Biological evaluation of the first stage of the management plan for fisheries exploiting the stocks of plaice and sole in the North Sea according to Council Regulation (EC) no 676/2007

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Summary

In 2006 the EC and scientific advisers concluded that the stocks of plaice and sole in the North Sea have been subjected to levels of mortality by fishing which have exceeded the levels determined by ICES as being consistent with the precautionary approach, and the stocks are at risk of being harvested unsustainably.
The Commission of the European Community has therefore proposed a long-term management plan, which was adopted by the Council of the European Union in June 2007 and first implemented in 2008 (Council Regulation (EC) No 676/2007). The long term plan for the management of plaice and sole in the North Sea is designed to gradually adjust the level of fishing activity so as to achieve greater catches, larger and more stable stocks and more profitable fisheries in the long term. The plan consists of two stages. The aim of the first phase is to ensure the return of the stocks of plaice and sole to within safe biological limits. The tools to achieve this objective are the same as those in a number of other long-term management plans already in place for other species. TACs applied will corresponds with fishing mortality that will be reduced by 10% year-on-year based on the most recent stock assessment until both stocks have been found have returned to safe biological limits for two years in succession. The annual variations in Total Allowable Catches (TACs) will be kept within limits (15% up or down). Other measures involve the regulation of fishing effort via the adjustment of the maximum level of fishing days at sea available for the relevant fleets necessary to take catches equal to the TACs.
The evaluation of the agreed management strategy, presented in this report, results from a request by the Dutch Ministry of Agriculture, Nature Conservation and Food Quality. ICES is invited to review this evaluation and advise whether the management plan is precautionary.

A simulation model was developed, which contains several modules. The **operating module** simulates the true stock and dynamics of the fishing fleet. An **observation module** mimics the indices generated by fisheries-independent surveys and the observed catches and catch at age composition from the commercial catches. Based on this information a **stock assessment module** using the XSA procedure is executed, which results in perceived stock numbers at age and fishing mortality rates per age group. The assessment results are inputs to calculate the TACs and the maximum number of days at sea following the rules of the management strategy in a **management module**.
Spatial and seasonal differentiation in stock abundance and fleet effort allocation were not included. Also the fleet structure was simplified. The operating model has been conditioned using data from the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), by calibrating catchability and recruitment levels from the historical data. The behaviour of the fishing fleet was simulated using two options on the fisher's response to the annual TAC management measures. This fleet behaviour is uncertain and therefore two extreme scenarios (overquota catch discarded or misreported, or overquota catch avoided) were formulated and run in combinations with some scenarios that are related to the interpretation of the rules for the technical procedure of setting the TACs.

It must be noted that the results of the simulations are sensitive to the choice of a Stock-Recruitment (SR) relationship, being Ricker in most scenarios. A summary of the results of 3 scenarios is given in table 1. Simulation results show that the objectives of the first stage of the management plan (both stocks above Bpa, fishing mortality below Fpa and for two years in succession), are likely to be reached in 2015, within 7 years after the implementation, with a probability of approximate 0.5. The probability of successfully attaining the objectives of the firsts stage of the plan increases to 0.8 two years later. Using the alternative SR relationship, Beverton and Holt, completion of stage one is expected to occur in 2018 with a probability of 0.5. The spawning stock biomass, SSB, of both species are expected to increase and the modal SSB prediction is above Bpa for plaice in 2012 and for sole in 2010, in case a Ricker SR was used. The risk that SSB will fall below Blim, the biomass below which recruitment is impaired, was found to be less then 5% for sole. In case of a Ricker SR relationship the risk that plaice SSB is lower then Blim was found 0.5 in 2008 and this probability decreases to less then 0.05 after 2010. Using the Beverton & Holt SR relationship the risk of plaice SSB's below Blim found was higher and decreased to less then 0.05 in 2014. Average TACs and landings vary depending on the scenario used. TACs and landings for sole seem to level of at 14000-15000 tons after approximately 10 years. For plaice the TAC and landings are predicted to increase depending on the scenarios (overquota catch discarded or misreported, or overquota catch avoided) to average levels of 70 000 and 110 000 respectively that are reached after approximately 10 years.

1 Introduction

This report gives a biological evaluation of the first stage of the multiannual plan for fisheries exploiting stocks of sole and plaice in the North Sea that was adopted by the Council of the European Union in June 2007 (Council Regulation (EC) No 676/2007) and that was implemented for the first time in 2008 (Council Regulation (EC) No 40/2008).

The ultimate aim of this management plan is an exploitation level so that stocks of plaice and sole are exploited on the basis of maximum sustainable yield and under sustainable economic, environmental and social conditions. The specific objectives in the first stage of the multiannual plan is to ensure the return of the stocks of plaice and sole to within safe biological limits.

The North Sea plaice and sole stocks are, since the implementation of the Regulation, managed by the setting of TACs and days at sea restrictions based on annual reductions of fishing mortalities. The stocks are exploited by several fisheries but most of the catch is taken by beam trawls in mixed flatfish fishery. Specific technical measures such as protected areas or possible measures to counter discards are not regarded in the adopted plan.

Fishing mortality (F per year) for plaice increased, with considerable variation in the annual estimates, from circa 0.4-0.5 per year around 1970 to circa 0.7 to 0.8 per year in the period from 1998 to 2003 (Figure 1a). The fishing mortality for sole increased with large variation as well, from circa 0.4-0.5 per year around 1970 to 0.5 to 0.6 per year in the period from 1998 to 2003.
The spawning stock biomass (SSB) of plaice declined from 1970 onwards but showed a temporal increase in the 1980s when both recruitment and growth rate were high (Figure 1b). The SSB of plaice has been below the precautionary biomass threshold (Bpa), the target biomass to reduce probability of Blim being hit, since 1994, with the exception of 2 years. The spawning stock biomass of sole varied around the Bpa level over a longer period. A series of strong year-classes caused the spawning stock biomass of sole to increase for around five years in the early 1990s. Recruitment estimates for all year classes since 2001 of both species are below the long term averages except for year class 2006 of plaice and year class 2005 of sole. In 2006 both stock SSBs were in between Blim and Bpa.

In 2007, a draft proposal by the European Commission for a management plan for plaice and sole in the North Sea was evaluated (Machiels et al., 2007). However, the current adopted plan differs on critical points from the previously evaluated plan. Because of the changes, the current management procedure was evaluated using the same approach as used in the evaluation of the draft proposal. The aim of the evaluation presented in this report was

- to find out whether management measures would achieve the objective stated in the agreement for the first stage;
- whether this could be achieved for both species simultaneously in the same time frame and
- to get an indication of consequences in this time frame in terms of development of TACs, landings and permitted effort.

The evaluation was carried out on request of the Dutch Ministry of Agriculture, Nature Conservation and Food Quality.

2 The management agreement

Objectives

On 11 June 2007 the Council of the European Union adopted a management agreement for fisheries exploiting stocks of plaice and sole in the North Sea. The multiannual agreement should be deemed to be a recovery phase during its first stage and a management plan during its second stage, within the meaning of art 5 and 6 of the Council Framework Regulation adopted under the reform of the Common Fisheries Policy (Council Regulation (EC) No 2371/2002).

The objective of the plan is to ensure, in a first stage, that stocks of plaice and sole in the North Sea are brought within safe biological limits, and in a second stage and after due consideration by the Council on the implementing methods for doing so that those stocks, are exploited on the basis of maximum sustainable yield and under sustainable economic, environmental and social conditions.

The operational objectives of the first stage of the agreement are to bring the two stocks to within safe biological limits. For plaice, these safe biological limits are a fishing mortality below 0.6 and an estimated spawning biomass exceeding 230 000 ton. For sole the safe biological limits are a fishing mortality below 0.4 for sole and 35 000 ton. TACs applied will corresponds with fishing mortality that will be reduced by 10% year-on-year until the target levels have been reached, while annual variations in TACs will be kept within 15%. According to article 5 of the Regulation the Council will amend the agreed plan when the stocks of plaice and sole have been found to have returned to within safe biological limits for two years in succession. The council shall decide on the basis of a review proposal from the European Commission that will permit the exploitation of the stocks at a fishing mortality rate compatible with maximum sustainable yield. The proposal for review shall be accompanied by a full impact assessment and takes into account the opinion of the North Sea Regional Advisory Council.

Advice on long-term management from ICES indicates that at low target fishing mortalities (considerably lower than the present levels), 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 fishing mortality will lead simultaneously to high yield and a low risk to reproduction (lower than the 5-10% risk which has generally been considered acceptable by managers).

Measures

The legal management measures agreed on by the Council of the European Union are (see also the flowchart of figure 2) given in Chapter II of the Regulation (total allowable catches). Chapter I deals with Subject-matter and objective (Article 1-4).

Article 6

Setting of total allowable catches (TACs)

1. Each year, the Council shall decide, by qualified majority on the basis of a proposal from the Commission, on the TACs for the following year for the plaice and sole stocks in The North Sea in accordance with Articles 7 and 8 of this Regulation.

Article 7

Procedure for setting the TAC for plaice

1. The Council shall adopt the TAC for plaice at that level of catches which, according to a scientific evaluation carried out by STECF is the higher of:
    a) that TAC whose application will result in a 10% reduction in the fishing mortality rate in its year of application compared to the fishing mortality rate estimated for the preceding year.
    b) that TAC whose application will result in the level of fishing mortality rate of 0.3 on ages 2 to 6 in its year of application.
2. Where application of paragraph 1 would result in a TAC which exceeds the TAC of the preceding year by more than 15%, the Council shall adopt a TAC which is 15% greater than the TAC of that year.
3. Where application of paragraph 1 would result in a TAC which is more than 15% less than the TAC of the preceding year, the Council shall adopt a TAC which is 15% less than the TAC of that year.

Article 8
Procedure for setting the TAC for sole

1. The Council shall adopt a TAC for sole at that level of catches which, according to a scientific evaluation carried out by STECF is the higher of:
   a) that TAC whose application will result in the level of fishing mortality rate of 0.2 on ages 2 to 6 in its year of application;
   b) that TAC whose application will result in a 10% reduction in the fishing mortality rate in its year of application compared to the fishing mortality rate estimated for the preceding year.
2. Where the application of paragraph 1 would result in a TAC which exceeds the TAC of the preceding year by more than 15%, the Council shall adopt a TAC which is 15% greater than the TAC of that year.
3. Where the application of paragraph 1 would result in a TAC which is more than 15% less than the TAC of the preceding year, the Council shall adopt a TAC which is 15% less than the TAC of that year.

Article 9
Fishing effort limitation

1. The TACs referred to in Chapter II shall be complemented by a system of fishing effort limitation established in Community legislation.
2. Each year, the Council shall decide by a qualified majority, on the basis of a proposal from the Commission, on an adjustment to the maximum level of fishing effort available for fleets where either or both plaice and sole comprise an important part of the landings or where substantial discards are made and subject to the system of fishing effort limitation referred to in paragraph 1.
3. The Commission will request from STECF a forecast of the maximum level of fishing effort necessary to take catches of plaice and sole equal to the European Community's share of the TACs established according to Article 6. This request will be formulated taking account of other relevant Community legislation governing the conditions under which quotas may be fished.
4. The annual adjustment of the maximum level of fishing effort referred to in paragraph 2 shall be made with regard to the opinion of STECF provided according to paragraph 3.
5. The Commission shall each year request the STECF to report on the annual level of fishing effort deployed by vessels catching plaice and sole, and to report on the types of fishing gear used in such fisheries.
6. Notwithstanding paragraph 4, fishing effort shall not increase above the level allocated in 2006.
7. Member States whose quotas are less than 5% of the European Community's share of the TACs of both plaice and sole shall be exempted from the effort management regime.
8. A Member State concerned by the provisions of paragraph 7 and engaging in any quota exchange of sole or plaice on the basis of Article 20(5) of Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy that would result in the sum of the quota allocated to that Member State and the quantity of sole or plaice transferred being in excess of 5% of the European Community's share of the TAC shall be subject to the effort management regime.
9. The fishing effort deployed by vessels in which plaice or sole are an important part of the catch and which fly the flag of a Member State concerned by the provisions of paragraph 7 shall not increase above the level authorised in 2006.

3 Evaluation

The biological evaluation is carried out using a numerical simulation model for the interplay between the biological dynamics of the stocks, and the economic dynamics of the fleet. A relational diagram of the -full feedback- model with 4 main modules is given in figure 4. *Biols* and *fleets* objects represent the operating module (the true state) while *stocks* and *manage* objects represent the observation module (the perception of the true state).

Biological operating model

The biological operating model consists of the age structured population state of the 'real' plaice and sole stocks in the North Sea, the *biols* objects, including the population dynamics of these stocks. The spawning stock biomass (SBB), the biomass of the sexually mature part of the population, determines the number of recruits of the next year. Two commonly used relations can be chosen: (1) Ricker and (2) Beverton & Holt. The Ricker and Beverton & Holt types of stock recruitment relationships were estimated using stock assessment results from 1957 to 2006. The stock numbers are affected by natural mortality, assumed to be constant for every age class, and fishing mortality that is calculated in the *fleets* module. The simulation was initiated in 1995. The stock numbers at age in the initial year where taken from the assessment results (ICES WGNSSK, 2007). Landings, discards and survivors of the two stocks were calculated for the successive years given the (natural & fishing) mortality rates. Recruits were taken from the assessments results. From 2007 onwards the simulation continues with recruits estimated from the stock-recruitment relationship, given the stock sizes, with random noise added that corresponds to the observed residual variation over the last 50 years. Natural mortality is assumed to be equal to 0.1 for all ages and all years for both species. Growth of individual fish is simulated via a weight at age relationship extracted from Working Group data (ICES WGNSSK, 2007) by calculating the mean weights at age from 1995 to 2006 and assumed to by constant over years. The mature fraction is assumed to be 1 from age 4 onwards for plaice and from age 3 for sole so all plaice age 4 and sole age 3 are mature. These values are the same as used in the routine assessment by ICES.

Fleet characteristics and the fishery

The fleet operating model assumes there is a single fleet fishing for the two flatfish stocks, for which selectivity and catchability (q) at age are estimated by combining fishery mortality estimates from the assessment results with observed fishing effort of the beam trawl fleet (ICES WGNSSK, 2007). Hence, the fleet operating model does not differentiate between fleets from the different countries fishing for sole and plaice. Possible increase of efficiency of the fleets over time has not been taken into account in the current model. The fleet operating model affects the number at age in the biols objects via the fishing mortality rate (F). F per year, for each age group is calculated as the product of fishing effort (f) and catchability (q) and selectivity. The fishing mortality reduces stock numbers per age group in the biological operating model module. This results in a simulated dataset with 'true' catch values for the two species, which can then be differentiated into landings and discards for a species and an age group using minimum landing sizes of the species.

Assessment and forecast

The information or perception on the stocks status is generated through the explicit inclusion of a stock assessment module (*stocks*) in the simulation. Catches and landings of the fleet are recorded and two survey fleets sample the stocks by fishing with a constant and low fishing effort. Catches per unit of effort that are linearly related to stock abundance, thus result in two survey indices on the state of the stocks. The implementation of the XSA stock assessment to the knowledge process explicitly takes into account the error generated by the stock assessment. To simulate observation error, the assessment input data (simulated landings, discards and survey catches) were generated with an error coefficient of variation of 10%. Biological parameters of the stocks in the assessment process are assumed to be equal to the biological parameters set in the operating model.

Conditioning the operating model means reflecting the states and dynamics of the operating model on our current understanding of the underlying biological and economical processes. The model was constrained to generate the observed variation of plaice and sole stock characteristics in terms of fishing mortality, landings, discards and SSB. The catchabilities for the two species in relation to the range in fishing mortality for the different age groups of the species were used to match the characteristics of the stocks and model predictions.

In order to set a management measure for year y, assessment data will be available up to year y-2 and the assessment itself is carried out in year y-1. The stock assessment process results in fishing mortalities estimates until year y-2 and survivor estimates and a SSB, estimate until year y-1. A deterministic short-term forecast procedure then calculates the TAC for year y, based on assumptions about F and recruitment in the year y-1 and y. The assessment output and short-term forecast data might deviate from the true population characteristics as modelled in the biological operating model module because of the introduction of process error, model error, estimation error and observation errors.

In the management module of the model (*manage*), the perceived fishing mortality (F), which is equal to the assessment estimate, and conservation target reference points from the management agreement are used as input to simulate a harvest control rule (HCR) and formulate advice for setting the TACs and intended fishing mortality. The results of the HCR procedure in terms of TAC and projected F-level affect the state and behaviour of the fleet during the year in which the HCR is implemented. Management changes in F-levels will result in a different effort of the fleet. HCR decisions are based on perceived or observed information on fishing mortality and results in TAC advises and intended or expected fishing mortality estimates under the HCR measure.

Simulation runs

The simulations are run with 100 Monte Carlo realizations (figure 5), where the two sources of noise are: (1) process error in the biology part, via random noise around the stock-recruitment relationship and (2) observation error in the management part, by including a random sampling error around the observed fleet and survey catches. In reality there are probably more sources of random noise, like for instance mortality rates.

In the simulation model a number of simplifications and assumptions were made:

- The fishery for all flatfish in the North Sea is a mixed fishery;
- There is no distinction of fleets differing in selectivity or catchability. Although the beam trawl fleet is the major fleet exploiting flatfish (about 70% of the plaice and 90% of the sole landings in the North Sea originates from beam trawlers), plaice and sole are also caught by other fleets which are only subject to the effort management regime of the Regulation if the individual member state has quota exceeding 5% of the European Community share.
- Catchability for plaice and sole by this fleet was estimated from the historical relationship between fishing mortality and beam trawl effort and was assumed to remain constant over years;
- Future recruitment is related to stock size in the model by a stock-recruitment relationship. The standard choice was for the Ricker type of function. The Ricker curve starts in the origin, has a maximum and is asymptotic to zero (Figure 3).
- It is assumed that information is available of landings and discards on an annual basis to be incorporated in the assessments for these species on which the calculations for the TACs and the allowed days at sea are based;
- The fishing behaviour as the response to the annual management measures was formulated as two alternative scenarios;
- The interpretation on which fishing mortality rate the reduction of 10% should apply is not clear and therefore three alternative HCR were formulated.

Fleet behaviour assumptions

In order to simulate the fishing behaviour of the fleet, assumptions had to be made about the fleet's response to the annual management measures. Since there is uncertainty about the fleet's behaviour, two possible scenarios were formulated.

1. The fleet will go on fishing until the last of the two TACs is fished up while discarding (or misreporting) the overquota catch of the other species.
2. The fleet will fish up both TACs while avoiding catching overquota fish.

Scenarios 1 and 2 both assume that fishermen will try to fish as long as possible and avoid a premature exhaustion of the TAC either by misreporting or discarding (scenario 1) or by avoiding any catches of the most restrictive TAC (through spatio-temporal effort allocation or directive fishing, scenario 2). From these extreme assumption, the 'true' behaviour is thought to be somewhere in between.

Simulation of the management plan

The Harvest Control Rule that was implemented looks step-wise as follows:

1. The F estimate (age 2-6) in last data year (y-2) equals the F estimate for plaice from the last assessment.
2. Calculate the multiplication factor for a F reduction of plaice in running year (y-1) of 10% according to Article 7[1] sub a (=0.9)
3. Calculate multiplication factor of plaice to reach target Fmsy ex. Article 7[1] sub b ($Fmsy/F_{(y-2)}$)
4. Take the maximum result of step 2 and 3 and use this as the plaice F multiplication factor for year y-1 ($F.mult_{y-1}$), resulting in the F estimate (age 2-6) in the running year (F_{y-1}).
5. Calculate the multiplication factor for a F reduction of plaice in year (y) of 10% ex. Article 7[1] sub a (=0.9)
6. Calculate multiplication factor of plaice to reach target Fmsy ex. Article 7[1] sub b ($Fmsy/F_{(y-1)}$)
7. Take the maximum result of step 5 and 6 and use this as the plaice F multiplication factor for year y ($F.mult_y$), resulting in the F estimate (age 2-6) in the year of the TAC's application (F_y) (Article 7[1]).
8. The multipliers applied in the short term forecast for plaice are $F.mult_{y-1}$ for year y-1 and $F.mult_{y-1}$ x $F.mult_y$ for the year y. Note that both multipliers refer to data year y-2.
9. Compare the resulting plaice TAC with the current –running-year (y-1) – TAC and if the difference exceeds 15%, estimate a new multiplication factor $F.mult_y$ so that the resulting TAC is within these 15% bounds (Articles 7[2] & 7[3]).
10. The F estimate (age 2-6) in last data year (y-2) equals the F estimate for sole from the last assessment.
11. Calculate the multiplication factor for a F reduction of sole in running year (y-1) of 10% according to Article 8[1] sub b (=0.9)
12. Calculate multiplication factor of sole to reach target Fmsy ex. Article 8[1] sub a ($Fmsy/F_{(y-2)}$)
13. Take the maximum result of step 11 and 12 and use this as the sole F multiplication factor for year y-1 ($F.mult_{y-1}$), resulting in the F estimate (age 2-6) in the running year (F_{y-1}).
14. Calculate the multiplication factor for a F reduction of sole in year (y) of 10% ex. Article 8[1] sub a (=0.9)
15. Calculate multiplication factor of sole to reach target Fmsy ex. Article 8[1] sub b ($Fmsy/F_{(y-1)}$)
16. Take the maximum result of step 14 and 15 and use this as the sole F multiplication factor for year y ($F.mult_y$), resulting in the F estimate (age 2-6) in the year of the TAC's application (F_y) (Article 8[1]).
17. The multipliers applied in the short term forecast for sole are $F.mult_{y-1}$ for year y-1 and $F.mult_{y-1}$ x $F.mult_y$ for the year y. Note that both multipliers refer to data year y-2.
18. Compare the resulting sole TAC with the current –running-year (y-1) – TAC and if the difference exceeds 15%, estimate a new multiplication factor $F.mult_y$ so that the resulting TAC is within these 15% bounds (Articles 8[2] & 8[3]).
19. Estimate the efforts needed to yield the plaice TAC and the sole TAC. Compare the two estimates so constraints in exploiting both fish stocks become clear. It is assumed that fishing continues until both TACs are caught, so the maximum of the estimated efforts is selected. This estimate is the effort used in the simulated year of the TAC's application y.
20. In case the TAC for a species is lower then the simulated landing using the effort estimate from step 19, under scenario 1 the surplus is to be regarded as overquota catch. As an alternative in scenario 2 the surplus catch is avoided and the estimated overquota are added to the stocks.

Because Article 7[1] sub a and 8[1] sub b are not clear on which years fishing mortality rate the rule should apply, two alternatives for the double multipliers used in step 8 and 17 were formulated. The HCR for scenario 1 and 2 described above assume that the F reduction of 10% in the year of the TAC's application, year y, refers to the running year, y-1.
For scenario 3 (discard overquota) and 4 (avoid overquota) it was assumed that the reduction of 10% in year y refers to the last data year, y-2, instead of the running year. This means that a single multiplier is used for year 1 and 2 in the forecast procedure and it is expected that the yearly F reductions are smaller in comparison with the reduction achieved under scenario 1 and 2 using a double multiplier
For scenario 5 (discard overquota) and 6 (avoid overquota) a TAC constraint for year (y-1) was used in the forecast procedure in stead of a multiplier. For the second year a double multiplier was used (i.e. it is assumed that the 10% reduction refers to the running year, y-1).

In the scenarios 1-6 a Ricker stock recruitment relation is assumed for the stock dynamics, Scenario 7 is run under the same assumptions as scenario 1, but for the stock dynamics a Beverton and Holt relation is assumed. The two stock recruitment relationships are shown in figure 3.

Summary of scenarios:

HCR multiplier alternatives:		*Double*	*Single*	*TAC constraint*
Alternative fleet behavior	discard/misreport overquota catches	**1/7**	**3**	**5**
	avoid overquota catches	**2**	**4**	**6**

The management measure in the agreement is a reduction of fishing mortality, which is partly implemented as a TAC reduction. The effort reduction is reached via the implementation of art 9 of the proposal. According to this rule, the adjustment in effort (days at sea) is based on a forecast of the maximum level of fishing effort necessary to land the TACs established according to Articles 7 and 8 of the regulation (step 19). In practice, effort will probably not restrict the fisheries. According to Article 9[6] of the Regulation the maximum level of fishing effort is the level allocated in 2006. The simulation study, therefore, does not implement limiting effort levels below the 2006 level.

The simulated landings for both plaice and sole show similar patterns as the observed landings before 2007. It means that the fit for selectivity and catchability mimics the perception in the real world. In case of plaice the simulated values showed large year to year variation and were systematically above the observations (figure 6). The initialization results indicate a better fit for sole.

The simulation model is developed using the FLR package (FLR Team 2006), a collection of data types and methods written in the R language (R Development Core Team 2005) as part of the EU EFIMAS-COMMIT-FISBOAT project cluster. FLR is an OpenSource project meaning that the source code is available to the users. It will be put on the FLR wiki (http://www.flr-project.org/) together with data and additional sources for checking/ validating/ evaluation.

4 Results

The simulation was done for the Regulation management agreement under 7 scenario's. The stochastic model was run for 100 iterations with generated recruitment of 18 successive assessment years (2007- 2025). Figures 7 to 15 show time series of TACs, landings, discards, perceived and implied fishery mortality, SSB and recruitment for scenario 1 and 2 as plots showing the distributions of these results by their 5th, 25th, 50th, 75th, and 95th percentile.

A summary of the result of all scenarios is given in Table 2 for sole and Table 3 for plaice. Except for scenario 7 where a Beverton and Holt stock recruitment relationship was used, in 50 out of the 100 runs the objective of the multi-annual plan in the first stage was attained in 2015, 7 years after implementing the management rules and the fraction increases to at least 80 of the 100 runs where both stocks were found having been returned for two years in succession to within safe biological limits 2 years later. In case a Beverton and Holt stock recruitment relationship was used, stage one is completed with a probability of 0.5 in 2017 and this probability increases to 0.75, 2 years later.

Direct comparison of the scenarios is presented in figure 16 to 19.

<u>Scenario 1 and 2</u>

(sole)

These scenarios assume that the F reduction of 10% in the year of the TAC's application, year y, refers to the running year, y-1.The (average) TAC and landings of sole initially decrease to approximately 11 500 tons after implementing (4-6 years). Subsequently, they increase to a stable level of around 14 000 tons with 25 and 75 percentile results being 11 000 and 20 000 tons respectively (figure 7). The changes in TAC and catches between the two scenarios are small, because the amounts of sole discarded due to an exhausted TAC is limited.

In on average 25 of the 100 realizations (those which generate large year classes) larger amounts of overquota fish as 500 tons will be caught and under scenario 1 removed from the stock. On average the quantity of overquota sole that will be caught is low (median equals 0 tons, figure 8).

The SSB gradually increases to 80 000 tons, which has a negative impact on recruitment because of the Ricker stock recruitment relationship that is assumed (figure 8). This relationship has a maximum at 50 000 tons. In general, average recruitment of sole varied between 60 and 100 million and showed a slight negative trend in time.

During the time when the application of the HCR is simulated, the observed F (as estimated by XSA, two years later) is slightly lower than the intended or implied F (two years earlier, see figure 10).

(plaice)

There are considerable differences in changes of TAC and catches between both scenarios especially on the long term. The differences are related to the assumption of avoiding or catching (extra mortality) of overquota fish. For scenario 2 (overquota catch avoided) the TAC of plaice increases to around 110 000 tons in the first 10 years. Landings show a similar increase (figure 12). Scenario 1 (overquota catch discarded or misreported) shows much lower TACs and landings on the medium to long term compared to scenario 2. The differences between the two scenarios is small in the first years after implementation of the agreement (on average 1000 tons) but increases up to 35 000 tons on medium term.

Discards of undersized plaice under scenario 2, avoiding overquota catches, decrease on average from initially approximately 40 000 tons to less then 20 000 tons in the medium term. Because the average biomass of the plaice stock increases the discarded fraction of the catch will decrease considerable. Undersized plaice discards under scenario 1 are higher then scenario 2. For plaice, on average no overquota fish are caught during the initial period. Thereafter plaice overquota increase up to on average 50 000 ton on the long term, which is a considerable proportion of the catch. Occasionally in some realizations large amounts of overquota fish (up to 90 000 tons) are caught (figure 13).

The SSB of plaice is expected to increase to around 550 000 tons on the medium term. This implies that SSB will reach a level well above Bpa, which secures a good buffer against bad year classes. Plaice recruitment is variable and initially around 0.8 to 1 billion. Note that in case SSB is above 300 000 tons, average recruitment decreases according to the Ricker model (figure 14).

The observed F (as estimated by XSA, two years later), gradually falls slightly below the implied or intended F (two years earlier (figure 15). The realized reduction of F during the initial period until 1012 was on average higher then 10% per year.

(scenarios 3,4,5,6 & 7)

TACs and landings for plaice show similar results for scenario 1, 3 and 5 (assuming overquota catches discarded or misreported) and for scenario 2, 4 and 6 (assuming avoidance of overquota fish). Within these groups, the scenarios differ by the way the TAC is calculated. The similar results found indicate that the short term forecast procedure with different F multipliers has little effect. Results under scenario 3 and 4 (single multiplier) projected TAC and landings are slightly higher during the first part of the projected period (figure 16). The differences between both groups is dominated by the assumption on the behaviour of the fleet.

TACs and landings for sole differ from plaice. For sole the way the TAC is calculated matters, in particular in the first part of the projected period. Also here the assumption of avoidance of overquota fish leads to higher TACs and higher catches in comparable scenarios.

TACs and landings results differ depending on the stock recruitment relationship assumed. Under the Ricker SR relationship average SSB levels off at 70 - 80 000 tons for sole and approximately 500 000 tons for plaice for all scenario's. Under the assumption of Beverton and Holt SR relationship (scenario 7), lower TACs, landings, recruitment and SSB are expected in the first part of the predicted trajectory. When the SSB increases all these entities increase because of the assumption of higher recruitment at high SSB. (Figure 1 and 17).

The number of occasions, per simulated scenario (with 100 iteration) and year, where the adjustment to the maximum level of fishing effort available for the fleets, based on observed or perceived information, was insufficient to yield the plaice or the sole TAC was over 50 for year 2009 and around 30 thereafter for all scenarios.

Average plaice undersized discards are initially around 40 000 tons and gradually decrease for the scenarios were overquota fishing is avoided to around 20 000 tons (figure 18). Under the scenarios where overquota catches are discarded or misreported (1, 3, 5 and 7), undersized discards levels decrease slightly but remain on a high level.

Overquota catches are low for sole. For plaice these catches are low only during the first years after implementing the management plan and gradually increase in the period thereafter. After 10-12 years, the levels remain stable at around 40 000 to 50 000 tons per year (figure 18). The problem of overquota fish seems to increase when fishing mortality is reduced. The assumption whether avoidance of plaice is possible becomes more relevant at low fishing mortalities when continued fishing for sole.

Average SSB of both species increase similar all scenarios, except from scenario 7 (Beverton and Holt recruitment) where the increase was less steep during the initial simulation period. Modal SSB predictions of sole appear to reach values above Bpa from 2009 onwards. The modal SSB prediction of plaice was found above Bpa from 2012 onwards (figure 17)

In all cases (Figure 19) perceived F as the observed result from the stock assessment, decrease from initial values of 0.55 for plaice and 0.35 for sole. The steepest reduction of plaice F was observed for scenarios 2 and 6, from 0.52 to 0.31 in 4 years, which is on average a 13 % reduction in F per year during this period. For scenario 3 this reduction is around 6 % per year and for scenario 1 and 5 around 9 % per year. For sole the perceived F reduces on average 10-11 % per year for scenarios 1, 2, 5 and 6 and with 8 % per year for scenarios 2 and 3.

Apart from scenario 7 (Beverton and Holt recruitment) in 2015, 7 years after the implementation, the probability that the objectives of phase 1 of the agreement are met is over 0.5 for all scenarios (Figure 20). In over 50 of the 100 iterations the two stocks have returned to within safe biological limits for two years in succession. The probability increase thereafter to approximate 0.8 in 2017 and is levelling off between 0.9 and 1 depending on the scenario. The completion of stage one of the management plan mainly depend on the state of the plaice stock (Figure 17). The sole stock returned to safe biological limits in 2013 with a probability of 0.6, except for scenario 7, where this occurs in 2015.

Figure 21 shows that in the short term the probability that the true state of the plaice stock is above Blim increases from 0.5 in 2008 to > 0.95 in 2010 for all scenarios, except when the Beverton and Holt S/R is assumed. The true sole SSB was found always to be above Blim in more then 95% of the runs, independent from the considered scenario's. This means that the risk that recruitment is impaired is found to be less then 5% from 2010 onwards for both stocks.

5 Discussion

This evaluation aims to indicate the changes in the fishery and stocks of North sea plaice and sole and their magnitude which may be expected under the simulated management with the simplifications and assumptions made. The evaluation does not aim to predict what happens exactly after implementing the management procedure of the Regulation. It includes a simulation of the future under various assumed scenarios and the results indicate a direction of the effect after the implementation including an indication of a time frame needed to achieve the objectives stated. The simulations are repeated 100 times to take into account the expected variation of model parameters, such as recruitment, sampling errors and observation errors. The results are presented as averages being the modal values of the 100 realizations and the percentiles defining the ranges of probabilities in which most realizations occurred. The results of individual runs indicate that output mainly varies, pending the occurrence of exceptional good or poor year classes. Here the risk associated with the harvest control rule and the other stochastic processes should be kept in mind. Communicating the risks associated with all these processes are a challenge to scientists, managers and administrators.

When evaluating the model, assumptions had to be made at different levels in the process. If the major assumptions are very different from the true situation, the effect of the measures are probably different from those indicated by the evaluation. In some cases it may be possible to demonstrate that making one or another assumption does have little effect on the final outcome of the evaluation. In that case we can conclude that the measure is robust to this assumption. From the result and comparison of the 7 scenarios we can conclude that the measure is robust to some of the various scenario options chosen. For example the way the TAC is calculated in case of plaice has little effect on the performance of the management strategy. As shown in the results the variation of the outcome between individual runs is to a large extent related to the stochastic recruitment pattern and related year class strengths. Still the results are sensitive to the underlying stock-recruitment relationship, because, depending on the function chosen, on average more or less recruits are generated given a certain amount of stock biomass. The Ricker function generates more recruits compared with the Beverton and Holt function while the SSB is less than 50 000 and 320 000 tons for sole and plaice respectively. When SSB is larger the Beverton and Holt function generates more recruits. Given the large uncertainty in the true stock-recruitment relationships, additional runs should be executed using a constant recruitment equal to 25th, 50th and 75th percentiles of the long year recruitment observations imposed with stochasticity and thus simulate low, average and high recruitment patterns.

The implementation of this management agreement results in a change in management strategy from a risk avoidance strategy (to stay within safe biological limits) to a strategy of optimal harvesting of the resource. This new strategy is in accordance with the commitments made at the World Summit on Sustainable Development at Johannesburg (2002). It can be envisaged that management of other stocks in EU waters will follow and be adjusted using similar management approach as currently used for plaice and sole. The management means a change from conservation or limit reference points to target reference point that are intended to meet management objectives. The concept of using the precautionary biomass threshold (Bpa) as a trigger for management action has disappeared in the present management. In the agreed plan, the biomass of the stock is only relevant for the management procedure to determine if the objectives of the multiannual plan in the first stage are reached: ensure the return of the stocks of plaice and sole to within safe biological limits. The management action is only conditional to the fishing mortalities estimates by the fishery scientists based on stock assessments. The assumptions made in the assessment procedure should be clear, together with the methods used to monitor the status of the stocks. In the current model spatial variation in fish abundance and fishing effort is not included. Conditioning of a model with areal differentiation is complicated (Pastoors et al. 2006; Poos et al. 2006) and the (XSA) observation model to which the results are compared do not include spatial variation either.

The realization of the objective of the agreed plan in the first stage (return to within safe biological limits) was on average achieved under most scenarios within 7 years after implementation, when over 50% of the runs reach the stated objectives. Although the specific objectives of the multiannual plan in the second stage (ensure the exploitation on the basis of maximum sustainable yield) are only clear after the transitional arrangements described in Article 5 of the Regulation, the simulations were continued after finalizing the first phase for an extended period and show that on average the preliminary target Fs can be reached within a time frame of stock rebuilding being less then 10 years. Apart from showing how the exploited species will respond to harvest control rules and management measures, the effects should also be evaluated in a broader perspective. According to the agreement, the fishing effort is limited by yearly adjustment to a maximum level necessary to take catches of sole and plaice equal to the TACs established. The social and economic impacts of the management measures, over both the short and the long term using performance indicators like precaution/safety, employment, profitability and administrative costs is a next step in assessing its consequences on the fishers, society and environment.

The initial proposal of the management plan by the European Commission in 2006 contained regulations on an annual proportional change of the fishing mortality of plaice and sole and was evaluated earlier (Machiels et al. 2007). The main difference between the agreed plan currently evaluated and the earlier proposed plan is that the effort limitation is mitigated by removing the direct link between the fishing mortality reduction of sole and the reduction of effort as fishing day's at sea. The direct link causes a strict reduction of the effort applied resulting in a limitation to land the agreed sole TACs, specially during the first few years after the implementation of the new management. The effort level in the agreed plan is set at such a level that both TACs can be exhausted with an upper limit of the 2006 level. The effect of the lack of the linkage has not been investigated in detail this study. It would be interesting to investigate how errors in one assessment may affect the performance of the HCR for the other species, particularly in case the observed fishing mortalities are low.

Some examples of assumptions made in the current evaluation are given here. For both plaice and sole stocks it has been assumed that productivity of the marine ecosystem in the projected period will remain within the same range as has been observed in the past 50 years. This assumption may not be true. Observations of changes in the species composition in the North Sea towards more southern species and observation on changes in stock dynamics of some other stocks may indicate that external factors, such as climate change, do also affect the ecosystem. In the evaluation, it has also been assumed that annual decisions will be made using a certain assessment method (the present assessment procedures) with its associated uncertainties. It can be envisaged that other methods may be used in the future and this may affect (improve or deteriorate) the effect of the management measures. It has also been assumed that all catches (landings and discards) are known with an assumed error of 10%. In practice this may not be true. In particular estimates of discards are much more variable and can have a large influence on the observed F which is used in the management procedure.
Most important are the assumptions on the behaviour of fishers in respond to the measures. The avoidance scenarios assume that fishers can avoid one target species and continue to fish on the other species after the TAC of the first species is exhausted. It is noted that the Regulation aims to control landings and not catch. Fishermen have the choice either to stop fishing when their quotas are depleted, or to discard over quota fish. Both scenarios must be considered as extremes. This behaviour of discarding is not illegal in waters under European Community legislation. To some extent, it may be possible to avoid catches of a target species, by selecting different fishing grounds or periods, or by modification to the gear but it is doubtful whether full avoidance, as assumed in some of the scenario's, is possible. The avoidance assumption is considered less realistic but is included to assess the sensitivity of the simulation for the extreme assumptions. The simulations show that results found for the plaice stock in terms of TAC and landings are sensitive for the assumption on overquota fish.

The simplification of not to differentiate between fleets may mask the problem of overquota fish because assigning plaice and sole quotas to multiple fleets in ratios which differ from the plaice and sole TACs ratio can result in behaviours that differs from fleet to fleet. The same problem exist under a ITQ system were the individual quota ratios vary between fishers.

The various interpretations on the technical procedure of setting the TACs showed that these had an effect on the simulation results only for sole during the first stage of the implementation. Results of the double multiplier (0.9·0.9) were comparable with the runs under the TAC constraint scenarios and both resulted in most cases in a reduction of fishing mortality which was larger then 10% per year on average. The HCR with the single multiplier (0.9) resulted in a reduction of fishing mortalities in the first stage of the plan of less then 10% per year.

The main conclusion of this evaluation is that the objectives for the first stage (stocks within safe biological limits) are expected to be achieved in 2015 under all scenarios evaluated except when a Beverton and Holt stock recruitment relationship was used. During this period the fishing mortalities decrease to levels around 0.3 for plaice and 0.2 for sole. Discard amounts of undersized plaice remain high during the first stage while the amounts of over quota fish start to increase later. Under all assumptions and scenarios the biomass of both stocks increase to levels which are higher then the precautionary levels assumed for these stocks.

6 Acknowledgement

This study was partly supported by the Commission of the European Communities Directorate General for Fisheries (DG XIV) under contract EFIMAS (Operational evaluation tools for fisheries management options).

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Figures and tables

Figure 1: Fishing mortalityrate (left) and SSB (right) for sole and plaice. Observations are represented by dots (plaice: closed ; sole: open). The broken and solid straight lines in the SSB graph show the precautionary biomass (B_{pa}) and the limit biomass (B_{lim}) respectively.

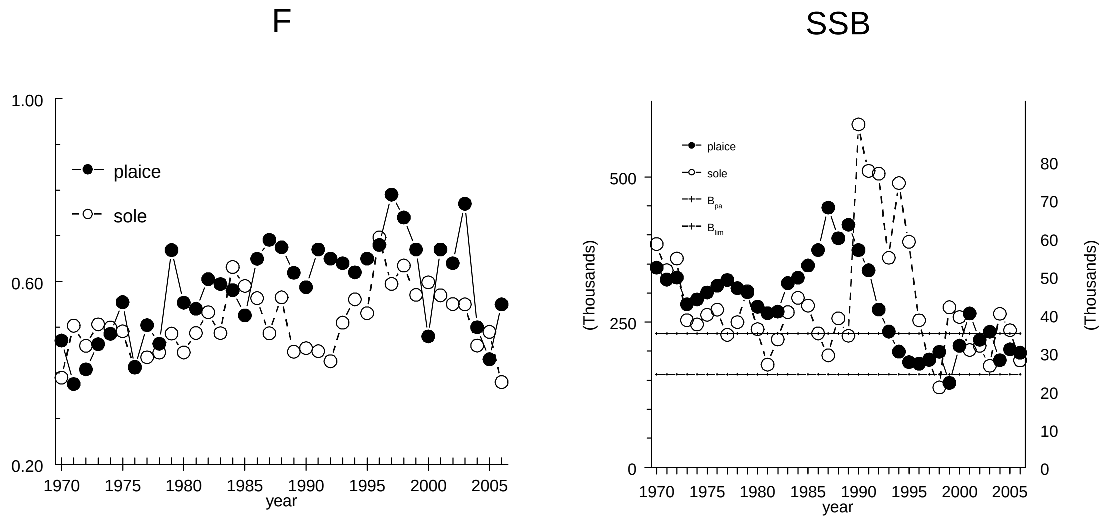


Figure 2. A schematic overview of the management types and harvest control rules extracted from the proposal and translated in the HCR algorithm for scenario 1 or 2.
TACy: TAC for the next management year.
TACy-1: TAC for the current year
Fy-1: F, assumed for the current year
Fmsy: F, assumed to result in a maximum catch at equilibrium.
mult: multiplication factors for F in year y relative to F in year y-2.

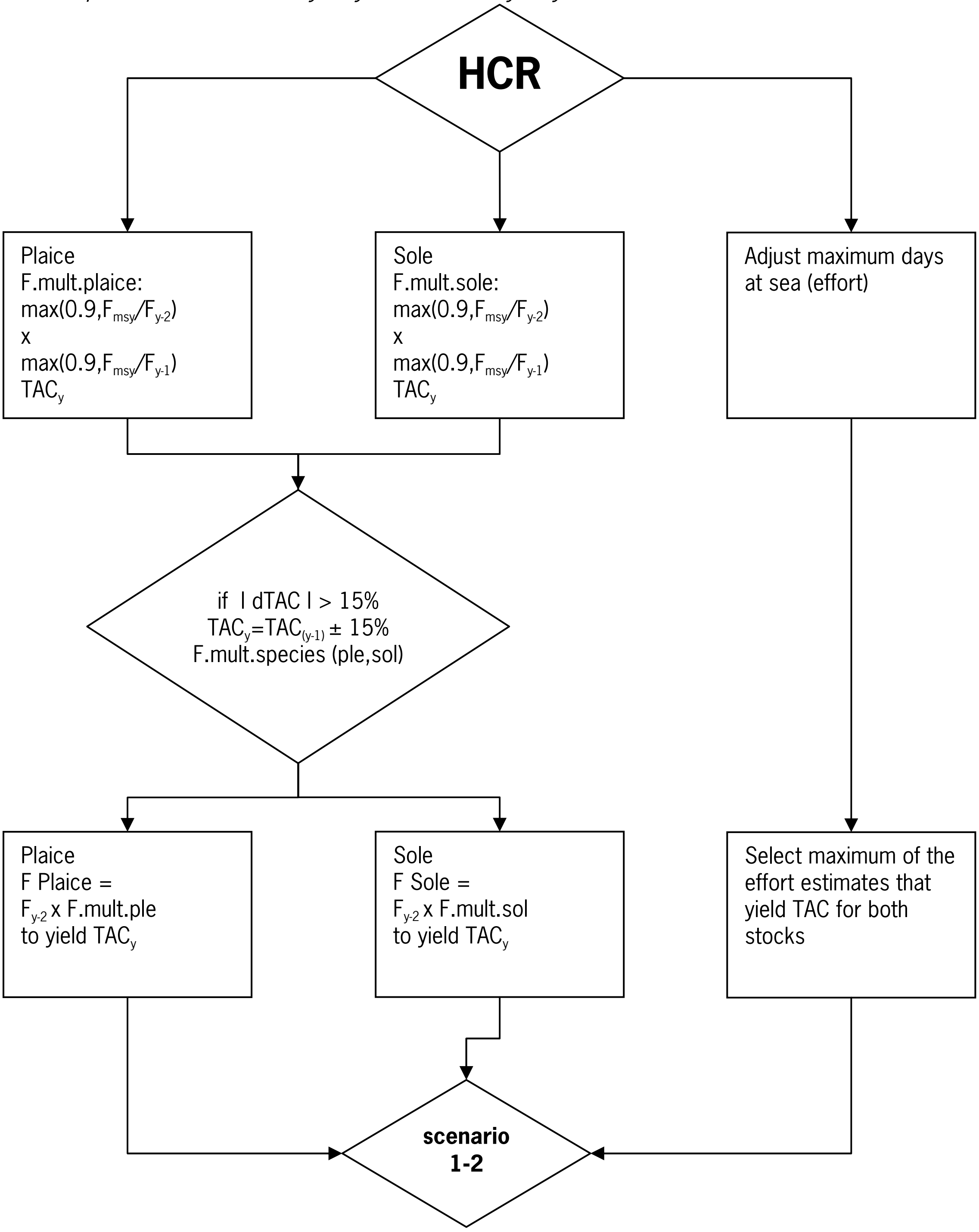


Figure 3. Stock recruitment relationship for sole (left) and plaice (right). Estimates are represented by black dots and predictions according to the Ricker or Beverton and Holt models are shown by lines (Ricker, solid black line; Beverton and Holt, broken red line). Note that the Ricker function generates more recruits compared with the Beverton and Holt function while the SSB is lower than 50 000 and 320 000 tons for sole and plaice respectively. When SSB is larger the Beverton and Holt function generates more recruits..

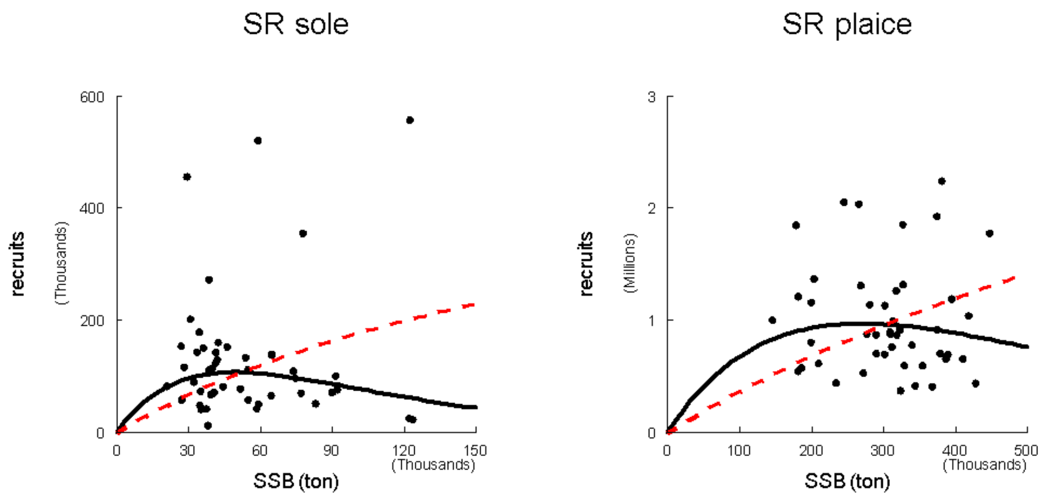


Figure 4. Relational diagram of the simulation model with 4 main modules. Biols and fleets represent the operating model (the true state) while stocks and manage represent the observation model (the perception of the true state)

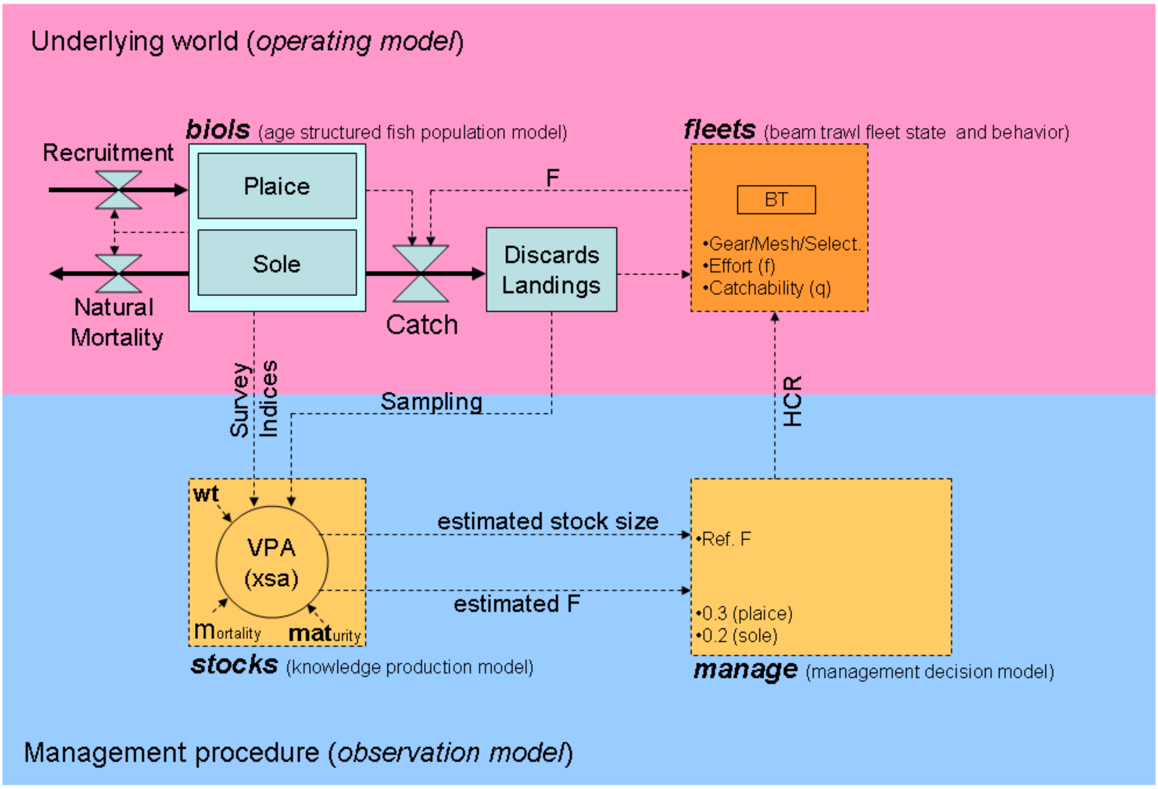


Figure 5. Results of 60 individual simulation runs (TAC plaice) from 2008 to 2025 under scenario 1.

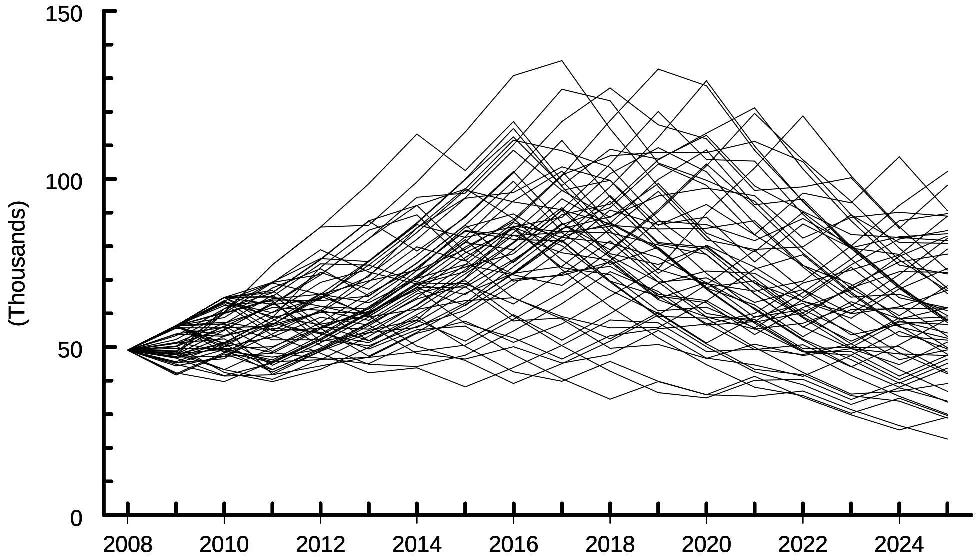


Figure 6. Comparison of the historic WG estimates of North sea sole and plaice landings over the period 1996-2006 and simulated results over the same period.

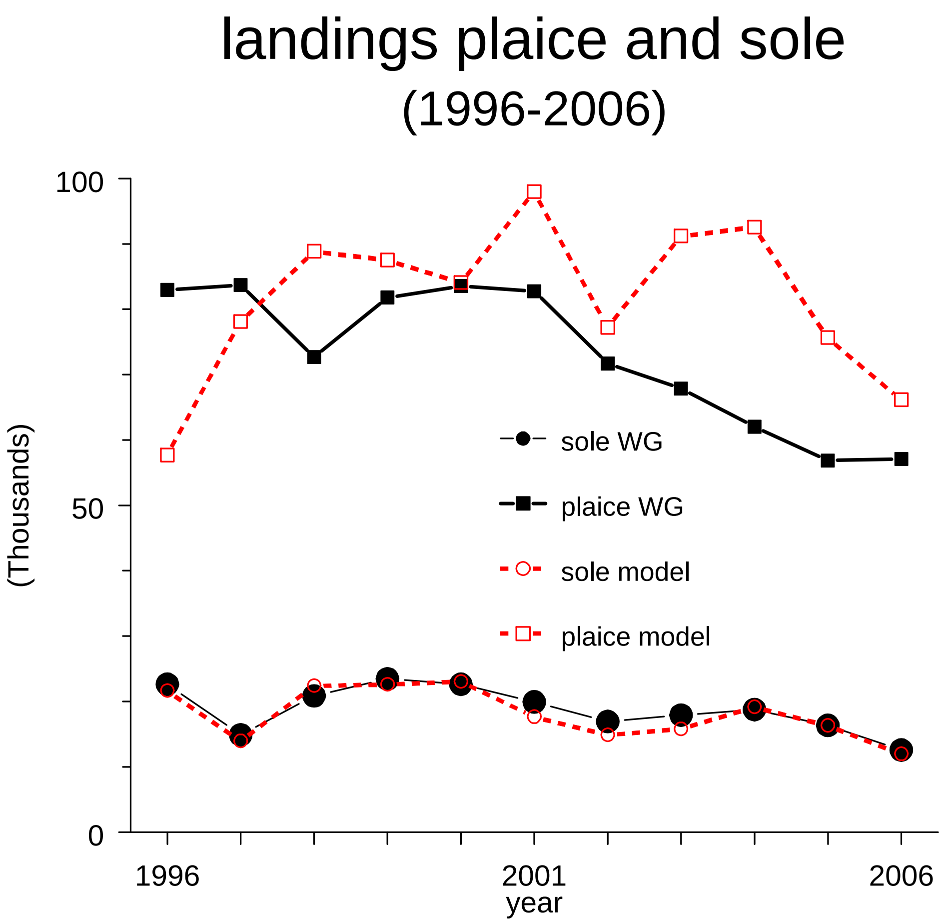
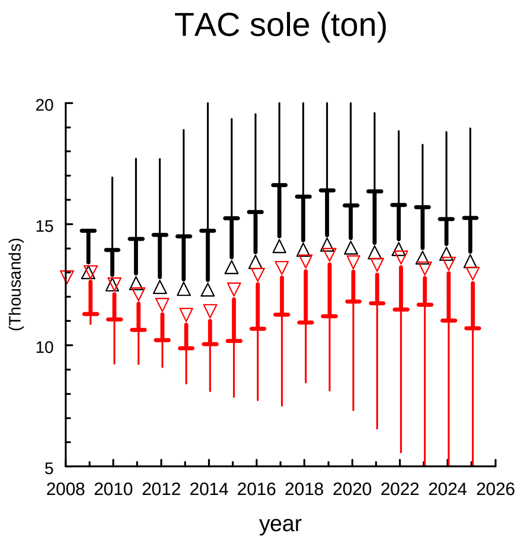


Figure 7. The sole TAC and landings (in thousand tons) over time. Red: scenario 1 (overquota catch discarded or misreported). Black: scenario 2 (overquota catch avoided). Triangles: medians. Thick lines end at the 25th (red) and the 75th (black) percentile respectively. Thin lines end at the 5th (red) and 95th (black) percentile respectively. For scenario 1 only the downward variation and for scenario 2 only the upward variation are shown, but the variability is expected to be similar between the scenarios.



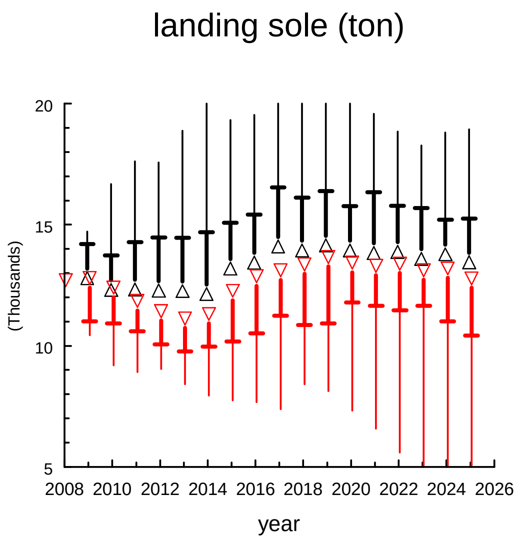


Figure 8. The overquota catches (in thousand tons) over time. Only scenario 1 is shown, because in scenario 2 overquota catches are avoided. Symbols and lines, see Figure 7. Note that the 50% quantiles for all years amount 0 (see summary table).

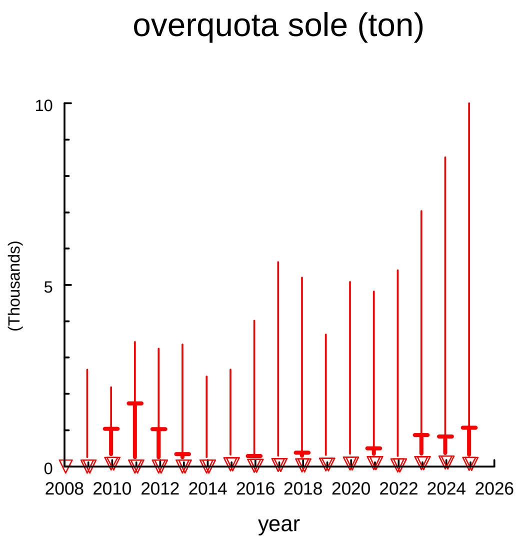


Figure 9. The number of sole recruits (in million over time) and SSB (in thousand ton). Red: scenario 1 (overquota catch discarded or misreported). Black: scenario 2 (overquota catch avoided). Symbols and lines, see Figure 7.

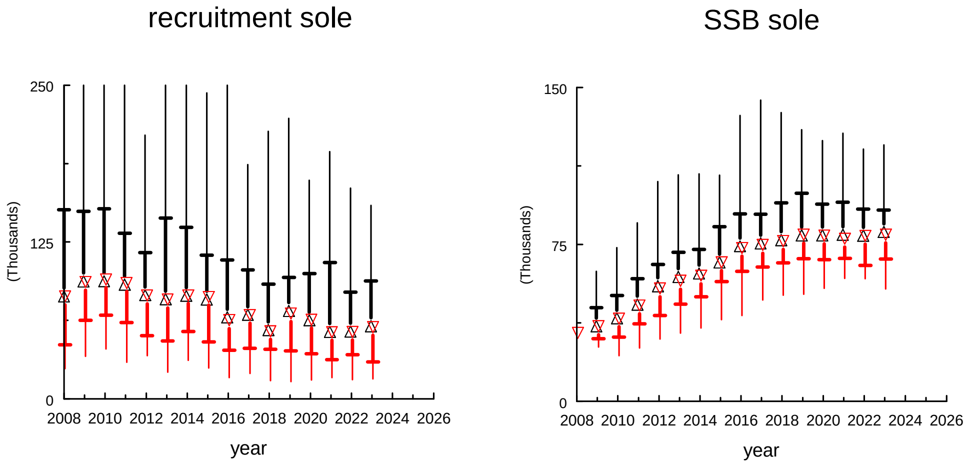


Figure 10. The sole fishing mortality (F) over time. Red: scenario 1 (overquota catch discarded or misreported). Black: scenario 2 (overquota catch avoided). The circles and squares connected by solid lines (right) represent the implied or expected F under the HCR-measure. The triangles (left) represent the F as estimated two years later by XSA. Vertical lines, see Figure 7.

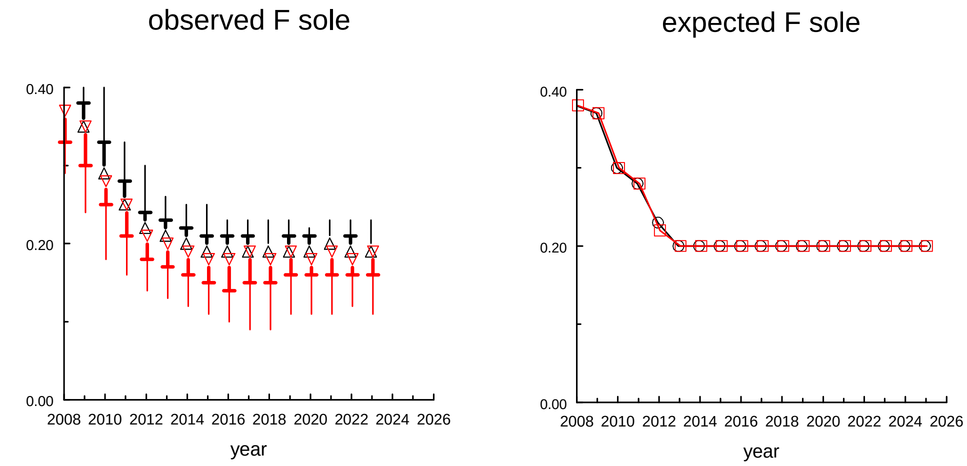


Figure 11. The relative fishing effort over time. Red: scenario 1 (overquota catch discarded or misreported). Black: scenario 2 (overquota catch avoided). Vertical lines, see Figure 7.

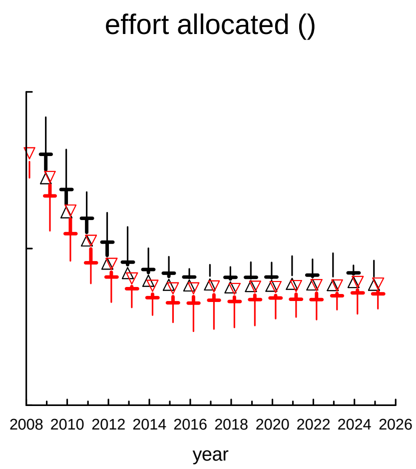


Figure 12. The plaice TAC and landings (in thousand tons) over time. Red: scenario 1 (overquota catch discarded or misreported). Black: scenario 2 (overquota catch avoided). Triangles: medians. Thick lines end at the 25th (red) and the 75th (black) percentile respectively. Thin lines end at the 5th (red) and 95th (black) percentile respectively. For scenario 1 only the downward variation and for scenario 2 only the upward variation are shown, but the uncertainty is expected to be similar between the scenarios.

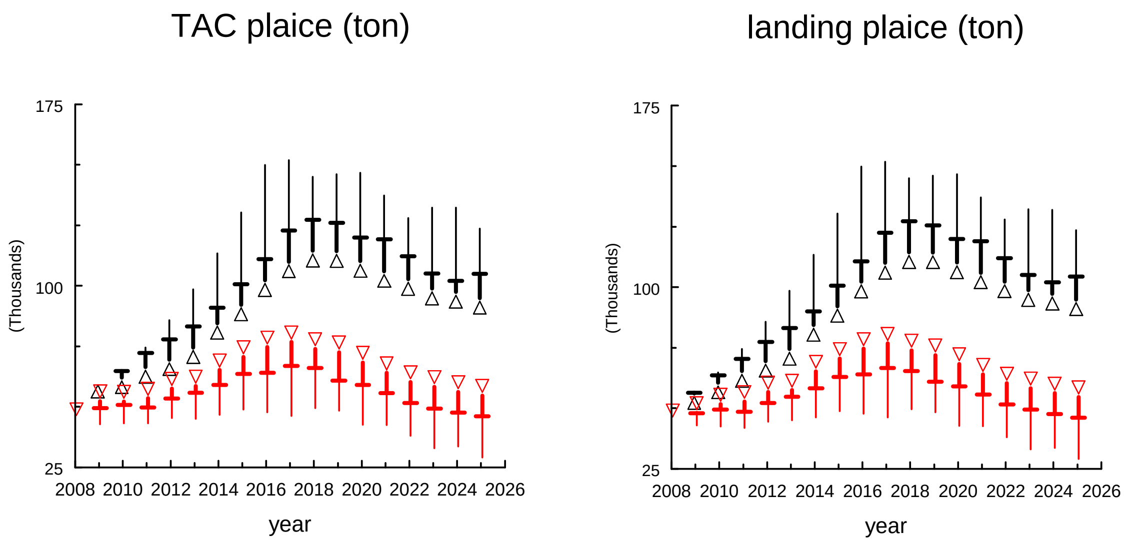


Figure 13. Plaice undersized discards (in thousand tons) and the overquota catches (in thousand tons) over time. Only scenario 1 is shown for overquota, because in scenario 2 overquota catches are avoided Symbols and lines, see Figure 12.

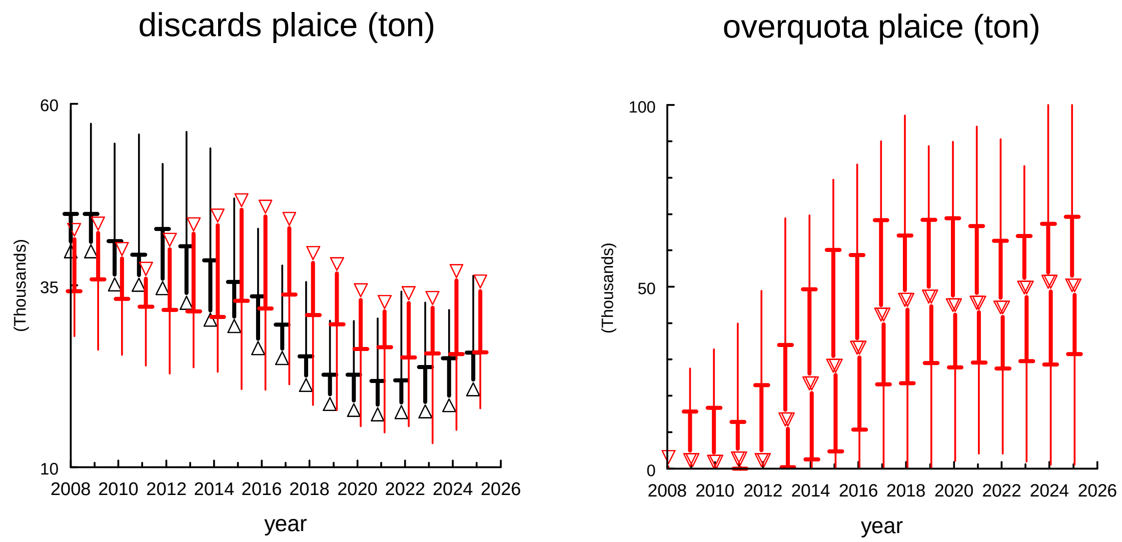


Figure 14. The number of plaice recruits (in million over time) and SSB (in thousand ton). Red: scenario 1 (overquota catch discarded or misreported). Black: scenario 2 (overquota catch avoided). Symbols and lines, see Figure 12.

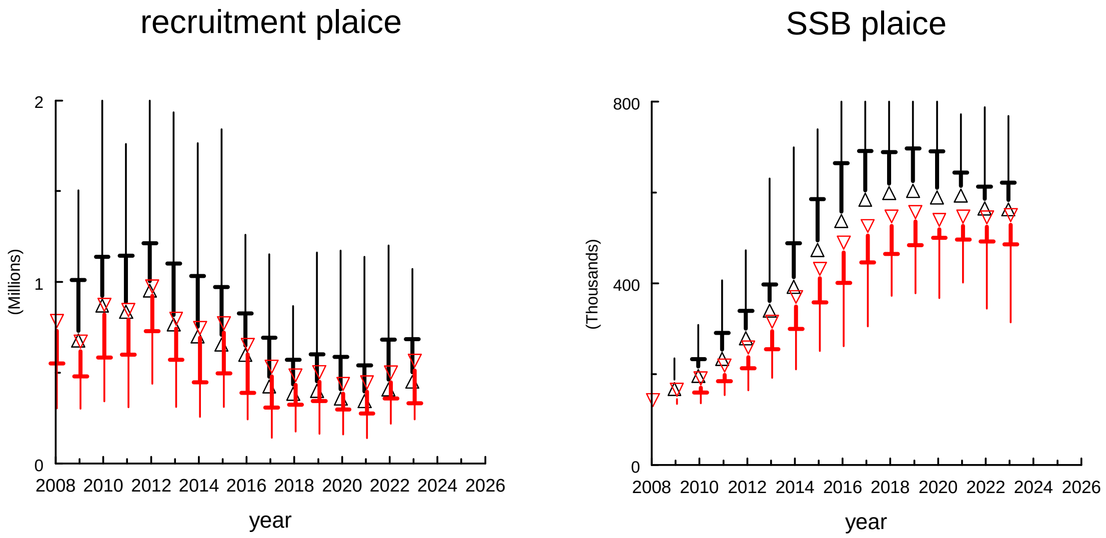


Figure 15. The plaice fishing mortality (F) over time. Red: scenario 1 (overquota catch discarded or misreported). Black: scenario 2 (overquota catch avoided). The circles and squares connected by solid lines (right) represent the implied or expected F under the HCR-measure. The triangles (left) represent the F as estimated two years later by XSA. Vertical lines, see Figure 12.

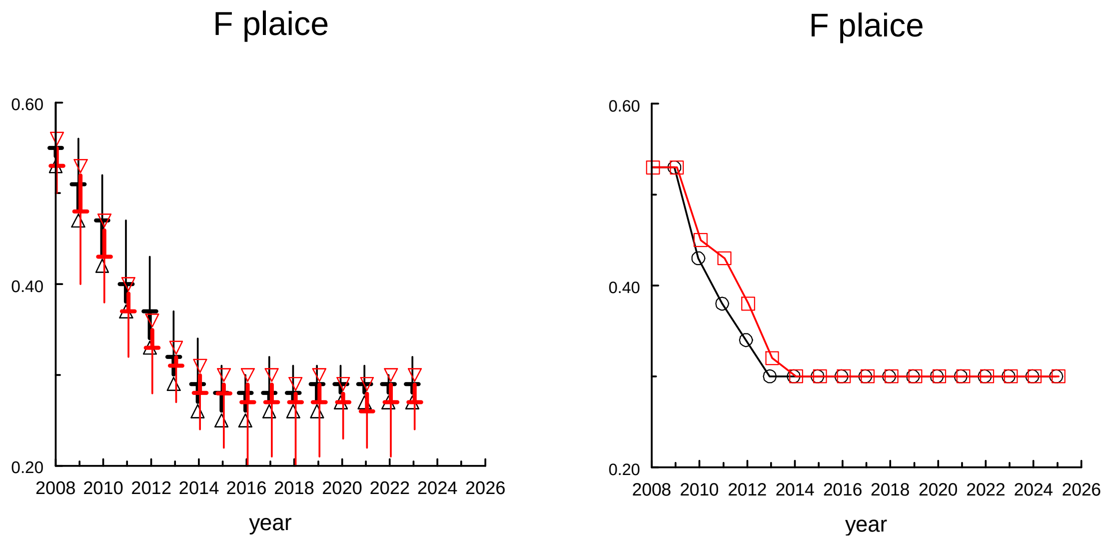


Fig 16. Average TACs and - landings for sole and plaice resulting from the 7 scenarios. Scenarios 1, 3, 5 and 7 (overquota catch discarded or misreported) are represented by red scatters. Scenarios 2, 4 and 6 (overquota catch avoided) are depicted black. Legend is in the figure.

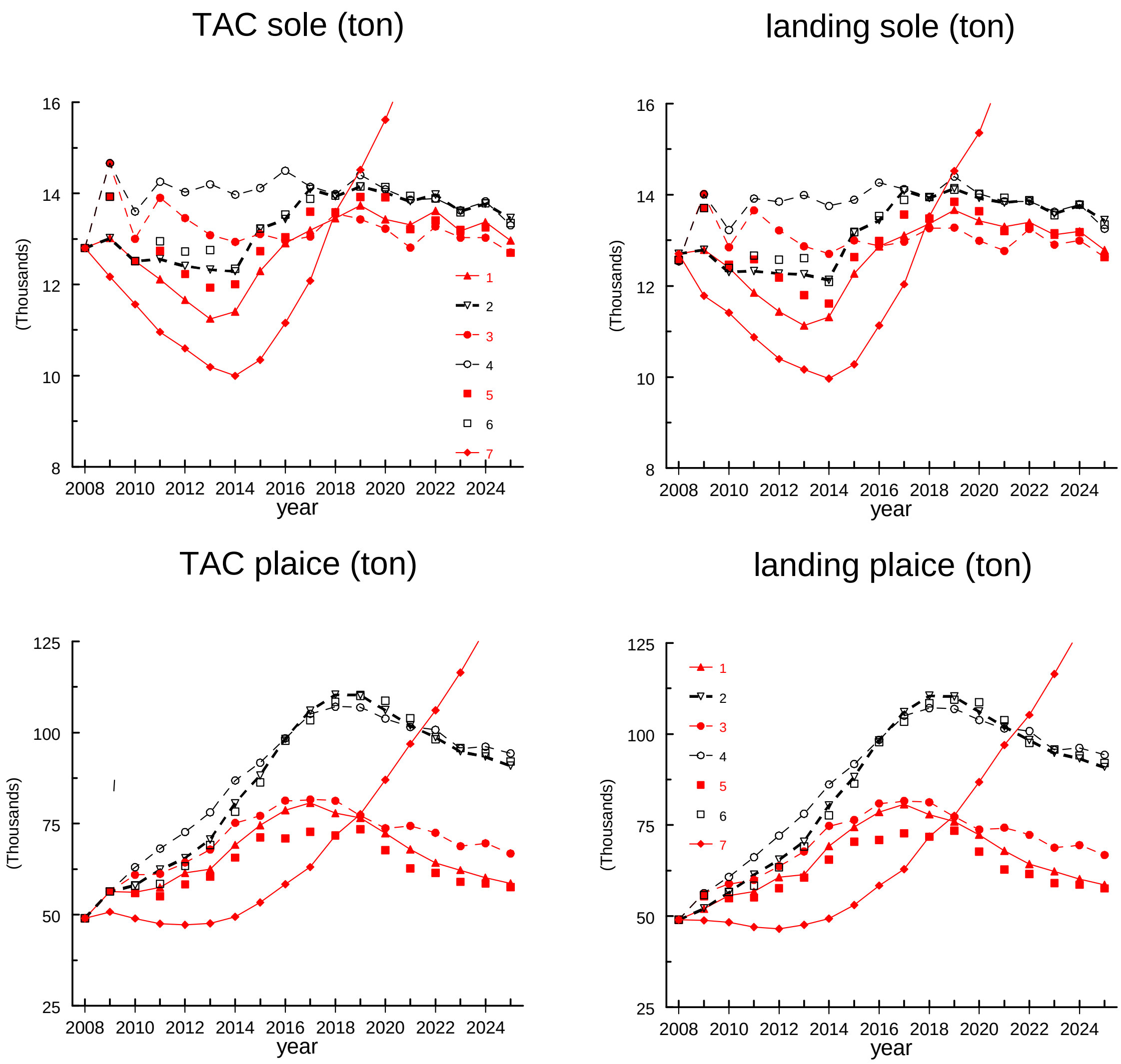


Fig 17. Average SSB and recruitment for sole and plaice resulting from the 7 scenarios. Scenarios 1, 3, 5 and 7 (overquota catch discarded or misreported) are represented by red scatters. Scenarios 2, 4 and 6 (overquota catch avoided) are depicted black. Legend is in the figure. Bpa values are depicted as horizontal red dotted lines.

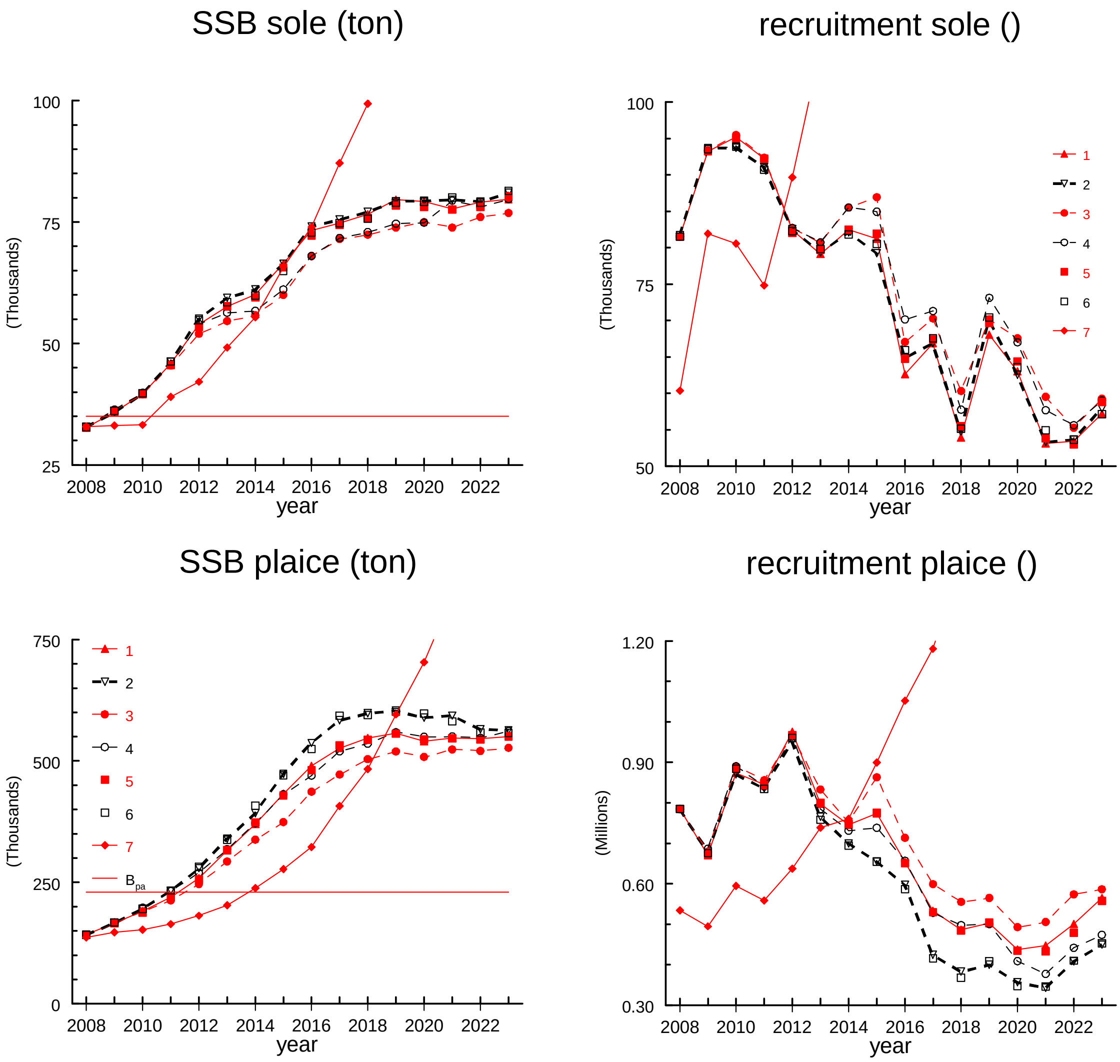


Fig 18. Average discards (plaice only) and overquota catches for plaice and sole resulting from the 7 scenarios. Scenarios 1, 3, 5 and 7 (overquota catch discarded or misreported) are represented by red scatters. Scenarios 2, 4 and 6 (overquota catch avoided) are depicted black. Legend is in the figure.

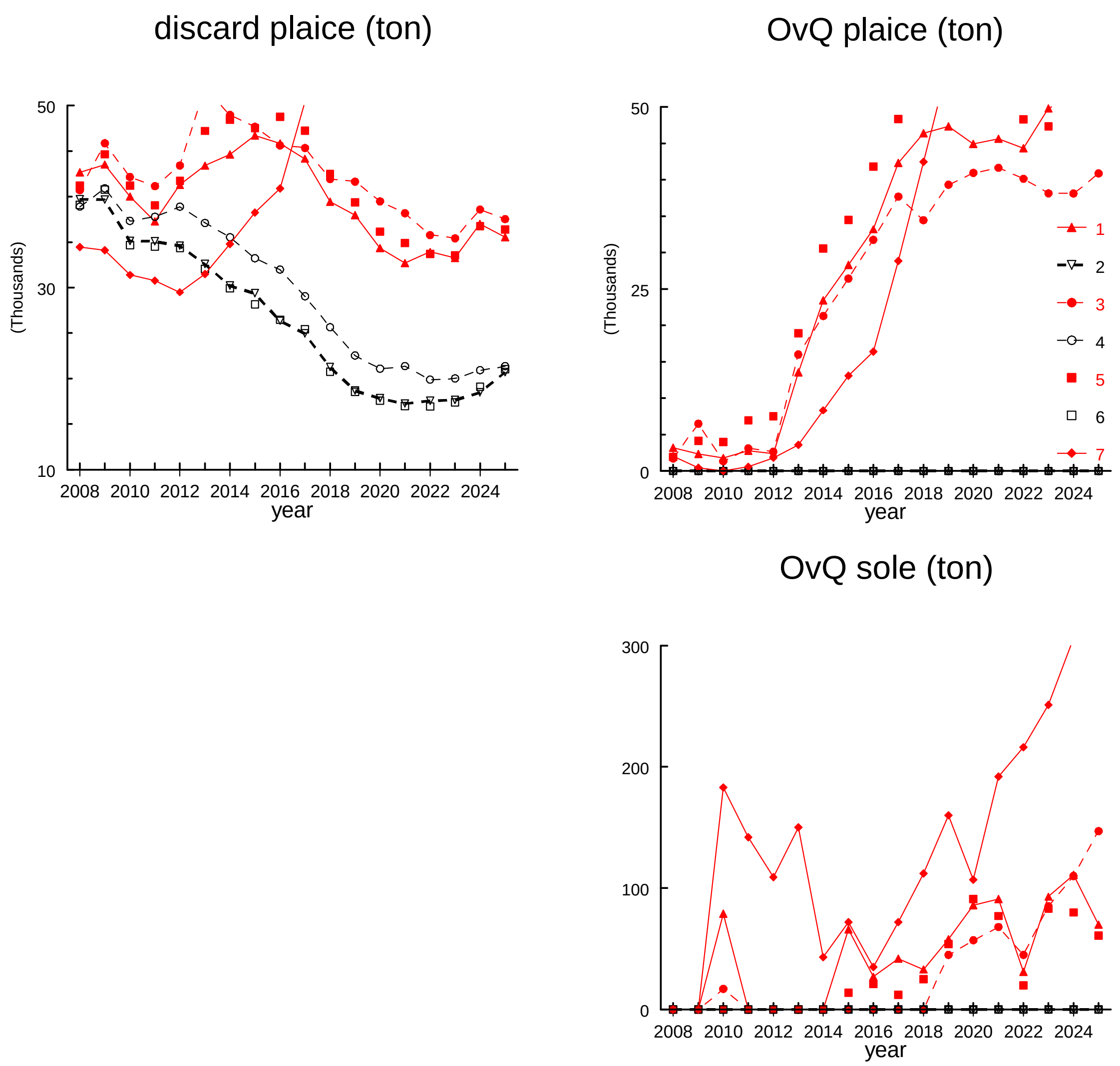


Fig 19. Average observed (left) and intended (right) fishing mortalityfor plaice and sole resulting from the 7 scenarios. Scenarios 1, 3, 5 and 7 (overquota catch discarded or misreported) are represented by red scatters. Scenarios 2, 4 and 6 (overquota catch avoided) are depicted black. Legend is in the figure.

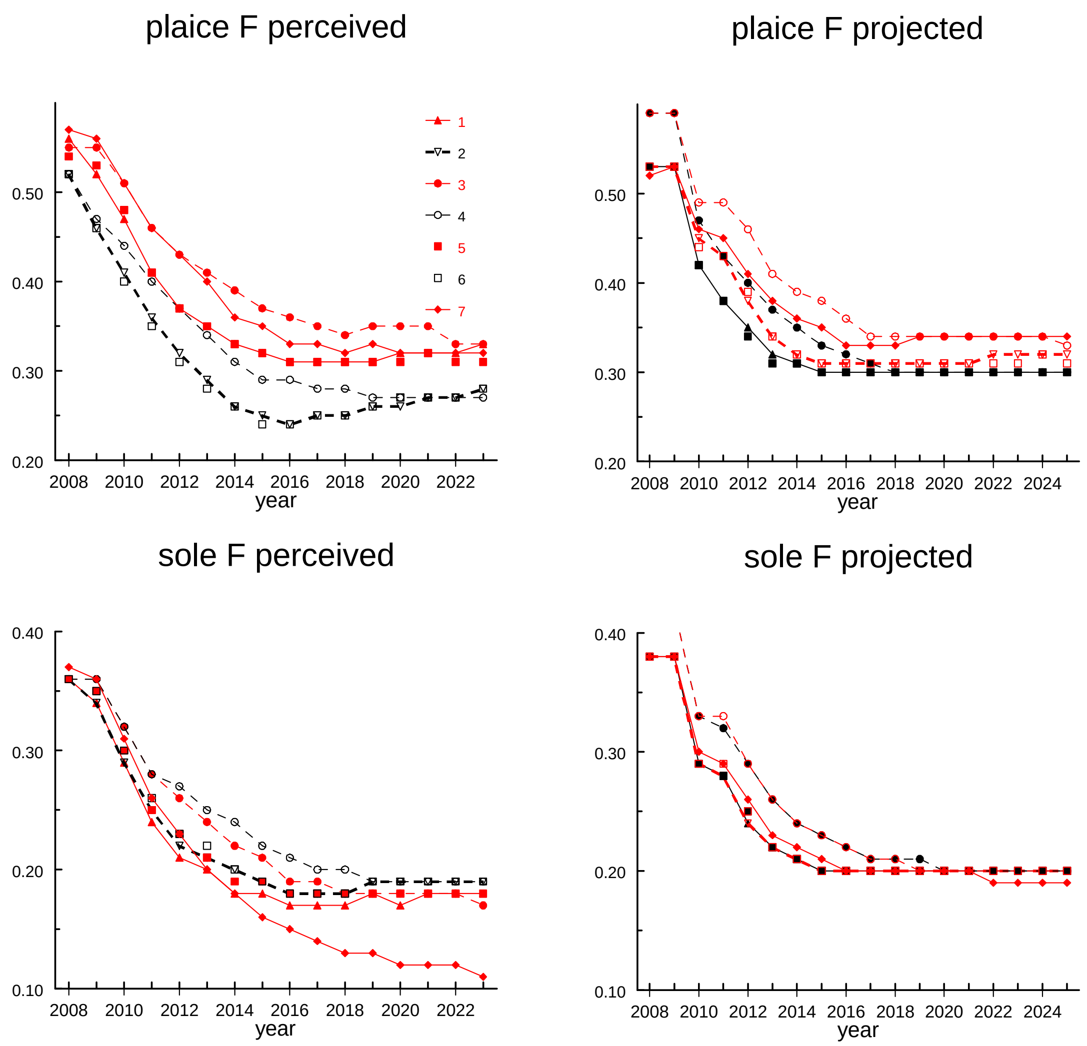


Fig 20. Probability of achieving the objective for phase one, expressed as fraction of the 100 iteration runs where the objective of the plan are achieved. Top figures represent the return of the individual stock of plaice and sole to within safe biological limits. Bottom figure represent the return of the stocks of plaice and of sole to within safe biological limits for the 7 scenarios. Scenarios 1, 3, 5 and 7 (overquota catch discarded or misreported) are represented by red scatters. Scenarios 2, 4 and 6 (overquota catch avoided) are depicted black. Legend is in the figure.

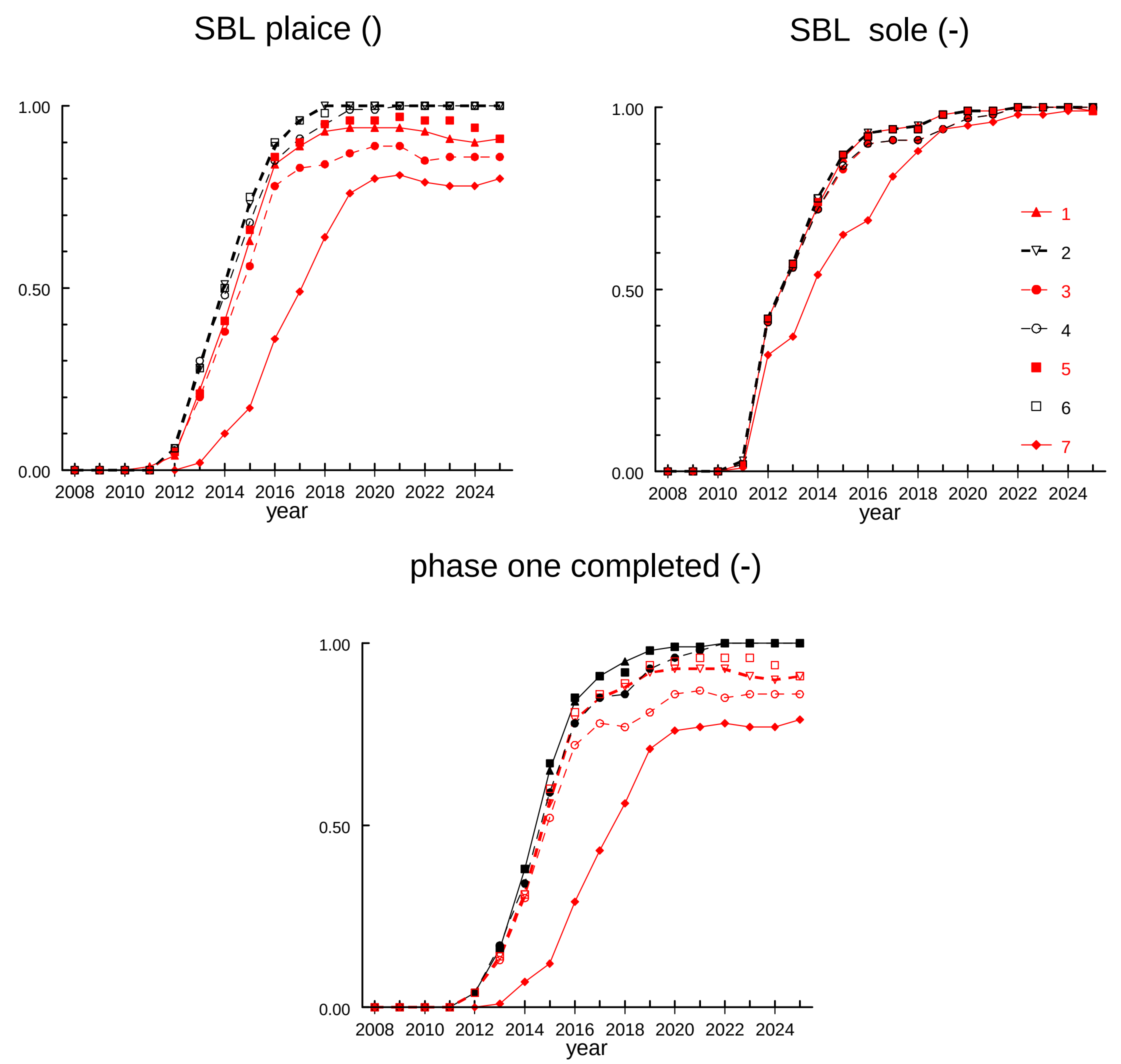


Fig 21. Fraction (-) of 100 iteration runs were the true SSB is above Blim for plaice (=160 000 ton) and sole (=25 000 ton) separately resulting from the 7 scenarios. Scenarios 1, 3, 5 and 7 (overquota catch discarded or misreported) are represented by red scatters. Scenarios 2, 4 and 6 (overquota catch avoided) are depicted black.

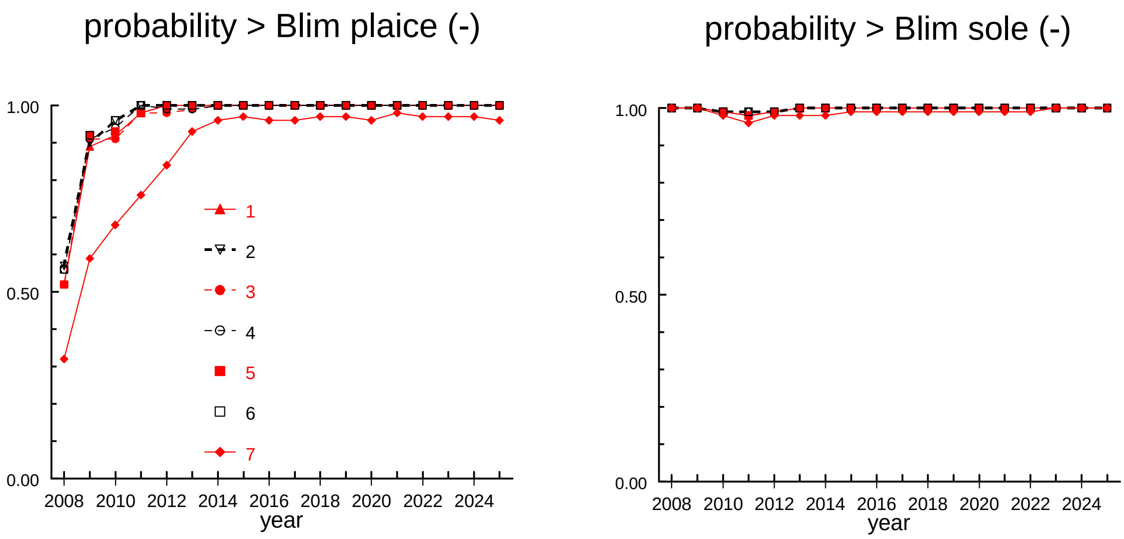


Table 1. A summary of the results after the objectives of stage 1 of the management plan are reached in more then 50 of the 100 iterations simulated for the alternative scenarios. Scenario 1 :overquota catch discarded or misreported, scenario 2: overquota catch avoided, scenario 7: similar as scenario 1 with Beverton & Holt SR relationship. Prob SBL represents the probability that the individual species return to safe biological limits. Fsq is the observed fishing mortality as estimated two years later by XSA.

	Scenarios:							
	Initial (2008)		1		2		7	
Species:	sole	plaice	sole	plaice	sole	plaice	sole	plaice
Year completed:			2015		2015		2018	
Probability	0.00	0.00	0.6		0.7		0.6	
Prob SBL	0.00	0.00	0.9	0.6	0.9	0.7	0.7	0.6
TACs (tons)	12800	49000	12300	74600	13200	88200	13600	71800
Landings	12700	49000	12300	74400	13200	88200	13500	71800
Discards		42700		46700		29400		57700
OvQ		3200	100	28300			100	42500
Fsq (per year)	0.4	0.6	0.2	0.3	0.2	0.3	0.1	0.3
SSB	34000	156000	67000	504000	69000	515000	92000	541000

Table 2. A summary of the results for sole of the 7 scenarios

scen	year	TAC	LAN	OvQ	Fsq	Fpro	Recr	SSB	phase2
	2008	12800	12705	0	0.37	0.38	67331	33358	0
	2009	13021	12794	0	0.35	0.37	86687	37289	0
	2010	12512	12402	79	0.28	0.3	85075	40646	0
	2011	12110	11854	0	0.25	0.28	80126	44875	0
	2012	11665	11434	0	0.21	0.22	66366	51952	0.04
	2013	11249	11132	0	0.2	0.2	74425	56808	0.14
	2014	11406	11315	0	0.19	0.2	74534	60757	0.31
	2015	12299	12273	66	0.18	0.2	72103	67225	0.56
1	2016	12911	12868	27	0.18	0.2	55260	74897	0.79
	2017	13190	13110	42	0.19	0.2	56991	76468	0.85
	2018	13454	13362	33	0.18	0.2	46515	76732	0.88
	2019	13737	13666	58	0.19	0.2	58314	78857	0.92
	2020	13432	13432	86	0.18	0.2	54735	78640	0.93
	2021	13313	13302	91	0.19	0.2	46788	77791	0.93
	2022	13617	13393	31	0.18	0.2	51194	79278	0.93
	2023	13173	13120	93	0.19	0.2	57208	79681	0.91
	2024	13371	13199	111		0.2			0.9
	2025	12963	12787	70		0.2			0.91
	2008	12800	12705		0.37	0.38	71690	33787	0
	2009	13021	12794		0.35	0.37	91981	38236	0
	2010	12512	12303		0.29	0.3	91304	41132	0
	2011	12561	12330		0.25	0.28	82088	48203	0
	2012	12409	12276		0.22	0.23	70236	56116	0.04
	2013	12327	12257		0.21	0.2	74853	61870	0.16
	2014	12294	12135		0.2	0.2	76843	63875	0.38
	2015	13229	13189		0.19	0.2	75615	68954	0.65
2	2016	13441	13441		0.19	0.2	60106	77038	0.84
	2017	14098	14098		0.19	0.2	57694	77393	0.91
	2018	13938	13938		0.19	0.2	48025	78054	0.95
	2019	14153	14146		0.19	0.2	60442	79920	0.98
	2020	14026	13936		0.19	0.2	54369	80830	0.99
	2021	13834	13834		0.2	0.2	47639	80311	0.99
	2022	13976	13879		0.19	0.2	51026	80017	1
	2023	13616	13587		0.19	0.2	57934	81002	1
	2024	13776	13776			0.2			1
	2025	13466	13445			0.2			1
	2008	12800	12541	0	0.37	0.42	69942	34086	0
	2009	14663	14018	0	0.37	0.42	93329	38320	0
	2010	13003	12850	17	0.31	0.33	90283	41528	0
	2011	13902	13658	0	0.29	0.33	80265	46591	0
	2012	13456	13218	0	0.25	0.28	68016	52538	0.04
	2013	13085	12867	0	0.24	0.26	70027	54880	0.13
	2014	12936	12702	0	0.23	0.23	75586	56610	0.3
	2015	13107	12998	0	0.21	0.22	78071	61002	0.52
3	2016	12966	12872	0	0.2	0.21	54759	66429	0.72
	2017	13051	12968	0	0.19	0.2	57271	68236	0.78
	2018	13549	13268	0	0.19	0.2	49514	73492	0.77
	2019	13431	13277	45	0.19	0.2	61492	74299	0.81
	2020	13224	12989	57	0.19	0.2	59121	73433	0.86
	2021	12809	12767	68	0.19	0.2	55619	73954	0.87
	2022	13273	13249	45	0.18	0.2	53424	73859	0.85
	2023	13027	12905	85	0.18	0.2	59280	76888	0.86
	2024	13028	12995	110		0.2			0.86
	2025	12701	12635	147		0.2			0.86
	2008	12800	12541		0.36	0.42	72597	34216	0
	2009	14663	14009		0.37	0.42	95213	39472	0
	2010	13601	13227		0.32	0.33	94993	41965	0
	2011	14255	13918		0.29	0.33	83937	47973	0
	2012	14026	13849		0.26	0.28	72040	54868	0.04
	2013	14199	13994		0.24	0.26	76450	58914	0.17
	2014	13971	13755		0.23	0.24	78916	58892	0.34
	2015	14114	13891		0.22	0.22	80810	64029	0.59
4	2016	14497	14268		0.21	0.21	64321	70832	0.78
	2017	14144	14124		0.2	0.2	61712	73422	0.85
	2018	13987	13948		0.2	0.2	50392	75107	0.86
	2019	14400	14400		0.2	0.2	65228	76989	0.93
	2020	14087	14016		0.19	0.2	58028	75742	0.96
	2021	13858	13858		0.2	0.2	50916	79424	0.98
	2022	13886	13858		0.19	0.2	53120	79058	1
	2023	13631	13630		0.19	0.2	59040	79708	1
	2024	13826	13792			0.2			1
	2025	13301	13255			0.2			1

scen	year	TAC	LAN	OvQ	Fsq	Fpro	Recr	SSB	phase2
	2008	12800	12567	0	0.36	0.38	69027	33604	0
	2009	13929	13713	0	0.36	0.37	90723	37490	0
	2010	12512	12462	0	0.29	0.29	87941	41035	0
	2011	12743	12581	0	0.26	0.3	82883	47291	0
	2012	12230	12181	0	0.22	0.23	70551	52780	0.04
	2013	11932	11796	0	0.21	0.21	74769	58353	0.14
	2014	12004	11612	0	0.2	0.2	76812	60270	0.31
	2015	12735	12636	14	0.19	0.2	74255	67086	0.6
5	2016	13042	12987	21	0.19	0.2	59064	74550	0.81
	2017	13597	13567	12	0.19	0.2	58021	76007	0.86
	2018	13588	13475	25	0.19	0.2	47520	75588	0.89
	2019	13923	13848	54	0.19	0.2	59715	78872	0.94
	2020	13910	13636	91	0.19	0.2	55842	77811	0.95
	2021	13215	13201	77	0.19	0.2	48155	77051	0.96
	2022	13410	13289	20	0.18	0.2	50252	78804	0.96
	2023	13197	13155	83	0.19	0.2	58796	80271	0.96
	2024	13257	13182	80		0.2			0.94
	2025	12696	12634	61		0.2			0.91
	2008	12800	12567		0.36	0.38	71783	33899	0
	2009	13929	13713		0.36	0.37	92299	38587	0
	2010	12512	12393		0.29	0.29	91504	41228	0
	2011	12950	12669		0.26	0.3	83148	48488	0
	2012	12727	12580		0.23	0.23	70507	55718	0.04
	2013	12753	12609		0.22	0.21	75084	61551	0.16
	2014	12347	12084		0.21	0.2	76198	62375	0.38
	2015	13227	13176		0.19	0.2	76611	68026	0.67
6	2016	13536	13536		0.19	0.2	60422	75738	0.85
	2017	13884	13884		0.19	0.2	59978	77101	0.91
	2018	13950	13950		0.19	0.2	48020	78069	0.92
	2019	14151	14110		0.19	0.2	61476	79780	0.98
	2020	14140	14028		0.19	0.2	55643	79422	0.99
	2021	13943	13935		0.19	0.2	48190	79905	0.99
	2022	13888	13877		0.19	0.2	50803	79826	1
	2023	13583	13547		0.19	0.2	57164	81433	1
	2024	13784	13784			0.2			1
	2025	13351	13351			0.2			1
	2008	12800	12702	0	0.38	0.38	50208	34062	0
	2009	12167	11783	0	0.37	0.37	69536	34331	0
	2010	11563	11413	183	0.32	0.31	69961	34381	0
	2011	10960	10877	142	0.27	0.3	59490	39133	0
	2012	10598	10395	109	0.23	0.26	70955	41062	0
	2013	10188	10167	150	0.2	0.22	88756	46772	0.01
	2014	9995	9967	43	0.18	0.2	81661	50714	0.07
	2015	10343	10276	72	0.16	0.2	103953	60710	0.12
7	2016	11158	11129	35	0.16	0.2	107899	68793	0.29
	2017	12080	12035	72	0.14	0.2	119230	79516	0.43
	2018	13590	13523	112	0.13	0.2	105742	92338	0.56
	2019	14519	14519	160	0.13	0.2	131058	107595	0.71
	2020	15614	15358	107	0.13	0.2	157316	119480	0.76
	2021	16930	16787	192	0.13	0.2	183459	136463	0.77
	2022	18362	18344	216	0.12	0.2	202939	146150	0.78
	2023	20384	20384	251	0.12	0.2	169639	164148	0.77
	2024	22453	22453	306		0.2			0.77
	2025	24993	24460	341		0.2			0.79

Table 3. A summary of the results for plaice of the 7 scenarios

scen	year	TAC	LAN	OvQ	DISC	Fsq	Fpro	Recr	SSB	phase2
	2008	49,000	49,000	3,194	42,660	0.56	0.53	827295	155,746	0
	2009	56,350	52,070	2,346	43,518	0.53	0.53	672966	176,903	0
	2010	56,186	55,614	1,806	40,006	0.47	0.45	877387	213,566	0
	2011	57,467	56,698	2,798	37,261	0.40	0.43	897292	246,418	0
	2012	61,524	60,646	2,373	41,289	0.36	0.38	980256	300,259	4/100
	2013	62,482	61,372	13,527	43,406	0.33	0.32	804287	359,999	14/100
	2014	69,173	69,173	23,420	44,610	0.31	0.30	762654	419,522	31/100
	2015	74,551	74,449	28,291	46,715	0.30	0.30	782659	503,856	56/100
1	2016	78,631	78,552	33,206	45,817	0.30	0.30	677434	564,541	79/100
	2017	80,694	80,694	42,336	44,165	0.30	0.30	520424	597,911	85/100
	2018	77,879	77,879	46,408	39,446	0.29	0.30	503092	616,801	88/100
	2019	76,512	75,911	47,326	37,951	0.30	0.30	486634	608,582	92/100
	2020	72,294	72,294	44,949	34,334	0.29	0.30	411205	588,815	93/100
	2021	67,936	67,936	45,636	32,713	0.29	0.30	418927	578,768	93/100
	2022	64,249	64,249	44,328	33,922	0.30	0.30	504527	561,162	93/100
	2023	62,232	62,232	49,815	33,260	0.30	0.30	565401	550,301	91/100
	2024	60,157	60,157	51,349	36,978		0.30			90/100
	2025	58,600	58,600	50,416	35,534		0.30			91/100
	2008	49,000	49,000		39,710	0.53	0.53	792840	149,293	0
	2009	56,350	52,173		39,684	0.47	0.53	638890	175,032	0
	2010	58,130	56,549		35,155	0.42	0.43	839462	213,022	0
	2011	62,426	61,369		35,109	0.37	0.38	836686	252,499	0
	2012	65,559	65,510		34,612	0.33	0.34	905593	311,193	4/100
	2013	70,615	70,460		32,613	0.29	0.30	734269	365,158	16/100
	2014	80,615	80,368		30,258	0.26	0.30	678076	432,979	38/100
	2015	88,206	88,206		29,405	0.25	0.30	659184	514,975	65/100
2	2016	98,284	98,284		26,369	0.25	0.30	575652	594,621	84/100
	2017	106,030	106,030		24,994	0.26	0.30	390269	645,356	91/100
	2018	110,459	110,459		21,287	0.26	0.30	387892	646,972	95/100
	2019	110,333	110,333		18,698	0.26	0.30	379021	652,160	98/100
	2020	106,222	106,222		17,848	0.27	0.30	341062	620,988	99/100
	2021	102,024	102,024		17,277	0.27	0.30	321404	614,125	99/100
	2022	98,746	98,323		17,569	0.27	0.30	395006	575,813	1
	2023	94,827	94,827		17,651	0.27	0.30	449724	562,928	1
	2024	93,472	93,271		18,505		0.30			1
	2025	90,944	90,944		20,707		0.30			1
	2008	49,000	49,000	1,727	40,701	0.55	0.59	839936	156,293	0
	2009	56,350	56,304	6,501	45,862	0.56	0.59	689526	181,236	0
	2010	60,981	58,825	1,334	42,141	0.50	0.50	906123	211,238	0
	2011	61,212	59,950	3,089	41,149	0.45	0.50	889031	239,495	0
	2012	64,314	63,684	2,648	43,407	0.43	0.45	996526	277,811	4/100
	2013	67,901	67,722	16,004	51,828	0.40	0.40	820833	331,398	13/100
	2014	75,192	74,747	21,291	48,971	0.37	0.38	769748	385,706	30/100
	2015	77,124	76,341	26,435	47,680	0.35	0.36	873580	429,131	52/100
3	2016	81,282	80,897	31,772	45,627	0.33	0.34	739005	493,420	72/100
	2017	81,577	81,577	37,696	45,347	0.33	0.31	621411	524,662	78/100
	2018	81,253	81,253	34,449	41,925	0.31	0.30	590184	554,727	77/100
	2019	77,193	77,193	39,320	41,642	0.32	0.30	554418	569,819	81/100
	2020	73,738	73,738	40,950	39,480	0.31	0.30	505412	548,499	86/100
	2021	74,376	74,272	41,643	38,164	0.30	0.30	477313	541,946	87/100
	2022	72,453	72,263	40,139	35,769	0.30	0.30	548587	531,615	85/100
	2023	68,792	68,792	38,136	35,425	0.30	0.30	586527	527,099	86/100
	2024	69,589	69,477	38,118	38,581		0.30			86/100
	2025	66,773	66,773	40,872	37,519		0.30			86/100
	2008	49,000	49,000		38,903	0.51	0.59	789057	150,131	0
	2009	56,350	56,304		40,901	0.48	0.59	635636	178,026	0
	2010	63,003	60,740		37,323	0.45	0.46	849538	212,150	0
	2011	68,135	66,159		37,786	0.41	0.43	832942	252,244	0
	2012	72,681	72,088		38,896	0.37	0.41	934875	292,729	4/100
	2013	78,070	78,070		37,104	0.33	0.37	742975	342,981	17/100
	2014	86,807	86,124		35,535	0.30	0.33	712909	395,600	34/100
	2015	91,705	91,705		33,229	0.29	0.30	709577	461,245	59/100
4	2016	98,399	98,399		31,988	0.29	0.30	647341	514,380	78/100
	2017	105,109	105,016		29,048	0.28	0.30	504081	568,755	85/100
	2018	107,090	107,090		25,657	0.28	0.30	501984	590,327	86/100
	2019	106,875	106,875		22,543	0.27	0.30	475138	600,822	93/100
	2020	103,812	103,812		21,083	0.27	0.30	393913	585,671	96/100
	2021	101,495	101,495		21,378	0.27	0.30	367076	574,429	98/100
	2022	100,761	100,761		19,891	0.28	0.30	421058	559,243	1
	2023	95,630	95,630		20,019	0.27	0.30	473760	561,806	1
	2024	96,136	96,136		20,918		0.30			1
	2025	94,270	94,270		21,367		0.30			1

scen	year	TAC	LAN	OvQ	DISC	Fsq	Fpro	Recr	SSB	phase2
	2008	49,000	49,000	1,948	41,199	0.55	0.53	829758	155,511	0
	2009	56,350	55,464	4,125	44,646	0.54	0.53	674242	178,907	0
	2010	55,929	54,896	3,982	41,197	0.47	0.44	887780	212,348	0
	2011	55,082	55,082	6,973	39,042	0.40	0.44	877495	247,876	0
	2012	58,325	57,638	7,520	41,750	0.36	0.38	982510	291,067	4/100
	2013	60,520	60,520	18,904	47,221	0.34	0.33	795927	356,346	14/100
	2014	65,648	65,518	30,560	48,451	0.32	0.30	758685	425,985	31/100
	2015	71,207	70,419	34,484	47,503	0.31	0.30	783419	494,109	60/100
5	2016	70,899	70,899	41,824	48,776	0.31	0.30	658098	563,365	81/100
	2017	72,741	72,741	48,331	47,236	0.30	0.30	539575	592,621	86/100
	2018	71,763	71,763	52,054	42,486	0.29	0.30	495189	604,484	89/100
	2019	73,441	73,441	53,845	39,366	0.30	0.30	495138	606,314	94/100
	2020	67,719	67,719	50,576	36,136	0.30	0.30	410238	594,110	95/100
	2021	62,730	62,730	52,100	34,889	0.30	0.30	413657	569,276	96/100
	2022	61,528	61,528	48,282	33,688	0.29	0.30	484789	554,005	96/100
	2023	59,033	59,033	47,330	33,527	0.29	0.30	557745	551,291	96/100
	2024	58,602	58,602	53,400	36,742		0.30			94/100
	2025	57,602	57,602	54,433	36,385		0.30			91/100
	2008	49,000	49,000		39,077	0.51	0.53	783133	148,708	0
	2009	56,350	55,763		40,766	0.48	0.53	630882	174,772	0
	2010	57,930	56,668		34,663	0.41	0.42	827023	209,957	0
	2011	58,505	58,329		34,495	0.36	0.39	834958	252,558	0
	2012	63,344	63,344		34,339	0.31	0.33	913215	302,137	4/100
	2013	69,153	69,135		32,067	0.28	0.30	719331	374,422	16/100
	2014	78,234	77,616		29,938	0.26	0.30	676009	434,441	38/100
	2015	86,323	86,323		28,160	0.26	0.30	645431	521,820	67/100
6	2016	97,782	97,782		26,452	0.25	0.30	561101	593,000	85/100
	2017	103,416	103,416		25,425	0.25	0.30	403188	645,109	91/100
	2018	108,434	108,434		20,761	0.26	0.30	368311	649,461	92/100
	2019	110,035	109,428		18,531	0.27	0.30	401616	651,943	98/100
	2020	108,721	108,721		17,571	0.27	0.30	338733	629,103	99/100
	2021	103,950	103,758		16,980	0.27	0.30	323241	604,105	99/100
	2022	98,197	97,519		16,940	0.28	0.30	392515	570,447	1
	2023	95,724	95,724		17,374	0.28	0.30	452863	557,465	1
	2024	94,317	94,086		19,106		0.30			1
	2025	91,984	91,984		21,032		0.30			1
	2008	49,000	49,000	2,032	34,460	0.57	0.53	524797	146,100	0
	2009	50,794	48,788	415	34,092	0.56	0.53	496260	159,425	0
	2010	48,980	48,285	43	31,391	0.51	0.46	593794	164,407	0
	2011	47,496	47,020	582	30,759	0.45	0.45	578466	181,942	0
	2012	47,195	46,540	1,807	29,501	0.41	0.41	644156	202,164	0
	2013	47,618	47,618	3,589	31,479	0.37	0.37	699896	227,631	1/100
	2014	49,400	49,326	8,336	34,799	0.34	0.33	826204	259,797	7/100
	2015	53,359	53,051	13,093	38,227	0.32	0.30	897695	306,211	12/100
7	2016	58,402	58,402	16,393	40,882	0.29	0.30	1034541	365,939	29/100
	2017	63,054	62,880	28,840	50,419	0.29	0.30	1191788	450,590	43/100
	2018	71,780	71,780	42,478	57,728	0.28	0.30	1341163	540,701	56/100
	2019	77,581	77,581	55,743	66,810	0.27	0.30	1266219	653,363	71/100
	2020	86,997	86,805	64,838	72,732	0.27	0.30	1610967	756,667	76/100
	2021	96,907	96,907	80,666	87,820	0.27	0.30	1652155	884,409	77/100
	2022	106,108	105,223	99,413	97,991	0.26	0.30	1849204	1,008,684	78/100
	2023	116,434	116,434	107,722	106,822	0.26	0.30	1873758	1,158,871	77/100
	2024	128,368	128,368	120,763	113,891		0.30			77/100
	2025	144,384	144,384	142,904	130,188		0.30			79/100

Justification

Report C031/08
Project Number: 4391209041

The scientific quality of this report has been peer reviewed by the Scientific Team of Wageningen IMARES.

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Head WOT

Signature:

Date: 21 April 2008

Approved: Dr.Ir. T.P. Bult
Head Fisheries Department

Signature:

Date: 21 April 2008

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