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Report; the short version

Number: C070/04

A simulation study of the effect of management choices on the sustainability and economic performance of a mixed fishery

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Commissioned by:	Ministerie van Landbouw, Natuur en Voedselkwaliteit dhr. ir. L.R.M. Lomans Postbus 20401 2500 EK DEN HAAG
Project number:	319 12430 04
Contract number:	Ond/2002-1/6c/1
Approved by:	Drs. E. Jagtman Head department Biology & Ecology
Signature:	____________________
Date:	15 October 2004

Number of copies:	32
Number of pages:	34
Number of tables:	3
Number of figures:	15

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Samenvatting

In de platvisvisserij op de Noordzee wordt een groot deel van de schol gevangen door de Nederlandse boomkorvloot als bijvangst in de tongvisserij. Deze vloot landt ongeveer 75% van de internationale hoeveelheid tong aan, en vangt daarbij ongeveer 45% van de internationale aangelande schol. Ondanks de sterke technische interactie tussen beide soorten, worden ze momenteel afzonderlijk beheerd onder de aanname dat er geen interactie is. Dit deelproject beoogde te onderzoeken wat de biologische en economische consequenties zijn van deze beheersvorm en van twee alternatieve beheersvormen, gegeven dat deze technische interactie bestaat. Er is gekozen voor de benadering waarbij elk van de drie beheersvormen experimenteel wordt toegepast, maar dan op een gesimuleerd systeem in plaats van in de werkelijkheid.

De drie beheersvormen die zijn onderzocht zijn:
Het huidige beheer d.m.v. Single Species TAC's voor schol en tong. In dit scenario was onze aanname dat jaarlijks de tong-TAC wordt opgevist en dan met vissen gestopt wordt, ongeacht hoeveel schol daarbij gevangen wordt, waarbij eventuele over-quota scholvangst gediscard en niet geobserveerd wordt.
Regulatie d.m.v. een beperking van de visserij-inspanning (bv. zeedagen), die jaarlijks afgestemd wordt op die soort (schol of tong) waarop de visserij het meest ingeperkt moet worden om onder de voorzorgsvisserijsterfte te blijven. Merk op dat onder deze beperking de andere soort dus in dat jaar volgens de perceptie onderbevist wordt.
Regulatie d.m.v. een Multi-Species TAC; deze wordt jaarlijks bepaald door de Single Species TAC's bij elkaar op te tellen.

Er is een simulatiemodel geconstrueerd, bestaande uit een gesimuleerde werkelijkheid en een perceptie op die werkelijkheid. De gesimuleerde werkelijkheid bestaat uit leeftijdsgestructureerde schol- en tongpopulaties waaraan jaarlijks door rekrutering vissen toegevoegd worden en door natuurlijke sterfte en visserij vissen onttrokken worden. De visserij wordt gesimuleerd door jaarlijkse vangsten te berekenen, gegeven de bestandsgrootte en onder de van kracht zijnde beheersmaatregel (volgens een van de drie gesimuleerde beheersvormen). Deze berekeningen worden gemaakt onder de aanname dat de visserij de netto opbrengsten maximaliseert en op beperkingen reageert door de reizen die het minst opleveren te laten vervallen. De perceptie op de werkelijkheid wordt gegenereerd door de dataverzameling en de toestandsbeoordeling te simuleren. De jaarlijkse terugkoppeling vanuit de perceptie naar de (gesimuleerde) werkelijkheid wordt gemaakt door vanuit de toestandsbeoordeling een beheersmaatregel te formuleren (a.h.v. een van de drie beheersvormen).

Bij het construeren van een simulatiemodel moet een groot aantal simplificerende aannames gedaan worden. De beginpopulaties van schol en tong zijn bijvoorbeeld geconstrueerd op basis van de bestandsschattingen van de demersale werkgroep van 2002. De respons van de vloot op opgelegde beperkingen is gesimuleerd op basis van een economische analyse van de VIRIS-gegevens van 2002. De technische interactie tussen schol en tong voor de Nederlandse vloot is geëxtrapoleerd naar de gehele Noordzee visserij. Een opvallende aanname die we gedaan hebben is dat er geen ondermaatse vis wordt gevangen en dus ook niet wordt gediscard. Het doen van dergelijke onrealistische aannames beperkt de waarde van de resultaten van de studie in die zin dat de uitkomsten niet als kwantitatieve voorspellingen gezien moeten worden. De waarde van de studie ligt meer in het verkrijgen van inzichten in de consequenties van de (beheers)aannames door de uitkomsten van de verschillende scenario's te vergelijken.

Onder de gedane aannames bleek scenario 2 het best uit de bus te komen. Wat de biologische duurzaamheid betreft was dit scenario het enige waarin de visserijsterfte meestal onder de voorzorgsgrens bleef. Ook waren in dit scenario de schol- en tongpaaibiomassa op termijn het grootst. Wat betreft de economische duurzaamheid gaf dit scenario de hoogste netto opbrengsten op termijn. Bovendien was in dit scenario de tussenjaarlijkse variatie in de

beheersmaatregel het laagst. Deze resultaten hebben tot twee inzichten geleid. Ten eerste blijkt dat, gegeven de onzekerheid en bias in de toestandsbeoordeling, een beheersstrategie waarin afwisselend een van beide soorten volgens de perceptie onderbevist wordt goed uitpakt. Ten tweede blijkt een stabiele visserijsterfte zichzelf te versterken, omdat de bias in de toestandsbeoordeling kleiner is onder een grotere stabiliteit, waardoor latere correcties van eerdere beheersmaatregelen minder nodig worden.

Vanwege het ontbreken van een gevoeligheidsanalyse om te testen hoe robuust de uitkomsten zijn t.a.v. de gedane aannames, moeten deze resultaten als voorlopig beschouwd worden.

Summary

The Department of Fisheries of the Dutch ministry of LNV[1] has asked for research on the question: "What are the possible effects of alternative fisheries management strategies (for example Multi-Species TACs) on the behaviour of the Dutch and international fleets and the manageability of fishing pressure?"

A simulation framework was used to investigate the performance with respect to the biological and economic sustainability of three alternative management scenarios in a two-species system. The system mimics the exploitation of sole and plaice in the North Sea. At present a large proportion of plaice is caught as by-catch of the main beam trawl fleet targeting sole, and yet current management of the two stocks assumes no interaction in their exploitation. Within the simulation, the annual stock assessment (using XSA) and projections are still carried out in a single species manner, but the management choices and decisions are executed interactively. The contrasting management scenarios are:

1. single species TACs (with the assumption that exploitation of sole determines the behaviour of the fleet)

2. effort regulation of the fleet (TACs and corresponding annual fleet efforts are estimated for each species and the lowest effort is chosen)

3. multi-species TAC (TACs for sole and plaice are summed, and economic objectives determine the catch ratio of sole to plaice).

Scenario 1 should be considered similar to the current situation. The fishery is assumed to respond to restrictions by dropping the least profitable trips using the economic performance of the Dutch fleet as a proxy for the whole North Sea. The performance of the management scenarios is compared on the basis of both ecological and economic sustainability.

All scenarios allow the plaice stock to recover above B_{pa} within 7 years. The simulation suggests that for both sole and plaice the target fishing mortality is rarely achieved in scenarios 1 and 3. Scenario 2 keeps the stocks within safe biological limits and exhibits the most stable biological performance and the highest economic profits in the long term. This suggests that a management strategy that occasionally results in perceived under-exploitation of the stocks may work best given that assessment error and bias exist. The results also suggest that stability in fishing mortality reinforces itself, because the assessment bias is lower under greater stability and corrections become less necessary. The results should be regarded as preliminary, because of the many restrictive assumptions in the model and the lack of a sensitivity analysis that tests the robustness to assumptions.

[1] Ministerie van Landbouw, Natuur en Voedselkwaliteit; the Ministry of Agriculture, Nature and Food Quality

1. Introduction

The Department of Fisheries of the Dutch ministry of LNV[1] has asked for research on the question: "What are the possible effects of alternative fisheries management strategies (for example Multi-Species TACs) on the behaviour of the Dutch and international fleets and the manageability of fishing pressure?"

There are many problems facing the management of plaice and sole stocks in the North Sea. One of them is that a large proportion of the catch of plaice comes from the directed sole fishery of Dutch beam trawlers and yet the exploitation of the two stocks is, to date, managed separately. This management does not account for the technical interactions between species and the economics of fishing for flatfish in the southern North Sea. With the commitment to the precautionary approach to fisheries management and the need for the Common Fisheries Policy (CFP) to be based on robust evidence, any change in the management of these two stocks must be clearly tested and the potential impact investigated.

Hypotheses in a fisheries management context are difficult to test, as it is virtually impossible to set up experiments in the real world in which alternative scenarios are tested and the results compared. However, the use of simulations of exploited populations and management actions does provide some insight into the sensitivities of a system to different management regimes (Kell *et al.* 1999, 2001, 2002).

The simulation tools developed (Kell *et al.* 1999, 2001, 2002) use a framework of both an underlying "true" population and a "perceived" system. The perceived system requires data to be collected from the "true" population, then stock assessments are made based on these data, and these assessments drive the management decisions. The management decisions are imposed on the "true" population (through the catch) and then the simulation moves forward to the next year (or another time window, Figure 1.1).

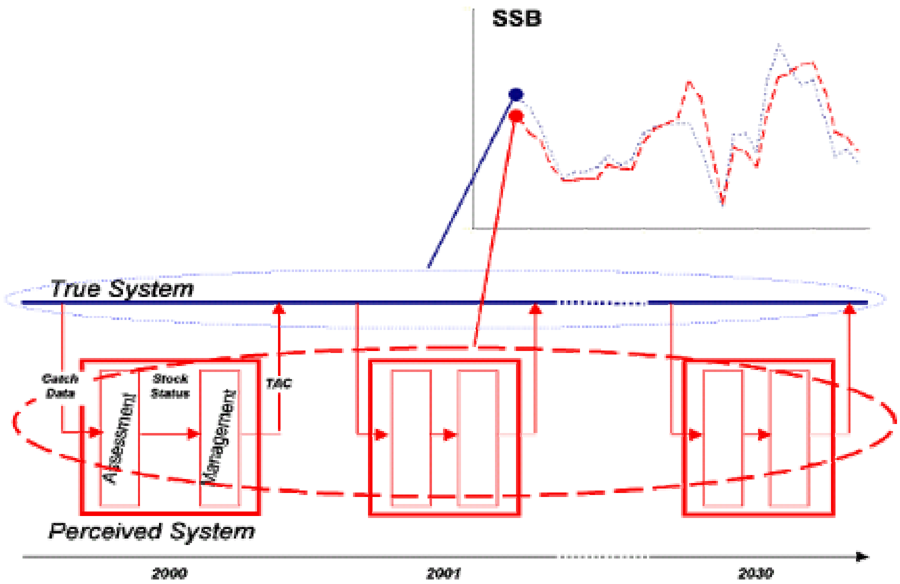

Figure 1.1. The simulation framework of "true" and perceived systems used to evaluate management strategies (from Anon. 2002).

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[1] Ministerie van Landbouw, Natuur en Voedselkwaliteit; the Ministry of Agriculture, Nature and Food Quality

The aim of this project includes the evaluation of the biological and the economic consequences of alternative management strategies. A fleet oriented approach is necessary to answer the question how fleets respond to alternative management forms. It was decided to base this project on the dynamics of the Dutch beam trawl fleet only, since no information on international fleets is available to us at present. The project is limited to North Sea sole and plaice; in future studies North Sea cod, which is also taken in the Dutch flatfish fishery, could be included. International research has started within the EU-projects TECTAC, COMMIT, and EFIMAS, which also aim at an evaluation of possible management strategies.

The broad objectives of our project were to:
- Develop a simulation model to evaluate management scenarios within a North Sea context combining both stock and economic criteria;
- Investigate management procedures that account for the strong linkage between the exploitation of plaice and sole.

The simulation framework is based on Kell *et al.* (2002) and Kell and Bromley (2004) but incorporates economic considerations. Simulations were run in a "Monte Carlo" set up to measure noise in the system and evaluate the variability in the final outcomes. Three management scenarios were investigated, all based on single species assessments of the operating model outputs, but varying the management decision and fleet behaviour:

Scenario 1 **Single species TAC advice, but under the assumption that the catch prospects of sole alone determine the fleet behaviour in respect of both species.** This scenario roughly reflects what is presumed to be the present situation. Sole and plaice are managed independently by single species TACs. However, it is assumed that the fishery ignores the plaice TAC, and continues fishing until the sole TAC is taken (sole being the most valuable species by a factor 4 to 5 per kg), resulting in under- or over-exploitation of the plaice TAC. Over-quota catch of plaice is not landed, and therefore not accounted for in the assessment, leading to a discrepancy between the "true" catch and the observed catch.

Scenario 2 **Effort advice and management, such that the lowest effort required by any of the two species is selected.** The TACs and corresponding annual fleet efforts are estimated for each species and the lowest effort is chosen.

Scenario 3 **Multi-species TAC advice and management.** The TACs for sole and plaice are summed.

To rank the management strategies, the following evaluation criteria were used:
- ecology:
    - frequency of SSB falling below B_{lim} in the course of the simulation period for each stock;
    - frequency of SSB falling below B_{pa} in the course of the simulation period for each stock;
    - frequency of F exceeding F_{pa} in the course of the simulation period for each stock;
    - average total catch over the whole simulation period;
    - variability in catch between consecutive years;
- economy:
    - short term net revenues (average over the first three years of simulation);
    - long term net revenues (average over the last three years of simulation);
    - total net revenues over the whole simulation period;
    - variability in net revenues between consecutive years;
- management:
    - variability in the measure imposed (single species TACs, allowable effort, or multi-species TAC respectively), between consecutive years.

2. The model

2.1. The Software

The simulation model is implemented in Excel and makes use of the FishLab simulation framework (Kell *et al.,* 1999, 2001, 2002).

2.2. The biological sub-model

The biological sub-model consists of two parts: the operating model (OM) simulates the "true" system and the management procedure (MP) simulates the perceived system and the management decision (see Figures 1.1 and 2.1). The OM contains two age-structured populations that mimic North Sea sole and plaice. These populations develop in annual time steps from a starting population in 1957, with yearly recruitment, and yearly mortality (natural mortality M and fishing mortality F). The MP simulates:

1) the observations taken from the populations such as commercial catch-at-age data and the tuning series (survey and/or commercial CPUE, see below),

2) stock assessment by XSA and the catch forecasts based on the biological targets (see below),

3) the management decisions according to one of the investigated management scenarios (see below).

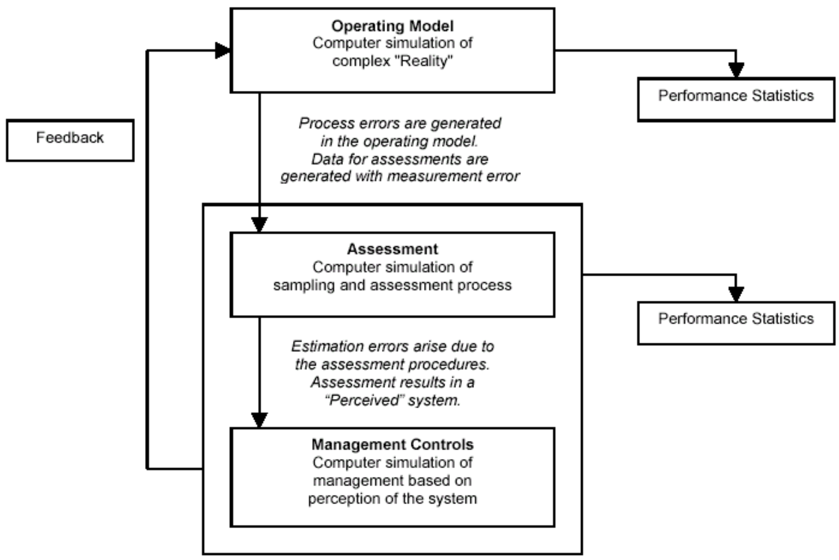


Figure 2.1. Simulation model structure (from Anon. 2002).

The simulation consists of a "historic" part spanning the years from 1957 to 2002. The year 2002 is the first year in which an assessment is performed leading to a management decision for the next year. Therefore, from 2003 onwards the fishing mortality F is affected by the management decision of the year before through a feedback loop. The simulation extends to the year 2015, implying that the effects of management strategies are simulated through 13 years (from 2003 to 2015). Monte Carlo runs (10) are used to assess the uncertainty in the simulated results.

Parameters for the “true” populations in the OM are based on estimates taken from ICES (2004). For the simulation period mean fish weights are assumed to be equal to the three-year running average, the exploitation pattern is assumed to be constant as the average of the last 5 years, and recruitment is modelled according to a Ricker model with random error. The recruitment is a source of variability between simulation runs.

The perceived catch data are equal to the “true” catch data for scenario 2 and 3, but not for scenario 1 (see below). In addition, for each species two CPUE series are generated for tuning. The generation of the tuning series with random error contributes a second source of variability between simulation runs.

Each year the “true” populations are assessed by XSA with settings as in ICES (2004). Subsequently, the assessed populations are projected forward to generate catch forecasts for the TAC year, based on an F *status quo* assumption for the current year. For these catch forecasts F_{pa} is taken as the target F (0.4 for sole and 0.3 for plaice).

In the three management strategies investigated the catch forecasts are modified by a harvest control rule, as is explained below.

In all three scenarios the technical interaction between sole and plaice in the Dutch beam trawl fishery is taken as a proxy for the linkage between the species. No discarding of undersized fish is assumed to take place.

2.2.1. Scenario 1 Single species TAC management

Advice is given as single species TACs for the two species. It is assumed that the fisheries target sole (the most valuable species), and that fishing continues until the sole TAC has been fully taken, irrespective of the plaice TAC. The plaice catch taken is calculated from the fishing effort needed to deplete the sole TAC (explained below). The plaice catch may thus be below the plaice TAC or exceed it. If the “true” catch is below the TAC, the perceived plaice catch will be the same as the “true” plaice catch. If the “true” catch exceeds the TAC, however, over-quota catch is not observed (discarded or not reported). Then the perceived plaice catch is equal to the plaice TAC. The age distribution of the perceived catch is assumed to be equal to the age distribution of the “true” catch.

2.2.2. Scenario 2 Effort management

Advice is given as allowable fishing effort. This effort is the lowest of two estimates, either the effort needed to fish the forecasted catch (equivalent to the TAC) for sole, or the effort needed to fish the forecasted catch (equivalent to the TAC) for plaice. From the allowable fishing effort the sole catch and the plaice catch taken are calculated. The calculation of effort and corresponding catches is explained below. Absolute compliance with the management is assumed. All catch is landed.

2.2.3. Scenario 3 Multi-species management

Advice is given in the form of one TAC for both species combined (MS-TAC), which is simply the sum of the two catch forecasts (equivalent to the single species TACs). The fishing effort needed to deplete the MS-TAC is calculated, and subsequently the sole and plaice catches taken with that effort are calculated (explained below). Absolute compliance with the management is assumed. All catch is landed.

2.2.4. Relationship to the economic sub-model

Effort and corresponding catches are calculated according to an economic sub-model (see below). This model is based on only the economy of the Dutch beam trawl fishery. Therefore, before calculating the fishing effort needed to deplete a TAC, it is necessary to scale the TAC down to the Dutch portion of that TAC. Similarly, the Dutch catches taken with that Dutch effort need to be scaled upwards again to the international catches. The proportions of the international sole and plaice TACs that are reserved for the Dutch beam trawl fishery are assumed to be constant at 74% and 45%, respectively. These values are based on the means over 1995-2002 of the international catch and the Dutch catch of the respective species (ICES 2004).

2.3. The economic sub-model

2.3.1. Relationship to the biological sub-model

The SSB of sole and plaice and the respective catch forecasts (TACs) as calculated in the biological sub-model are input for the economic sub-model in each year. In the economic sub-model the value of SSB is treated as an index with SSB = 1 for the first year (2002). The economic sub-model calculates catches, costs and revenues for each year on the basis of current SSB of sole and plaice. The catches are feedback for calculations in the biological sub-model.

The three management scenarios are assumed to have the following economic consequences:

1. Single species TACs: Fishermen are assumed to maximize the net revenues per unit value of the sole and plaice quota that they hold.

2. Effort restriction: The number of horse power days (hp-days) is the only restriction for the fishery. For the individual fishing company this restriction will come down to a restriction of the number of sea-days. It is assumed that in this case fishing companies will try to maximize the net revenues per sea-day.

3. Multi-species TAC: The total catch weight of sole and plaice combined is restricted. Fishing companies are assumed to maximize net revenues per unit of the multi-species quota.

2.3.2. Modelling the behaviour of the Dutch beam trawl fleet

The economic sub-model has been designed as a short-term model to predict adjustments within the existing fleet in response to different management policies. For individual vessels, this may concern seasonal adjustments, adjustments of fishing gear or of the number of effective sea-days. Adjustments can be made relatively smoothly within the Dutch fleet because fishing rights are tradable. Effects on investment and disinvestments are beyond its scope.

A basic assumption of the model is that for every restriction of the fishery, the least efficient trips will be cancelled first (Figure 2.2). These are the trips with lowest net revenues per unit of the restricted factor in the management scenario concerned.

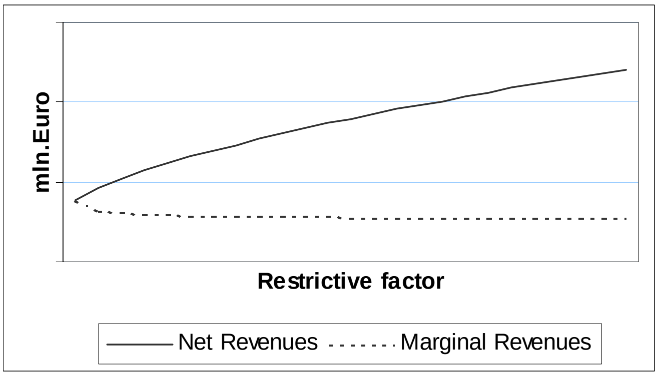


Figure 2.2. Relation between net revenues and restrictive factor

The reaction of fishing companies to single species TACs, an effort restriction, or a multi-species TAC, is deducted from historical catch and effort data and corresponding economic data from 2002. The vessel-month-gear combinations have for each policy measure been sorted on basis of descending net revenues per unit of the restrictive factor. Subsequently, all records have been cumulated and a regression has been made of landings on effort.

The exponential regression of landings on fishing effort has been designed as a classical Cobb-Douglas production function with fishing effort measured in hp-days and SSB (index) as the only variable inputs. An important feature of this type of production function is decreasing returns to scale: increasing fishing effort will lead to increasing landings but with further increase of fishing effort the increase of landings will become smaller.

The Cobb-Douglas function has the following shape:

$$L_i = \alpha_i \bullet SSB_i \bullet E^{\beta_i}$$

$$\beta < 1$$

where:

L = output (landings)
E = production factor (fishing effort in hp-days)
SSB = Spawning Stock Biomass index: SSB will vary per year and is calculated in the biological sub-model.
i = species
α, β = constants

A different production function has been calculated for each management scenario, as fishermen will follow a different strategy according to the type of restriction that they are confronted with.

Calculation of catches for each period is performed in two steps:

1. Calculation of fishing effort for the given value of the restrictive factor on the basis of the production function and the value of the SSB index. The catch forecasts that follow from the biological sub-model serve as input for the economic sub-model.

2. Calculation of catches for each species corresponding to fishing effort as calculated in step 1.

In all management scenarios fishing effort is the crucial variable, but its determination varies. The full explanation of these calculations and the values of the parameters used can be found in the complete version of the report.

3. Results

3.1 Scenario 1 Single species TAC management; sole catches determine fleet effort

3.1.1 Biology

This scenario shows an initial recovery of the plaice SSB to above B_{pa}, followed by a decline of the plaice SSB below B_{pa} again. Sole SSB rises in the first half of the simulation period and then declines just to the level of B_{pa} (Figure 3.1.1). Due to problems caused by the shrinkage of F (*i.e.* a setting in XSA that pulls F in the last year towards the recent average), the fishing mortality on sole is allowed to rise too high when the stock is already decreasing in size, so that the sole catches must be reduced later on in the simulated period (Figure 3.1.1). The lag in perception of the stock development caused by shrinkage in the assessment can be seen when the “true” population and perceived population estimates from each Monte Carlo run are compared (Figure 3.1.2). Due to this lag, a cyclical alternation of underestimation and overestimation occurs (note that when SSB is underestimated, F – which is not shown – is overestimated and *vice versa*).

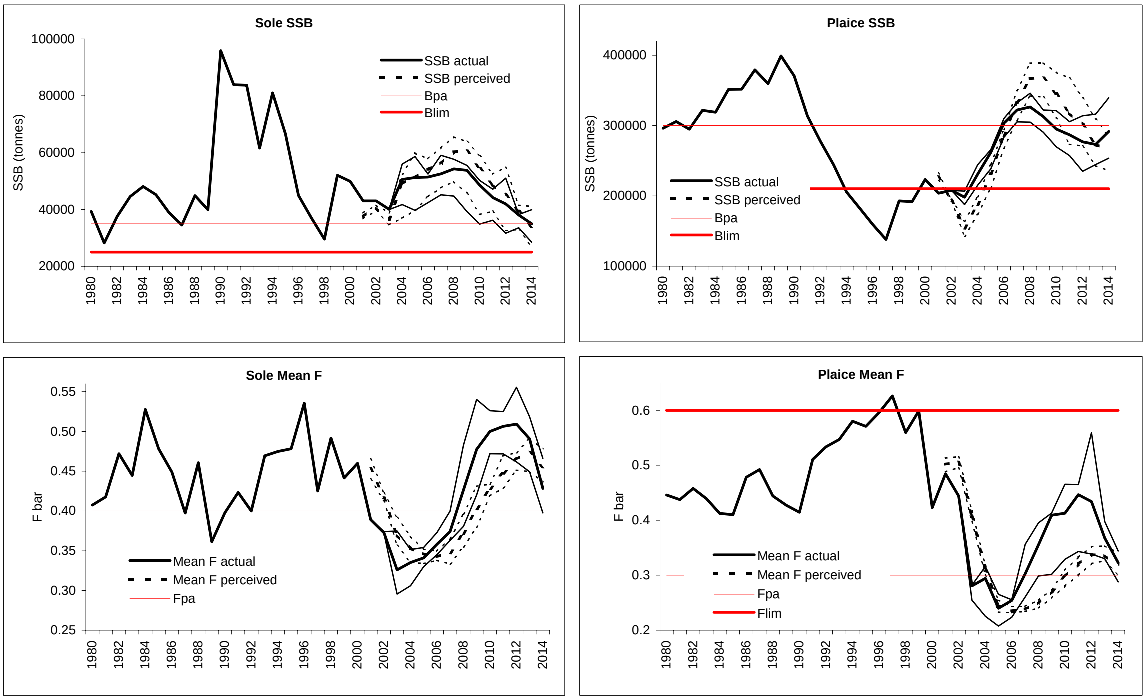
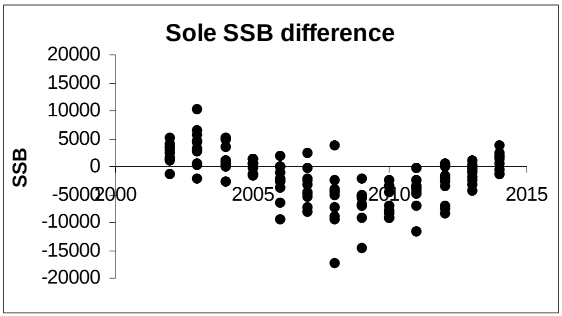


Figure 3.1.1. Scenario 1. Sole and plaice population characteristics from 1980 to the end of the projection period. Solid lines denote the “true” (actual) population, dotted lines denote the perceived population. In the projected part of the simulation the average of 10 Monte Carlo runs of the model is shown bounded by the central 50% range of the estimates (i.e. the 2 central quartiles). Variability in the Monte Carlo runs comes from recruitment and sampling error.



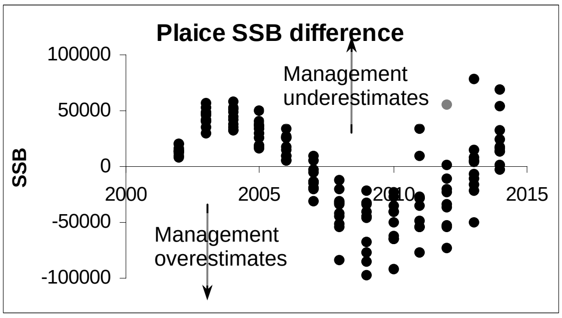


Figure 3.1.2. Scenario 1. The difference between "true" and perceived estimates of SSB, for each Monte Carlo run for sole and plaice during the projected part of the simulation. Positive values mean that the perceived population is underestimated compared to the "true" population. Variability in the Monte Carlo runs comes from recruitment and sampling error.

Throughout the whole simulation period over-quota fishing of plaice occurs in at least some Monte Carlo runs (Figure 3.1.3), resulting in the perceived plaice yield being lower than the "true" plaice yield (=catch) (Figure 3.1.4). This over-quota fishing of plaice occurs because the set target Fs for sole and plaice do not correspond to similar effort levels, leading to conflict. In this scenario, fishing is tuned to the target F for sole, resulting in over-quota fishing for plaice. From Figure 3.1.3 it can be seen that over-quota fishing occurs more often in the period 2004-2008 than in the period 2009-2014. In the first period the plaice TAC is relatively more restrictive than the sole TAC, whereas in the latter period the reverse is true.

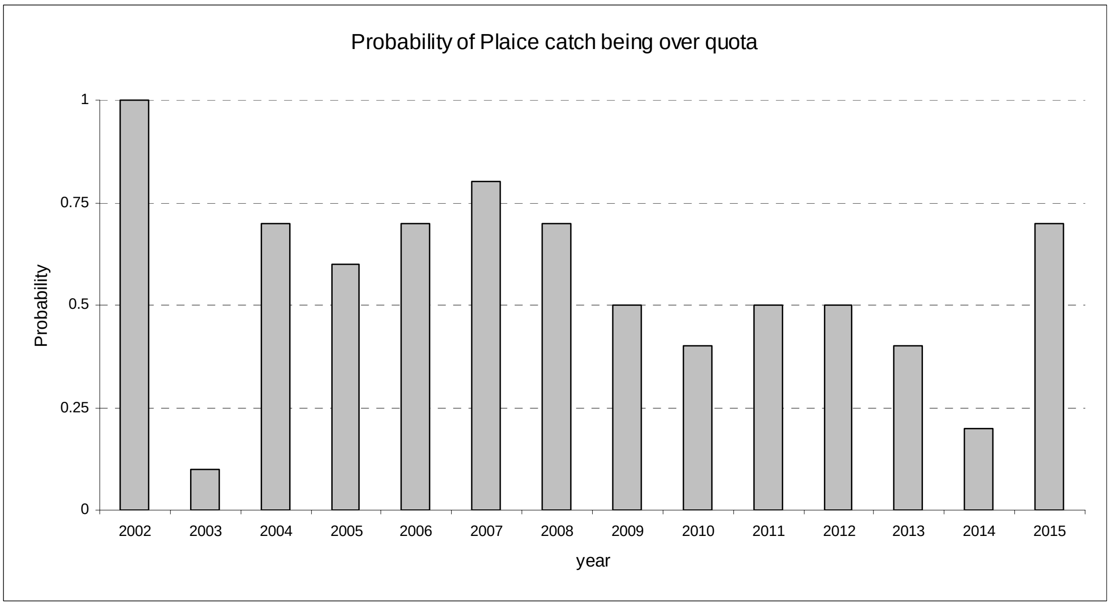
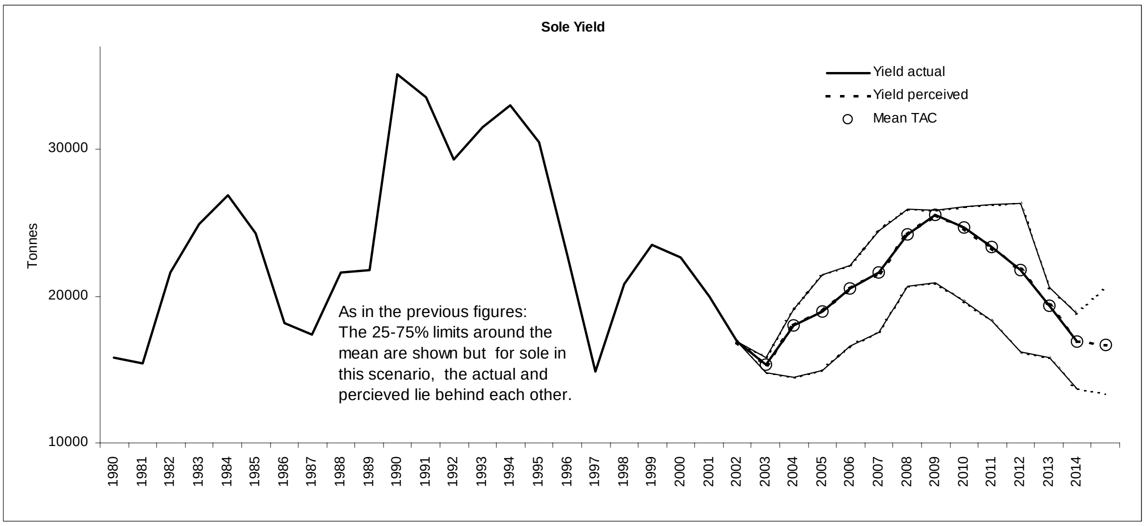


Figure 3.1.3. Scenario 1. The probability that the plaice catch will be over quota and discarding or un-official landings will occur in the projection part of the simulation.



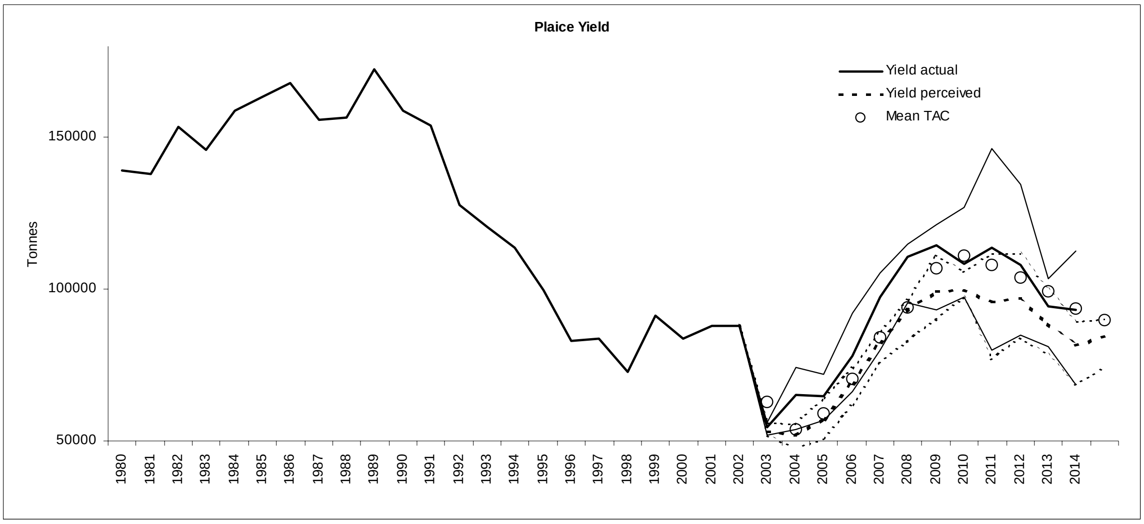


Figure 3.1.4. Scenario 1. The yield (catch) of sole and plaice from 1980 to the end of the projection period. Solid lines denote the "true" catch, dotted lines denote the perceived catch. In the projected part of the simulation the average of 10 Monte Carlo runs of the model is shown bounded by the central 50% range of the estimates (i.e. the 2 central quartiles). The mean TAC from the Monte Carlo runs is show by the circles.

3.1.2. Economy

Figure 3.1.5 illustrates the economic consequences for this scenario. For convenience the sole and plaice TACs and the perceived plaice landings are presented again (sole landings are equal to the TACs in this scenario). It can be seen that price developments of both sole and plaice mirror the developments in the landings. Sole prices first go down and then come up again, whereas plaice prices go down and then stay low while rising only slightly. The Dutch effort, and thereby the variable costs, show large fluctuations, especially at the start of the simulation period, and overall rise over the simulation period from 54 to 75 million hp-days and from 78,000 to 108,000 kiloEuros respectively. Both the total and net revenues increase when the sole landings increase and decrease when the sole landings decrease.

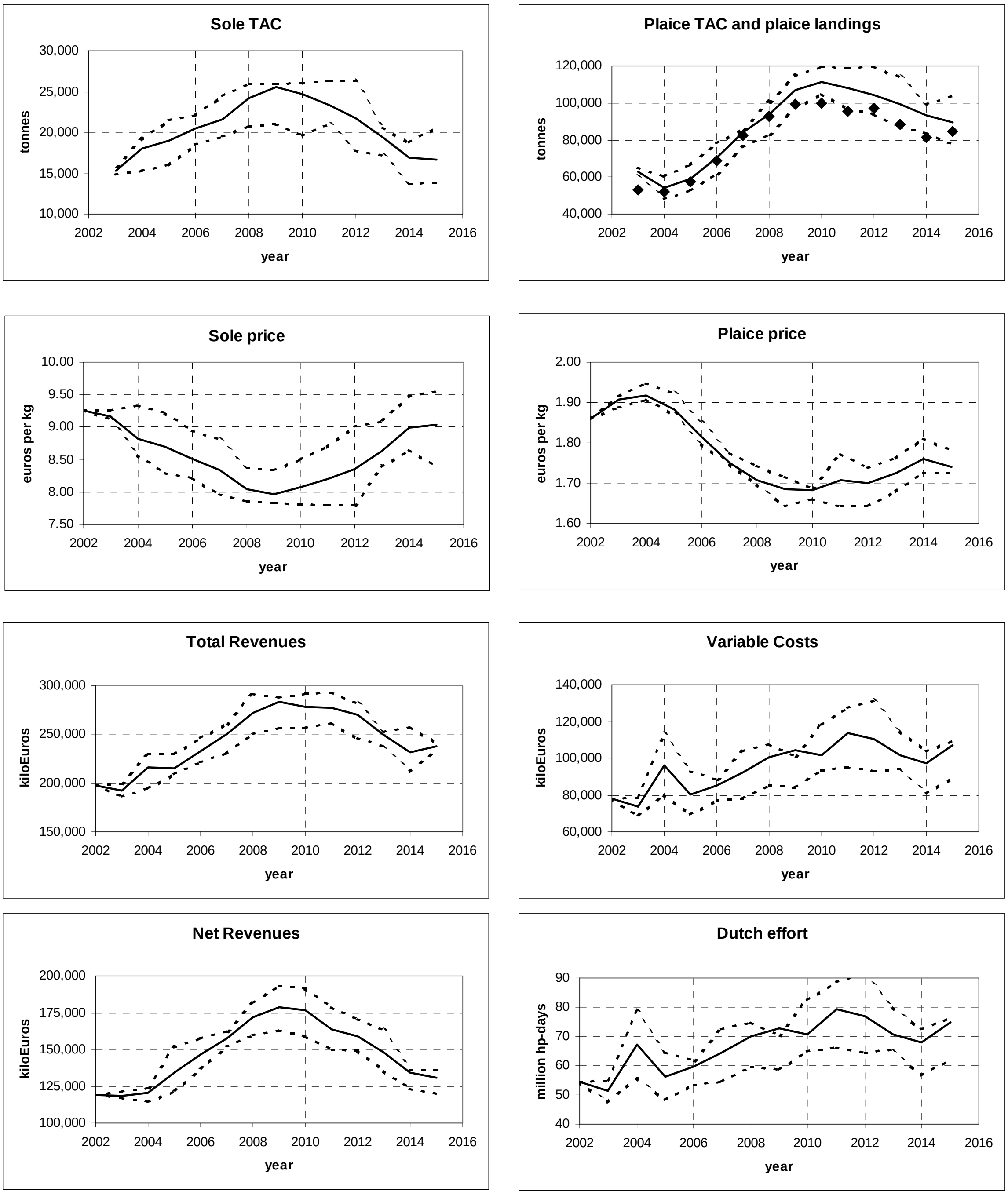


Figure 3.1.5. Scenario 1. Sole TAC, plaice TAC (and landings), sole price, plaice price, total revenues, variable costs, net revenues, and Dutch effort. Solid lines: mean; stippled lines: upper and lower quartiles; diamonds: mean landings.

3.2 Scenario 2 Effort management

3.2.1 Biology

In contrast to scenario 1, in this scenario the plaice SSB remains above B_{pa} after initial recovery and continues to rise. As in scenario 1, sole SSB initially increases and then declines, but here SSB does not decline as far as to the level of B_{pa} (Figure 3.2.1), which is the case in scenario 1 (cf. Figure 3.1.1). The decline in sole is due again to the underestimation of F (Figure 3.2.1). However, in contrast to scenario 1, in this scenario the sole “true” F as well as the plaice “true” F generally remain below their respective F_{pa}, and they are relatively stable. This high degree of stability in F results in more stable population increases than in scenarios 1 and 3, and also in smaller discrepancies between the perceived and the “true” states of the populations (cf. Figures 3.1.1 and 3.3.1 respectively).

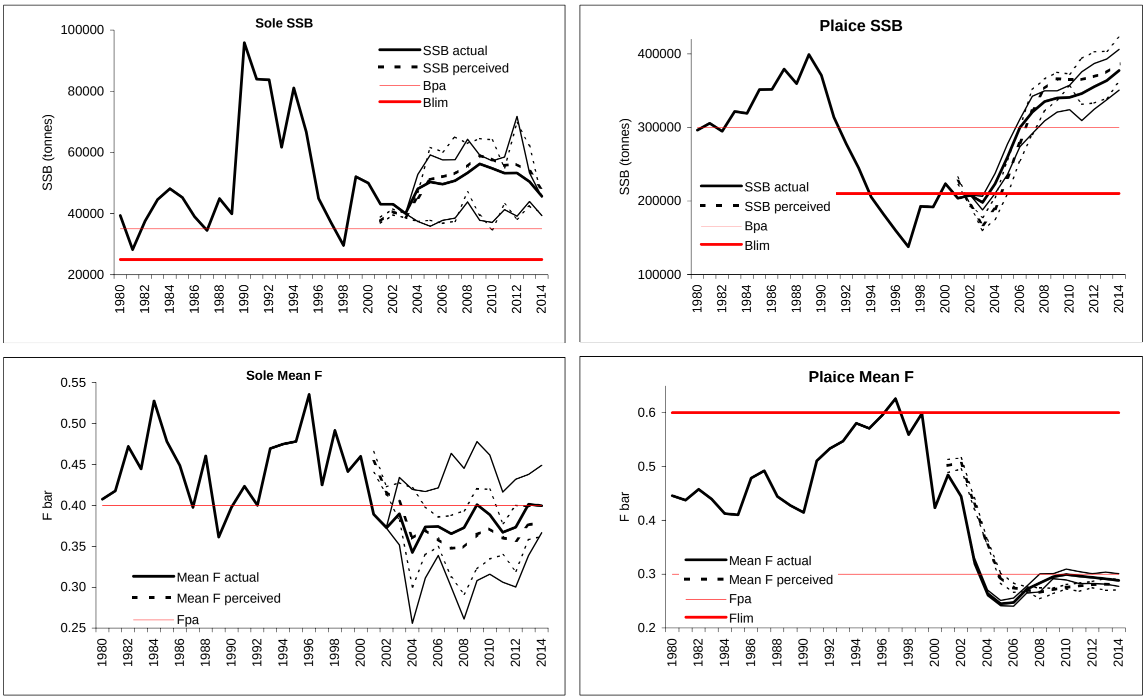


Figure 3.2.1. Scenario 2. Sole and plaice population characteristics from 1980 to the end of the projection period. Solid lines denote the “true” (actual) population, dotted lines denote the perceived population. In the projected part of the simulation the average of 10 Monte Carlo runs of the model is shown bounded by the central 50% range of the estimates (i.e. the 2 central quartiles). Variability in the Monte Carlo runs comes from recruitment and sampling error.

In this scenario the effort restriction is sometimes determined by the plaice assessment (Figure 3.2.2), leading to lower effort and hence lower F, whereas in scenario 1 the fishing effort is always determined by the sole assessment. Despite the fact that the effort restriction alternates between being determined by the sole assessment and the plaice assessment, the resulting effort restriction is fairly constant over the years (Figure 3.2.2). The conflict that exists between the respective target Fs in this scenario leads to effort restrictions resulting in yields that sometimes under-exploit the respective calculated TAC (= the catch forecast under the target F). Note that over-exploitation (*i.e.* catching more than the calculated TAC) is not expected to occur in a scenario where the lower of two efforts is used. However, over-exploitation sometimes does occur, in sole as well as plaice (Figure 3.2.3). This occurs because the management procedure calculates allowable effort based on the predicted SSBs, whereas the “true” SSBs may be higher and lead to higher catches under the set allowable effort than anticipated in the management procedure.

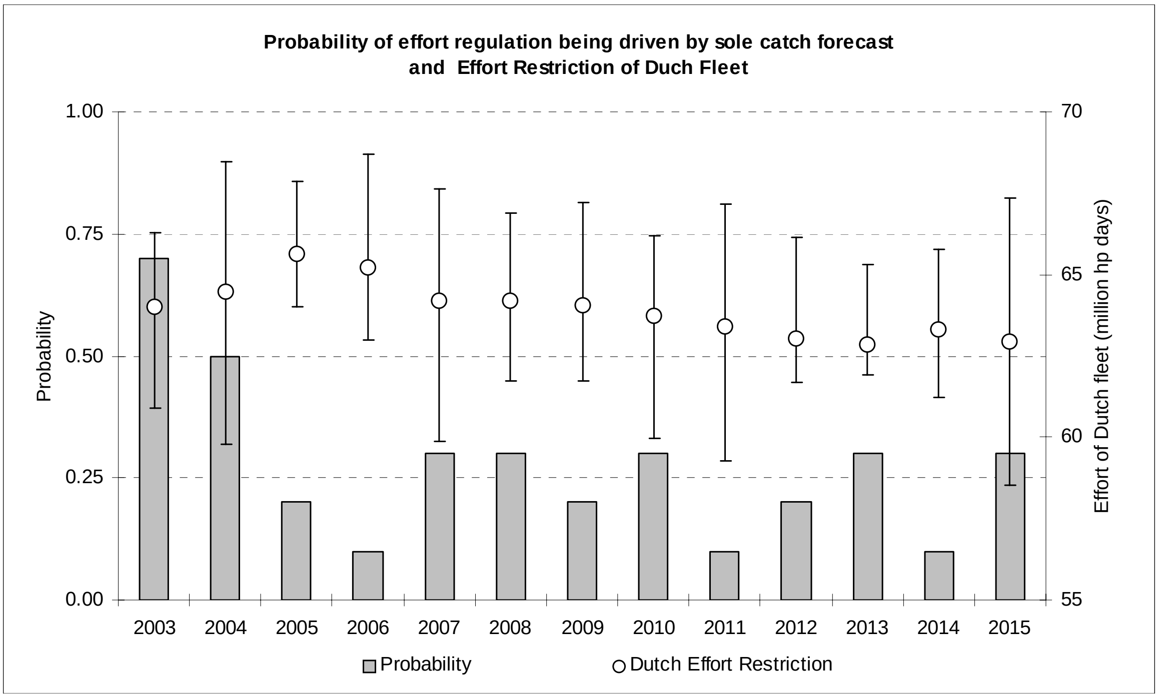
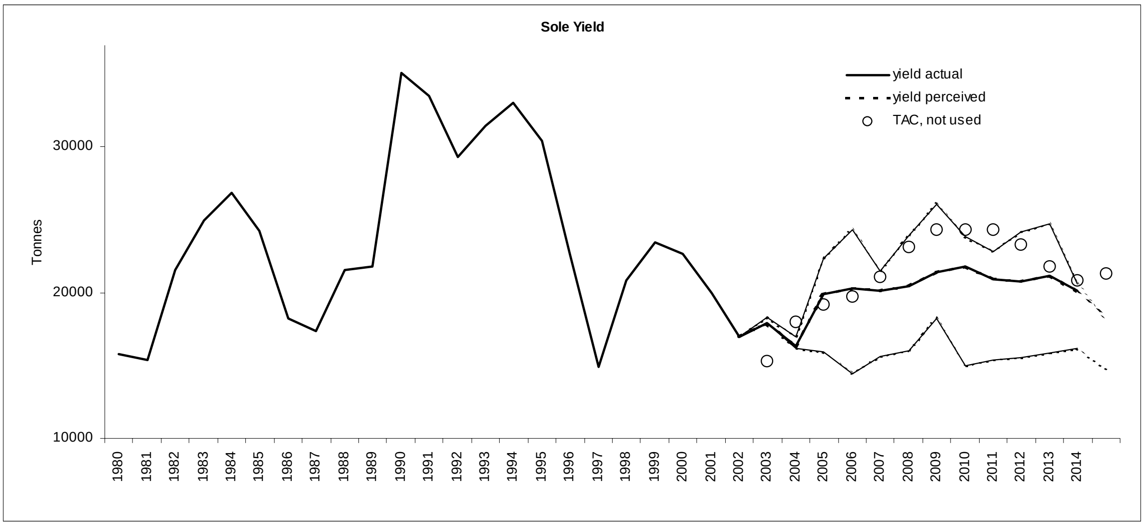


Figure 3.2.2. Scenario 2. The probability that the sole catch forecast will determine the effort restrictions (bars) and the allowable effort for the Dutch fleet (circles) in the projection part of the simulation. Error bars around the circles denote the 25% and 75% percentiles of the Monte Carlo runs.



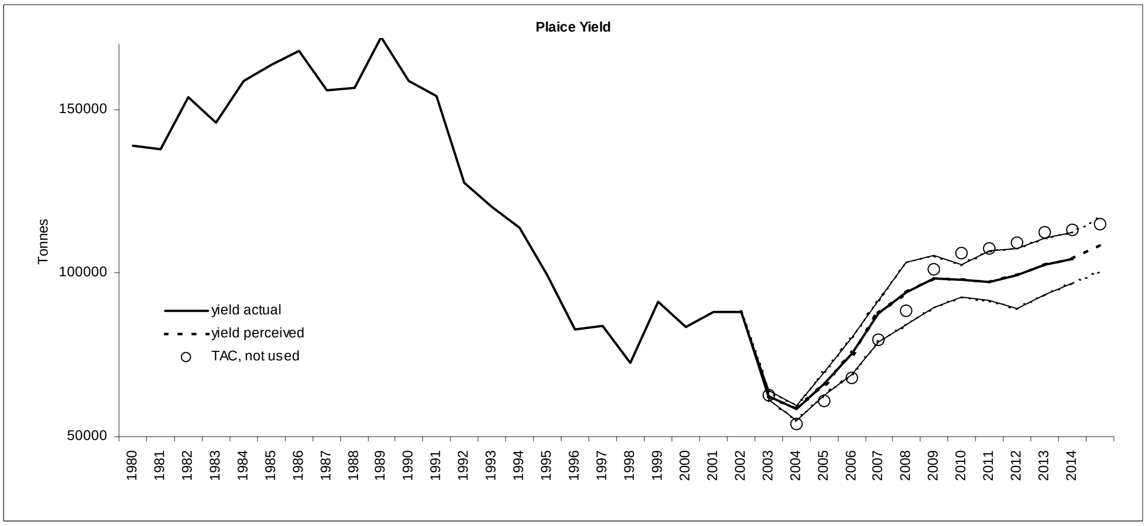


Figure 3.2.3. Scenario 2. The yield (catch) of sole and plaice from 1980 to the end of the projection period. Solid lines denote the "true" catch, dotted lines denote the perceived catch. In the projected part of the simulation the average of 10 Monte Carlo runs of the model is shown bounded by the central 50% range of the estimates (i.e. the 2 central quartiles). The mean TAC from the Monte Carlo runs is shown by the circles.

3.2.2 Economy

Figure 3.2.4 shows that the sole prices drop slightly at first and then slightly rise again, whereas plaice prices drop a bit later but then stay low and even continue to decrease slightly. The sole prices do not drop as much as in the other two scenarios (cf. Figures 3.1.5 and 3.3.3). Effort and variable costs increase immediately and then remain rather constant, at levels of 64 million hp-days and 90,000 kiloEuros respectively. The revenues follow the development of the sole landings. Unlike the other two scenarios (cf. Figures 3.1.5 and 3.3.3), this scenario generates net revenues that remain almost stable and only decrease at a very slow rate at the end of the time series.

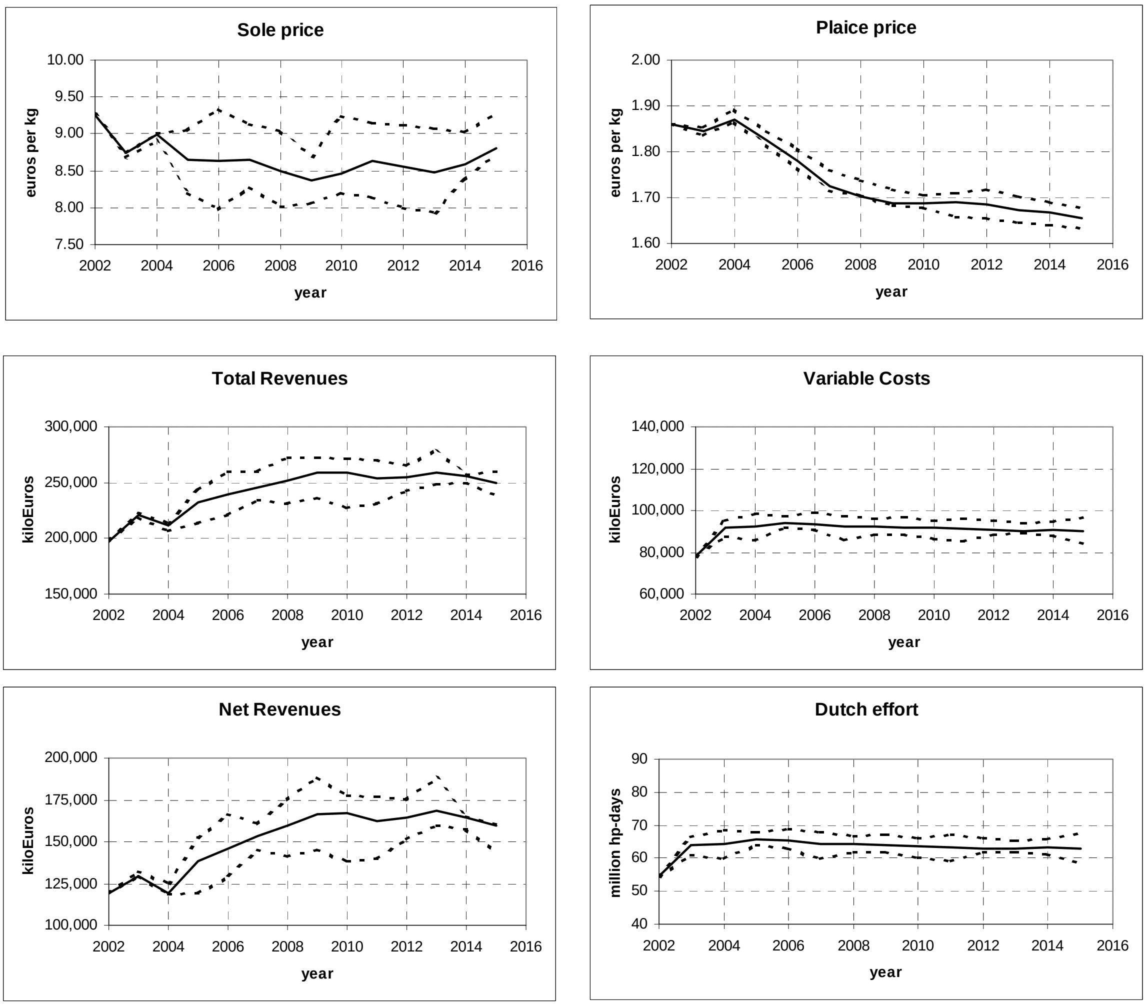


Figure 3.2.4. Scenario 2. Sole price, plaice price, total revenues, variable costs, net revenues, and Dutch effort. Solid lines: mean; stippled lines: upper and lower quartiles.

3.3 Scenario 3 Multi-species management

3.3.1 Biology

The results of scenario 3 look very similar to the results of scenario 1, but slightly better. The sole SSB grows initially and then declines steeply, but does not fall as low as B_{pa} within the simulation period (Figure 3.3.1). The plaice SSB recovers and declines again, but usually stays above B_{pa} after recovery within the simulation period. As in scenario 1, but in contrast to scenario 2, sole "true" F and plaice "true" F are unstable again: they first drop below their respective F_{pa} and then rise above F_{pa} again. For both sole and plaice, the perceived Fs lag behind the "true" Fs.

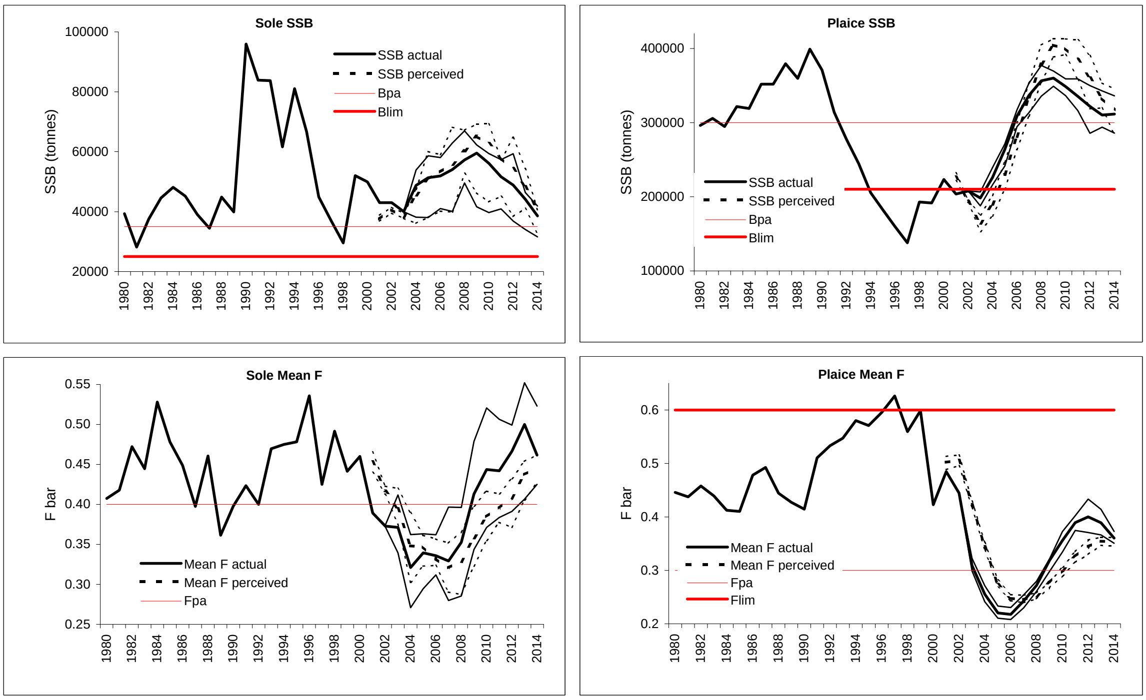


Figure 3.3.1. Scenario 3. Sole and plaice population characteristics from 1980 to the end of the projection period. Solid lines denote the "true" (actual) population, dotted lines denote the perceived population. In the projected part of the simulation the average of 10 Monte Carlo runs of the model is shown bounded by the central 50% range of the estimates (i.e. the 2 central quartiles). Variability in the Monte Carlo runs comes from recruitment and sampling error.

The total multi-species catch initially increases and slightly declines again after 2011 (Figure 3.3.2). In this scenario the conflict between the two target Fs is resolved: the MS-TAC that is calculated corresponds to the requirements for both stocks at once and no over-exploitation takes place. The catch composition, determined by manipulating effort according to profitability, stays rather constant after 2009. It should be noted that this scenario does not allow for the discarding of any adult fish. All fish caught are landed against quota.

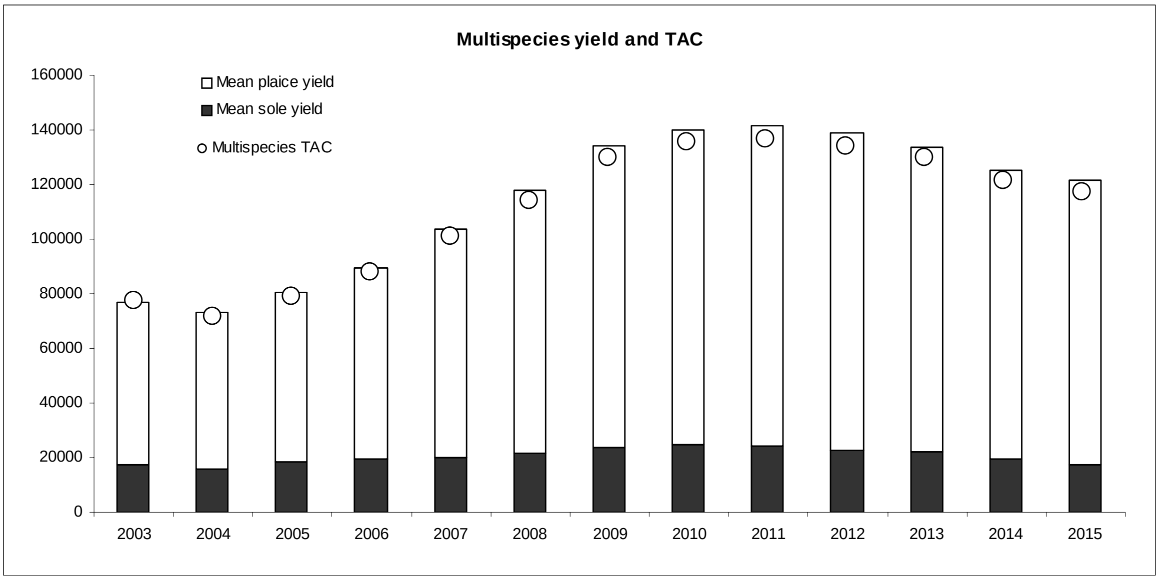


Figure 3.3.2. Scenario 3. The mean yield (in tonnes) of plaice and sole from 10 Monte Carlo runs of scenario 3 during the projected period of the simulation. The multi-species TAC is also overlaid.

3.3.2 Economy

Figure 3.4.3 indicates that the sole prices initially drop and then increase in the second half of the simulation period. The plaice prices drop a bit later, and stay low, but slightly increase. Effort and variable costs increase with minor fluctuations; both the fluctuations as well as the increase are not as large as in scenario 1. In this scenario, net revenues rise higher than in the other two scenarios half way through the simulation period, but than decline again to a level higher than that in scenario 1 but lower than that in scenario 2 (cf. Figures 3.2.5. and 3.3.4 respectively).

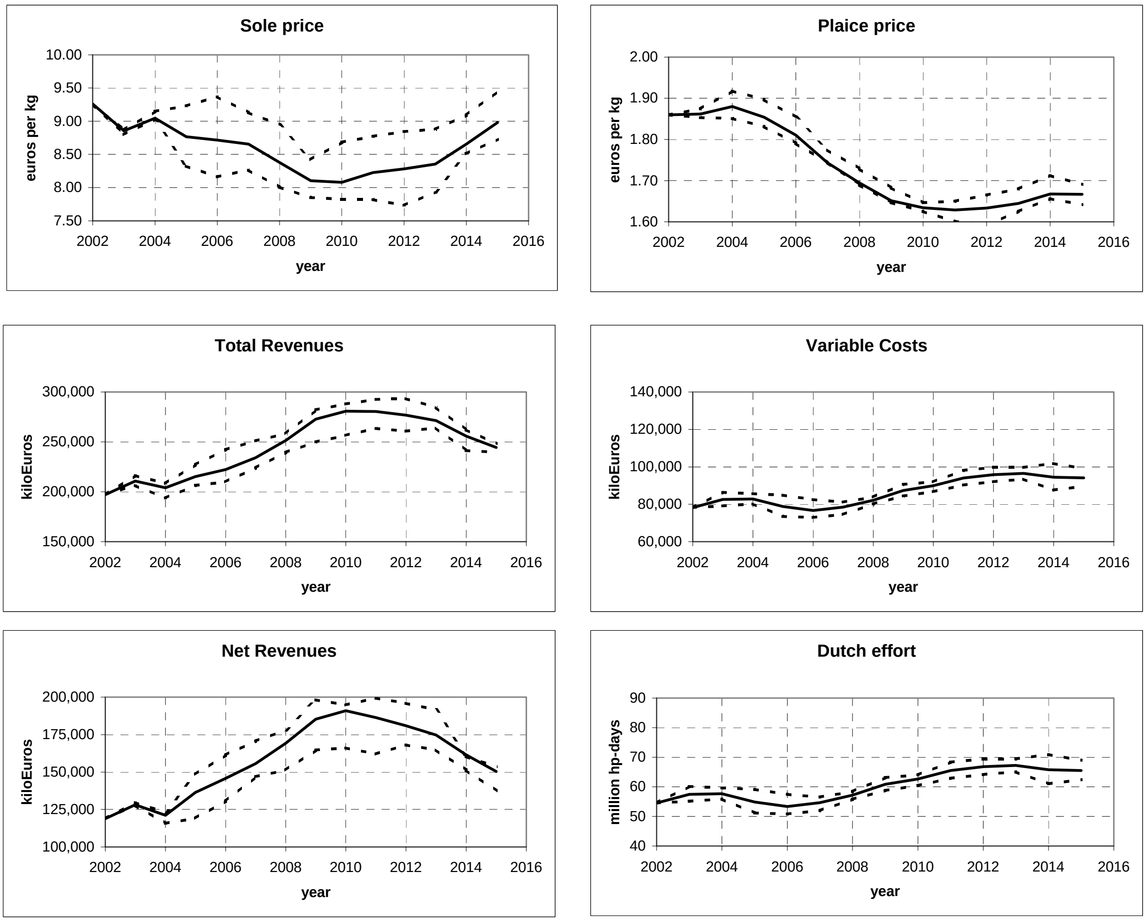


Figure 3.3.3. Scenario 3. Sole price, plaice price, total revenues, variable costs, net revenues, and Dutch effort. Solid lines: mean; stippled lines: upper and lower quartiles.

3.4. Comparative evaluation of the three scenarios.

Tables 3.4.1, 3.4.2, and 3.4.3 summarize outcomes of the three scenarios according to the evaluation criteria mentioned in the introduction. Scenario 2 and scenario 3 appear to perform better than scenario 1 in terms of the sustainable exploitation of sole and plaice (Table 3.4.1). Scenario 2 performs especially well in terms of the sustainability of the plaice stock, although the time to recovery is one year later than in scenario 3. In scenario 2, sole “true” SSB is least likely to go below B_{pa} while the probability of falling below B_{lim} is low, and plaice “true” SSB is least likely to go below B_{pa} and has 0 probability of falling below B_{lim} after recovery of the stock above B_{pa}. Also the probability of “true” F rising above F_{pa} is lowest for both stocks in scenario 2. On the other hand, scenario 2 results in the lowest total “true” yields over the whole simulation period for both stocks. The mean (absolute) change between consecutive years in “true” yield differs among the scenarios. However, the variability in these annual changes in yield is quite large (see CV rows in Table 3.4.1) thus making comparisons of mean annual change in catches between scenarios inappropriate.

Also from the economic point of view scenario 2 and scenario 3 appear to perform better than scenario 1 (Table 3.4.2). Scenario 2 generates the highest net revenues in the short term as well as in the long term, although total net revenues over the whole period are lower than in scenario 3. The economic stability between years is slightly worse in scenario 2 than in scenario 1 and scenario 3.

From the management point of view, scenario 2, effort restriction, is the most stable: advised effort restrictions vary from year to year on average by only 4% (Table 3.4.3). This would make the management policy easy to sell, because while the fishermen can fish at more or less the same rate each year, their varying revenues are not due to varying policy measures but to varying fish abundance. The multi-species TAC in scenario 3 is more stable between years (mean annual variation 10%) than the single species TACs in scenario 1 (mean annual variation 15% and 12% for sole and plaice respectively).

Table 3.4.1. Biological evaluation criteria.

	criteria	scenario 1 Single species TAC	scenario 2 Effort restriction	scenario 3 Multi-species TAC	units
Sole	$F>F_{pa}$ (Target F)	52.9	**38.6**	**39.3**	%
	$SSB<B_{lim}$	2.1	0.7	**0.0**	%
	$SSB<B_{pa}$	20.0	**13.6**	15.0	%
	Mean total “true” yield summed over 13 years	**283,834**	276,423	**283,712**	tonnes
	Mean absolute difference in “true” yield between two consecutive years (annual change in “true”yield)	**2,617**	3,415	**2,604**	tonnes
	CV on annual change in “true” yield (over the 10 MC runs and the 13 years)	111	100	119	%
Plaice	Year of recovery > 50% of MC runs $SSB>B_{pa}$	2009	2009	**2008**	
	From 2009 to 2015, once above B_{pa}				
	$F>F_{pa}$ (Target F)	80.0	**34.3**	94.3	%
	$SSB<B_{lim}$	7.1	**0.0**	**0.0**	%
	$SSB<B_{pa}$	51.4	**12.9**	22.9	%
	Mean total “true” yield summed over 13 years	**1,294,236**	1,241,214	**1,298,105**	tonnes
	Mean absolute difference in “true” yield between two consecutive years (annual change in “true”yield)	23,097	**8,914**	11,996	tonnes
	CV on annual change in “true” yield (over the 10 MC runs and the 13 years)	99	81	76	%

Bold denotes best score

Table 3.4.2. Economic evaluation criteria.

criteria	scenario 1 Single species TAC	scenario 2 Effort restriction	scenario 3 Multi-species TAC	units
Mean net revenues in the short term (2003-2005)	124,487	**129,063**	128,602	kEuro
Mean net revenues in the long term (2013-2015)	137,509	**164,073**	162,227	kEuro
Mean net revenues over the whole period (2003-2015)	149,244	153,750	**160,517**	kEuro
Mean absolute difference in net revenues between two consecutive years	**9**	11	**9**	%

Bold denotes best score

Table 3.4.3. Management evaluation criteria.

criterion	scenario 1 Single species TAC	scenario 2 Effort restriction	scenario 3 Multispecies TAC	units
Mean absolute difference in management measure between consecutive years	Sole TAC: 15 Plaice TAC: 12	Allowable effort: **4**	MS TAC: 10	%

Bold denotes best score

4. Discussion

The discussion will first focus on the restrictive assumptions of this simulation exercise. Subsequently, a discussion of the comparison of the three scenarios will follow. Finally, the similarity between the effort restriction scenario and mixed-fisheries management will be discussed.

4.1 Restrictive assumptions

The “true” population was based on similar assumptions that are used in the assessment and the estimation of the perceived population. The same equations are used to create the population and then to assess it. This can lead to over-confidence in the results (Kell pers. comm.) and must be acknowledged as a possible weakness in this kind of analysis.

An important restriction on the above analysis is that the underlying data are based on the present policy situation: single species TACs and quota (with complementary effort restrictions). It may be questioned whether the catch per unit of effort will change when single species TACs are replaced by a multi-species TAC or effort restriction. In both cases the freedom of catch composition will increase and this may affect the direction of the fishery.

It can be questioned whether the targeting of the fisheries will change when single species quota are replaced by effort restrictions or a multi-species quota. In the analysis above it is assumed that the target of the fishery will not change because the present fishery is primarily a sole fishery. In the case of an effort restriction or multi-species TAC, the fishery will still be directed towards the most profitable species, which is sole.

In our analysis we have assumed that the most efficient vessels will not buy more hp-days than they loose by the effort restriction, or buy more quota than they loose by a quota restriction. In this way there will be no new vessel-month-gear combinations.

Another assumption is fisheries behaviour with regard to high-grading. In the present situation with single species quota it would be plausible that catches are higher than landings because of high-grading and discarding of over-quota catches. However, there are no data on high-grading and discarding for the present situation. In the effort restriction scenario there is no need for high-grading and over-quota discards so landings per unit of effort might increase. If high-grading percentages by species would be available for the present situation, these could be taken into account. In that case the production curve for the effort scenario would shift upwards. In the multi-species TAC scenario, discarding of over-quota catches of one species will not be necessary and on the other hand there are new incentives for high-grading: discarding plaice in order to land more sole. Also these effects have not been taken into account in the estimation of the production function. In fact, it is assumed that there is no high-grading or discarding of over-quota species in the present situation and this will also not be the case in the multi-species TAC scenario. In other words, the production functions are based on landings data only but they are used in the model as if they generate catch data. In reality the landings are likely to be smaller than the catch, which could cause underestimation of modelled catches.

The problem of discarding of undersized plaice is completely ignored in this analysis. The Dutch sole-directed fishery uses 80 mm mesh size. Due to the different body shapes of sole and plaice, the selectivity of this mesh size is very different for sole and plaice. The length at which 50% is retained in nets of 80 mm mesh size is 27 cm for sole (3 cm above the minimum landing size), but 18 cm for plaice (9 cm under the minimum landing size). This implies that large quantities of undersized plaice are caught and discarded. These catches are not taken into account in the current plaice stock assessment, which is potentially causing problems of discrepancy between the true state of the population and the perceived state (van Keeken *et al.*

2004). In our simulations we have assumed that this discard fraction does not exist. The implicit assumption of our analysis is that the selectivity of the fishery is such that for both species only fish above their respective minimum landing sizes are caught. At present not enough information is available to simulate the catch of undersized fish.

Apart from over-quota plaice catch in scenario 1, it is assumed that there is absolute compliance to the management measure. In reality, it may be the case that when TACs drop by a large extent, compliance is lower than when TACs remain stable. We did not incorporate such implementation bias into the model.

In our simulation we assumed that the "true" natural mortality and the "true" maturity-at-age, as well as the "true" historical weights are available to the assessment and management. In reality this is of course not the case. Furthermore, it was assumed that the "true" catch is available, except over-quota plaice catch in scenario 1. The implicit assumption here is that the market sampling programme gives exact estimates of the catch, which is in reality not the case. Even in the case of over-quota fishing in scenario 1, the implicit assumption is that the "true" age composition of the landed catch is known. Thus our simulation results may be over-optimistic with regards to how well the management procedure is able to monitor the "true" developments of the stocks.

The technical interaction between sole and plaice in the Dutch beam trawl fishery is taken as a proxy for the linkage between the species. This assumption poses a friction with another assumption of the model, namely that the Dutch catches are multiplied by fixed but different factors for each species to arrive at the respective international catches (1.35 for sole, and 2.25 for plaice). The friction arises because the different multipliers imply that internationally more plaice is caught than can be accounted for by the mixed fishery interaction.

Summarizing, the basic assumptions of the analysis are:

- The present fishery is primarily a sole fishery and other species are caught until the sole quota are exhausted.
- After abolishment of single species quota the fishery will be directed toward the most profitable species, in this case sole. In other words the direction of the fishery will not change.
- In the present situation there is no high-grading or discarding of over-quota species and this will not change after introduction of a multi-species TAC.
- The selectivity of the fishery is such that no undersized fish are caught.
- An effort restriction will be applied proportionally to all vessels (before the start of trade in hp-days).
- The efficient vessels will not buy more hp-days than they loose by an effort restriction. In the multi-species TAC scenario they will not buy more quota than they will loose by a quota restriction.
- Besides the possibility of over-quota plaice catch in scenario 1 there is absolute compliance with the management measure.
- Natural mortality, maturity, weight, and catches are known without error in the management procedure.
- Production functions are based on landings only but are used to predict catches.
- The technical interaction between sole and plaice in the Dutch beam trawl fishery is taken as a proxy for the linkage between the species, but the Dutch catches are multiplied by different factors to arrive at the international catches.

A more complete list of the assumptions, together with a discussion of how these might affect the results and whether they could be relaxed, is given in Appendix 1.

All of these assumptions are questionable and limit the interpretation possibilities of the results.

In the simulation framework it is possible to add uncertainty with regards to perceived natural mortality, maturity, and catch, in order to investigate the robustness of management measures to these uncertainties. We decided, however, to keep the study simple and, with the objectives of the project in mind, investigate only the effects of the different management strategies with just two sources of random error (in recruitment and CPUE sampling).

4.2 Comparison of the three scenarios

It should be kept in mind that the projections are not to be viewed as stock forecasts or predictions. This study was not undertaken to predict development of the stocks in a quantitative sense. The exercise was undertaken to discover how the different management scenarios differentially affect the developments of the stocks, the fishery, its economy and its management requirements. The absolute values of the results are therefore of lesser importance than the understanding of how the differences come about. Kell and Bromley (2004) suggest that no management scenario in the southern North Sea flatfish fishery could be rationally considered without the discarding of undersized fish taken into account. It is not clear whether the current conclusions would still hold if some of the assumptions, such as the assumption that no undersized fish are caught, would be relaxed. Therefore, the current results should be interpreted carefully and only as an indication of possible ways forward.

The criteria chosen to evaluate the scenarios seem to suggest that scenario 2, management through effort restriction tuned to the species that most needs restriction, is the most positive form of management for the flatfish fleet (considering all the assumptions). This scenario results in the most positive biological development of the stocks, and also has the highest economic profits in the short term as well as in the long term, but not over the whole period. Also in terms of stability of the annual management measure, this scenario performs best. Since the development of the stocks is most positive under scenario2, it is to be expected that the net revenues will remain favourable in the long term even beyond the simulation period.

It seems that in scenario 2 the stocks are fished in a more sustainable way than in the other scenarios, because in the long term the fishing effort is lower and more stable than in the other scenarios. The reason for this is, that in scenario 2 an effort restriction is implemented that is tuned to the species most in need of restriction. This often leads to catches of the other species that are lower than the suggested catch forecast (*i.e.* perceived under-exploitation of that stock), which is favourable for the development of that stock. In scenario 3, however, fishing is always to the limit of the perceived management requirements for both species, which implies that, due to assessment error and bias, the stocks are more likely to be over-exploited. Scenario 1, mimicking the current situation, performs badly because the sole catch determines fishing, whereby the plaice stock is often over-exploited. The management then attempts to correct for this over-exploitation, leading to instability.

The development of the stocks is most stable under scenario 2, leading to lower assessment bias and error (lower discrepancy between the perceived and the “true” states of the stocks). Assessment bias due to shrinkage may reinforce instability. Conversely, stability is reinforced, because the effect of assessment bias due to shrinkage is lowered. This could then, in turn, lead to setting more appropriate measures, in this case the effort restrictions.

4.3 The relation between the investigated scenarios and the mixed fishery approach

Originally we intended to investigate another management strategy, namely one where single species TACs are modified according to mixed fisheries considerations, such that the TACs can be depleted synchronously. In this scenario we intended to mimic the use of MTAC, a program that was developed for the calculation of such modified TACs (see Kraak 2004). Due to technical reasons we did not complete the implementation of this scenario into our model. Moreover, in February 2004, the ICES study group SGDFF (ICES 2004b) concluded that MTAC should not be used (see also Kraak (2004)).

However, we believe that many aspects of such a mixed fishery approach scenario are incorporated in our scenario 2 (effort management). In scenario 2, the lower of two efforts is chosen. The model then calculates the catches that the fishery will take under that effort restriction. MTAC would calculate a weighted average of the two efforts and calculate catches that will be taken with that effort. In the real world, this weighting of the effort would be chosen by managers. If in our model we would simulate giving absolute weight to the weakest species, it would then coincide with scenario 2.

There is, however, a difference between effort management and single species TAC management, even if the single species TACs would be modified according to MTAC. In the case of effort management, fishermen would favour trips that result in higher catches of the more valuable species, whereas in the case of TAC management, fishermen are constrained by the respective TACs and would favour trips in which they catch more non-quota species. This difference could be investigated in a future project.

5. Conclusions

This study is a useful first step in the process of developing simulation models to evaluate management strategies. Compared to similar studies, our study contains some new elements, namely that economic data are used to mimic changes in fleet behaviour in response to management and that the economic performance of the management strategies is also evaluated. However, the fleet response to management has not been fully simulated since no new species compositions of vessel-month-gear combinations were introduced other than those present in the 2002 data set. It is likely that in real life, species composition of the catch will change in response to new management strategies. Furthermore, there is some friction in the model between using the data from the Dutch beam trawl fleet only, yet simulating the international North Sea flatfish fishery and all catches of sole and plaice in the North Sea.

The simulation model also suffers from some unrealistic assumptions (*e.g.* no discarding of undersized fish), which limits the direct usefulness of this evaluation of the management strategies. It has been noted that no management scenario in the southern North Sea flatfish fishery could be rationally considered without the discarding of undersized fish taken into account (Kell and Bromley 2004). Moreover, the robustness of the results has not been tested against an array of assumptions (sensitivity analysis), and this limits the validity of the conclusions as well. In future studies, attempts could be made to model the international catches in a better way, to include discarding of undersized fish, and to carry out a sensitivity analysis.

The finding that the effort restriction management strategy appeared to lead to the highest sustainability of the fishery (in biological as well as economic terms), must be considered with reservations, owing to the limitations mentioned above. Many of the differences between the scenario outcomes are due to the way the management measures deal with the conflicting target Fs for sole and plaice, and the inconsistent fleet effort required to apply these fishing mortalities. Our study suggests that a management strategy that occasionally results in perceived under-exploitation of the stocks may work best given that assessment error and bias exist. The results also suggest that stability in fishing mortality reinforces itself, because the assessment bias is lower under greater stability and corrections become less necessary. In our model it is scenario 2 that performs best, but other management strategies may be envisaged that do so as well or even better.

The original question leading to this project was "What are the possible effects of alternative fisheries management strategies (for example Multi-Species TACs) on the behaviour of the Dutch and international fleets and the manageability of fishing pressure?" This question has been answered to the extent that some possible effects have been identified. However, as was noted above, the present results are to be viewed as preliminary because of the many restrictive assumptions and the lack of a sensitivity analysis.

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Appendix 1. Assumptions

Below is a list of the unrealistic restrictive assumptions and to what extent they lead to an unrealistic view of the effects of the alternative management scenarios and whether they can be easily relaxed. It must be noted that there are two issues here.

(1) Unrealistic assumptions will cause the projections to badly reflect real developments, but the differences in outcome that are due to applying different management strategies may still be valid.
(2) Unrealistic assumptions may have differential effects depending on the management strategy applied.

In the first case, the objective of the study is not jeopardized, since the intention was not to interpret the projections as forecasts or predictions. In the second case, the objective of the study could be jeopardized, since the ranking of the scenarios according to the evaluation criteria may change under different assumptions. Without running simulations with different sets of assumptions, it is difficult to say whether and which assumptions have the effect mentioned under point (2).

General

- The operating model represents the dynamics of the system with the appropriate processes and appropriate uncertainties.
    - This is a fundamental assumption because the operating model is the basis for the whole evaluation process. The only way to assess whether the operating model performs the way it is expected is by exploring different assumptions and parameter values in the operating model, and thereby test the robustness of the outcomes against the assumptions.
- The Dutch sole catch is multiplied by 2.25 and the Dutch plaice catch by 1.35 to arrive at the respective international catches. These multipliers are based on the average Dutch catches and average international catches as reported in ICES (2004) for 1995-2002.
    - It is not clear how this assumption biases the outcome, but it quite likely does. This assumption “fixes” the division of catches by country when in practice they can be changing (due to trading or reflagging). The assumption could be relaxed if the economic details needed for the model would be known for all fisheries exploiting the sole and plaice stocks. However, this would require a more complicated multi-fleet model and this would make the results less tractable.
- The technical interaction between sole and plaice in the Dutch beam trawl fishery is taken as a proxy for the linkage between the species.
    - This assumption certainly affects the outcome. The linkage between the species is certainly different for the different fleets. This assumption could be relaxed if the details needed for the economic model would be known for all fisheries exploiting the sole and plaice stocks. However, this would require a more complicated multi-fleet model and this would make the results less tractable. Note that in the model this assumption conflicts with the previous one, and that the effects of this friction are not entirely understood.
- The parameters of the economic production function are based on landings data, but the production function is assumed to generate total catches.
    - This assumption certainly causes a bias: it results in underestimation of the catches with any given effort. It would only be possible to relax this assumption if information on the true catches were known. This issue is related to the assumptions of discarding, high-grading, and over-quota fishing.

Biology

- Natural mortality at age in the “true” system is constant.
    - This could be a cause for bias in those stocks where natural mortality can be expected to fluctuate (e.g. due to fluctuations in predators or environmental conditions). The assumption could be relaxed by allowing random or systematic

variation in natural mortality to occur. It would be difficult to parameterize such a change in natural mortality.

- Maturity at age in the "true" system is constant.
    - Since we know that maturity at age has been changing over the past decades, this assumption is likely to bias the outcome. Since we have data on maturity in the Dutch catches, it is possible to relax this assumption to a certain extent.

Fishery

- The "true" exploitation pattern for the projected period is constant.
    - This assumption may render the outcome unrealistic to an unknown extent, because in reality the fishery may change their spatial distribution in response to management measures. It will not be possible to relax this assumption as long as we do not have more knowledge on fleet behaviour in response to management.
- The selectivity of the fishery is such that no undersized fish are caught; *i.e.* no discarding of undersized fish takes place.
    - This assumption certainly results in an unrealistic view. So far it has not been possible to reconstruct discard time series. However on the basis of some informed assumptions it would be possible to incorporate discards into future evaluations.
- No high-grading takes place.
    - This assumption may result in an unrealistic view. So far no information on high-grading is available except for anecdotal information. High-grading has not been observed in discard-trips. If we would be able to estimate high-grading, it would be possible to relax this assumption.
- Except for plaice in scenario 1, there is full compliance with the management measures, *i.e.* no exceeding of quota or effort restrictions.
    - This assumption is likely to cause a bias, since it is expected that when quota or allowable effort decrease substantially, the incentive to fish more than allowed increases. It may be possible to relax this assumption and replace it with an assumption that relates over-quota catches or the exceeding of allowable effort in a simple way to the magnitude of the downward change in the management measure. Although the assumption would be relatively straightforward, it would be difficult to parameterize.
- Except for plaice in scenario 1, all catches are landed and reported.
    - This assumption is likely to cause a bias, since it is expected that when quota decrease substantially, the incentive to fish more than allowed increases. See above for a possible solution.
- In the case of scenario 1, over-quota catch of plaice (not reported) has the same age distribution as the reported catch.
    - This assumption is likely to cause a bias because high-grading is a method of grading the catch based on the desired landings composition. Therefore, it is likely that the high-graded part of the catch will have a different age composition than the landed part of the catch. So far no information on high-grading is available except for anecdotal information. High-grading has not been observed in discard-trips. If we would be able to estimate high-grading, it would be possible to relax this assumption.

Assessment

- The "true" catch numbers are known to the observers (except for over-quota catch of plaice in scenario 1) without error.
    - The lack of random error will probably result in an underestimation of the discrepancy between the perceived and the "true" systems. Since we know the CVs of the catch numbers at age resulting from the market sampling, it is possible to include this error in future exercises.
- "True" natural mortality at age is known to the observers.

    - The lack of any error will probably result in an underestimation of the discrepancy between the perceived and the "true" systems. It would be relatively easy to evaluate the effects of a bias in the perceived natural mortality.
- "True" maturity at age is known to the observers.
    - Since we know that maturity at age has been changing over the past decades, this assumption is likely to bias the outcome. If we would change "true" maturity (see above) it would be possible to run simulations where perceived maturity is constant and thereby different from "true" maturity.
- "True" weights at age in the stock and in the catch of all previous years are known to the observers without error.
    - The lack of random error will probably result in an underestimation of the discrepancy between the perceived and the "true" systems. Since we know the CVs of the weights at age resulting from the market sampling, it is possible to include this error in future exercises.
- The XSA model settings are the same for each year.
    - This assumption may render the outcome unrealistic to an unknown extent, because in reality the assessments (at least benchmark assessments) are likely to change the model settings based on the model diagnostics. It may be possible to relax this assumption by adding random changes in the model settings, but it is doubtful whether these changes mimic the behaviour of working groups.

Management
- The management decisions are based on the advice generated by the assessment and forecast without modifications.
    - This assumption may cause a bias, since it is expected that when the advice is increasingly restrictive, managers may be more likely to deviate from the advice. However, since the aim is to simulate management strategies as formulated, it makes no sense to relax this assumption as such. Instead, different management strategies could be investigated. Deviations from advice when stocks are going down could be one of the explicit management strategies.

Economy
- The economic model is based on data from 2002, *i.e.* on data valid under the current policy situation.
    - This assumption may render the outcome unrealistic to an unknown extent, because the relations considered in the economic model will be different under different management regimes, *e.g.* the species composition of the catch will be different. It will not be possible to relax this assumption as long as we do not have more knowledge on fleet behaviour in response to management.
- The direction of the fishery will not change: the fishery is directed toward the most profitable species, in this case sole.
    - This assumption is probably quite realistic, since sole will probably remain the most profitable species at least for the part of the future that is considered.
- The efficient vessels will not buy more hp-days than they loose by an effort restriction. In the multi-species TAC scenario they will not buy more quota than they will loose by a quota restriction.
    - This assumption certainly causes bias, because the most efficient vessels can be expected to buy more hp-days or quota than they will loose. Therefore, this assumption results in underestimation of the catches. It is not clear how this assumption could be relaxed, as long as we cannot predict quantitatively what the vessel owners will do in response to management measures.
- Economic effects on investment and disinvestment are not modelled.
    - This assumption may render the outcome unrealistic to an unknown extent, because investments and disinvestments will take place in response to management. It will be difficult to model the incentives for investments and disinvestments.

- The ratio between the sole and the plaice price used in the economic model for scenario 1 is constant (from 2002).
    - It is not clear whether and to what extent this assumption causes bias, but the ratio of prices did not change to a large extent in the simulation runs. It will be quite difficult to relax this assumption because it requires a yearly feedback loop between the model and the production functions, which would then need to be re-estimated for each year.