Aquaculture
Deliverable 4913
Management Stragegy Evaluation Error Model
Technical Report

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Contents

1 Abstract

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2 Introduction

The Deliverable description is:

A Management Strategy Evaluation (MSE) simulates major components of a fishery system, including management, biology and fishing fleet, to assess a variety of fishery management options. Within an MSE an 'implementation error model' describes fleet activity and links management decisions to the level of fishing. This approach will allow the JRC to include economic information within an operating model, a large step toward including bioeconomics within an MSE simulation.

Management Strategy Evaluation (MSE) is a simulation framework that allows the comparison and evaluation of proposed fisheries management plans (Kell et al., 2007). Instead of simply focussing on the biology, MSE simulates all of the major components of a fishery system including the fleet behaviour, the biological dynamics, the stock assessment and the management decision making. An example simulation framework can be seen in Figure 1.

The combination of the fleet activity and biological components is known as the operating model and is considered to represent the 'true' status of the system. The management procedure is a combination of data collection, the stock assessment process (to estimate the status of the stock) and the management decision (based on the outcome of the stock assessment process).

The components are linked together so that there is feedback between the management plan and observations of the 'true' operating model (the fleets and the biological components). This is in contrast to a standard projection approach where the management is fixed and does not dynamically change according to the estimated stock status.

In the real world, a fisheries system is full of uncertainty. A key feature of MSE is the consideration of uncertainty. Uncertainty comes in many flavours including model (for example, the choice of model to simulate the growth and reproduction of the biological stock), process (for example, the natural variance in the biological growth parameters), sampling (for example, the difference between the actual catch numbers and the catch numbers reported to the stock assessment process) and estimation (for example, the uncertainty surrounding the estimated stock abundances from the stock assessment process). These sources of uncertainty are very important because they allow the proposed managment strategy to be tested against them, thereby investigating its robustness. There is little point proposing a plan that works well under perfect conditions, but does not work when confronted by uncertainty.

The dynamics of the fleet is one of the less well developed areas of an MSE. The response of fishers to changing environmental and economic conditions is relatively understudied. A full understanding of

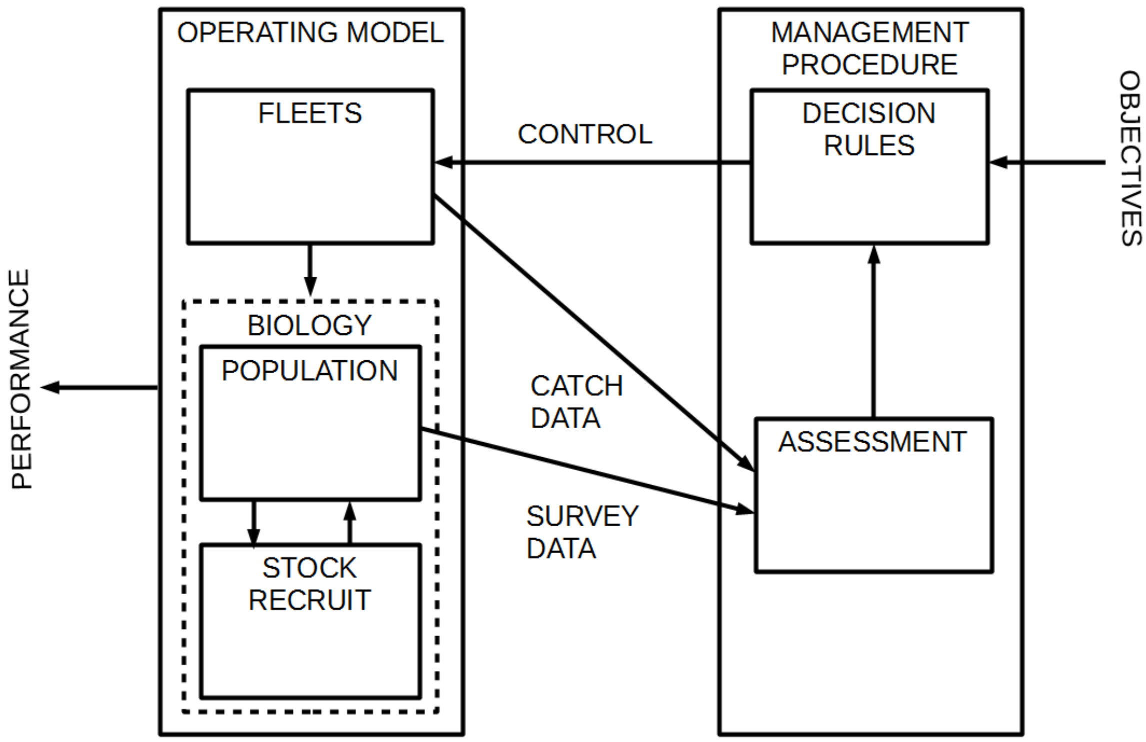

Figure 1: A schematic block diagram of a Management Strategy Evaluation framework. Each component of a fishery system, including the biology, fleets and managment processes and the links between them are modelled. Implementation error focuses on the linkages between the output of the *Management Procedure* and the fishing pressure on the *Biology* components

this response requires the consideration of many factors including the costs, prices, regulations (e.g. the new Landings Obligations), proximity to ports, employment, the habits and experiences of the captains, historical catch rates, distribution of fish stocks and any enforcement regimes that may be in operation. This makes trying to understand the dynamics of the fleet as it responds to management decisions particularly challenging as the interactions of these factors is poorly understood. When simulating fleet dynamics, often only purely economic drivers are considered. For example, it is often assumed that fishers are aiming to simply maximise their profits and so objective functions to model prices and costs are set accordingly. However, this approach can lead to unexpected and unlikely behaviour (e.g. STECF, 2015). Alternative and additional objectives of fishers include being the top producer of a region and maximising employment.

Many MSEs include the sources of uncertainty described above. However, an additional source of uncertainty that is not frequently considered is *implementation error*. This can be thought of as the difference between what the management decision prescribed (for example, a TAC or effort limit) and what actually happened (the actual catch or effort executed by the fishing fleet). In terms of Figure 1, it is the linkage between the output of the *Management Procedure* and the fishing pressure on the *Biology* components. Here we are interested in the impact of implementation error on the robustness of the fisheries management plan.

To investigate this a simple MSE based on cod (*Gadus morhua*) in ICES Divisions VIIe–k (Eastern English Channel and Southern Celtic Seas) is used. The management procedure aims to fish the stock at FMSY. In the projections the stock is managed by a quota which is set every year. Note that the results should be considered as illustrative only and not actual predictions as to the future state of this stock. The exercise is intended to investigate possible impacts of implementation error and not to provide specific advice.

Implementation error is introduced by the fleet taking a higher catch than the TAC (thereby ignoring situations where the actual catch is less than the TAC). The reported catches are assumed to be correct, i.e. there is no underreporting.

There are many reasons why fishers may be motivated to intentionally catch more than the TAC. As discussed above, fishers responses are hard to simulate due to the range of drivers. The basic assumption is that overcatching happens because it is economically beneficial to the fisher. Even though catching more fish will incur greater fishing costs in terms of fishing effort expended (through fuel use and other variable costs), the additional revenue from selling the overcaught fish still makes the operation profitable. Whether the overcaught fish can be landed legally or not (e.g. black landings) may change the price of the catch. An additional concern is that of enforcement. When the actual catches are higher than the TAC the assumption is that there is no or insufficient penalty for catching too much, i.e. that there is no enforcement regime or that any penalty incurred is lower than the value of the excess catch. The costs and benefits of fisheries enforcement is another challenging area to simulate (EC, 2009).

To simulate implementation error in sufficient detail it is therefore necessary to model the economic drivers of fishing (for example, costs and prices). The consequences of any enforcement program should also be considered. Due to the current limitations of the available tools these economics are not actually modelled in these projections. The tools are being developed at the JRC. However, the simulations presented in this document still demonstrate the potential impacts of implemetation error.

3 The MSE

The MSE was based on cod in the Eastern English Channel and Southern Celtic Seas, a stock that is currently assumed to be overexploited (ICES, 2013). A stock assessment using *a4a* was run to approximately replicate the current assessment up to 2012 (Jardim et al., 2014). The results of the stock assessment were then re-simulated from the fit to generate a stock that included estimation uncertainty.

A segmented regression stock-recruitment relationship (SRR) was used. Although it can be argued that this is not biologicaly realistic, it is used here to reduce the impact that the choice of SRR model has on the results. When the spawning stock biomass (SSB) is greater than the inflection point, the recruitment level is fixed and independent of the SSB. By using this SRR model, the impact of different levels of implementation error will be easier to isolate. If a more dynamic relationship (such as a Beverton-Holt model) was used, the resulting stock dynamics will be more heavily influenced by the recruitment model, and the impact of the implementation error harder to separate. The inflection point of the SRR is set at SSB = 13,429 t. When predicting recruitment in the projection, randomly selected residuals from the SRR fit were applied to the predicted recruitment to include process uncertainty in the projections.

The objective of the management strategy was simply to fish the stock at FMSY (F=0.41), i.e. there was no harvest control rule to set a desired level of F based on the current estimates of biomass. The stock is managed by setting a TAC every year. The management decision is based on fisheries information from the previous year (a common situation).

Within each timestep of the MSE several things happen in sequence. Catch data is taken from the operating model in the previous timestep (which may be subject to underreporting, see below). A survey index was generated based on the stock abundance in the operating model in the previous timestep combined with the observed historical error between the survey and the estimated abundance. These were used in a simple *a4a* stock assessment to estimate the status of the stock in the previous timestep (Jardim et al., 2014). The management procedure attempts to set a TAC for the following timestep. To do this it runs a short-term forecast of two years: the current year and the following year. The fishing mortality in the current year is set to be the mean of the estimates of the last three years taken from the stock assessment results (i.e. at 'status quo'). The fishing mortality in the following year is set to the target level of fishing mortality. The resulting projected catch in the following year is then used as the TAC in the following year. This TAC is then used to project the operating model (the 'true' fleet and biology) by a year and the sequence starts again.

Implementation error was considered in a very simple way. The actual catches taken by the fleet were equal to the TAC multiplied by a factor to represent the implementation error, i.e. there was a percentage increase in removals over and above that specified by the TAC. There was no uncertainty about the level of implementation error with each iteration being subject to the same level in every year. Three levels of implementation error were tested: no error (x1), 20% (x1.2) and 40% (x1.4).

The MSE projection started in 2013 and ran for 50 years when the dynamics had become approximately stable. 250 iterations of each scenario were run. The sources of uncertainty were the starting stock status in 2012 (given by the estimation uncertainty) and the inclusion of randomly sampled residuals in the stock recruitment prediction.

The MSE is implemented in FLR (Kell et al., 2007) and using the code in Appendix A.

4 Results

The time series of the three stocks can be seen in Figure 2. The recruitment shows the same pattern for all three stocks. This is because a segmented regression model is used and the simulated levels of SSB in the MSE projection are beyond the inflection point resulting in recruitment that is independent of the SSB. The variance in the recruitment time series comes from the inclusion of the stock recruitment residuals in the projection. As implementation error increases, the median SSB gets lower while the fishing mortality increases. The median catch (realised, not TAC) was approximately the same for all three scenarios.

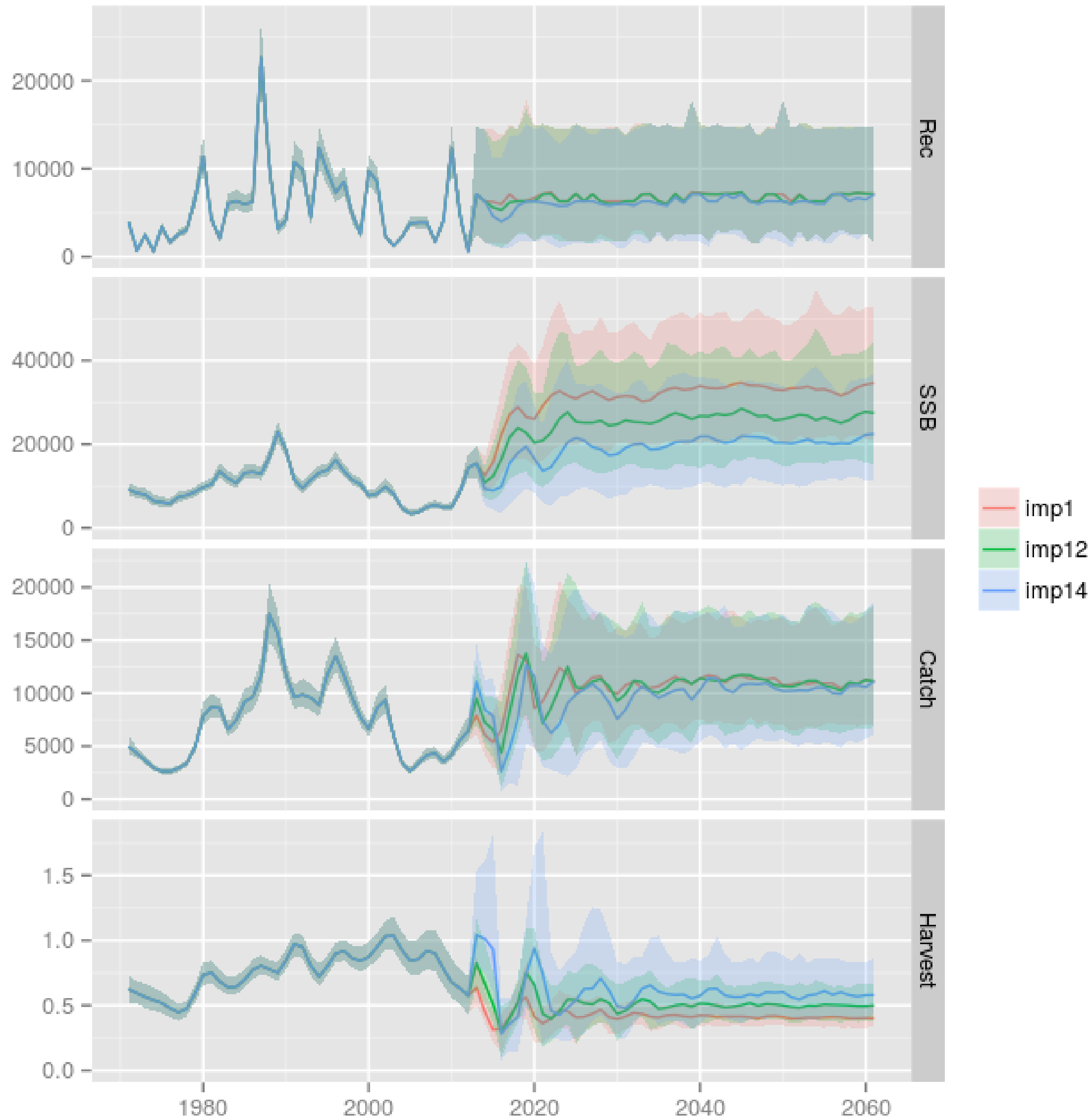

Figure 2: Time series of the three stocks with increasing levels of implementation error (none, 20%, 40%). The line shows the median value of the 250 iterations. The ribbons cover the 10 - 90% quantiles. The MSE simulations start in 2013.

Plotting the median in the time series plots in Figure 2 can give the impression that iterations of each simulation converge. It is therefore useful to investigate the variance in the simulations by examining a small number of iterations Figure 3.

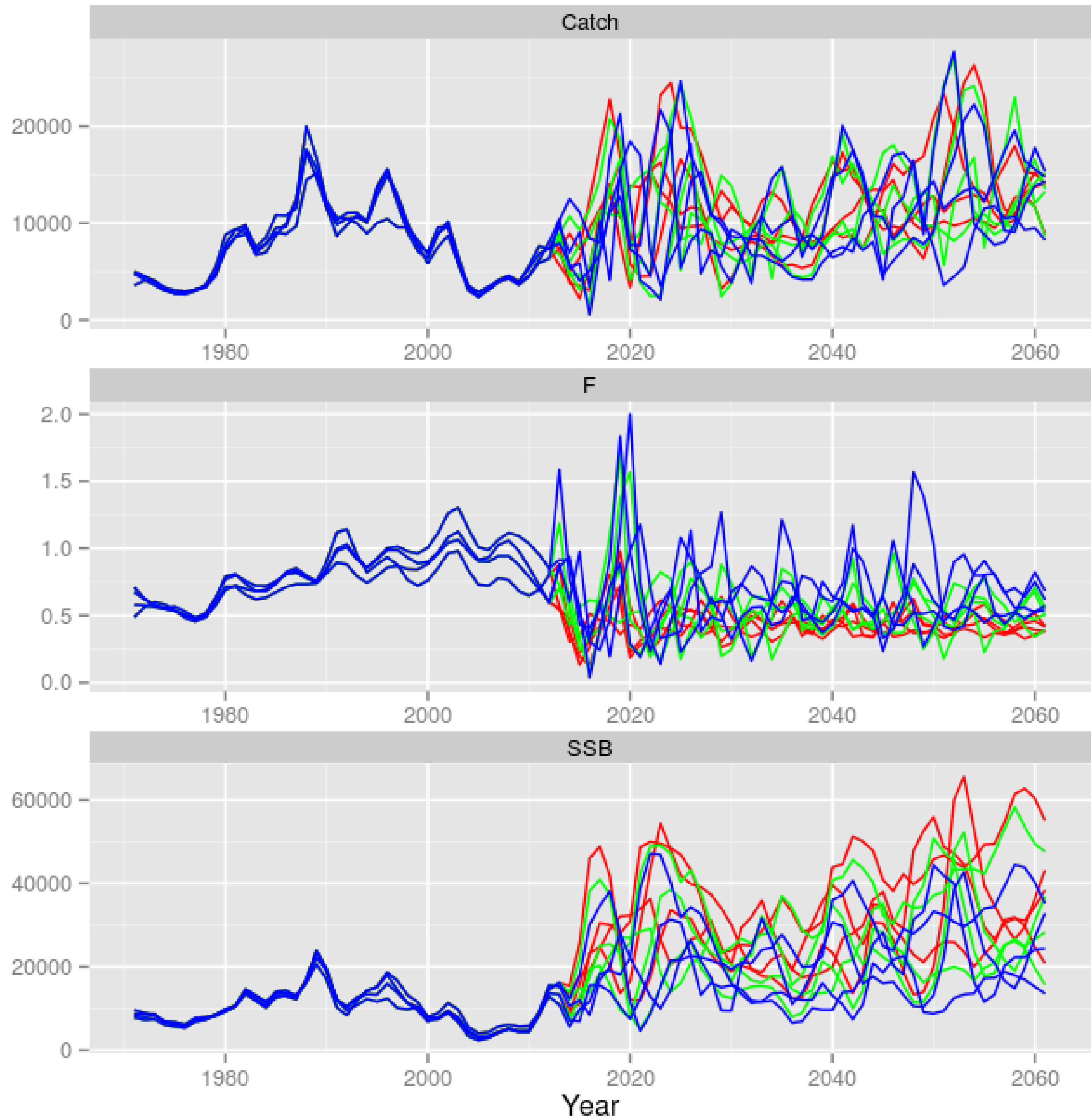

Figure 3: Four iterations of the actual catch, fishing mortality and SSB from each scenario (no implementation error is red, 20% is green, 40% is blue).

As implementation error increases the spread of values also increases, meaning that as implementation error increases so does the uncertainty (Figure 4 and Table 1).

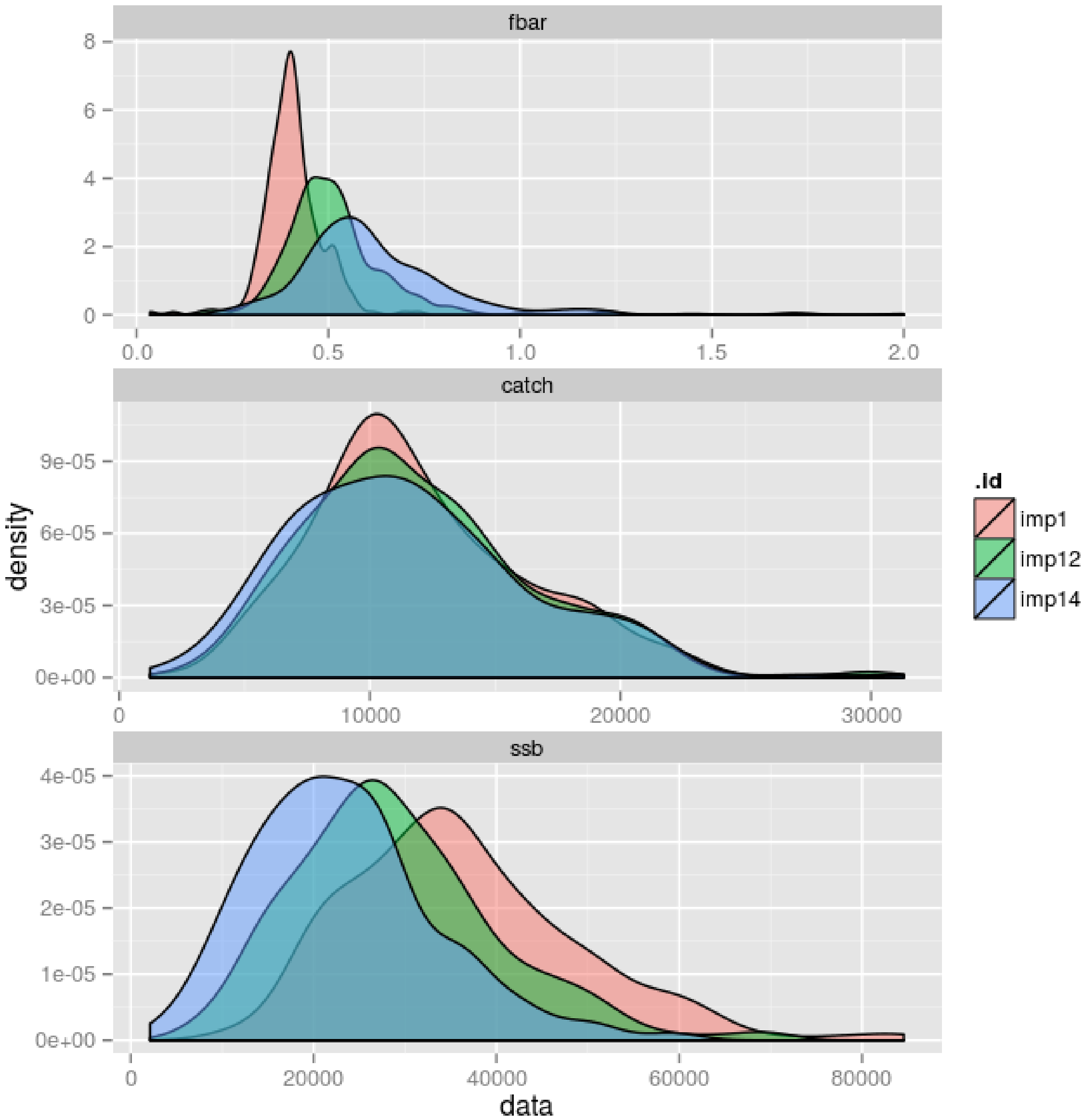

Figure 4: Distributions of the fishing mortality, catch and SSB in the final year of the projections for all three implementation error scenarios (none, 20%, 40%). There is no underreporting.

Measure	Imp. error level	Qu. 10%	Median	Qu. 90%	CV
F	0%	0.32	0.40	0.51	0.18
F	20%	0.35	0.50	0.67	0.26
F	40%	0.36	0.58	0.86	0.36
SSB	0%	19203.18	34640.36	52773.26	0.35
SSB	20%	13896.88	27423.70	44254.24	0.39
SSB	40%	9175.71	22453.07	36788.64	0.44
catch	0%	5571.95	11077.64	18333.81	0.36
catch	20%	5610.87	11148.33	18506.84	0.38
catch	40%	4911.99	11101.54	18622.98	0.41

Table 1: Summary statistics (10 and 90% quantile, median and coefficient of variation) for fishing mortality, SSB and catch in the final year of the projection

Why is the realised catch approximately the same across three scenarios? With implementation error, the realised catch is always higher than the desired TAC. The stock abundance is therefore lower than without implementation error. As there is no underreporting, the stock assessment correctly estimates the status of the stock to be lower and the fishing mortality to be higher. The TAC set to hit the desired fishing mortality target is therefore lower than the TAC without the implementation error. It is lower by a factor approximately equal to the level of implementation error (the factor is different for each iteration given the uncertainty in the projections). For example, if we look at the TACs in the final year between the no implementation error scenario and the implementation error scenarios, the median ratios are approximately equal to the level of implementation error:

```
# Approximately equal to 1.2
TAC1[,"2061"] / TAC12[,"2061"]

## An object of class "FLQuant"
## iters:  250
##
## , , unit = unique, season = all, area = unique
##
##      year
## TAC   2061
##   all 1.1876(0.105)
##
## units:  NA

# Approximately equal to 1.4
TAC1[,"2061"] / TAC14[,"2061"]

## An object of class "FLQuant"
## iters:  250
##
## , , unit = unique, season = all, area = unique
##
##      year
## TAC   2061
##   all 1.4367(0.239)
##
## units:  NA
```

This means that when implementation error is applied, the realised catch is at the same level as the TAC without implementation error. Consequently, the realised median catches for all three implementation error scenarios are approximately the same, although the spread of values increases as the implementation error increases.

The main differences between the scenarios is that the stock becomes more exploited (lower SSB, higher F) with implementation error and greater uncertainty is introduced into the results.

5 Conclusion

This document has described the implementation of a simple MSE to investigate the potential impacts of management plan implementation error on the sustainability stock. It was found that including implementation error in the projections (i.e. the realised catch being greater than the desired TAC) not only led to the stock being more exploited (lower SSB, higher fishing mortality) but also increased the uncertainty in the stock status. This will be of particular interest when a risk-based approach to fisheries management is being considered (e.g. Francis and Shotton, 1997). The results are illustrative only and are not meant to provide advice for this particular stock.

The implementation error is modelled here in a very simplistic manner. A single factor is applied to the TAC which then affects all ages and iterations equally and is the same for every year. An improved application of the error would require the combination of some age-specific bias and variance randomly sampled from a distribution so that the overrcatch was not equally applied to all ages and iterations. Additionally, the level of overfishing should change every year as a result of market forces (changes in demand and prices etc.). This is not a trivial matter to generalise, particularly given the heterogenous nature of fisheries. The method used here is sufficient to illustrate the main impacts of implementation error but for more detailed MSE work further consideration of the generation of the implementation error is required.

Underreporting is not considered in this work. This is a limitation as it is unlikely for fishers to catch more than the TAC and then openly declare it. When underreporting was tested in the projections, the results showed that including implementation error and underreporting had no impact on the ability to sustainably manage the stock. This seems unlikely so the results are not presented here. This pattern was also found during the STECF International dimension working group and highlights the difficulty in successfully modelling these issues (STECF, 2012).

As mentioned in the introduction, when there is implementation error but no underreporting it can be thought as of a scenario with no functioning enforcement regime where fishers are allowed to benefit from overcatching with no penalty (or a penalty that is insufficient to dissuade them from overcatching). Bioeconomic modelling work that considers the impact and design of enforcement regimes has been performed under EU COBECOS projects (EC, 2009, 2013), which looke at the costs and benefits of enforcement.

The issues of management plan implementation error and underreporting are complicated as they deal with the dynamics of individual fishing vessels. The dynamics will be determined by a large of number of factors including economics (prices and costs), regulations (such as the recent introduction of the Landings Regulations) and enforcement. This study has not been able to cover these issues in detail.

The implementation model will be greatly improved through more detailed economic modelling. The work presented here focuses on only how the implementation error affects the sustainability of the stock (through the fishing mortality and abundance). It does not consider the impacts of implementation error on the economic viability of the fishing fleet. This is being planned for future work, particularly through the development of the FLR package *FLasher*.

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Appendices

A MSE code

```
#==============================================================================
# libraries and constants
#==============================================================================
library(FLa4a)
library(FLash)
library(FLAssess)
library(ggplotFL)
library(testthat)
source("funs.R")

set.seed(0)

overcatch <- 1
underreport <- 1

#==============================================================================
# Read data
#==============================================================================

cod.idx <- readFLIndices("fleets-xsa-final.txt")
cod.idx[[1]] <- trim(cod.idx[[1]], age=1:6)
cod.idx[[2]] <- trim(cod.idx[[2]], age=1:4)
cod.idx <- rz(cod.idx)
load("COD.RData")
cod.stk <- stock
# Need to name them
names(cod.idx) <- c("one","two")

#==============================================================================
# Fit a4a model to replicate official assessment as much as possible
#==============================================================================

fmod <- ~ I(age^2) + age + te(age, year, k=c(3, 10)) + s(year, k=5)
cod.fit <- sca(cod.stk, cod.idx, fit="assessment", fmodel=fmod)

cod <- cod.stk + cod.fit
fbar(cod)
#==============================================================================
# Single species MSE to show example of envelope analysis
#------------------------------------------------------------------------------
# Frange: 0.27-0.55
# Btrig: 10300
# Bpa: 10300
# Blim: 7300
# Fmsy: 0.4
#==============================================================================

# stock
stk <- cod

# S/R
sr <- fmle(as.FLSR(stk, model="segreg"))
```

```
# fixed variables
it <- 250
amx <- range(stk)["max"]
y0 <- range(stk)["minyear"] # initial data year
ny <- 50 # number of years to project

dy <- 2011 # data year
ay <- 2012 # assessment year
iy <- 2012 # initial projections year (also intermediate)
fy <- iy + ny -1 # final year
vy <- ac(iy:fy)
nsqy <- 3 # number of years to compute status quo metrics
mny <- 2015 # min year to get to trg
mxy <- 2015 # max year to get to trg

# management
flo <- 0.27
fup <- 0.55
fmsy <- flo + ((fup - flo) / 2)
#fsq <- mean(c(fbar(stk)[,ac(dy)]))
bpa <- 10300
blim <- 7300

# fixed objects
TAC <- FLQuant(NA, dimnames=list(TAC="all", year=vy, iter=1:it))
omCatch <- FLQuant(NA, dimnames=list(TAC="all", year=vy, iter=1:it))
BB <- FLQuant(0, dimnames=list(TAC="all", year=vy, iter=1:it))

# stock
sstk <- cod.stk + simulate(cod.fit, it)
pstk <- stf(sstk, ny, 5, 5)
landings.n(pstk) <- propagate(landings.n(pstk), it)
discards.n(pstk) <- propagate(discards.n(pstk), it)

# S/R residuals
sr.res <- window(rec(pstk), iy, fy)
sr.res[] <- sample(c(residuals(sr)), ny*it, replace=TRUE)

# index (pulled to 1st of January)
lst <- mcf(list(cod.idx[[1]]@index, stock.n(stk)))
idx.lq <- log(lst[[1]]/lst[[2]])
idx.qmu <- idx.qsig <- stock.n(iter(pstk,1))
idx.qmu[] <- yearMeans(idx.lq)
idx.qsig[] <- log((sqrt(yearVars(idx.lq))/yearMeans(idx.lq))^2 + 1)
idx.q <- idx <- FLQuant(NA, dimnames=dimnames(stock.n(pstk)))
idx.q[,ac(y0:dy)] <- propagate(exp(idx.lq[,ac(y0:dy)]), it)
idx.q <- rlnorm(it, idx.qmu, idx.qsig)
plot(window(trim(idx.q, age=1:5), 1983, 2032))
idx <- idx.q * stock.n(pstk)
idx <- FLIndex(index=idx, index.q=idx.q)
range(idx)[c("startf", "endf")] <- c(0, 0)
plot(window(trim(index(idx), age=1:5), 1983, 2032))

dt <- date()
ftrg <- fmsy

# go fish
```

```r
for(i in vy[-length(vy)]){
        gc()
        ay <- an(i)
        cat(i, " > ")
        vy0 <- 1:(ay-y0) # data years (positions vector)
        sqy <- (ay-y0-nsqy+1):(ay-y0) # status quo years (positions vector)

    #----- Management ------
    # Generating the 'perceived' stock
        stk0 <- pstk[,vy0]
    # *** Add underreporting here if necessary ***
        catch.n(stk0) <- (catch.n(stk0) + 1) * underreport # avoid zeros
    # Generate the indices
        idx0 <- idx[,vy0]
        index(idx)[,i] <- stock.n(pstk)[,i]*index.q(idx)[,i]
    # Simple assessment
        fit <- sca(stk0, FLIndices(idx0))
        stk0 <- stk0 + fit
        # Perceived 2 year STF
    # Yr 1 is Fsq, Yr 2 is target F
        fsq0 <- yearMeans(fbar(stk0)[,sqy])
        dnms <- list(iter=1:it, year=c(ay, ay+1), c("min", "val", "max"))
        arr0 <- array(NA, dimnames=dnms, dim=unlist(lapply(dnms, length)))
        arr0[,,"val"] <- c(fsq0, rep(ftrg, it))
        arr0 <- aperm(arr0, c(2,3,1))
        ctrl <- fwdControl(data.frame(year=ay:(ay+1), quantity='f', val=NA))
        ctrl@trgtArray <- arr0
        stkTmp <- stf(stk0, 2)
        stkTmp <- fwd(stkTmp, ctrl=ctrl, sr=sr,
                  sr.residuals = exp(sr.res[,ac(ay:(ay+1))]),
                  sr.residuals.mult = TRUE)
    # Get TAC for following year that results from hitting the F in STF
        TACtemp <- catch(stkTmp)[,ac(ay+1)]
        TAC[,ac(ay+1)] <- TACtemp

    #--------- OM --------------
    # *** Add overcatch here ***
    omCatch[,ac(ay+1)] <- TAC[,ac(ay+1)] * overcatch
        ctrl@target <- ctrl@target[2,]
        ctrl@target[,"quantity"] <- "catch"
        ctrl@trgtArray <- ctrl@trgtArray[2,,,drop=FALSE]
        ctrl@trgtArray[,"val",] <- c(omCatch[,ac(ay+1)]) #+ BB[,ac(ay)])
        pstk <- fwd(pstk, ctrl=ctrl, sr=sr,
                sr.residuals = exp(sr.res[,ac(ay+1)]),
                sr.residuals.mult = TRUE)
}
```

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