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Bioeconomic Modelling for Fisheries

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Abstract

Current fisheries advice requires an increased consideration of bioeconomics and the interactions of fishing fleets with the biological stocks. This is particularly important when evaluating proposed multi-annual management plans. To achieve this, modelling tools need to be able to consider the dynamics of individual fisheries. This becomes more challenging with mixed fisheries when multiple species are caught by multiple fleets. A suitable balance needs to be found between replicating the details of the complex fishery system and simplifying a model to the level that makes it tractable but still useful.

Much of the bioeconomic fisheries modelling work performed at the JRC uses the FLR software framework (Kell et al., 2007). The JRC has developed a new FLR package, `FLasher`, for performing projections and forecasts with multiple individual fisheries and multiple species. This allows the dynamics of mixed fisheries to be more accurately modelled and allows the evaluation of the economic performance of alternative management decisions.

This document presents some of the features and capabilites of `FLasher` using a case study based on a semi-realistic flatfish fishery: two fleets with different selectiviuty patterns, bottom trawl and gillnet, catching two species with different life histories and maximum sizes, European plaice (*Pleuronectes platessa*) and common sole (*Solea solea*) `FLasher` expands the current modelling capabilities of FLR, allowing the impacts of proposed management plans to be evaluated in greater detail by (1) explicitly modelling the dynamics of each individual fleets, which could be affected in different ways by management, (2) forecasting in parallel the full species and fleet assemblage found in mixed fisheries, and (3) employing the latest iteration of the C++ language and a new library for automatic differentation.

1. Introduction

Current fisheries advice requires an increased consideration of bioeconomics, particularly in the context of multi-annual management plans (European Parliament and Council of the European Union, 2013). To achieve this, modelling tools need to be able to consider the dynamics of individual fisheries. This becomes more challenging with mixed fisheries when multiple species are caught by multiple fleets (Mackinson et al., 2009).

Much of the bioeconomic fisheries modelling work performed at the JRC uses the FLR software framework (Kell et al., 2007) based on the R statistical programming environment (R Core Team, 2016). The main software package for performing projections is the `FLash` package. `FLash` is limited in that it is not able to model multiple individual fisheries and instead combines all fisheries into a single object and is only able to model one species at a time. As such, `FLash` is not able to fully model a mixed fishery with multiple species. Additionally, economic considerations in `FLash` are limited.

The JRC has developed a new FLR package, `FLasher`, for performing projections with multiple individual fisheries and multiple species. This allows the dynamics of mixed fisheries to be more accurately modelled and allows the evaluation of economic performance. The package is presented in this report.

The original FLR projection package, `FLash`, is based on the *FLStock* class. The new package, `FLasher`, is not based on the *FLStock* class (although it can use it) but is instead based on the *FLBiol* and *FLFishery* classes. This oftens more flexibility for modelling specific fleets and can include more than one stock. Targets and limits can be set for the projections. The independent variables are the effort of each fishery in each time step. For example, in the full mixed fishery case study below there are two fisheries. This means that in each year there are two independent variables (the effort of each fleet). This limits the number and type of targets that can be set. `FLasher` is also capable of including stochasticity in the projections. This is not shown in the following examples to avoid over complication.

A mixed fishery case study, based on two fishing fleets catching European plaice (*Pleuronectes platessa*) and common sole (*Solea solea*), is used to demonstrate the capabilities of `Flasher`. Projections of the fishery are performed under different management options, including economic metrics. Plaice and sole are two species that are commonly caught together, for example in the North Sea (ICES, 2016a). However, the case study presented here is not based on a real scenario and is presented to demonstrate the capabilities of the new modelling tool. The case study could form the basis for a real case study given the appropriate data. In this example, the two stocks are fished by a beam trawl fishery and a gillnet fishery. These have different selectivities and fishing effort that is independent of each other.

This document contains all the R code in the analysis including the outputs. The results are presented 'live' using the R package `knitr`. All the code and data used in this report can be found at the Git repository:

`https://fishreg.jrc.ec.europa.eu/gitlab/scottfi/FLasher_mixed_fishery_example.git`

2. Making the operating model components

In this section the R objects used for the projections are created.

```
library(FLasher)
```

2.1 The biological stocks

The life history characteristics of the plaice and sole stocks are taken from the latest North Sea stock assessments (ICES, 2016b).

```
load("../data/plaice_stk.RData")
load("../data/sole_stk.RData")
```

We make two new stocks based on the stock assessment results. The life history characteristics are based on the mean of the last 5 years of data.

```
ple_stk <- stock_maker(plaice_stk, 20, 5, desc="Plaice", name="ple")
sol_stk <- stock_maker(sole_stk, 20, 5, desc="Sole", name="sol")
```

Unlike the earlier projection package, `FLash`, the new package is not based on the *FLStock* class. Instead it uses the *FLBiol* class.

Here we make the two *FLBiol* objects, including the previously fitted stock recruitment relationship (based on the North Sea assessment result).

```
ple <- as(ple_stk, "FLBiol")
rec(ple) <- predictModel(model=ricker()$model, params=params(plaice_srr))
sol <- as(sol_stk, "FLBiol")
rec(sol) <- predictModel(model=ricker()$model, params=params(sole_srr))
biols <- FLBiols(ple=ple, sol=sol)
```

2.2 The fisheries

In this example we create two fisheries (a beam trawl fleet and a gillnet fleet). Each fishery catches the two stocks of plaice and sole.

2.2.1 The *FLCatch* objects

We need to make an *FLCatch* object for each stock for each fishery.

```
pleBT <- as(ple_stk, "FLCatch")
solBT <- as(sol_stk, "FLCatch")
pleGN <- as(ple_stk, "FLCatch")
solGN <- as(sol_stk, "FLCatch")
```

The selectivity pattern for each of the *FLCatch* objects needs to be set. This could be set by looking at the partial fishing mortalities or partial catches of each fishery if the data was available. Here we assume that the beam trawl has a logistic selection pattern and the gillnet has a dome shaped selection pattern.

```
# Trawl sel based on logistic
trawl_sel <- function(ages,k,a50){
    sel <- 1/(1+exp(-k*(ages-a50)))
    # scale it up so max is 1
    sel <- sel * (1/max(sel))
    return(sel)
}

# Gill sel is a double normal
gill_sel <- function(ages, amax, sdleft, sdright){
```

```
    lhs <- dnorm(ages, mean=amax, sd=sdleft)
    lhs <- lhs * (1 / max(lhs))
    rhs <- dnorm(ages, mean=amax, sd=sdright)
    rhs <- rhs * (1 / max(rhs))
    sel <- c(lhs[ages <= amax], rhs[ages > amax])
    return(sel)
}
```

We assume the selection pattern is constant in time (although this does not have to be the case).

```
ple_bt_sel <- trawl_sel(ages=1:10,k=5,a50=2.5)
ple_gn_sel <- gill_sel(ages=1:10,amax=3,sdleft=1,sdright=1)
sol_bt_sel <- trawl_sel(ages=1:10,k=2,a50=3)
sol_gn_sel <- gill_sel(ages=1:10,amax=2,sdleft=0.5,sdright=2)
catch.sel(pleBT)[] <- ple_bt_sel
catch.sel(solBT)[] <- sol_bt_sel
catch.sel(pleGN)[] <- ple_gn_sel
catch.sel(solGN)[] <- sol_gn_sel
```

The resulting selection patterns can be seen in Figure 1.

```
par(mfrow=c(2,1))
plot(1:10,ple_bt_sel, type="l", col="black",ylim=c(0,1),xlab="Ages",
    ylab="Selectivity", main="Plaice")
lines(1:10,ple_gn_sel, col="blue")
plot(1:10,sol_bt_sel, type="l", col="black", ylim=c(0,1),xlab="Ages",
    ylab="Selectivity", main="Sole")
lines(1:10,sol_gn_sel, col="blue")
```

We also need to set the catchability parameter α for each *FLCatch* to link the fishing effort to the fishing mortality through the selection pattern. Here we set α so that an effort of 1 yields a desired mean fishing mortality (F). All of the projected effort values can then be considered as relative to this effort rather than an as absolute fishing effort. Each stock is being fished by two fisheries. Here we assume that the catchability of the beam trawl gear is twice that of the gillnet. The total target F for an effort of 1 is set to be 0.3.

```
# Set the catch.q params to get the right level of F
# effort = 1 to hit a desired fbar
# Assume that the catchability of trawl is 2 x gill net
abt_fun <- function(agn, bt_sel, gn_sel, fbar){
    abt <- agn * 2
    f <- (abt * bt_sel) + (agn * gn_sel)
    fbarhat <- (mean(f[2:6]) - fbar)^2
    return(fbarhat)
}

ple_agn <- optimize(abt_fun, c(0,20), bt_sel=ple_bt_sel, gn_sel=ple_gn_sel,
    fbar=0.3)$minimum
sol_agn <- optimize(abt_fun, c(0,20), bt_sel=sol_bt_sel, gn_sel=sol_gn_sel,
    fbar=0.3)$minimum
catch.q(pleGN)[] <- c(ple_agn, 0)
catch.q(pleBT)[] <- c(ple_agn*2, 0)
catch.q(solGN)[] <- c(sol_agn, 0)
catch.q(solBT)[] <- c(sol_agn*2, 0)
```
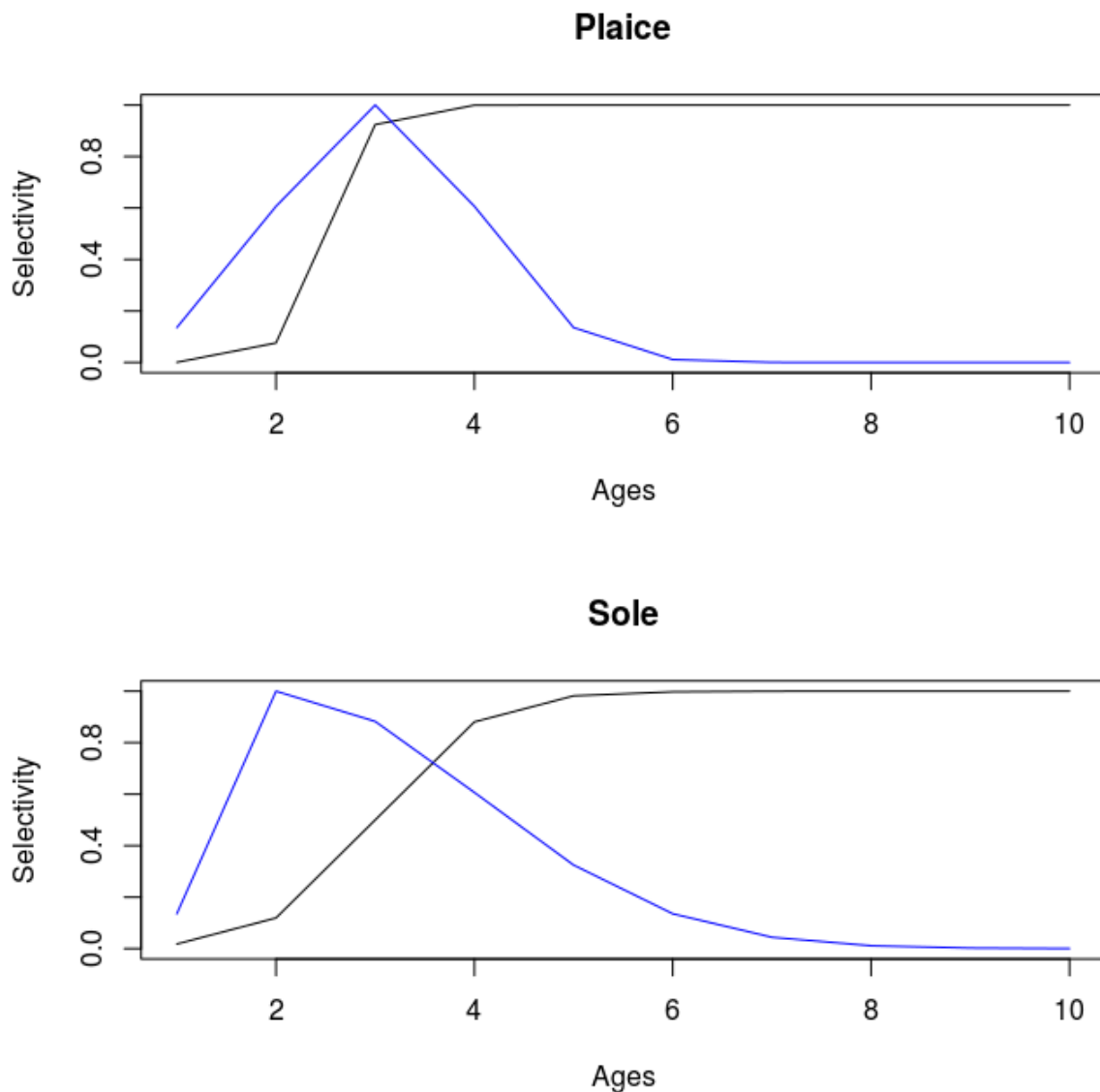
Finally, we set some prices for the stocks. Sole is more valuable than plaice.

```
# Set some prices
sol_price <- 10
```

Figure 1: Selection patterns for the beam trawl (black) and gillnet (blue) fisheries on sole and plaice.

```
ple_price <- 2
pleBT@price[] <- ple_price
solBT@price[] <- sol_price
pleGN@price[] <- ple_price
solGN@price[] <- sol_price
```

2.2.2 The *FLFishery* objects

We make two *FLFishery* objects with the *FLCatch* objects and set the initial effort to 1. This will be used in the final set of examples. Simpler *FLFishery* objects will also be created for simpler examples.

```
bt <- FLFishery(pleBT=pleBT, solBT=solBT)
gn <- FLFishery(pleGN=pleGN, solGN=solGN)
gn@effort[] <- 1
bt@effort[] <- 1

# Make the FLFisheries
```

```
flfs <- FLFisheries(bt=bt, gn=gn)
```

3.   Example: A single fishery and a single stock

Here we show a simple example with only a single fishery (the beam trawl) catching a single stock (plaice) (Figure 2). In all of the projections, the targets are hit by finding the fishing effort of each fishery in the projection. Fishing effort is the only indpendent variable over which managers have any control. All other measures (landings, fishing mortality etc) are driven by the fishing effort.
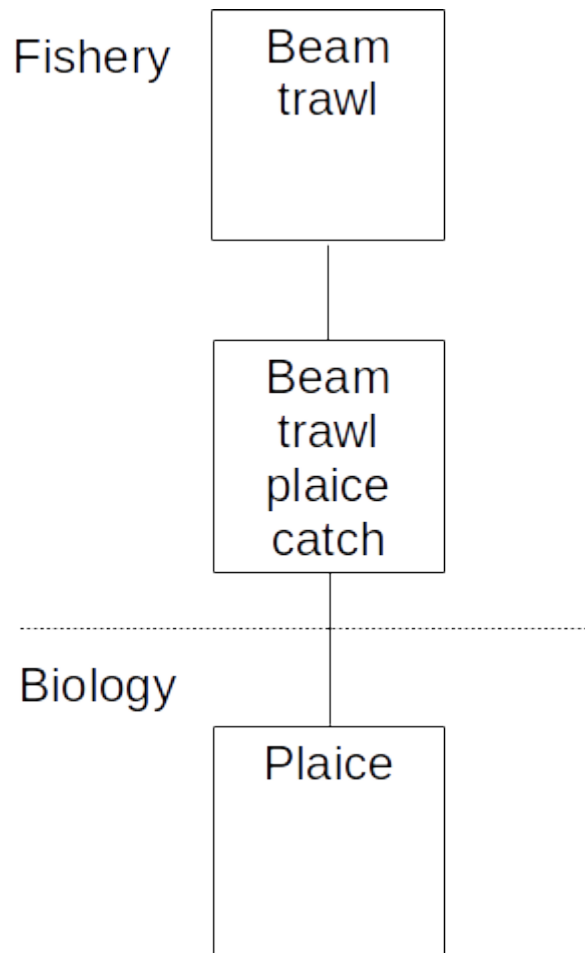
Figure 2: The beam trawl fishery fishing on the plaice stock.

First we make the fishery and biology objects based on the ones created above:

```
# Single fishery on 1 stock
bt1 <- FLFishery(pleBT=pleBT)
# Set the initial effort
bt1@effort[] <- 1
flfs1 <- FLFisheries(bt=bt1)
biols1 <- FLBiols(ple=ple)
```

In the first example we set a constant total catch target for 20 years (we assume that there is no fishing in year 1).

```
catch_target <- 100000
flasher_ctrl_target <- data.frame(year = 2:20,
                     quant = "catch",
```

```
                       biol = 1,
                       value = catch_target)
flasher_ctrl <- fwdControl(flasher_ctrl_target)
flasher_ctrl@FCB <- matrix(1, nrow=1, ncol=3, dimnames=list(1,c("F","C","B")))
test <- fwd(biols=biols1, fisheries=flfs1, control=flasher_ctrl)
```

We can see that the constant catch target has been hit in the target years (Figure 3). The plot also shows the resulting fishing mortality, relative effort, revenue of the fishery and biomass of the stock. The biomass is also driven by the stock-recruitment relationship of the stock and the initial dynamics will be affected by the initial age structure.
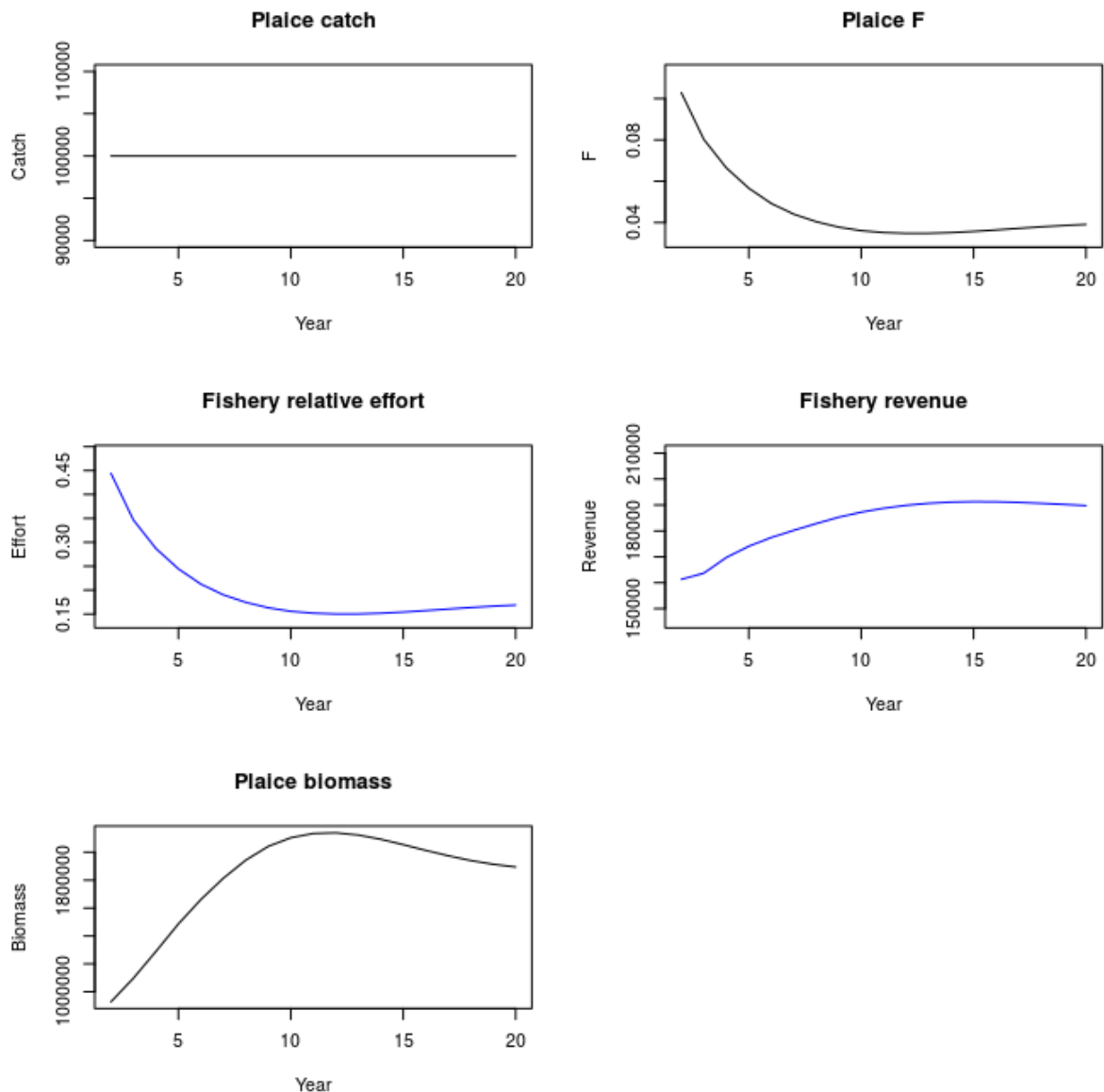
Figure 3: Summary results of projecting a single stock with a single fishery with a constant catch target.

4. Example: A single fishery with two stocks

In this example, we build on the previous example and introduce the sole stock as an additional catch (Figure 4). We still only have one fishery which gives us only one independent variable (the fishing effort) in each year. The same fishing effort is applied to both stocks as they are caught by the same fishery.

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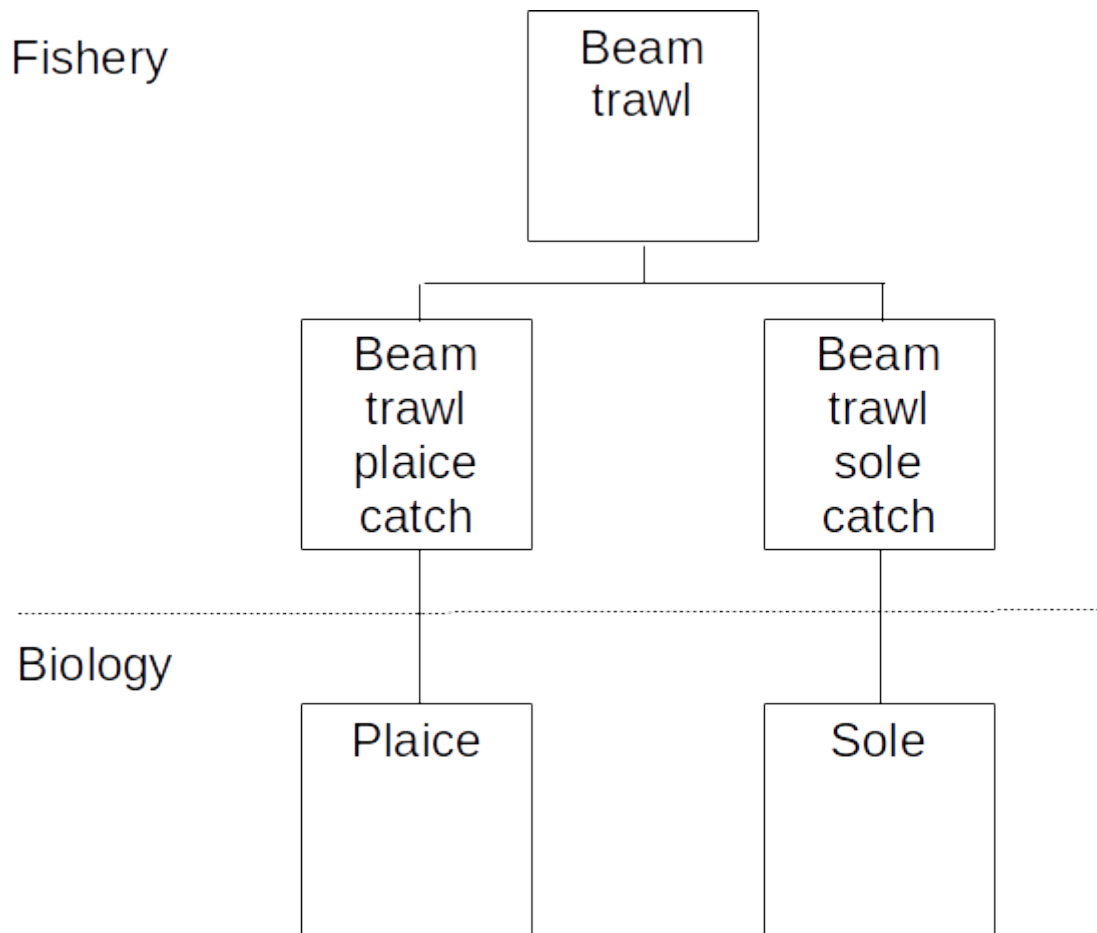
Figure 4: The beam trawl fishery fishing on the plaice and sole stocks.

```
# Single fishery on 2 stocks
bt2 <- FLFishery(pleBT=pleBT, solBT=solBT)
bt2@effort[] <- 1
flfs2 <- FLFisheries(bt=bt2)
biols2 <- FLBiols(ple=ple, sol=sol)
```

As we have only one independent variable we cannot set a catch target for each stock (i.e. two dependent variables) because that would require two independent variables. Additionally, the catches of the two stocks are of course linked as they are caught by the same fishery. We do not have the freedom to hit all of our targets at the same time. This is a typical mixed fishery problem!

In this first example we set only a catch target for the plaice stock.

```
plaice_catch_target <- 250000
flasher_ctrl_target <- data.frame(year = 2:20,
                        quant = "catch",
                        biol = 1,
                        value = plaice_catch_target)
flasher_ctrl <- fwdControl(flasher_ctrl_target)
flasher_ctrl@FCB <- matrix(c(1,1,1,2,1,2), nrow=2, ncol=3,
    dimnames=list(1:2,c("F","C","B")))
test <- fwd(biols=biols2, fisheries=flfs2, control=flasher_ctrl)
```

We can see that the plaice catch target has been hit (Figure 5). We also look at the resulting sole catches, Fs, relative effort, revenue and biomasses that resulted from fishing at the effort that yielded the plaice target catch.
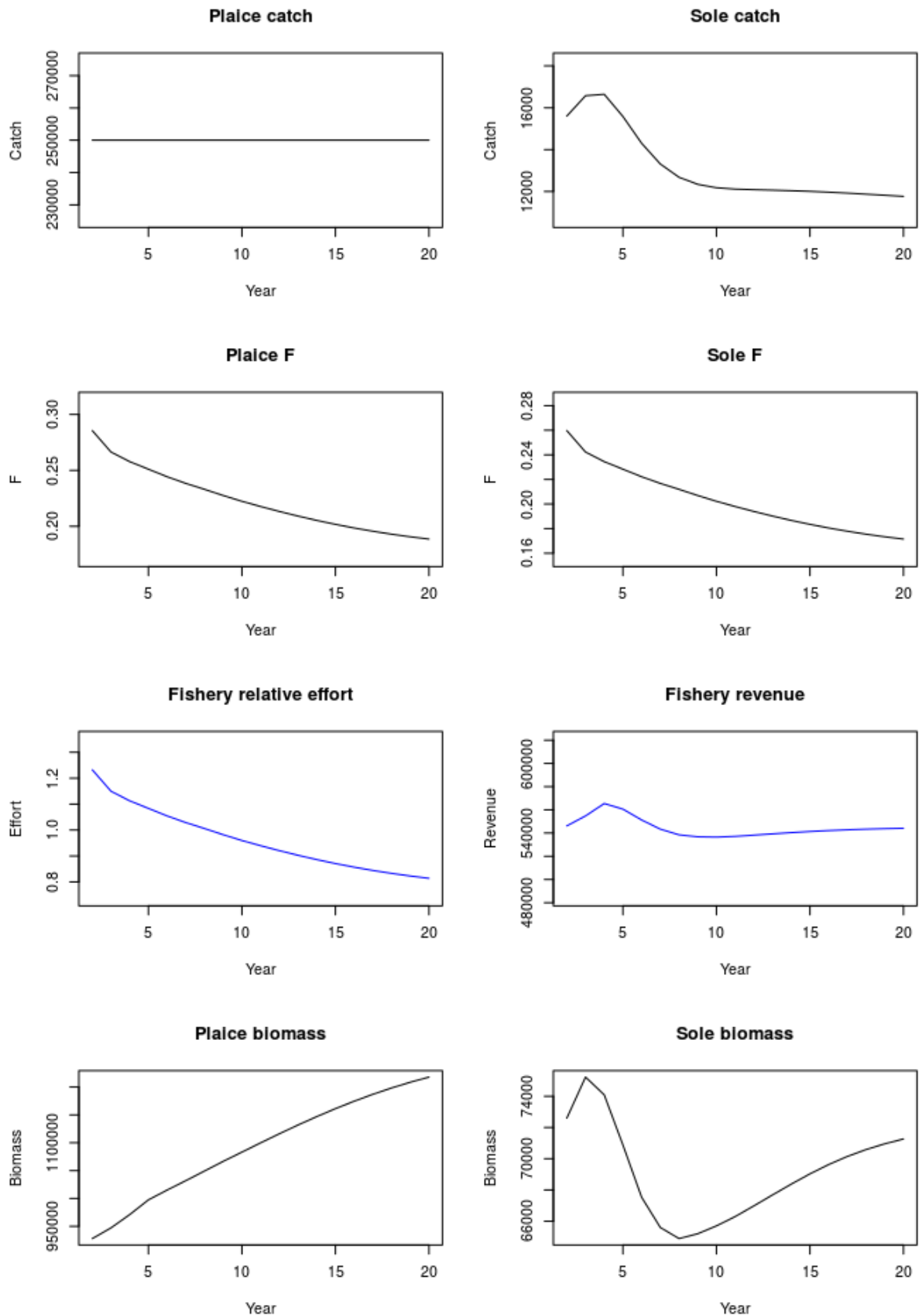
Figure 5: Summary results of projecting two stocks with a single fishery with a constant catch target on plaice.

As mentioned above, we cannot also have a target for the sole catch that is hit simultaneously as the plaice catch target. However, we can add a limit to the amount of fishing

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pressure that sole is subject to. For example, we can set a maximum F for sole if we had F-based reference points.

We saw in the last example that catching the plaice catch target results in a maximum F for sole of about 0.26. We can set a limit of maximum F of 0.2 (this number is made up for the sake of the example).

```
plaice_catch_target <- 250000
sole_f_limit <- 0.2
# Make the control object in two bits
flasher_ctrl_target1 <- data.frame(year = 2:20,
                        quant = "catch",
                        biol = 1,
                        value = plaice_catch_target,
                        max = NA, minAge = NA, maxAge = NA)
flasher_ctrl_target2 <- data.frame(year = 2:20,
                        quant = "f",
                        biol = 2,
                        max = sole_f_limit,
                        value=NA,
                        minAge=2, maxAge=6)
flasher_ctrl_target <- rbind(flasher_ctrl_target1, flasher_ctrl_target2)
flasher_ctrl <- fwdControl(flasher_ctrl_target)
flasher_ctrl@FCB <- matrix(c(1,1,1,2,1,2), nrow=2, ncol=3,
    dimnames=list(1:2,c("F","C","B")))
test <- fwd(biols=biols2, fisheries=flfs2, control=flasher_ctrl)
```

We can see that the maximum limit of F on sole has come into effect at the start of the projection and continues until 5 (Figure 6). The catches on plaice in those years has been limited and the target catch has not been hit. After year 5, the required fishing effort to catch the plaice target is sufficiently low that the resulting F on sole is less than 0.2. This demonstrates how `FLasher` can be used to simulate management decisions on a fishery that fishes multiple stocks.

5. Example: Two fisheries on a single stock

In this example we simulate two different fisheries (beam trawl and gillnet) that are fishing the same stock (sole) (Figure 7).

```
# Two fisheries on a single stock
bt3 <- FLFishery(solBT=solBT)
bt3@effort[] <- 1
gn3 <- FLFishery(solGN=solGN)
gn3@effort[] <- 1
flfs3 <- FLFisheries(bt=bt3, gn=gn3)
biols3 <- FLBiols(sol=sol)
```

We have two fisheries which means we have two independent variables (the effort from each of the fisheries) to manipulate to hit the targets. This means that we cannot set just a single target for the total catch of sole because there are an infinite number of ways that the two effort levels can be set to hit the total catch.

One option is to set target catches for each of the fisheries, i.e. a target catch for sole caught by the beam trawl and a target catch for sole caught by the gillnet. For example, if the stock is managed by a single TAC, we can use the individual fleet quotas for targets. Here the total catch target is 15000, split between the two fisheries.

```
sole_bt_catch_target <- 10000
sole_gn_catch_target <- 5000
flasher_ctrl_target <- data.frame(year = rep(2:20, each=2),
                    quant = "catch",
                    fishery = c(1,2),
                    catch = 1,
```
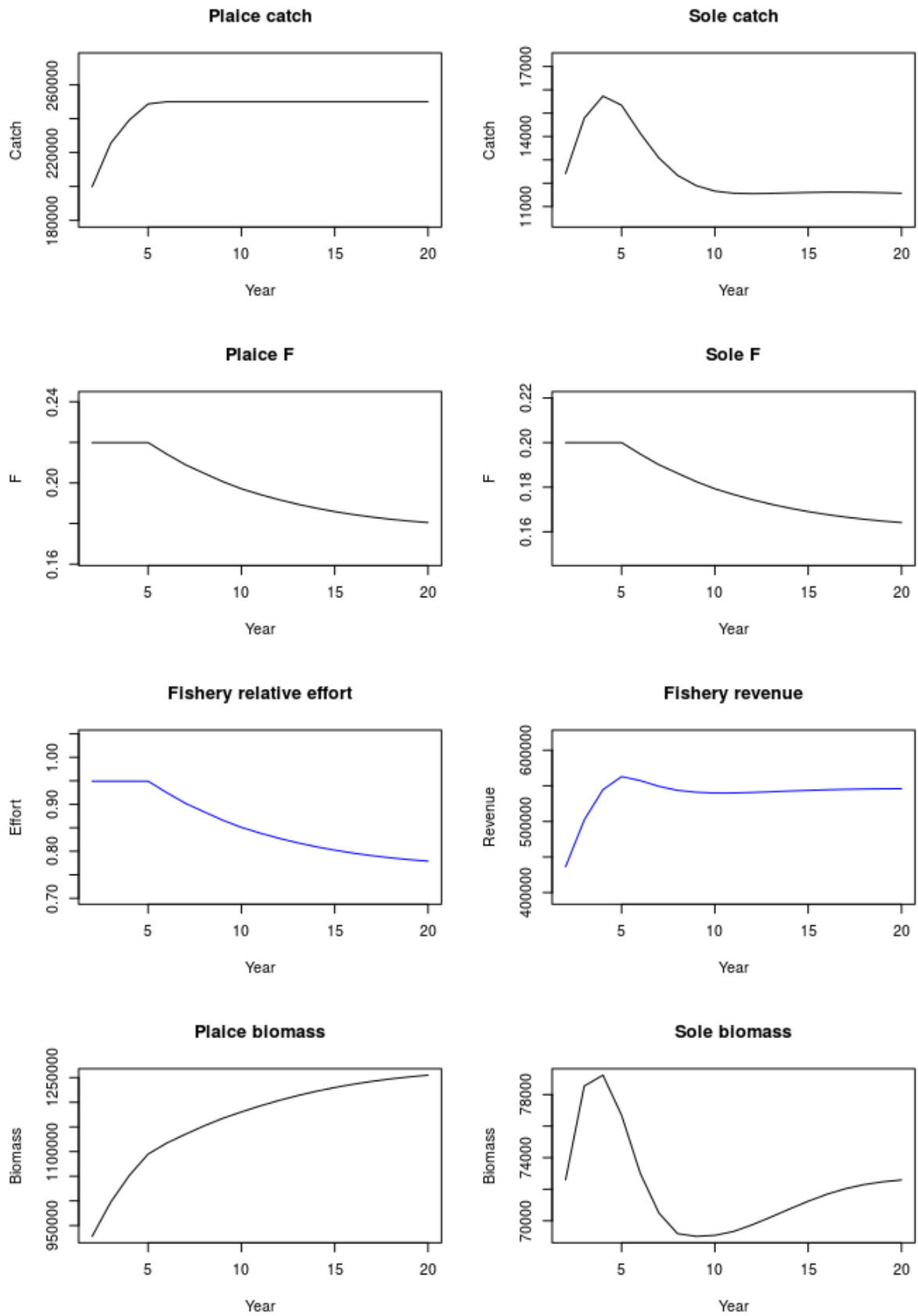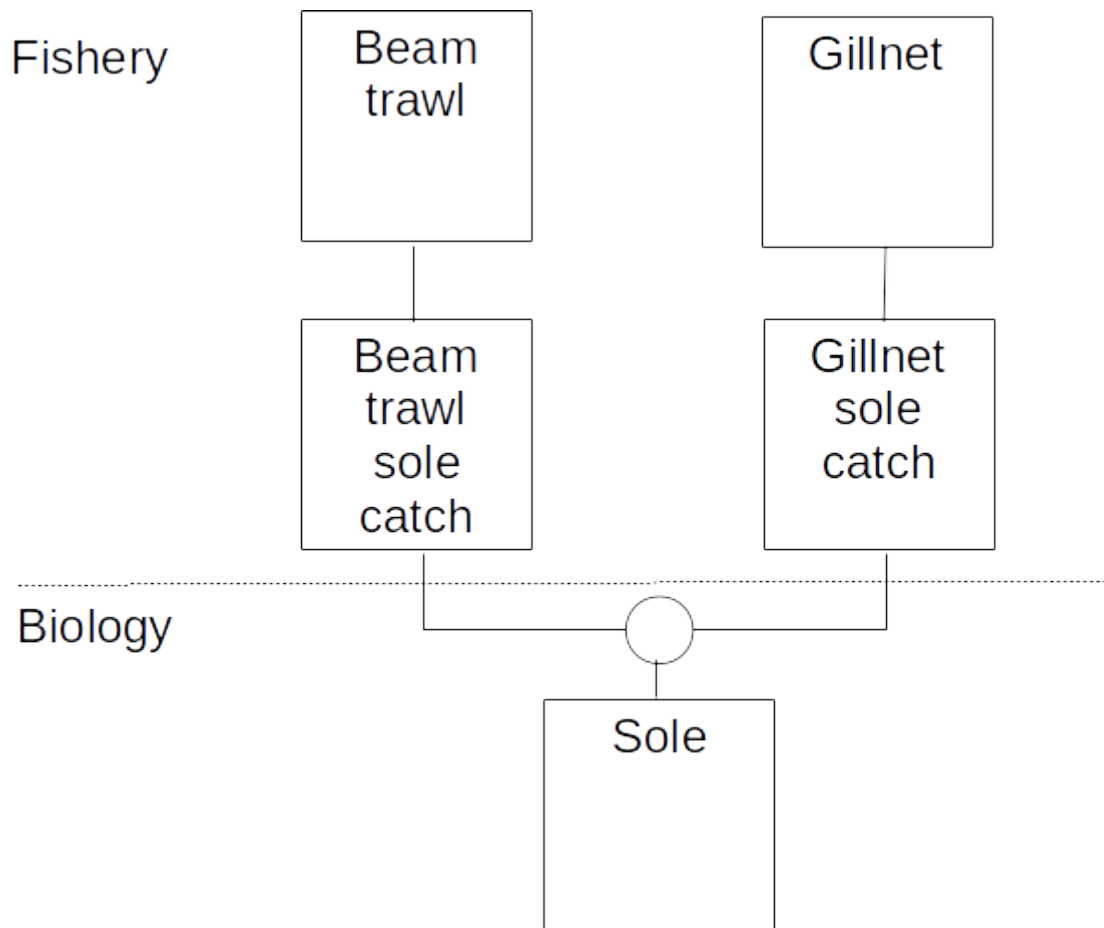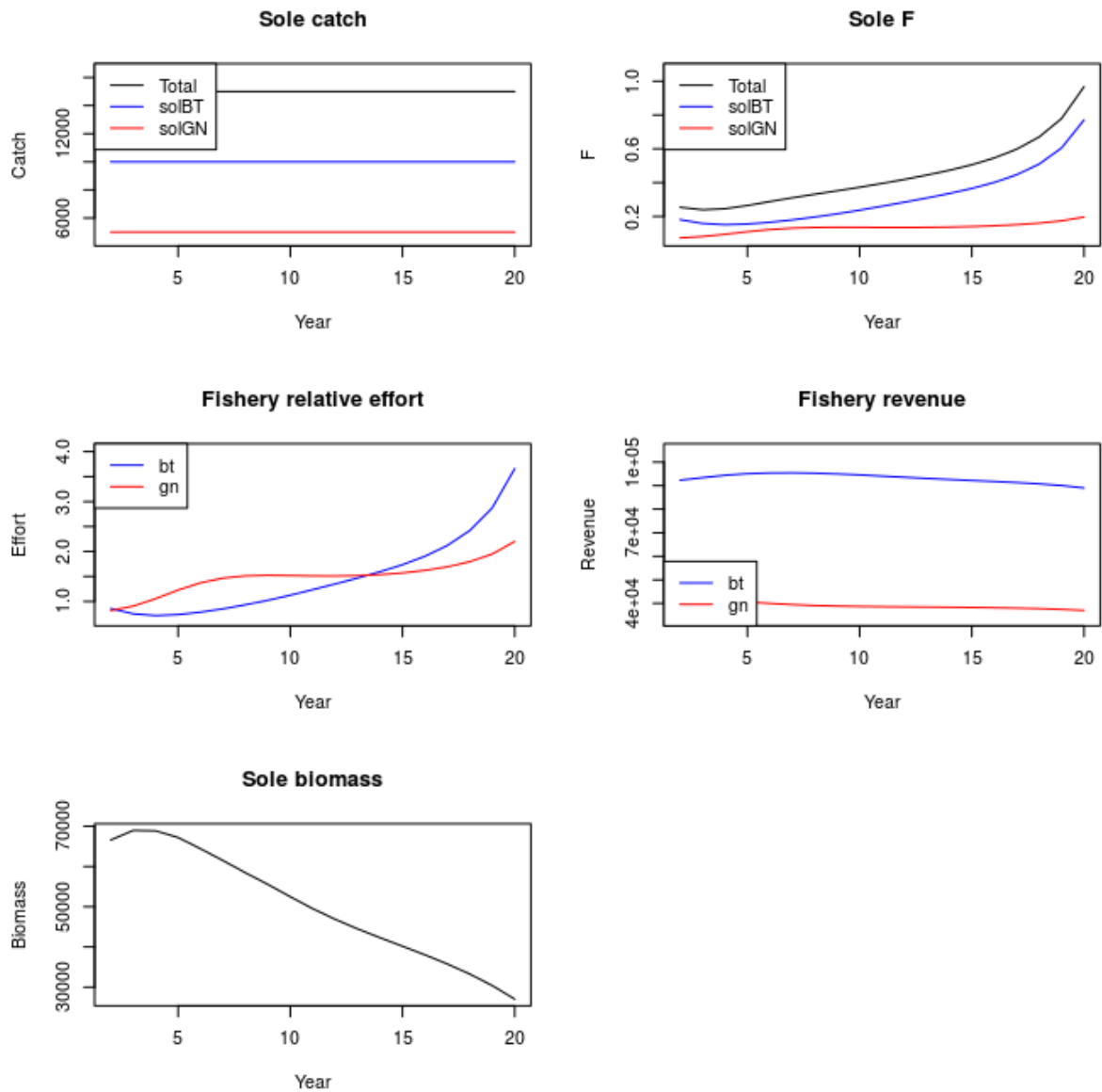
Figure 6: Summary results of projecting two stocks with a single fishery with a constant catch target on plaice and a maximum F limit on sole.

Figure 7: The beam trawl and gillnet fisheries fishing on the sole stock.

```
                          biol = NA,
                          value = c(sole_bt_catch_target, sole_gn_catch_target))
flasher_ctrl <- fwdControl(flasher_ctrl_target)
flasher_ctrl@FCB <- matrix(c(1,2,1,1,1,1), nrow=2, ncol=3,
    dimnames=list(1:2,c("F","C","B")))
test <- fwd(biols=biols3, fisheries=flfs3, control=flasher_ctrl)
```

Both catch targets been hit although this has resulted in increasing fishing mortality on the stock (Figure 8). The plot also shows the partial fishing mortality from each fishery and it can be seen that the most of the fishing mortality comes from the beam trawl fishery. The beam trawl also also has a correspondingly higher revenue even though the relative effort is not higher (suggesting the profit will be higher, something which can be explored when further economic indicators are added to `FLasher`).

An alternative approach is to set a total catch at the stock level (for example, if the stock was managed through a TAC) and set *relative* catches between the fisheries (for example, by maintaining the historic relative stability of the fleets). In this way we do not explicitly specify how much the fisheries will catch, only that the total must be equal to the TAC and the historic relative stability must be respected. Here we set a total catch target of the stock to be 12000 and also that the catch of the beam trawl fishery is twice that of the gillnet.

```
sole_catch_target <- 12000
sole_bt_gn_catch_relative <- 2
flasher_ctrl_target1 <- data.frame(year = 2:20,
                    quant = "catch",
                    relYear = NA, relSeason = NA,
                    fishery = NA, relFishery=NA,
```
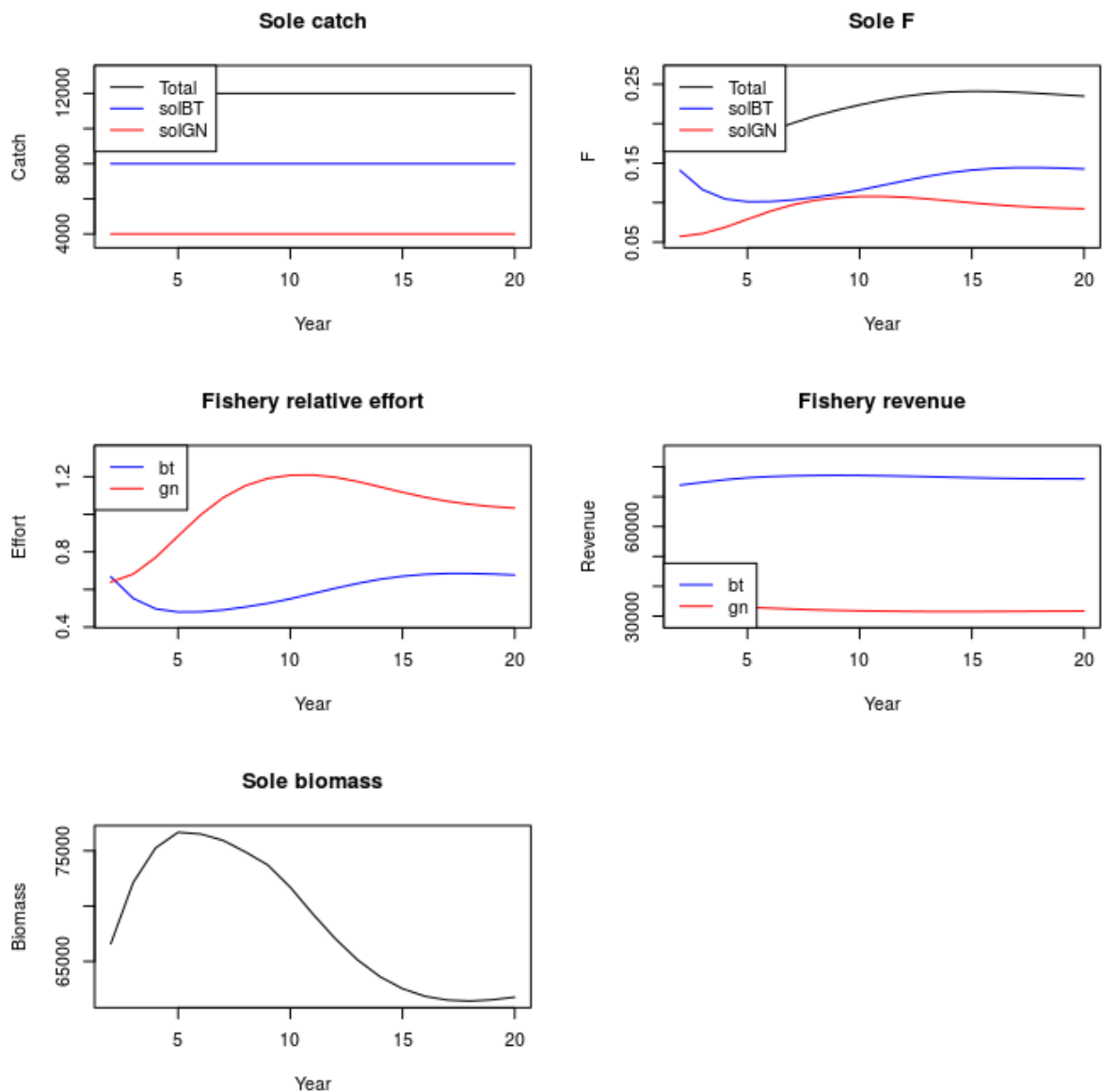
Figure 8: Summary results of projecting one stock with two fisheries with a constant catch target on both fisheries

```
                        catch = NA, relCatch=NA,
                        biol = 1,
                        value = sole_catch_target)
flasher_ctrl_target2 <- data.frame(year = 2:20,
                        quant = "catch",
                        relYear = 2:20, relSeason = 1,
                        fishery = 1, relFishery=2,
                        catch = 1, relCatch = 1,
                        biol = NA,
                        value = sole_bt_gn_catch_relative)
flasher_ctrl_target <- rbind(flasher_ctrl_target1, flasher_ctrl_target2)
flasher_ctrl <- fwdControl(flasher_ctrl_target)
flasher_ctrl@FCB <- matrix(c(1,2,1,1,1,1), nrow=2, ncol=3,
    dimnames=list(1:2,c("F","C","B")))
test <- fwd(biols=biols3, fisheries=flfs3, control=flasher_ctrl)
```

We can see that the relative catch target between the fisheries has been hit (Figure 9). Also, the total catches from both fisheries is the same as the total catch target.

Figure 9: Summary results of projecting one stock with two fisheries with a constant total catch target and relative catch

6. Example: a mixed fishery

In this example we have a full mixed fishery consisting of two fisheries (a beam trawl and a gill net) each of which catch from two stocks (plaice and sole).

```
bt <- FLFishery(pleBT=pleBT, solBT=solBT)
gn <- FLFishery(pleGN=pleGN, solGN=solGN)
gn@effort[] <- 1
bt@effort[] <- 1
# Make the FLFisheries
flfs <- FLFisheries(bt=bt, gn=gn)
# Make the biols
biols <- FLBiols(ple=ple, sol=sol)
```

We have two independent variables (the fishing effort of the two fisheries) so we need to set two targets for each timestep of the projection. However, there is no guarantee that the targets can be met. For example, setting a very low total catch of sole and a high total catch of plaice cannot be achieved simultaneously because catching plaice means sole are also caught.

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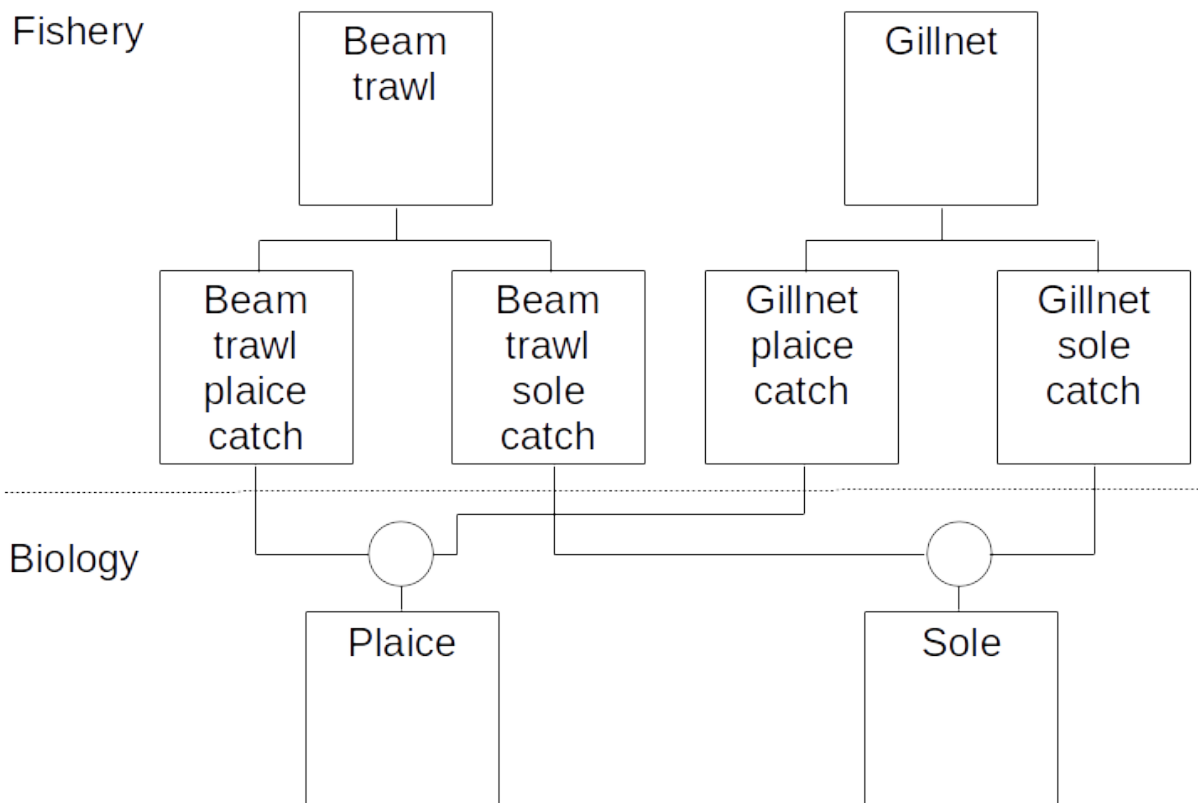
Figure 10: The full monty. The beam trawl and gillnet fisheries fishing on the plaice and sole stocks.

Sole is more valuable than plaice so it is assumed that the total TAC of sole will be taken at the expense of taking all of the plaice TAC (essentially forgoing the plaice catch to maximise the sole catch). An extra target is the relative catches of plaice are to be based on the historic relative stability, i.e. if we take all of the sole TAC we don't know what the eventual total catch of plaice will be but we want the relative catches of plaice to be fixed.

In this example we set a total sole catch and also a relative plaice catch between the fisheries (the beam trawl fishery takes 1.5 times as much plaice as the gillnet fishery).

```
sole_catch_target <- 12000
plaice_bt_gn_catch_relative <- 1.5
flasher_ctrl_target1 <- data.frame(year = 2:20,
                    quant = "catch",
                    relYear = NA, relSeason = NA,
                    fishery = NA, relFishery=NA,
                    catch = NA, relCatch=NA,
                    biol = 2,
                    value = sole_catch_target)
flasher_ctrl_target2 <- data.frame(year = 2:20,
                    quant = "catch",
                    relYear = 2:20, relSeason = 1,
                    fishery = 1, relFishery=2,
                    catch = 1, relCatch = 1,
                    biol = NA,
                    value = plaice_bt_gn_catch_relative)
flasher_ctrl_target <- rbind(flasher_ctrl_target1, flasher_ctrl_target2)
flasher_ctrl <- fwdControl(flasher_ctrl_target)
flasher_ctrl@FCB <- matrix(c(1,1,1,1,2,2,2,1,1,2,2,2), byrow=TRUE, ncol=3,
    dimnames=list(1:4,c("F","C","B")))
test <- fwd(biols=biols, fisheries=flfs, control=flasher_ctrl)
```

The total sole catch target from both fisheries has been hit with the gillnet fishery taking

more of it (Figure 11). The target of relative catches of plaice has also been hit. The beam trawl takes more plaice than the gillnet and this difference is enough to mean that the revenue of the beam trawl is higher than for the gillnet, despite the sole catches of the gillnet being higher than for the beam trawl. The relative effort of the gillnet fishery is also higher than for the beam trawl. Both stocks experience an increase followed by decrease in biomass (the dynamic being partly driven by the age structure of the initial population).

6.1   A more complicated example with decreasing catches

In this more complicated example we set the total catch of sole to decrease yearly to 90% of the previous year. We also set the relative plaice catch from the beam trawl to be 1.5 the catch from the gillnet.

```
# 15% TAC in sole TAC
# BT plaice = 1.5 GN plaice
sole_catch_target_initial <- 20000
sole_catch_decrease <- 0.9
plaice_bt_gn_catch_relative <- 1.5
flasher_ctrl_target1 <- data.frame(year = 2:20,
                    quant = "catch",
                    relYear = c(NA,c(2:19)), relSeason = c(NA,rep(1,18)),
                    fishery = NA, relFishery=NA,
                    catch = NA, relCatch=NA,
                    biol = 2, relBiol=c(NA,rep(2,18)),
                    value = c(sole_catch_target_initial, rep(sole_catch_decrease,18)))
flasher_ctrl_target2 <- data.frame(year = 2:20,
                    quant = "catch",
                    relYear = 2:20, relSeason = 1,
                    fishery = 1, relFishery=2,
                    catch = 1, relCatch = 1,
                    biol = NA, relBiol=NA,
                    value = plaice_bt_gn_catch_relative)
flasher_ctrl_target <- rbind(flasher_ctrl_target1, flasher_ctrl_target2)
flasher_ctrl <- fwdControl(flasher_ctrl_target)
flasher_ctrl@FCB <- matrix(c(1,1,1,1,2,2,2,1,1,2,2,2), byrow=TRUE, ncol=3,
    dimnames=list(1:4,c("F","C","B")))
test <- fwd(biols=biols, fisheries=flfs, control=flasher_ctrl)
```

The sole catches have decreased by 0.9 each year (Figure 12). The plaice catches have also decreased but the relative catches between the fisheries remains constant. The biomass of both stocks increases rapidly whilst the revenue decreases along with the relative effort.

7.   Economic targets

The examples so far have focussed on setting catch and F targets. It is also possible to set the revenue as a target at either the catch (for example, the revenue from the plaice portion of the beam trawl catch) or the fishery (sum of revenues from all the catches of that fishery) level. More economic indicators, such as costs and profits, will be added in the future.

We saw in the previous example that the revenues of both fisheries decreases as the sole catches decrease by 10% each year. Although, the stock biomasses increase, the decrease in revenue is likely to be unacceptable by the fishing industry. Given their costs of operation they may expect a minimum revenue, even if means the total catch exceeds the TAC. In this example a minimum revenue is set for each fishery.

```
sole_catch_target_initial <- 20000
sole_catch_decrease <- 0.9
plaice_bt_gn_catch_relative <- 1.5
bt_min_revenue <- 150000
gn_min_revenue <- 100000
```
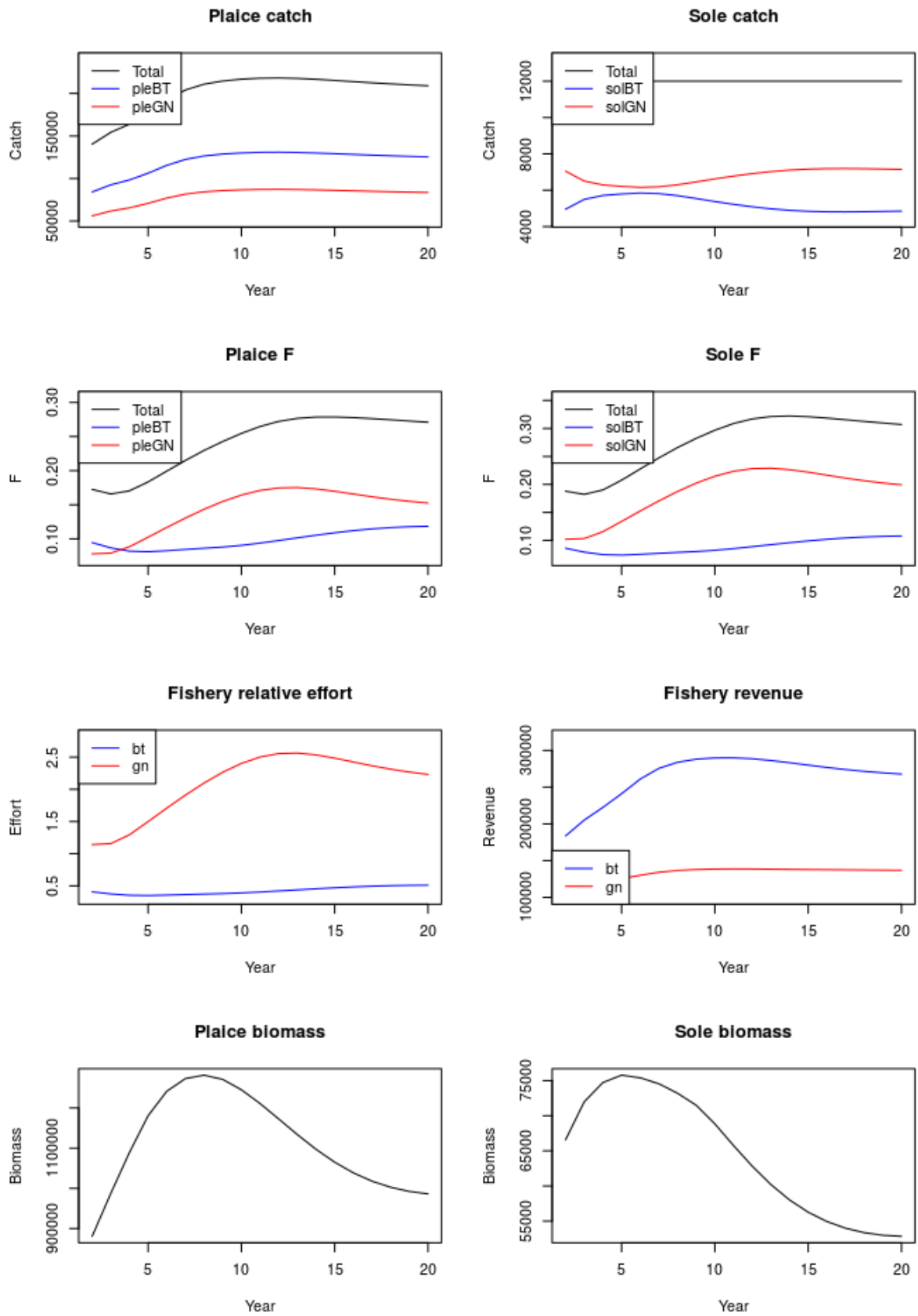
Figure 11: Summary results of projecting a mixed fishery with two stocks and two fleets with a constant sole catch target and a relative plaice catch
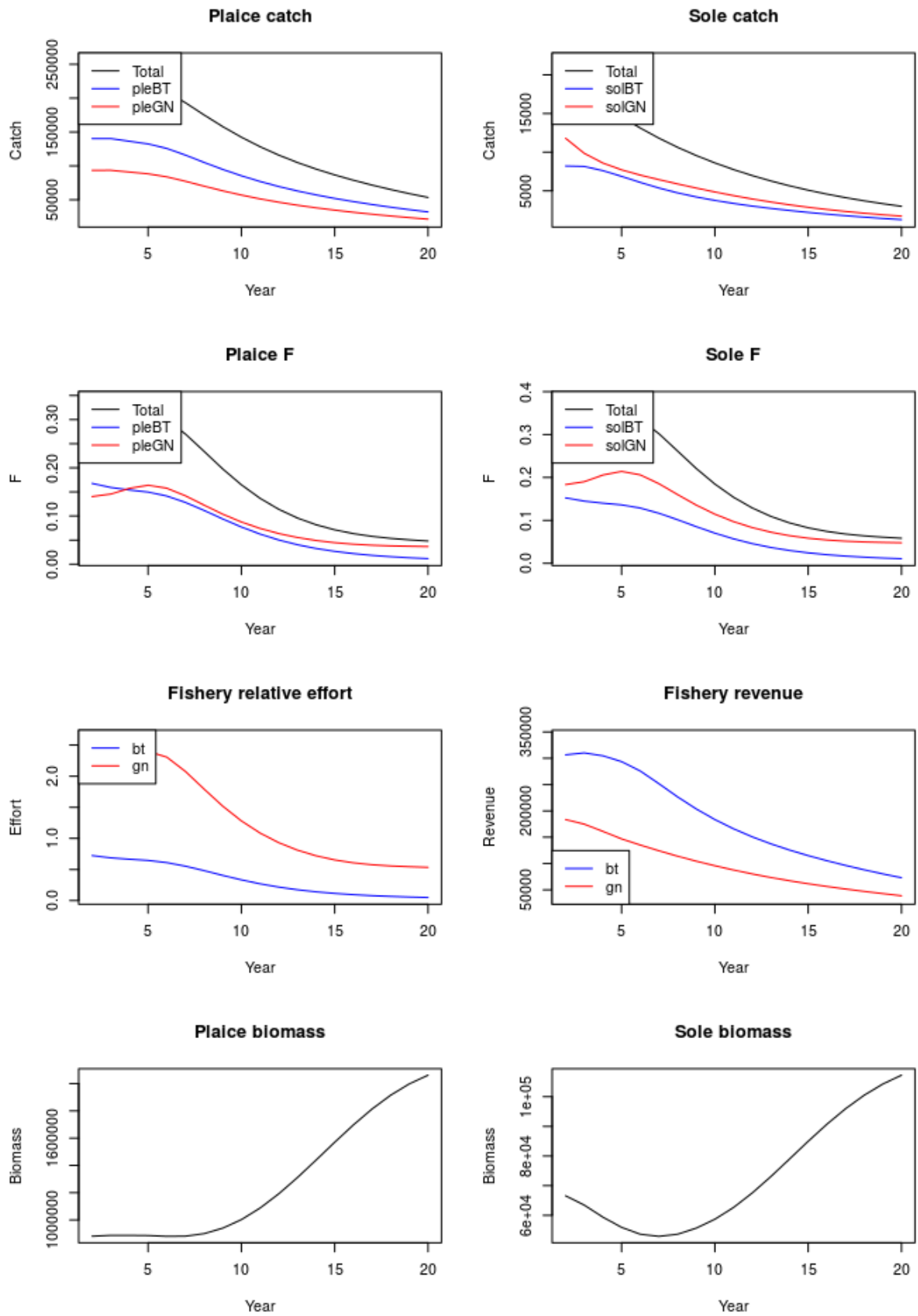
Figure 12: Summary results of projecting a mixed fishery with two stocks and two fleets with a decreasing sole catch target and a relative plaice catch

```
# Sole catch
flasher_ctrl_target1 <- data.frame(year = 2:20,
                    quant = "catch",
                    relYear = c(NA,c(2:19)), relSeason = c(NA,rep(1,18)),
                    fishery = NA, relFishery=NA,
                    catch = NA, relCatch=NA,
                    biol = 2, relBiol=c(NA,rep(2,18)),
                    value = c(sole_catch_target_initial,
                    rep(sole_catch_decrease,18)), min=NA)
# Relative plaice catch
flasher_ctrl_target2 <- data.frame(year = 2:20,
                    quant = "catch",
                    relYear = 2:20, relSeason = 1,
                    fishery = 1, relFishery=2,
                    catch = 1, relCatch = 1,
                    biol = NA, relBiol=NA,
                    value = plaice_bt_gn_catch_relative, min=NA)
# Minimum BT revenue
flasher_ctrl_target3 <- data.frame(year = 2:20,
                    quant = "revenue",
                    relYear = NA, relSeason=NA,
                    fishery = 1, catch = NA, biol = NA,
                    relFishery = NA, relCatch = NA, relBiol = NA,
                    value = NA, min = bt_min_revenue)
# Minimum GN revenue
flasher_ctrl_target4 <- data.frame(year = 2:20,
                    quant = "revenue",
                    relYear = NA, relSeason=NA,
                    fishery = 2, catch = NA, biol = NA,
                    relFishery = NA, relCatch = NA, relBiol = NA,
                    value = NA, min = gn_min_revenue)
flasher_ctrl_target <- rbind(flasher_ctrl_target1, flasher_ctrl_target2,
    flasher_ctrl_target3, flasher_ctrl_target4)
flasher_ctrl <- fwdControl(flasher_ctrl_target)
flasher_ctrl@FCB <- matrix(c(1,1,1,1,2,2,2,1,1,2,2,2), byrow=TRUE, ncol=3,
    dimnames=list(1:4,c("F","C","B")))
test <- fwd(biols=biols, fisheries=flfs, control=flasher_ctrl)
```

What happened? We can see that the minimum revenue of the gillnet fishery comes into effect in year 10 (Figure 13). After this year, the gillnet revenue hits the minimum level and does not decrease further. This has knock-on effects. From year 10, the annual decrease in sole catches is no longer 10% and the total sole catches remain approximately constant. The minimum revenue of the beam trawl fishery is never breached. With the limit on the sole revenue being reached, it is not possible to continue to hit the relative plaice catch targets between the fisheries (although it gets as close as possible).

8. Conclusions

This document has demonstrated the new FLR projection software package, `FLasher`. The package is able to simulate a mixed fishery with multiple fleets and stocks. It expands the current modelling capabilities, which were previously restricted to a single stock and fleet, allowing the impacts of proposed management plans to be evaluated in more detail. The interactions between fleets and stocks can be clearly explored, allowing for more detailed evaluations of multi-annual management plans.

The revenue of a fleet and a catch can be used as target type allowing some basic economic indicators to be used. The addition of future economic indicators is planned, including profit and costs.
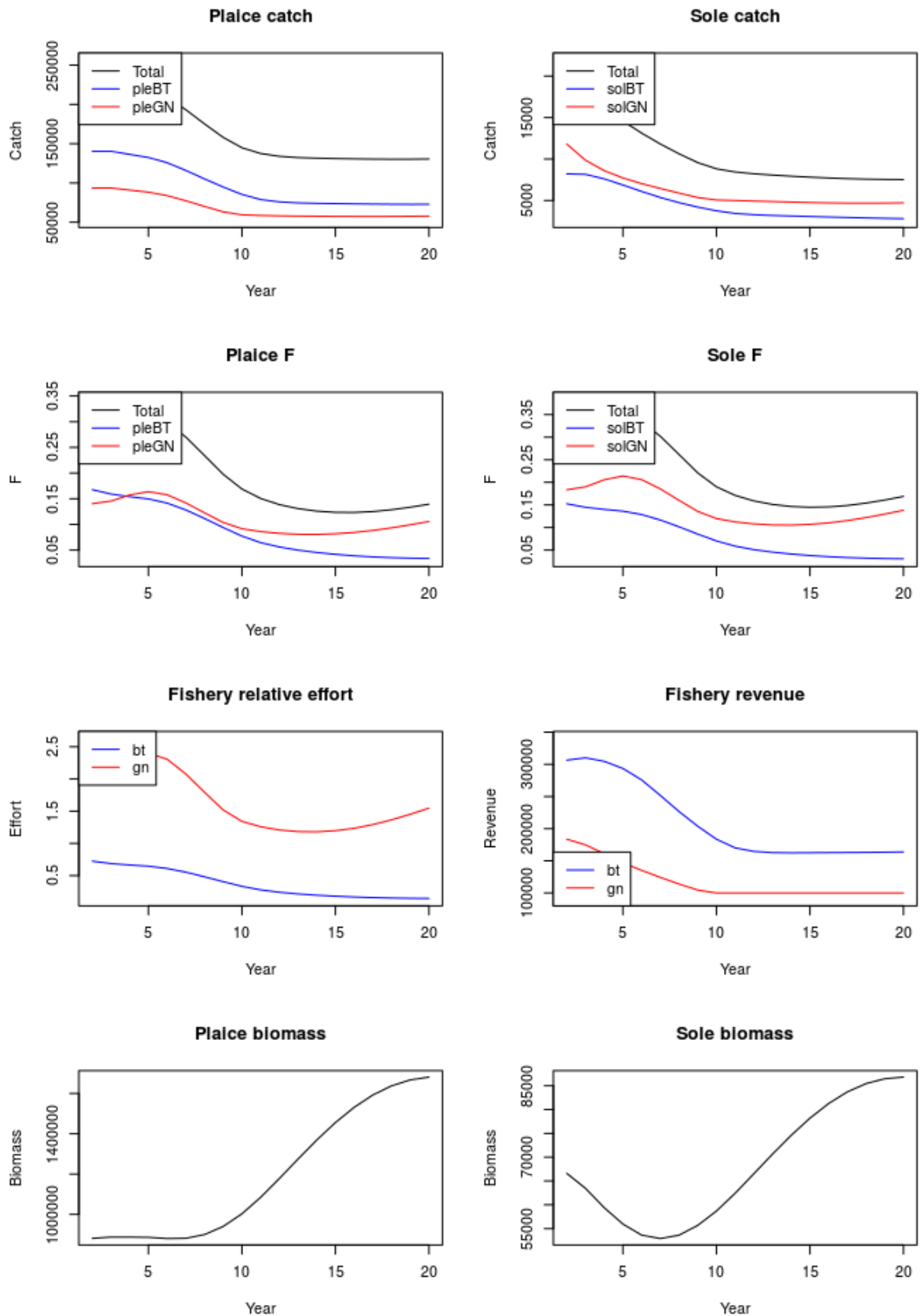
Figure 13: Summary results of projecting a mixed fishery with two stocks and two fleets with a decreasing sole catch target and a relative plaice catch. Minimum limits to the revenues of both fleets are also included.

References

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List of abbreviations and definitions

F Fishing mortality

List of figures

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JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

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