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Report of the *ad hoc* Group on Long Term Advice (AGLTA)

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ICES Headquarters

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Conseil International pour l'Exploration de la Mer

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Contents

1 Introduction

The ad hoc Group on Long Term Advice (AGLTA) met in ICES, Copenhagen 12–13 April 2005 to produce technical background for the ICES advisory response to a joint request from EC and Norway and a request from the EC. The text of the requests is:

Joint request from the EC and Norway:

'Background

The Community and Norway have developed work on long-term management modelling of shared stocks through work reported in "Multi-Annual management plans for stocks shared by EU and Norway, Brussels, 14 to 18 June 2004" and "Evaluation of Harvest Control Rules for North Sea Cod. Report of a two-day Meeting of Scientists from Norway and the Community.

Brussels, 18th. and 19th. March 2002". These two documents are forwarded to ICES under separate cover.

The Community and Norway wish three additional issues to be addressed in the context of ICES long-term management advice:

a) *Appropriate long-term management of the North Sea cod stock in any eventual post-recovery situation;*
b) *An updating of the simulation studies for North Sea plaice to take account of new data and perceptions of discarding.*
c) *Management strategies for western horse mackerel, sandeel, Norway pout and anglerfish.*

The detailed request *is as follows:*

1) *ICES is requested to evaluate a range of harvest rules for the North Sea cod (from a starting point of SSB=Bpa) and North Sea plaice (from a starting point based on the ICES assessment made in 2004) with respect to medium and long term yields, stability of yield and effort; stock status with respect to safe biological limits. Evaluations shall at a first instance be made on a single species basis, but the experts shall, to the extent possible, quantify mutual compatibility of the rules for cod with those for other stocks that are exploited in mixed fisheries.*
    - *The types of harvest rules to be considered should include*
    - *Harvest rules where TACs and/or fishing effort are derived according to a target fishing mortality, supplemented with a rule for reducing the mortality if the spawning stock biomass is below a trigger level, to ensure avoiding a limit value for the spawning biomass.*
    - *Harvest rules as above, but with an additional constraint on the year to year variation of the TAC including a +/- 15% limit on TAC variation.*
    - *Evaluate alternative approaches to limit year-to-year changes in TAC. The current simulated harvest control rule uses a fixed target F (F_{LT}) above a trigger biomass (B_{trig}). Increased stability can be achieved by replacing F_{LT} with a F rule that implies reducing F with increasing stock size. One candidate is the rule corresponding to a fixed TAC for stock sizes above B_{trig}.*
    - *Alternative rules if feasible.*
2) *The rules shall be evaluated through simulations taking into account inter alia:*
    - *Alternative scenarios for future recruitments, weights and maturities at age, assessment error, discarding and other unaccounted mortality.*
    - *Changes in fishing practice (i.e. selection at age).*

- *Feedback between stock assessment and fisheries management.*

3) *The performance of the rules shall be evaluated both with respect to the perceived state of the stock and to the state of the underlying operating model population. The performance criteria shall include:*
    - *Compatibility with the precautionary approach and relevant international standards and agreements.*
    - *Probability distributions of TACs, yield, spawning stock biomass and fishing mortality.*
    - *Year to year variation in TACs, yield and fishing mortality.*
    - *The risk of entering rebuilding situations ($B<B_{trig}$) in simulations without the year-to-year limitations in TAC change.*
4) *Evaluations shall show:*
    - *The robustness of the harvest rules in assuring stock recovery and maintaining stocks within safe biological limits, considering a plausible range of scenarios as outlined in 3 and a range of alternative parameters as outlined in 2.*

Request concerning western horse mackerel, anglerfish, sandeels and norway pout:

1. *Advise on appropriate management systems including management strategies, objectives and ecosystem considerations for western horse mackerel, anglerfish, sandeels and Norway pout.'*

Request from the EC:

'Background

1. The Commission understands that ICES has requested the WGBFAS to investigate long-term management strategies for cod stocks in the Baltic Sea in the context of the current Memorandum of Understanding. This is a topic of urgent management interest, which the Commission had foreseen should be addressed in a meeting of STECF in July 2005. If, however, appropriate advice can be provided by ICES then it may prove possible to remove this topic from STECF's terms of reference.

1) *The terms of reference being issued to STECF follow.*

2) *STECF is requested to provide advice concerning targets for sustainable exploitation, and harvesting rules for catch and/or fishing effort limits the Cod in the Baltic Sea.*

3) *Such targets and harvest rules should be commensurate with conservation status of the stocks. The rules should also be based on the precautionary principle (in that the absence of adequate scientific information should not be used as a reason for postponing or failing to take management measures to conserve the stocks concerned).*

The detailed request

(1). STECF is requested to evaluate a range of harvest rules for the stocks named in paragraph 1. with respect to medium and long term yield, stability of yield and effort and stock status with respect to safe biological limits. Evaluations shall in the first instance be made on a single species basis but the experts shall, to the extent possible, quantify mutual compatibility of the rules for the target species with the conservation needs of other species caught in the same fisheries.

The types of harvest rule to be considered shall include :

(a) Target conservation reference points, and (where appropriate) limit reference points.

(b) Harvest rules where TACs and/or fishing effort are derived according to a target fishing mortality, supplemented with a rule for reducing the mortality if the spawning biomass is below a trigger level, to ensure avoiding a limit value for the spawning biomass.

(c) Harvest rules as in (a) but including an additional constraint on the year -to-year variation of the TAC including a +/- 15% limit on TAC variation.

(d) Evaluate alternative approaches to limit the year-to-year changes in TAC as considered appropriate.

(e) Where available data are not adequate to estimate stock size and fishing mortality by conventional techniques, identify adaptive harvest rules (such as those directly based on survey data) that are appropriate to reaching the conservation objectives.

(2). STECF is requested to advise whether effort management is necessary to achieve the effective implementation of the harvest rule and the attainment of conservation targets.

(3) The rules shall be evaluated through simulations that take into account the variabilities and uncertainties considered appropriate by the scientists.

(4) The performance of the rules should be evaluated both with respect to the perceived state of the stock and to the state of the underlying operating model population. The performance criteria shall include :

> *Compatibility with the precautionary approach and relevant international standards and agreements.*
>
> *Probability distributions of yield, TACs, spawning stock biomass and fishing mortality and (where relevant) fishing effort.*
>
> *Year to to year variation in TACs, yield, spawning stock biomass and fishing mortality.*
>
> *The risk of entering rebuilding situations in simulations without the year-to-year limitations in TAC change.*

(5) Evaluations shall show the robustness of the harvest rules in assuring stock recovery and maintaining stocks inside safe biological limits, considering a plausible range of scenarios. '

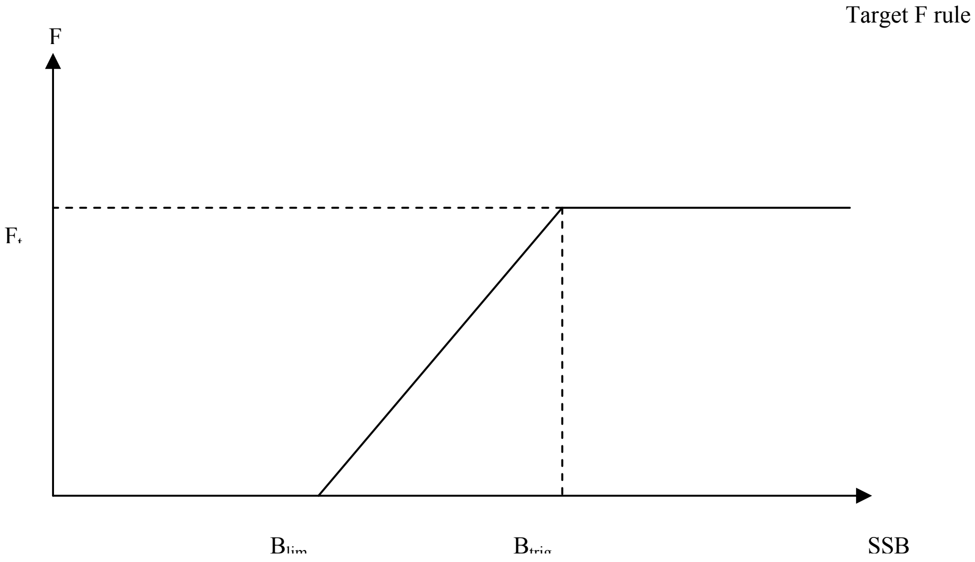
2 Framework

The evaluation of management strategies follows the framework of SGMAS 2005 (ICES, 2005a). The AGLTA provides a technical background document (this report) which will then be discussed by the WGFS in relation to contextual issues. The technical background document and the WGFS comments will serve as the basis for the ACFM meeting in May 2005, which will then finalise the response.

Based on the request, the objectives of the management strategies to be evaluated are in all cases assumed to be high medium and long term yields and good stock status with respect to safe biological limits /translated into low risk of SSB falling below a conservation limit). Important performance criteria are taken to be stability of yield and effort and robustness to both assumptions concerning stock productivity (translated into stock-recruitment relationship) and the precision and bias of stock assessments.

The evaluations for North Sea cod and plaice and Baltic cod are based on simulations using the STPR3 software. This is software for stochastic medium term (10 years) projections, taking into account uncertainty in initial stock numbers at age, future recruitments, individual weights and maturities, as well as uncertainty and bias in future assessments and implementation. It does not perform annual assessments in each of the simulation years, however, but just draws random assessment errors. It allows simulating harvest rules which can be applied independently for two fleets. The harvest rules which can be evaluated with this software includes fixed F and fixed TAC rules for 3 intervals of SSB, with the option to let F decline linearly with SSB within the intermediate SSB interval. It also allows constraints on year-to-year variation in TAC, F and SSB. In addition to the basic program STPR3, two extensions were available. One, termed s3s, allows screening over ranges of values for selected input parameters. The other was made specifically for the cod study. It dumps stock numbers to a file for each bootstrap replica in the second year where the stock was above a recovery target SSB. This collection of stock numbers at age was used as representations of stock numbers at age in a newly recovered stock, and used as input in new runs of STPR to investigate harvest rules for a recovered cod stock.

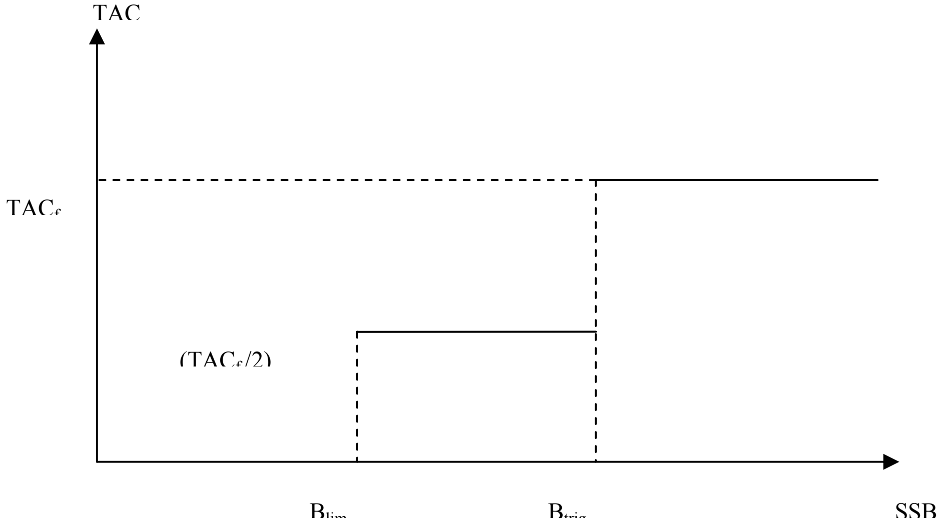
The management strategies evaluated included a harvest control rule with three parameters – a target F (F_t), a limit spawning stock biomass (B_{lim}) and a trigger spawning stock biomass (B_{trig}):



The figure represents the decision rule and not the realised fishing mortality. The actual fishing mortality will be different due to assessment and implementation error. In the simulations, which have been part of the evaluation, such errors have been included. A small fishing mortality below B_{lim} has also been included to simulate a small unavoidable mortality which must be assumed to exist even if management decisions for closure of targeting and important mixed fisheries catching the species in question has been made.

Another set of strategies evaluated for some stocks were based on a fixed TAC (TAC_f) and the same two biomass parameters:

Fixed TAC rule



While B_{lim} is supposed to be an estimate of a property of nature (namely the spawning stock below which reproduction is at risk of being impaired) both F_t, TAC_f and B_{trig} are only parameters of the decision rule. These parameters can be decided entirely on basis of the desired objectives and performance of the management strategy. The evaluations of target F strategies are thus performed in two steps: first B_{trig} is kept constant while simulations for a range of F_t are made. The range of F_t which performs best in terms of meeting objectives and performance criteria is then identified. An exploratation is then made of the impact on objectives and performance of various levels of B_{trig}. This sequence was chosen based on experience that the likelihood of meeting objectives and performance criteria is much more sensitive to the choice of F_t than to the choice of B_{trig}. The evaluations of fixed TAC strategies are similarly performed in two steps, with TAC_f replacing F_t.

In some cases with fishing mortalities far below what has been observed in several decades, the simulated long term spawning stock levels of both cod and plaice grow well beyond what has been observed historically. It is emphasised that simulations which do not take biological interactions and density dependence into account will not produce results which are reliable in an absolute quantitative sense when conditions far away from the present situation are simulated. The results should therefore only be taken as indicative of the direction of change when simulations are well beyond the historical range of fishing mortalities.

For Sandeel and Norway pout the management strategy will be based on in-year information from either an initial fishery (sandeel) or surveys (Norway pout). The present simulation software available does not enable simulation of this and a process is therefore proposed in this document which will enable simulations and advice to be produced through 2005.

For western horse mackerel there is not sufficient data to specify a simulation. However, the spasmodic nature of spawning indicates that a dual management regime is needed with different management rules for the cases where a large year class is or is not present. The conditions for such a regime is discussed and a process devised though which proposals for a management strategy can be produced.

For anglerfish there is insufficient catch data, no survey information and important aspects of the biology are unknown. This report therefore includes a proposal for a two-step adaptive approach which will enable better information to be produced after which management measures could be adapted.

3 North Sea cod

3.1 Methods

The first ToR for the AGLTA meeting requests that the Group "…evaluates a range of harvest rules for North Sea cod (from a starting point of SSB = Bpa)…". North Sea cod is currently estimated to be well below B_{pa}, so the first task of the Group was to simulate the development of the stock from the current position to a state of recovery (defined here as two consecutive years with the projected value of B above B_{pa}). Only then could the required harvest-rule evaluations be performed.

It was possible that most or all of the available STPR3 run settings (TAC constraints, implementation biases, etc) could have had an effect on the probability of stock recovery. However, for the purposes of responding to the EU-Norway request, we were only interested in post-recovery population dynamics in simulations in which recovery occurred. Exploratory analyses suggested that, while HCR trigger points and implementation bias had effects on the speed of recovery, the principal determining factor was the imposed level of fishing mortality. Therefore, a series of combinations of fishing mortality due to landings and discards were used to determine which would lead to recovery within a 10-year time frame, Stochastic population numbers from the year of recovery where then used as bootstrapped starting abundances for post-recovery simulations.

The full analysis methodology was thus:

1) Fit a changepoint (Ockham) stock-recruitment model to the scatterplot of estimated historical stock-recruitment pairs. Run simple test simulations. Adjust the mean level of the changepoint model (i.e. the flat line to the right of the changepoint) until the frequency distribution of simulated recruitments matches that of historical recruitments.

2) Scan over a range of values of landings and discard fishing mortalities to determine which leads to recovery within 10 years.

3) Rerun the pre-recovery simulation with the selected *Fs*, and write stochastic population numbers at recovery time to a separate file.

4) Restart simulations from the time of recovery, using population numbers from the aforementioned file as bootstrapped starting points.

5) Explore the consequences of alternative landings and discard *F*s, TAC constraints, implementation bias and stock-recruitment models on the probability of being below B_{lim} ten years after recovery.

This approach is necessarily rather more complicated than that used for North Sea plaice (see Section 4), since in the case of cod the first task is to achieve recovery. Only then can the performance of the HCR in a post-recovery situation be evaluated.

3.2 Input data

Input data for STPR3 runs for North Sea cod (see Tables 3.1–3.5) were derived from the final accepted assessment presented by the 2004 WGNSSK meeting (ICES, 2005b). This assessment was generated by the BADAPT model, and included estimated discards and multipliers on catch to accommodate otherwise unaccounted mortality (which may be interpreted as misreporting, black landings, changes in natural mortality, etc). The exploitation patterns for landings and discards, and the stock numbers at age at the start of the intermediate year (2004), were based on a simple *status quo F* and estimated survivors.

3.3 Evaluation of recovery probability

3.3.1 Model settings

Table 3.8 lists the model settings used in the cod analysis. B_{pa} (= 150 000 t) was used as a reference level to indicate that recovery had occurred.

Several values of long-term $F_{landings}$ below the *status quo F* were used to explore which would give a likely recovery of the stock within 10 years. The long-term discard Fs were derived from the landings Fs by dividing by 3, as this was close to the ratio observed historically.

Recruitment was modelled by an Ockham (changepoint) function. This was fitted using an SPLUS implementation of the algorithm due to Julious (2001). Only stock-recruit data from the 1980 yearclass onwards were used, as recruitment before that year was considerably more variable about a higher mean. Because the density histogram of simulated recruitments from the fitted model did not compare well with that of the recruitments from the historical assessment, the alpha parameter of the Ockham model was adjusted (from 503.47 to 400.0) to improve the match between distributions. The final recruitment distribution for a sample run is compared with the observed values in Figure 3.1.

Unless stated otherwise, a stochastic error on the annual assessments with a CV of 0.3 was used. It was assumed that there was no bias in either implementation or assessment, since exploratory runs showed that the presence of either of these (their effects are essentially additive) reduced to near zero the probability of recovery (this issue is discussed further in the Conclusions below). For a similar reason, no implementation error was assumed. The biomass at which the upper level of fishing mortality was triggered ($B_{trigger}$) was set at 100 kt for the pre-recovery phase: although this had less effect on recovery probability in exploratory runs than had bias and error, we still found that 100 kt maximised the likelihood of recovery.

3.3.2 Results

The following table summarises the probability of biomass B being below B_{lim} or B_{pa} by 2014:

$F_{LANDINGS}$	$F_{DISCARDS}$	PROB. B<70 KT	PROB. B<150 KT	PROB. OF RECOVERY
0.21	0.07	0%	0%	100%
0.30	0.10	0%	1%	99%
0.33	0.11	1%	2%	98%
0.45	0.15	16%	28%	72%
0.57	0.19	59%	72%	28%
0.69	0.23	89%	95%	5%

Fishing mortalities of around 0.3 (landings) and 0.1 (discards) give a high probability of recovery by 2014 (99%). Stochastic stock numbers from the F=0.3 scenario were written to an output file from the point at which the median estimate of B had been above B_{pa} for two consecutive years: the time when this occurred varied from simulation to simulation, but was generally around 2010.

3.4 Evaluation of post-recovery harvest-control rule

STPR3 runs were performed, using as starting abundance estimates the output from the pre-recovery runs as described above. Model settings are described in the preceding section, and are listed in Table 3.6.

Five sets of simulations were carried out, as follows:

1) $B_{trigger}$ was set to the current B_{pa} (150 kt), no implementation bias or noise was used and assessment noise was set to 0.3 with no bias. There was no TAC constraint. Figure 3.2 summarises the trade-off between risk to B_{lim} in 2020 and the cumulative landings yield during 2018–2020. Fishing mortalities smaller than

around 0.45 (landings) and 0.15 (discards) lead to a less than 10% probability of being below B_{lim}. Long-term yield decreased monotonically as fishing mortality increased within the range 0.2–0.7. In the analysis below, F_{landings} = 0.3 and F_{discards} = 0.1 were used as an example of a strategy that gave low probability of being below B_{lim} in 2020.

2) The next analysis examined the results of different values of B_{trigger} at the F_{landings} = 0.3 strategy with all other inputs remaining unchanged. STPR3 runs were generated for B_{trigger} = 75 kt, 100 kt, 125 kt, 150 kt, and 175 kt. Results, in terms of long-term yield and risk as before, are summarised in Figure 3.3. It is clear that the value used for B_{trigger} has no detectable effect on the stock prognosis. This is because there is a low risk of reaching the trigger point associated with the low *F*s used here.

3) Fixing target *F* to 0.3 (landings) and 0.1 (discards), and B_{trigger} to 150 kt, the next analysis examined the effects of interannual TAC variation (± 5%, ± 10%, ± 15%, ± 20%, and no restriction). Implementation and assessment bias and noise were as before. Increasing the interannual variation in TACs reduced the risk to B_{lim}, although the risks are all less than 2% (Figure 3.4). The differences are greater in terms of long-term yield, with a maximum yield being achieved with TAC variation constrained to ± 20%. This setting was retained in subsequent runs.

4) The next analyses looked at the effects of implementation bias, using values (1.0, 1.1, 1.2, 1.3, 1.4, 1.5). Results are summarised in Figure 3.5. Implementation bias has a large effect on both yield and risk. In particular, a bias of more than 10% (1.1) gives rise to a risk to B_{lim} of more than 5%.

5) The final analyses tested the influence of different stock-recruitment models on the conclusions. Seven such models were used: the baseline changepoint model summarised above (CP 1), the original changepoint model fitted to post-1980 data (i.e. without adjustment of the alpha parameter: CP 2), a changepoint model fitted to the full time-series (CP 3), and Ricker and Beverton-Holt models fitted to the post-1980 and full time-series (Ric, BH, Ric 2, BH 2). Figure 3.6 shows the model fits, and Figure 3.7 summarises their effects in terms of yield and risk. The post-1980 Ricker and Beverton-Holt models (Ric, BH) give the largest recruitments at high stock sizes, but their indication of continued stock increase with no upper limit does not seem to be biologically realistic. The lowest recruitments are given by the baseline changepoint model (CP 1) and the full time-series Ricker model (Ric 2) which may be the preferred choices given current perceptions of ecosystem change. None of the SRR scenarios have used a dome-shaped curve with diminishing recruitment at higher stock sizes (see below)

Finally, Figure 3.8 summarise in more detail the outcomes from one particular analysis, with the following settings:

- Target *F* = 0.3 (landings), 0.1 (discards).
- B_{trigger} = 150 kt.
- Implementation bias = 1.0 (no noise), assessment noise = 0.3 (no bias).
- TAC constraint = ± 20%
- Recruitment model = post-1980 changepoint with reduced alpha.

Median SSB reached a maximum of around 800 kt by 2018 under these assumptions. This is over three times the estimated historical maximum, achieved in the early 1970s. Herein lies the difficulty with these simulations – fishing mortality low enough to produce recovery within the initial 10-year period leads to an infeasible explosion in stock numbers, a dome-shaped stock-recruitment curve might alleviate this to a certain extent. An analysis with such a curve has not yet been carried out: there is little evidence for it and to impose one seems arbitrary.

3.5 Conclusions

The Group was asked to "*evaluate a range of harvest rules for the North Sea cod (from a starting point of SSB=Bpa) [...] with respect to medium and long term yields, stability of yield and effort; stock status with respect to safe biological limits.*". The evaluation of the probability of recovery to B_{pa} was not part of the request. In order to derive a starting population at B_{pa}, we evaluated several scenarios on how the recovery could be achieved. In the course of these analyses it became clear that fishing mortality and implementation bias were the key driving factors in determining the speed and extent of recovery. If implementation bias was absent, values of F of not more than about 0.3 (landings) and 0.1 (discards) gave high probabilities of stock recovery above B_{pa} within 10 years.

Regarding recovery it was concluded that:

- Recovery is unlikely unless F can be substantially reduced from current levels.
- Implementation bias over 10% seriously reduces the likelihood of the cod recovery.
- Recovery time and probability are dependent on the continued influx of at least moderate recruitment.

Evaluating harvest control rules for cod have demonstrated the following:

- Target Fishing mortalities (HC) below 0.3 will result in low risk to $\mathrm{B}_{\mathrm{lim}}$ and high long term yields.
- Risk to B_{lim} is reduced when a light constraint on year to year variation in TAC (± 20%) is used, probably because we started out with a relatively low TAC. .
- $B_{trigger}$ has little effect on post-recovery population dynamics at or below F=0.3.

However:

- Several potentially important factors have not yet been tested, such as the possible density-dependent reduction in recruitment at high stock sizes, and alternative HCRs based on fixed TACs.
- The realism of the simulations depends on the stability of the ecosystem. It is possible (though as yet unproven) that the North Sea ecosystem (biotic and abiotic) has changed to the extent that a recovery of cod to 150 kt and beyond may actually be very unlikely. Certainly the rapid post-recovery growth of the stock in the simulations needs to be viewed with scepticism, as should the assumption (required in order to generate recovery) of no implementation bias.
- Simulations assume unchanged weights, maturities, and frequency of good recruitments from the past. Any of these could change in the future, potentially rendering the simulation presented above inappropriate.

3.6 Summary presented in response to request:

The evaluation of the probability of recovery to $\boldsymbol{B}_{pa}$ was not part of the request. However, in order to derive a starting population for a recovered North Sea cod stock at $\boldsymbol{B}_{pa}$, ICES has evaluated several scenarios by which the recovery might be achieved and has concluded that:

- recovery is unlikely unless F can be substantially reduced from current levels;
- implementation bias over 10% seriously reduces the likelihood of the cod recovery; and
- recovery time and probability are dependent on the continued influx of at least moderate recruitment.

The last point is critical and cannot be predicted as the stock presently is in a state where future reproduction is unknown. For this reason, ICES in 2003 concluded that a precautionary recovery plan must include an adaptive element implying that the fisheries for cod remains closed until an initial recovery of the cod SSB has been proven.

In relation to the joint request, the evaluations of harvest control rules for North Sea cod have demonstrated the following:

- target fishing mortalities (covering all catches) below 0.4 (ages 2–4) result in a low risk of SSB falling below the conservation limit $\mathbf{B}_{\mathrm{lim}}$ and high long-term yields. With fishing mortalities below 0.4 the following conclusions can be drawn:
  - a low risk to reproduction when a constraint on year-to-year variation in TAC (down to ± 5%) is used;
  - a constraint to year-to-year variation in TAC of less than ± 20% results in reductions in long-term yields;
  - implementation error above 10% results in significant increases in risk to $\mathbf{B}_{\mathrm{lim}}$.

However, a word of caution is necessary. In the simulations with low fishing mortalities, the absolute stock sizes projected are very high and well outside of the historically observed ranges. It is unknown whether such high stock sizes can actually be achieved given the constraints within the natural system and what effects this would have on the dynamics of the stock. However, the numerical results of the simulations in terms of risk to reproduction and expected yield are conditional on these large stock sizes. The conclusions regarding the general direction required are not sensitive to density-dependent effects – i.e. significant reductions in fishing mortality to achieve simultaneously a low risk to reproduction and high long-term yield. It is therefore suggested that an implementation of long-term management plans is based on an adaptive approach whereby the development of the stock is monitored as the effects of the reduced fishing mortality are developing, and the specific numerical values within the management plan may then be modified on the basis of the outcome of the fishing mortality reductions.

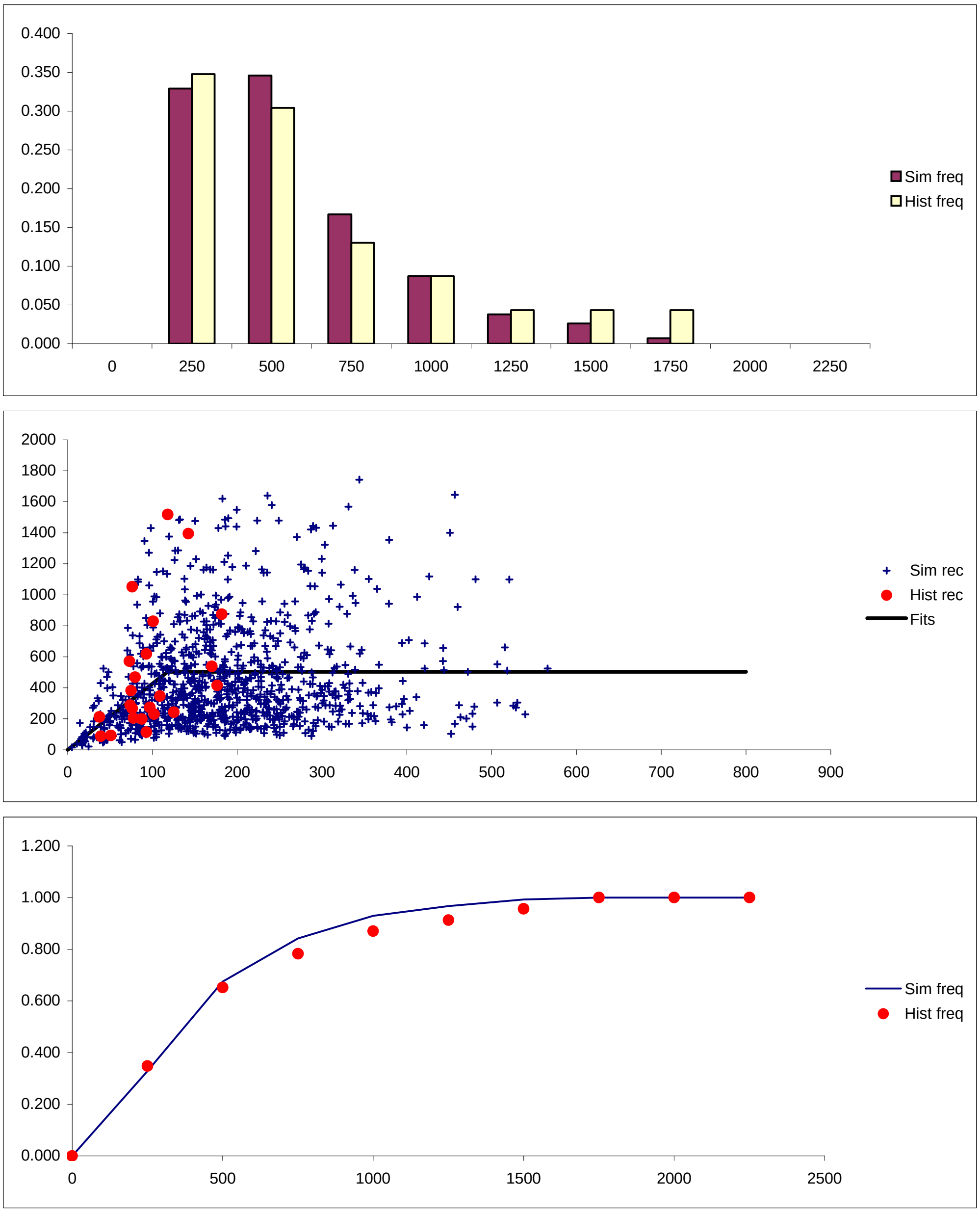


Figure 3.1: North Sea cod. Comparison of observed and simulated recruitment.

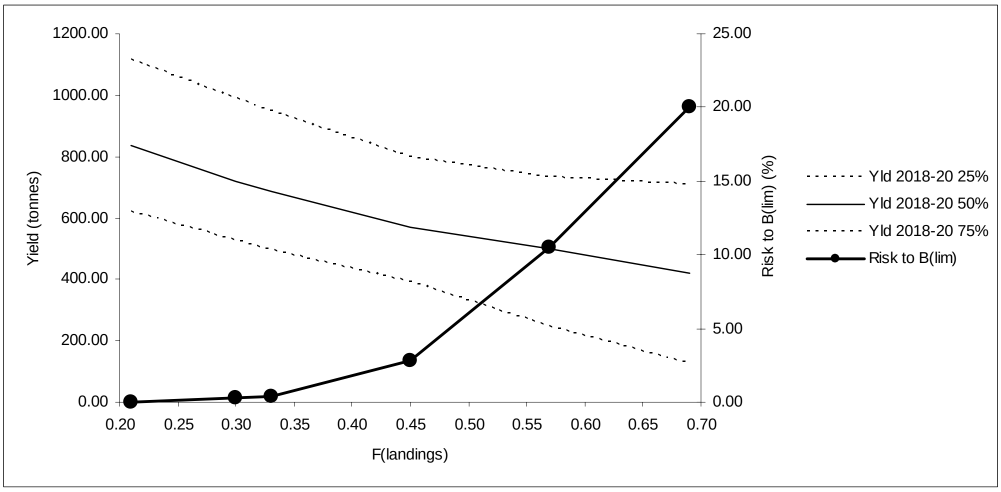


Figure 3.2: North Sea cod. Illustration of trade-off between long-term yield (sum of landings 2018—2020) and risk of $B < B_{\text{lim}}$ for different levels of target fishing mortality. For these simulations B_{trigger} = 150 kt, implementation bias = 1.0 (no noise), assessment noise = 0.3 (no bias), there was no TAC constraint, recruitment model = post-1980 changepoint with reduced alpha.

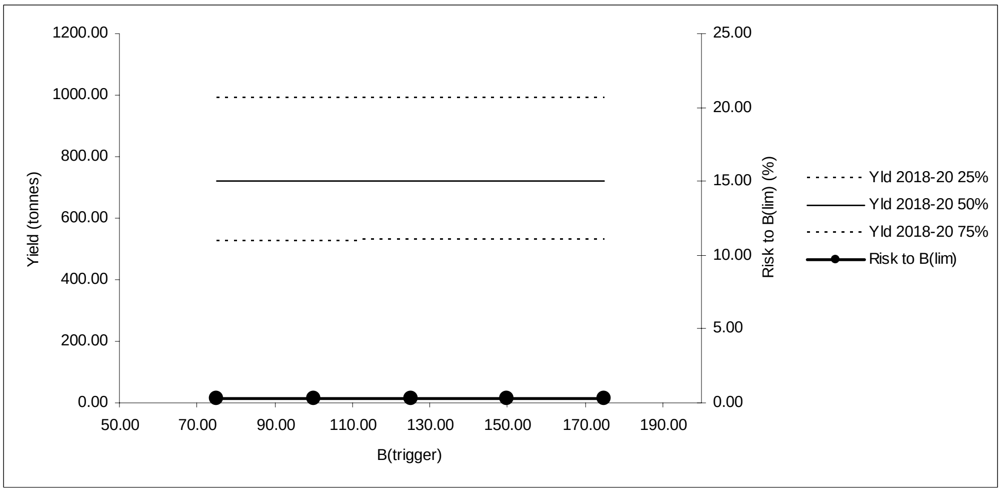


Figure 3.3: North Sea cod. Illustration of trade-off between long-term yield (sum of landings 2018—2020) and risk of $B < B_{\text{lim}}$ for different levels of B_{trigger}. For these simulations target F = 0.3 (landings) and 0.1 (discards), implementation bias = 1.0 (no noise), assessment noise = 0.3 (no bias), there was no TAC constraint, and recruitment model = post-1980 changepoint with reduced alpha.

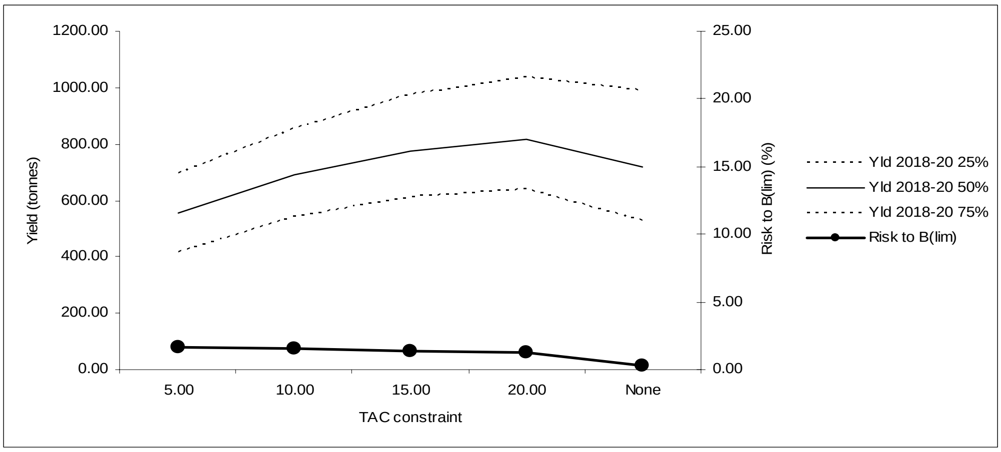


Figure 3.4: North Sea cod. Illustration of trade-off between long-term yield (sum of landings 2018—2020) and risk of $B < B_{\text{lim}}$ for different levels of TAC constraint. For these simulations target $F = 0.3$ (landings) and 0.1 (discards), $B_{\text{trigger}} = 150$ kt, implementation bias = 1.0 (no noise), assessment noise = 0.3 (no bias), recruitment model = post-1980 changepoint with reduced alpha.

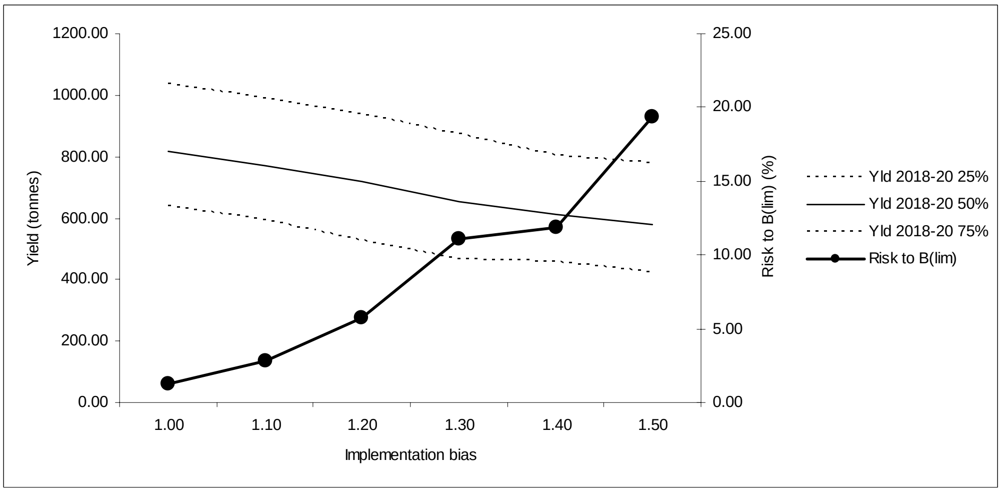


Figure 3.5: North Sea cod. Illustration of trade-off between long-term yield (sum of landings 2018—2020) and risk of B < Blim for different levels of implementation bias. For these simulations target F = 0.3 (landings) and 0.1 (discards), Btrigger = 150 kt, TAC constraint = ±20%, there was no implementation noise, and assessment noise = 0.3 (no bias).

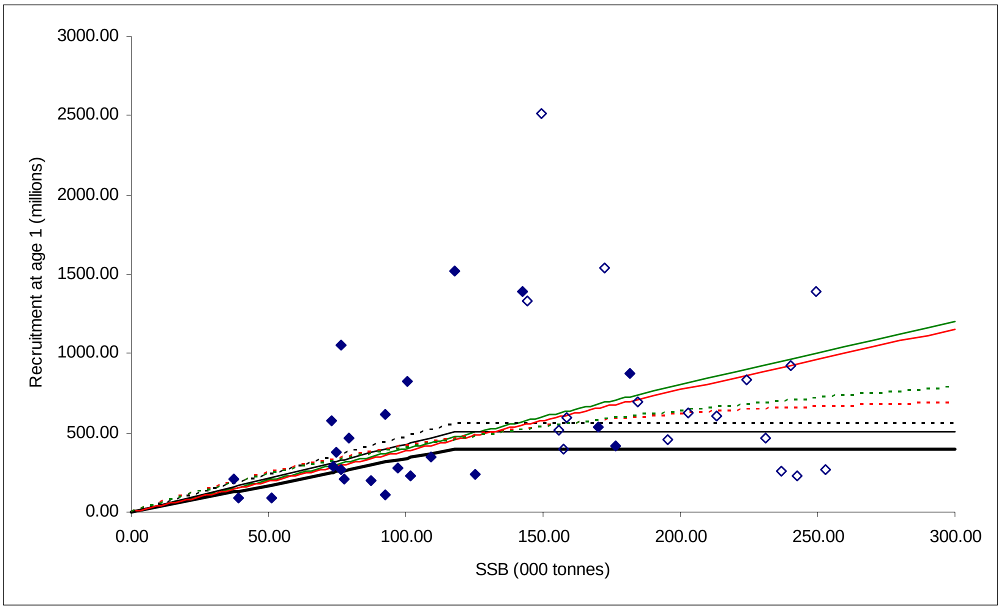


Figure 3.6: North Sea cod. Stock-recruitment model fits. Dots show historical estimates (open = pre-1980; closed = post-1980). Black lines are changepoint model fits (thick = post-1980 with reduced alpha; thin = post-1980; dotted = full time-series), red lines are Ricker model fits (thin = post-1980; dotted = full time-series), and green lines are Beverton-Holt model fits (thin = post-1980; dotted = full time-series).

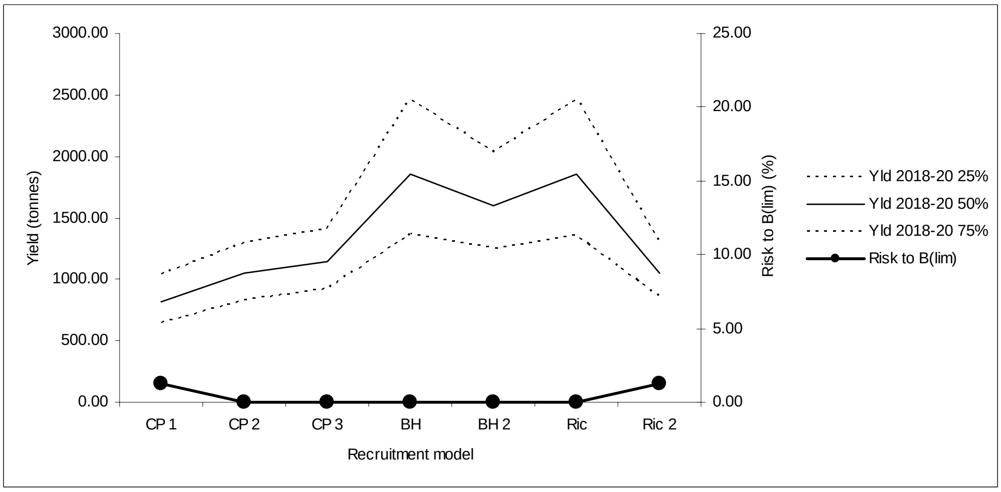


Figure 3.7: North Sea cod. Illustration of trade-off between long-term yield (sum of landings 2018—2020) and risk of $B < B_{\text{lim}}$ for different stock-recruitment models (see text for a description of model codes). For these simulations target $F = 0.3$ (landings) and 0.1 (discards), $B_{\text{trigger}} = 150$ kt, TAC constraint = ±20%, implementation bias = 1.0 (no noise), and assessment noise = 0.3 (no bias).

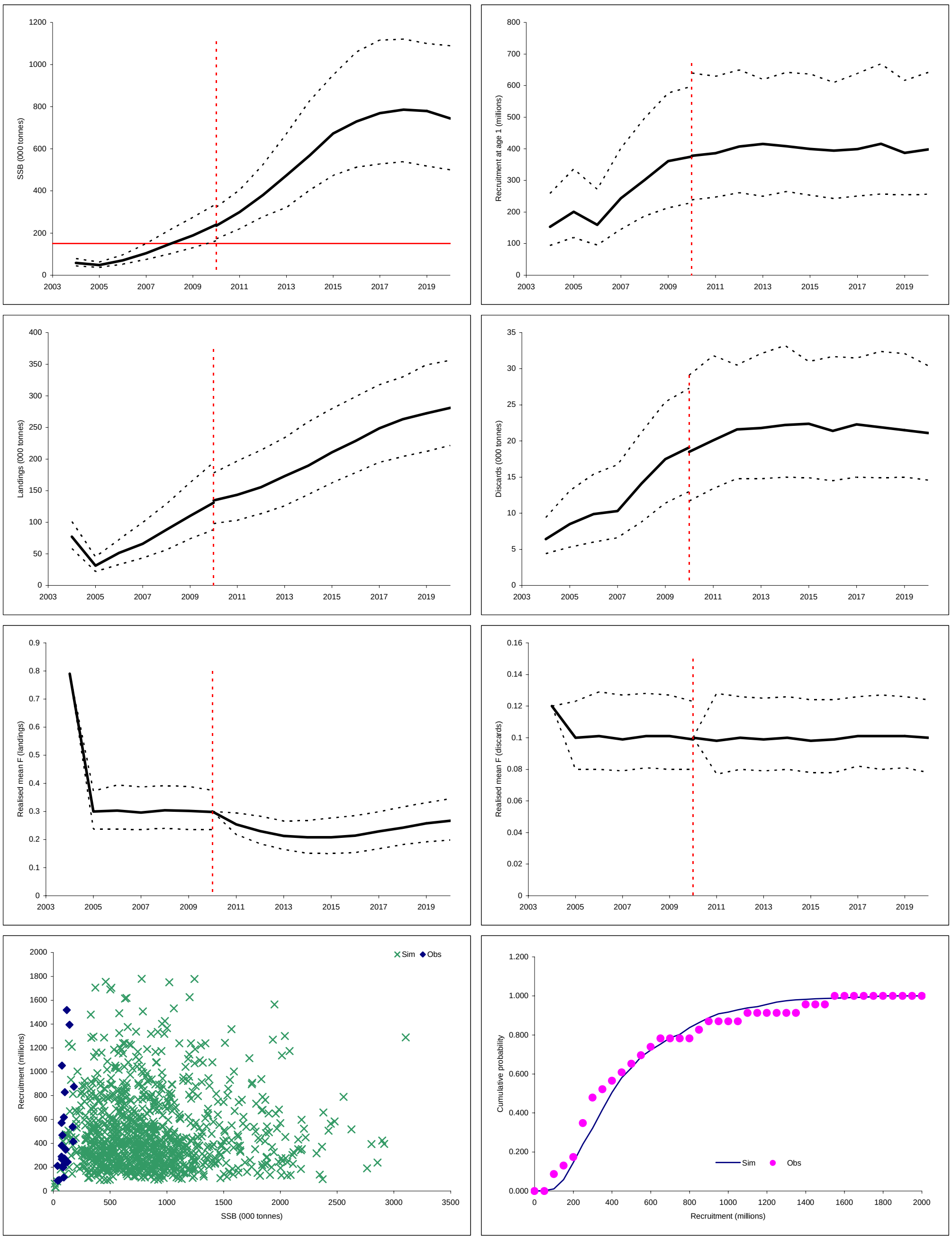


Figure 3.8: North Sea cod. Summary plots of example post-recovery simulation. Target F = 0.3 (landings) and 0.1 (discards), B_{trigger} = 150 kt, TAC constraint = ±20%, implementation bias = 1.0 (no noise), assessment noise = 0.3 (no bias), recruitment model = post-1980 changepoint with reduced alpha. The horizontal red line is B_{pa}, while the dotted vertical read lines show the approximate year of recovery.

Table 3.1: S3S/STPR3 input files for North Sea cod.

cod.adt **Fleet-specific selection**

age	M	Hcons F	Disc F	
0	0			Proportion of F and M before spawning
1	0.8	0.042	0.217	
2	0.35	0.388	0.433	
3	0.25	0.816	0.17	
4	0.2	0.904	0.007	
5	0.2	1.053	0.013	
6	0.2	0.968	0.006	
7	0.2	0.969	0.006	

cod.ydt **Yearly SSB and recruitments (last 10 years only)**

year	recruitment	ssb
1994	1051982	79516
1995	468262	97013
1996	273808	100841
1997	828759	92731
1998	114034	77396
1999	204246	74775
2000	381625	51084
2001	92026	37517
2002	211507	39153
2003	87592	42924

Table 3.2: S3S/STPR3 input files for North Sea cod.

cod.wc **Weights-at-age in the catch by fleet**

Fleet 1 = h. cons., fleet 2 = discards

year	fleet	weights-at-age						
1963	1	0.538	1.004	2.657	4.491	6.794	9.409	11.941
1964	1	0.496	0.863	2.377	4.528	6.447	8.520	10.886
1965	1	0.581	0.965	2.304	4.512	7.274	9.498	12.194
1966	1	0.579	0.994	2.442	4.169	7.027	9.599	12.536
1967	1	0.590	1.035	2.404	3.153	6.803	9.610	12.438
1968	1	0.640	0.973	2.223	4.094	5.341	8.020	9.481
1969	1	0.544	0.921	2.133	3.852	5.715	6.722	9.794
…								
1981	1	0.723	0.837	2.190	4.615	7.045	8.884	10.863
1982	1	0.589	0.962	1.858	4.130	6.785	8.903	11.506
1983	1	0.632	0.919	1.835	3.880	6.491	8.423	10.728
1984	1	0.594	1.007	2.156	3.972	6.190	8.362	11.116
1985	1	0.590	0.932	2.141	4.164	6.324	8.430	11.502
1986	1	0.583	0.856	1.834	3.504	6.230	8.140	10.878
1987	1	0.635	0.976	1.955	3.650	6.052	8.307	11.777
1988	1	0.585	0.881	1.982	3.187	5.992	7.914	11.369
1989	1	0.673	1.052	1.846	3.585	5.273	7.921	10.852
1990	1	0.737	0.976	2.176	3.791	5.931	7.890	11.078
1991	1	0.670	1.078	2.038	3.971	6.082	8.033	10.463
1992	1	0.699	1.146	2.546	4.223	6.247	8.483	10.564
1993	1	0.699	1.065	2.479	4.551	6.540	8.094	10.380
1994	1	0.677	1.075	2.201	4.471	7.167	8.436	10.363
1995	1	0.721	1.021	2.210	4.293	7.220	8.980	10.923
1996	1	0.699	1.117	2.147	4.034	6.637	8.494	10.558
1997	1	0.656	0.960	2.120	3.821	6.228	8.394	10.720
1998	1	0.542	0.922	1.724	3.495	5.387	7.563	10.118
1999	1	0.640	0.935	1.663	3.305	5.726	7.403	9.314
2000	1	0.611	1.021	1.747	3.216	4.903	7.488	10.018
2001	1	0.725	1.004	2.303	3.663	5.871	7.333	9.849
2002	1	0.758	1.082	1.916	3.857	5.372	7.991	10.205
2003	1	0.608	1.173	1.848	3.255	5.185	7.409	9.906
1963	2	0.270	0.393	0.505	0.000	0.000	0.000	0.000
1964	2	0.270	0.393	0.508	0.000	0.000	0.000	0.000
1965	2	0.269	0.392	0.506	0.000	0.000	0.000	0.000
1966	2	0.269	0.392	0.509	0.000	0.000	0.000	0.000
1967	2	0.269	0.392	0.506	0.000	0.000	0.000	0.000
1968	2	0.269	0.392	0.505	0.000	0.000	0.000	0.000
1969	2	0.268	0.392	0.504	0.000	0.000	0.000	0.000
…								
1981	2	0.279	0.396	0.517	0.000	0.000	0.000	0.000
1982	2	0.274	0.489	0.593	0.000	0.000	0.000	0.000
1983	2	0.297	0.458	0.534	0.000	0.000	0.000	0.000
1984	2	0.270	0.469	0.509	0.000	0.000	0.000	0.000
1985	2	0.276	0.376	0.652	0.000	0.000	0.000	0.000
1986	2	0.242	0.365	0.437	0.000	0.000	0.000	0.000
1987	2	0.237	0.353	0.000	0.000	0.000	0.000	0.000
1988	2	0.300	0.339	0.463	0.000	0.000	0.000	0.000
1989	2	0.326	0.431	0.484	0.000	0.000	0.000	0.000
1990	2	0.260	0.371	0.526	0.000	0.000	0.000	0.000
1991	2	0.315	0.366	0.395	0.000	0.000	0.000	0.000
1992	2	0.314	0.408	2.309	0.000	0.000	0.000	0.000
1993	2	0.274	0.429	0.705	0.000	0.000	0.000	0.000
1994	2	0.287	0.362	0.483	0.000	0.000	0.000	0.000
1995	2	0.316	0.404	0.553	0.000	0.000	0.000	0.000
1996	2	0.342	0.380	0.515	0.000	0.000	0.000	0.000
1997	2	0.313	0.453	0.616	0.000	0.000	0.000	0.000
1998	2	0.358	0.375	0.481	0.000	0.000	0.000	0.000
1999	2	0.257	0.389	0.422	0.000	0.000	0.000	0.000
2000	2	0.298	0.422	0.000	0.000	0.000	0.000	0.000
2001	2	0.232	0.361	0.406	0.000	0.000	0.000	0.000
2002	2	0.294	0.420	0.340	0.000	0.000	0.000	0.000
2003	2	0.259	0.344	0.540	0.675	2.272	2.849	3.962

Table 3.3: S3S/STPR3 input files for North Sea cod.

cod.ws **Weights-at-age in the stock**

year	weights-at-age						
1963	0.317	0.818	2.647	4.491	6.794	9.409	11.941
1964	0.361	0.768	2.368	4.528	6.447	8.520	10.886
1965	0.314	0.903	2.295	4.512	7.274	9.498	12.194
1966	0.315	0.841	2.437	4.169	7.027	9.599	12.536
1967	0.328	0.874	2.395	3.153	6.803	9.610	12.438
1968	0.330	0.851	2.215	4.094	5.341	8.020	9.481
1969	0.419	0.759	2.128	3.852	5.715	6.722	9.794
1970	0.452	0.848	2.029	4.001	6.131	7.945	10.512
1971	0.315	0.838	2.188	4.258	6.528	8.646	11.312
1972	0.301	0.732	2.080	3.968	6.011	8.246	10.298
1973	0.338	0.705	1.913	3.776	5.488	7.453	9.760
1974	0.306	0.907	2.207	4.156	6.174	8.333	11.314
1975	0.310	0.770	2.348	4.226	6.404	8.691	11.284
1976	0.200	0.739	2.452	4.577	6.494	8.620	10.777
1977	0.301	0.700	2.132	4.606	6.714	8.828	10.764
1978	0.444	0.757	2.001	4.146	6.530	8.667	10.917
1979	0.292	0.907	2.411	4.423	6.579	8.474	11.616
1980	0.258	0.923	1.948	4.401	6.109	9.120	10.843
1981	0.330	0.773	2.186	4.615	7.045	8.884	10.863
1982	0.360	0.912	1.856	4.130	6.785	8.903	11.506
1983	0.409	0.884	1.834	3.880	6.491	8.423	10.728
1984	0.305	0.931	2.156	3.972	6.190	8.362	11.116
1985	0.318	0.806	2.133	4.164	6.324	8.430	11.502
1986	0.299	0.803	1.823	3.504	6.230	8.140	10.878
1987	0.447	0.794	1.955	3.650	6.052	8.307	11.777
1988	0.472	0.760	1.976	3.187	5.992	7.914	11.369
1989	0.366	0.952	1.817	3.585	5.273	7.921	10.852
1990	0.390	0.706	2.168	3.791	5.931	7.890	11.078
1991	0.395	0.908	1.999	3.971	6.082	8.033	10.463
1992	0.405	0.992	2.545	4.223	6.247	8.483	10.564
1993	0.332	0.863	2.478	4.551	6.540	8.094	10.380
1994	0.309	0.818	2.189	4.471	7.167	8.436	10.363
1995	0.433	0.786	2.207	4.293	7.220	8.980	10.923
1996	0.438	0.859	2.103	4.034	6.637	8.494	10.558
1997	0.413	0.816	2.117	3.821	6.228	8.394	10.720
1998	0.374	0.650	1.647	3.495	5.387	7.563	10.118
1999	0.340	0.770	1.434	3.305	5.726	7.403	9.314
2000	0.360	0.918	1.747	3.216	4.903	7.488	10.018
2001	0.395	0.624	2.134	3.663	5.871	7.333	9.849
2002	0.479	0.945	1.744	3.857	5.372	7.991	10.205
2003	0.276	0.799	1.583	3.195	5.119	7.321	9.836

Table 3.4: S3S/STPR3 input files for North Sea cod.

cod.prm **Proportion mature at age**

year	maturity-at-age						
1963	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1964	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1965	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1966	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1967	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1968	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1969	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1970	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1971	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1972	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1973	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1974	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1975	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1976	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1977	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1978	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1979	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1980	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1981	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1982	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1983	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1984	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1985	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1986	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1987	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1988	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1989	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1990	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1991	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1992	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1993	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1994	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1995	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1996	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1997	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1998	0.010	0.050	0.230	0.620	0.860	1.000	1.000
1999	0.010	0.050	0.230	0.620	0.860	1.000	1.000
2000	0.010	0.050	0.230	0.620	0.860	1.000	1.000
2001	0.010	0.050	0.230	0.620	0.860	1.000	1.000
2002	0.010	0.050	0.230	0.620	0.860	1.000	1.000
2003	0.010	0.050	0.230	0.620	0.860	1.000	1.000

cod.nin **Initial stock numbers-at-age (diagonal elements = CVs from SEN file)**

1	157309	0.58	0.00	0.00	0.00	0.00	0.00	0.00
2	27874	0.00	0.22	0.00	0.00	0.00	0.00	0.00
3	26393	0.00	0.00	0.22	0.00	0.00	0.00	0.00
4	3710	0.00	0.00	0.00	0.23	0.00	0.00	0.00
5	4694	0.00	0.00	0.00	0.00	0.23	0.00	0.00
6	322	0.00	0.00	0.00	0.00	0.00	0.41	0.00
7	101	0.00	0.00	0.00	0.00	0.00	0.00	0.41

Table 3.5: S3S/STPR3 input files for North Sea cod. An example cod.opt file.

```
          1          7                                                               Ages
          1                                                                          Number of years between spawning and recruitment
          2          4                                                               Mean F range for hcons.
          2          4                                                               Mean F range for discards
       2004                                                                          The intermediate year
F                                                                                    Int. yr.: Constraint type for hcons. (C=catch, F=mortality)
       0.79                                                                          Int. yr.: Value of constraint for hcons.
F                                                                                    Int. yr: Constraint type for discards (C=catch, F=mortality)
       0.12                                                                          Int. yr.: Value of constraint for discards
        0.0        0.3        0.1     1000.0     1000.0                              HCR1: lower bound on SSB, max F hcons., max F discards, max catch hcons, max catch discards
       70.0        0.3        0.1     1000.0     1000.0                              HCR2 lower bound on SSB, max F hcons., max F discards, max catch hcons, max catch discards
      100.0        0.3        0.1     1000.0     1000.0                              HCR3: lower bound on SSB, max F hcons., max F discards, max catch hcons, max catch discards
          1                                                                          Linear increase of F in level 2? (0=no, 1=yes)
       0.00       0.00       0.00                                                    Annual catch variation max increase (both, hcons., disc)
       0.00       0.00       0.00                                                    Annual catch variation min increase (both, hcons., disc)
       0.00       0.00       0.00                                                    Annual F variation: max increase (both, hcons., disc)
       0.00       0.00       0.00                                                    Annual F variation: min increase (both, hcons., disc)
        0.0          0                                                               Min increase in SSB, which fleet takes burden (0=both)
        3.0        3.0                                                               Max possible F by fleet
        2.0        2.0                                                               Max permitted F by fleet
          2          1  4.000E+02  1.180E+02      0.000      0.690      1.500 Recruitment model: type (Ricker), stochastic basis (lognormal), alpha, beta, not used, sigma (residual SD), truncation
          0                                                                          Number of autoregressive terms used
       0.00       0.00       0.00       0.00       0.00                              AR terms (from RecAn output for AR(1))
          0                                                                          Apply SR relation in year 0? (0=no, 1=yes)
       1.00       0.30          0                                                    Assessment bias multiplier (mean and SD)
       1.00       0.00                                                               TAC deviation multiplier (mean and SD)
          1                                                                          Initial numbers (0: det., 1: log, 2: norm, 3: bootstrap)
```

Table 3.6: S3S/STPR3 run settings for North Sea cod. Where there are several values given for a parameter, pre-recovery settings are shown in bold: the remaining values were used in post-recovery evaluation simulations.

SETTING	VALUE	JUSTIFICATION
Age range	1-7+	
Reference F age range	2–4	
F-constraint	Pre-recovery: 0.79 (landings), 0.12 (discards) Post-recovery: 0.3 (landings), 0.1 (discards)	*Status quo F*
B_{lim}	70000 t	
Trigger biomass (B_{trig})	75 000 t, **100 000 t**, 125 000 t, 150 000 t, 175 000 t	
F-level 1 (both components)	Pre-recovery: 0.3 (landings), 0.1 (discards) Post-recovery: 0.1 (landings), 0.05 (discards)	Expected that there will always be some fishing for cod
F-level 2 (both components)	Linear change from level 1 to level 3	
F-level 3 (long-term landings mean *F*)	0.21, **0.3**, 0.33, 0.45, 0.57, 0.69	*Status quo* mean landings *F* is 0.79. Increments intended to be divisible by 3.
F-level 3 (long-term discards mean *F*)	0.07, **0.1**, 0.11, 0.15, 0.15, 0.23	Landings *F* divided by 3, except where reduced to avoid crash.
Maximum TAC change	**No constraint**, ±5%, ±10%, ±15%	
Maximum *F* change	Not constrained.	
Maximum *F* possible	3.0	
SRR model	Ockham (changepoint)	Parsimonious model.
	P1	400.00 (adjusted from fitted value 503.47 to improve distribution of simulated recruitments)
	P2	118.0
	Residual standard deviation	0.69
	Truncation level	1.5
Assessment bias	1.0	
Assessment SD	0.3	Assessment is thought to be uncertain.
Implementation bias	**1.0**, 1.1, 1.2	
Implementation SD	0.0	

4 North Sea plaice

4.1 Input data

Input data for STPR3 and S3S runs for North Sea plaice (see Table 4.1–Table 4.5) were derived from the final accepted assessment presented by the 2004 WGNSSK meeting (ICES, 2005b). This assessment included simulated (1957–1998) and estimated discards (1999–2003). The exploitation patterns for landings and discards, and the stock numbers at age at the start of the intermediate year (2004), were based on a status quo F and estimated survivors.

The stock recruitment data for North Sea plaice is not very informative on the functional relationship between spawners and recruitment. Therefore, alternative representations on stock and recruitment have been explored to test the sensitivity of the model results to the assumed relationship (see sensitivity analysis).

4.2 Model settings

SETTING	VALUE	JUSTIFICATION
Age range	1-10+	
Reference F age range	2–6	
Intermediate year	F hc= 0.43, F disc = 0.28	F *status quo F*
B_{lim}	160 000 t	
Trigger biomass (B_{trig})	230 000 t	Set equal to B_{pa}
F-level 1 (both components)	0.05	Expected that there will always be some fishing for plaice
F-level 2 (both components)	not used	
F-level 3 (long-term landings mean *F*)	landings: 0.1, 0.2, 0.3, 0.4, 0.5, 0.6 discards: using a fixed multiplier, or 0.5 * fixed multiplier	
Maximum TAC change	**Not constrained,** ±15%	
Maximum *F* change	**Not constrained**	
Maximum *F* possible	1,5 (hc), 1.0 (disc)	
SRR model	**Shepherd (5.0, 430 000, 1.9)** Shepherd (4.0, 300 000, 3.0) low, Shepherd (5.35, 430 000, 1.9) middle, Ockham (900 000, 160 000)	Different stock recruitment curves corresponding to scenario's about high and low recruitment included in the sensitivity analysis. Including depensation at high stock size.
SRR residual variation	0.4	
SRR truncation level	0.9	
Assessment bias	1.0	Substantial assessment bias has been observed in the past but the sign of this bias is likely to change.
Assessment SD	0.1, 0.2, **0.3**	Bias in assessment is here conceptualized as random variation at different levels.
Implementation bias	1.0	Implementation bias for plaice has been observed in the 1980s but not in recent period
Implementation SD	0	

Note: base case in bold

An example of the STPR3 option file is presented in Table 4.6.

4.3 Analytical approach

The following analytical approach was followed:

1) Parameterize the stock recruitment relationship so that simulated distributions at observed fishing mortality mimicks the observed recruitment distributions.

2) Carry out F_{sq} forecasts, without a HCR to develop a base case against which comparisons can be made.

3) Explore consequences of alternative HC (human consumption) F's (F_t) and discard F's on the probability of being below B_{lim} in 2014

4) Explore consequences of alternative time-trajectories to achieve different HCR's

5) Explore the sensitivity of the 2014 situation to the assumptions on the underlying population dynamics (e.g. stock recruitment relationship) and the perception status (e.g. standard deviation on stock status).

4.4 Results

4.4.1 Stock recruitment calibration

Calibration of the stock recruitment curve. An STPR3 analysis was carried out, using Fsq (0.43 HC, 0.28 disc) with different parameter values for standard deviation and truncation on the recruitment draws. Results are presented in terms of observed and simulated stock and recruitment pairs and in terms of cumulative recruitment distributions (Figure 4.1) for a SD of 0.4 and truncation 0.9.

4.4.2 Fsq forecast

Results of the status quo fishing mortality analysis are summarized in Figure 4.2. Continued fishing at current fishing mortality (F hc=0.43, F disc=0.28) is expected to result in a decline of the stock towards 100–150 thousand tonnes, which is well below the Blim of 160 000 t.

4.4.3 Scanning different possible HCRs

The S3s software was used to scan the effects of different combinations of parameters on the development in stock size, recruitment, landings and discards of North Sea plaice.

A first set of simulations was devoted to exploring the effects of different levels of fishing mortality. Six effort multipliers were used on both landings and discard F, so that the landings F varied between 0.1 and 0.6 and the discards F between 0.07 and 0.39. A second series was derived by using the same F values for landings but assuming that discards mortality could be halved (by additional measures that have not been specified) so that they ranged between 0.03 and 0.19). Results of these analysis are presented in Figure 4.3 to Figure 4.5. The risk to B_{lim} in 2014 is highly dependent on the overall level of fishing mortality (Figure 4.3). At F_{sq}, the risk to B_{lim} is around 25%. In order to achieve a low risk to B_{lim} in 2014 of e.g. 5%, fishing mortality on landings should be reduced to around 0.3 under the assumption that discard mortality would be decreased in proportion to that. However, if discards mortality could be reduced more than proportionally, the F_t on landings could be in the order of 0.4 while still achieving a low risk to being below B_{lim}.

If the objective is to obtain a high long term yield in combination with a low risk to B_{lim}, the preferred level of human consumption fishing mortality could be around F_t=0.2 (Figure 4.4). At F_t=0.2, the expected landings in the final years of the simulation are around 125 000 t, while the short term landings are expected to be around 60 000 t. If discards could be reduced in addition, the expected landings in the longer term may even amount to over 150 000 t.

The explanation for the high landings at low fishing mortality can be found in Figure 4.5 where the expected SSB (including 25th and 75th percentiles) are shown. A fishing mortality around 0.2 is associated with very high expected stock sizes of around 600 000 to 800 000 t., which is well above the maximum stock size observed in the period 1957–2003 (450 000 t.). The potential effects of such high stock sizes on growth rates and reproduction are unknown, but they could have an important impact on the expected results of the simulation in terms of risk to B_{lim} and expected landings.

The dependency between B_{trig} and risk to B_{lim} and expected landings is shown in Figure 4.6 for two scenario's on F_t which give a low risk – high long term yield option: F_t (hc)=0.2 and F_t (hc)=0.3 (with F discards scaled proportionally). Varying B_{trig} between 180 000 t and 280 000 t. did not have a large influence on the risk to B_{lim} profile in either F_t scenario. Also, the expected landings were relatively insensitive to the B_{trig} value.

An alternative HCR approach could be to use a TAC based rule (fixed TAC, TAC_f) rather than an F based rule. This could circumvent the dependency on annual updates of stock assessments. However, the simulation of a fixed TAC rule in STPR3 is not strictly comparable with the F-based rule which was discussed before. This is because a fixed TAC rule cannot use the sliding area between B_{lim} and B_{trig}; the only option is to set another fixed TAC in that area. This means that annual assessment updates will still be necessary in the situation that it is likely that the stock is below B_{trig}. Therefore, we implemented the TAC rule in STPR3 as follows:

- For each human consumption TAC_f , when the stock is above Btrig,
- Define a human consumption TACf/2 when the stock is between Blim and Btrig
- Assume that discards mortality is at Fsq when the stock is above Btrig
- Assume that discards mortality is at 0.5 * Fsq when the stock is between Blim and Btrig

We implicitly assume that discards mortality does not change with different TAC levels, even though this assumption may be problematic, because different TACs also imply different levels of fishing mortality. The results of the simulation with respect to the risk to B_{lim}, the expected landings in the short and long term and the expected SSB in the long term are shown in Figure 4.7. All scenario's indicate that the expected risk to B_{lim} are below or around 5% in 2014, but the expected yield from the stock is substantially lower than when the stock would be harvested from an F based rule. For example, at a TAC_f of 80 000 t, the expected short term landings would be substantially below that target (because the stock is still below B_{trig}) and only in the longer time, would the overall landings approach the target of 80 000 t. But that is still well below the 125–150 000 t expected from the F based rules.

4.4.4 Alternative time trajectories for HCRs

Four scenario's were selected for further analysis on the expected time trajectories that they imply. The selection was based on the criteria of low risk to Blim (at or below 5%) and high long term landings. Discards mortality was expected to scale proportionally with landings mortality. The four cases were:

- Ft =0.2, no cap on interannual TAC change (Figure 4.8)
- Ft =0.2, cap of 15% on interannual TAC change (Figure 4.9)
- Ft = 0.3, no cap on interannual TAC change (Figure 4.10)
- Ft =0.3, cap of 15% on interannual TAC change (Figure 4.11)

The results of the bootstrap simulations using STPR3 are summarized in 6 graphs: SSB, recruitment, landings, discards, SSB-recruitment pairs and cumulative probability profiles of recruitment between simulated and observed (stock assessment) values.

In the cases where no constraint is applied on the interannual change in TAC, the median and 25th and 75th percentiles of landings and discards show a large decrease in 2005 compared to 2004, after which the stock is expected to recover rapidly due to the lower fishing mortality on both landings and discards. When a fishing mortality of F_t = 0.2 is applied, the stock is expected to increase to around 600 000 t. and with F_t = 0.3 to 300 000 t. The difference between these two scenario’s can be explained by the overall lower recruitment in the latter case, due to the higher fishing mortality which keeps the stock away from the most productive areas. So the combined effect of higher harvest rates and lower recruitment cause the F_t =0.3 to stabilize on an equilibrium stock value which is well below the F_t =0.2 scenario.

The introduction of a cap on the interannual change in TAC (15%) is shown in Figure 4.9 and Figure 4.11. Note that this cap only applies to the landings and not to the discards, so that discards are allowed to vary more from year to year. The introduction of a cap on TAC change appears to have a positive effect on stock trajectory, which can be explained by the fact that the increase of the stock due to recruitment and growth cannot be mirrored by an increase in TAC due to the cap on changes.

4.4.5 Sensitivity analysis

The senstivity to the underlying assumptions was explored by investigating different stock recruitment relationships (Figure 4.13) and different assumptions about the uncertainty in the stock status (perception). The comparison of different stock recruitment relationships is shown in Figure 4.14. The conclusion from the graphs is that at current discard mortality (0.3), the risk to B_{lim} is sensitive to the assumed stock recruitment relationship, especially when HC fishing mortality is also high. When the recruitment scenario is lower (i.e. lower recruitment at given stock size, e.g. due to less favourable environmental situations), the risk to B_{lim} would be higher.

The sensitivity to the assumed variance in stock status is shown in Figure 4.15. A SD of 0.3 was used as the base case. At lower standard deviations, the risks to B_{lim} is also lower. The real interest here would be to model the interaction between bias in the assessment and feedback into the management procedure. However, this is not feasible within the STPR framework and this has therefore not been pursued at present.

4.5 Discussion

If the objective is to obtain a high long term yield in combination with a low risk to Blim, the preferred level of human consumption fishing mortality could be in the area of F_t =0.2 to F_t =0.3 (Figure 4.4). At F_t =0.2, the expected landings in the final years of the simulation are around 125 000 t, while the short term landings are expected to be around 60 000 t. A major improvement to the stock development and to the landings is expected by the additional reduction of discard mortality. When the simulated fishing mortalities are very low, the resulting stock sizes can be rather high with expected stock sizes of around 600 000 to 800 000 t. This is well above the maximum stock size observed in the period 1957–2003 (450 000 t.). The potential effects of such high stock sizes on growth rates and reproduction are unknown and results should only be seen as indicative of the direction of change rather than as absolute forecasts. High stock sizes could have an important impact on the expected results of the simulation in terms of risk to B_{lim} and expected landings.

As an alternative to F-based HCRs, we evaluated the likely behaviour of a fixed TAC based rule which consisted of three area: (1) stock above B_{trig} (fish at TAC_f), (2) between B_{lim} and B_{trig} (fish at $TAC_{f/2}$) and (3) below B_{lim} (fish only at a very low bycatch F). The simulations indicated that the expected risk to B_{lim} were below or around 5% in 2014, but the expected yield from the stock was substantially lower than when the stock would be harvested from an F based rule.

The simulation procedure in STPR3 does not incorporate a full feedback loop, where an operating model is used on which a stock assessment process is carried out, which then forms the basis for a management decision and an implementation. The stock assessment process and the implementation process are mimicked in STPR3 by application of a fixed bias and a standard deviation. Because the stock assessment process is not explicitly incorporated, we cannot evaluate how a stock could be traced at lower fishing mortalities when in general stock assessment models tend to break down. It is similarly not possible to simulate the effects of changing assessment bias in the high F case that nonreporting may increase when TAC's become increasingly restrictive.

The individual STPR3 analysis in section 4.4.4 were presented as percentiles of 1000 bootstrap iterations. We also looked at individual bootstrap realizations of two of the explored scenario's in order to evaluate the consistency between the iterations. Results are summarized in Figure 4.12 for the scenario's F_t =0.3 both without cap on TAC variation and with a 15% cap on variations. We looked at the observed F (the basis for the decision), the true landings, the true F (given the true landings) for the first 10 iterations and we compared this to the percentile distribution of the true landings of all 1000 iterations. Both scenario's were based on biomass tresholds of 160 000 t (B_{lim}) and 230 000 t (B_{trig}). The scenario without TAC constraint gave very high variations in true landings. This was caused by the observed F which often jumped from very low to very high values on the basis of an uncertain stock status which could re-estimate the size with a 30% error. The individual trajectories of true landings are much more varying than would be implied by the percentile distributions over all iterations. The scenario with a 15% cap on TAC variation appeared to be behave much better, because it would not allow the F to jump up and down given that the TAC could not vary by more than 15%. Thus the 15% cap could act as a useful method to dampen the noise in the assessment process.

The simulations are based on an F_{sq} assumption fro the current year (2004). From this assumption, a catch (both landings and discards) is derived. This is also used as a basis for the application of the cap on TAC variations. Therefore, the initial reductions in TACs in the intial years of the simulation can be somewhat biased as the status quo catch forecast for 2004 is substantially higher than the agreed TAC. However at present this is a limitation in STPR3 which could not be remedied during the meeting.

The results of the simulations are sensitive to the assumptions within the model. The uncertainty in stock status and the uncertainty in the stock-recruitment relationship are directly reflected in, for example, the risk to B_{lim}. A higher uncertainty in the assessed stock status will mean that more often "wrong" decisions will be derived from the "assessment" thus giving rise to higher chances of depletion of the stock. If the recruitment at a given stock size is lower than expected, than the derived yield may be too high, which again could give rise to a higher risk to B_{lim}. In general these sensitivities mainly operate at higher fishing mortalities; strategies which aim at lower fishing mortalities appear to be less sensitive to the model uncertainty.

4.6 Conclusions

If the objective is to obtain a high long term yield in combination with a low risk to B_{lim}, the preferred level of human consumption fishing mortality could be in the area of F_t =0.2 to F_t =0.3 (Figure 4.4). At F_t =0.2, the expected landings in the final years of the simulation are around 125 000 t, while the short term landings are expected to be around 60 000 t. A major improvement to the stock development and to the landings is expected if an additional (i.e. more than proportional) reduction of discard mortality could be achieved. A cap on annual TAC variations is expected to improve the performance both in terms of minimising short term landings variation and in terms of making the system less sensitive to the noise in annual assessments. At a F_t in the range of 0.2 to 0.3 the likelihood of meeting objectives and performance criteria is relatively insensitive to assumption regarding stock productivity and assessment error and bias.

A fixed TAC regime with TAC_f below 80 000t is expected to produce the same results in terms of maintaining stock status above the trigger biomass but will result in considerably lower average landings in the longer term.

In the simulations with low fishing mortalities, the absolute stock sizes come out rather high and well outside of the historically observed ranges. It is unknown whether such high stock sizes can actually be achieved given the constraints within the natural system and what effects it would have on growth rates and reproduction. However, the results of the simulations in terms of risk to B_{lim} and expected landings are conditional on these large stock sizes.

4.7 Summary presented in response to request

The starting population for the simulations on North Sea plaice was taken from the last ICES assessment made in 2004 (ICES CM 2005/ACFM:07) which included simulated discards (1957–1998) and estimated discards (1999–2003). The exploitation pattern used is thus based on assessments including landings and discards.

In relation to the joint request, the evaluations of harvest control rules for plaice have demonstrated, under the assumption of the current exploitation pattern, that target fishing mortalities (covering all catches) in the range 0.3–0.4 (ages 2–6) result in a low risk to reproduction and high long-term yields. The performance of a long-term management plan with target Fs below 0.4 is not sensitive to choices of $\mathbf{B}_{trig}$. A major improvement to the stock development and to the landings is expected if an additional (i.e. more than proportional) reduction of juvenile mortality could be achieved, in which case the target mortality could be reconsidered. A constraint on annual TAC variations is expected to improve the performance both in terms of minimising short-term landings variation and in terms of making the system less sensitive to the noise in annual assessments. For $\mathbf{F}_t$ in the range of 0.3 to 0.4, the likelihood of meeting objectives and performance criteria is relatively insensitive to assumptions regarding stock productivity and assessment error and bias.

A fixed TAC regime with TAC below 80 000 t is expected to produce the same results in terms of low risk to reproduction, but will result in considerably lower average landings in the longer term.

The simulations investigated have neither taken biological interactions nor density dependent growth/maturity into account and are thus merely indicative of the direction of outcomes from the management strategies prescribed in the joint request. However, the conclusions regarding the general direction required are not sensitive to density-dependent effects – i.e. significant reductions in fishing mortality to achieve simultaneously a low risk to reproduction and high long-term yield. It is therefore suggested that an implementation of long-term management plans is based on an adaptive approach whereby the development of the stock is monitored as the effects of the reduced fishing mortality are developing, and the specific numerical values within the management plan may then be modified on the basis of the outcome of the fishing mortality reductions.

Table 4.1 North Sea plaice. Natural mortality and Selection at age (fleet1 = human consumption, fleet2=discards) (ple.adt)

	0	0	
1	0.1	0.001	0.170
2	0.1	0.039	0.774
3	0.1	0.346	0.377
4	0.1	0.559	0.156
5	0.1	0.606	0.089
6	0.1	0.576	0.007
7	0.1	0.616	0.027
8	0.1	0.475	0.000
9	0.1	0.275	0.000
10	0.1	0.275	0.000

Table 4.2 North Sea plaice. Initial population size and variance coefficients (ple.nin)

1	906483	0.53	0	0	0	0	0	0	0	0	0
2	522118	0	0.36	0	0	0	0	0	0	0	0
3	665186	0	0	0.23	0	0	0	0	0	0	0
4	89541	0	0	0	0.2	0	0	0	0	0	0
5	57003	0	0	0	0	0.17	0	0	0	0	0
6	29463	0	0	0	0	0	0.17	0	0	0	0
7	19460	0	0	0	0	0	0	0.16	0	0	0
8	18793	0	0	0	0	0	0	0	0.19	0	0
9	2514	0	0	0	0	0	0	0	0	0.2	0
10	4532	0	0	0	0	0	0	0	0	0	0.19

Table 4.3 North Sea plaice. Proportion mature (ple.prm)

1957	0	0.5	0.5	1	1	1	1	1	1	1
1958	0	0.5	0.5	1	1	1	1	1	1	1
1959	0	0.5	0.5	1	1	1	1	1	1	1
1960	0	0.5	0.5	1	1	1	1	1	1	1
1961	0	0.5	0.5	1	1	1	1	1	1	1
1962	0	0.5	0.5	1	1	1	1	1	1	1
1963	0	0.5	0.5	1	1	1	1	1	1	1
1964	0	0.5	0.5	1	1	1	1	1	1	1
1965	0	0.5	0.5	1	1	1	1	1	1	1
1966	0	0.5	0.5	1	1	1	1	1	1	1
1967	0	0.5	0.5	1	1	1	1	1	1	1
1968	0	0.5	0.5	1	1	1	1	1	1	1
1969	0	0.5	0.5	1	1	1	1	1	1	1
1970	0	0.5	0.5	1	1	1	1	1	1	1
1971	0	0.5	0.5	1	1	1	1	1	1	1
1972	0	0.5	0.5	1	1	1	1	1	1	1
1973	0	0.5	0.5	1	1	1	1	1	1	1
1974	0	0.5	0.5	1	1	1	1	1	1	1
1975	0	0.5	0.5	1	1	1	1	1	1	1
1976	0	0.5	0.5	1	1	1	1	1	1	1
1977	0	0.5	0.5	1	1	1	1	1	1	1
1978	0	0.5	0.5	1	1	1	1	1	1	1
1979	0	0.5	0.5	1	1	1	1	1	1	1
1980	0	0.5	0.5	1	1	1	1	1	1	1
1981	0	0.5	0.5	1	1	1	1	1	1	1
1982	0	0.5	0.5	1	1	1	1	1	1	1
1983	0	0.5	0.5	1	1	1	1	1	1	1
1984	0	0.5	0.5	1	1	1	1	1	1	1
1985	0	0.5	0.5	1	1	1	1	1	1	1
1986	0	0.5	0.5	1	1	1	1	1	1	1
1987	0	0.5	0.5	1	1	1	1	1	1	1
1988	0	0.5	0.5	1	1	1	1	1	1	1
1989	0	0.5	0.5	1	1	1	1	1	1	1
1990	0	0.5	0.5	1	1	1	1	1	1	1
1991	0	0.5	0.5	1	1	1	1	1	1	1
1992	0	0.5	0.5	1	1	1	1	1	1	1
1993	0	0.5	0.5	1	1	1	1	1	1	1
1994	0	0.5	0.5	1	1	1	1	1	1	1
1995	0	0.5	0.5	1	1	1	1	1	1	1
1996	0	0.5	0.5	1	1	1	1	1	1	1
1997	0	0.5	0.5	1	1	1	1	1	1	1
1998	0	0.5	0.5	1	1	1	1	1	1	1
1999	0	0.5	0.5	1	1	1	1	1	1	1
2000	0	0.5	0.5	1	1	1	1	1	1	1
2001	0	0.5	0.5	1	1	1	1	1	1	1
2002	0	0.5	0.5	1	1	1	1	1	1	1
2003	0	0.5	0.5	1	1	1	1	1	1	1

Table 4.4 North Sea plaice. Weight in the catch by fleet (fleet 1 = human consumption, fleet 2 = discards) (ple.wc)

1957	1	0.00	0.17	0.20	0.26	0.35	0.46	0.53	0.59	0.40	1.00
1958	1	0.00	0.20	0.22	0.26	0.34	0.45	0.51	0.62	0.67	0.99
1959	1	0.00	0.22	0.25	0.29	0.36	0.47	0.59	0.62	0.75	1.00
1960	1	0.00	0.20	0.24	0.29	0.39	0.49	0.60	0.68	0.72	1.09
1961	1	0.00	0.19	0.23	0.30	0.41	0.51	0.60	0.67	0.81	1.07
1962	1	0.00	0.21	0.25	0.30	0.40	0.54	0.57	0.69	0.78	1.13
1963	1	0.00	0.25	0.29	0.32	0.40	0.53	0.62	0.67	0.72	1.03
1964	1	0.00	0.25	0.27	0.31	0.39	0.49	0.63	0.70	0.74	1.00
1965	1	0.00	0.24	0.28	0.32	0.39	0.47	0.54	0.66	0.73	0.89
1966	1	0.00	0.23	0.27	0.35	0.44	0.48	0.56	0.62	0.69	0.93
1967	1	0.00	0.23	0.28	0.32	0.43	0.55	0.60	0.66	0.74	0.98
1968	1	0.00	0.27	0.30	0.33	0.37	0.52	0.59	0.60	0.69	0.91
1969	1	0.22	0.29	0.31	0.33	0.36	0.41	0.57	0.66	0.66	0.89
1970	1	0.32	0.29	0.32	0.36	0.42	0.44	0.50	0.67	0.74	0.89
1971	1	0.26	0.32	0.36	0.40	0.45	0.51	0.54	0.61	0.70	0.89
1972	1	0.25	0.30	0.35	0.43	0.49	0.54	0.61	0.65	0.67	0.94
1973	1	0.27	0.32	0.34	0.41	0.49	0.54	0.61	0.63	0.68	0.84
1974	1	0.29	0.31	0.35	0.41	0.48	0.55	0.61	0.69	0.71	0.93
1975	1	0.25	0.30	0.33	0.42	0.50	0.59	0.64	0.70	0.78	1.02
1976	1	0.27	0.30	0.34	0.38	0.51	0.59	0.64	0.71	0.74	0.98
1977	1	0.25	0.32	0.35	0.38	0.42	0.56	0.65	0.72	0.72	0.98
1978	1	0.24	0.32	0.37	0.40	0.44	0.49	0.61	0.69	0.78	0.95
1979	1	0.24	0.31	0.35	0.39	0.43	0.47	0.55	0.68	0.80	0.96
1980	1	0.24	0.29	0.34	0.40	0.47	0.55	0.59	0.66	0.77	1.01
1981	1	0.24	0.27	0.33	0.42	0.51	0.56	0.60	0.64	0.73	1.01
1982	1	0.28	0.26	0.31	0.42	0.51	0.61	0.66	0.71	0.74	0.98
1983	1	0.20	0.25	0.30	0.38	0.52	0.60	0.68	0.77	0.82	0.98
1984	1	0.23	0.26	0.28	0.38	0.49	0.61	0.68	0.73	0.84	1.03
1985	1	0.25	0.26	0.29	0.34	0.46	0.58	0.68	0.73	0.80	1.02
1986	1	0.22	0.27	0.30	0.35	0.43	0.49	0.68	0.75	0.85	1.01
1987	1	0.22	0.25	0.30	0.35	0.40	0.50	0.58	0.73	0.83	0.99
1988	1	0.22	0.25	0.28	0.35	0.45	0.51	0.61	0.70	0.81	1.01
1989	1	0.24	0.28	0.31	0.33	0.39	0.53	0.60	0.67	0.79	0.94
1990	1	0.27	0.29	0.30	0.32	0.37	0.45	0.60	0.69	0.76	1.00
1991	1	0.23	0.29	0.29	0.31	0.37	0.46	0.53	0.67	0.75	0.92
1992	1	0.25	0.26	0.29	0.32	0.34	0.43	0.53	0.61	0.72	0.89
1993	1	0.25	0.27	0.29	0.33	0.36	0.42	0.52	0.63	0.72	0.86
1994	1	0.23	0.26	0.29	0.34	0.40	0.45	0.50	0.61	0.73	0.91
1995	1	0.27	0.28	0.30	0.34	0.40	0.45	0.53	0.61	0.73	0.91
1996	1	0.24	0.28	0.31	0.36	0.42	0.49	0.50	0.59	0.72	0.86
1997	1	0.21	0.27	0.31	0.36	0.46	0.52	0.60	0.62	0.68	0.92
1998	1	0.15	0.26	0.31	0.39	0.50	0.61	0.63	0.70	0.70	0.91
1999	1	0.25	0.25	0.28	0.36	0.46	0.55	0.63	0.68	0.75	0.81
2000	1	0.23	0.27	0.28	0.31	0.43	0.50	0.68	0.71	0.75	0.89
2001	1	0.24	0.27	0.29	0.31	0.37	0.48	0.59	0.71	0.80	0.80
2002	1	0.24	0.26	0.29	0.32	0.35	0.45	0.51	0.69	0.76	0.90
2003	1	0.23	0.25	0.29	0.33	0.37	0.41	0.49	0.65	0.77	0.85
1957	2	0.05	0.10	0.15	0.18	0.20	0.23	0.24	0.23	0.00	0.00
1958	2	0.05	0.09	0.16	0.19	0.20	0.24	0.24	0.24	0.00	0.00
1959	2	0.05	0.11	0.16	0.18	0.19	0.23	0.00	0.00	0.00	0.00

1960	2	0.05	0.11	0.16	0.19	0.20	0.21	0.23	0.00	0.00	0.00
1961	2	0.05	0.10	0.16	0.19	0.20	0.21	0.21	0.24	0.00	0.00
1962	2	0.04	0.10	0.16	0.19	0.21	0.22	0.22	0.22	0.00	0.00
1963	2	0.05	0.10	0.16	0.19	0.20	0.23	0.22	0.23	0.00	0.00
1964	2	0.03	0.11	0.16	0.19	0.20	0.22	0.23	0.23	0.00	0.00
1965	2	0.04	0.07	0.17	0.19	0.20	0.22	0.22	0.24	0.00	0.00
1966	2	0.04	0.10	0.13	0.19	0.20	0.23	0.22	0.23	0.00	0.00
1967	2	0.04	0.10	0.16	0.17	0.21	0.21	0.23	0.23	0.00	0.00
1968	2	0.06	0.09	0.16	0.19	0.19	0.24	0.21	0.24	0.00	0.00
1969	2	0.06	0.14	0.16	0.18	0.20	0.21	0.24	0.22	0.00	0.00
1970	2	0.06	0.11	0.18	0.19	0.19	0.24	0.21	0.23	0.00	0.00
1971	2	0.06	0.11	0.18	0.20	0.21	0.00	0.00	0.23	0.00	0.00
1972	2	0.06	0.14	0.17	0.20	0.20	0.24	0.00	0.00	0.00	0.00
1973	2	0.05	0.13	0.18	0.19	0.20	0.23	0.24	0.00	0.00	0.00
1974	2	0.06	0.10	0.17	0.21	0.21	0.23	0.24	0.00	0.00	0.00
1975	2	0.07	0.13	0.16	0.20	0.22	0.24	0.23	0.00	0.00	0.00
1976	2	0.09	0.15	0.18	0.19	0.22	0.24	0.24	0.24	0.00	0.00
1977	2	0.07	0.16	0.19	0.19	0.20	0.21	0.00	0.00	0.00	0.00
1978	2	0.07	0.14	0.20	0.20	0.20	0.21	0.22	0.00	0.00	0.00
1979	2	0.07	0.15	0.18	0.20	0.22	0.23	0.22	0.23	0.00	0.00
1980	2	0.06	0.15	0.19	0.21	0.22	0.24	0.24	0.00	0.00	0.00
1981	2	0.05	0.13	0.18	0.21	0.22	0.24	0.00	0.00	0.00	0.00
1982	2	0.06	0.12	0.18	0.20	0.23	0.23	0.24	0.00	0.00	0.00
1983	2	0.05	0.12	0.18	0.20	0.20	0.24	0.24	0.00	0.00	0.00
1984	2	0.06	0.12	0.17	0.21	0.20	0.00	0.24	0.00	0.00	0.00
1985	2	0.06	0.14	0.18	0.19	0.23	0.24	0.00	0.00	0.00	0.00
1986	2	0.05	0.12	0.18	0.19	0.21	0.24	0.23	0.00	0.00	0.00
1987	2	0.04	0.10	0.17	0.20	0.21	0.23	0.00	0.00	0.00	0.00
1988	2	0.05	0.10	0.15	0.18	0.21	0.23	0.00	0.00	0.00	0.00
1989	2	0.05	0.10	0.16	0.18	0.19	0.24	0.24	0.00	0.00	0.00
1990	2	0.05	0.11	0.16	0.18	0.20	0.23	0.00	0.00	0.00	0.00
1991	2	0.06	0.13	0.16	0.18	0.20	0.22	0.22	0.22	0.00	0.00
1992	2	0.06	0.12	0.17	0.19	0.20	0.21	0.22	0.23	0.00	0.00
1993	2	0.06	0.12	0.17	0.20	0.20	0.23	0.23	0.24	0.00	0.00
1994	2	0.06	0.14	0.18	0.19	0.21	0.23	0.24	0.22	0.00	0.00
1995	2	0.06	0.14	0.19	0.20	0.21	0.23	0.23	0.24	0.00	0.00
1996	2	0.05	0.12	0.18	0.20	0.22	0.23	0.00	0.24	0.00	0.00
1997	2	0.04	0.12	0.16	0.20	0.22	0.24	0.00	0.00	0.00	0.00
1998	2	0.05	0.09	0.17	0.20	0.21	0.00	0.24	0.00	0.00	0.00
1999	2	0.05	0.10	0.14	0.19	0.21	0.24	0.00	0.00	0.00	0.00
2000	2	0.06	0.11	0.15	0.17	0.23	0.00	0.20	0.00	0.00	0.00
2001	2	0.07	0.12	0.17	0.18	0.19	0.23	0.00	0.23	0.00	0.00
2002	2	0.06	0.12	0.17	0.19	0.20	0.21	0.00	0.00	0.00	0.00
2003	2	0.07	0.11	0.17	0.18	0.20	0.20	0.22	0.18	0.00	0.00

Table 4.5 North Sea plaice. Weight in the stock (ple.ws)

1957	0.04	0.10	0.16	0.25	0.33	0.49	0.72	0.68	0.84	1.14
1958	0.04	0.09	0.19	0.28	0.30	0.44	0.58	0.78	0.79	1.11
1959	0.05	0.10	0.18	0.27	0.33	0.47	0.65	0.69	0.91	1.04
1960	0.04	0.11	0.19	0.28	0.36	0.47	0.63	0.73	0.85	1.09
1961	0.04	0.10	0.19	0.31	0.34	0.48	0.58	0.69	0.78	1.07
1962	0.04	0.09	0.18	0.31	0.42	0.57	0.68	0.81	0.87	1.30
1963	0.04	0.10	0.18	0.28	0.38	0.54	0.66	0.79	0.88	1.25
1964	0.03	0.11	0.19	0.30	0.37	0.48	0.65	0.67	0.85	1.23
1965	0.03	0.07	0.20	0.30	0.33	0.43	0.52	0.60	0.72	0.91
1966	0.03	0.10	0.13	0.31	0.40	0.46	0.50	0.57	0.58	0.98
1967	0.03	0.10	0.18	0.21	0.44	0.53	0.59	0.65	0.70	0.98
1968	0.06	0.09	0.18	0.29	0.34	0.53	0.59	0.36	0.67	0.89
1969	0.05	0.15	0.19	0.27	0.34	0.39	0.57	0.62	0.68	0.86
1970	0.05	0.11	0.25	0.28	0.37	0.41	0.47	0.64	0.73	0.90
1971	0.05	0.11	0.26	0.35	0.41	0.49	0.51	0.58	0.70	0.88
1972	0.06	0.15	0.23	0.41	0.47	0.53	0.58	0.61	0.66	0.93
1973	0.04	0.13	0.25	0.32	0.47	0.52	0.57	0.58	0.62	0.80
1974	0.05	0.10	0.23	0.43	0.44	0.52	0.57	0.63	0.65	0.85
1975	0.07	0.14	0.20	0.40	0.48	0.54	0.61	0.67	0.70	0.94
1976	0.08	0.17	0.24	0.31	0.48	0.55	0.59	0.66	0.69	0.93
1977	0.07	0.18	0.28	0.32	0.41	0.55	0.63	0.69	0.67	0.94
1978	0.07	0.15	0.33	0.38	0.41	0.47	0.55	0.63	0.70	0.94
1979	0.06	0.18	0.27	0.37	0.41	0.46	0.54	0.67	0.76	1.00
1980	0.05	0.16	0.30	0.44	0.44	0.52	0.58	0.65	0.78	1.06
1981	0.04	0.14	0.25	0.43	0.47	0.54	0.57	0.62	0.71	1.03
1982	0.05	0.13	0.26	0.36	0.49	0.59	0.63	0.68	0.73	0.98
1983	0.05	0.13	0.25	0.39	0.49	0.56	0.62	0.71	0.75	0.92
1984	0.05	0.13	0.23	0.42	0.46	0.57	0.65	0.69	0.79	1.03
1985	0.05	0.14	0.24	0.33	0.45	0.54	0.64	0.66	0.76	1.01
1986	0.04	0.12	0.25	0.32	0.44	0.53	0.69	0.78	0.89	1.09
1987	0.04	0.10	0.21	0.38	0.40	0.50	0.57	0.71	0.75	0.98
1988	0.04	0.10	0.18	0.27	0.43	0.47	0.55	0.64	0.71	0.97
1989	0.04	0.10	0.20	0.25	0.36	0.48	0.55	0.62	0.76	0.88
1990	0.05	0.11	0.19	0.27	0.34	0.42	0.56	0.65	0.71	0.99
1991	0.05	0.13	0.19	0.27	0.34	0.40	0.46	0.64	0.66	0.85
1992	0.05	0.12	0.21	0.27	0.32	0.40	0.50	0.58	0.70	0.87
1993	0.05	0.12	0.22	0.33	0.33	0.39	0.49	0.60	0.65	0.86
1994	0.05	0.14	0.22	0.30	0.37	0.41	0.47	0.55	0.68	0.87
1995	0.05	0.14	0.26	0.34	0.40	0.45	0.52	0.61	0.71	0.85
1996	0.04	0.12	0.24	0.37	0.39	0.46	0.49	0.57	0.69	0.88
1997	0.03	0.12	0.19	0.37	0.44	0.49	0.56	0.59	0.68	0.90
1998	0.04	0.08	0.21	0.34	0.47	0.58	0.59	0.66	0.68	0.87
1999	0.05	0.09	0.15	0.32	0.44	0.52	0.59	0.68	0.70	0.83
2000	0.05	0.11	0.17	0.22	0.41	0.47	0.69	0.74	0.71	0.90
2001	0.06	0.12	0.21	0.24	0.33	0.45	0.56	0.64	0.80	0.83
2002	0.05	0.12	0.22	0.31	0.34	0.43	0.46	0.65	0.71	0.90
2003	0.06	0.11	0.23	0.27	0.34	0.39	0.46	0.60	0.71	0.79

Table 4.6 North Sea plaice. Example of a simulation option file.

```
        1       10                                                             Ages
        1                                                                      Number of years between spawning and recruitment
        2       6                                                              Mean F range for h.cons.
        2       6                                                              Mean F range for discards
        2004                                                                   The intermediate year
F                                                                              Int. yr.: Constraint type for h.cons. (C = catch, F = mortality)
        0.43                                                                   Int. yr.: Value of constraint for h.cons.
F                                                                              Int. yr: Constraint type for discards (C = catch, F = mortality)
        0.28                                                                   Int. yr.: Value of constraint for discards
        0       0.05    0.065        300000      300000                 HCR 1: lower bound on SSB, max F hc, max F disc, max catch HC, max catch disc
        160000  0.05    0.065        300000      300000                 HCR 2: lower bound on SSB, max F HC, max F disc, max catch HC, max catch disc
        230000  0.2     0.13         300000      300000                 HCR 3: lower bound on SSB, max F HC, max F disc, max catch HC, max catch disc
1                                                                              Linear increase of F in level 2? (0 = no, 1 = yes)
        0       0.15       0                                                      Annual catch variation: max change (both, h.cons., disc)
        0       0.15       0                                                      Annual catch variation: min change (both, h.cons., disc)
        0       0       0                                                      Annual F variation: max change (both, h.cons., disc)
        0       0       0                                                      Annual F variation: min change (both, h.cons., disc)
        0       0                                                              Min increase in SSB, which fleet takes burden (0 = both)
        1.5     1                                                              Max possible F by fleet
        1.5     1                                                              Max permitted F by fleet
        5       1       5.0         430000   1.9     0.4      0.9       Recruitment: Shepherd, lognormal, alpha, beta, gamma, sigma (SD), truncation
        0                                                                      Number of autoregressive terms used
        0       0       0            0        0                                AR terms (from RecAn output for AR(1))
        0                                                                      Apply SR relation in year 0? (0 = no, 1 = yes)
        1       0.3      1                                                     Assessment bias multiplier (mean and SD)
        1       0                                                              TAC deviation multiplier (mean and SD)
        1                                                                      Initial numbers (0: det, 1: log, 2: norm, 3: bootstrap)
```

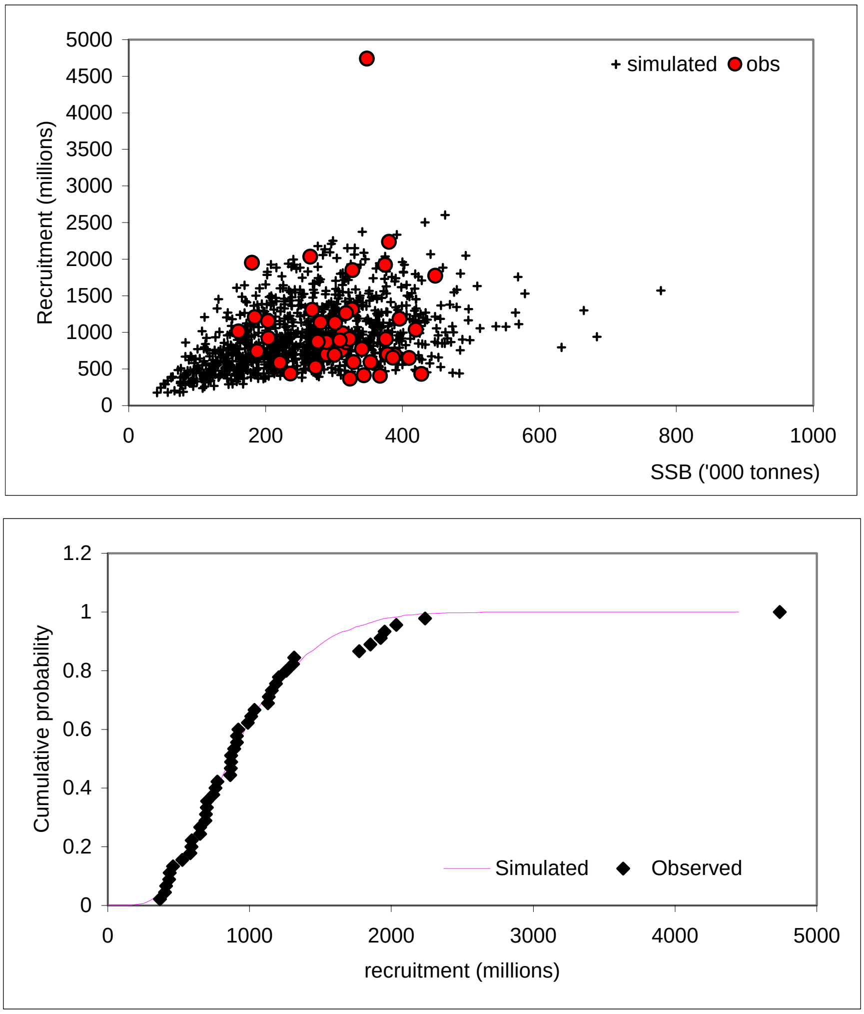


Figure 4.1 North Sea plaice: parameterization of the stock recruitment curve (constrained Shepherd)

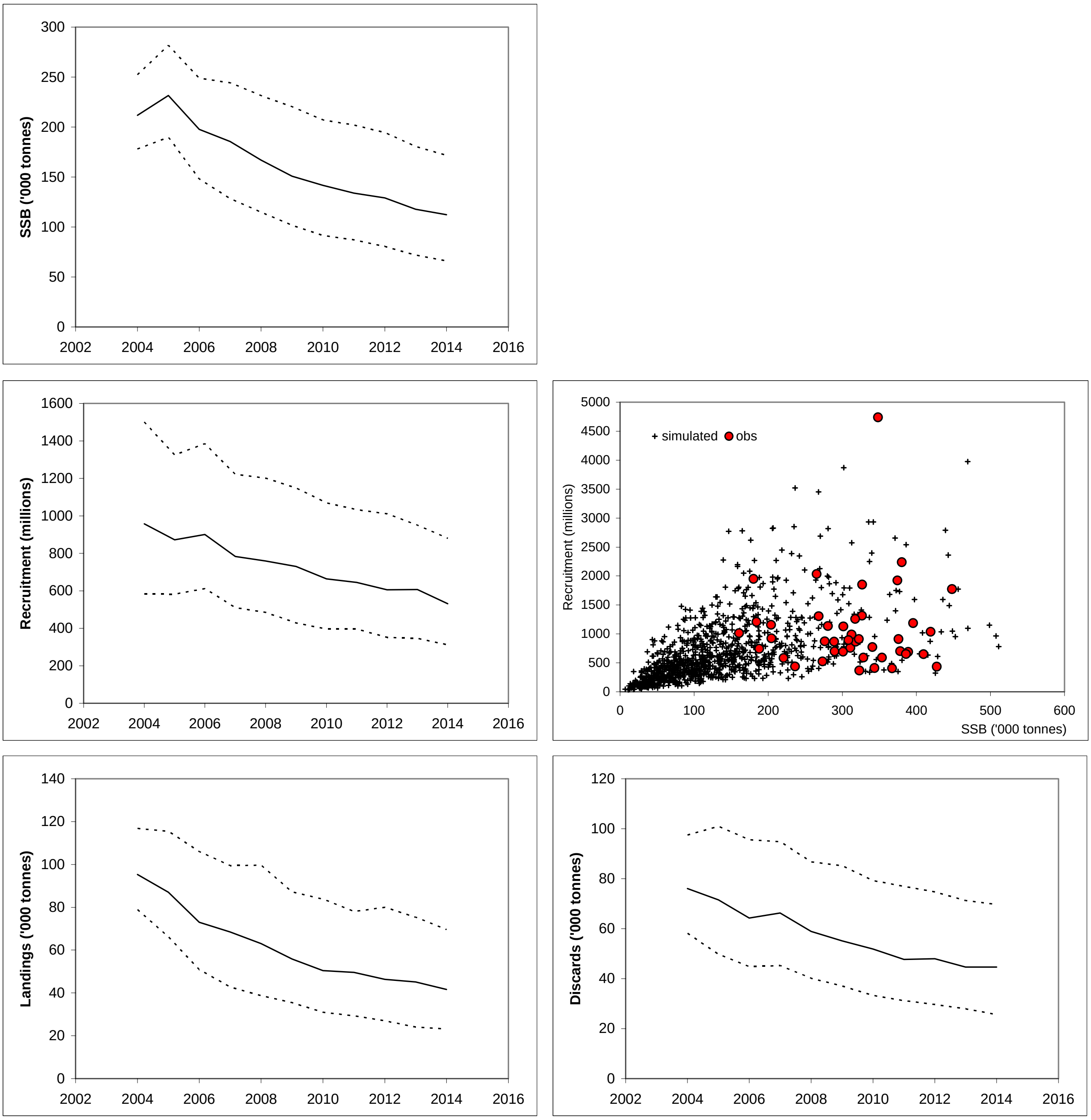


Figure 4.2 North Sea plaice. STPR3 analysis using Fsq for both human consumption (0.43) and discards (0.28). Shepherd stock recruitment relationship (with SD 0.6, truncation 1.4). Solid lines indicate the median of the bootstrapped distributions, the dotted lines the 25th and 75th percentiles. Trends in SSB, recruitment, landings and discards. Relationship between SSB and recruitment in simulations and as observed in most recent stock assessment.

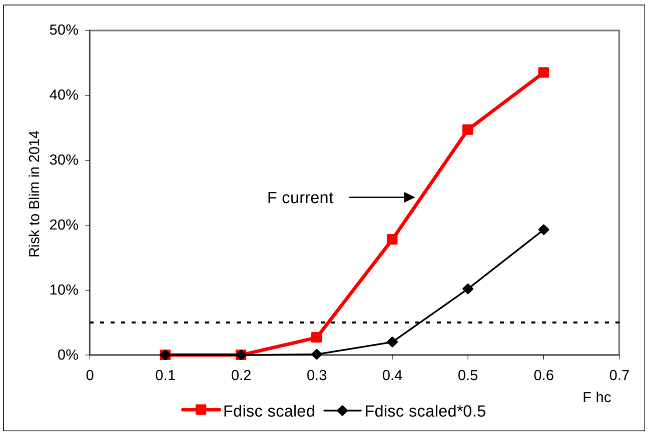


Figure 4.3 North Sea plaice. Risk to Blim in 2014 at different HC F's. Discards F are either scaled with HC F's or divided by two and then scaled with HC F.

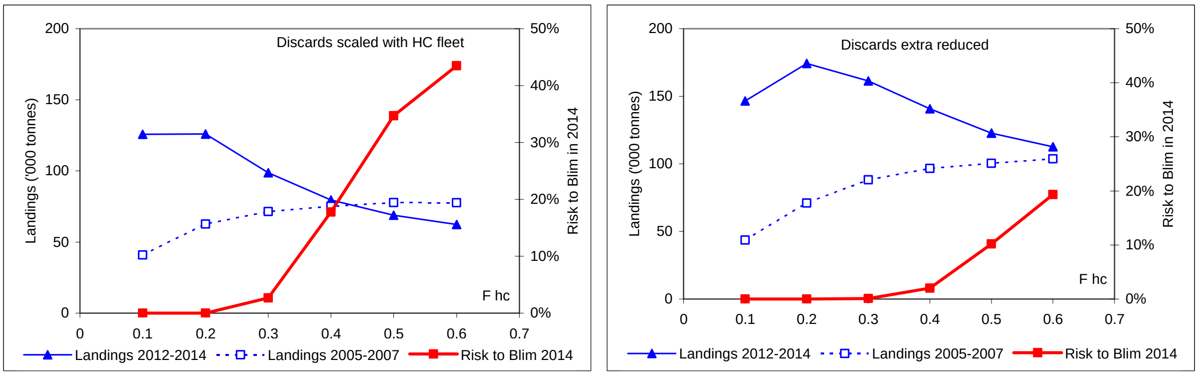


Figure 4.4 North Sea plaice. Trade-off between HC fishing mortality, long term risk to Blim and short term and long term landings. Discards F are either scaled with HC F's or divided by two and then scaled with HC F.

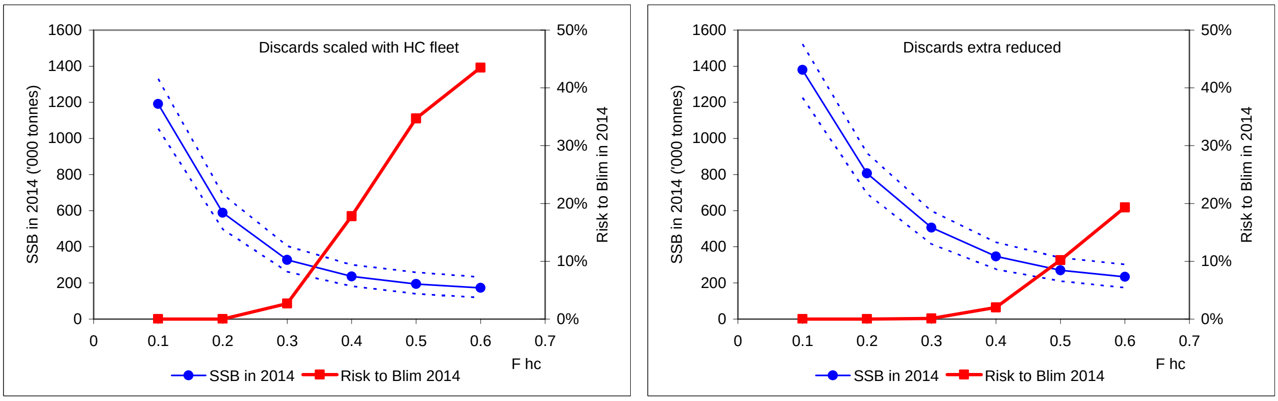


Figure 4.5 North Sea plaice. Trade-off between HC F, SSB in 2014 (including 25th and 75th percentiles) and long term risk to Blim. Discards F are either scaled with HC F's or divided by two and then scaled with HC F.

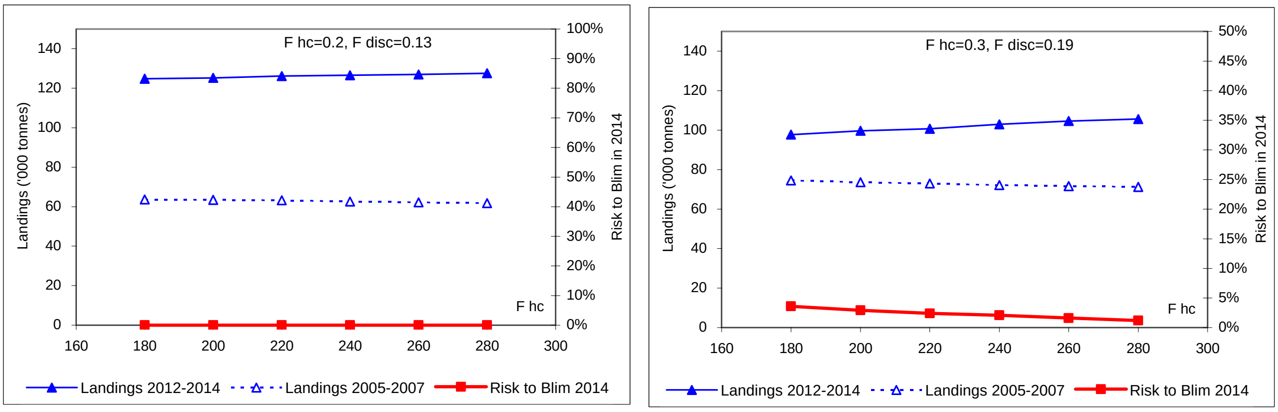


Figure 4.6 North Sea plaice. Trade-off between Btrigger, long term risk to Blim and short term and long term landings. Left: F hc=0.2. Right: F hc=0.3.

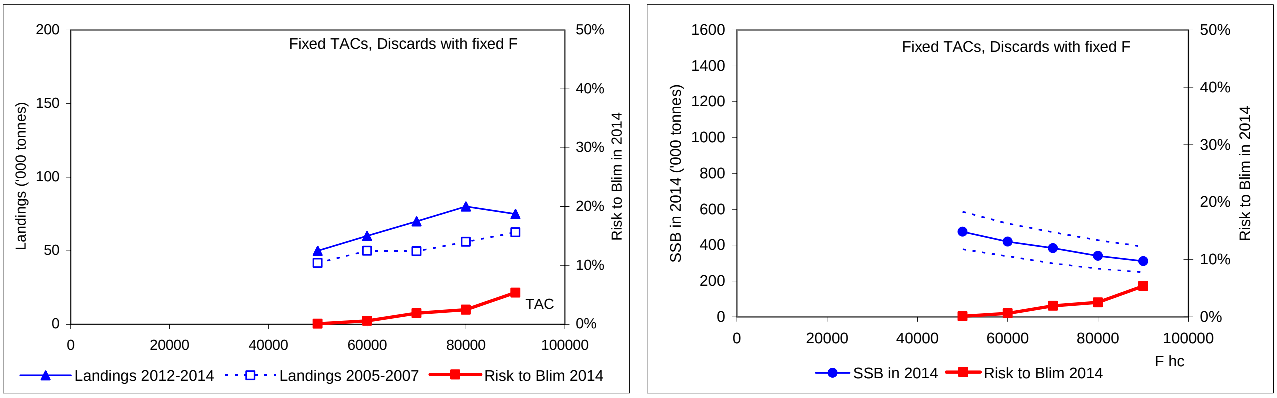


Figure 4.7 North Sea plaice. Left: Trade-off between TACs, long term risk to Blim and short term and long term landings. Right: Trade-off between TAC, SSB in 2014 (including 25th and 75th percentiles) and long term risk to Blim.

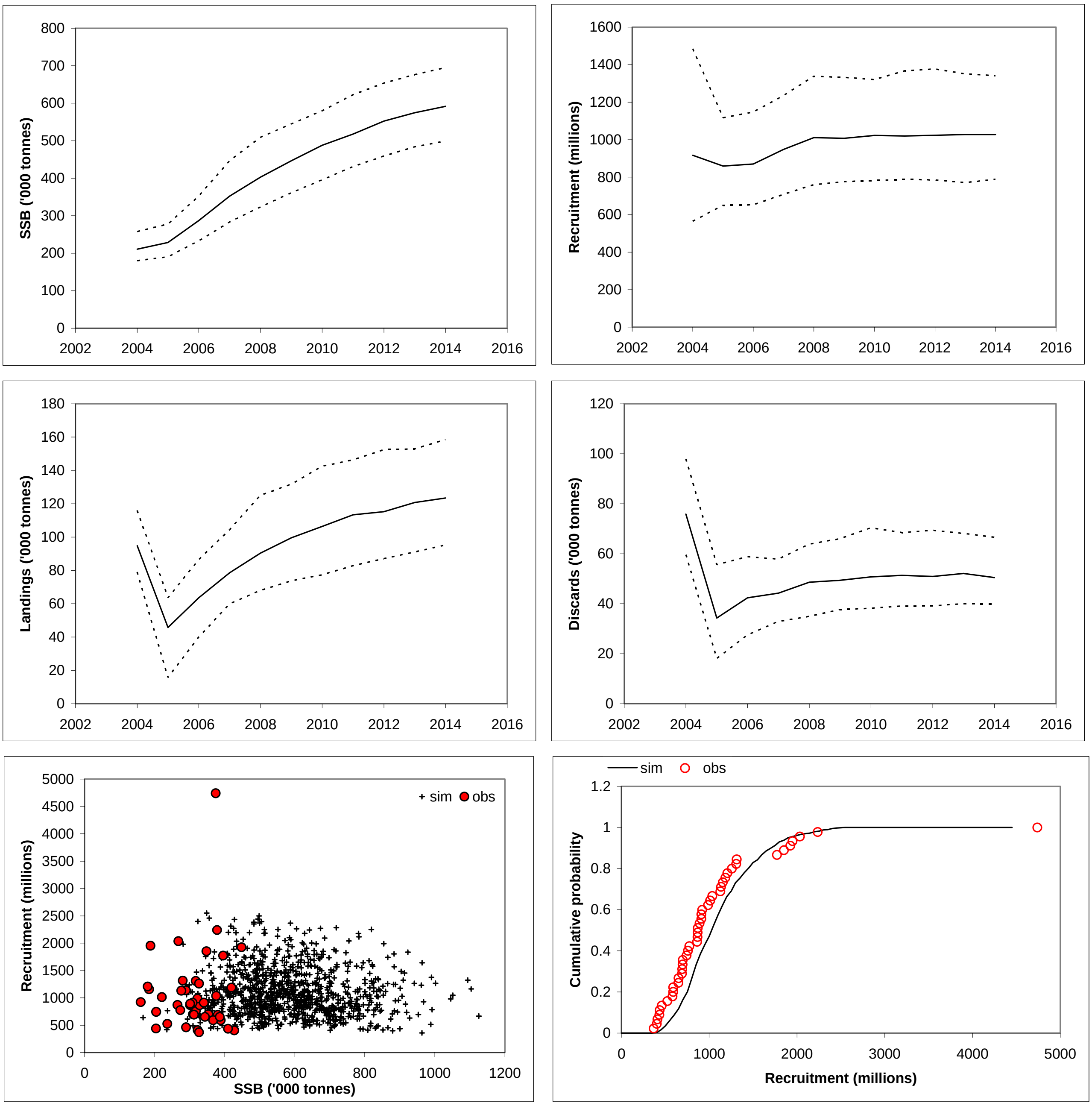


Figure 4.8 North Sea plaice. F hc =0.2, F disc=0.13, No TAC constraint

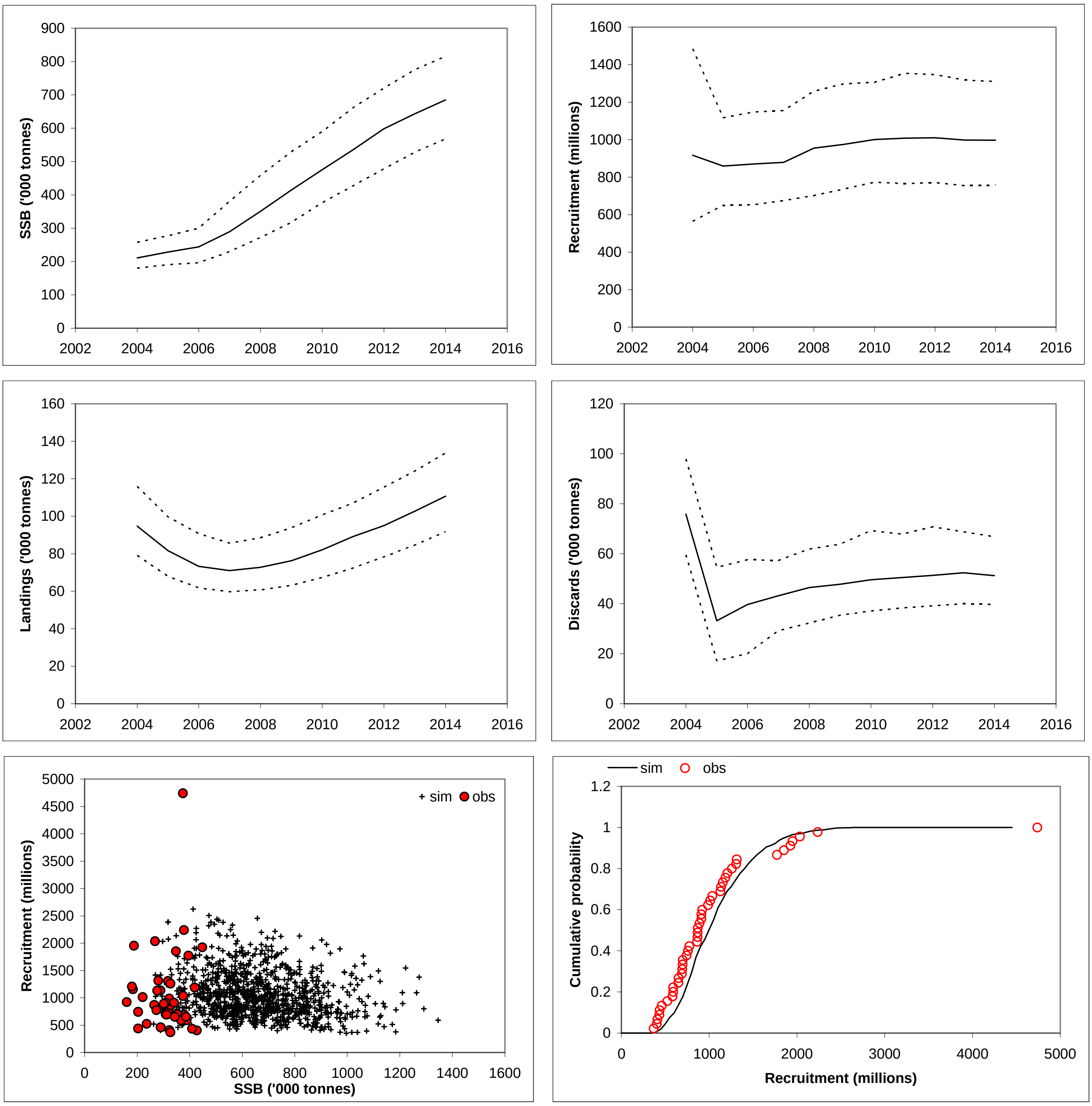


Figure 4.9 North Sea plaice. F hc =0.2, F disc=0.13, 15% TAC constraint

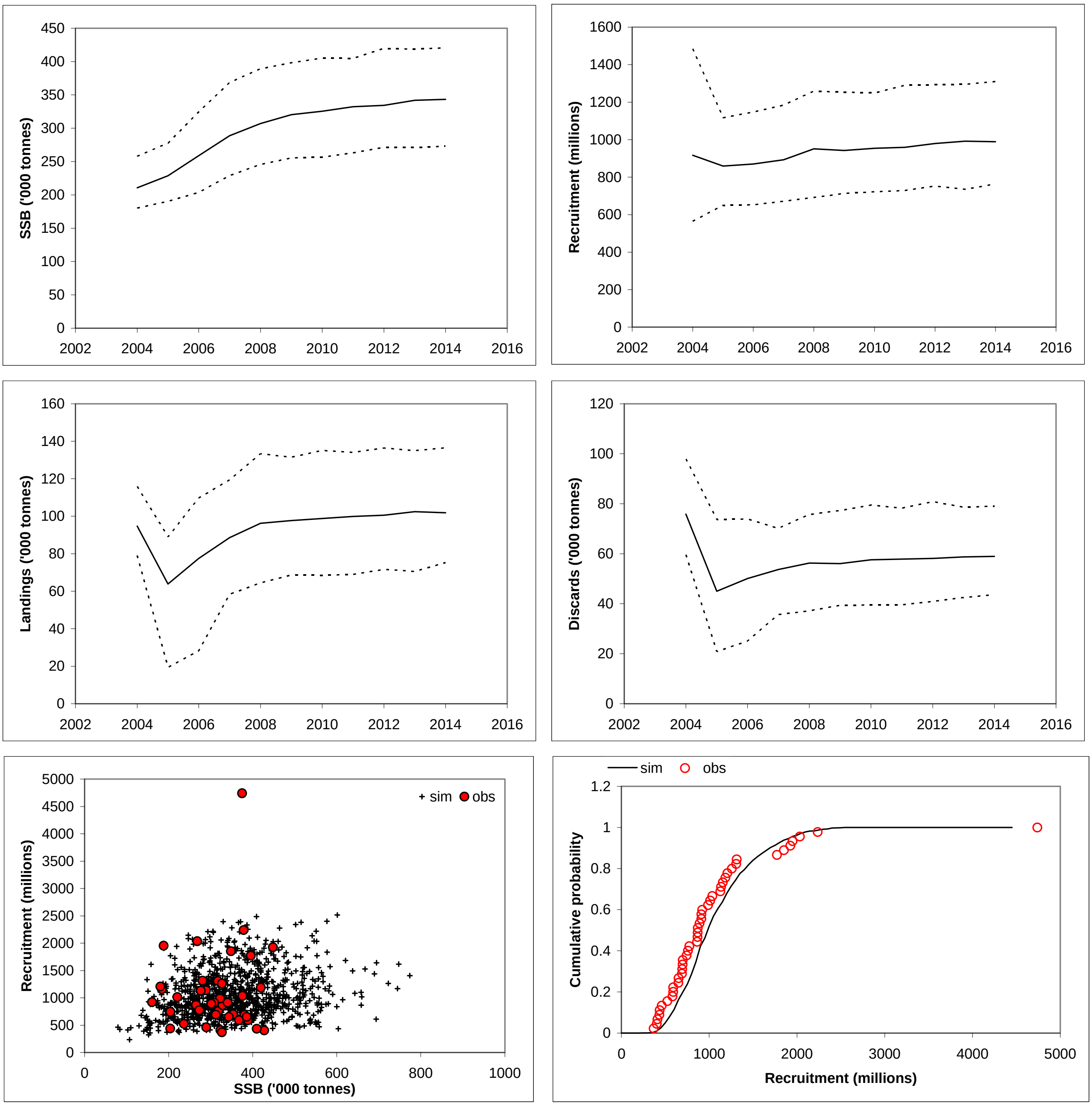


Figure 4.10 North Sea plaice. F hc =0.3, F disc=0.13, No TAC constraint

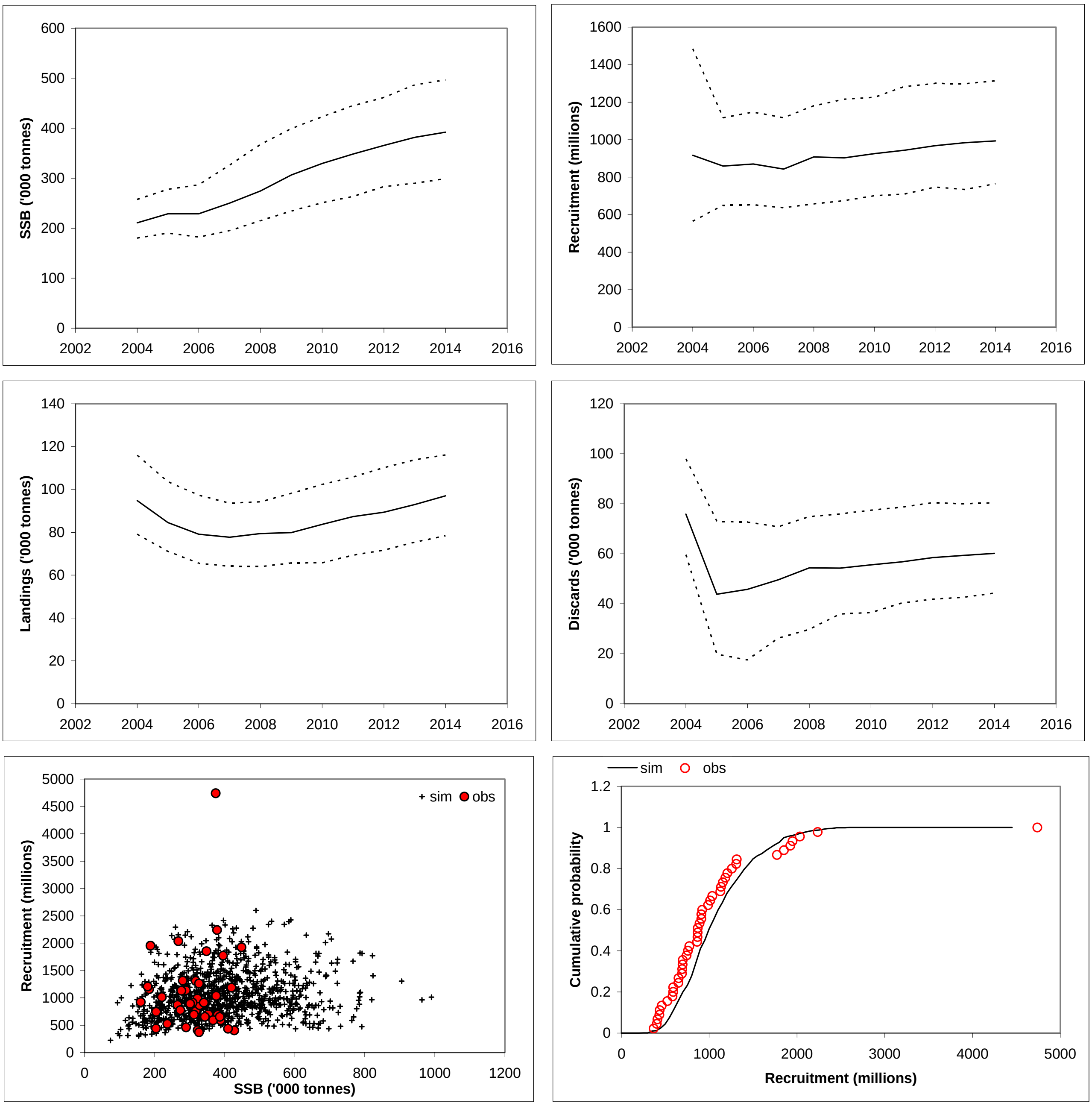


Figure 4.11 North Sea plaice. F hc =0.3, F disc=0.13, 15% TAC constraint

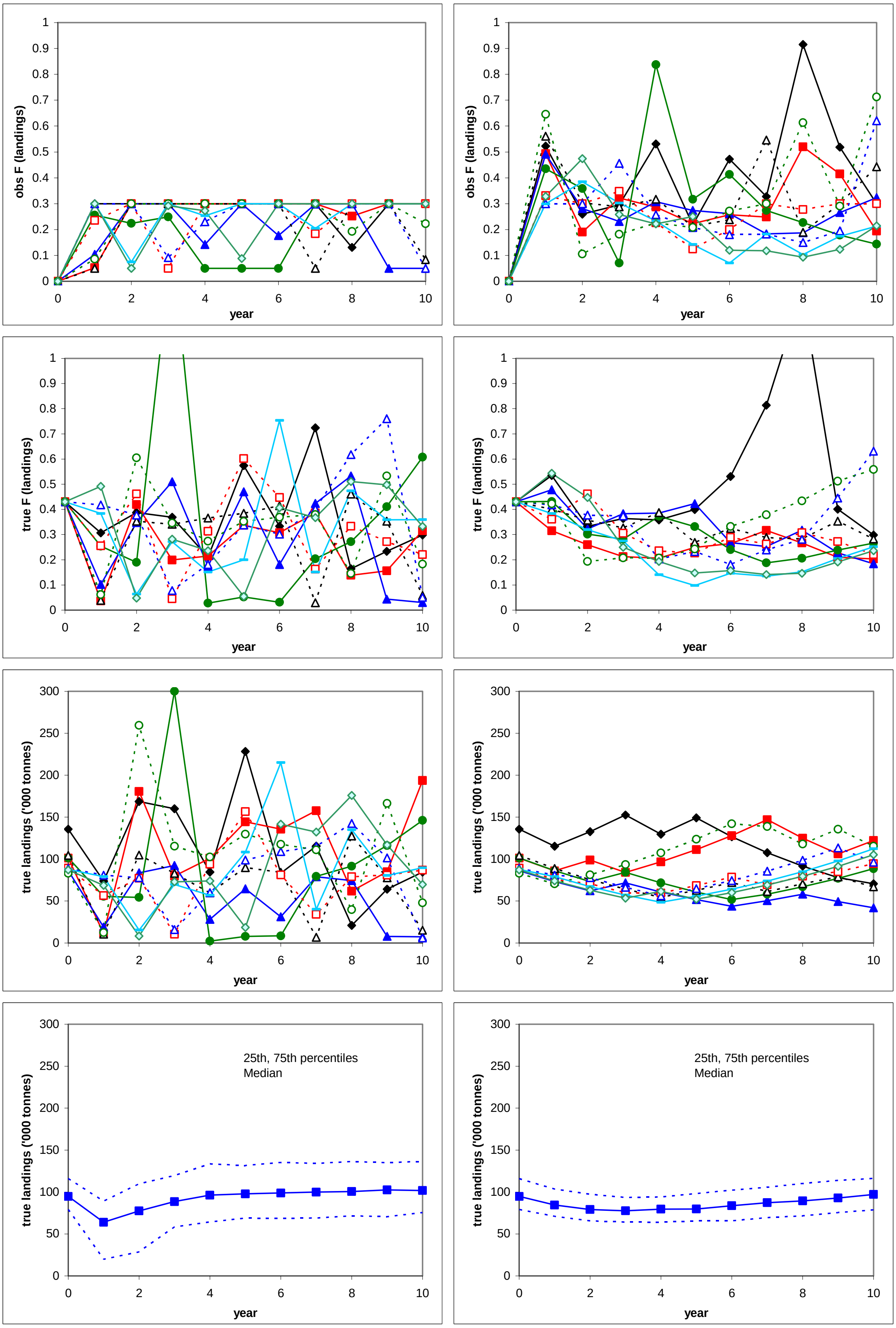


Figure 4.12 North Sea plaice. Left: F hc =0.3, F disc=0.13, No TAC constraint. Right: F hc =0.3, F disc=0.13, 15% TAC constraint. Top three graphs: first 10 iterations in terms of observed F (basis for decision), true F (after taking the catch), true landings (tonnes). Last graph shows the pecentiles over all (1000 iterations).

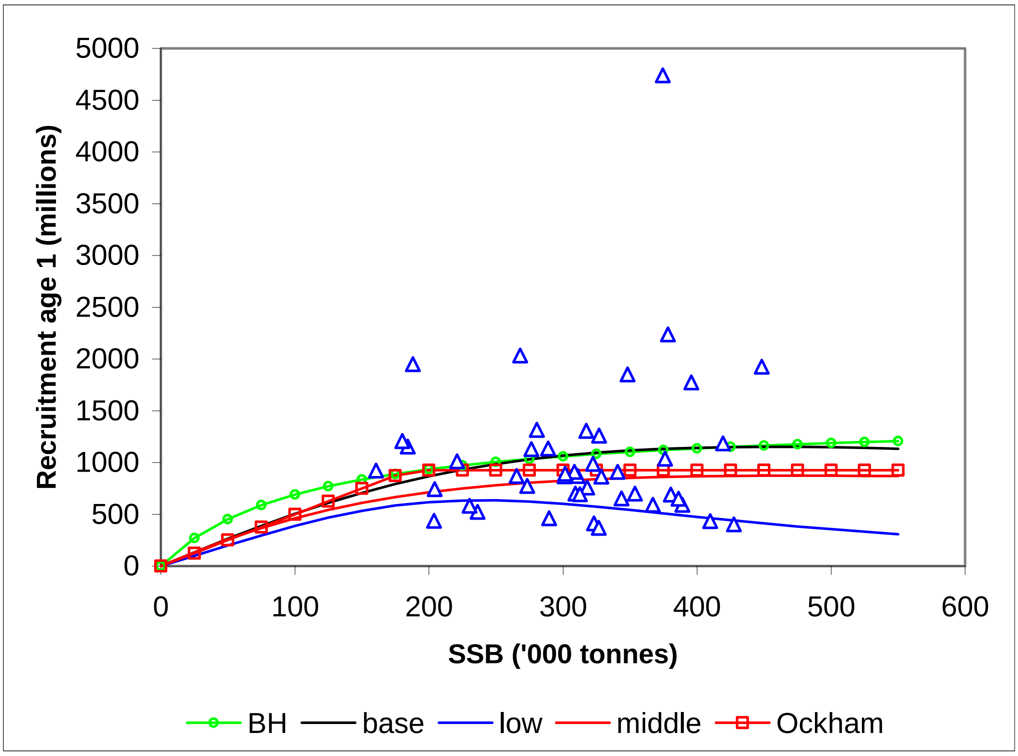


Figure 4.13 North Sea plaice. Different stock recruitment relationships. BH = Beverton-Holt. Base, low and Middle refere to Shepherd stock recruitment relationships with different parameterizations. The Ockham relationship is geometric mean recruitment, plus a linear decline to the origin below the lowest observed SSB. The base shepherd has been used as the base case in subsequent analysis.

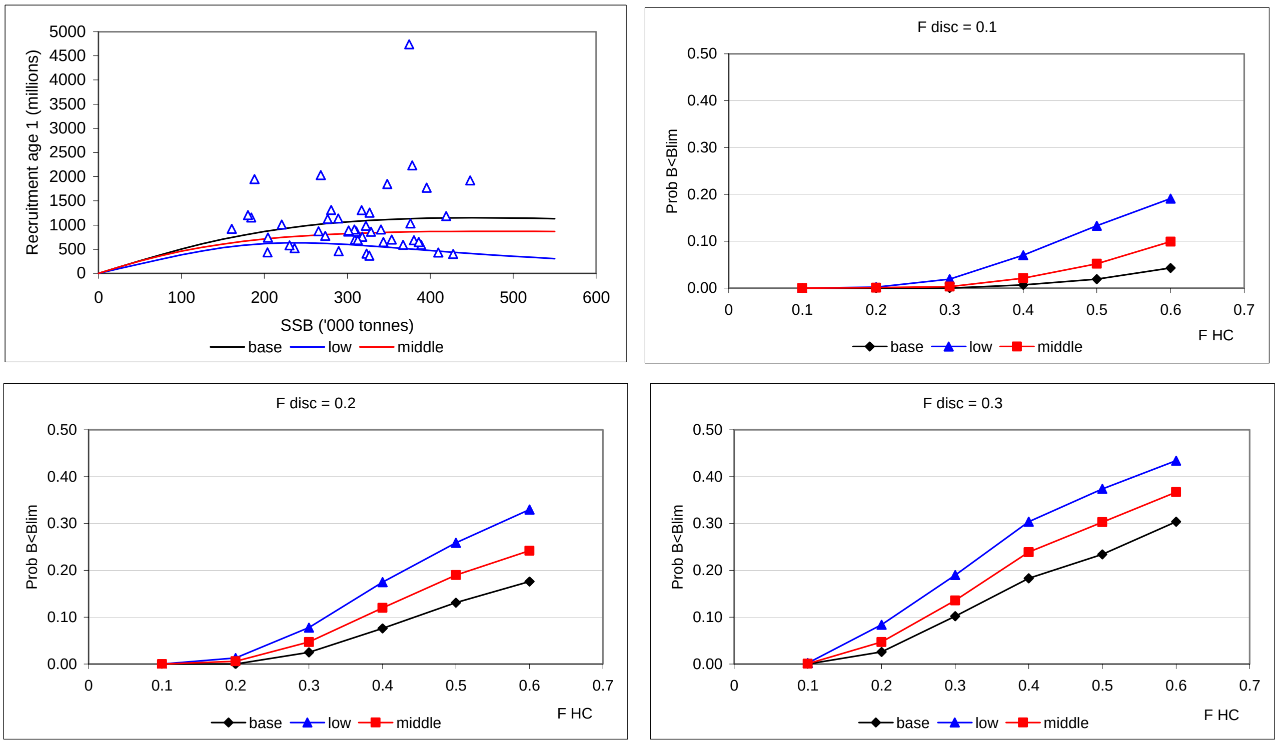


Figure 4.14 North Sea plaice. Sensitivity to the assumed stock recruitment relationship . Variable of interest: probability of being below Blim in 2014. Shepherd stock recruitment relationships (base, middle and low). Different fishing mortalities for HC on the horizontal axis and different fishing mortalities on discards in the different graphs. Top left: Stock recruitment curves. Top right and bottom graphs: probabilities to Blim in 2014 at different discards mortalities and different stock recruitment curves. Note that discards F and HC F are varied independently in this analysis.

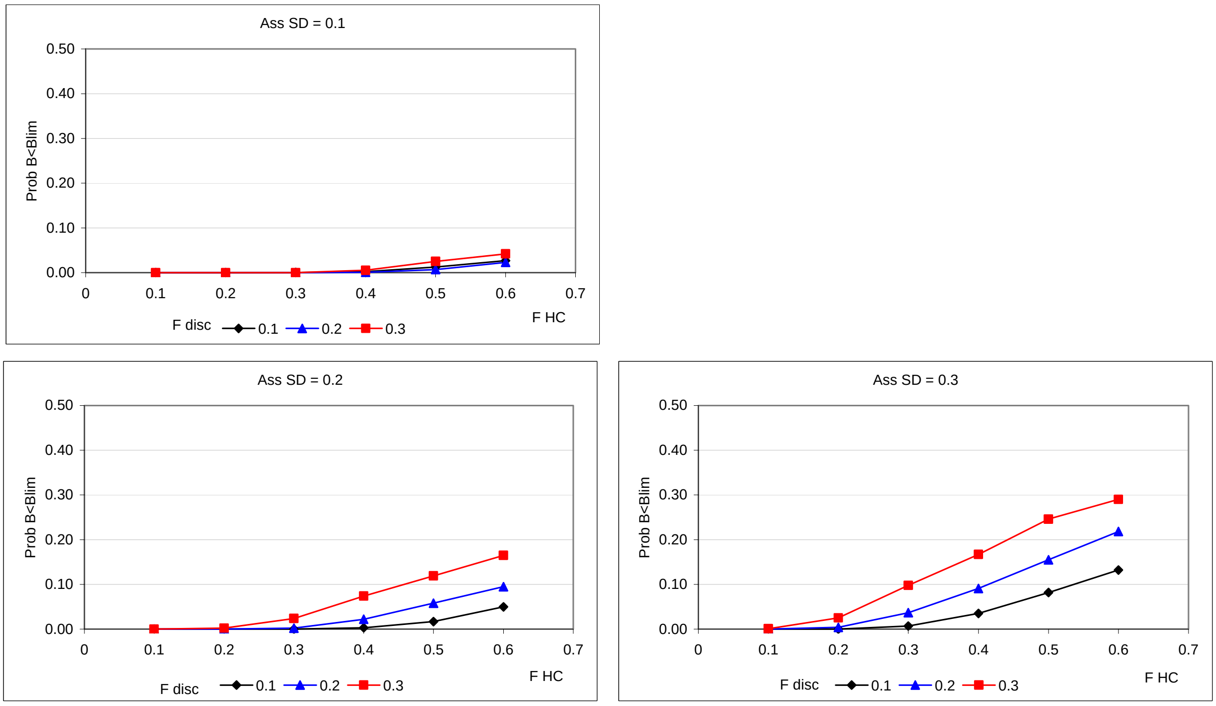


Figure 4.15 North Sea plaice. Sensitivity to the assumed standard deviation in the assessment of stock status. Variable of interest: probability of being below Blim in 2014 Shepherd base stock recruitment relationship (base). Different fishing mortalities for HC on the horizontal axis and different fishing mortalities on discards in the different graphs. Note that discards F and HC F are varied independently in this analysis.

5 Sandeel in the North Sea

In response to the joint EU Norway request concerning anglerfish:

"Advise on appropriate management systems including management strategies, objectives and ecosystem considerations for western horse mackerel, anglerfish, sandeels and Norway pout."

5.1 Background

The landings of sandeel from the North Sea were at a historic low level in 2003, due to a very small 2002 year class and the stock size and fishery in 2004 were therefore very dependent on the size of the 2003 year class. For this reason EU adopted an *ad hoc* harvest control rule for the 2004 fishery for sandeel in the North Sea (Council Regulation (EC) No 2287/2003 of 19 December 2003). The HCR operates with three levels of 2004 effort set on the basis of the size of the 2003 year class, as specified below:

- where STECF estimates the size of the 2003 year class of North Sea sandeel to be at or above 500 000 million individuals at age 0, no restrictions in kilowatt-days shall apply;
- where STECF estimates the size of the 2003 year class of North Sea sandeel to be between 300 000 and 500 000 million individuals at age 0, the number of kilowatt-days shall not exceed the level in 2003 as calculated in total kilowatt-days;
- where STECF estimates the size of the 2003 year class of North Sea sandeel to be below 300 000 million individuals at age 0, fishing with demersal trawl, seine or similar towed gears with a mesh size of less than 16mm shall be prohibited for the remaining of 2004.

The 0-group CPUE from the commercial fishery in 2003 is a poor predictor of year class strength and an "*ad hoc* STECF working group on sandeel fisheries" (REF) was established February 2004 with the specific purpose to assessing the strength of the 2003 year class. The group established a methodology where 1-group abundance (and thereby the number of 0-groups the year before) was estimated from a standardised CPUE from the commercial fishery in the beginning of the fishing season. This proposed real time monitoring of the fishery was afterwards implemented in the 2004 fishery. Based on data from the fishery until the end of April an estimate of the 2003 year-class was made mid May as the basis for the effort regulation.

STECF reviewed the methodology in May 2004 and concluded that when the year class are from average to weak, the method was highly uncertain to classify the year class strength in relation to the levels specified in the Council Regulation.

From an estimate of the 2003 year-class and the uncertainty associated with that estimate STECF considered that continued fishing throughout 2004 with unrestricted effort carried the risk of overexploitation of the North Sea sandeel stock. The Council Regulation, in which it is stated that the number of kilowatt-days in 2004 must not exceed the level in 2003 as calculated in total kilowatt-days, was therefore maintained. This effort limit was reached for the Danish fleet in September and the Danish fishery for sandeels in the North Sea and Skagerrak (areas IV and IIIa) was closed from 13th September 2004. At that time the very seasonal sandeel fishery was almost stopped anyhow. No effort restrictions have been implemented on the Norwegian sandeel fishery for 2004.

In October 2004, ACFM advised that the management of the sandeel fishery in 2005 should attempt to rebuild SSB to B_{pa} by 2006. However, the SSB in 2006 will largely be dependent upon the 2004 year-class for which there was no reliable estimate at the time. Unable to provide predictions that could be used in the setting of a TAC for 2005, ICES advised that the sandeel fishery should initially be managed through effort control.

Furthermore, ICES advised that this procedure would require an *ad hoc* working group to meet before the start of the 2005 sandeel fishery for a full evaluation of the real-time monitoring system and to outline the real-time monitoring methodology and harvest control rule initially for the fishery in 2005 and subsequently, in future years.

The ICES' proposal of setting up an *ad hoc* working group was not fulfilled. The STECF "*ad hoc* STECF working group on sandeel fisheries" had however its second meeting in February 2005 to review and update the methodology for the assessment of recruitment in support of the Commission's harvest control rule for North Sea sandeel. The *ad hoc* group developed further the methodology such that the precision of the year class estimate was improved for low or average year class strengths. Further a short-term evaluation of the Commission's harvest control rule for 2005 was undertaken. This indicated that for low to average recruitment in 2004, SSB in 2006 was unlikely to reach $B_{pa.}$ The working group concluded that the present harvest control rules needs revision and came up with a suggestion for new rules based on a deterministic forecast of the stock.

5.2 Activities for 2005

A thorough long-term evaluation of the current HCR, incorporating uncertainty is needed to improve the basis for North Sea sandeel management. ICES proposes that such work should be undertaken inter-sessionally through stochastic simulations and should identify suitable long-term fishing mortality and trigger biomasses to replace those in the current HCR. The outline of such work is presented in the Report of the Study Group on Management Strategies, SGMAS (ICES, 2005a). Available software like STPR3 is probably not well suited for such task as it operates with annual time steps and does not allow in-year adjustment of fishing mortality or TAC. Therefore, new software has to be developed such that the sandeel specific tasks can be taken into account. In addition to the "standard" functionality defined by SGMAS the simulations should incorporate at least the following:

- the accuracy of the estimate of the 1-group year-class as function of monitoring duration and sampling activity of biological parameters (age distribution and mean weight);
- the mortality implied by the fishery by the end of the monitoring period or potential delays in implementation of management;
- the possibility to evaluate the performance of a HCR based on stock numbers (as the present one) or based on biomass.

It was not possible to prepare such software and run simulations before this AGLTA meeting. Our expectation is that this will be done inter-sessionally by WGNSSK members before the next WGNSSK meeting in September 2005 and might then form the basis for ACFM advice later this year in October 2005. The plan is to implement HCR in the Stochastic Multispecies Model, SMS (Lewy and Vinther 2004). SMS is made to model biological interaction, however the model can be run with one species only in "single species mode" such that it can be used for the sandeel assessment. The short-term benefits of an SMS implementation are to make use of the build in MCMC functionality in the forecast. On a longer term, the implementation can be used to evaluate HCR in a multispecies context taking multispecies interactions into account. Such simulation software is not trivial to develop, even in "single species mode", and a full simulation framework might not be available in September. If this were the case, then WGNSSK will as a minimum:

- up-date time series with 2005 data and apply the methodology developed by the STECF "a*d hoc* working group on sandeel fisheries" for the estimating the basic relation between CPUE and stock size;
- set-up a deterministic forecast, based on the most recent assessment, as a basis for defining HCR for 2006 following the alternative methodology suggested by

STECF "a*d hoc* working group on sandeel fisheries" (Section 6 of the report, (STECF 2005)).

The currently used method for real time monitoring of sandeel fishery will be reviewed by an ACFM review group after the WGNSSK meeting and before the ACFM October meeting.

5.3 Fishery independent data

ACFM pointed out that given the current dependency on the data from the commercial fishery and the potentially critical state of the stock, there is an urgent need to develop fishery-independent surveys of sandeel stock development. Some progress has been made:

- Dredge survey on selected sandeel fishing grounds, conducted by DIFRES in the late autumn 2003 and 2004. Preliminary results indicate some relation between survey index and stock size. In addition, CEFAS has conducted dredge surveys on localised sandeel fishing grounds in March and June since 2000.
- Larvae survey, conducted by DIFRES in 2004 and planned for 2005. During the night time selected sandeel commercial vessels apply a modified MIK for estimation of sandeel larvae abundance.
- Exploratory survey to be conducted spring 2005 by IMR using different sampling gears and hydro-acoustic.

6 Norway pout

In response to the joint EU Norway request concerning Norway pout:

"Advise on appropriate management systems including management strategies, objectives and ecosystem considerations for western horse mackerel, anglerfish, sandeels and Norway pout."

6.1 Background

Based on the most recent assessment of Norway pout, ICES considered that there was no basis for fishing on this stock in 2005 due to the low state of the stock and the low recruitments in most recent years. The fishery was consequently closed in 2005.

The population dynamics of Norway pout in the North Sea and Skagerrak are very dependent on changes caused by recruitment variation and variation in predation mortality (or other natural mortality causes). Recruitment is highly variable and influences SSB and TSB rapidly due to the short life span of the species. With present fishing mortality levels in recent years and especially in 2003 and 2004 the status of the stock is more determined by natural processes and less by the fishery.

It may be more appropriate to formulate reference points based on total mortality, recruitment and stock biomass for use within management procedures using surveys and real-time monitoring of catches.

Both the first and third quarter IBTS survey and the fourth quarter commercial fishery index seems in general for all ages in the stock to be relatively good indicators of the size of the youngest year class and older ages.

The fishery for Norway pout has not a distinct season but is mainly conducted outside the sandeel fishing season (second quarter and first part of the third quarter).

6.2 Activities for 2005

A real time management system for Norway pout has not yet been defined. In contrast to the situation for sandeel, fishery independent indices do exist for Norway pout and both surveys and commercial catch rates should be used for a real time management procedure. Data from surveys are available from surveys in the first and second quarter and fisheries data are available mainly from the first, third and fourth quarter. That gives the opportunity to define a real time management procedure where the fishing effort can be adjusted several times during the year. Norway pout recruit to the fishery as 0-group in the third quarter and the year class strength mainly determines the fishery opportunity the following year. It might be possible to set a maximum effort based on the IBTS and commercial catches in the third quarter. This effort level could then be adjusted a half year later based on data from the first quarter IBTS and from the commercial fishery.

ICES proposes that the work of defining a suitable real time management procedure including stochastic simulations should have a high priority before and at the next WGNSSK meeting in September 2005. This might then form the basis for ACFM advice later this year in October 2005. This work can benefit from the software developed for the evaluation of the real time procedure for sandeel, however additional functionality needs to be added:

- the use of, and weighting of, information from several data sources (survey index and commercial CPUE);
- the possibility for several in-year adjustments of fishing effort to evaluate the costs (less stable fishing effort) and benefits (higher precision in stock size estimation) of in-year adjustments.

It is foreseen that the definition and a full evaluation of a real time management procedure for Norway pout cannot be completed this year. For a potential re-opening of the fishery in 2006 WGNSSK will as a minimum assess the Norway pout stock at the meeting in September 2005, using a methodology entirely based on survey data for 2005, as the fishery is closed this year.

Management of short-lived species is not limited to the North Sea sandeel and Norway pout and there is an urgent need to develop an approach for management strategy evaluations for such stocks.

7 Western horse mackerel

In response to the joint EU Norway request concerning western horse mackerel

“Advise on appropriate management systems including management strategies, objectives and ecosystem considerations for western horse mackerel, anglerfish, sandeels and Norway pout.”

7.1 Background

Horse mackerel in the northeast Atlantic is considered to be separated into 3 stocks (Figure 7.1). By far the largest of these is the western stock. In the main it can be considered to be a migratory shelf edge pelagic species, with a longevity of about 35 years, maturing at between 3 and 4 years. Fecundity has been recently considered to be indeterminate. The nature of recruitment in western horse mackerel is highly spasmodic with a single extraordinary large (20 times the average) year class observed in the past 25 years. All these features create challenges in producing an accurate assessment.

The fisheries for horse mackerel are predominantly pelagic industrial in nature (not for reduction) except around the Iberian Peninsula where it is also caught by bottom gear, often as a by catch. Dealing with the western stock, the fishery expanded in line with the 1982 year class and remained an adult fishery until the abundance of this year class declined in the early to mid nineties. Since 1996 a fishery for juvenile horse mackerel has developed in the Channel and VIIIa. In the most recent years 60% of the catch is fish between the ages of 1–3. The fishery in the channel (VIId and e) straddles the North Sea and western stocks. The TAC for the western stock has been decreased in line with ICES advice, but the catches have been much higher than advised since the TAC does not cover the total fishing area.

The age structure of the population and catches of western horse mackerel is dominated by the sporadic nature of recruitment. Furthermore there is no age disaggregated information is available for model calibration. This has created difficulties in the assessment of the stock.

7.2 ICES advice 2000–2005

Since 2000 ICES has advised the following for western horse mackerel;

- That since 1982 no equivalent year class has recruited to the stock
- That the SSB is declining from a high in the late 1980's
- That ICES are concerned with an increasing juvenile fishery at a time when the adult stock is declining and there is no analytical assessment as to the size of that stock, and no verification of the size of any recruiting year classes.
- That the juvenile fishery overlaps the stock boundary between the North Sea and western areas, and that the TAC for the North Sea is not precautionary.
- That a management strategy should be developed that takes into account fisheries for both adults and juveniles (similar to North Sea herring).
- That the TAC area and stock distribution areas are mismatched. That the catches considerably overshot the TAC from 1988 to 1997, but have been below or close to the TAC since. That the decrease in overshoot for the western area corresponds with an increase in North Sea horse mackerel catches.

In 2002 an analysis was carried out by ICES to examine the trade off for the stock between fishing on adult or juvenile populations based on a long-term equilibrium yields (see Figure 6.11.3 in ICES, 2003). The following were the main conclusions;

- maximum biomass in the stock is reached between ages 3–6, and that from a biological point of view the fishery should take place from age 3 onwards (avoid growth over fishing)
- That a fishery on juveniles reduces the SSB and the catch and increases fishing mortality

7.3 Possible management instruments

Given the knowledge on the geographical distribution of the fisheries, which has been reported by the ICES for the past 10 years, a series of closed areas could be used to limit the fishing mortality on juveniles.

If a TAC control were used (covering all the fishery areas) the application of the TAC to the fishery should be mindful of the circumstances of the fisheries. In the first instance managers need to agree the appropriate trade-off between the exploitation of adults and juveniles, and be mindful that the tolerance of a juvenile fishery will necessarily lower the overall yield. In the second instance managers need to ensure that catches are not misreported between adjoining areas in which the distribution of the juveniles of both the North Sea and western stocks is contiguous.

If a TAC instrument were to be used to limit the exploitation of the horse mackerel stocks in the northeast Atlantic, managers should consider (in addition to harmonising stock distribution areas with the TAC's) imposing a precautionary TAC on the North Sea stock as the fishery has expanded rapidly, without any estimate of stock size or status.

Considerations on a management strategy should be based on the following observations:

- Horse mackerel is a spasmodic spawner
- The western horse mackerel stock has declined since the early 1990's, the status of the North Sea stock is unknown, but the fishery here has expanded in recent years.
- The distribution of both stocks is contiguous
- Control measures are required to prevent overexploitation of both stocks
- To be effective, the exploitation control measures must apply to all areas where the stocks are fished. These control measures may need to be managed independently.

7.4 Recommendations

Given that horse mackerel is a spasmodic recruiter, a dual mode harvest strategy could be planned to take advantage of large year classes when such are abundant and keeping exploitation at a low level when no large year classes are abundant. This would require an identification of which information would be used to decide on the occurrence and abundance of large year classes. If commercial catches are the only means to establish the presence of a large year class, there is an intractable problem of distinguishing a large recruitment event from a targeting change by the fishery. The only way to establish the magnitude of recruitment at present is to develop a fishery independent recruit index. Horse mackerel is taken in existing demersal trawl surveys but it remains to be investigated how useful the horse mackerel data from these surveys are. An exploration of the IBTS data for North Sea horse mackerel has highlighted problems with catchability or other technical problems related to the abundance of this species in bottom trawling conducted by research vessels.

SGMAS suggest that where an assessment is not available management could be based on setting a TAC at a low level, which is adjusted only slowly based on changes in trend indicators. If a constant (unknown) fecundity for horse mackerel could be accepted, this trend indicator could be based on egg abundance from the triennial egg survey. An alternative is use of indices from existing demersal surveys subject to an investigation demonstrating that informative indices can be developed. This could be expanded to a dual mode management strategy if allowance is made for a change from a low level TAC to a longer term mining of an abundant year class with a fishing mortality of an order which would maximise the yield from that year-class over its lifetime.

Process: a scoping paper for evaluation of management strategies for western horse mackerel along the lines indicated above will be developed by CEFAS and presented to ACFM at its meeting in May. In the response to the request mid-June a general outline of candidate management plans will be presented and reference will be made to a response based on full evaluations to be produced as a part of the October advice. In the WGMHSA meeting these evaluations will be finalised and ACFM will on this basis, as an output from the October meeting, present candidates for management plans. The scoping document is included as Annex 2.

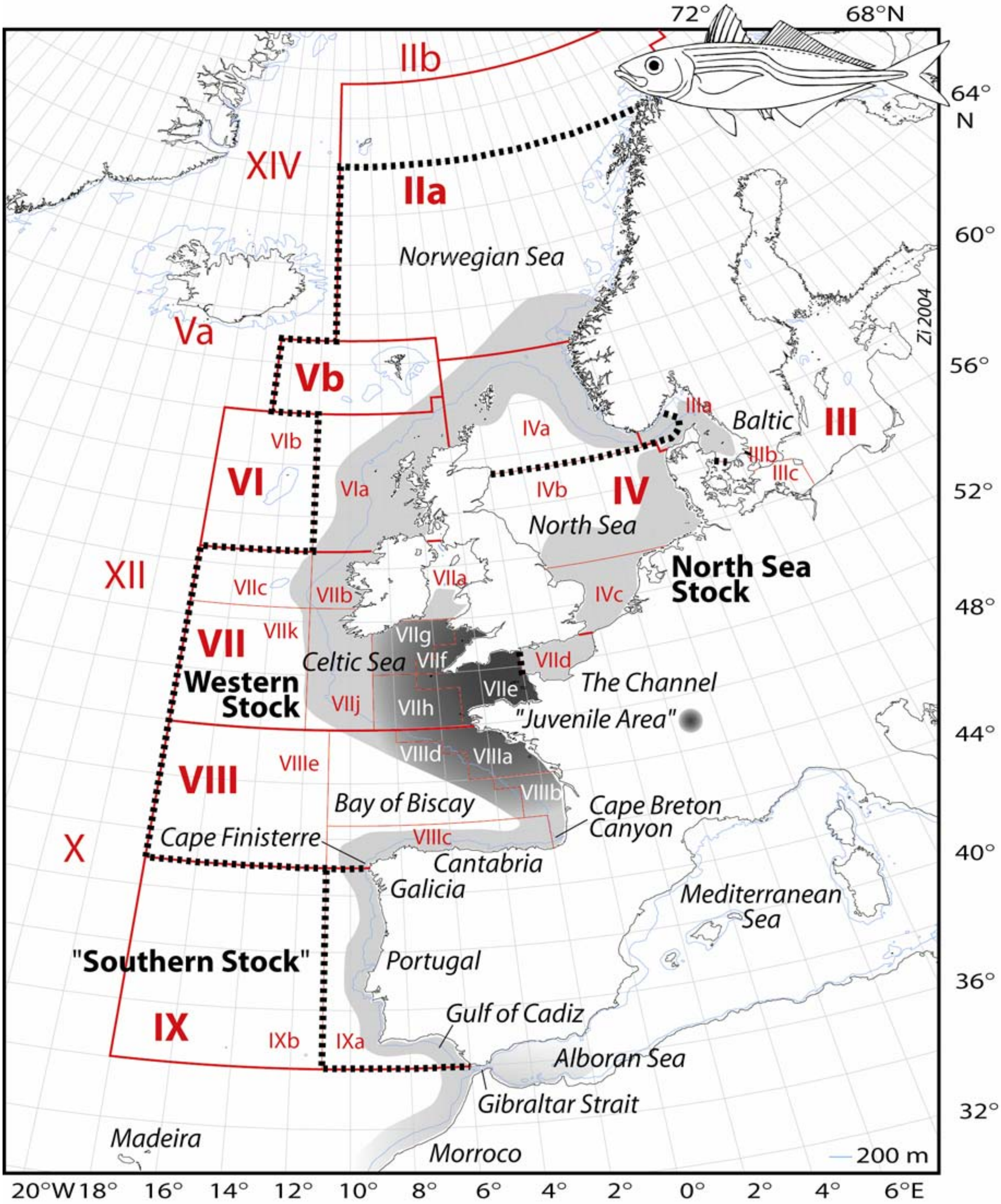


Figure 7.1: Distribution of Horse Mackerel in the Northeast-Atlantic: Stock definitions as used by the 2004 WG MHSA. Note that the "Juvenile Area" is currently only defined for the Channel area for the Western Stock– Juveniles also occur in other areas of the Western Stock distribution (VIIIc) and obviously in other stock areas (VIId for the North Sea stock and IXa for the Southern Stock). Map source: GEBCO, polar projection, 200 m depth contour drawn.

8 Anglerfish

This section deals with the response to the joint EU Norway request concerning anglerfish to: "*Advise on appropriate management systems including management strategies, objectives and ecosystem considerations for western horse mackerel, anglerfish, sandeels and Norway pout.*"

8.1 Background

In 2004 ICES advised that 'The effort in this fishery should not be allowed to increase and the fishery must be accompanied by mandatory programmes to collect catch and effort data on both target and bycatch fish.'

The basis for this advice was that catch data were not of sufficient quality to enable an analytical assessment or a catch forecast to be carried out. In such situations, ICES would often advise on a precautionary TAC based on recent landings. However, the landing data are not reliable due to extensive misreporting under a TAC regime which is not effectively enforced. There are no surveys that provide fishery independent information on anglerfish.

The lack of knowledge about the biology of anglerfish exacerbates this situation. Anglerfish are subject to significant fishing mortality before attaining full maturity. Their body shape means that at a young age they are easily retained by the minimum mesh size currently in force. The spatial distribution of the mature stock is not known; the mature stock may not be fully available to the fishery and catches of mature individuals are infrequent. The key features of the species' life history with respect to exploitation risks are: (1) the location of the main spawning areas in relation to the distribution of the fishery, (2) whether or not there is any systematic spawning migration of younger fish back into the deeper waters, and (3) some life-history characteristics of anglerfish suggest that it may be particularly vulnerable to high exploitation. At present, despite the large increase in catches, there is no apparent contraction in distribution; fish are still recruiting to relatively inshore areas such as the Moray Firth in the northern North Sea. The fact that spawning appears to occur largely in deep water off the edge of the continental shelf may offer the stock some degree of refuge. However, this assumes that the spawning component of the stock is resident in the deep water, and is thus not subject to exploitation. It is not known to what extent this is true, but it is clear that the current expansion of the fishery into deeper water is undesirable. Given the spatial expansion of the fishery, it cannot be ruled out that the serial depletion of fishing grounds may be occurring.

8.2 Developments in 2005

Current information on anglerfish is restricted to official statistics and to the (skippers) diary analysis work which was conducted at FRS in 2004. FRS and CEFAS are now developing a programme of science and monitoring to bolster information on anglerfish. This includes a new anglerfish survey (see below) and the establishment of a tally book scheme for a significant proportion of the fleet – the latter should improve information on effort and provide more detail than just days at sea. It is hoped that on-board monitoring will also be improved. FRS is expected to gain access to VMS data and this could provide valuable information on the aggregation of effort in areas where anglerfish abundance is known to be high.

As a parallel development, Scottish Executive Environment and Rural Affairs Department (SEERAD) are expected to develop a more robust management scheme for anglerfish including limiting the size of the target fleet.

8.3 Fishery independent data

A new three-year survey for anglerfish is being planned by FRS in collaboration with partners from the Scottish fishing industry. The survey is intended to estimate the total abundance of anglerfish on the northern European shelf. The survey will cover the area of the known distribution of northern shelf anglerfish (ICES divisions IVa, VIa and VIb at Rockall) and take place initially in November 2005 and will be continued in 2006 and 2007. The project also includes a trial of video technology for counting anglerfish visually and the deployment of data storage tags to understand their vertical and horizontal movements. The future of the survey beyond the lifespan of the three-year project is not yet clear.

It will be a multivessel survey, incorporating the research vessel Scotia, and up to three commercial fishing vessels. The fishermen will follow specific scientific instructions as overseen by participating scientific staff. The instructions will be drawn up by an industry-science survey planning group which will be set up at the start of the project. Appropriate industry representatives will help to determine how best to incorporate fishing vessel effort and fishermen's expertise into various aspects of the survey (design, gear etc.). These instructions will be formulated into a set of protocols which may be more generally applied if the survey proves to be successful. Initial planning meetings have taken place with senior representatives from the industry and the planning group is in the latter stages of formation.

Subsequent surveys (2006 and 2007) will be based on a similar amount of effort per year but allocation of this effort in time and space may change according to the results of the first survey. The abundance estimates will be based on the swept-area approach which assumes that a known proportion of fish are sampled from the area swept by the trawl. An additional project will run concurrently to determine the catchability of the trawl for anglerfish.

Each vessel will survey for ten days using a standard trawl as agreed by the planning group. Trawl samples will be taken over 13 hours each day, with the duration and number of samples being determined by the planning group. FRS staff will process the catch from each sample and all anglerfish will be measured, weighed, and examined for gut contents and maturity. Otoliths and lures will be collected and sent back to the laboratory for ageing. Gear mensuration devices will be attached to the wingends, doors and belly of each trawl. Data will be transmitted to instrumentation on the bridge of the each vessel and collected on a PC, allowing for the swept area to be calculated. The fish density from each trawl will then be interpolated using design based interpolation methods to estimate the total abundance of anglerfish with the associated measure of uncertainty.

At the end of the three year project, the survey time series will be analysed using abundance at age survey based assessment (SURBA) models developed in an EC/FRS funded project (FISBOAT). This is expected to give estimates of (relative) abundance with associated uncertainty.

8.4 Recommendations

The uncertainties in catches and the limited knowledge about the dynamics and the distribution of anglerfish means that simulations of management plans would be so generic that they would tell little about the expected outcomes.

In this situation the most productive way forward would be a two step approach, the first step would be a period with a management regime and data collection which would enable an information base to be assembled while keeping exploitation under control. On the basis of the information assembled during the first step a management approach for a second step would then be identified. This is in accordance with ICES' conclusion in 2004, that the best route would be to allow the fishery to continue with the current effort (inasmuch as this can be determined) but accompanied by a detailed and stringent monitoring programme, including the mandatory reporting of both catch and effort data in logbooks. This should allow the collection of high quality effort and landings data. In this way it will be possible to obtain realistic information about the fishery and in the longer term to have a basis for evaluation of the outcomes of management.

Furthermore, with the targetted survey now planned for 2005 onwards it is expected that fishery independent information will be available at the end of the first step. Normally it takes about five years before the time-series is sufficiently long to allow quantitative use of such data. After some years with a management regime which enables good catch and effort information and through which a time series of survey information is established, management measures could then be adapted on basis of this information

The management regime during the first step should be designed to ensure catch and effort reporting and to prevent effort from increasing. Initially the recent effort with important catches of anglerfish must be identified both in order to establish a reference level and to identify the fleet to be included in an effort based access control. An effective collection of catch and effort data would include access control, a controlled logbook system and use of VMS.

8.5 Summary presented in response to request

There are major uncertainties about catch and effort data for anglerfish, as well as limited knowledge about population dynamics and distribution. In addition, existing surveys have not proven useful in describing the population. For these reasons, simulations of management plans would have to be so generic that they would tell little about the expected outcomes.

In this situation the most productive way forward would be a two-stage approach. The first stage would be to substantially improve the quality and quantity of data collected on the fishery while maintaining exploitation at its current level. This was the basis of ICES recommendation (ACFM 2004) to allow the fishery to continue with the current effort (inasmuch as this can be determined). This was to be accompanied by a detailed and stringent monitoring programme, including the mandatory reporting of both catch and effort data in logbooks, as well as the use of VMS data. The programme would also include the development of a targeted, industry collaboration trawl survey to start in 2005.

A key point in this recommendation was that the restrictive TAC in 2004 and previous years had led to extensive mis-reporting. Management aimed at maintaining effort at or below that of 2004, but without a specific TAC, would have allowed the accurate reporting of catch and effort. In the event, a TAC-based regime was retained, although at an increased level. To date it is not clear if this has improved the quality of the landings data, however, the TAC is still perceived as restrictive by the industry. The existing tally book scheme is to be continued and extended, and observers will be placed on as many vessels as is feasible. The targeted survey is planned to go ahead in the autumn of 2005 and analysis of VMS data at approximately the same time. More robust management measures to control the targeted fishery have been proposed in the UK.

This first stage of data collection would be expected to take at least five years to establish useable time-series of fisheries-dependent and -independent data. The second stage could then be launched to use these data to examine alternative management approaches and harvest control rules appropriate to this fishery in a fashion similar to that used elsewhere within this response; e.g. North Sea cod and plaice. Should evidence appear of a decline in the stock size during this period of data collection, the management of this stock should be revisited and appropriate management measures initiated.

9 Baltic cod 22-24

9.1 Input data

Input data for STPR3 and S3S (both programs in the biased corrected version) runs for Baltic cod 22–24 (see Table 9.1–9.5) were derived from the final accepted assessment by WGBFAS (ICES 2005c). This assessment included discards.

The stock recruitment data for Baltic cod 22-24 has not been as heavily investigated as for cod 25–-32. Recruitment is not clearly influenced by environmental factors or by predator-prey species interactions. However, because stock recruitment relationships is so important for medium and long term analysis alternative representations on stock and recruitment have been explored to test the sensitivity of the model results to the assumed relationship (see sensitivity analysis).

9.2 Model settings

SETTING	VALUE	JUSTIFICATION
Age range	1-7+	
Reference F age range	3-6, 1-3	
Intermediate year	F hc= 1.15, F disc = 0.11	F *status quo F*
B_{lim}	9 000 t, **20 000 t** , 44 000 t	No Blim defined for this stock
Trigger biomass (B_{trig})	23 000 t, 30 000 t, **40 000 t**, 50 000 t, 60 000 t	B_{pa} = 23 000 t
F-level 1 (both components)	0.05	Expected that there will always be some fishing for plaice
F-level 2 (both components)	not used	
F-level 3 (long-term landings mean *F*)	landings: 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 discards: 0.01, 0.06, 0.11,	
Maximum TAC change	**Not constrained,** ±15%	
Maximum *F* change	**Not constrained**	
Maximum *F* possible	1.8 (hc), 0.5 (disc)	
SRR model	Ricker (from WGBFAS) alfa=3.72 beta=0.0000121 **Ockham (54 000, 20 000)** Ockham (118 000, 44 000)	ICES defined Blim to 9000 t in 1998, but have had it undefined since xxxx, due to indications that it should be much higher. This has been confirmed as more years of data have added to the time series and now the 44 000 t is a significant breakpoint and there are no timetrend in residuals. The Ockham curve of 54 000 R and 20 000 t S, is an adaptive step in between the previous Blim and the present segmented regression result. The R value is chosen to give the same slope of the first part of the curve as the segmented regression analysis.
SRR residual variation	0.6	R vary quite a bit more around the S-R curve and thus the variance is set high (at 0.6).
SRR truncation level	1.2	
Assessment bias	**1.0**, 1.2,	No substantial assessment bias has been observed in the past
Assessment SD	**0.35**, 0.55	Random variation of the asssessment. The 0.55 represents a SURBA assessment situation.
Implementation bias	**1.0**, 1.2, 1.4	Implementation bias for cod 22–24 has been observed in most

		years and sometimes up to 40%, but here assumed to be on average 20% due to expected improved enforcement.
Implementation SD	0.05	

Note: base case in bold

An example of the STPR3 option file is presented in Table 4.6.

The CV of the initial stock number estimates is assumed to be 0.6 for ages 1 and 7+ and 0.5 for ages 2–6. This is higher than CVs estimated directly from the XSA with unreported catches include by WGBFAS, and are intended to reflect the uncertainty in model specification expressed by WGBFAS. It is also higher than reflected in retrospective analysis of historical assessments (see table 9.7), where CV of SSB forecasted for the beginning of the TAC year is estimated to be around 0.3 for SSB total. But this is based on only for 8 data points, so this is probably an underestimate, and there are no strong arguments for this particular assessment to be better than for other ICES stocks.

9.3 Analytical approach

The following analytical approach was followed:

1) Carry out F_{sq} forecasts, without a HCR to develop a base case against which comparisons can be made.

2) Explore consequences of alternative HC (human consumption) Fs (F_{hc}) and discard Fs on the probability of being below B_{lim} in 2015.

3) Explore consequences of alternative time-trajectories to achieve different HCRs .

4) Explore the sensitivity of the 2015 situation to the assumptions on the underlying population dynamics (e.g. stock recruitment relationship) and the perception status (e.g. standard deviation on stock status).

5) For the HCR, F is a function of SSB surviving the TAC year. The STRP3 program had to be used “creatively” by setting spawning time to end of the year and using maturity at age and weight at age in the stock shifted one year. This also means that the parameter ‘number of years between spawning and recruitment’ is set to 1, as SSB in year y in the calculations is in fact SSB at year y+1.

6) For the situation where ICES regards commercial data and assessment too uncertain to be a basis for a traditional forecast, a forecast can be based on only survey data, using SURBA to give initial stock numbers based on a calibration between relative commercial catch at age from SURBA and real commercial catch at age for years where no mis-reporting is suspected. The precision of these initial stock number estimates are lower than an ordinary assessment, with CVs around 0.7 per age group (equal to cod 25–32 where it was deducted from Sparholt and Tomkiewicz (2000), assuming that the new survey with the new gear TV3 is not worse than the old survey).

9.4 Results

9.4.1 Stock recruitment CV

The stock recruitment CV around the tested models is set to 0.6. This is based on historical time series analyses using a segmented regression analysis and takes into model specification uncertainty (Figure 9.1). The truncation is set to 1.2 in order to get the simulated cumulative R fit the observed one.

9.4.2 Fsq forecast

Results of the status quo fishing mortality analysis are summarized in Figure 9.2. Continued fishing at current fishing mortality (F hc=1.15, F disc=0.11) is expected to result in a stock size around 20 000 t, and the landings around 30 000 t per year.

9.4.3 Scanning different possible HCRs

The S3s software was used to scan the effects of different combinations of parameters on the development in stock size, recruitment, landings and discards of Baltic cod 22-24.

A first set of simulations was devoted to exploring the effects of different levels of fishing mortality. Six effort multipliers were used on landings F, so that the landings F varied between 0.3 and 1.0 and the discards F set to either 0.01, 0.06 or 0.11. Results of these analyses are presented in Figure 9.3–9.5. The risk to B_{lim} in 2015 is highly dependent on the overall level of fishing mortality (Figure 9.3). At F_{sq}, the risk to B_{lim} is around 20%. In order to achieve a low risk to B_{lim} in 2015 of e.g. 5%, fishing mortality on landings should be reduced to around 0.6. However, if discards mortality could be reduced to 0.01, the F_{hc} on landings could be in the order of 0.9 while still achieving a low risk to being below B_{lim}.

If the objective is to obtain a high long term yield in combination with a low risk to B_{lim}, the preferred level of human consumption fishing mortality could be around F_t=0.6 (Figure 9.4). At F_t=0.6, the expected landings in the final years of the simulation are around 34 000 t, while the average landings (2006–2015) are expected to be around 32 000 t.

A fishing mortality around 0.6 is associated with high expected stock sizes of around 50 000 t (Figure 9.5), which is however still well below the maximum stock size observed in the early1980s (55 000 t.). The potential effects of such high stock sizes on growth rates and reproduction are not expected to be major judged from historical experience.

The dependency between B_{trig} and risk to B_{lim} and expected landings is shown in Figure 9.6 for three scenarios on F_{hc} which give a low risk – high long term yield option: F_{hc} =0.5, F_{hc} =0.6, and F_{hc}=0.7 (with F discards 0.11). Varying B_{trig} between 25 000 t and 55 000 t did not have a large influence on the risk to B_{lim} profile in neither of the F scenario. Also, the expected landings were relatively insensitive to the B_{trig} value. The was however a tendency that with increase in Fhc a larger Btrigger would be beneficial for the risk to Blim and for the landings.

9.4.4 Alternative time trajectories for HCRs

Four scenarios were selected for further analysis on the expected time trajectories that they imply. The selection was based on the criteria of low risk to Blim (at or below 5%) and high long term landings. Discards mortality was set to 0.11. The four cases were:

- Fhc =0.5, no cap on interannual TAC change (Figure 9.8)
- Fhc =0.5, cap of 15% on interannual TAC change (Figure 9.9)
- Fhc = 0.6, no cap on interannual TAC change (Figure 9.10)
- Fhc =0.6, cap of 15% on interannual TAC change (Figure 9.11)

The results of the simulations using STPR3 are summarized in 6 graphs: SSB, recruitment, landings, discards, SSB-recruitment pairs and cumulative probability profiles of recruitment between simulated and observed (stock assessment) values.

In the cases where no constraint is applied on the inter-annual change in TAC, the median and 25th and 75th percentiles of landings and discards show a large decrease in 2006 compared to 2005, after which the stock is expected to recover rapidly due to the lower fishing mortality on landings. When a fishing mortality of F_{hc} = 0.5 is applied, the stock is expected to increase to around 60 000 t. and with F_{hc} = 0.6 to 50 000 t. The difference between these two scenarios can be explained by the overall less old fish in the latter case. However, the catches are a few thousands tonnes higher for Fhc=0.6, similar in the two cases.

The introduction of a cap on the inter-annual change in TAC (15%) is shown in Figure 9.9 and Figure 9.11. Note that this cap only applies to the landings and not to the discards, so that discards are allowed to be constant at 0.11. The introduction of a cap on TAC change appears to have a strong effect on the stock trajectory being negative in the beginning of the period but positive in the end where the stock are build up above the level in the "no cap" simulations. However, the landings are for most of the time period lower than in gthe "no cap" simulations. Recruitment is a little lower for a few years in the "cap" simulations but catches more stable from year to year of course (Figure 9.11).

9.4.5 Sensitivity analysis

The senstivity to the underlying assumptions was explored by investigating different stock recruitment relationships (Figure 9.13–9.15) and different assumptions about the uncertainty in the stock status (perception) (Figure 9.16). Alternative simulation to the base simulation (Fhc =0.6, S-R Ockhams Racer with R=54 millions for SSB above 20 000 t) were done with a Ricker S-R model and the segmented regression analysis based on the WGBFAS 2005 assessment data (Figure 9.14–9.15). The conclusion from the graphs is that the potential catches from this stock is very much higher than the historical catches if F is reduced from the present level of 1.1 to 0.6.

The sensitivity to the assumed variance in stock status is shown in Figure 9.15. A SD of 0.35 was used as the base case. At higher standard deviations, the risks to B_{lim} is also higher. The real interest here would be to model the interaction between bias in the assessment and feedback into the management procedure. However, this is not feasible within the STPR framework and this has therefore not been pursued at present.

9.5 Discussion

If the objective is to obtain a high long term yield in combination with a low risk to Blim, the preferred level of human consumption fishing mortality could be in the area of F_{hc} =0.5 to F_{hc} =0.7 (Figure 9.4). At F_{hc} =0.6, the expected landings in the final years of the simulation are around 32 000 t, while the average landings (mean 2006–2015) are expected to be around 30 000 t. Some improvement to the stock development and to the landings is expected by the additional reduction of the already low discard mortality. The simulated fishing mortalities used are all expected to keep the stock well inside what has been experienced in the past and the potential effects of stock size on growth rates and reproduction are expected to be minor unless the alternative S-R models turn out to be the correct ones.

The simulation procedure in STPR3 does not incorporate a full feedback loop, where an operating model is used on which a stock assessment process is carried out, which then forms the basis for a management decision and an implementation. The stock assessment process and the implementation process are mimicked in STPR3 by application of a fixed bias and a standard deviation. Because the stock assessment process is not explicitly incorporated, we cannot evaluate how a stock could be traced at lower fishing mortalities when in general stock assessment models tend to break down. It is similarly not possible to simulate the effects of changing assessment bias in the high F case that non-reporting may increase when TACs become increasingly restrictive.

The individual STPR3 analyses were presented as percentiles of 1000 bootstrap iterations. We also looked at individual bootstrap realizations of two of the explored scenarios in order to evaluate the consistency between the iterations. Results are summarized in Figure 9.12 for the scenarios Fhc =0.6 both without cap on TAC variation and with a 15% cap on variations. We looked at the true landings for the first 10 iterations and we compared this to the percentile distribution of the true landings of all 1000 iterations. Both scenarios were based on biomass thresholds of 20 000 t (B_{lim}) and 40 000 t (B_{trig}). The scenario without TAC constraint gave very high variations in true landings. This was caused by the observed F which often jumped from very low to very high values on the basis of an uncertain stock status which could re-estimate the size with a 35% error. The individual trajectories of true landings are much more varying than would be implied by the percentile distributions over all iterations. The scenario with a 15% cap on TAC variation appeared to behave much better, because it would not allow the F to jump up and down given that the TAC could not vary by more than 15%. Thus the 15% cap could act as a useful method to dampen the noise in the assessment process. However, this benefit is on the cost of significant lower average catches in all years except 2006.

The simulations are based on an F_{sq} assumption fro the current year (2005). From this assumption, a catch (both landings and discards) is derived. This is also used as a basis for the application of the cap on TAC variations. Therefore, the initial reductions in TACs in the initial years of the simulation can be somewhat biased as the status quo catch forecast for 2004 is substantially higher than the agreed TAC. However at present this is a limitation in STPR3 which could not be remedied during the meeting.

The results of the simulations are sensitive to the assumptions within the model. The uncertainty in stock status and the uncertainty in the stock-recruitment relationship are directly reflected in, for example, the risk to B_{lim}. A higher uncertainty in the assessed stock status will mean that more often “wrong” decisions will be derived from the “assessment” thus giving rise to higher risks of depletion of the stock. If the recruitment at a given stock size is lower than expected, than the derived yield may be too high, which again could give rise to a higher risk to B_{lim}. In general these sensitivities mainly operate at higher fishing mortalities; strategies which aim at lower fishing mortalities appear to be less sensitive to the model uncertainty.

The sensitivity of the HCR to Blim values was analysed by considering sets of Blim and Btrigger values (9000 t and 23 000 t, 19 000 t and 38 000 t, 29 000 t and 58 000 t, and 39 000 t and 78 000 t). Fhc was set to 0.6 and Fdisc=0.11. The S-R model used was the Ockhams Racer” R=54 millions, and Sbreak = 20 000 t (Figure 9.17). The results was that both landings in 2015 and average landings (2006–2015) increased with the Blim value. Of course the risk to Blim also increased as with the increase in Blim.

9.6 Conclusions

The simulations illuminate the outcomes of low F regimes. The simulations do however reflect decision rules which assume that Fishing mortality and Biomass can be measured and that TAC’s or other measures to restrict F are impelemented efficiently. None of these assumptions are presently true as there are indications of considerable amounts of non-reported landings indicating lack of implementation and making estimates of F and B very uncertain. The simulations illustrates what would be expected if some means of effectively reducing F are implemented in the future.

If the objective is to obtain a high long term yield in combination with a low risk to B_{lim}, the preferred level of human consumption fishing mortality could be in the area of F_{hc} =0.5 - 0.6 (Figure 9.4). At F_t =0.5– 0.6, the expected landings in the final years of the simulation are around 32 000 t, while the short term landings are expected to be around 25 000 t (mean 2006–2008). Some improvement to the stock development and to the landings is expected by the additional reduction of the already low discard mortality. The cap on annual TAC variations is expected to improve the performance in terms of minimising short term landings variation and in terms of making the system less sensitive to the noise in annual assessments, but at the cost of reduced medium term catches. At an F_{hc} in the range of 0.5 to 0.6 the likelihood of meeting objectives and performance criteria is furthermore insensitive to assumption regarding stock productivity and assessment error and bias.

The analysis shows that plausible (maybe even more than the model used) alternative stock recruitment models give substantially higher stock and yields at F between 0.5-0.7 than the present F around 1.1. Management that results in increasing the stock to historical high levels could give some further insights into the potential for much higher yield.

If the normal assessment cannot be performed due to uncertainties in un-reporting of commercial an assessment based on survey data only can be performed. This will however have a lower precision than a normal assessment and in order to avoid a high risk to B_{lim} Fhc should rather be 0.4 to 0.6 (Figure 9.16).

Both the landings in 2015 and the average landings (2006–2015) increased by increasing B_{lim} from 9000 t to 44 000 t.

9.7 Summary presented in response to request

The starting population for the simulations on western Baltic cod was taken from the last ICES assessment made in 2005 (ICES CM 2005/ACFM:19) which includes discards. The exploitation pattern used is thus based on assessments including landings and discards.

The evaluations of harvest control rules for western Baltic cod have demonstrated, under the assumption of the current exploitation pattern, that target fishing mortalities (including all catches) between 0.3–0.6 (ages 3–6) result in a low risk to reproduction and high long-term yields. There is presently not an estimate of $\mathbf{B}_{\mathrm{lim}}$ available for this stock, but this conclusion is robust to assumptions of $\mathbf{B}_{\mathrm{lim}}$ up to 30 000 t. A major improvement to the stock development and to the landings is expected if an additional reduction of juvenile mortality could be achieved. If juvenile mortality is halved the upper range of the target fishing mortality could be increased by 0.1.

The target mortality of 0.6 is higher than that which has been estimated for other stocks and this is associated with a stock-recruitment relationship that maintains recruitment at low spawning stock sizes.

A word of caution regarding the simulations is necessary. In the simulations with low fishing mortalities, the absolute stock sizes projected are very high and well outside of the historically observed ranges. It is unknown whether such high stock sizes can actually be achieved given the constraints within the natural system and what effects this would have on the dynamics of the stock. However, the numerical results of the simulations in terms of risk to reproduction and expected yield are conditional on these large stock sizes. The conclusions regarding the general direction required are not sensitive to density-dependent effects – i.e. significant reductions in fishing mortality to achieve simultaneously a low risk to reproduction and high long-term yield. It is therefore suggested that an implementation of long-term management plans is based on an adaptive approach whereby the development of the stock is monitored as the effects of the reduced fishing mortality are developing, and the specific numerical values within the management plan may then be modified on the basis of the outcome of the fishing mortality reductions

Table 9.1 Baltic cod 22–24. Natural mortality and Selection at age (fleet1 = human consumption, fleet2=discards) (cod.adt)

```
0.99 0.99
1  0.2000 0.05 0.06
2  0.2000 0.37 0.17
3  0.2000 0.98 0.10
4  0.2000 1.33 0.01
5  0.2000 1.21 0.02
6  0.2000 1.18 0.00
7  0.2000 1.19 0.00
```

Table 9.2 Baltic cod 22–24. Initial population size and variance coefficients (cod.nin)

```
1    62565  0.6 0 0 0 0 0 0
2    61725  0 0.6 0 0 0 0 0
3     9254  0 0 0.6 0 0 0 0
4     5212  0 0 0 0.6 0 0 0
5      809  0 0 0 0 0.6 0 0
6      199  0 0 0 0 0 0.6 0
7       68  0 0 0 0 0 0 0.6
```

Table 9.3 Baltic cod 22–24. Proportion mature (cod.prm)

```
2000  0.1 0.64 0.87 0.93 0.91 0.96 0.96
2001  0.1 0.64 0.87 0.93 0.91 0.96 0.96
2002  0.1 0.64 0.87 0.93 0.91 0.96 0.96
2003  0.1 0.64 0.87 0.93 0.91 0.96 0.96
2004  0.1 0.64 0.87 0.93 0.91 0.96 0.96
```

Table 9.4 Baltic cod 22–24. Weight in the catch by fleet (fleet 1 = human consumption, fleet 2 = discards) (cod.wc)

```
2001    1      0.68    0.80    1.04    1.47    2.80    4.21    6.51
2001    2      0.31     0.323   0.302   0.429   0.5     0.5     0.5
2002    1      0.68    0.80    1.04    1.47    2.80    4.21    6.51
2002    2      0.31     0.323   0.302   0.429   0.5     0.5     0.5
2003    1      0.68    0.80    1.04    1.47    2.80    4.21    6.51
2003    2      0.31     0.323   0.302   0.429   0.5     0.5     0.5
2004    1      0.68    0.80    1.04    1.47    2.80    4.21    6.51
2004    2      0.31     0.323   0.302   0.429   0.5     0.5     0.5
```

Table 9.5 Baltic cod 22–24. Weight in the stock (cod.ws)

```
2000 0.363 0.825 1.464 2.392 2.869 3.961 6.544
2001 0.363 0.825 1.464 2.392 2.869 3.961 6.544
2002 0.363 0.825 1.464 2.392 2.869 3.961 6.544
2003 0.363 0.825 1.464 2.392 2.869 3.961 6.544
2004 0.363 0.825 1.464 2.392 2.869 3.961 6.544
```

Table 9.6 Baltic cod 22–24. Example cod of a simulation option file.

1 7	Ages
1	Number of years between spawning and recruitment
3 6	Mean F range for h.cons.
1 3	Mean F range for discards
2005	The intermediate year
F	Int. yr.: Constraint type for h.cons. (C = catch, F = mortality
1.15	Int. yr.: Value of constraint for h.cons.
F	Int. yr: Constraint type for discards (C = catch, F = mortality
0.11	Int. yr.: Value of constraint for discards
0.0 0.00 0.00 30000.0 30000	HCR 1: lower bound on SSB, max F hc, max F disc, max catch HC, max
9000.0 0.00 0.00 60000.0 30000	HCR 2: lower bound on SSB, max F HC, max F disc, max catch HC, max
23000.0 1.00 0.10 99000.0 60000	HCR 3: lower bound on SSB, max F HC, max F disc, max catch HC, max
1	Linear increase of F in level 2? (0 = no, 1 = yes)
0.0 0.0 0.0	Annual catch variation: max change (both, h.cons., disc)
0.0 0.0 0.0	Annual catch variation: min change (both, h.cons., disc)
0.0 0.0 0.0	Annual F variation: max change (both, h.cons., disc)
0.0 0.0 0.0	Annual F variation: min change (both, h.cons., disc)
0.0000000 0	Min increase in SSB, which fleet takes burden (0 = both)
1.5	Max possible F by fleet
1.5	Max permitted F by fleet
3 1 3.72 0.0000121 0 0.6 1.20000000	Recruitment: Shepherd, lognormal, alpha, beta, gamma, sigma (SD), truncation
0	Number of autoregressive terms used
0.0 0.0 0.0 0.0 0.0	AR terms (from RecAn output for AR(1))
0	Apply SR relation in year 0? (0 = no, 1 = yes)
1.0000000 0.010000 0	Assessment bias multiplier (mean and SD)
1.0000000 0.0100000	TAC deviation multiplier (mean and SD)
1	Initial numbers (0: det, 1: log, 2: norm, 3: bootstrap)

Table 9.7. **Cod Central Baltic (Sub-divisions 22–24). CV of 'forecasted' SSB can be calculated to about 0.3 from the table below.**

			SSB start of the "TAC year", i.e. SSB ("TAC year) given the actual catch taken in the "TAC year" ('000 t)	
"Current year"	"TAC year" +1	Catch in "TAC year" '000t	"Forecasted"	WGBFAS 2005 estimate "the truth"
1988	1990	18.52	28	25.7
1989	1991	17.78	13	14.4
1990	1992	16.69	26	10.4
1991	1993	18.00	15	8.5
1992	1994	21.23	19	15.8
1993	1995	30.70	34	29.0
1994	1996	33.90	NA	30.2
1995	1997	50.85	NA	36.8
1996	1998	43.62	NA	37.6
1997	1999	34.21	26	18.8
1998	2000	42.15	30	23.6
1999	2001	38.36	32.1	28.6

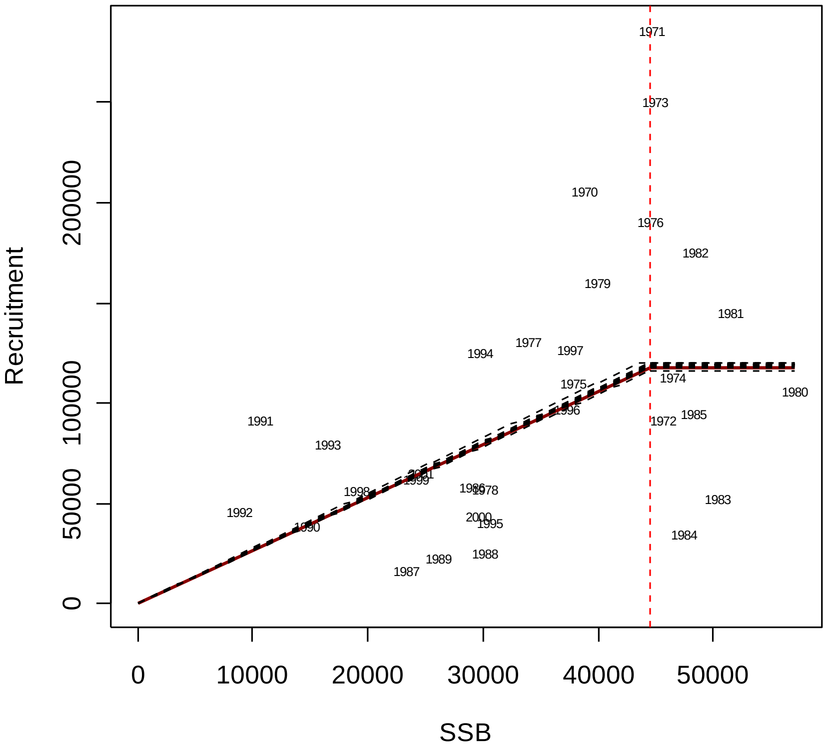


Figure 9.1 Baltic cod 22–24: stock recruitment plot with break point from segmented regression analysis on time series from 1970–2001. R at age 1.

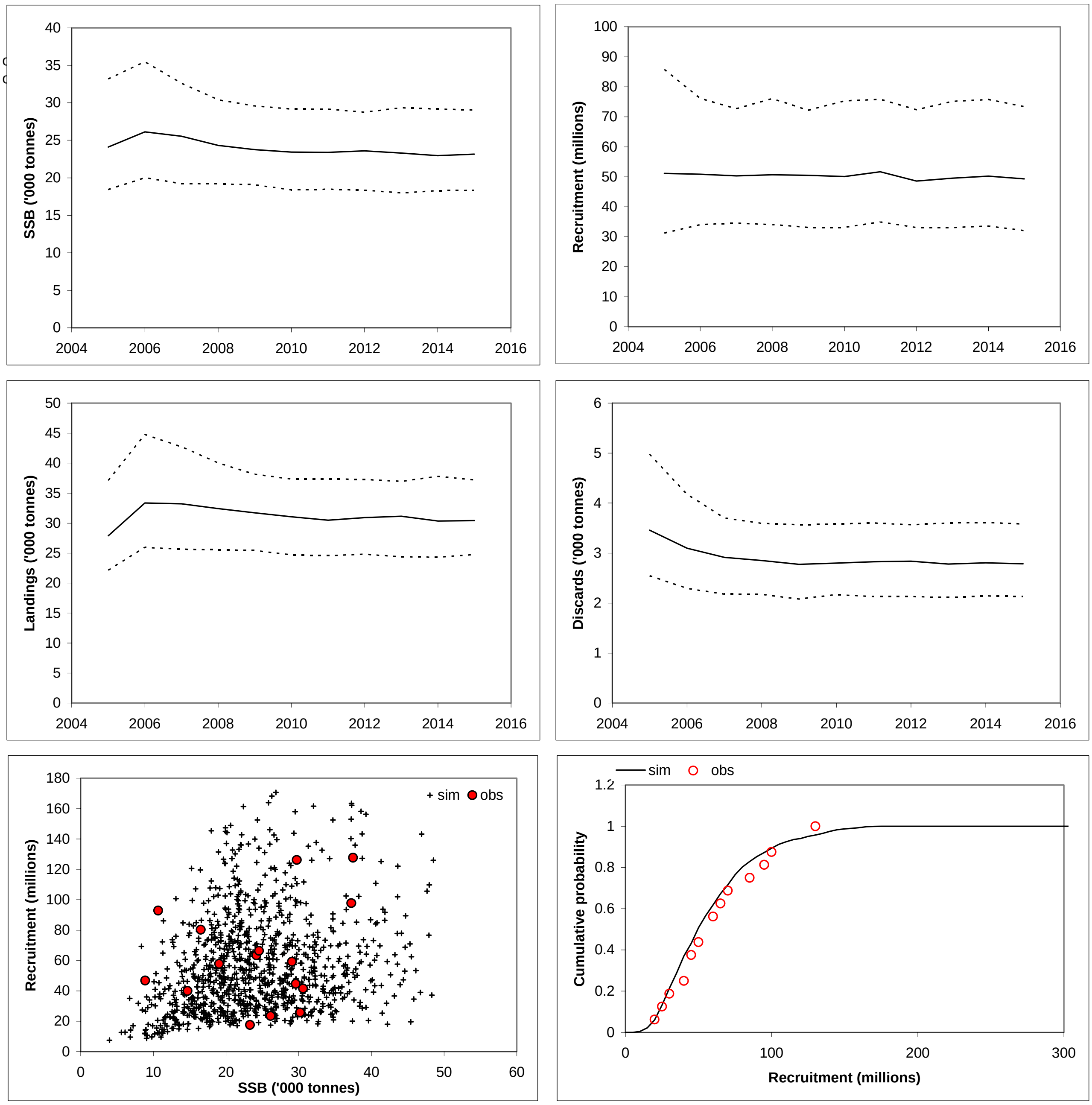


Figure 9.2 Baltic cod 22–24. STPR3b analysis using Fsq for both human consumption (1.15) and discards (0.11). Ockhams stock recruitment relationship (SSB break point at 20 000 t and R = 54 million age 1 above that SSB, with SD 0.6, truncation 1.2). Solid lines indicate the median of the bootstrapped distributions, the dotted lines the 25th and 75th percentiles. Trends in SSB, recruitment, landings and discards. Relationship between SSB and recruitment in simulations and as observed in most recent stock assessment.

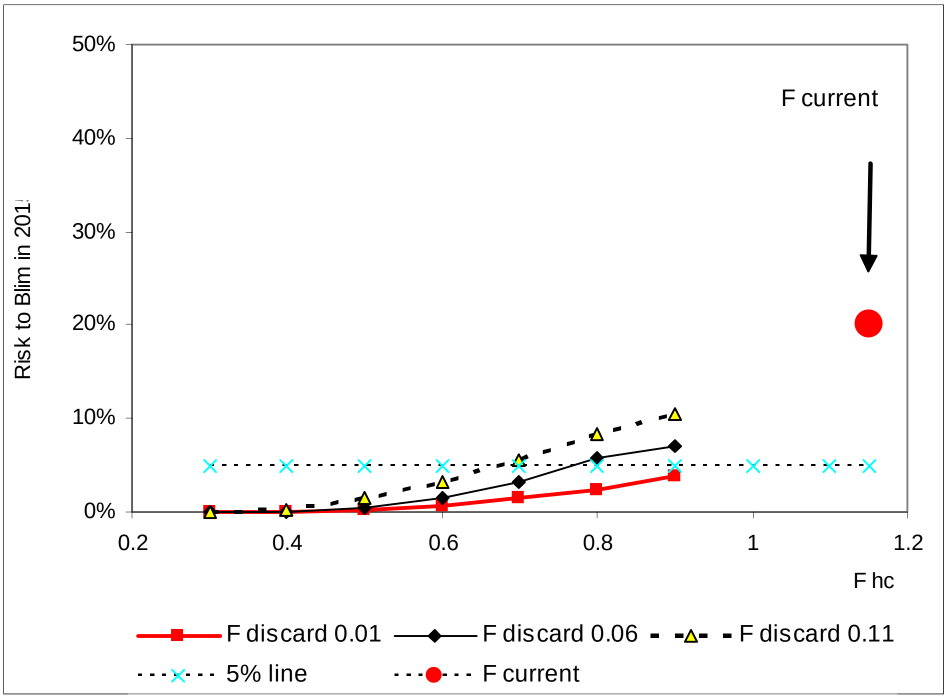


Figure 9.3 Cod Baltic 22–24. Risk to Blim in 2015 at different HC F's. Discards F are constant at 0.01, 0.06 and 0.11 (status quo 2004 value). HCR with "Blim" 20 000 t and Btrigger 40 000 t; the F value shown is that for SSB above Btrigger.

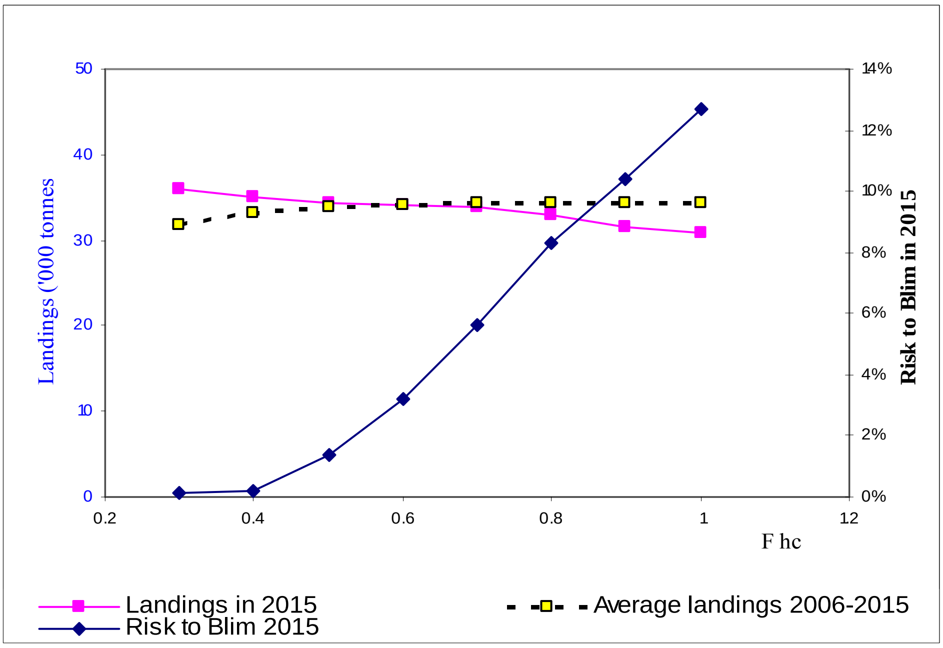


Figure 9.4 Cod Baltic 22–24. Trade-off between HC fishing mortality, long term risk to Blim and short term and long term landings. Discards F are set to 0.11. "Blim" to 20 000 t and Btrigger to 40 000 t.

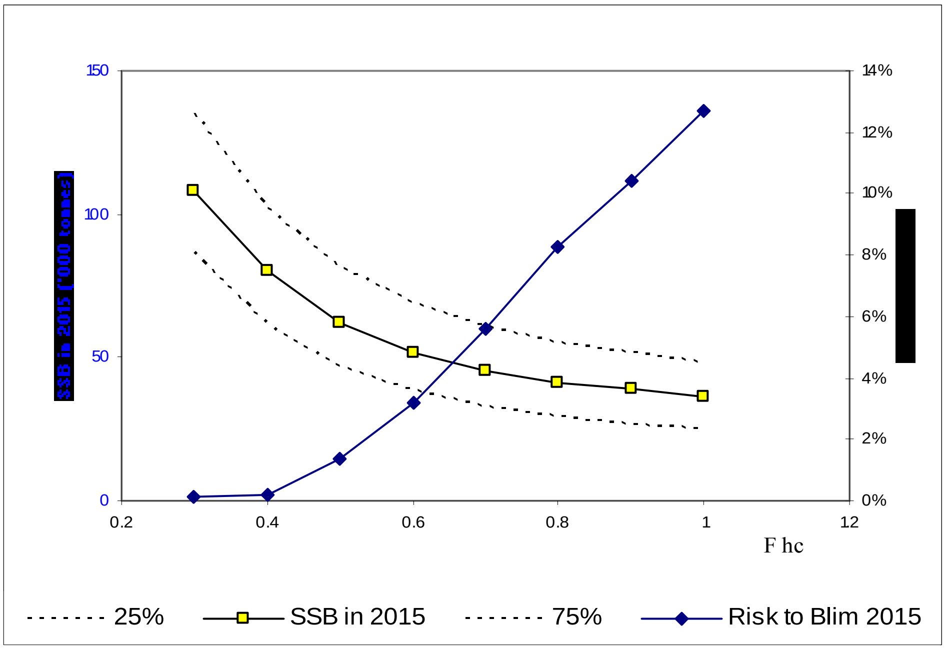
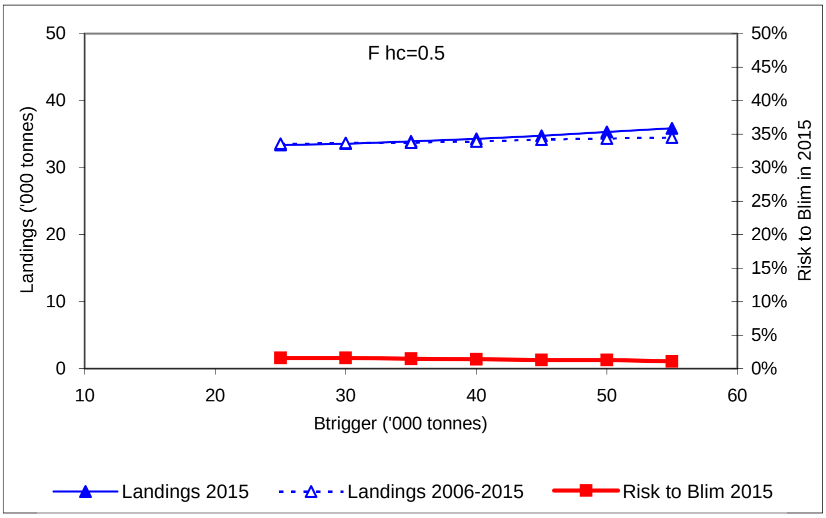
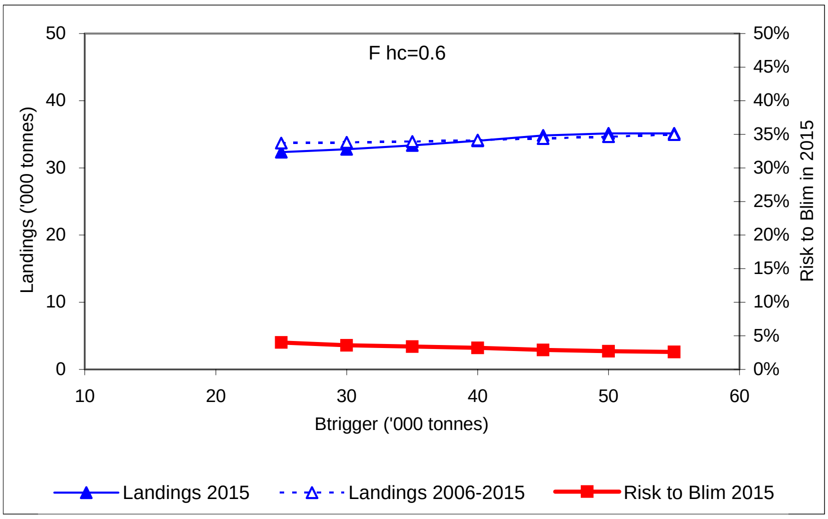


Figure 9.5 Baltic cod 22–24. Trade-off between HC F, SSB in 2015 (including 25th and 75th percentiles) and long term risk to Blim. Discards F set to 0.11.





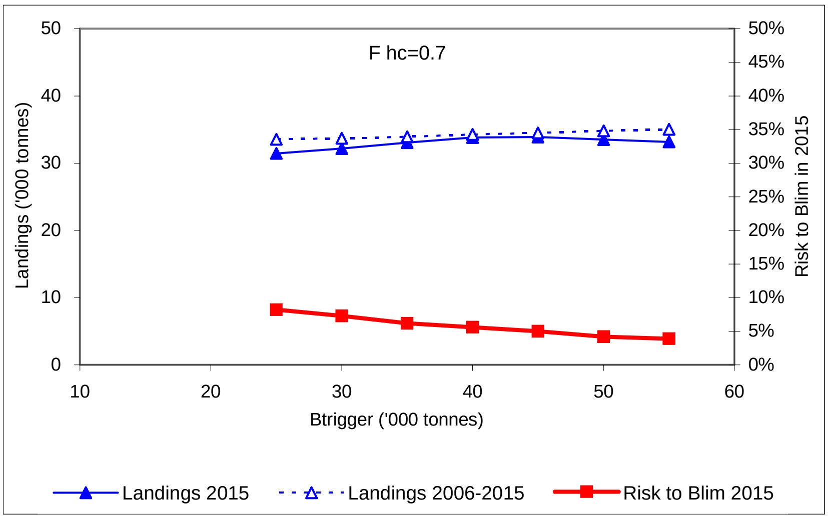


Figure 9.6 Baltic cod 22–24. Trade-off between Btrigger, long term risk to Blim and mean and long term landings. Top: Fhc=0.5. Middle: Fhc=0.6. Bottom: Fhc=0.7. Fdiscards=0.11 in all cases.

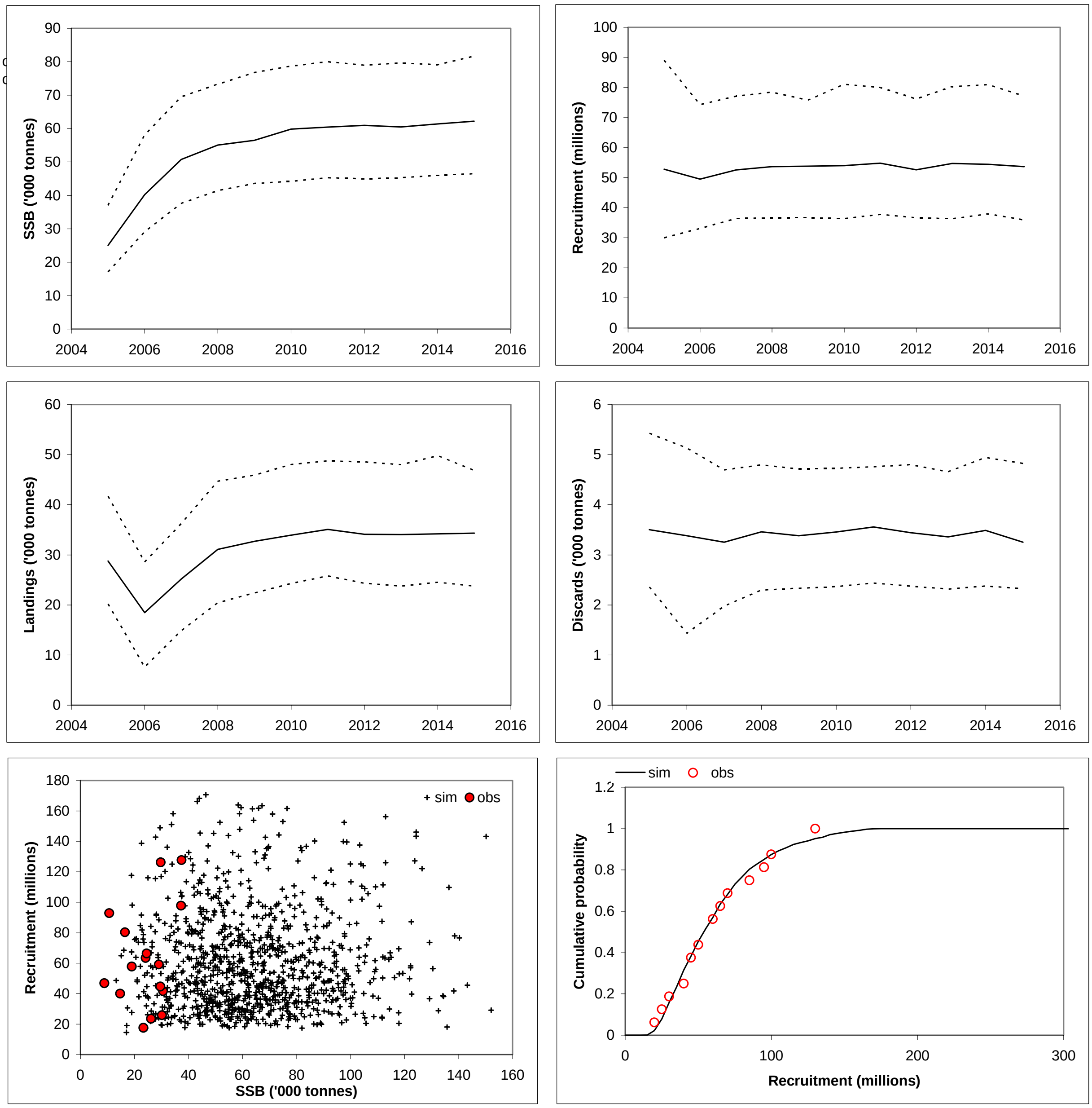


Figure 9.7 Baltic cod 22–24. F hc =0.5, F disc=0.11, No TAC constraint

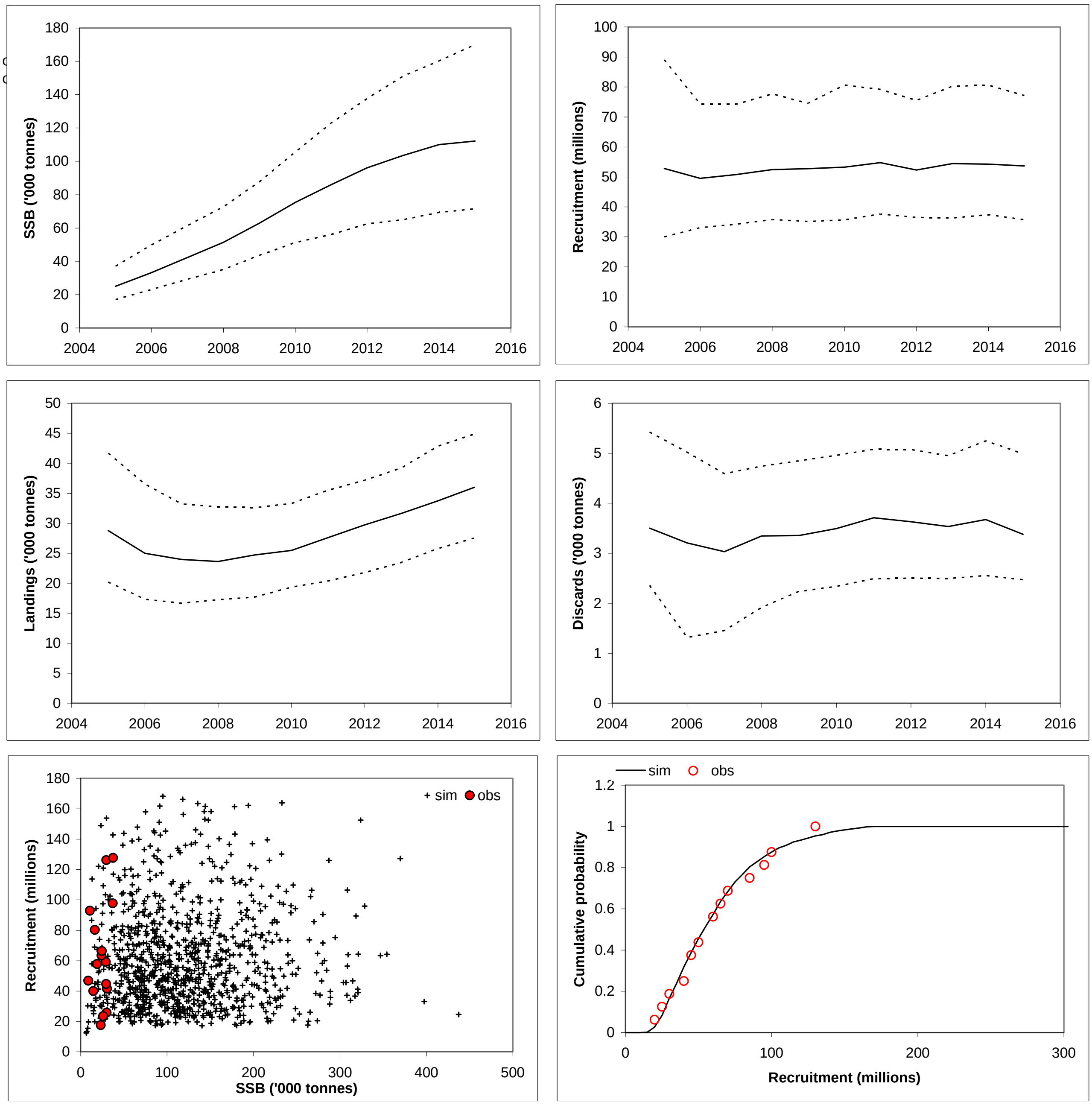


Figure 9.8 Baltic cod 22–24. F hc =0.5, F disc=0.11, 15% TAC constraint

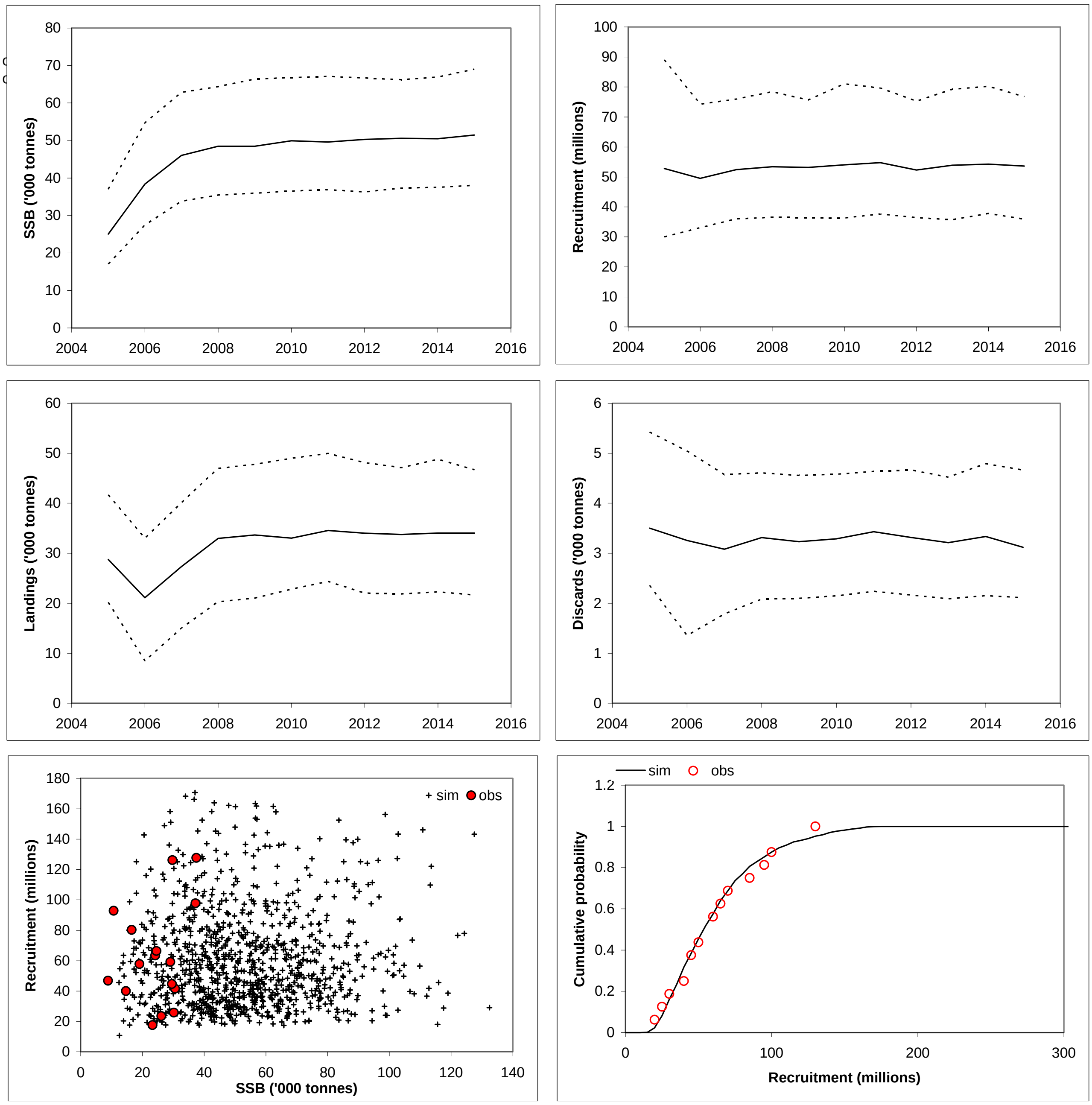


Figure 9.9 Baltic cod 22–24. F hc =0.6, F disc=0.11, No TAC constraint.

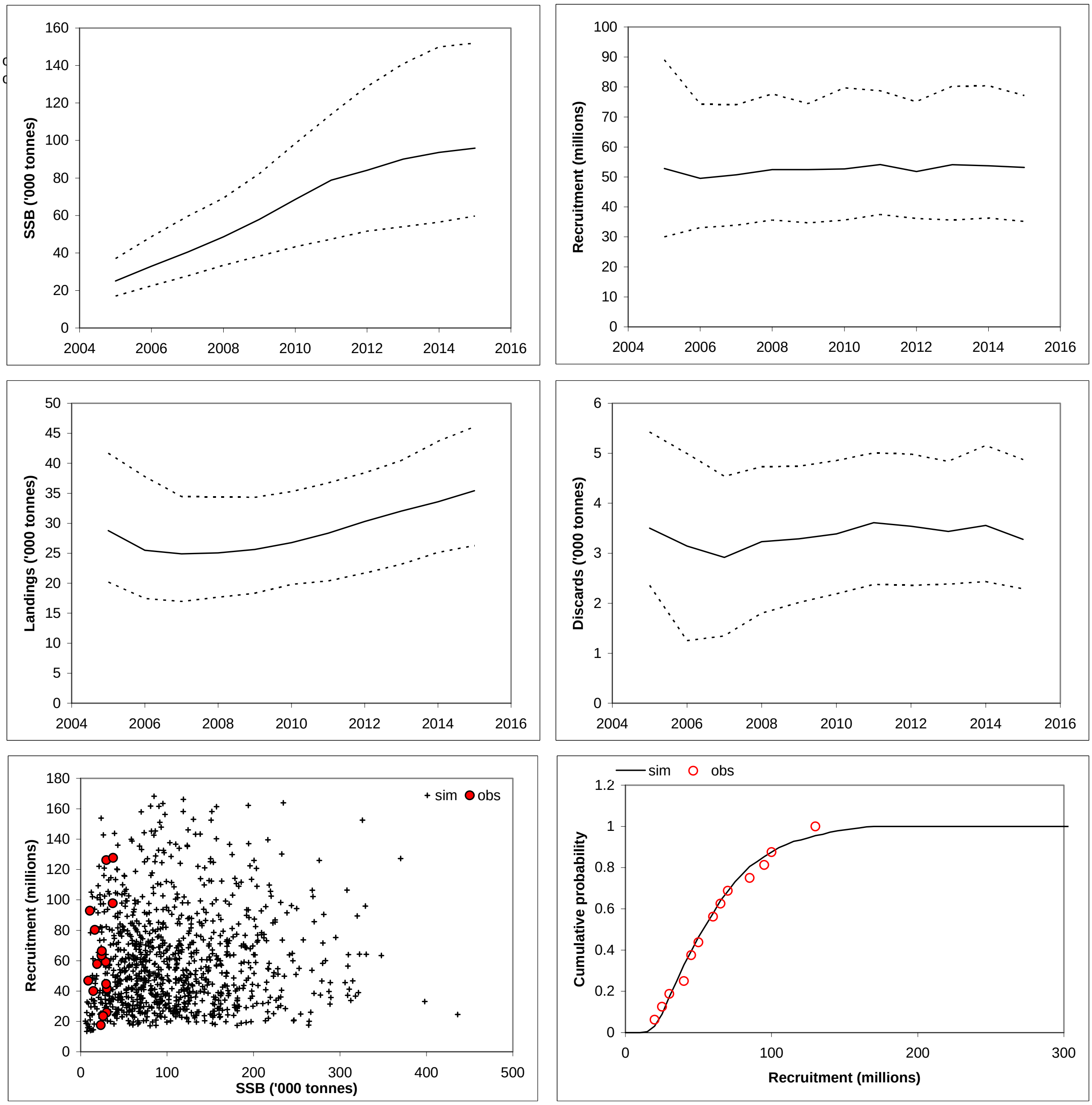


Figure 9.10 Baltic cod 22–24. F hc =0.6, F disc=0.11, 15% TAC constraint.

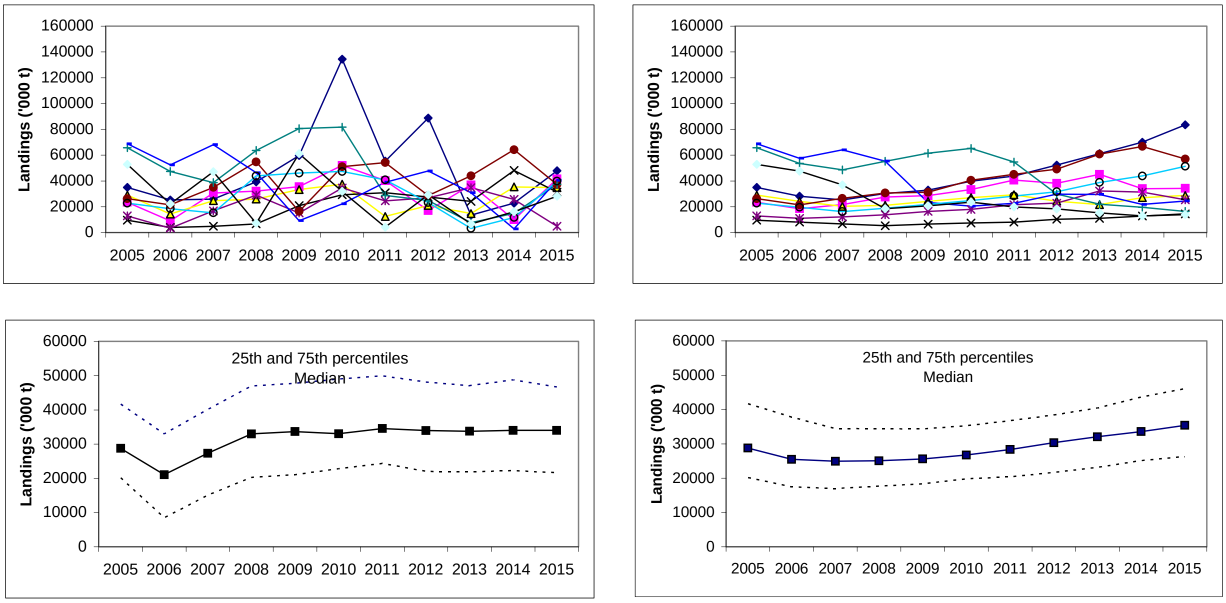


Figure 9.11 Baltic cod 22–24. Left: F hc =0.6, F disc=0.11, No TAC constraint. Right: F hc =0.6, F disc=0.11, 15% TAC constraint. Top graphs: first 10 iterations in terms of true landings (tonnes). Last graph shows the pecentiles over all (1000 iterations).

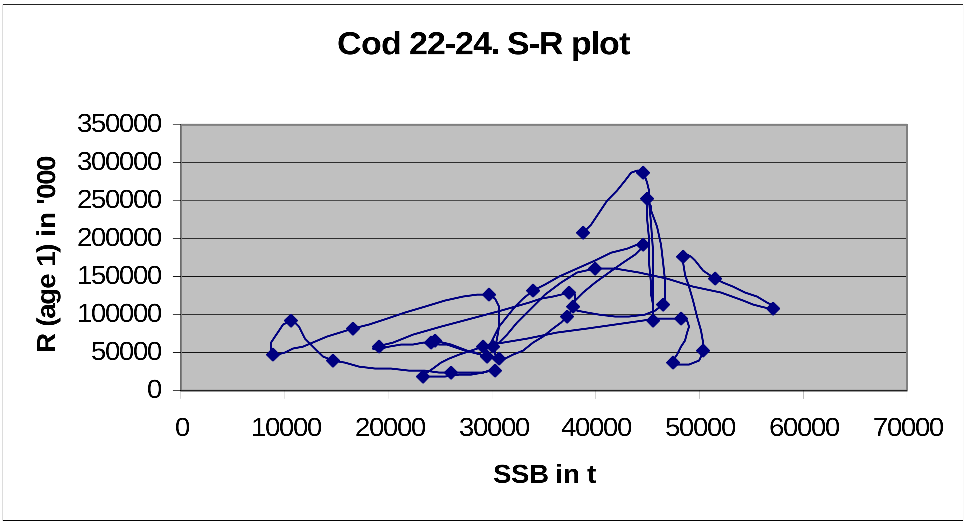


Figure 9.12 Baltic cod 22–24. Stock recruitment relationships. No obvious time trends are seen.

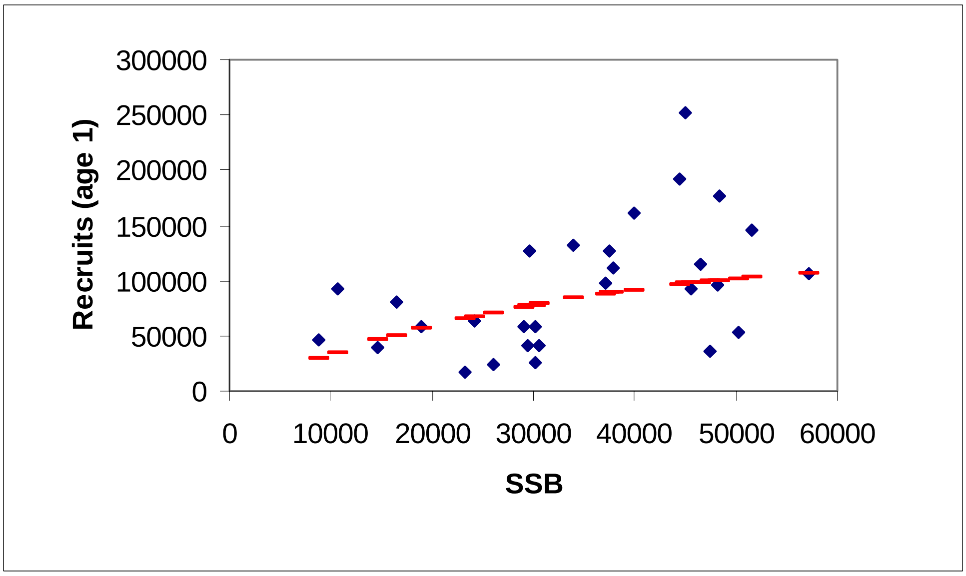


Figure 9.13 Baltic cod 22–24. Stock recruitment relationships 1970-2003. Fitted Ricker curve.

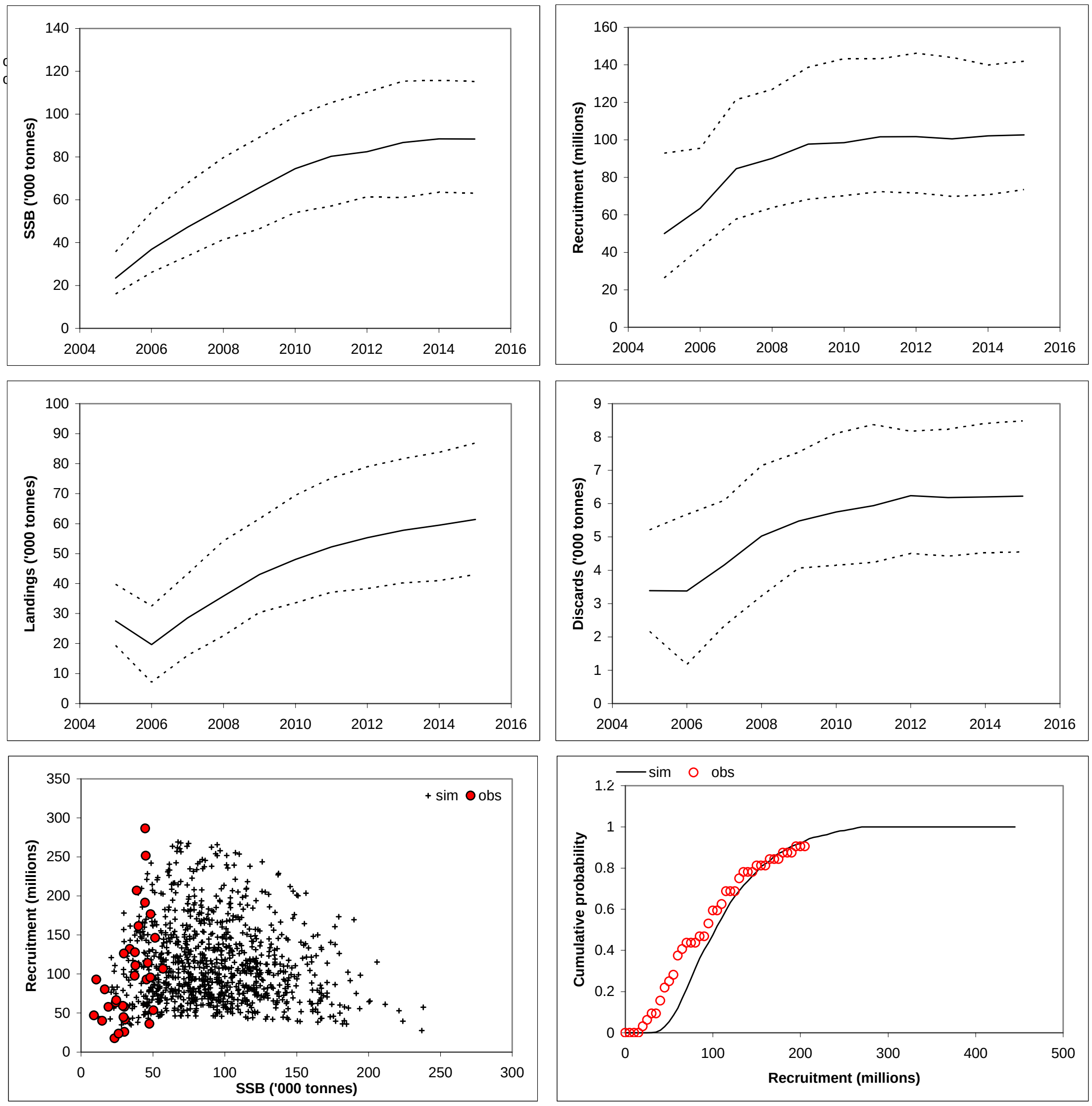


Figure 9.14 Baltic cod 22–24. Alternative stock recruitment relationship - Ricker curve from WGBFAS 2005. Fhc =0.6, Fdics=0.11, "blim"=20 000 t Btrigger=40 000 t. No TAC constraint.

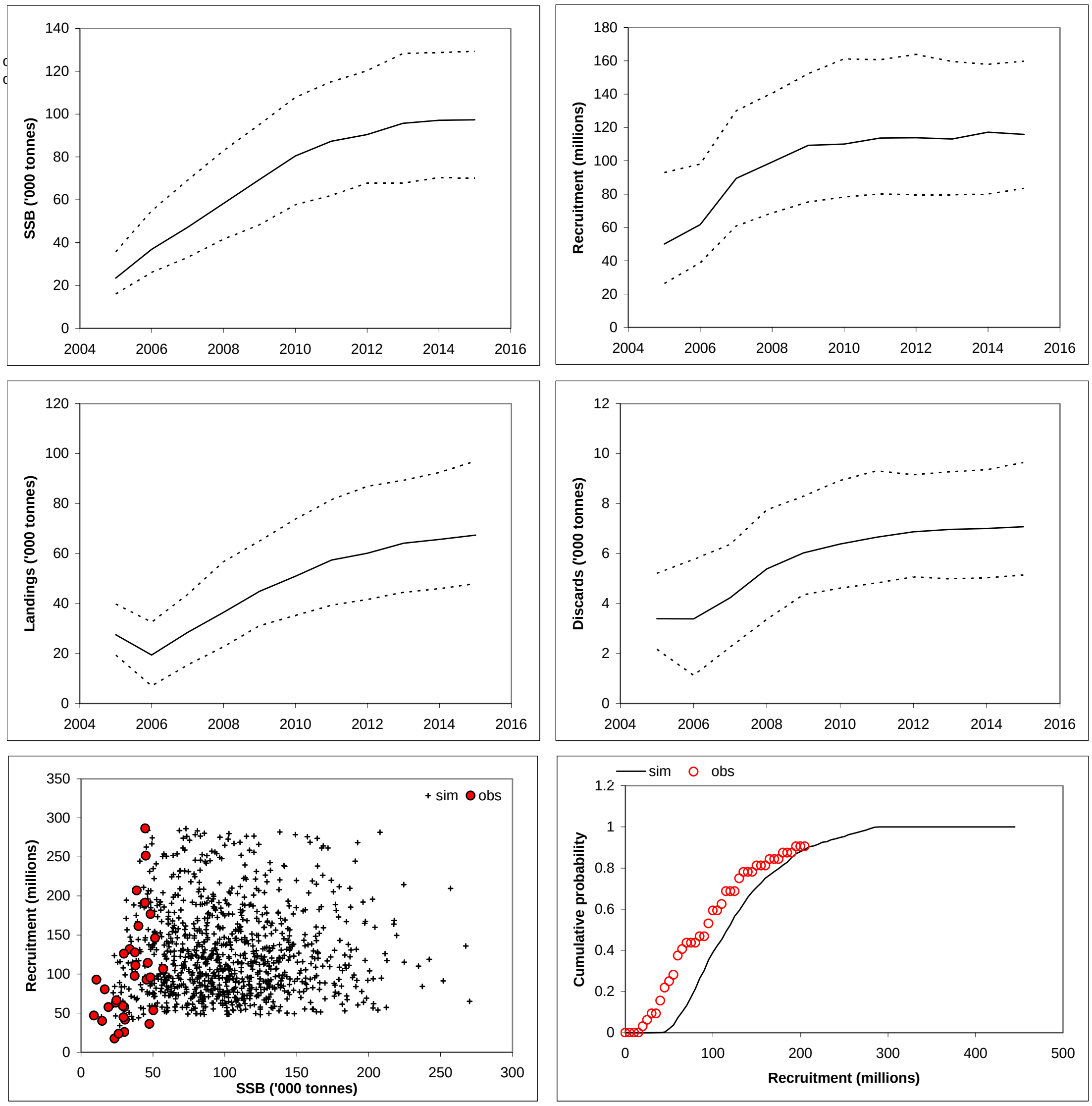


Figure 9.15 Baltic cod 22–24. Alternative stock recruitment relationship - "Ockhams razor" from segmented regression (R = 118 million age 1 at SSB above 44 000 t). Fhc =0.6, Fdics=0.11, "blim"=20 000 t Btrigger=40 000 t. No TAC constraint.

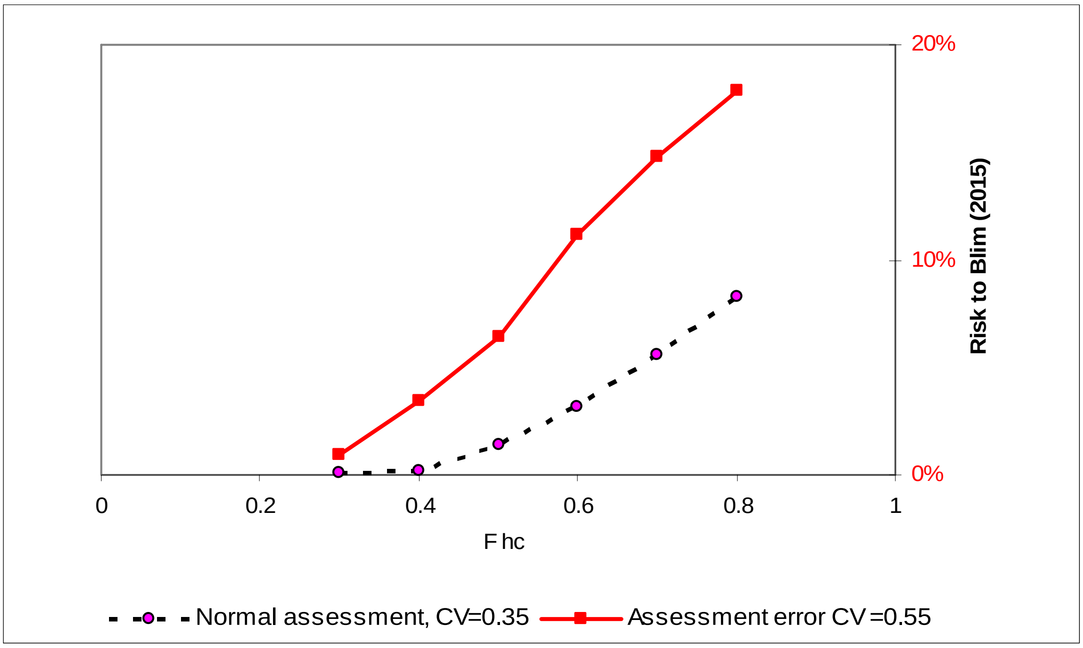


Figure 9.16 Baltic cod 22–24. Sensitivity to the assumed standard deviation in the assessment of stock status. An assessment based on only survey data (using SURBA for instance, because the uncertainty of the black landings are too great) assuming an CV of 0.55 (equal to that of cod 25-32) compared to the normal assessment based on XSA type analysis assuming a CV of 0.35. Variable of interest: probability of being below "Blim" (=20 000 t) in 2015. Different fishing mortalities for HC on the horizontal axis. F on discards assumed to be 0.11.

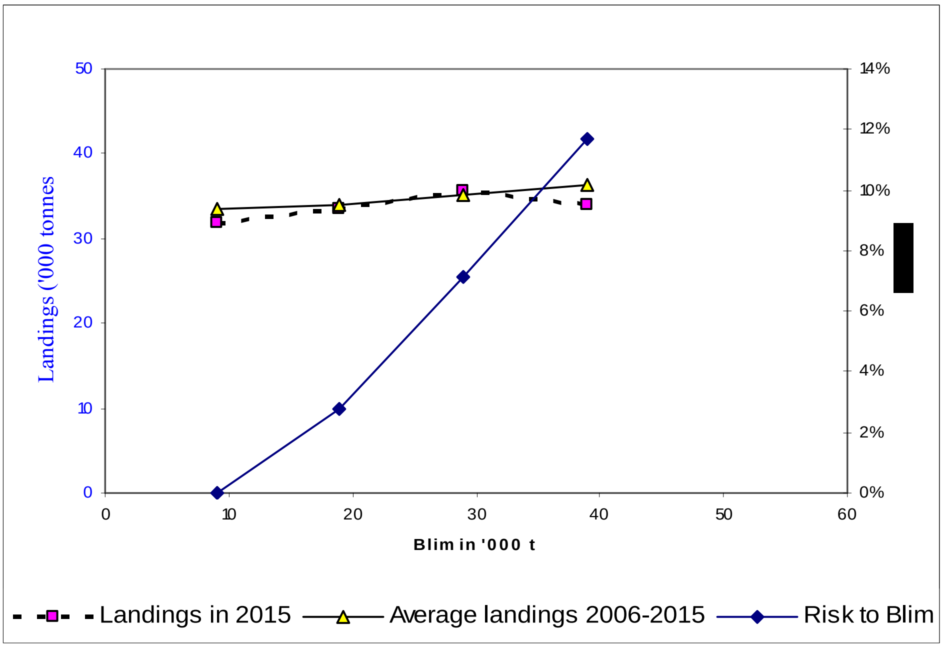


Figure 9.17 Baltic cod 22–24. Sensitivity to the assumed Blim. Different Blim's on the horizontal axis. Fhc =0.6, F on discards assumed to be 0.11. Btrigger is assumed to be twice Blim except for Blim=9000 t where it is set to 23 000 t (the present Bpa).

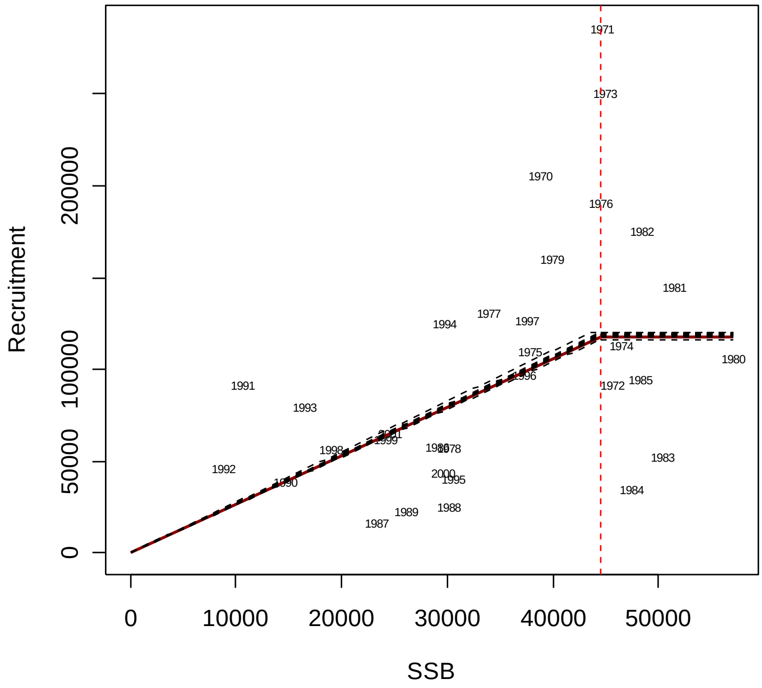
9.8 Appendix Baltic cod 22–24. The S-R relationship.

S-R data from WGBFAS 2005 (ICES, 2005c) with XSA output data from 1970–2002 (from 2002 only R (age 1) is used and this is shifted back to match the SSB from 2001 – thus the last 3 years from the XSA not used regarding SSB and regarding R the last 2 years).

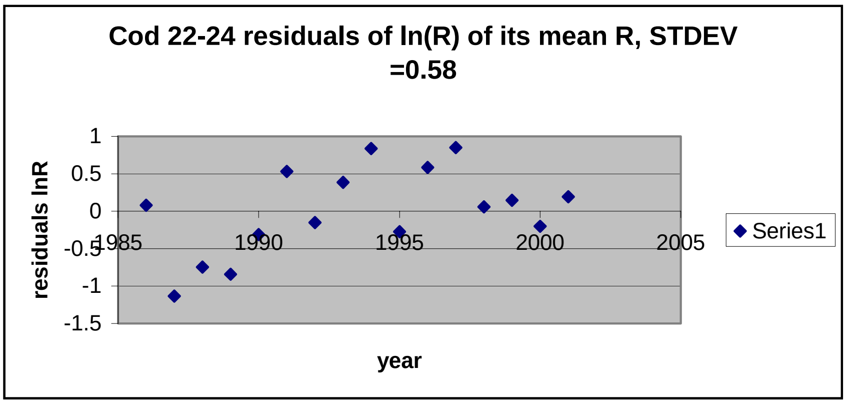
Break point at SSB = 44000 t, P<1%.

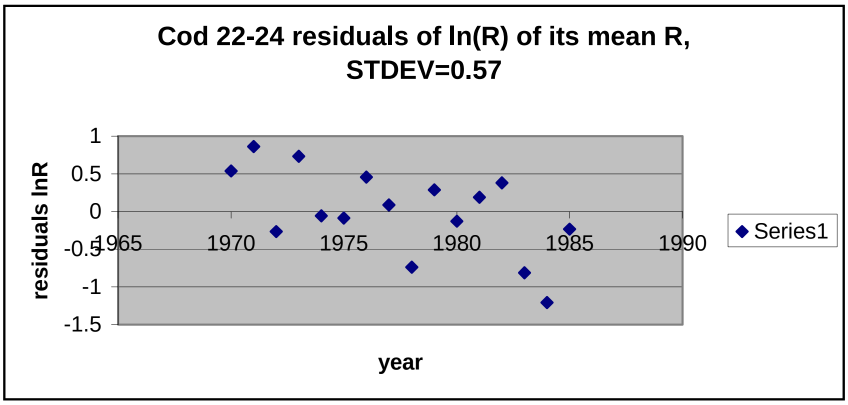
==========================

R for SSB>44000t = 118 millions at age 1.



Residuals of ln R for determining truncations in S-R models used in s3s runs. Time series divided into two time periods 1970–1985 and 1986–2001. Based on this truncations can be set to 1.2, then it will only truncate simulated Rs deviating more than the historical values have deviated from the mean by period. CV can be set to 0.60.


Cod 22-24 residuals of ln(R) of its mean R, STDEV =0.58
residuals lnR
1
0.5
0
-0.5
-1
-1.5
1985
1990
1995
2000
2005
year
Series1


Cod 22-24 residuals of ln(R) of its mean R, STDEV=0.57
residuals lnR
1
0.5
0
-0.5
-1
-1.5
1965
1970
1975
1980
1985
1990
year
Series1

10 Baltic cod 25-32

10.1 Input data

Input data for STPR3 and S3S runs (both programs in the biased corrected version) for Baltic cod 25-32 (see Table 10.1–Table 10.5) were derived from the final accepted assessment by WGBFAS (ICES 2005c). This assessment included un-reported illegal landings and discards.

The stock recruitment data for Baltic cod 25–32 has been heavily investigated during the most recent decade (see e.g. Köster *et al.*,2001). Recruitment is clearly influenced by environmental factors and by predator-prey species interactions. Therefore, alternative representations on stock and recruitment have been explored to test the sensitivity of the model results to the assumed relationship (see sensitivity analysis).

10.2 Model settings

SETTING	VALUE	JUSTIFICATION
Age range	2-8+	
Reference F age range	4-7, 2-4	
Intermediate year	F hc= 0.95, F disc = 0.03	F *status quo F*
B_{lim}	160 000 t	
Trigger biomass (B_{trig})	240 000 t	Set equal to B_{pa}
F-level 1 (both components)	0.05	Expected that there will always be some fishing for plaice
F-level 2 (both components)	not used	
F-level 3 (long-term landings mean *F*)	landings: 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 discards: 0.01, 0.02, 0.03	
Maximum TAC change	**Not constrained,** ±15%	
Maximum *F* change	**Not constrained**	
Maximum *F* possible	1,5 (hc), 0.5 (disc)	
SRR model	**Ockham (130 000, 90 000) (CV=0.3, truncation=0.4)** Ockham (174 000, 160 000) (CV=0.6,truncation=0.9) Ockham (93 000, 90 000) (CV=0.6,truncation=0.9) Ockham (387 000, 356 000) (CV=0.6,truncation=0.9)	R=174 000, gives the same slope in the S-R graph for break point SSB=160 000 t, as 387 000 for break point SSB=356 000 t. The Ockham(93 000, 90 000) a very similar slope and is based on a segmented regression on 1989 and onwards data (as used by WGBFAS 2005). Different stock recruitment curves corresponding to scenarios about high and low recruitment included in the sensitivity analysis. No depensation is included because most studies suggests that for cod 25–32, this does not occur until SSB is above app. 0.5 million t.
SRR residual variation	0.3	
SRR truncation level	0.4	
Assessment bias	**1.0**, 1.2,	Substantial assessment bias has been observed in the past but the sign of this bias is likely to change.
Assessment SD	**0.35**, 0.55	Random variation of the asssessment. The 0.55 represents a SURBA assessment situation.

Implementation bias	1.0, **1.2**, 1.4	Implementation bias for cod 25–32 has been observed in most years and sometimes up to 40%, but here assumed to be on average 20% due to expected improved enforcement.
Implementation SD	0.1	

Note: base case in bold

An example of the STPR3 option file is presented in Table 10.6.

The CV of the initial stock number estimates is assumed to be 0.6 for ages 2 and 8+ and 0.5 for ages 3–7. This is higher than CVs estimated directly from the XSA with unreported catches include by WGBFAS, and are intended to reflect the uncertainty in model specification expressed by WGBFAS. It also reflects the precision level as shown in retrospective analysis of historical assessments (see Table 10.7), where CV of SSB forecasted for the beginning of the TAC year is estimated to be around 0.6.

10.3 Analytical approach

The following analytical approach was followed:

1) Carry out F_{sq} forecasts, without a HCR to develop a base case against which comparisons can be made.

2) Explore consequences of alternative HC (human consumption) Fs (F_{hc}) and discard Fs on the probability of being below B_{lim} in 2015

3) Explore consequences of alternative time-trajectories to achieve different HCRs

4) Explore the sensitivity of the 2015 situation to the assumptions on the underlying population dynamics (e.g. stock recruitment relationship) and the perception status (e.g. standard deviation on stock status).

5) For the HCR, F is a function of SSB surviving the TAC year. The STRP3 program had to be used "creatively" by setting spawning time to end of the year and using maturity at age and weight at age in the stock shifted one year. This also means that the parameter 'number of years between spawning and recruitment' is set to 1, as SSB in year y in the calculations is in fact SSB at year y+1.

6) For the situation where ICES regards commercial data and assessment too uncertain to be a basis for a traditional forecast, a forecast can be based on only survey data, using SURBA to give initial stock numbers based on a calibration between relative commercial catch at age from SURBA and real commercial catch at age for years where no mis-reporting is suspected. The precision of these initial stock number estimates are lower than an ordinary assessment, with CVs around 0.7 per age group (as deducted from Sparholt and Tomkiewicz (2000), assuming that the new survey with the new gear TV3 is not worse than the old survey).

10.4 Results

10.4.1 Stock recruitment CV

The stock recruitment CV around the tested models are set to 0.3 based on historical time series analyses by a segmented regression analysis (Figure 10.1) and truncation 0.4. This was based on data from 1987–2001. Break point to 90 000 t. Based on fit between cumulative observed R and cumulative simulated R, R was set 130 million at age 2 at the "plateau". It should be noted that fitting to the cumulated R curve in this case has the results that the plateau of R is high and thus the slope of the S-R curve high for S values below the break point. This might be seen as an inconsistency between using the last 15 years of S-R data only in order to reflect the recent poor environmental condition for cod reproduction and at the same time have a high R at low S values (for instance compared to the entire time series analysis where the break point is at S=354 000 t, but recruitment at low S values is lower than in the base model used here). However, sensitivity analysis to various the S-R models are performed and the results can be seen below.

10.4.2 Fsq forecast

Results of the status quo fishing mortality analysis are summarized in Figure 10.2. Continued fishing at current fishing mortality (F hc=0.95, F disc=0.03) is expected to result in a SSB around 80 000 t, which is well below the Blim of 160 000 t.

10.4.3 Scanning different possible HCRs

The S3s software was used to scan the effects of different combinations of parameters on the development in stock size, recruitment, landings and discards of Baltic cod 25–32.

A first set of simulations was devoted to exploring the effects of different levels of fishing mortality. Six effort multipliers were used on landings F, so that the landings F varied between 0.3 and 0.8 and the discards F set to either 0.01 or 0.03. Results of these analyses are presented in Figure 10.3–10.5. The risk to B_{lim} in 2015 is highly dependent on the overall level of fishing mortality (Figure 10.3). At F_{sq}, the risk to B_{lim} is around 45%. In order to achieve a low risk to B_{lim} in 2015 of e.g. 5%, fishing mortality on landings should be reduced to between 0.3–0.4. Reducing discard mortality to 0.01, does not change this more than by 1–2 %.

If the objective is to obtain a high long term yield in combination with a low risk to B_{lim}, the preferred level of human consumption fishing mortality could be around F_t=0.3 (Figure 10.4). At F_t=0.3, the expected landings in the final years of the simulation are around 90 000 t, while the average (2006–2015) landings are expected to be around 75 000 t.

The explanation for the high landings at low fishing mortality can be found in Figure 10.5 where the expected SSB (including 25th and 75th percentiles) are shown. A fishing mortality around 0.3 is associated with high expected stock sizes of around 200 000 to 350 000 t, which is however still well below the maximum stock size observed in the early1980s (500 000–600 000 t). The potential effects of such high stock sizes on growth rates and reproduction are not expected to be major judged from historical experience.

The dependency between B_{trig} and risk to B_{lim} and expected landings is shown in Figure 4.6 for two scenarios on F_{hc} which give a low risk – high long term yield option: F_{hc} =0.3 and F_{hc}=0.4 (with F discards 0.02). Varying B_{trig} between 200 000 t and 300 000 t did not have a large influence on the risk to B_{lim} profile in either F scenario. Also, the expected landings were relatively insensitive to the B_{trig} value.

10.4.4 Alternative time trajectories for HCRs

Four scenarios were selected for further analysis on the expected time trajectories that they imply. The selection was based on the criteria of low risk to Blim (at or below 5%) and high long term landings. Discards mortality was set to 0.02. The four cases were:

- Fhc =0.3, no cap on interannual TAC change (Figure 10.8)
- Fhc =0.3, cap of 15% on interannual TAC change (Figure 10.9)
- Fhc = 0.4, no cap on interannual TAC change (Figure 10.10)
- Fhc =0.4, cap of 15% on interannual TAC change (Figure 10.11)

The results of the simulations using STPR3 are summarized in 6 graphs: SSB, recruitment, landings, discards, SSB-recruitment pairs and cumulative probability profiles of recruitment between simulated and observed (stock assessment) values.

In the cases where no constraint is applied on the inter-annual change in TAC, the median and 25th and 75th percentiles of landings and discards show a large decrease in 2006 compared to 2005, after which the stock is expected to recover rapidly due to the lower fishing mortality on landings. When a fishing mortality of $F_{hc} = 0.3$ is applied, the stock is expected to increase to around 275 000 t. and with $F_{hc} = 0.4$ to 225 000 t. The difference between these two scenarios can be explained by the overall less old fish in the latter case. However, the catches are similar in the two cases.

The introduction of a cap on the inter-annual change in TAC (15%) is shown in Figure 10.9 and Figure 10.11. Note that this cap only applies to the landings and not to the discards, so that discards are allowed to be constant at 0.02. The introduction of a cap on TAC change appears to have a very negative effect on the stock trajectory in the beginning of the period but positive in the end where the stock are build up above the level in the “no cap” simulations. However, the average landings are also significant lower than in the “no cap” simulations. It is also apparent that recruitment is going to zero in some of the “cap” simulations, and stock collapse is a risk. The catches in the “cap” simulations are more stable from year to year of course (Figure 10.11).

10.4.5 Sensitivity analysis

The senstivity to the underlying assumptions was explored by investigating different stock recruitment relationships (Figure 10.13–10.14) and different assumptions about the uncertainty in the stock status (perception). The comparison of different stock recruitment relationships is shown in Figure 10.14. The conclusion from the graphs is that the risk to B_{lim} is sensitive to the assumed stock recruitment relationship, especially when HC fishing mortality is also high. When the recruitment scenario is lower (i.e. lower recruitment at given stock size, e.g. due to less favourable environmental situations), the risk to B_{lim} would be higher.

The sensitivity to the assumed variance in stock status is shown in Figure 10.15. A SD of 0.35 was used as the base case. At higher standard deviations, the risks to B_{lim} is also higher. The real interest here would be to model the interaction between bias in the assessment and feedback into the management procedure. However, this is not feasible within the STPR framework and this has therefore not been pursued at present.

10.5 Discussion

If the objective is to obtain a high long term yield in combination with a low risk to Blim, the preferred level of human consumption fishing mortality could be in the area of $F_{hc} =0.3$ to $F_{hc} =0.4$ (Figure 10.4). At $F_{hc} =0.4$, the expected landings in the final years of the simulation are around 90 000 t, while the average landings (mean 2006–2015) are expected to be around 75 000 t. No major improvement to the stock development and to the landings is expected by the additional reduction of the already low discard mortality. The simulated fishing mortalities used are all expected to keep the stock well inside what has been experienced in the past and the potential effects of stock size on growth rates and reproduction are expected to be minor.

The simulation procedure in STPR3 does not incorporate a full feedback loop, where an operating model is used on which a stock assessment process is carried out, which then forms the basis for a management decision and an implementation. The stock assessment process and the implementation process are mimicked in STPR3 by application of a fixed bias and a standard deviation. Because the stock assessment process is not explicitly incorporated, we cannot evaluate how a stock could be traced at lower fishing mortalities when in general stock assessment models tend to break down. It is similarly not possible to simulate the effects of changing assessment bias in the high F case that non-reporting may increase when TACs become increasingly restrictive.

The individual STPR3 analysis were presented as percentiles of 1000 bootstrap iterations. We also looked at individual bootstrap realizations of two of the explored scenarios in order to evaluate the consistency between the iterations. Results are summarized in Figure 10.12 for the scenarios Fhc =0.4 both without cap on TAC variation and with a 15% cap on variations. We looked at the true landings for the first 10 iterations and we compared this to the percentile distribution of the true landings of all 1000 iterations. Both scenarios were based on biomass thresholds of 160 000 t (B_{lim}) and 240 000 t (B_{trig}). The scenario without TAC constraint gave very high variations in true landings. This was caused by the observed F which often jumped from very low to very high values on the basis of an uncertain stock status which could re-estimate the size with a 30% error. The individual trajectories of true landings are much more varying than would be implied by the percentile distributions over all iterations. The scenario with a 15% cap on TAC variation appeared to behave much better, because it would not allow the F to jump up and down given that the TAC could not vary by more than 15%. Thus the 15% cap could act as a useful method to dampen the noise in the assessment process. However, this benefit is on the cost of significant lower average catches in all years except 2006 and 2007.

The simulations are based on an F_{sq} assumption fro the current year (2005). From this assumption, a catch (both landings and discards) is derived. This is also used as a basis for the application of the cap on TAC variations. Therefore, the initial reductions in TACs in the initial years of the simulation can be somewhat biased as the status quo catch forecast for 2004 is substantially higher than the agreed TAC. However at present this is a limitation in STPR3 which could not be remedied during the meeting.

The results of the simulations are sensitive to the assumptions within the model. The uncertainty in stock status and the uncertainty in the stock-recruitment relationship are directly reflected in, for example, the risk to B_{lim}. A higher uncertainty in the assessed stock status will mean that more often “wrong” decisions will be derived from the “assessment” thus giving rise to higher risks of depletion of the stock. If the recruitment at a given stock size is lower than expected, than the derived yield may be too high, which again could give rise to a higher risk to B_{lim}. In general these sensitivities mainly operate at higher fishing mortalities; strategies which aim at lower fishing mortalities appear to be less sensitive to the model uncertainty.

10.6 Conclusions

The simulations illuminate the outcomes of low F regimes. The simulations do however reflect decision rules which assume that Fishing mortality and Biomass can be measured and that TAC’s or other measures to restrict F are impelemented efficiently. None of these assumptions are presently true as there are indications of considerable amounts of non-reported landings indicating lack of implementation and making estimates of F and B very uncertain. The time series of surveys is too short to provide an alternative basis for F and B estimation as the survey was revised in 1996. The simulations illustrate what would be expected if some means of effectively reducing F are implemented in the future.

If the objective is to obtain a high long term yield in combination with a low risk to B_{lim}, the preferred level of human consumption fishing mortality could be in the area of F_{hc} =0.3 - 0.4 (Figure 10.4). At F_t =0.3- 0.4, the expected landings in the final years of the simulation are around 90 000 t, while the average landings are expected to be around 75 000 t (mean 2006–2015). No major improvement to the stock development and to the landings is expected by the additional reduction of the already low discard mortality. The cap on annual TAC variations is expected to improve the performance in terms of minimising short term landings variation and in terms of making the system less sensitive to the noise in annual assessments, but at the cost of reduced medium term catches and (a small) risk of stock collapse. At an F_{hc} in the range of

0.3 to 0.4 the likelihood of meeting objectives and performance criteria is furthermore insensitive to assumption regarding stock productivity and assessment error and bias.

If the normal assessment cannot be performed due to uncertainties in un-reporting of commercial an assessment based on survey data only can be performed. This will however have a lower precision than a normal assessment and in order to avoid a high risk to Blim Fhc should rather be 0.3 than 0.4 (Figure 10.15).

10.7 Summary presented in response to request

The starting population for the simulations on eastern Baltic cod was taken from the last ICES assessment made in 2005 (ICES CM 2005/ACFM:19) which includes discards and estimates of misreporting. The exploitation pattern used is thus based on assessments including catches and discards.

Evaluations demonstrated that under the current exploitation pattern target fishing mortalities (all catches) close to 0.3 (ages 4–7) result in a low risk to reproduction and high long-term yields.

The management plan is only in accordance with the precautionary approach if effectively implemented and enforced. The situation in recent years with significant amounts of non-reported cod landings indicates that overall, enforcement has not been effective

The management plan assumes that there are estimates of fishing mortality (F) and spawning stock biomass (SSB) available. Such estimates are derived from time series of commercial catch data and of stock abundance indices obtained from scientific research cruises and proper estimates of F and SSB can only be provided if these input data are complete and reliable. The situation in recent years with significant amounts of non-reported cod landings renders scientific estimates next to being useless in the context of a management plan which assumes precise estimates of present stock parameters.

When catch data are unreliable only indices based on abundance survey time series of stock and mortality trends can be provided. The major survey time series includes a break in 2000 when gears and design were standardized. There has been significant work done on modelling the bridge before and after 2000 but there are uncertainties related to this break in the time series that are not and probably cannot be resolved. Therefore, a consistent time series is only available for 2000 and onwards.

The simulations have neither taken biological interactions nor density dependent growth/maturity into account and thus, are merely indicative of the direction of outcomes from the management strategies prescribed in the joint request. However, the conclusions regarding the general direction required – significant reductions in fishing mortality to achieve simultaneously a low risk of SSB falling below the conservation limit B_{lim} and high long-term yield – is not sensitive to density dependent effects.

It is therefore suggested that an implementation of long term management plans is based on an adaptive approach whereby the development of the stock is monitored as the effects of the reduced fishing mortality are developing and the specific numerical values within the management plan may then be modified on basis of the outcomes of the fishing mortality reductions.

Table 10.1 Baltic cod 25–32. Natural mortality and Selection at age (fleet1 = human consumption, fleet2=discards) (ple.adt).

```
0.99 0.99
2  0.2000 0.07 0.06
3  0.2000 0.43 0.03
4  0.2000 0.88 0.00
5  0.2000 1.06 0.01
6  0.2000 0.87 0.00
7  0.2000 0.98 0.00
8  0.2000 0.98 0.00
```

Table 10.2 Baltic cod 25–32. Initial population size and variance coefficients (ple.nin).

```
2   195425  0.6 0 0 0 0 0 0
3    64887  0 0.5 0 0 0 0 0
4    39715  0 0 0.5 0 0 0 0
5    21344  0 0 0 0.5 0 0 0
6     3789  0 0 0 0 0.5 0 0
7     1687  0 0 0 0 0 0.5 0
8      786  0 0 0 0 0 0 0.6
```

Table 10.3 Baltic cod 25–32. Proportion mature (ple.prm).

```
1999    0.36    0.83    0.94    0.96    0.96    0.98    0.98
2000    0.36    0.83    0.94    0.96    0.96    0.98    0.98
2001    0.36    0.83    0.94    0.96    0.96    0.98    0.98
2002    0.36    0.83    0.94    0.96    0.96    0.98    0.98
2003    0.36    0.83    0.94    0.96    0.96    0.98    0.98
2004    0.36    0.83    0.94    0.96    0.96    0.98    0.98
```

Table 10.4 Baltic cod 25–32. Weight in the catch by fleet (fleet 1 = human consumption, fleet 2 = discards) (ple.wc).

```
2004    1       0.4462  0.6711 0.9272  1.3493  2.0538  3.3782  5.6310

2004    2       0.2700  0.3030 0.3650  0.9400  1.2340  1.5430  2
```

Table 10.5 Baltic cod 25–32. Weight in the stock (ple.ws).

```
2000    0.606   0.986   1.272   2.068   3.462   6.093 7
2001    0.487   1.004   1.349   1.928   2.594   3.407 7
2002    0.527   0.889   1.185   1.774   2.238   4.142 7
2003    0.495   0.874   1.262   1.803   2.266   2.861 7
2004    0.536   0.881   1.295   1.996   3.075   4.038 7
```

Table 10.6 Baltic cod 25–32. Example of a simulation option file.

2 8	Ages
1	Number of years between spawning and recruitment
4 7	Mean F range for h.cons.
2 4	Mean F range for discards
2005	The intermediate year
F	Int. yr.: Constraint type for h.cons. (C = catch, F = mortality
0.95	Int. yr.: Value of constraint for h.cons.
F	Int. yr: Constraint type for discards (C = catch, F = mortality
0.03	Int. yr.: Value of constraint for discards
0.0 0.00 0.00 30000.0 30000	HCR 1: lower bound on SSB, max F hc, max F disc, max catch HC, max
160000.0 0.4 0.00 300000.0 30000	HCR 2: lower bound on SSB, max F HC, max F disc, max catch HC, max
240000.0 0.4 0.022 600000.0 60000	HCR 3: lower bound on SSB, max F HC, max F disc, max catch HC, max
1	Linear increase of F in level 2? (0 = no, 1 = yes)
0.0 0.0 0.0	Annual catch variation: max change (both, h.cons., disc)
0.0 0.0 0.0	Annual catch variation: min change (both, h.cons., disc)
0.0 0.0 0.0	Annual F variation: max change (both, h.cons., disc)
0.0 0.0 0.0	Annual F variation: min change (both, h.cons., disc)
0.0000000 0	Min increase in SSB, which fleet takes burden (0 = both)
1.5 0.5	Max possible F by fleet
1.5 0.5	Max permitted F by fleet
2 1 358000 352000 0.00000000 0.60 0.90000	Recruitment: Shepherd, lognormal, alpha, beta, gamma, sigma (SD), truncation
0	Number of autoregressive terms used
0.0 0.0 0.0 0.0 0.0	AR terms (from RecAn output for AR(1))
0	Apply SR relation in year 0? (0 = no, 1 = yes)
1.0000000 0.010000 0	Assessment bias multiplier (mean and SD)
1.2000000 0.0100000	TAC deviation multiplier (mean and SD)
1	Initial numbers (0: det, 1: log, 2: norm, 3: bootstrap)

Table 10.7. Cod Central Baltic (Sub-divisions 25–32). CV of 'forecasted' SSB can be calculated to about 0.60 from the table below.

			SSB start of the "TAC year", i.e. SSB ("TAC year) given the actual catch taken in the "TAC year" ('000 t)	
"Current year"	"TAC year" +1	Catch in "TAC year" '000t	"Forecasted"	WGBFAS 2005 estimate "the truth"
1988	1990	179	367	216
1989	1991	154	285	151
1990	1992	123	253	92
1991	1993	55	143	114
1992	1994	45	82	195
1993	1995	93	126	244
1994	1996	108	NA	170
1995	1997	122	NA	149
1996	1998	89	342	112
1997	1999	67	220	90
1998	2000	73	203	115
1999	2001	66	141	105

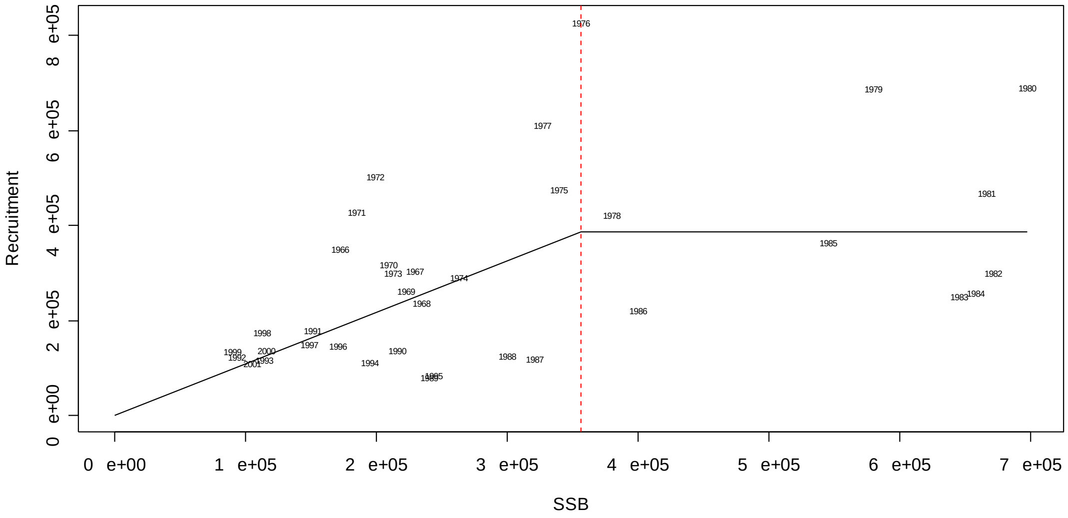


Figure 10.1 Baltic cod 25–32: stock recruitmentr plot with break point from segmented regression analysis on time series from 1966–2001. R at age 2.

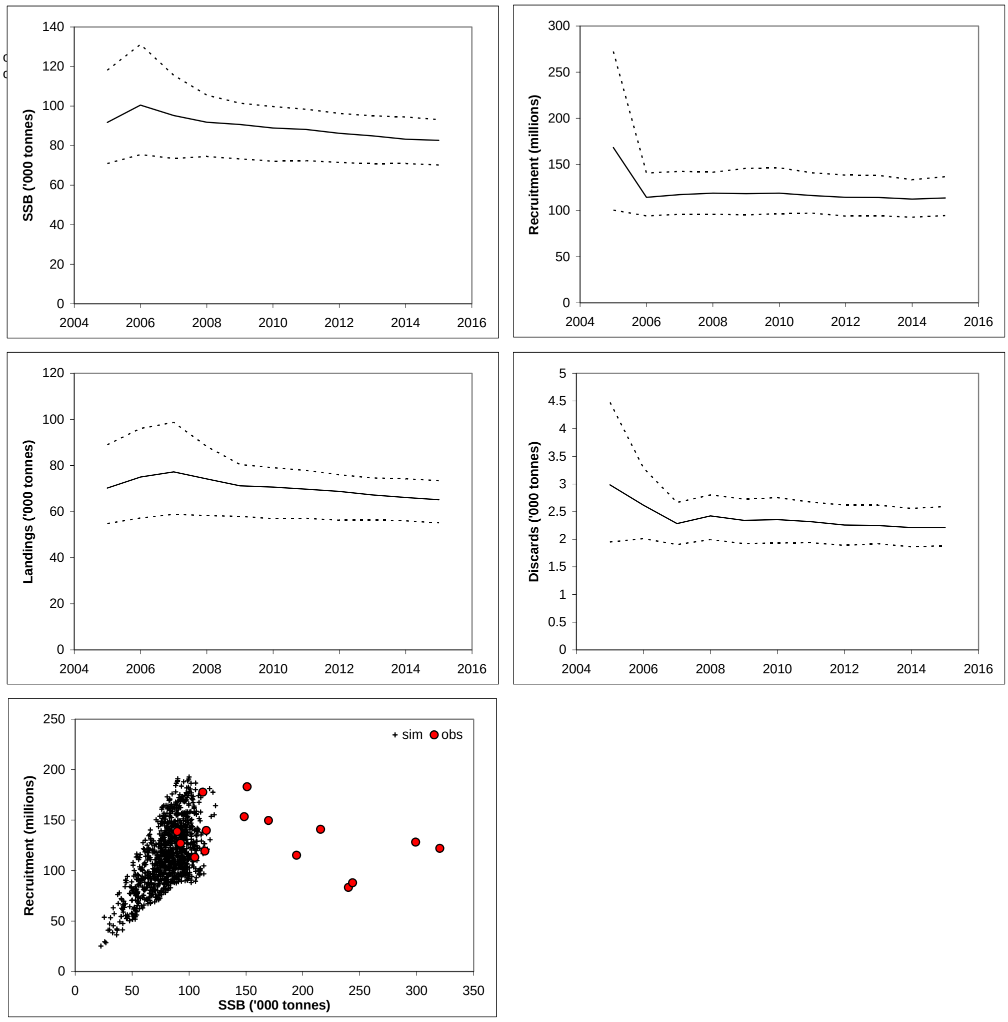


Figure 10.2 Baltic cod 25–32. STPR3b analysis using Fsq for both human consumption (0.95) and discards (0.03). Ockhams stock recruitment relationship (SSB break point at 90 000 t and R = 130 million age 2 above that SSB, with SD 0.3, truncation 0.4). Solid lines indicate the median of the bootstrapped distributions, the dotted lines the 25th and 75th percentiles. Trends in SSB, recruitment, landings and discards. Relationship between SSB and recruitment in simulations and as observed in most recent stock assessment.

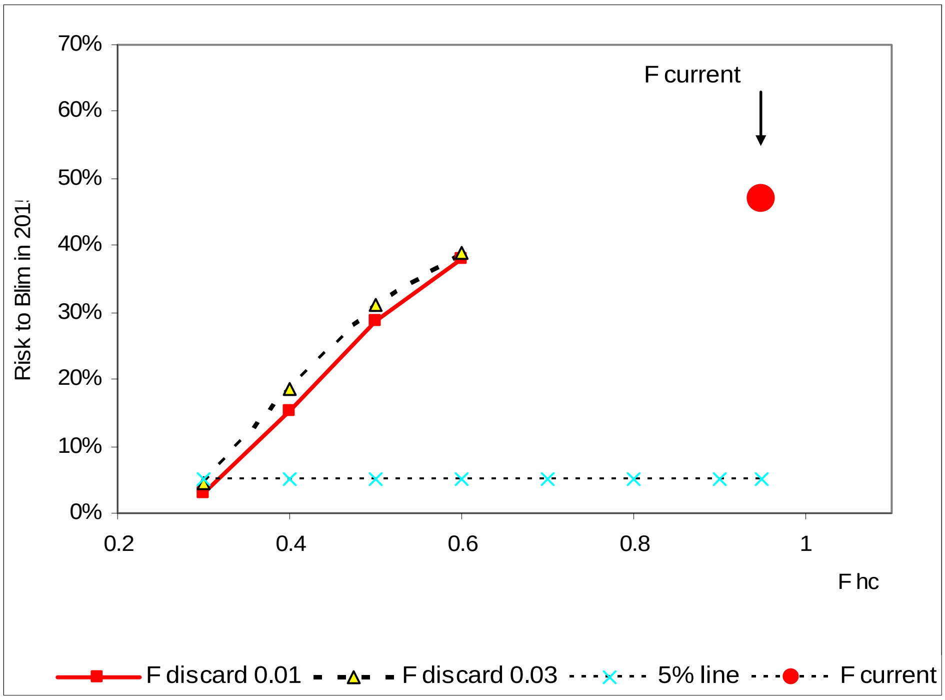


Figure 10.3 Cod Baltic 25-32.. Risk to Blim in 2015 at different HC F's. Discards F are constant at 0.03 (status quo 2004 value) or reduced to 0.01. HCR with Blim 160 000t and Btrigger 240 000t; the F value shown is that for SSB above Btrigger.

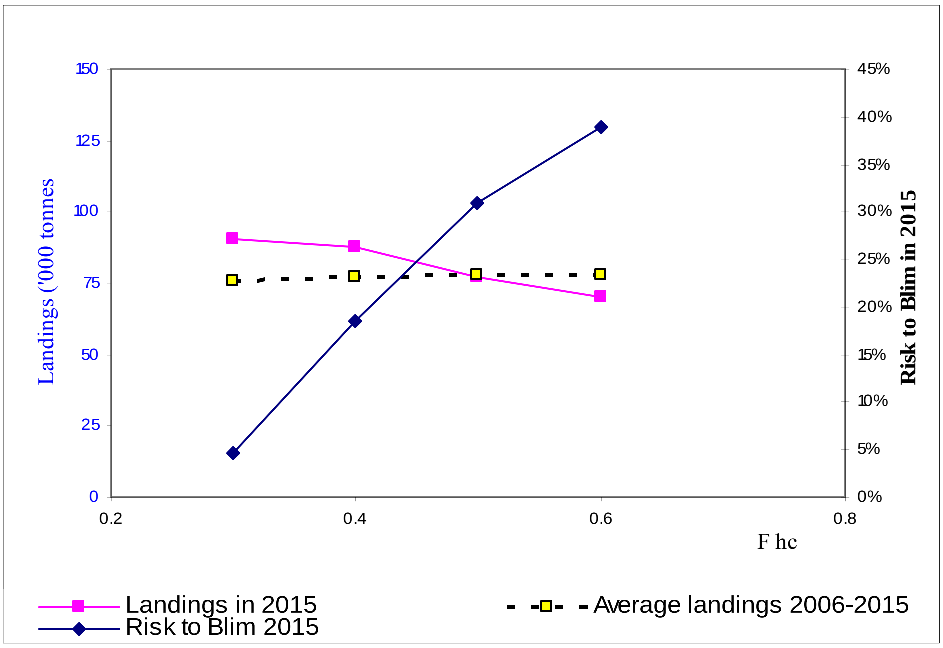


Figure 10.4 Cod Baltic 25–32. Trade-off between HC fishing mortality, long term risk to Blim and short term and long term landings. Discards F are set to 0.03.

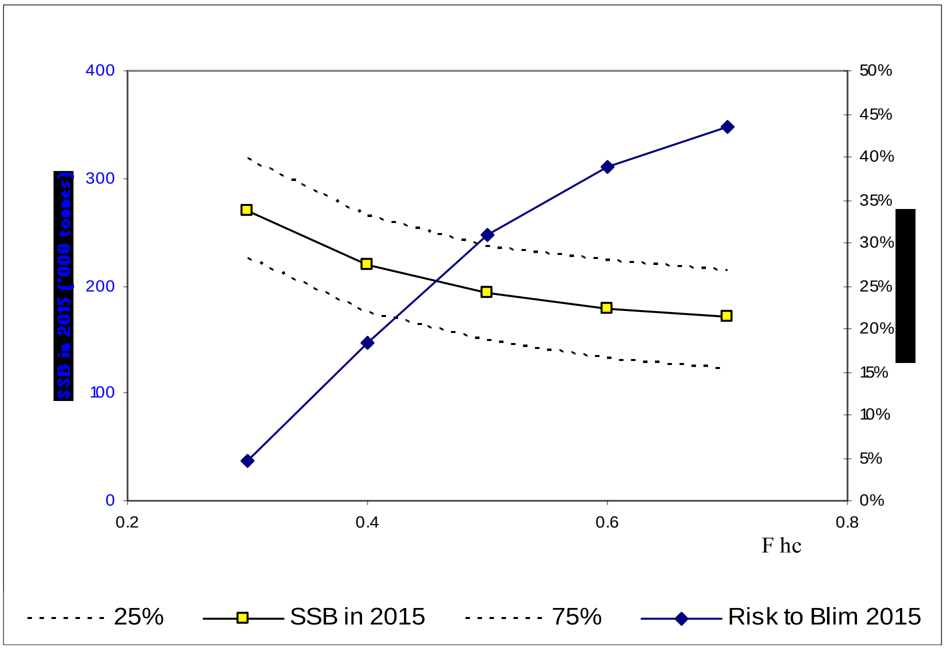


Figure 10.5 Baltic cod 25–32. Trade-off between HC F, SSB in 2015 (including 25th and 75th percentiles) and long term risk to Blim. Discards F set to 0.03.

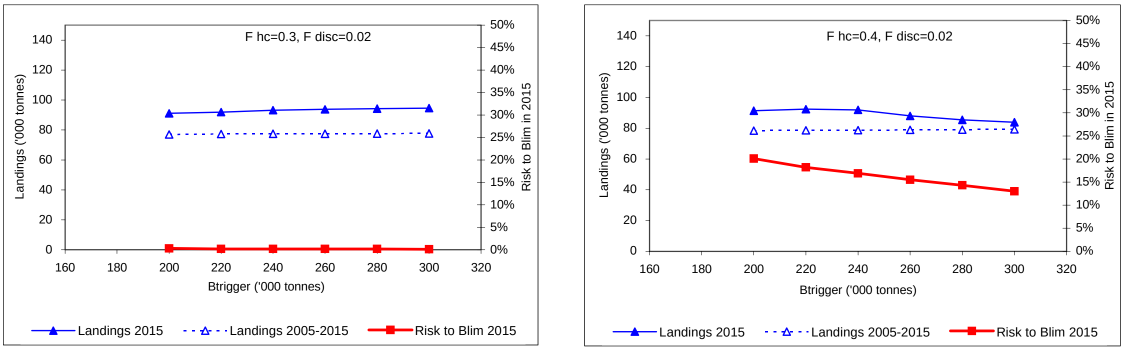


Figure 10.6 Baltic cod 25–32. Trade-off between Btrigger, long term risk to Blim and mean and long term landings. Left: F hc=0.3. Right: F hc=0.4.

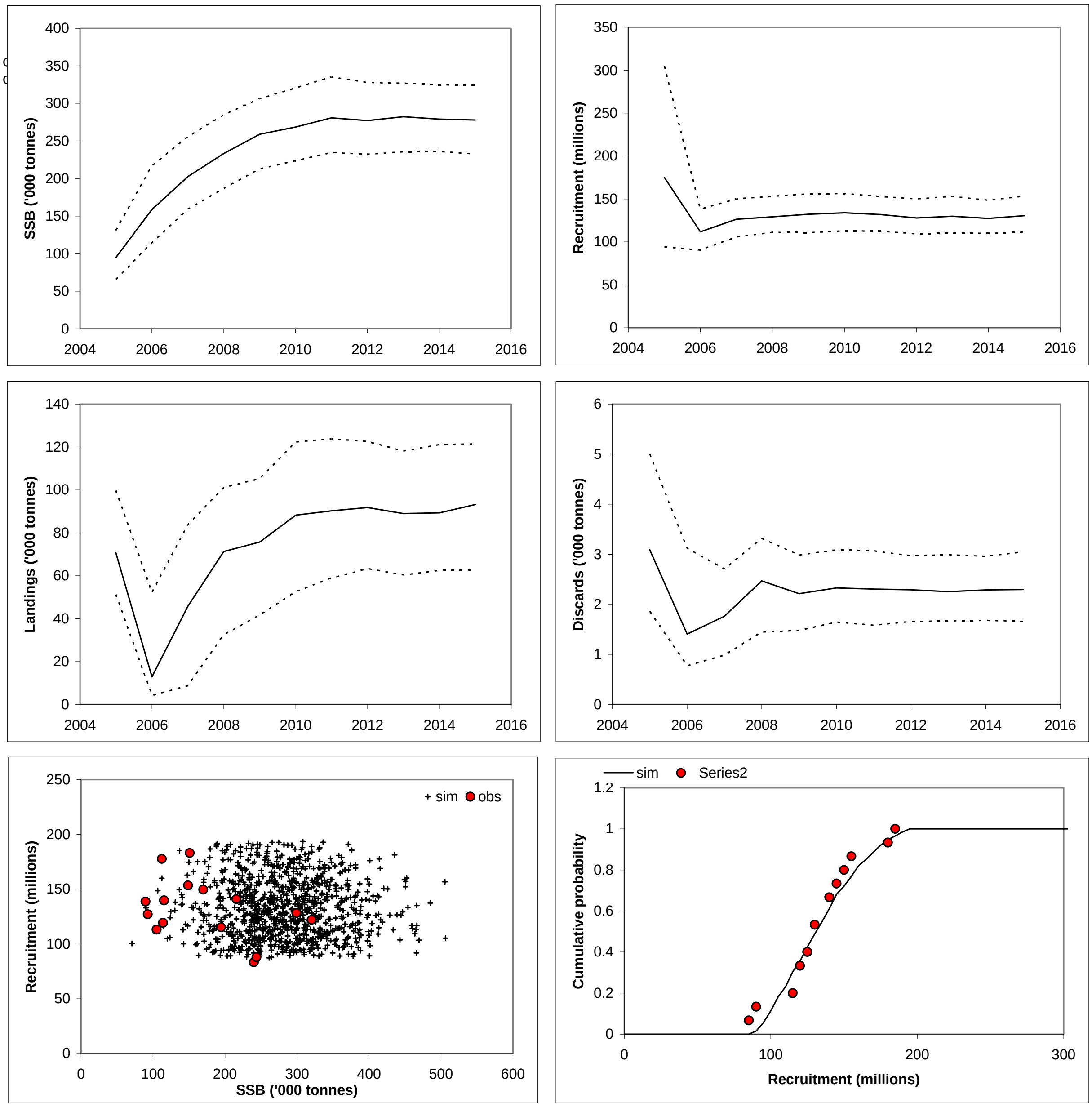


Figure 10.7 Baltic cod 25–32. F hc =0.3, F disc=0.02, No TAC constraint.

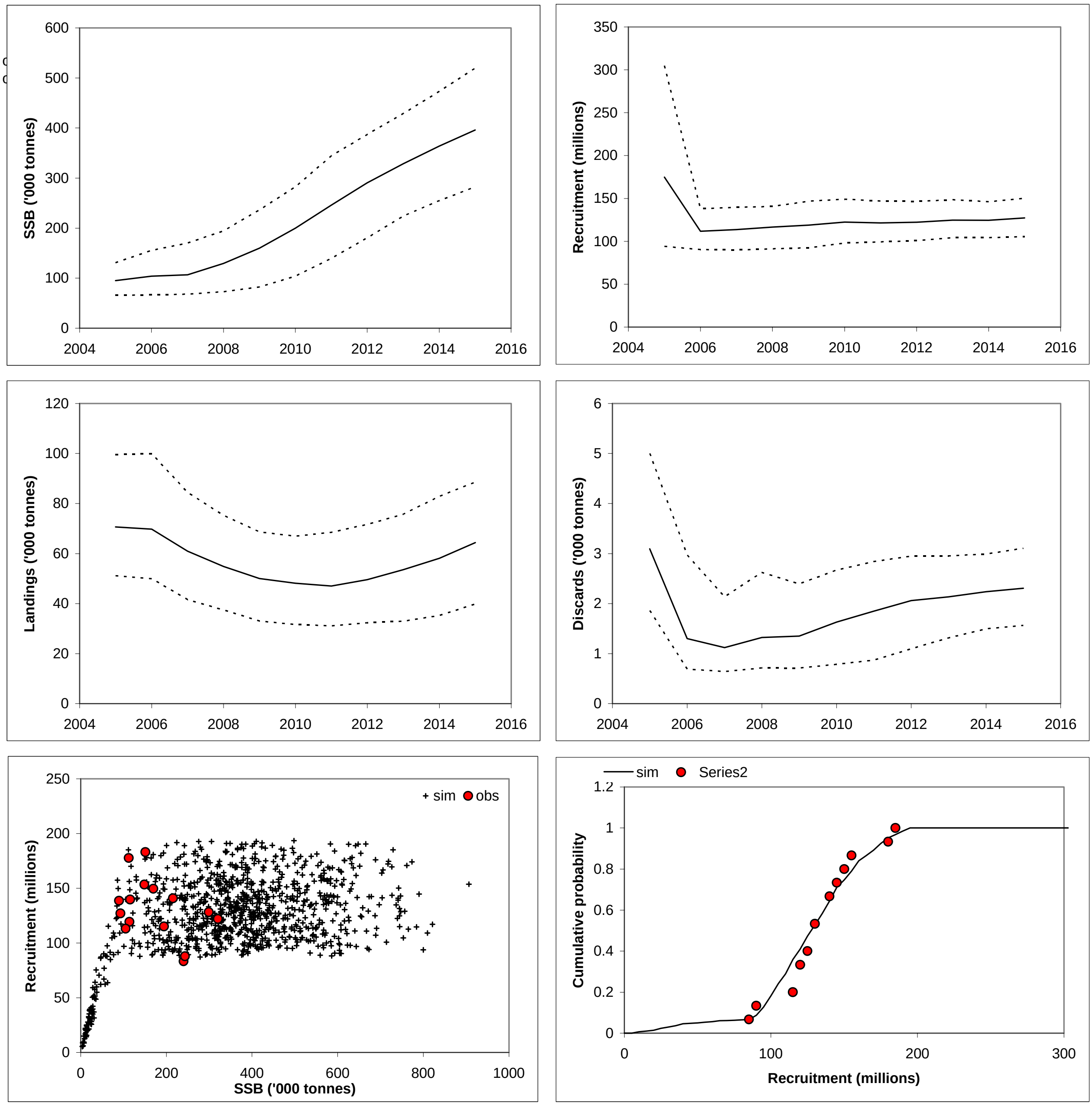


Figure 10.8 Baltic cod 25-32. F hc =0.3, F disc=0.02, 15% TAC constraint.

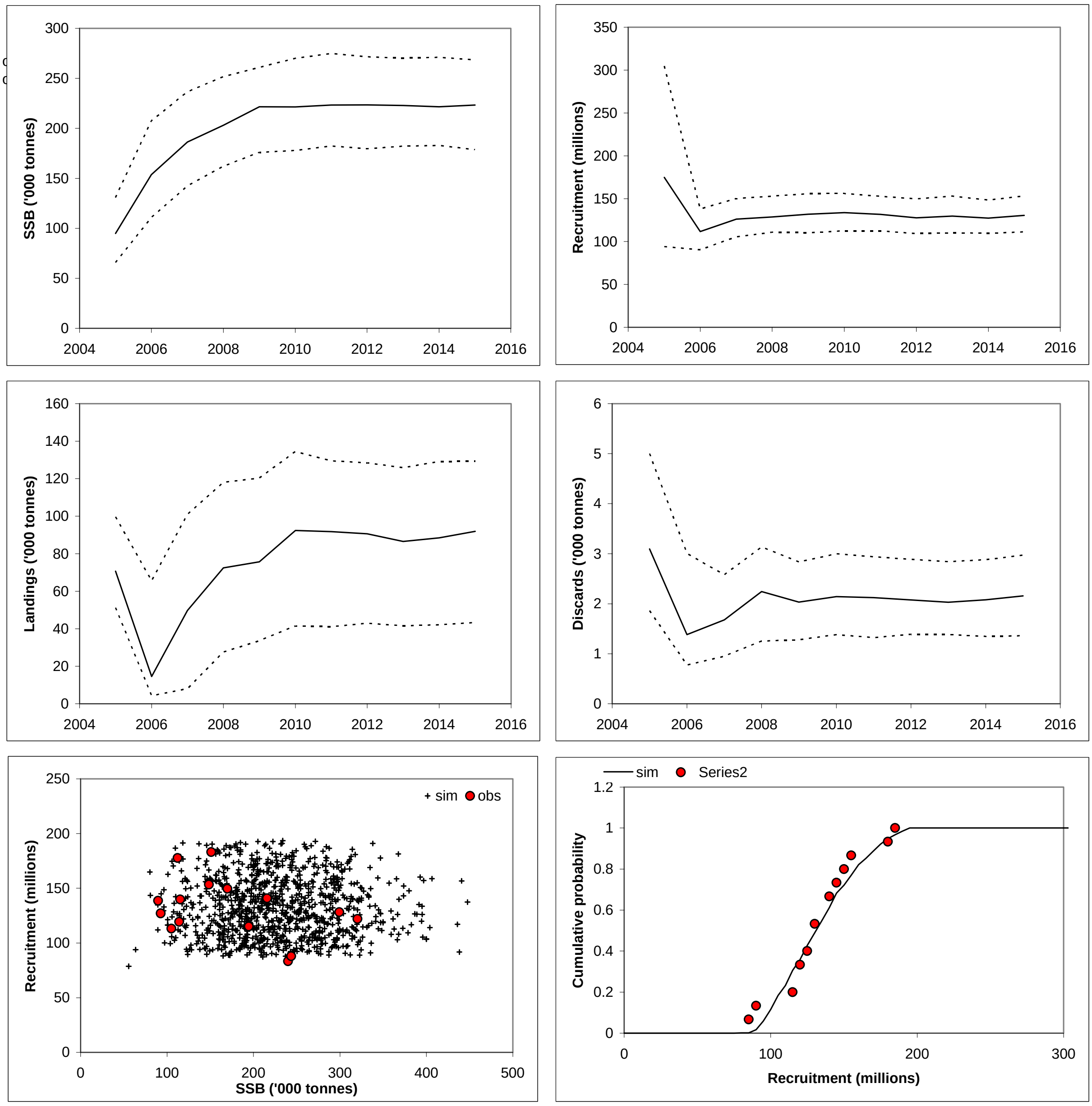


Figure 10.9 Baltic cod 25–32. F hc =0.4, F disc=0.02, No TAC constraint.

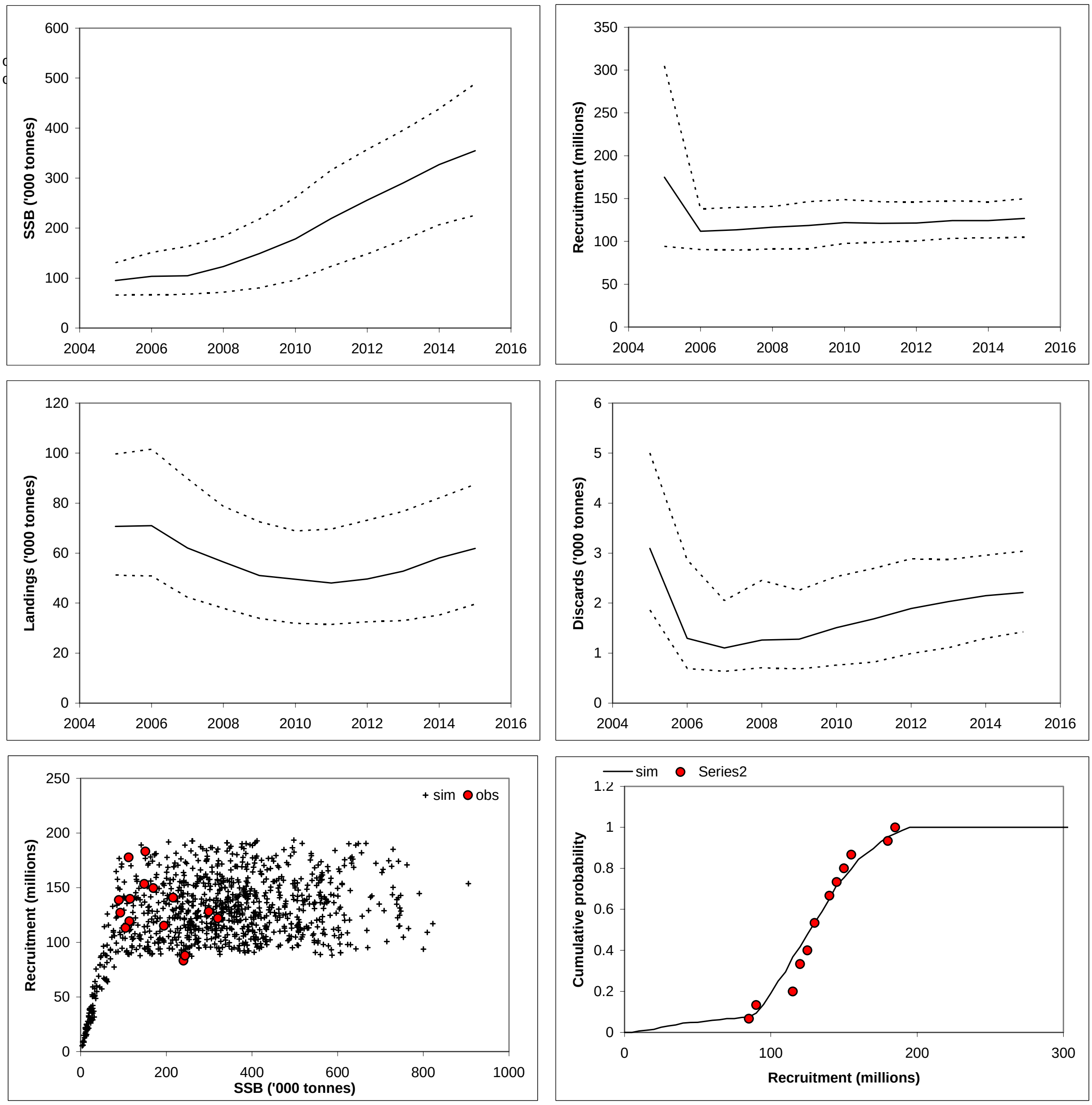


Figure 10.10 Baltic cod 25–32. F hc =0.4, F disc=0.02, 15% TAC constraint.

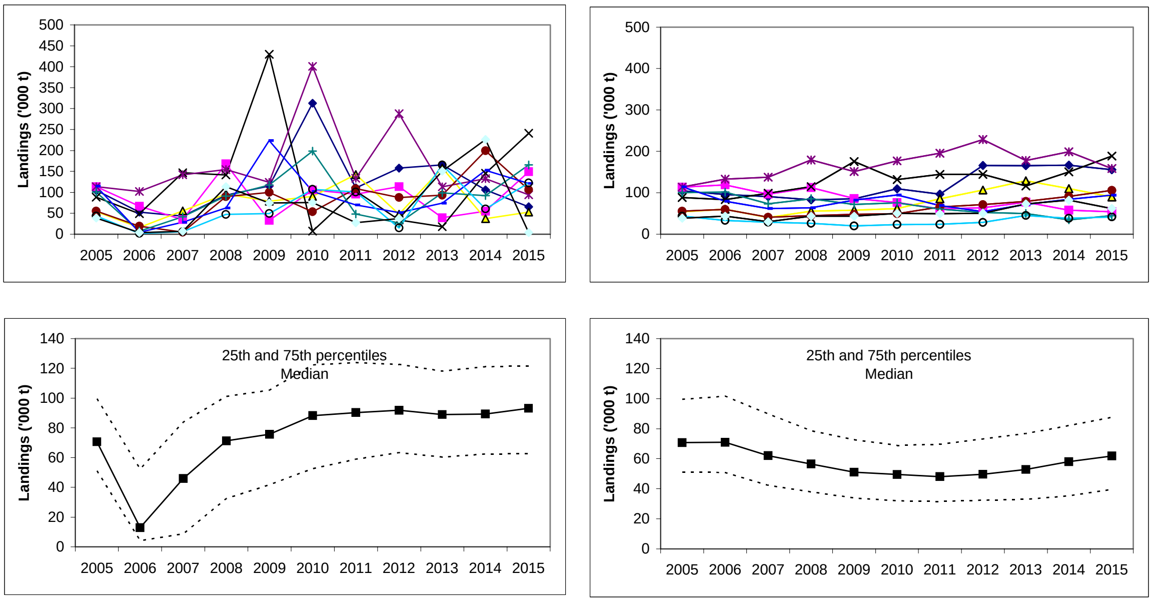


Figure 10.11 Baltic cod 25–32. Left: F hc =0.4, F disc=0.02, No TAC constraint. Right: F hc =0.4, F disc=0.02, 15% TAC constraint. Top graphs: first 10 iterations in terms of true landings (tonnes). Last graph shows the pecentiles over all (1000 iterations).

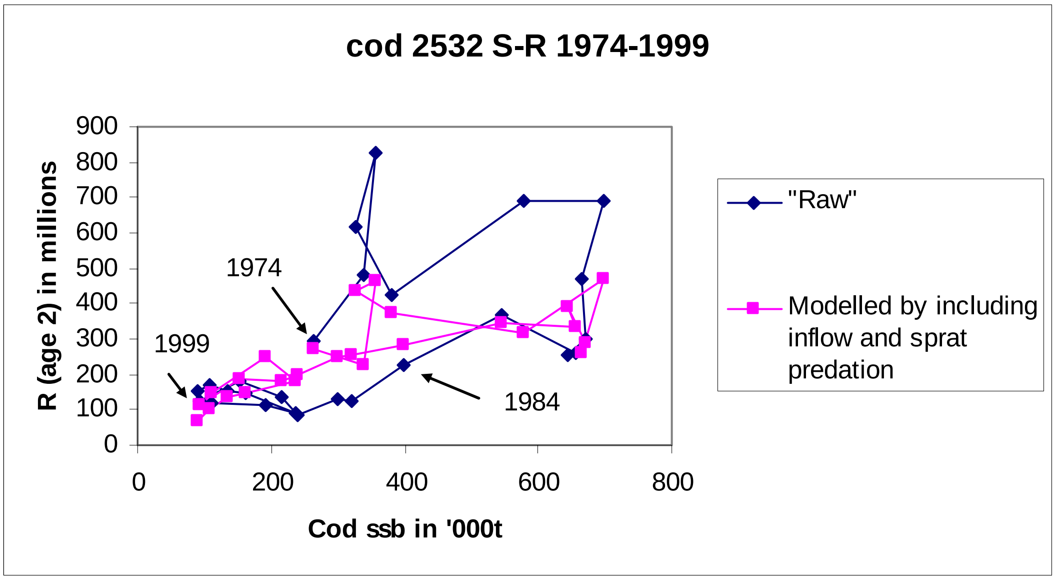


Figure 10.12 Baltic cod 25–32. Stock recruitment relationships. Some of the time trend is removed by the model but not all. It can for instance be observed that the high Rs for SSBs between about 250 to 400 thousands t (in 1974–1978) is only partly mimicked by the model and also the low values of R for about the same SSBs 1984–1988 are not low according to the model. See Appendix 1 for details of the model and Köster *et al.* (2002) for an elaborate analysis of the S-R relationship for this stock.

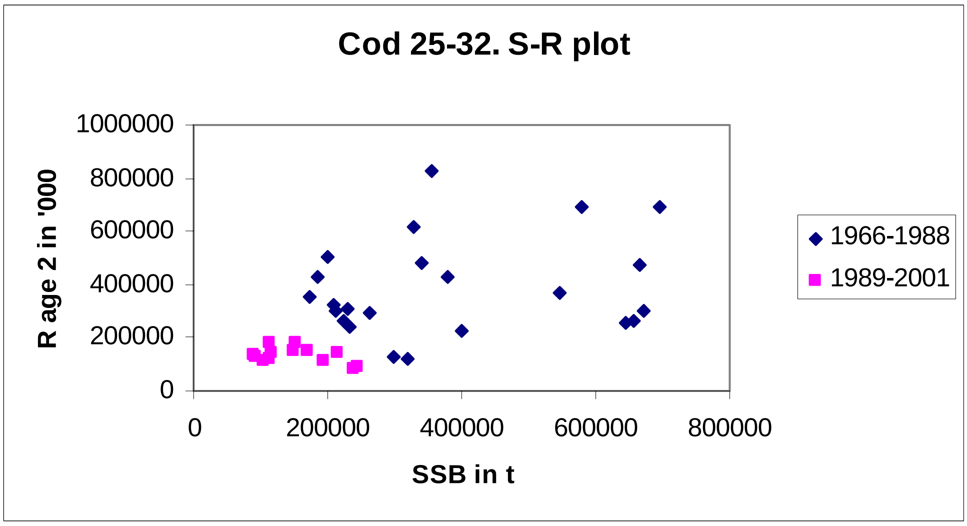


Figure 10.13 Baltic cod 25–32. Stock recruitment relationships 1966–2001. If the time series is restricted to 1989–2001 the S-R relationship looks quite different from when the entire time series is considered.

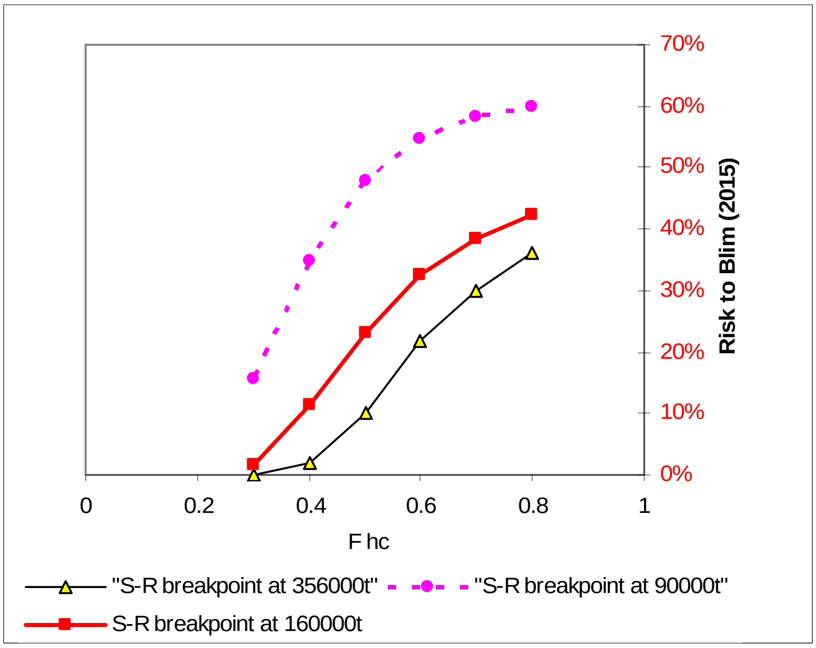


Figure 10.14 Baltic cod 25–32. Sensitivity to the assumed stock recruitment relationship . Variable of interest: probability of being below Blim in 2015. Different fishing mortalities for HC on the horizontal axis. F on discards assumed to be 0.02. "Ockhams razor" S-R models with breakpoints at 90 000 t and R at 93 million (from WGBFAS 2005), 160000t and R at 174 millions (implicit in current Blim), and 356 000 t and R at 387 millions (from a segmented regression on 1966–2001 S-R data from the WGBFAS 2005 assessment).

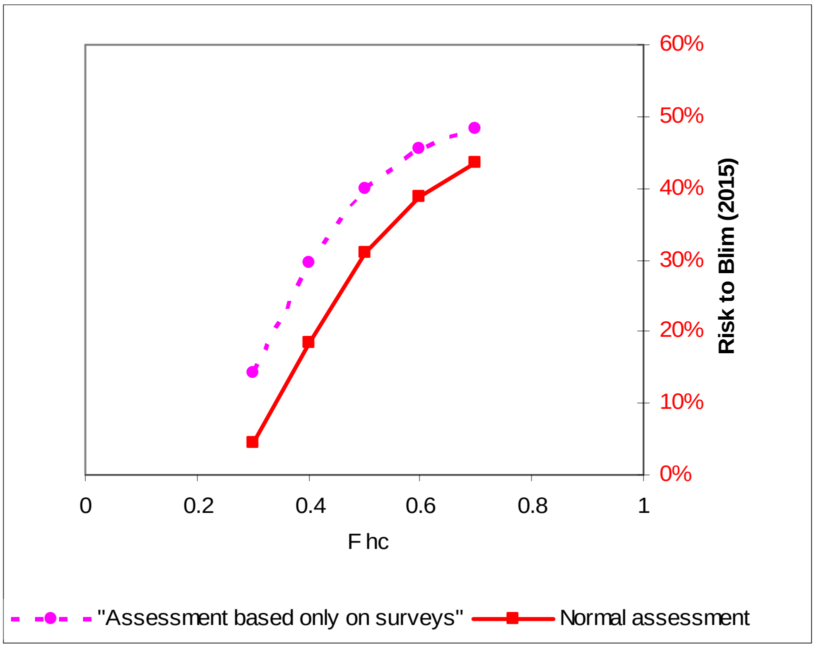
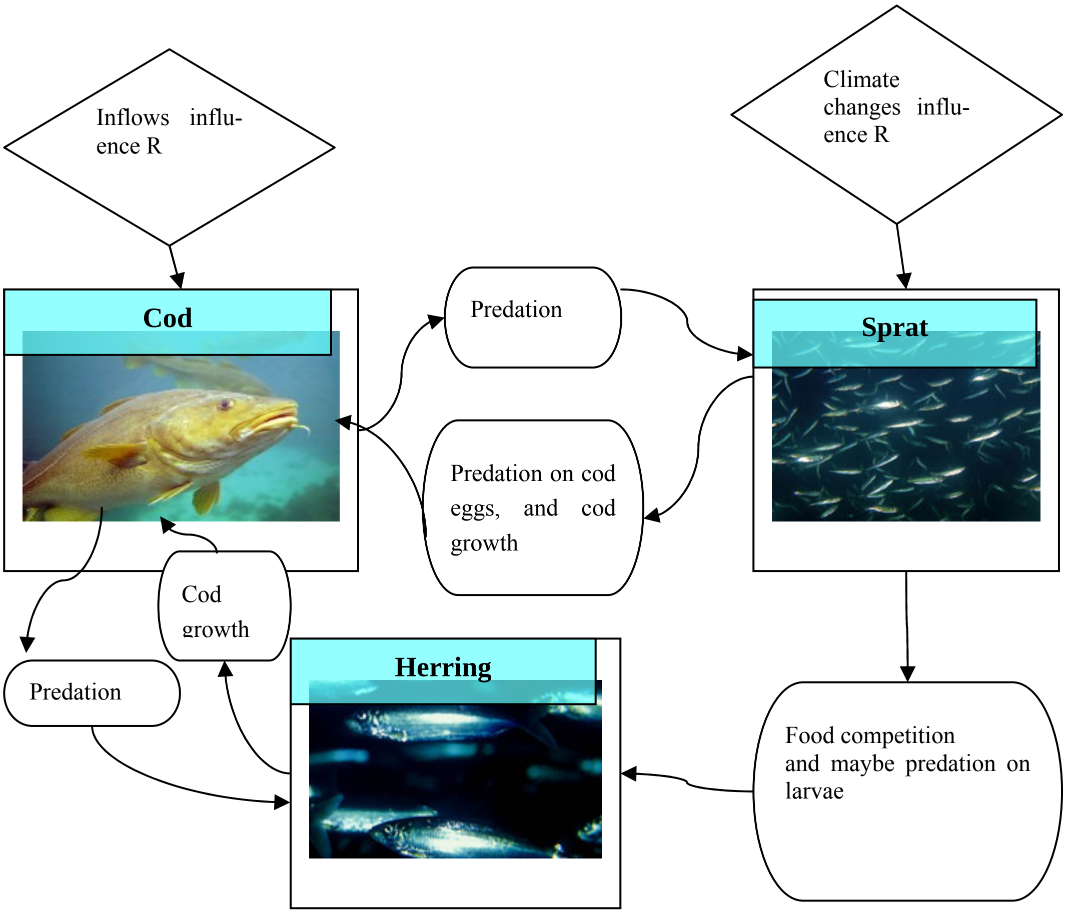


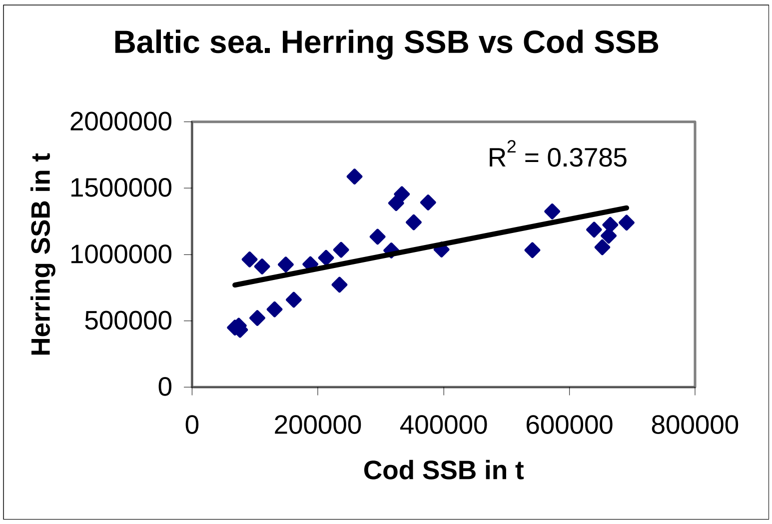
Figure 10.15 Baltic cod 25–32. Sensitivity to the assumed standard deviation in the assessment of stock status. An assessment based on only survey data (using SURBA for instance, because the uncertainty of the black landings are too great) assuming an CV of 0.55 compared to the normal assessment based on XSA type analysis assuming a CV of 0.35. Variable of interest: probability of being below Blim in 2015. Different fishing mortalities for HC on the horizontal axis. F on discards assumed to be 0.02.

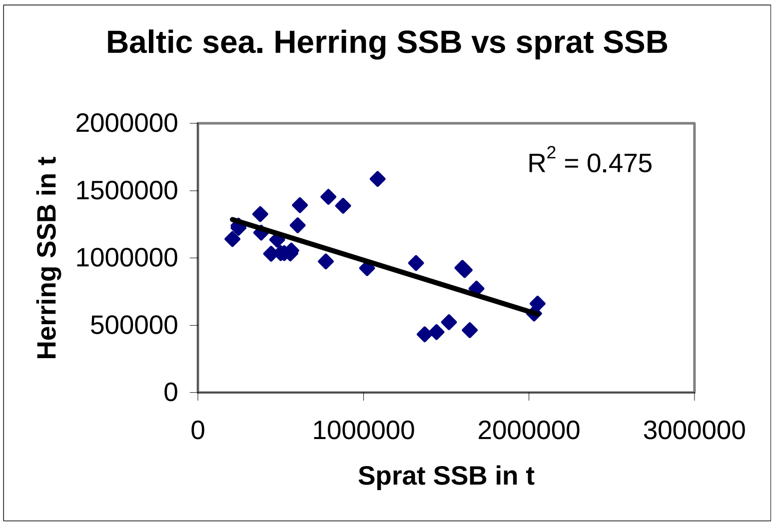
10.8 Appendix Baltic cod 25–32. The S-R relationship.

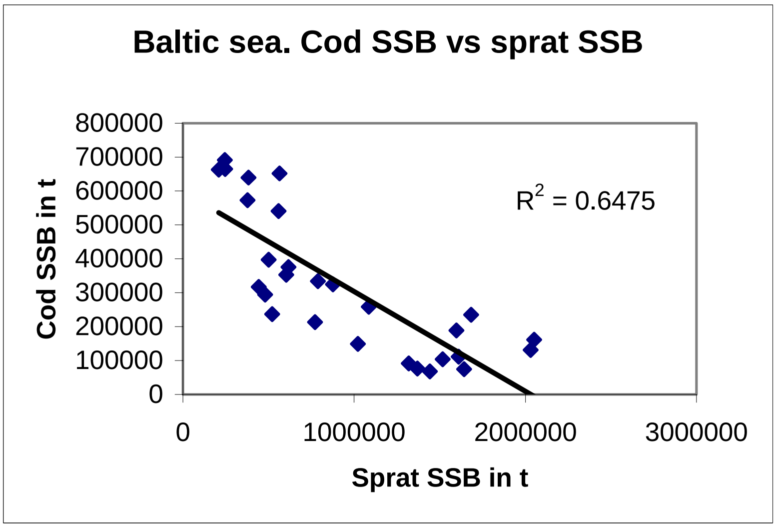
Conceptual model of the Central Baltic Sea fish community.

Only relationships included for which there are good and scientifically documented evidence.

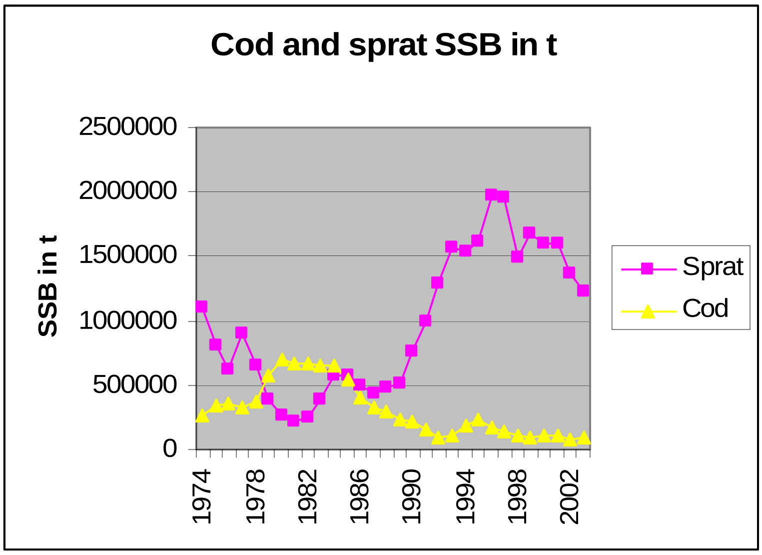


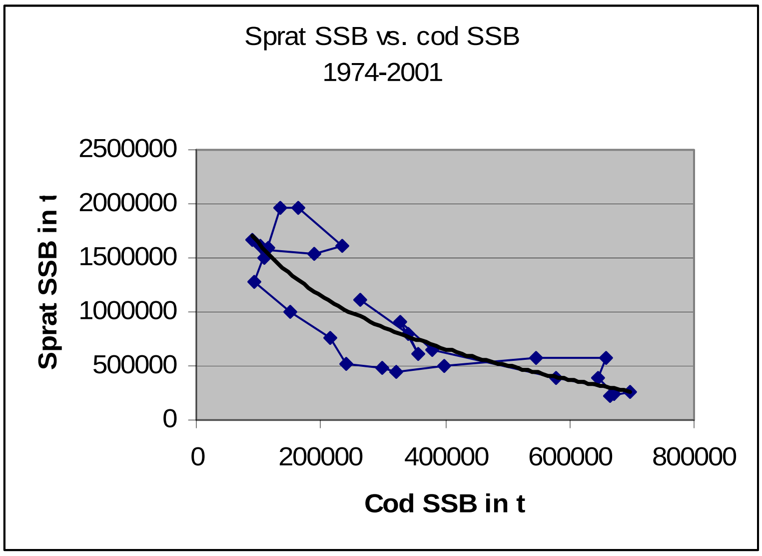

Baltic sea. Herring SSB vs Cod SSB
Herring SSB in t
Cod SSB in t
$R^2 = 0.3785$
0
500000
1000000
1500000
2000000
0
200000
400000
600000
800000


Baltic sea. Herring SSB vs sprat SSB
Herring SSB in t
Sprat SSB in t
$R^2 = 0.475$
0
500000
1000000
1500000
2000000
0
1000000
2000000
3000000


Baltic sea. Cod SSB vs sprat SSB
Cod SSB in t
Sprat SSB in t
$R^2 = 0.6475$
0
100000
200000
300000
400000
500000
600000
700000
800000
0
1000000
2000000
3000000

It seems that Cod SSBs above approximately 400 000 t reduces sprat SSB to approximately 600 000 t, and a further increase in cod SSB reduces sprat SSB to below 600 000 t.





Herring and sprat mean SSB as a function of cod SSB, for 1974–2001. In ‘000 t. The table should be read in the following way: take the first row, this shows that cod SSB have in 4 years been between 50–100 kt and that in the same period herring SSB has on average been 576 kt and sprat SSB 1443 kt.

Cod 2532	No of years	Herring 25-29+32	Sprat 22-32
50-100	4	576	1443
101-200	6	755	1638
201-300	5	1101	908
301-400	6	1257	638
401-500	0	-	-
501-600	2	1179	467
601-700	5	1169	329

Year	Cod SSB	R age 2 shifted 2 years	Sprat SSB	Reproductive Volume in km3
1966	171.99	353.83		
1967	228.65	306.47		
1968	233.93	239.84		
1969	222.63	264.63		
1970	208.82	322.05		
1971	184.16	431.92		
1972	198.97	506.67		
1973	211.97	303.52		
1974	262.93	293.32	1104.02	320.00
1975	339.51	478.91	803.60	75.00
1976	355.54	829.06	618.51	535.00
1977	326.90	615.00	903.11	576.00
1978	379.18	425.73	648.22	274.00
1979	579.63	689.60	395.47	122.00
1980	696.70	693.29	260.95	385.00
1981	666.10	472.10	217.30	64.00
1982	670.90	302.75	245.27	87.00
1983	645.21	252.88	393.21	233.00
1984	657.62	260.11	576.34	167.00
1985	544.88	367.75	573.03	174.00
1986	399.35	224.17	503.13	103.00
1987	320.45	122.35	440.14	96.00
1988	299.24	128.05	477.68	100.00
1989	240.24	82.57	517.09	71.00
1990	215.95	136.12	765.76	80.00
1991	151.40	181.72	1001.27	185.00
1992	92.49	127.03	1283.50	161.00
1993	112.30	119.44	1566.15	261.00
1994	190.87	115.46	1537.47	381.00
1995	235.84	88.16	1610.98	113.00
1996	163.08	149.14	1964.88	147.00
1997	134.78	151.39	1958.44	170.00
1998	108.53	171.84	1491.91	100.00
1999	90.00	151.22	1672.99	50.00

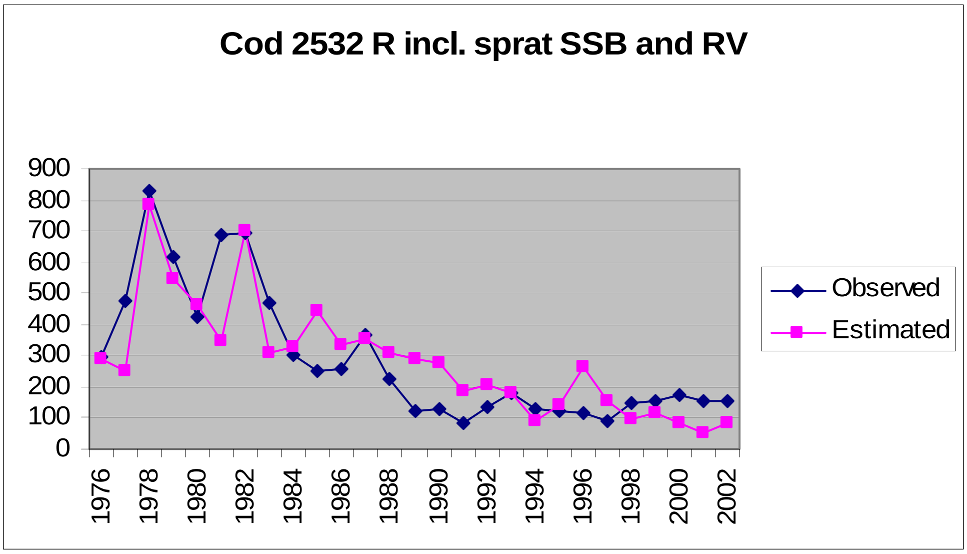
alfa= 0.328069
beta= 0.00183
factor to sprat x= 0.000214
factor to RV y= 0.345229

Ricker S-R model with environmental parameters included:

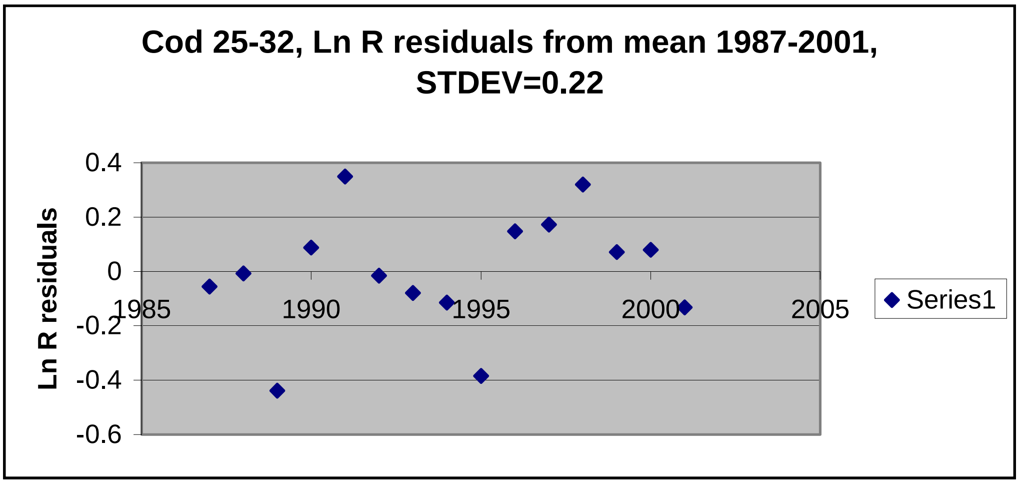
$$ln(R) = ln(\alpha) - x*SSB(sprat)+y*ln(RV)+ln(SSB(cod))-\beta*SSB(cod),$$

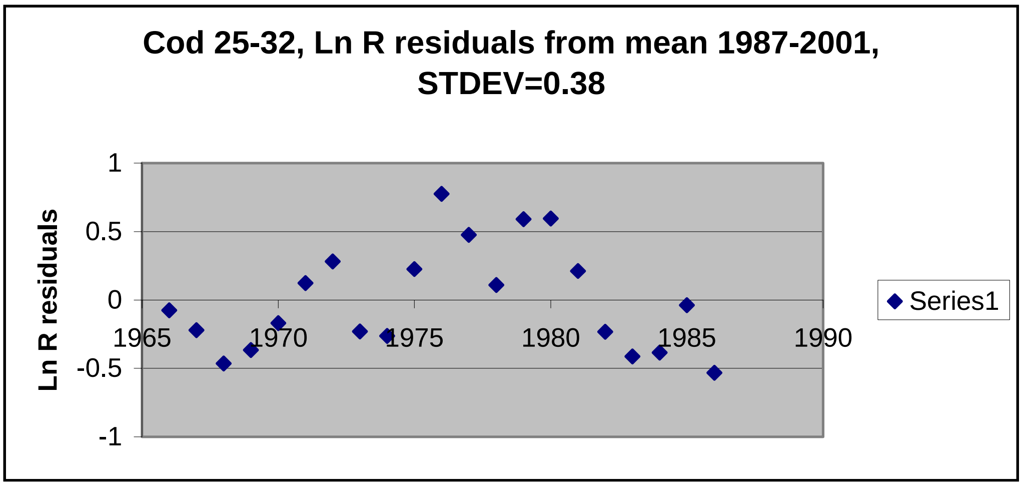
or

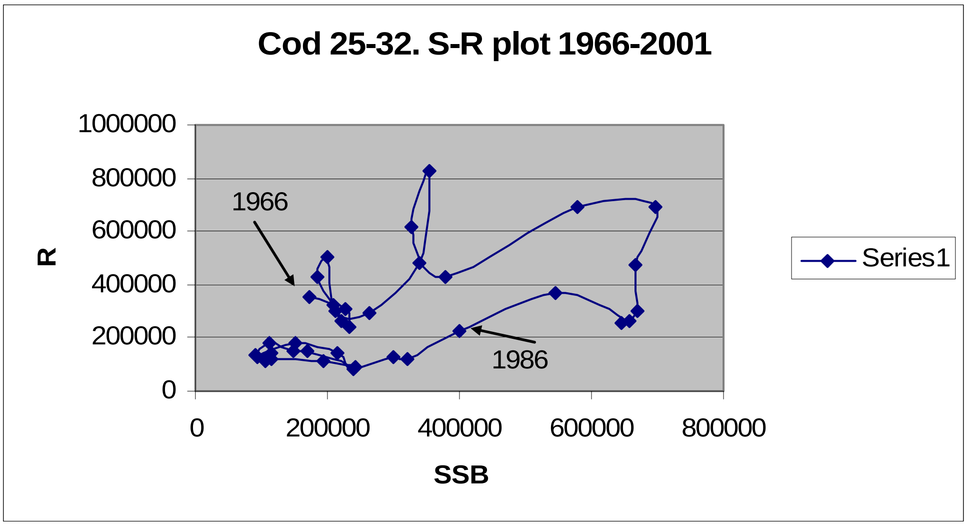
$$R=p1*exp(-aSSB(sprat)))*b*SSB(cod)*exp(-p2*SSB(cod))$$



Residuals of ln R for determining truncations in S-R models used in s3s runs. Time series divided into two time periods 1966–1986 and 1987–2001. Based on this truncations can be set to 0.5, then it will only truncate simulated Rs deviating more than the historical values have deviated from the mean by period. CV can be set to 0.30.


Cod 25-32, Ln R residuals from mean 1987-2001, STDEV=0.22
Ln R residuals
0.4
0.2
0
-0.2
-0.4
-0.6
1985
1990
1995
2000
2005
◆ Series1


Cod 25-32, Ln R residuals from mean 1987-2001, STDEV=0.38
Ln R residuals
1
0.5
0
-0.5
-1
1965
1970
1975
1980
1985
1990
◆ Series1


Cod 25-32. S-R plot 1966-2001
R
1000000
800000
600000
400000
200000
0
1966
1986
0
200000
400000
600000
800000
SSB
Series1

11 Overall conclusions

Some overall conclusions regarding management strategies may be drawn across the stocks studied. These conclusions are based on the stocks for which simulations were made:

- At low target Fs (considerably lower than the present F), low risk to reproduction and high long-term yields are achieved simultaneously. The general pattern is that there is no conflict between the two objectives. A low Ft will lead to high yield simultaneously with a low risk to reproduction that is lower than the 5-10% risk which has generally been considered acceptable by managers.
- Once stocks have recovered and fishing mortality is around a low F target, the outcomes are insensitive to B_{trig}. Criteria for the selection of B_{trig} in this situation are discussed below.
- Fixed TAC regimes are feasible, but result in lower long-term yield for the same risk to reproduction.
- At low target Fs there is low sensitivity to recruitment assumptions (recruitment model used in simulations).
- Implementation errors above 10–20% disrupt achievement of low risk to reproduction and high long-term yield.
- There is a need to develop the framework to include context and process. In the case of Baltic cod for instance, a HCR based on measurements of F and B cannot be implemented presently because there are large uncertainty about actual catches and there is as yet not a sufficiently long time series of the survey which was revised in 2000
- The outcomes of simulations must be presented as a range of options rather than as singular prescriptive recommendations

The selection of F_t and B_{trig} is evaluated by simulated outcomes of management strategies in terms of the achievement of objectives and performance criteria. While the simulations provide clear indications of the relevant ranges of F_t, the outcomes may be insensitive to choices of B_{trig} once low Fs have been achieved. Some general supplementary considerations in the choice of B_{trig} are:

- As low risk to SSB is a prioritised objective the normal assumption will be that $\mathbf{F}_t$ will be lower than $\mathbf{F}_{pa}$ and that $\mathbf{B}_{trig}$ will be higher than $\mathbf{B}_{pa}$.
- The main role of having a $\mathbf{B}_{trig}$ is to have an early response to a declining SSB. A high $\mathbf{B}_{trig}$ is more robust to implementation and assessment error and poor recruitment.
- As a rule-of-thumb, $\mathbf{B}_{trig}$ should be chosen to be well above $\mathbf{B}_{lim}$ and take into account the uncertainty in the annual SSB estimate.
- A low $\mathbf{B}_{trig}$ is expected to result in large interannual variations in the Fs prescribed by the decision rule. This will result when the variance in the biomass estimates results in estimates of SSB changing from one year to the next from being above $\mathbf{B}_{trig}$ to being below or close to $\mathbf{B}_{lim}$, and vice versa.
- A high $\mathbf{B}_{trig}$ will result in faster response and thus more proactive action in worst case situations of consecutive years with low recruitment.

12 References

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Annex 1: List of participants

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Annex 2: Harvest control rules for Horse Mackerel: scoping document

by Beatriz A. Roel (Prepared in consultation with Jose De Oliveira and Chris Darby)

Background

In response to the joint EU-Norway request concerning western horse mackerel:

“Advise on appropriate management systems including management strategies, objectives and ecosystem considerations for western horse mackerel, anglerfish, sandeels and Norway pout.”

The WGMHSA submitted a document to the Study Group on *ad hoc* Long-Term Advice which met on 12-13 April 2005. An evaluation of simple stock assessment approaches and management was requested. Carl O’Brien of CEFAS, present at the meeting, proposed that a scoping document identifying options be prepared by CEFAS to be presented for discussion at the May 2005 meeting of ACFM. Dependent on the subsequent ACFM advice, a simulation study could be presented to the ICES WG on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy [WGMHSA] at its September 2005 meeting.

A management strategy for Western horse mackerel should include decisions on objectives such as sustainable utilisation and compatibility with the precautionary approach. Other much more specific objectives need to be agreed between scientists and managers. Experience has shown that explicit statements are seldom given at the start of the process of developing harvest control rules (HCRs). The process has often been to evaluate how various HCRs perform according to broad objectives. Having done the evaluation, managers are in a better position to refine or define their objectives (ICES, 2005).

Relevant features pertaining to the Stock and Fishery

Issues to be taken into account when considering a management strategy for western horse mackerel are the following:

- Horse mackerel is a spasmodic recruiter.
- At present, the strength of a year class cannot be confirmed before it is 5 years old, when it is fully recruited to the fishery.
- The only fishery-independent information available is an estimate of egg abundance made every third year.
- Fecundity is unknown.
- The fishery has expanded in recent years to take a large proportion of juvenile fish.
- There is a mismatch between the area of distribution of the stock and the TAC area.
- The western horse mackerel stock has declined since the early 1990s and the status of the North Sea stock is unknown, although the fishery in the latter area has expanded in recent years.
- The distribution of both stocks is contiguous (see Figure 1).

Given that horse mackerel is a spasmodic recruiter, a harvesting strategy could be designed to take advantage of large year classes if maximising yields was an objective in this fishery. However, if commercial catches are the only means of establishing the presence of a large year class, there is an intractable problem of distinguishing a large recruitment event from a targeting change by the fishery. The only way to establish the magnitude of recruitment at present is to develop a fishery-independent recruit index. Moreover, exploration of the IBTS data for North Sea horse mackerel has demonstrated catchability or other technical problems associated with estimating its abundance through bottom trawling by research vessels.

The only fishery-independent information is available from the triennial egg survey based on the Annual Egg Production Method. In the past, this application resulted in an estimate of SSB given an estimate of total fecundity that was also obtained during the survey. In recent years, horse mackerel have almost certainly been reclassified as indeterminate spawners, so total fecundity is unknown. Recent analytical assessments have used the triennial estimates of egg abundance as indices of SSB.

In the document presented to the SG on *ad hoc* advice, the WGMHSA stated that if a TAC control were to be used (covering all fishery areas), application of a TAC to the fishery should be mindful of the circumstances of the fisheries. In the first instance, managers would need to agree an appropriate trade-off between exploiting adults and juveniles, and also be mindful that the tolerance of a juvenile fishery will necessarily lower the overall yield (see Figure 2 in the WG document presented to the Study Group on *ad hoc* Long-Term Advice (SGLTA)). In the second instance, managers would need to ensure that catches are not misreported between adjoining areas in which the distribution of the juveniles of both the North Sea and western stocks is contiguous. Although we recognize this last point as a potential problem, investigation of the impact of the western horse mackerel fishery on the North Sea stock is considered to be beyond the scope of this study.

Harmonizing stock distribution areas with the TAC appears to be highly relevant if the stock is to be managed rationally. However, implementing such changes could be a long process, and the stock needs to be managed in the meantime. Therefore, SGLTA has recommended that a simple approach based on information on stock trends be used to deduce a TAC for the reduced area. Also, SGMAS suggested that for stocks where an assessment was not available, a low TAC could be adjusted slowly, based on changes in trend indicators. If a constant (unknown) fecundity of horse mackerel could be accepted scientifically, such a trend indicator could be based on egg abundance from the triennial egg survey.

Proposed approach

Management strategies appropriate for what is known about the dynamics of Western horse mackerel stock and fishery need to be tested by simulation.The simulation framework will take into account the main sources of uncertainty such as the ones related to observation and process error (see Appendix), estimation error and implementation uncertainty. Given time constraints we propose to undertake the simulation study in two phases. In the first phase, to be completed in September, the following will be developed:

- Simulation framework coded in FORTRAN, detail presented in the Appendix. The time-lag in the current management cycle will be incorporated in the simulations. The assessment will be mimicked by introducing appropriate levels of uncertainty and bias.

Our first phase approach may pose problems at the time of assessing the merits of a particular strategy against management objectives expressed in absolute terms, i.e. attaining certain catch level over a period of time. However, the approach proposed was found appropriate to assess and to compare the performance of selected management strategies against each other in the case of the Thames herring (Roel *et al.*,2004).

Kell *et al.* (2005, *in press*) point to a need to incorporate full assessment feedback in the ramework. Therefore, in the second phase of this study we propose:

- Simulation framework as in previous point but performing a Separable ADAPT (SAD) assessment when required.

- Use of FLR (Fisheries Library in R) which would imply performing the assessment by means of SAD and, for the purpose of comparison, possibly other assessment models available in the framework.

In the **next** section we describe the work that can be prepared for the September WGMHSA meeting.

Simulation **testing**

Operating model

This will be based on the parameters estimated in the last assessment. There is a scaling problem in the estimated numbers-at-age by the SAD assessment, and we propose solving it by introducing a Bayes-like approach to estimate fecundity. The model will incorporate a prior for fecundity that will be based on existing information for other horse mackerel stocks and/or stocks with similar dynamics.

Weight of the stock and of the catch, age-at-maturity and natural mortality will be based on historical data. Uncertainty in weights at age and maturity will be incorporated by means of a bootstrapping re-sampling algorithm which will preserve the errors structure.

Fishery model

Both fisheries, the one that catches primarily juveniles and the one that catches adults, need to be regulated. Therefore, the behaviour of both fleets will be taken into account in the operating model.

Stock assessment

Estimates of egg abundance and SSB will be based on the numbers-at-age generated by the operating model and on estimates of fecundity. Bias and error will be introduced in the numbers-at-age generated by the operating model to simulate the assessment process. Bias will be estimated using Jonsson and Hjorleifsson (2002) for retrospective SSB trajectories resulting from SAD. The simulations will be run under a range of assessment errors to test performance of the HCRs to those.

Harvest control rule

Given the recent development of a fishery on juveniles (consisting of fish 1–3 years old) and the impact that fishing mortality on such ages is likely to have on the sustainability of the stock, separate harvest rules applying to the juvenile area and to the adult area need to be considered. In the absence of a recruitment index, the juvenile fishery can only be regulated by a fixed catch or by limiting effort. Effort control on a shoaling species such as horse mackerel would be difficult to implement successfully, so it may need to be combined with area closures. However, testing area closure approaches will require developing an operating model that takes spatial distribution into account or modelling availability, both beyond the scope of this study. Therefore, we only propose harvest rules that result in a TAC as a form of managing the fishery.

The WGMHSA (ICES, 2003) examined the selectivity patterns in the juvenile and adult areas (Figure 2) showing that the proportion of juveniles caught in the juvenile area is much larger compared to the adult area. For computation purposes the TAC could consist of two components: one applied in the juvenile area (referred to as $TAC_{j)}$ and the other to the adult area (TAC_{ad}).

Juvenile area:

a range of fixed TAC_j and

TACj adjusted on the basis of a recruitment index and an *SSB* index.

Adult area:

1) Constant catch
2) Constant proportion strategy:

$$TAC_{ad,y} = \alpha \ SSB_y$$

3) Adult catch adjusted according to trends in *SSB* index data for x years ($x \leq 3$)

$$TAC_{ad,y} = TAC_{ad,y-1}(1 + f(slope))$$

4) Combinations of the above, for example a fixed catch regime, unless the slope was above or below certain critical values, in which cases the TAC_{ad} would be altered by a fixed proportion.

Results will be presented for combinations of TAC_j and TAC_{ad} and will also be compared with the WG approach in which TAC_j consists of a fixed proportion of the total TAC (G. Eltink (RIVO) *pers com*).

Another question is whether an annual or rather a multi-annual TAC is more appropriate in this case. At present, the TAC is adjusted every year on the basis of the results from an analytical assessment performed with the SAD model. Conversely, an assessment could be provided every third year when the egg survey results become available, in which case a multi-annual three-year TAC could be considered. Some arguments in favour of multi-annual TACs for northeast Atlantic mackerel also apply to western horse mackerel:

- the assessment data, apart from catches in numbers at age, are restricted to one point estimate of the SSB every third year;
- the SSB data are noisy, the noise carrying over to the assessment of recent years' stock abundance;
- if variability in recruitment is not particularly great (extraordinary year classes are not taken into account) and there are no clear changes in weight and maturity over time, then those could also be arguments in favour of multi-annual TACs.

Implementation error model

We propose to model the mismatch between TAC area and the area where the stock's catch is taken as implementation error. Examination of trends in TAC overshoot suggests that, when the year class is strong, the TAC was largely exceeded. In recent years, as the strong 1982 year class has virtually disappeared from the fishery, total catches have been close to or slightly below the TAC, likely related to stock availability. For the purpose of this simulation testing exercise, the overshoot will be a function of year-class strength, with random variation added.

Performance statistics

The following performance statistics will be computed to provide managers and stakeholders with the tools to make an informed decision between the strategies presented:

Risk $SSB<B_{threshold}$: probability of the SSB falling at least once within the simulation period below one of the biomass reference points. $B_{threshold}$,equated to the biomass that produced the extraordinary 1982 year-class, should be kept consistent with the assessment results.

Frequency $< B_{threshold}$: average over 1000 simulations of the number of times SSB fell below the biomass reference point during the 20-year projection period.

Mean catch: median value over 1000 simulations of the average of 20 years of annual catch.

Mean SSB, end SSB: median values over 1000 simulations of the average of 20 years of SSB, and of the biomass at the end of the 20-year projection period.

Median interannual catch variability: median value over 1000 simulations of the average 20-year interannual catch variability (*ICV*):

$$ICV = \{\sum_{y=a}^{z} \mathrm{abs}[(C_{y-1}-C_y)/C_{y-1}]\}/(z-a),$$

where *abs* denotes the absolute value, and *a* and z the first and last years in the projections, respectively.

Performance statistics could also be presented for the short and medium-term if so required.

Stochasticity

See comments under operating model and formulation in the Appendix.

Choice of simulation period

Given the spasmodic nature of recruitment, the simulation period needs to be sufficiently long on average for at least two major episodic events to be included. Managers may wish to consider how they want to make best use of an outstanding year class, so the simulation period should ideally see such a year class through until it has disappeared from the fishery. In practice, the simulation period should be fixed, and given that SAD models 10 true ages, the simulation period should be at least 20 years.

Communication of results

A WG document can be presented for consideration and discussion at the Mackerel, Horse Mackerel, Sardine and Anchovy WG in September 2005.

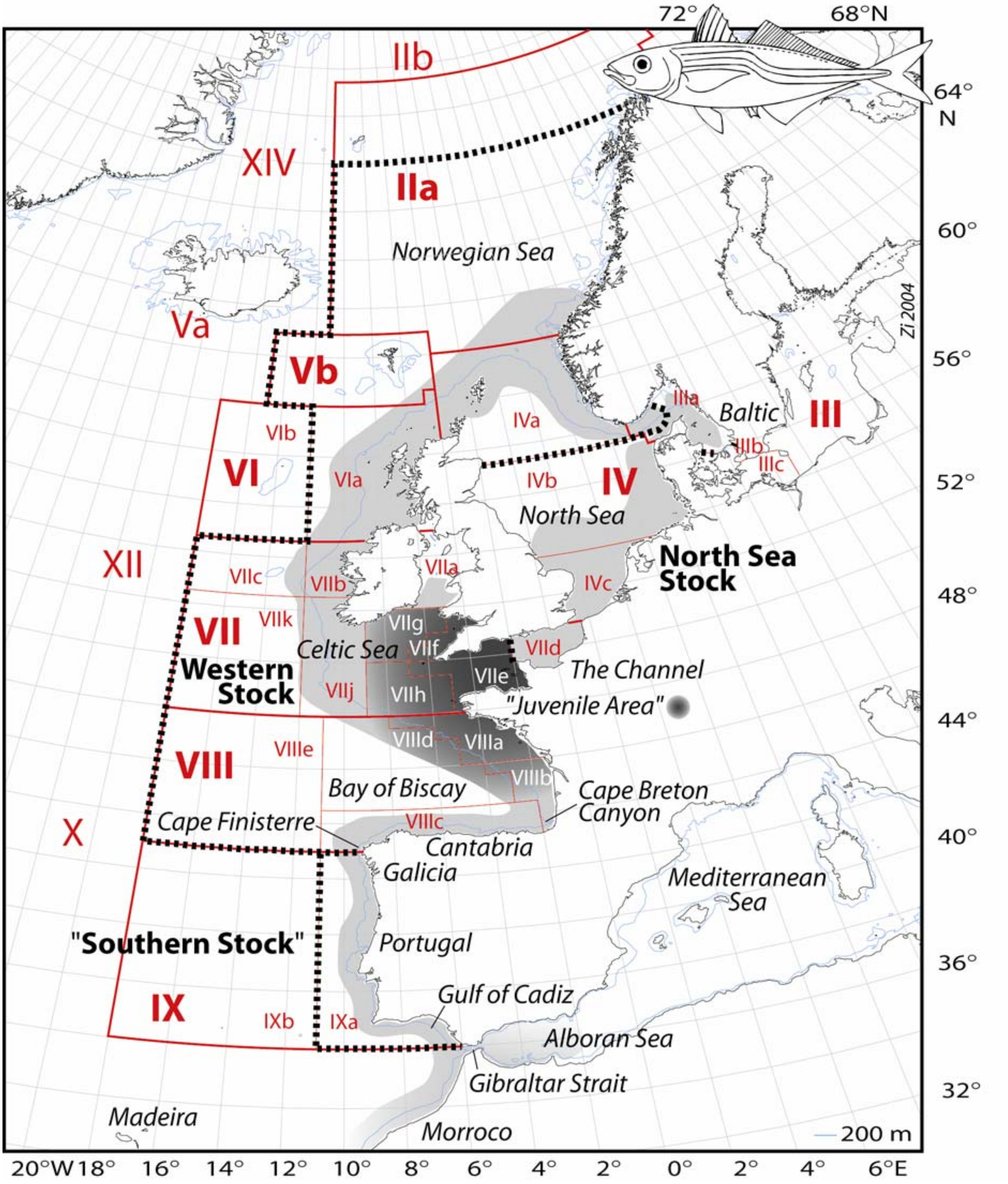

Figure 1. Distribution of horse mackerel stocks.

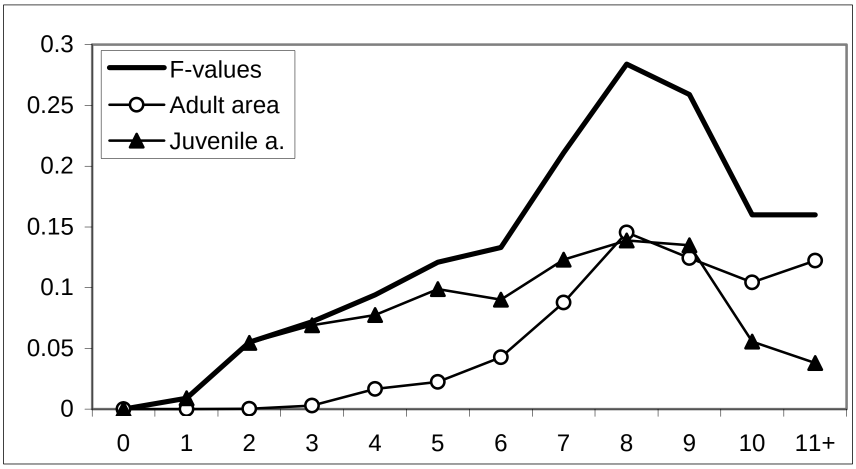

Figure 2. Fishing mortality patterns in the juvenile and adult areas.

APPENDIX (from De Oliveira *et al.*)

Spawning stock biomass:

The spawning stock biomass in the underlying model, referred to as the "true" spawning stock biomass, is calculated as follows:

$$SSB_y^{true} = \sum_{a=1}^{11+} N_{y,a} Q_a w_a^{stock} e^{-p_F s_a F_y - p_M M_a} \qquad y = 2002,...,2021 \qquad A1$$

where

$N_{y,a}$	is the number of fish aged a in year y;
Q_a	is the proportion of mature fish aged a;
w_a^{stock}	is the mean weight of fish aged a in the stock;
s_a	is the selectivity at age a;
F_y	is the fishing mortality in year y;
M_a	is the natural mortality at age a;
p_F	is the proportion of fishing mortality that occurs before spawning; and
p_M	is the proportion of natural mortality that occurs before spawning.

Recruitment

Recruitment is generated using a combination of the Ricker stock-recruit function with parameters a and b estimated from a fit to stock-recruit estimates derived from the SAD model (ICES, 2003), and a process that allows the influx of very large recruitment with a frequency of roughly one in 20 years (equation A2). The recruitment variation and serial correlation parameters, σ_R and ρ_{ser} (equations A2 and A3), are derived from this fit.

$$N_{y,0} = \begin{cases} a\ SSB_y^{true}\ e^{-b\ SSB_y^{true}}\ e^{\sigma_R \zeta_y - \frac{1}{2}\sigma_R^2} & \text{for } \psi \geq 0.05 \\ 45 \text{ billion fish} & \text{for } \psi < 0.05 \end{cases} \qquad A2$$

where y = 2002,...,2021, ψ is independently drawn form a U[0; 1] distribution, and

$$\begin{aligned} \zeta_y &= \rho_{ser}\ \zeta_{y-1} + \sqrt{1-\rho_{ser}^2}\ \xi_y \\ \xi_y &\sim N[0;1] \end{aligned} \qquad A3$$

Numbers-at-age

An age-structured deterministic underlying model is used, and is based on a separable assumption with regard to fishing mortality and selectivity, and assumes a plus group at age 11. Uncertainty in the starting numbers at age will be taken into account.

$$\left.\begin{aligned} N_{y+1,a+1} &= N_{y,a}\ e^{-s_a F_y - M_a} \qquad a = 0,...,9 \\ N_{y+1,11+} &= N_{y,10}\ e^{-s_{10} F_y - M_{10}} + N_{y,11+}\ e^{-s_{11+} F_y - M_{11+}} \end{aligned}\right\} \quad y = 2002,...,2021 \qquad A4$$

Calculating the fishing mortality and catch

The fishing mortality that results from applying Cy is calculated by solving for Fy from the following:

$$C_y = \sum_{a=0}^{11+} N_{y,a}\, w_a^{catch} \frac{s_a F_y}{s_a F_y + M_a}(1 - e^{-s_a F_y - M_a}) \qquad A5$$

An upper limit is placed on catching efficiency. To achieve this, Fy is restricted to be ≤ 20, which results in $\frac{s_a F_y}{s_a F_y + M_a}(1 - e^{-s_a F_y - M_a}) \leq 0.98$ for any age group, given the values used for sa and Ma. If no implementation error is considered (i.e. no mismatch between TAC and catch is modelled), then as long as Fy < 20, it follows that Cy = TACy. However, when Fy is restricted to a value of 20, this is no longer the case and Cy is calculated by solving equation A5 (with Fy = 20) after replacing TACy with Cy. If implementation error is considered, then generally Cy ≠ TACy, even when Fy < 20.

Generating egg abundance observations

In order to generate egg abundance observations, the "true" egg abundance needs to be obtained from the "true" spawning stock biomass (equation A1). It is modelled on the basis of the relationship between egg abundance and spawning stock biomass estimated from the SAD model (ICES, 2003). To incorporate different components of variance into this relationship, the total variance can be apportioned into a "process" error component (λegg) linking true egg abundance to true spawning stock biomass (where fecundity plays a role), and an "observation" error component (cvegg) linking observed egg abundance to true egg abundance through the sampling CV of egg abundance estimates.

EGG^{true} is derived from SSB^{true} with process error, as follows:

$$EGG_y^{true} = \frac{1}{q} SSB_y^{true}\, e^{\lambda_{egg}\eta_y} \qquad A6$$

where $\eta_y \sim N[0;1]$. In equation A6, 1/q is the constant of proportionality linking egg abundance to spawning stock biomass, and λ_{egg}^2 represents the process error component of the total variance of the egg abundance versus spawning stock biomass relationship (in log-terms), which could in part be due to variability in fecundity. The observed egg abundance is generated from EGGtrue, with observation error as follows:

$$EGG_y^{obs} = EGG_y^{true}\, e^{cv_{egg}\,\omega_y} \qquad A7$$

where $\omega_y \sim N[0; 1]$, and cv_{egg} represents the sampling CV related to observed egg abundance estimates.

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