MSY reference points for haddock in VIIbce-k
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Abstract

This document explores reference points for haddock in VIIbce-k. Firstly the relationships between stock and recruits for all major haddock (*Melanogrammus aeglefinus*) stocks are explored. These findings are then used to inform the choice of stock-recruit model and potential harvest-control rules. Haddock stocks are strongly driven by recruitment, resulting in highly fluctuating stock levels. It is difficult to estimate B_{lim} because it is not clear that low SSB reduces the reproductive capacity of the stock (but a number of consecutive years of low recruitment quickly leads to low SSB). Most haddock stocks appear to be able to generate good recruitment from low stock levels and rapidly rebuild the stock. For haddock in VIIbce-k, stock weights-at-age fluctuate considerably over time; this may be a significant source of uncertainty in simulations of SSB and yield. F_{MSY} for VIIbce-k haddock was estimated to be 0.40 when using a segmented regression to model the stock-recruit relationship and under the assumption that over-quota discards will not occur (with a 95% range of MSY of 0.26 - 0.60). This is considerably higher than the current F_{MSY} reference point for this stock (0.33) which is based on the current discarding pattern. Fishing above F_{MSY} in the short term, results low risk to SSB (Fp.05 = 0.74 and $F_{crash5\%} = 1.00$).

Introduction

The F_{MSY} reference point for haddock in VIIbce-k is currently 0.33 and is based on a deterministic F_{max} from a yield-per-recruit analysis carried out in 2012 (ICES, 2012). There are a number of issues regarding this reference point. Firstly, F_{max} may not be sufficiently precautionary given the assessment and input uncertainties. It is important to investigate whether this is the case for this stock. Secondly, the YPR analysis used to define this F_{MSY} proxy does not take account of the stock and recruit relationship for haddock. It is important to consider the potential impact of a S/R relationship on the estimation of F_{MSY}. Thirdly, because of the high discard rates of haddock in the recent past, the impact of discarding patterns on the F_{MSY} proxy also requires further exploration. The current F_{MSY} proxy was estimated when the quota was very restrictive and discarding over the MLS was particularly prevalent. It is be appropriate to include discards above MLS or high grading in the MSY calculations because these fish can be utilised as yield. Since 2012, measures have been introduced to improve selection in the fishery (EC, 2012). It is not yet possible to evaluate if these measures have significantly affected the selectivity of haddock (STECF, 2013). However, management measures to reduce discards and improve selection are expected to have a significant beneficial impact on landings yield and F_{MSY}.

The ICES advice for 2015 is based on the "ICES MSY approach" agreed with clients which implies that fishing mortality should be reduced to F_{MSY} by 2015 (ICES, 2014a). For Celtic Sea haddock this results in a very large reduction in advised catches by 2015 at a time when a strong year class will be recruiting to the fishery. Haddock fishing mortality in the Celtic Sea is linked to other species, primarily cod and whiting, because they are caught together in the mixed demersal fisheries. In the past, restrictive TACs have been unsuccessful in reducing fishing mortality due to this mixed nature of the fishery. It could be informative to managers to evaluate the long-term risk to the stock and impact on yield at various fishing mortality rates. It should be noted that the stock has shown an increasing trend over the last 20 years while the fishing mortality has been well above F_{MSY} for the whole period.

Stock-recruit meta-analysis

Haddock stocks are characterised by erratic recruitment and for most stocks there is no obvious relationship between the size of the spawning stock and the numbers of recruits it produces. In order to investigate the nature of the stock-recruit relationship for haddock, data for all the major haddock stocks were compiled. Stock assessment outputs for ICES stocks were obtained from the ICES Stock Assessment Database (`http://standardgraphs.ices.dk/`) data for Georges Bank (GB) and Gulf of Maine (GM) haddock were obtained from the RAM legacy database (Ricard et al., 2012) and data for haddock on the Southern Scotian Shelf and Bay of Fundy (4X5Y) were obtained from Showell et al. (2013).

Figure 1 shows the highly variable nature of recruitment of haddock stocks which is characterised by sporadic episodes of very high recruitment. The SSB tends to increase sharply after such an episode and often declines rapidly after. The general trend is that SSB is strongly driven by recruitment; this is clearly illustrated by the time series showing the running mean.

Figure 1 also shows that for many stocks there is no obvious SSB below reproductive capacity is reduced (B_{lim}). For some stocks, the stock-recruit plots show an apparent B_{lim} (e.g. had-faro, had-GB, had-iris all have observations of low recruitment at low SSB). However cause and effect are not obvious. In general these stocks suffered a number of years of poor recruitment *before* SSB declined. Recruitment then remained poor for some years, resulting in years with low SSB and low recruitment. It is possible that the low SSB resulted in a reduced likelihood of good recruitment, but it is also possible that an external factor (e.g. temperature, food availability, predation, competition, etc.) resulted in a period of poor recruitment. There appears to be some auto-correlation in the recruitment of most stocks: a year with low recruitment is likely to be followed by another year of low recruitment. This is also true for stocks that have an entirely flat stock-recruit relationship, so it seems likely that periods with low recruitment are not (always) caused by low SSB.

Another important conclusion from Figure 1 is that while for many stocks the SSB has fluctuated by a factor of 10 or more over the time series, none of the stocks have collapsed[1]. In all cases, recruitment levels were eventually restored, leading to a rapid rebuilding of the stock.

Summary

- Haddock stocks are strongly driven by erratic recruitment, resulting in highly fluctuating stock levels.
- It is difficult to estimate B_{lim} because it is not clear that low SSB reduces the reproductive capacity of the stock.
- Haddock stocks appear to be able to generate good recruitment from low stock levels (e.g. <10% of the largest observed SSB) and rapidly rebuild the stock.

Stock weights

Stock weights of many haddock stocks show strong fluctuations over time. Figure 2 shows the stock weights of VIIbce-k h haddock (data from the 2014 assessment, (ICES, 2014c)). Figure 3 shows that there appear to be some year-effects as well as some cohort effects. The low SSB at the start of the time-series appears to correspond to above-average stock weights for some age classes in those years, while the low recruitment during 1996-8 correlates with above-average stock weights for those cohorts. However there is no evidence of above-average weights for the 2009 (and 2010) cohorts which were also very weak. The time series is too short to draw firm conclusions about the causes of the variation in weights-at-age.

It may be important to take into account cohort related growth rates into account in the short-term forecast (STF). Particularly if there is evidence of strong cohort effects. Jaworski (2011) concluded that linear cohort-based growth models was the most appropriate method for characterising North Sea haddock growth and this is used the STF.

Summary

- Stock weights fluctuate considerably over time; this may be a significant source of uncertainty in simulations of SSB and yield.

MSY reference points

The approach outlined by WKMSYREF2 (ICES, 2014d) and WKMSYREF3 (ICES, 2014b) was applied to Celtic Sea haddock (VIIbce-k) using the R-library ‘msy’. The ASAP assessment results from WGCSE 2014 (ICES, 2014c) were converted to an FLStock object and used as inputs. The R script used for the final MSY simulation is given in Appendix 1.

[1] Faroe haddock have suffered a long period of poor recruitment and SSB is at a historic low; it is too early to tell if this stock is at reduced reproductive capacity. Ironically this stock has been harvested around F_{MSY} for most of the last 40 years.

The 'msy' R-library (equilibrium approach with variance) is intended to provide robust estimation of deterministic (i.e. no future process error) MSY. It fits stock-recruit functions to estimate MSY quantities. Uncertainty in MSY estimates is characterised by MCMC sampling of the joint pdf of the stock-recruit parameters and sampling from the distributions of other productivity parameters (i.e. natural mortality, weights-at-age, maturities, and selectivity). Stock-recruit model uncertainty is also taken into account (ICES, 2014d).

Because there is evidence of strong fluctuations in the stock weights, the argument bio.years (the years over which to sample maturity, weights and M from) was set to the full time series (note that maturity and M are unchanged over the full time-series). The selection pattern from the last 5 years was used (but see paragraph about discarding, below). The assessment error of F in the advisory year (Fcv) is unknown; the assessment error of F in the final year of the assessment was 0.18, however there is some additional error resulting from the propagation of the error through the short-term forecast, therefore a higher (more precautionary) value of 0.30 was used. The extreme values were trimmed by removing the highest and lowest 5% of runs. Median yield (rather than mean yield) was used to compute F_{MSY} because median yield is the most likely value.

B_{lim} was taken to be the lowest observed SSB (B_{loss}, 6,670 t) from the most recent assessment (ICES, 2014c); there is no evidence of reduced reproductive capacity at any of the observed SSB levels. B_{pa} was estimated from B_{lim} plus assessment error of SSB in the final year (i.e. SSB should be estimated to be above B_{lim} with a 95% probability). The CV for SSB in the final year of the 2014 assessment was 0.26, the one-sided 95% confidence level can be approximated by 1.645 * CV, if the errors are assumed to be multiplicative then $B_{pa} = 6.670$ t * exp(1.645 * 0.26) = 10,000 t. Note that the previous B_{loss} was estimated at 7,500 t which was used by ICES as MSY $B_{trigger}$; the B_{pa} of 10,000 t could be considered as a more appropriate MSY $B_{trigger}$ for this stock. An alternative way of estimating $B_{trigger}$ is the value of 5% on the distribution of SSB at F = F_{MSY} with no assessment error, which is 21000 t (21109 to be exact; this is a slightly lower value than SSB at F05 in Table 1 because assessment error was not included). This is considerably higher than F_{pa}.

A segmented regression (hockey stick) model was used describe the relationship between stock size and recruitment (Figure 4). There are two observations with with low recruitment at high SSB, suggesting that a Ricker curve may be appropriate but it is unlikely that these low recruitment values are caused by the high biomass; there is no evidence of cannibalism in haddock and for there is no evidence of reduced recruitment at high stock levels for any of the other haddock stocks (Figure 1), therefore a Ricker curve was not considered appropriate. Because there is also no evidence of reduced recruitment at low stock levels there is very little data to inform a Beverton and Hold curve either and a segmented regression was considered to be most appropriate. (This follows the recommendation from ICES (2014b) for stocks with: "*Constant recruitment at all values of SSB are estimated*".) Figure 4 shows the observed and modelled stock-recruit relationship.

Because a considerable amount of discarding occurs in this stock, the choice of metric for yield will determine to a large extent where F_{MSY} lies. For this reason, three options are explored: yield includes all catches; yield consists of the landings assuming the current discard pattern and an intermediate approach where yield consists of the landings that would occur if all marketable fish (>MLS) would be landed, i.e. the 'ideal' case where over-quota discarding and high-grading do not occur. This corresponds to 10% of age-1 fish, 50% of age-2 fish, 90% of age-3 fish and 100% of all older fish being landed. These proportions were applied to the catch numbers to simulate the landings yield that would have resulted from discarding of unmarketable fish only. Note that this is in line with recommendations of WKMSYREF2: "*Care should be taken to understand any discarding and to ensure that utilisable fish above minimum landing sizes is treated as utilised yield (in an MSY context) if it is being discarded just due to a shortage of quota.*"

A number of simulations were performed, following the example of Annex II in the WKMSYREF2 report (ICES, 2014d): a run with no error in the biological or assessment data; a run with only error in the biological data; a run with error in the biological and assessment data and finally a run that implements a harvest-control rule based on $B_{trigger}$ (which was chosen to be B_{pa}). The estimated F_{MSY} based on the median yield was 0.45 for the runs without error and with biological error only, for the runs with biological and assessment error, F_{MSY} was estimated as 0.40. Including a $B_{trigger}$ harverst-control rule did not affect this estimate. The 'final' run was chosen to be the run with error in both the biological and assessment data.

Figure 5 shows the summary plot of the simulation and Table 1 gives the estimated reference points. F_{MSY} is estimated to be 0.40 if all fish >MLS would be landed. With the current discard pattern, F_{MSY} would be 0.30 and if all catches would be landed F_{MSY} would be 0.50. Note that all catches are assumed to be dead, so the fate of the catch (discards or landings) is irrelevant to the risk of the stock. It should also be noted that fishing mortalities up to 0.74 are expected to lead to a low (5%) probability of reaching B_{lim} and that $F_{crash5\%}$ is 1.00. There is considerable uncertainty in the simulated yield, but the probability of fishing at F_{MSY} has a narrow distribution (Figure 5, panel d), suggesting that F_{MSY} is estimated quite precisely.

Figure 6 shows the range of F values that fall within 95% of MSY for the mean yield this range is 0.26 - 0.60.

F_{lim}, which is F with a 50% probability of SSB<B_{lim} is estimated to be 1.41. F_{pa} could be estimated from this using the assessment error in F in the final year of the assessment (CV = 0.28) as follows F_{pa} = 1.41 * exp(-1.645 * 0.28) = 0.89.

Figure 7 shows the yield-per-recruit curves for the catch, landings and landings of >MLS fish. Because the stock-recruit relationship is flat, F_{MSY} equals F_{max}. It is clear from this figure why F_{MSY} is so strongly dependent on how much of the catch is included in the yield. It is also obvious how much yield is wasted through discarding.

Figure 8 shows retrospective estimates of F_{MSY} which were obtained by repeating the analysis after iteratively removing the most recent year from the dataset. The figure indicates that the F_{MSY} estimate has been quite stable over time.

In recent years, technical measures have been introduced (mainly square-mesh panels) to improve the selectivity of the otter trawl fleet in the Celtic Sea. Improved selectivity should improve survival of young fish is expected to increase the length at 50% selectivity of TR1 gears from 26.6 to 29.3 (STECF, 2003), which is very close to the minimum landing size. This is expected to result in a considerable reduction of fishing mortality of young fish as catches (and discards) of small fish decrease. Improved selectivity is expected to lead to an increase in F_{MSY} and F_{lim}. However it is not yet possible to evaluate if these measures have actually had the expected effect; a longer time series would be needed to establish this (STECF, 2013) and it will be necessary to review the reference points again in the near future.

Summary

- B_{loss} for the most recent assessment is 6,700 t; B_{pa} could be defined as B_{lim} + assessment error at 10,000 t
- $B_{trigger}$ could be taken as B_{loss} or Bp05 at 21,000 t.
- F_{MSY} is strongly dependent on how much of the catch is considered to be yield.
- F_{MSY} is estimated to be 0.40 when over-quota discards do not occur, i.e. taking into account the potential yield of the catches (with a range of 95% of MSY of 0.26 - 0.60). This is higher than the current F_{MSY} reference point for this stock (0.33) which assumes that the current discarding pattern continues.
- F_{pa} could be defined as F_{lim} - assessment error at 0.89.
- Fishing above F_{MSY} in the short term results low risk to SSB (Fp.05 = 0.74) and leads to minimal reductions in expected long-term yield.

Table 1: Reference points for haddock in VIIbce-k. Landings refer to the landings assuming the current discarding pattern; Landings* refer to the landings that would occur if discarding of over-quota fish would not occur (if all fish >MLS would be landed; i.e. taking into account all potential yield from the catches). The suggested new F reference point is highlighted in yellow.

	F05	F50	meanMSY	Crash5%
catch F	0.74	1.41	0.50	1.00
landings* F	0.74	1.41	0.40	1.00
landings F	0.74	1.41	0.30	1.00
catch	13089	7771	13711	11257
landings*	13089	7771	11695	11257
landings	13089	7771	8257	11257
catch SSB	22774	6710	35090	14428
landings* SSB	22774	6710	35090	14428
landings SSB	22774	6710	54463	14428

Management of haddock in VIIbce-k

Haddock stocks appear to retain full reproductive potential at stock sizes that are quite small compared to the maximum observed stock size. Because recruitment is highly variable, the stock size is mainly driven by recruitment and not very sensitive to F. This results in a stock that is quite robust to fishing above F_{MSY}. In the past, restrictive TACs have been unsuccessful in reducing fishing mortality due to the mixed nature of the haddock fisheries. In a mixed fisheries context it may be more beneficial to allow fishing mortality above F_{MSY} for haddock in the short-term in order to fish other stocks closer to their F_{MSY} targets. Given the impending discard ban, measures to reduce discarding, particularly high-grading induced by restrictive quotas, need to be considered.

Recruitment-driven stocks (e.g. small pelagics) are often managed by setting a minimum population threshold below which no catches are allowed to occur, sometimes in combination with indicators or environmental variables (Hurtado-Ferro, 2014; Kelly and Codling, 2006). This is not an option for VIIbce-k haddock because this stock is caught in a mixed fishery, making it difficult to fully close the fishery. Nevertheless, it should be possible for the fishery to reduce fishing mortality of haddock if the incentives existed (e.g. by avoiding areas or gears that result in catches with high proportions of haddock, (Gerritsen et al., 2012)).

Management of this stock should include a long-term target of fishing at F_{MSY} (0.40) but could allow fishing up to the higher range of F_{MSY} (0.63) if the change in TAC that is needed to achieve F_{MSY} point estimate is not in line with that of the other target species in the main fisheries that catch haddock (whiting, cod and also monkfish) and if the haddock SSB is high. The target F could, for example, be increased to F_{MSY} times the ratio of current SSB to $B_{trigger}$ with a maximum of 0.63. If SSB falls below $B_{trigger}$ (B_{pa}; 9318t), the target F should be reduced to F_{MSY} times the ratio of current SSB to $B_{trigger}$.

Overall conclusions

- B_{loss} for the most recent assessment is 6,700 t; B_{pa} could be defined as B_{lim} + assessment error at 10,000 t and this may be a more appropriate MSY $B_{trigger}$.

- The current F_{MSY} reference point for this stock s too low; it is based on current discard patterns and therefore does not account for all utilisable yield. A new F_{MSY} reference point of 0.40 is proposed with a range of 0.26-0.60 that is within 95% of MSY.

- Fishing above the new F_{MSY} (up to Fp.05 of 0.74) in the short term poses a low risk to the stock and only results in a small loss of yield.

- If selectivity improves due to the recent introduction of technical measures, it is likely that both F_{MSY} and F_{lim} will increase.

- For this stock it may be appropriate to transition to F_{MSY} more gradually, rather than aim for F_{MSY} in 2015.

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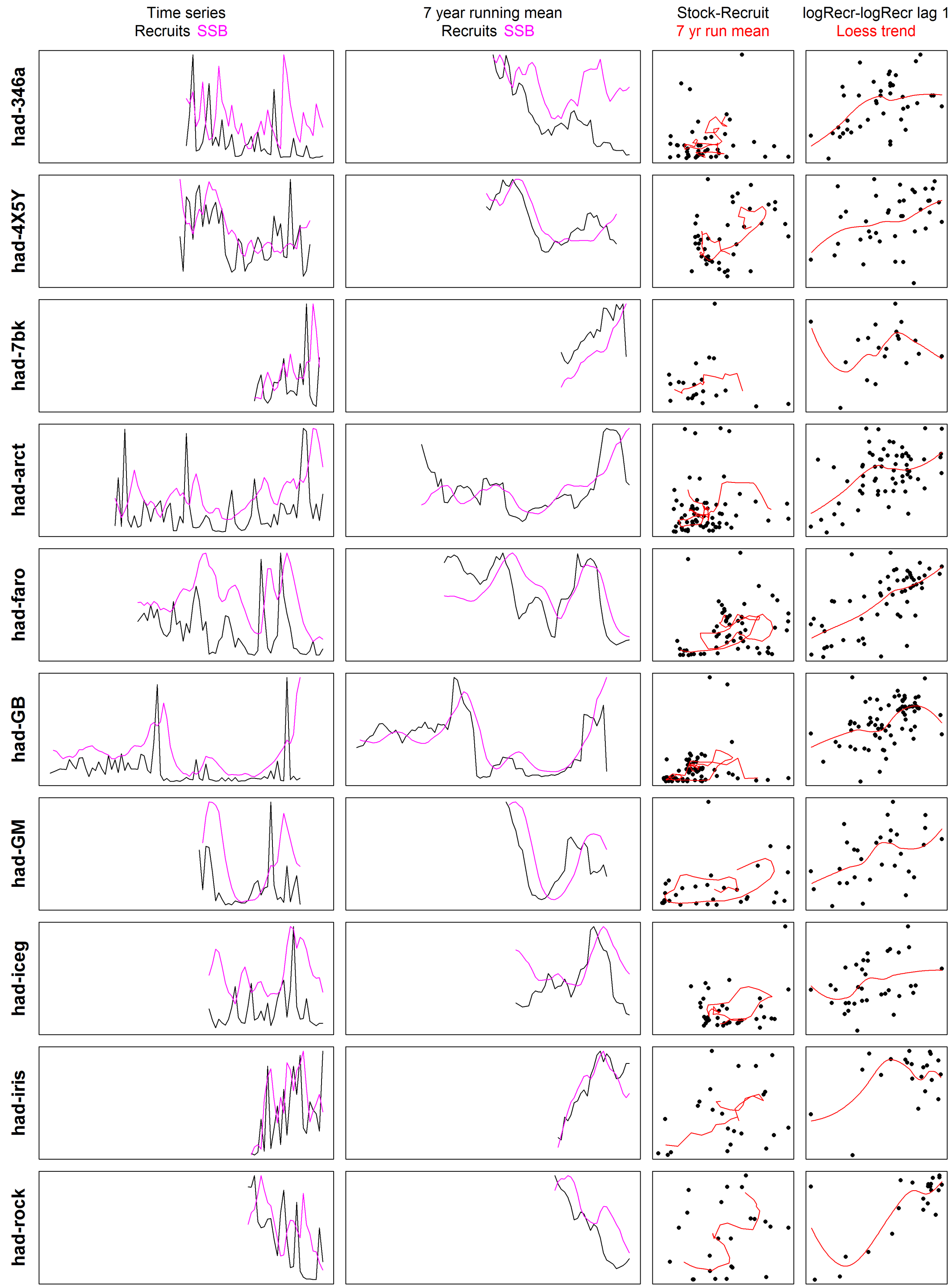

Figure 1: Stock (SSB) and recruit data for the main haddock stocks: had-346a (North Sea, Skagerak and W. Schotland), had-4X5Y (S Scotian Shelf and Bay of Fundy), had-7bk (Celtic Sea and W Ireland), had-arct (NE Arctic), had-faro (Faroe Plateau), had-GB (Georges Bank) had-GM (Gulf of Maine) had-iceg (Iceland) had-iris (Irish Sea) had-rock (Rockall). For each stock the leftmost plot shows the time series of SSB and recruits. The second plot shows the 7-year running mean of the same time series. The third plot shows the stock recruit-relationship and the rightmost of plot shows the relationship of the number of recruits in a given year to the number of recruits in the following year (on a log scale).

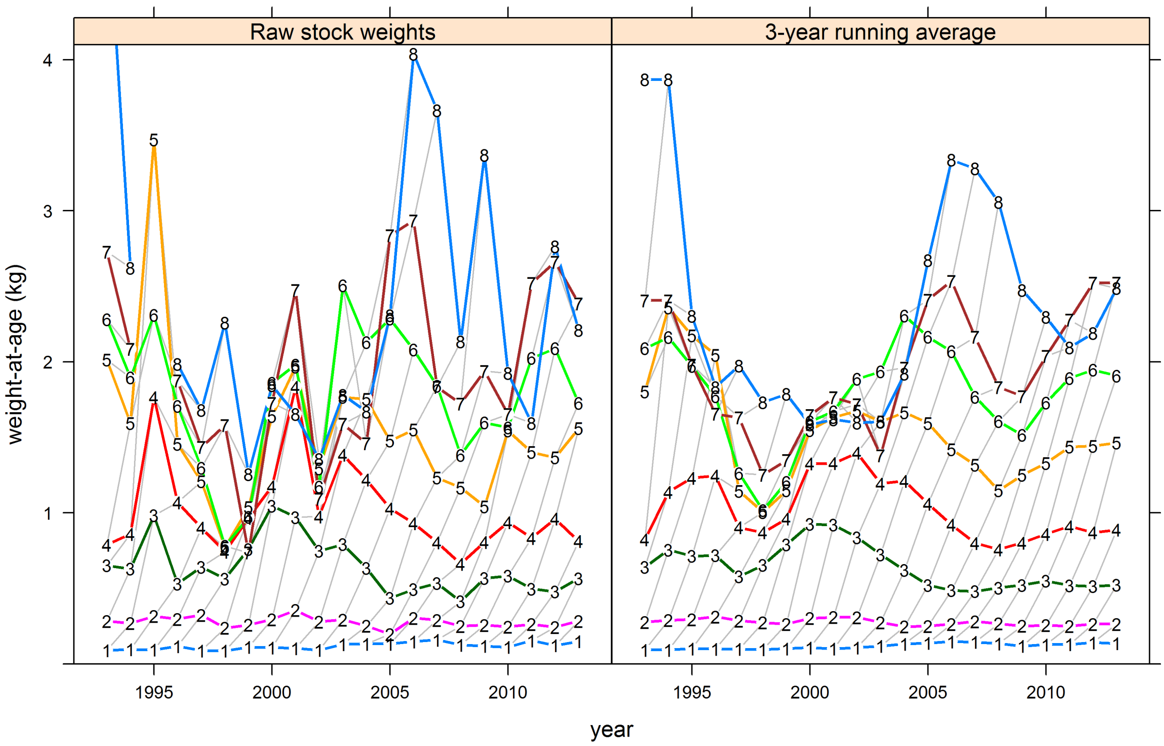

Figure 2: Stock weights of haddock in VIIbce-k. Raw stock weight (left) and 3-year running average stock weights (right).

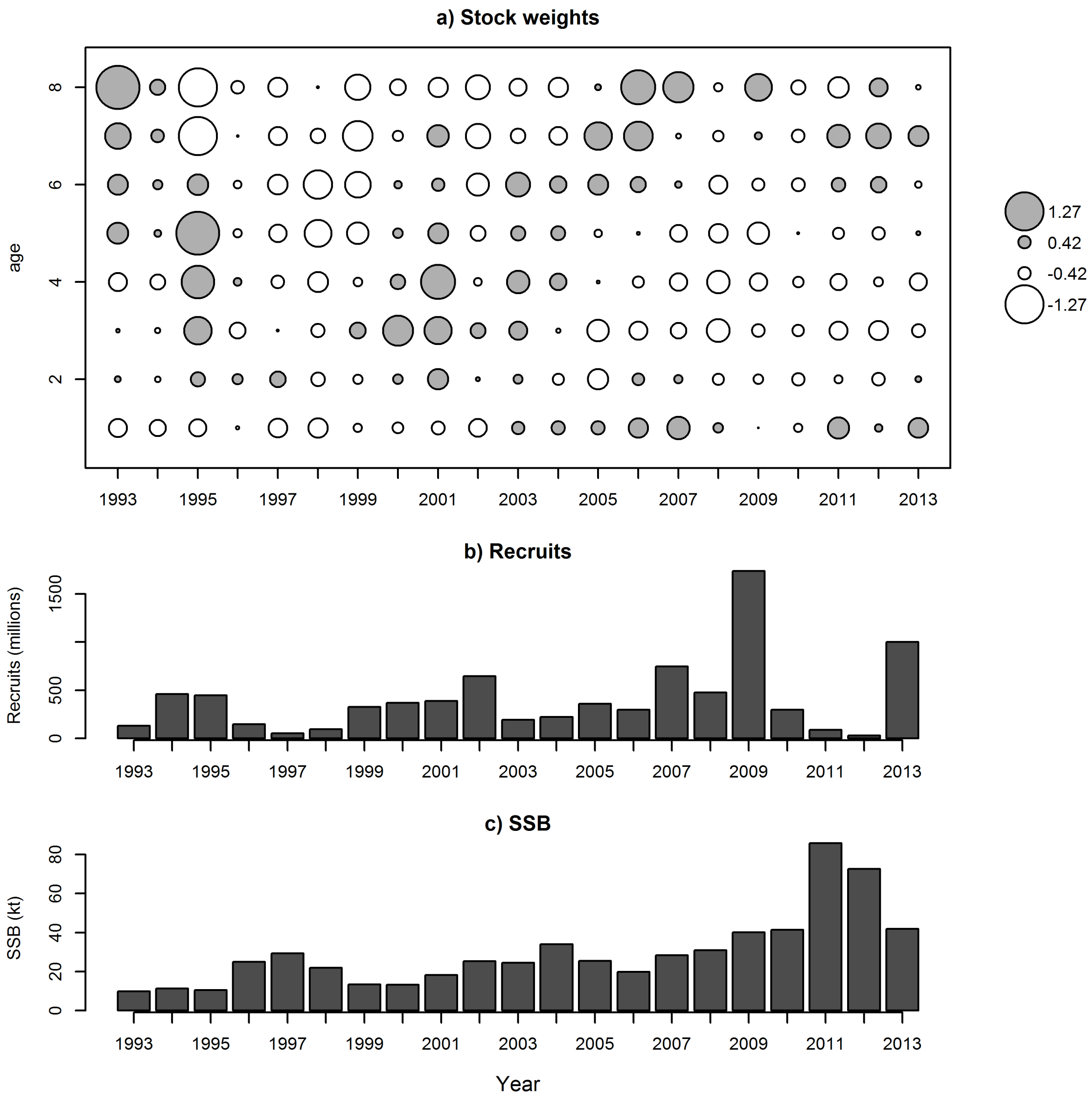

Figure 3: Stock weights of haddock in VIIbce-k: a) standardised difference from the mean weight-at-age $(x - \bar{x})/\bar{x}$; b) recruitment (age 0) and c) SSB. Some year effects seem to exist at the start of the time-series: the low SSB levels at the start of the time-series appear to correspond to above-average stock weights for some age classes in those years. Additionally, some cohort-effects can be seen: the weak 1996-9 cohorts appear to have had above-average weights, while the 2002-4 cohorts appear to have had below-average weights, although these cohorts were not particularly strong.

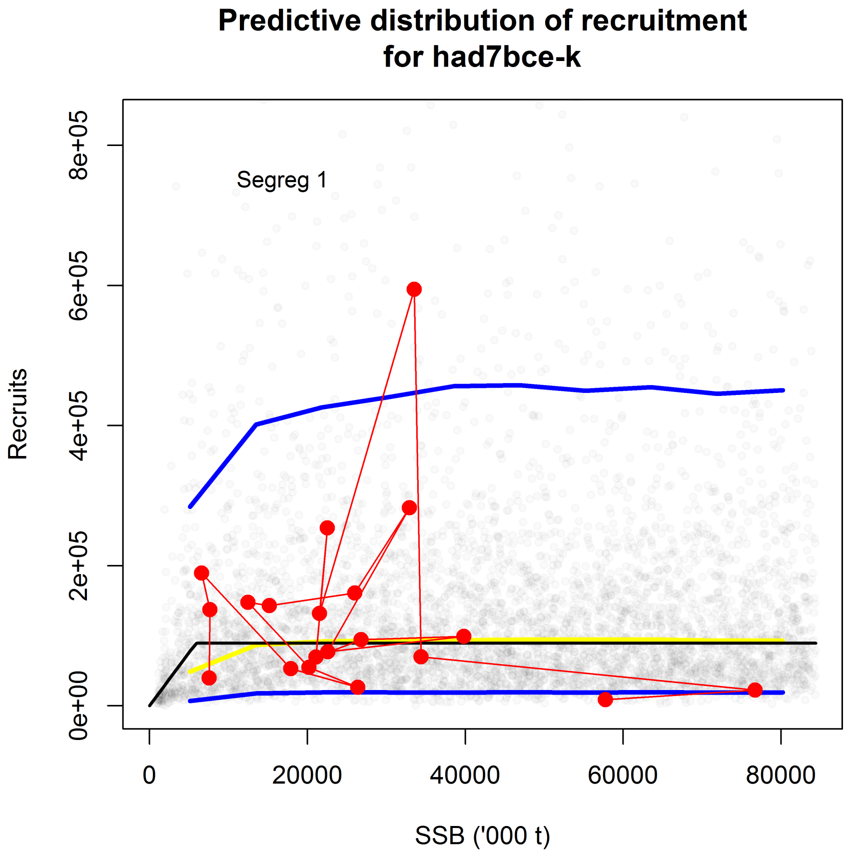

Figure 4: Stock-recruits for haddock in VIIbce-k. Red points: historic recruits; black line: segmented regression model; blue lines 5^{th} and 95^{th} percentiles; yellow line: 50^{th} percentile

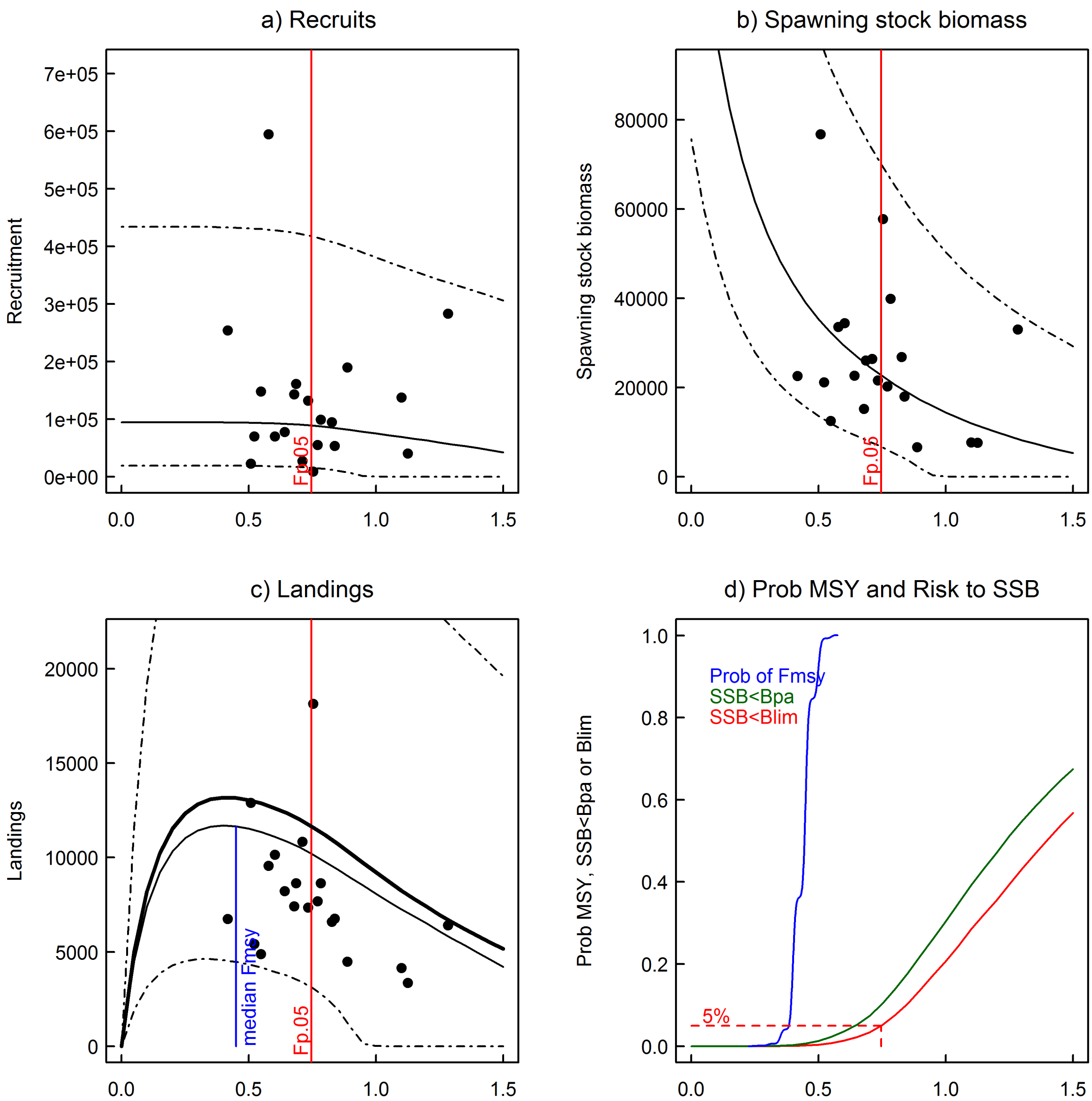

Figure 5: Equilibrium exploitation of had7bce-k against target F (the x-axis shows Fbar 3-5 in all panels) under the assumption that all catches >MLS are landed. Panels a), b) and c): black dots represent the observed values; solid black line is the median and dash-dot lines are the 5th and 95$^{\text{th}}$ percentiles; red vertical line represents F_{lim}. In panel c) the thick black line is the mean; the blue vertical line is the MSY based on the median yield. In panel d) the blue line represents the cumulative probability distribution of F_{MSY}; the green line is the risk that SSB falls below B_{pa} and the red line is the risk that SSB falls below F_{lim}.

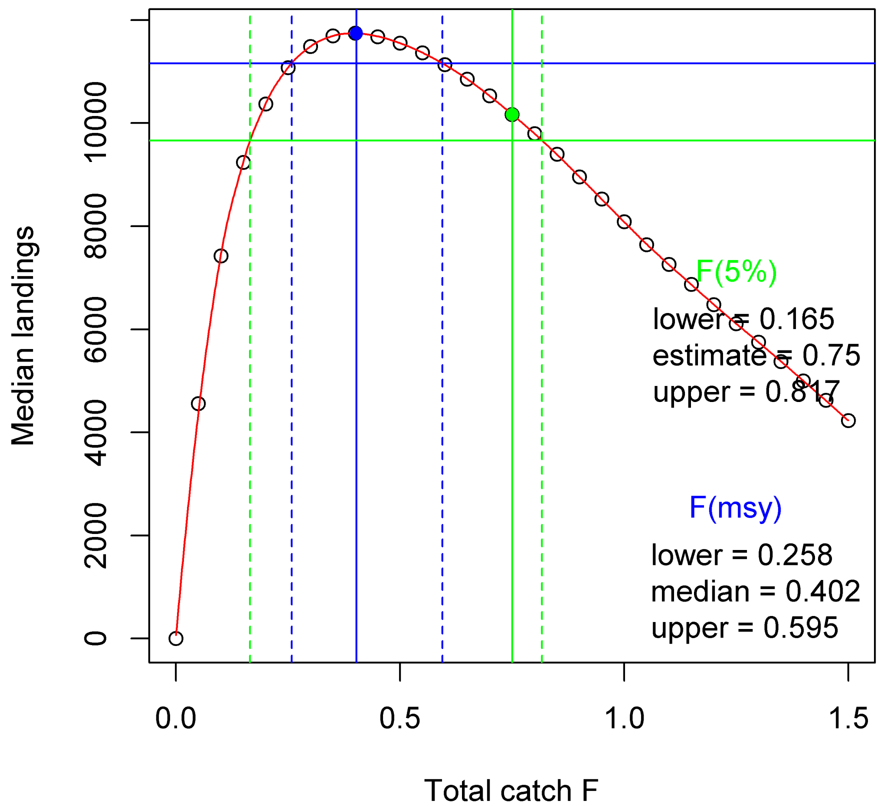

Figure 6: Yield curve and F_{MSY} with upper and lower ranges (vertical blue lines) and F_{lim} with upper and lower ranges (vertical green lines).

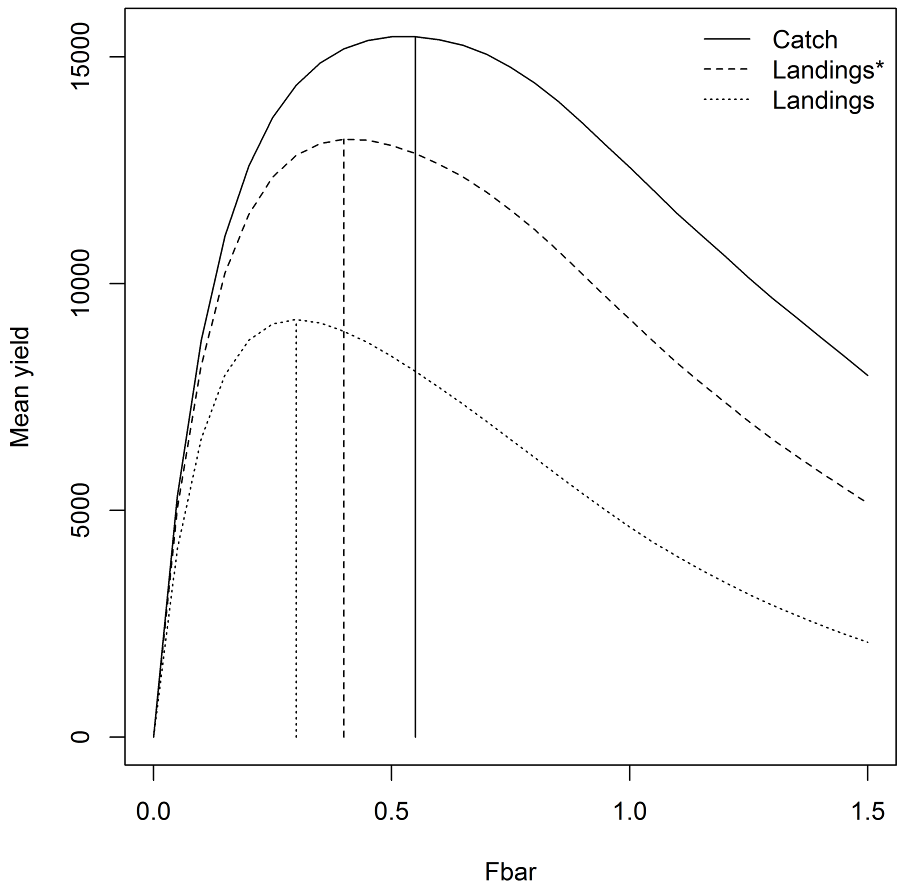

Figure 7: Yield curves and F_{MSY} (vertical lines) for catch, landings* and landings, where landings* refer to the landings that would occur if discarding of over-quota fish would not occur (if all fish >MLS would be landed).

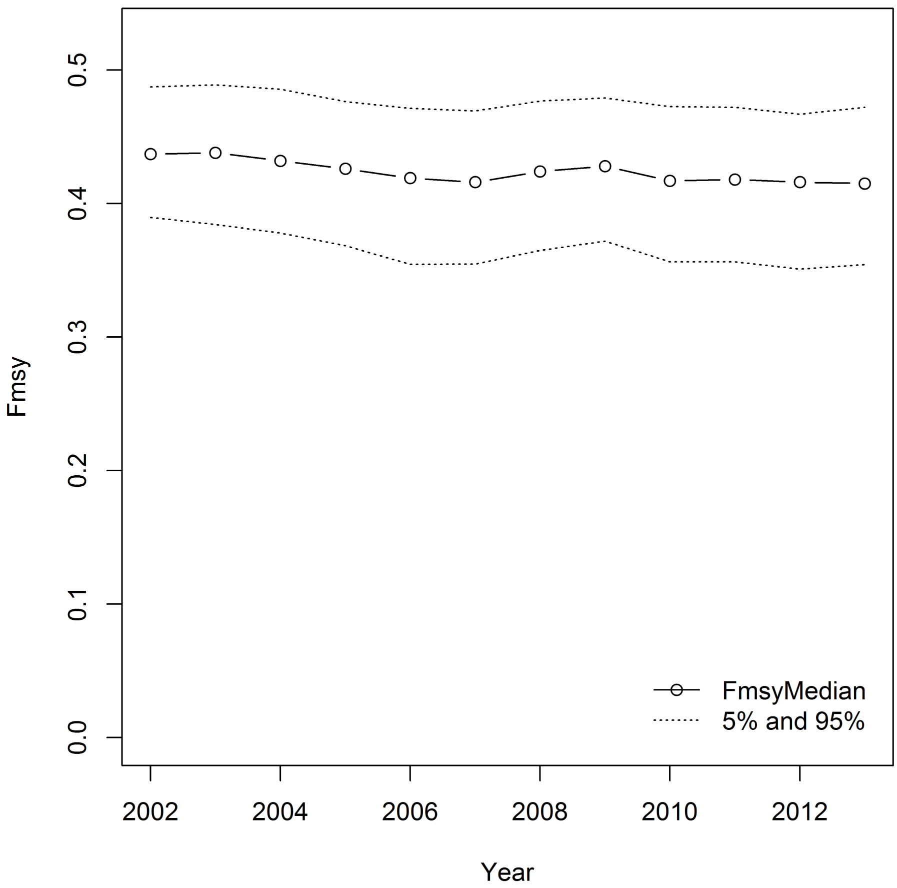

Figure 8: 'Retrospecitve' estimates of Fmsy, the last year of data was iteratively removed from the simulation. The solid line represents the F_{MSY} estimate based on the median yield; the dashed line is F_{MSY} based on the trimmed mean yield; dotted lines represent the 5^{th} and 95^{th} percentiles of FmsyMean.

Appendix 1

```
library(msy)
library(FLCore)
# R version 3.1.2 (2014-10-31)
# Platform: x86_64-w64-mingw32/x64 (64-bit)
# msy_0.1.16
# FLCore_2.5.20150309

load('HadCS.Rdata')
# remove age 0 data (catch nos are all zero at this age anyway)
hadCS <- trim(hadCS,age=1:8)
# and replace zero catch nos at age with 0.001 (3 occurences)
hadCS@catch.n <- ifelse(hadCS@catch.n==0,0.001,hadCS@catch.n)

# dont want to include over-quota discards, so use discard prop
# from start of the time-series when TACs were not restrictive
pdis <- c(0.9,0.5,0.1,0,0,0,0,0)
hadCS@discards.n <- hadCS@catch.n*pdis
hadCS@landings.n <- hadCS@catch.n*(1-pdis)

hadsetup <- list(data = hadCS,
  bio.years = c(1993, 2013),
  bio.const = FALSE,
  sel.years = c(2009, 2013),
  sel.const = FALSE,
  Fscan = seq(0,1.5,by=0.05),
  Fcv = 0.30, Fphi = 0.28,
  Blim = signif(6669.75, 2),
  Bpa = signif(6669.75 * exp(1.624 * 0.26) ,2),
  extreme.trim=c(0.05,0.95)
  )

had_res <- within(hadsetup,
{
  fit <- eqsr_fit(data, nsamp = 1000, models = "Segreg")
  sim <- eqsim_run(fit, bio.years = bio.years, bio.const = bio.const,
  sel.years = sel.years, sel.const = sel.const, Fscan = Fscan,
  Fcv = Fcv, Fphi = Fphi, Blim = Blim, Bpa = Bpa,
  extreme.trim = extreme.trim)
})

had_res$sim$Refs

eqsim_plot_range(had_res$sim, type="median")
eqsim_plot_range(had_res$sim, type="ssb")
eqsr_plot(had_res$fit,ggPlot=FALSE)
eqsim_plot(had_res$sim, catch = FALSE)
```