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Report; the complete version

Number: C071/04

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 of Department Biology & Ecology
Signature:	____________________
Date:	14 October 2004

Number of copies:	25
Number of pages:	54
Number of tables:	3
Number of figures:	19
Number of annexes:	1

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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:

1. 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.
2. 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.
3. 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 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 performance of the management scenarios is compared on the basis of both ecological and economic sustainability. 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.

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 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 interactions between species-specific catchability 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 and the validity of many assumptions (Kell *et al.* 1999, 2001, 2002).

Harwood and Stokes (2003) argue that some of the most interesting methods for taking account of uncertainty in ecological systems have been developed by fisheries scientists. These simulation methods evaluate the relative performance of different management procedures with the use of mathematical and statistical models that synthesize knowledge and speculation about the system of interest. Recent advances in computer-intensive statistics have made it possible to combine this approach with model fitting, so that the uncertainties and risks associated with different outcomes of management can be quantified. Harwood and Stokes (2003) suggest that this methodology can be applied to problems where the advice that scientists provide to decision makers is likely to be clouded by uncertainty.

The framework generally used in fisheries science was originally developed in the International Whaling Commission (Kirkwood 1997, McAllister *et al.* 1999) and is based on examination of the management objectives, assessment of data uncertainties and simulation of alternative management approaches. Operating models and simulations are caricatures of the real world that try to incorporate sufficient aspects of the dynamics of real systems into a useful test bed for evaluating management strategies (Butterworth and Punt 1999; Sainsbury *et al.*, 2000; Punt *et al.* 2002a; Punt *et al.* 2002b; Punt *et al.* 2002c; Fulton *et al.*, in press).

The simulation tools developed 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). This framework allows for the analysis of the interactions between all system components and provides an integrated way to evaluate the impact of components to the overall success of management (Wilimovsky 1985; De La Mare 1998).

The framework allows for the presence and quantification of a variety of sources of uncertainty. These include process error caused by natural variation (*e.g.* recruitment and growth), measurement error when collecting observations from the real population, estimation error during the assessment, and implementation error of management actions (Restrepo and Rosenberg 1995). Within any simulation approach care must be taken not to include too much

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system detail because the model often cannot be parameterised at such detail and the system dynamics are not easily explained (Punt *et al.* 2002a; 2002b; 2002c).

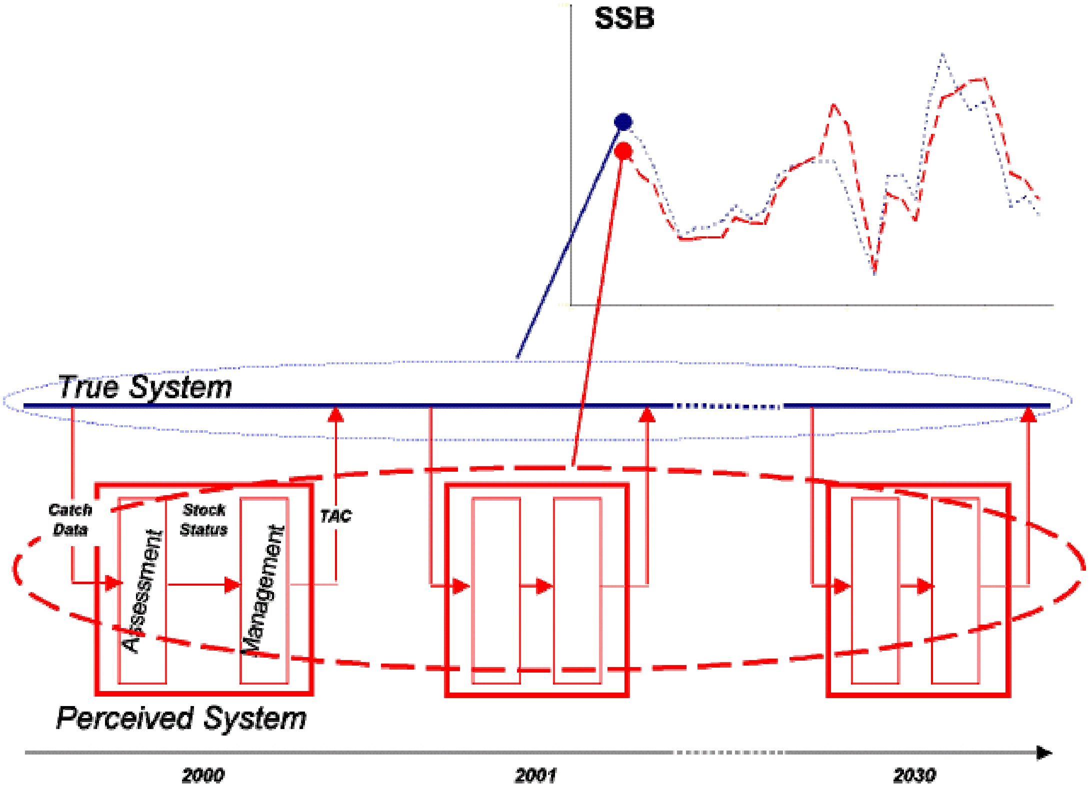


Figure 1.1. The simulation framework of "real" ("true") and observed (perceived) systems used to evaluate management strategies (from Anon. 2002).

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. The simulation model consists of two parts: an operating model (the "true" population) and a management procedure (the perceived population and decision making component).

The economic impact of alternative management strategies has been analysed for various fisheries (*e.g.* Frost 1997; Sutinen 1999). Simulation tools to assess economic impact have rarely been used, since this requires economical data sets of fleets, or preferably of individual vessels or rather details on trip level. Examples of simulation studies on fleet level are Salz and Frost (2000), on individual vessel basis Pascoe *et al.* (2001), and on trip level De Wilde (1999) and Holland and Sutinen (1999).

Four management scenarios were investigated, all based on single species assessments of the operating model outputs, but varying the management decision and fleet behaviour:

Scenario 0 **Single species TAC advice, with sole and plaice in the North Sea managed independently of each other and no fishery interaction assumed**. The scenario was investigated to provide a baseline for contrasting the other scenarios and to test the sensitivities of assumptions other than through interaction in the fishery. Because the scenario was considered unrealistic, economics were left out completely.

Scenario 1 **Single species TAC advice (as above), 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). In other words, exploitation of sole determines the behaviour of the whole fleet, 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 (scenarios 1, 2 and 3 only):

- 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 implemented as a set of dynamic link libraries (DLLs) that can be called from within Excel (Kell *et al.,* 1999, 2001, 2002). The model uses the basic tools available in FishLab that were provided to RIVO by Dr. Kell in May 2003, and no new DLLs have been developed[1].

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).

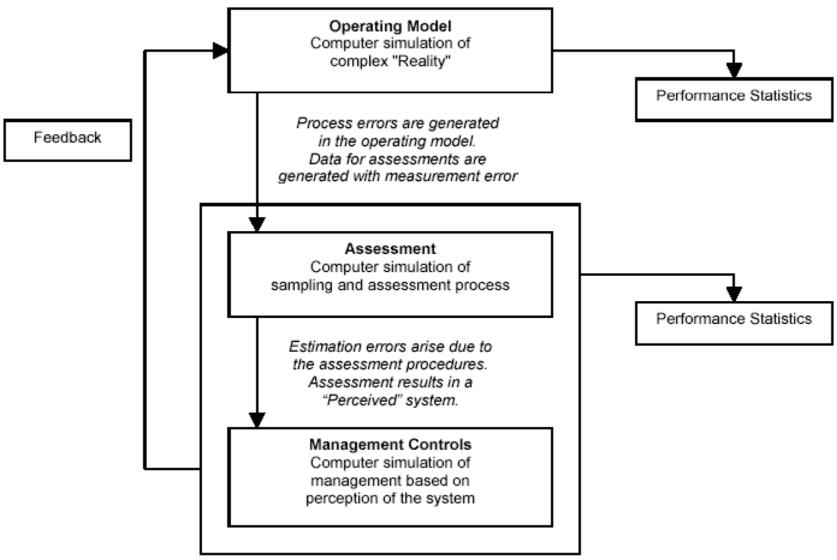


Figure 2.1. Simulation model structure (from Anon. 2002).

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

[1] The DLL functions used are FLOM for the development of the fish stocks in the operating model, the "truth", FLMATES_MP for the assessment and advice, and FLXSACPUE for the tuning series.

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/sensitivity in the simulated results.

2.2.1. Input data

The following input data are required for the OM.

- **Natural mortality-at-age M**; assumed constant for the whole period, taken from ICES (2004);
- **Maturity-at-age**; assumed constant for the whole period, taken from ICES (2004);
- **Mean fish weight-at-age in the stock (SWt) and in the catch (CWt)**; for 1957-2001 taken from ICES (2004), and for 2002-2015 taken to be the average of the previous three years (three-year running average);
- **The exploitation pattern**; for 1957-2001 taken as F-at-age from ICES (2003), and for 2002-2015 assumed constant as the average of the last 5 years (1997-2001);
- **Recruits**; for 1957-2001 taken from ICES (2004), and for 2002-2015 according to a Ricker model with a log-normal error distribution with the following parameters: sole – α=5.1055, β=0.0000168, s.d. for error=0.5; plaice – α=3.81, β=0.00000331, s.d. for error=0.35. The parameters were determined by regressing recruits on SSB using data from ICES (2004); the standard deviations were chosen through visual inspection of the resulting variation.
- **Yield**; for 1957-2002 for sole from ICES (2004) and for plaice from Kell (personal communication); from 2003 onwards the yield is determined by the management decision set in the previous year.

The recruitment in 2002-2015 is a source of variability between simulation runs.

From these input data the following quantities are calculated for both stocks for each year: **catch-at-age**, **population numbers-at-age (N)**, **F-at-age**, **Spawning Stock Biomass (SSB)**, and **F_{bar} ($F_{2\text{-}8}$)**.
The input required for the MP is as follows.

- **Perceived catch-at-age**; for all but one management scenario (see below) equal to “true” catch-at-age in the OM;
- **Perceived M**; equal to “true” M in the OM;
- **Perceived maturity-at-age**; equal to “true” maturity in the OM;
- **Perceived SWt and CWt**; the averages of the “true” values of the previous three years in the OM.

In addition, for each species two CPUE series are generated for tuning, from “true” N-at-age, “true” M-at-age, “true” F-at-age, and catchabilities (Q, see below), without a power model. Both series are set to take place in the autumn, taking into account the proportion of the year the fish have been exploited (the start at 0.66 and the end at 0.75). CPUE series 1 commences in 1984 and involves ages 1-9, while CPUE series 2 commences in 1982 and involves ages 1-3 (both species). The catchabilities and their standard errors for each species and series are given in the text table below. These values are taken from existing survey tuning series (ICES 2003), except for ages 2-9 of sole CPUE series 1, where values are from the commercial tuning series output (ICES 2004). The generation of the tuning series with random error contributes a second source of variability between simulation runs.

Input values into the MP for the tuning series:
Catchability-at-age and standard error of CPUE series for both sole and plaice.

	Sole				*Plaice*			
Age	Q1	SE1	Q2	SE2	Q1	SE1	Q2	SE2
1	8.89	0.29	3.94	0.18	7.29	0.54	2.47	0.37
2	6.22	0.50	4.92	0.31	7.70	0.31	3.62	0.43
3	5.27	0.24	5.57	0.50	8.62	0.24	4.93	0.49
4	5.11	0.22			9.48	0.21		
5	5.09	0.22			10.13	0.22		
6	5.27	0.19			10.45	0.28		
7	5.31	0.26			10.73	0.29		
8	5.31	0.27			10.76	0.34		
9	5.31	0.20			11.08	0.38		

In the MP the yearly assessment is performed by XSA, using the perceived data, with the following settings for both stocks, as used in ICES (2004) for plaice.

Parameters	
Last Recruit Age	-1
Const Q Age	10
F Shk SE	0.5
Shk 2 F	TRUE
Shk 2 N	TRUE
TS Range	99
TS Power	0
Shk 2 F Yr	5
Shk 2 F Age	5
Min N SE	0.3
Max Iters	30
Tol	1E-19
Plus Group	15

In addition, simulations were run with reduced shrinkage with the following settings (only the parameter values in the gray boxes are different).

Parameters	
Last Recruit Age	-1
Const Q Age	10
F Shk SE	2
Shk 2 F	TRUE
Shk 2 N	TRUE
TS Range	99
TS Power	0
Shk 2 F Yr	3
Shk 2 F Age	5
Min N SE	0.3
Max Iters	30
Tol	1E-19
Plus Group	15

The assessment generates values for **perceived F-at-age**, **perceived N-at-age**, **perceived F_{bar}**, and **perceived SSB** up to the last data year.

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, and recruits predicted as the geometric mean over the previous 3 years. For these catch forecasts F_{pa} is taken as the target F (0.4 for sole and 0.3 for plaice).

The catch forecasts thus generated can then be used as input yields in the OM. The fishing fleets are then assumed to show absolute compliance to the TAC advice equating the catch forecast. This scenario, which supposes no linkage between the fisheries for sole and plaice, is followed in simulation runs of the scenario 0.

In the three management strategies investigated, however, scenarios are constructed where the catch forecasts are modified by a harvest control rule before the catches are input in the OM, as is explained below.

2.2.2. The scenarios

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.

2.2.2.1. 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. In both cases the calculated plaice catch is input for the plaice yield in the OM (the “true” catch). If the “true” catch is below the TAC, the perceived plaice catch in the MP will be the same as the “true” plaice catch in the OM. If the “true” catch exceeds the TAC, however, over-quota catch is not observed in the MP (discarded or not reported). Then the perceived plaice catch in the MP is equal to the plaice TAC. The distribution of the perceived catch over the age groups is assumed to be equal to the distribution of the “true” catch over the age groups.

2.2.2.2. 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. The respective catches are input yields in the OM, and the perceived catches in the MP are equal to them. Absolute compliance with the management is assumed. All catch is landed.

2.2.2.3. 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). The respective catches are input yields in the OM, and the perceived catches in the MP are equal to them. Absolute compliance with the management is assumed. All catch is landed.

2.2.3. 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. Fishing effort is assumed to be directed to sole, the most expensive species, and the fishery continues until the sole quota is exhausted. This may result in under-exploitation or over-exploitation (discards or black landings) of the plaice quota.

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. In figure 2.2 the trips have been sorted and cumulated according to descending net revenues per unit of the restricted factor.

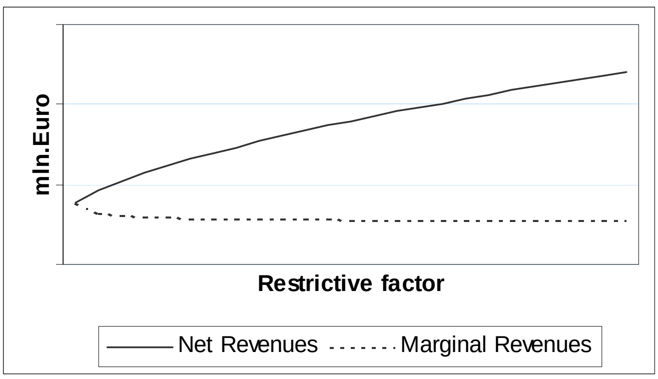


Figure 2.2. Relation between net revenues and restrictive factor.

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. To limit the number of records in the database, trips were replaced by vessel-month-gear combinations, taking several trips with the same gear in the same month together. The vessel-month-gear combinations have for each policy measure been sorted on basis of descending net revenues per unit of the restrictive factor. In scenario 1 the vessel-month-gear combinations are sorted according to descending net revenues per unit of weighted quota, where sole and plaice quota have been summed after multiplying these with fixed average prices. In scenario 2, the vessel-month-gear combinations are sorted according to descending net revenues per hp-day, and in scenario 3 according to descending net revenues per unit of quota of sole and plaice together (without weighting by price). Subsequently, all records have been cumulated and a regression has been made of landings on the restrictive factor. This relation between factor and landings of each species leads to a different production function for each policy measure.

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. This will be elaborated for each management scenario in section 2.3.3.

2.3.3. The economic sub-model

Calculation of catches and economic results for each period is performed in three steps:

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

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

3. Calculation of prices, costs, revenues and profit.

In all management scenarios fishing effort is the crucial variable, but its determination varies:

1. Single species TAC: the catch C_p may contain over-quota catches of plaice.

$$C_s = Q_s \tag{1}$$

$$E = \alpha_0 \bullet \left(SSB_s\right)^{-\beta_0} \bullet Q_s^{\beta_0} \tag{2}$$

$$C_p = \alpha_p \bullet SSB_p \bullet E^{\beta_p} \tag{3}$$

2. Effort restriction: allowable effort is determined by the species for which the catch forecast imposes the most severe restriction on fishing effort. (equation 4).

$$E = MIN\left((\alpha_{0,s} \bullet \left(SSB_s\right)^{-\beta_0^s} \bullet Q_s^{\beta_0^s}), (\alpha_{0,p} \bullet \left(SSB_p\right)^{-\beta_0^p} \bullet Q_p^{\beta_0^p})\right) \tag{4}$$

$$If \left((\alpha_{0,s} \bullet \left(SSB_s\right)^{-\beta_0^s} \bullet Q_s^{\beta_0^s}\right) \leq \left((\alpha_{0,p} \bullet \left(SSB_p\right)^{-\beta_0^p} \bullet Q_p^{\beta_0^p}\right)$$

$$C_s = Q_s \tag{5}$$

$$C_p = \alpha_p \bullet SSB_p \bullet E^{\beta_p} \tag{6}$$

$$If \left((\alpha_{0,s} \bullet \left(SSB_s\right)^{-\beta_0^s} \bullet Q_s^{\beta_0^s}\right) > \left((\alpha_{0,p} \bullet \left(SSB_p\right)^{-\beta_0^p} \bullet Q_p^{\beta_0^p}\right)$$

$$C_p = Q_p \tag{7}$$

$$C_s = \alpha_s \bullet SSB_s \bullet E^{\beta_s} \tag{8}$$

3. Multi-species TAC: fishing effort is proportional to the multi-species quota and the weighted sum of SSB's for sole and plaice (equation 10). The weights are the respective catches of sole and plaice in year 0 (2002).

$$Q_{sp} = Q_s + Q_p \tag{9}$$

$$E = \alpha_0 \bullet \left(\frac{\sum \left(L_i^0 \bullet SSB_i\right)}{\sum L_i^0} \right)^{-\beta_0} \bullet Q_{sp}^{\beta_0} \tag{10}$$

$$C_i = \alpha_i \bullet SSB_i \bullet E^{\beta_i} \tag{11}$$

where:

$i = s, p$; s = sole, p = plaice
α, β = constants

The calculation of prices (P_i), variable costs (C_V) and revenues (R_T = total revenues and R_N = net revenues) is similar for all management scenarios:

$$P_i = P_i^0 \bullet \left(\frac{L_i}{L_i^0} \right)^{e_i} \tag{12}$$

$$R_O = R_O^0 \bullet \left(\frac{E}{E^0} \right) \tag{13}$$

$$R_T = \sum \left(L_i \bullet P_i \right) + R_O \tag{14}$$

$$C_V = \alpha_c + \beta_c \bullet E \bullet 1000 \tag{15}$$

$$R_N = R_T - C_V \tag{16}$$

where:

L = landings, in all cases but one equal to the catch; only in scenario 1 (single species TACs) the plaice catch may exceed the plaice landings due to over-quota fishing (see description of scenario 1 in the biological sub-model, section 2.2.2).

The values of coefficients α and β in the production functions determine the relation between fishing effort and catches of the different species. These values differ by management scenario and can be found in annex 1. The values for the 0-year (2002), P^0_i, L^0_i, R^0, E^0, as well as the values for the price elasticity, e_i, can also be found in annex 1.

Units used in the model:
Catch forecasts, catches, and landings: tonnes
Revenues and costs: kEuros
Effort: million hp-days

2.3.4. Analysis of variance

The economic sub-model assumes that the efficiency of month-vessel-gear combinations is not random and can be "manipulated". An analysis of variance on the net revenues per hp-day has been performed in order to test this hypothesis. Selected potential explanatory variables for the net revenues are:

- month
- gear
- combination of month and gear
- gear and month
- hp-days: available hp-days per year
- vessel
- hp-group (not in the analysis per hp-group)
- combination gear-hp-group (not in the analysis per hp-group)
- combination hp-group and hp-days (not in the analysis per hp-group)

The detailed results of the analysis of variance are presented in appendix 1 and are summarized below.

The analysis of variance has been performed for the entire fleet as well as separately for each hp-group. For the entire fleet 56% of the variance of net revenues per hp-day can be explained by these variables. The most important explanatory variables were vessel, hp-group, and gear. For the individual hp-groups the percentage of explained variance varies between 53% for euro cutters 79% for vessels with engine power over 2000 hp, and the most important explanatory variables were vessel and month.

Conclusions

The variance in net revenues per hp-day is explained by the model for more than 50%. This is true for analysis of the entire fleet as well as for analysis of separate hp-groups. The most important explanatory variables for the variance in net revenues per hp-day are vessel and month (season). This means that it is possible for the sector to cancel the least efficient trips in case of a restriction of the fishery. Net revenues will decrease less than proportionally with the restriction. In practice this less than proportional decrease of net revenues will be effectuated by (a) concentration of trips in the most efficient seasons, and (b) trade of hp-days from less efficient vessels to more efficient vessels. In the long term this may cause less efficient vessels to be withdrawn from the fishery.

3. Results

3.1 The behaviour of the model without links by fleet (Scenario 0).

Scenario 0 was carried out to look into the model assumptions prior to investigating the interaction between plaice and sole. The variability (coefficient of variation, CV) that was entered into the simulation model (recruitment and sampling error of the surveys or CPUE series) was investigated to ensure that the variability of the inputs and the outputs was equivalent. Projected recruitment in the operating model was produced from a Ricker relationship with added CVs of 50% for sole and 35% for plaice. Analysis of the recruits per tonne SSB generated by the operating model shows mean CVs of 57% for sole and 37% for plaice, which are not significantly different from the input values. Similarly, the output variance in the surveys (or CPUE series) is similar to the input estimates of survey variability in catchability (q). The transparency in the functionality and determination of the variance using the simulation framework is poor, and differences have proven difficult to replicate and interpret.

Initial runs of the simulation of scenario 0, showed an apparent lag between the “true” and the “perceived” populations of both sole and plaice, particularly evident in the annual estimates of mean F, of both sole and plaice (Figure 3.1.1). It appeared difficult to stabilise mean F at the target value (0.4 for sole, 0.3 for plaice). At the end of the simulation period the SSBs of both species were below the B_{pa}. An investigation of the individual differences between “true” and perceived values for each Monte Carlo run revealed that this pattern was very strong (Figure 3.1.2). The perceived population fluctuated cyclically around the “true” population. When F was overestimated, unsurprisingly SSB was underestimated and *vice versa*. The under- and overestimations are partly resolved within the assessment model by adjusting the recruitment in the same cyclical manner (Figure 3.1.2): from 2003 to 2006 recruitment was 25% underestimated and from 2009 to 2012 recruitment was 12% overestimated. The phenomenon means that the managers are unaware of the true levels of SSB and F and impose incorrect measures each year, thus reacting late to any requirements to restrict fishing or to increase the catch.

The reason for this lag is suggested in Figure 3.1.1. In both species the perceived F is high at the onset of the projected period (2001) and F was overestimated in both species. The simulations were carried out using the normal XSA settings with high shrinkage of F (ICES 2004). In other words, the assumption that F is similar to the average of recent years supports the convergence of the model (see Dickey-Collas *et al.* 2004). XSA allows adjustment of the strength of the shrinkage and of the period over which the average is taken. In both assessments the shrinkage of F to recent values is strong (SE = 0.5) and the average of F is taken over 5 years. Many other stocks are now assessed without shrinkage of F, because the underlying assumption that F is stable is considered inappropriate. Both the sole and the plaice had declining trends in F from 1996 onwards. Hence, estimates of F in 2001 were “pulled” back up to the recent average by the XSA assessment, and thus overestimated.

To test the hypothesis that strong shrinkage of F caused the initial overestimation of F during the projection period, and the cyclical nature of the differences between perceived and “true” population, simulations were run with exactly the same settings as previous but with the level of shrinkage of F reduced (SE = 2.0) and the period for averaging reduced to 3 years. The agreement between the “true” and the perceived population became much closer and fishing mortality stabilized at approximately the target F (Figure 3.1.3). The sole SSB did not decline as quickly and the plaice stock recovered and did no longer decline in the 2010s (cf. with Figures 3.1.1 and 3.1.2). The removal of the cyclical feature by using lower shrinkage becomes also apparent by investigating the individual differences between “true” and perceived values for each Monte Carlo run (Figure 3.1.4). The F is estimated more accurately and so is SSB.

The strength of the recruiting year classes is estimated with greater accuracy and the annual catch became more stable (CV is reduced by 30%) (see also Figure 3.1.5). This occurred both in sole and plaice after the first 5 years of the simulation. However there still is a slight bias (Figure 3.1.4). From beyond 2005, F is underestimated by 5-6%, and SSB overestimated by 4-5%. The bias appears stable but the reasons for this bias remain unclear.

An economic model was not applied to this scenario.

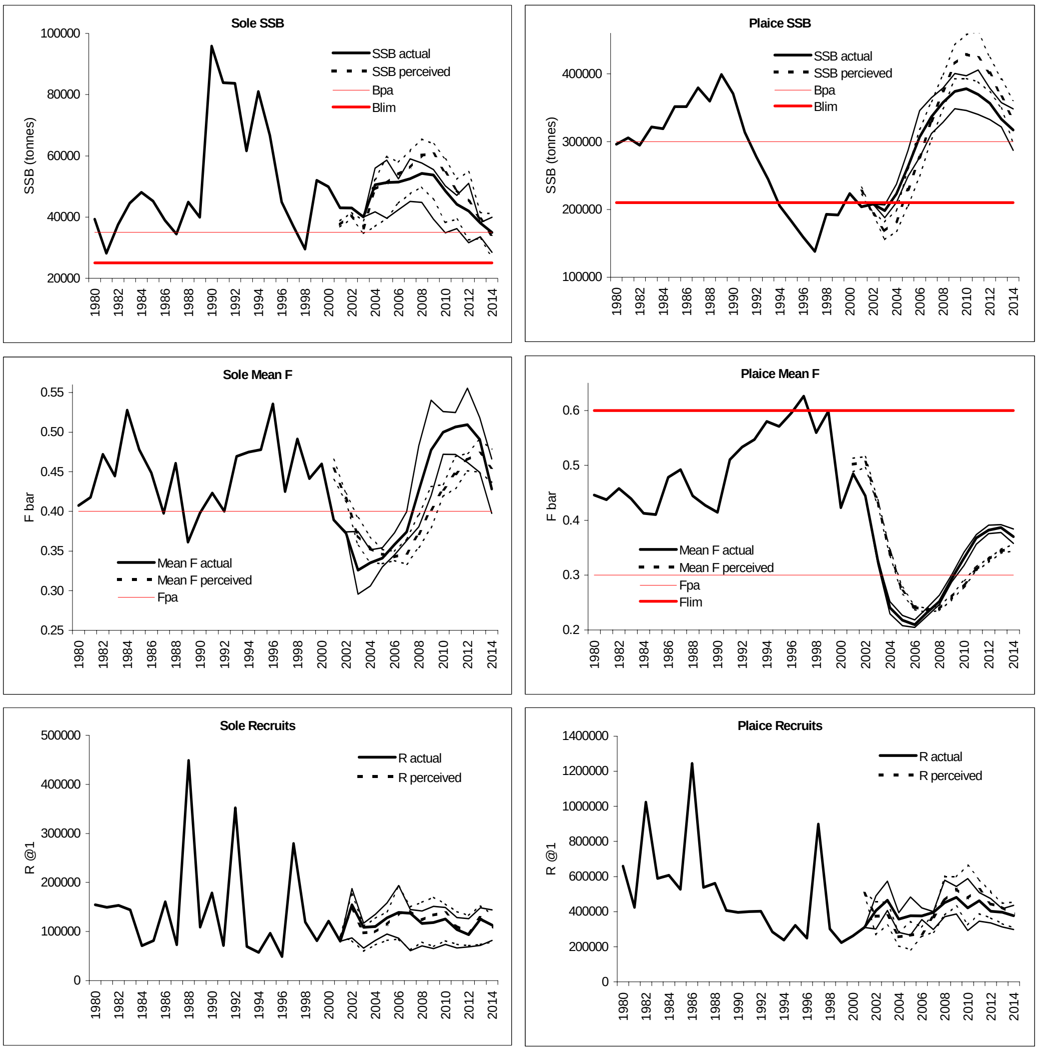


Figure 3.1.1. Scenario 0. Sole and plaice population characteristics from 1980 to the end of the projection period. Solid lines denote the "true" (actual) population, dotted lines denote the perceived population. In the projected part of the simulation the average of 10 Monte Carlo runs of the model 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. **Shrinkage on fishing mortality (F) as in the current XSA assessments (0.5 for 5 years).**

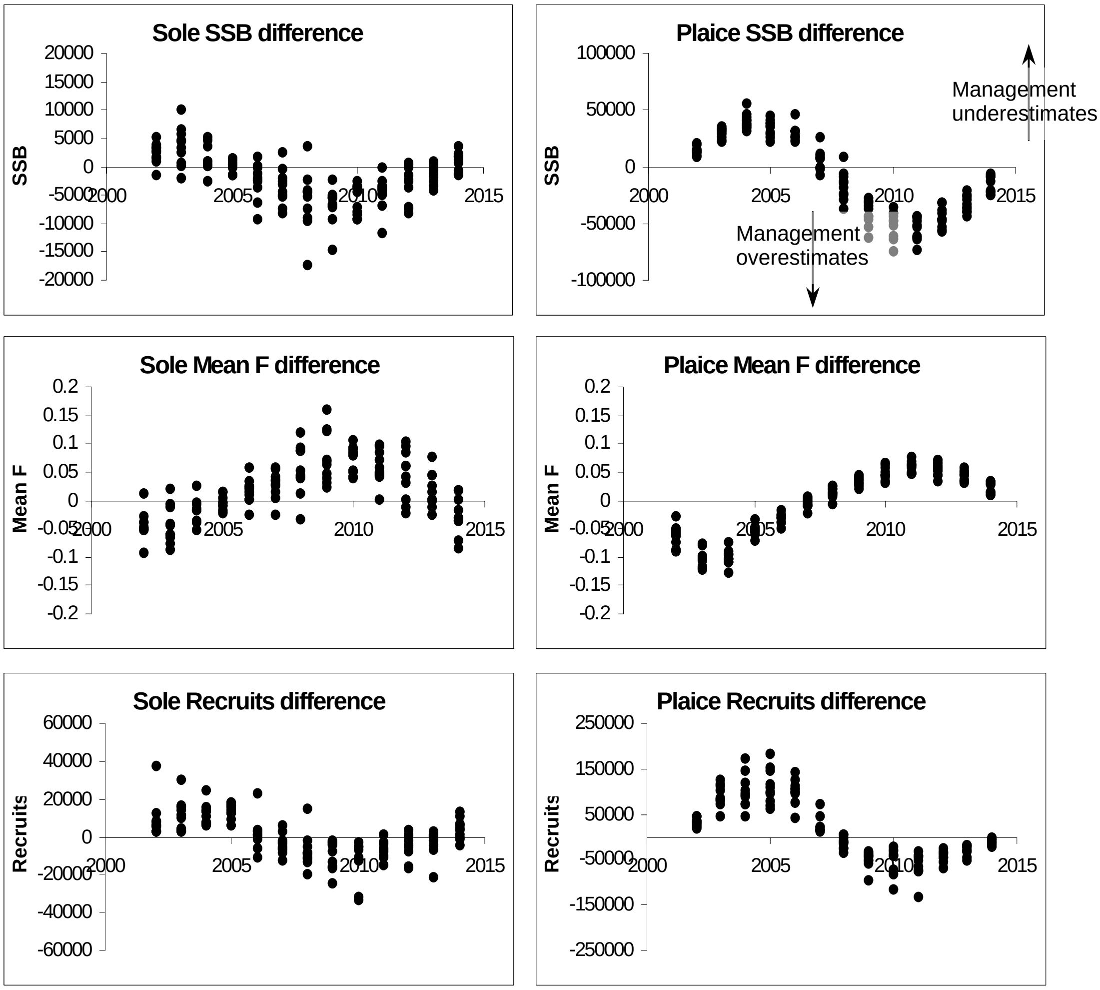


Figure 3.1.2. Scenario 0. The difference between "true" and perceived estimates of SSB, F and recruitment for each Monte Carlo run for sole and plaice during the projected part of the simulation. Positive values mean that the perceived population is under estimated compared to the "true" population. Variability in the Monte Carlo runs comes from recruitment and sampling error. **Shrinkage on fishing mortality (F) as in the current XSA assessments (0.5 for 5 years).**

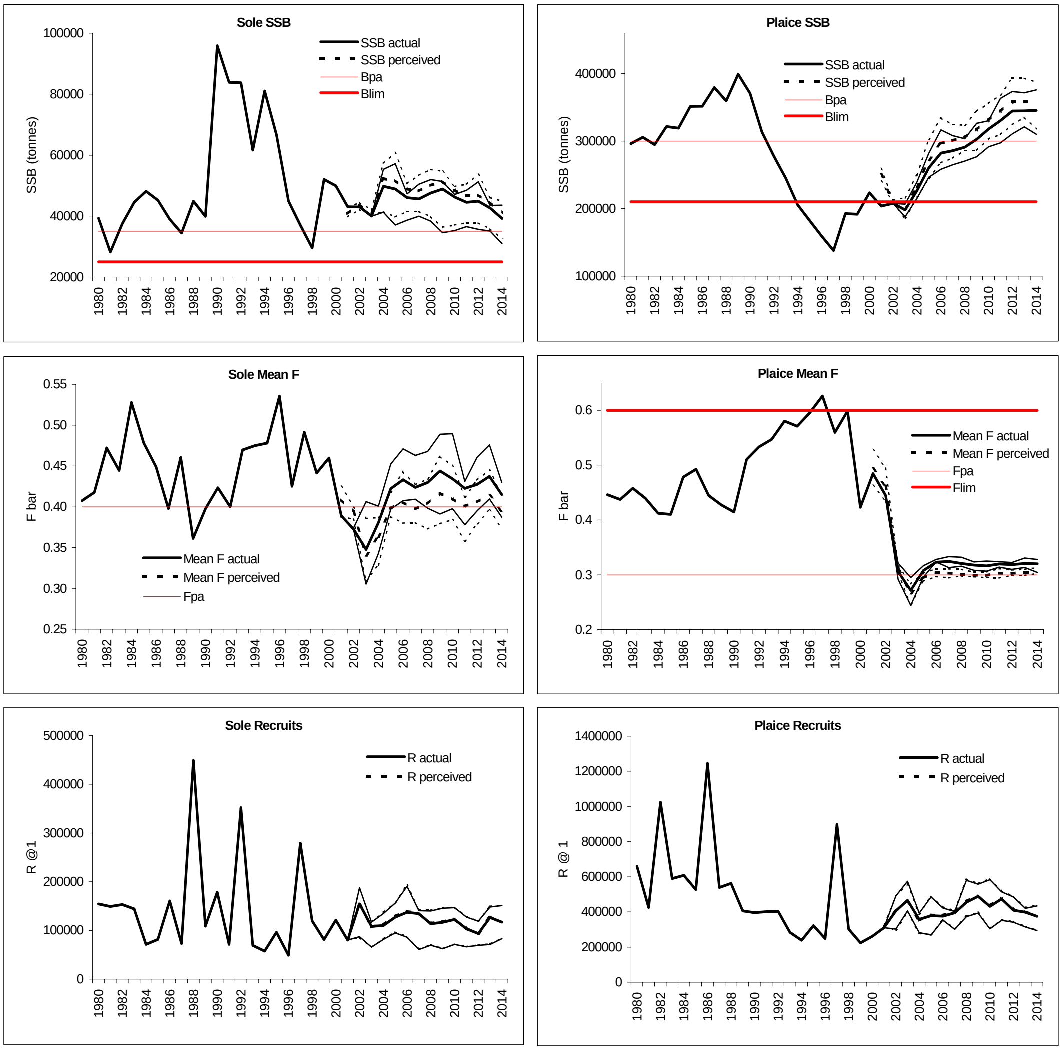


Figure 3.1.3. Scenario 0. Sole and plaice population characteristics from 1980 to the end of the projection period. Solid lines denote the "true" (actual) population, dotted lines denote the perceived population. In the projected part of the simulation the average of 10 Monte Carlo runs of the model 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. **Shrinkage on fishing mortality (F) set at a lower influence for the XSA assessments (2.0 for 3 years).**

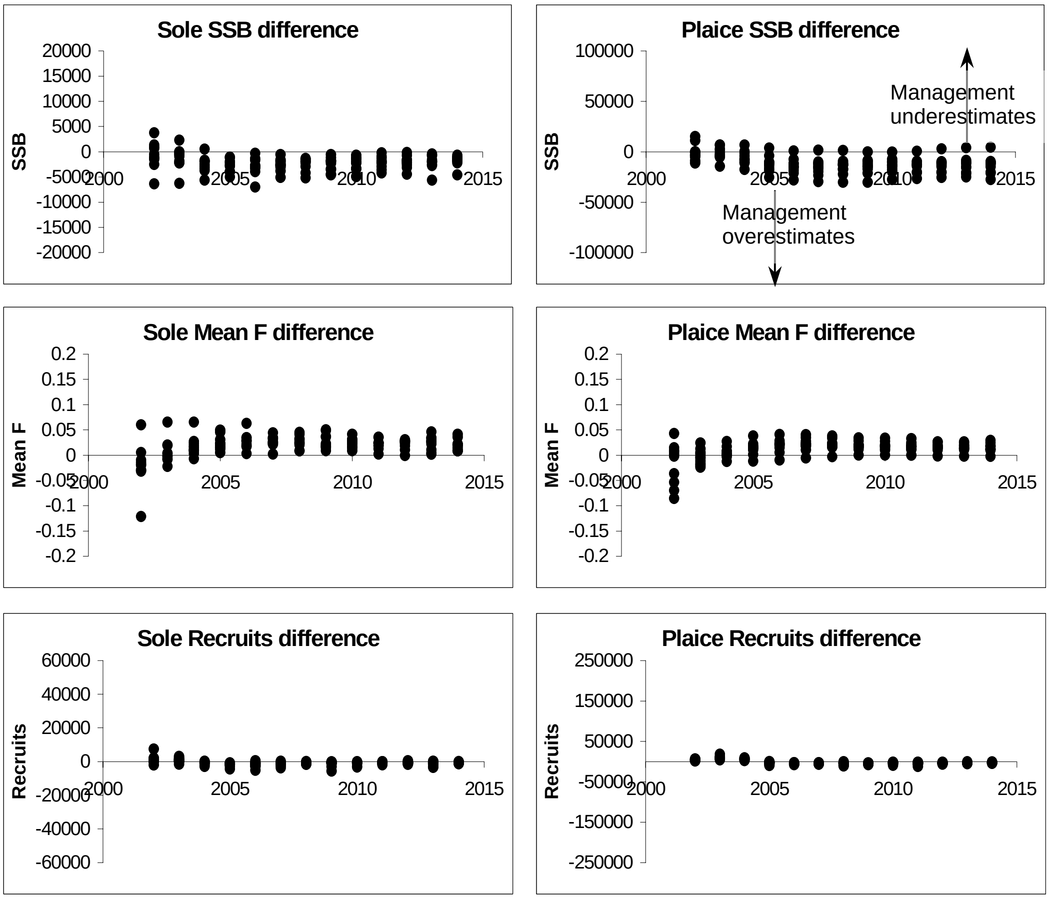


Figure 3.1.4. Scenario 0. The difference between "true" and perceived estimates of SSB, F and recruitment for each Monte Carlo run for sole and plaice during the projected part of the simulation. Positive values mean that the perceived population is under estimated compared to the "true" population. Variability in the Monte Carlo runs comes from recruitment and sampling error. **Shrinkage on fishing mortality (F) set at a lower influence for the XSA assessments (2.0 for 3 years).**

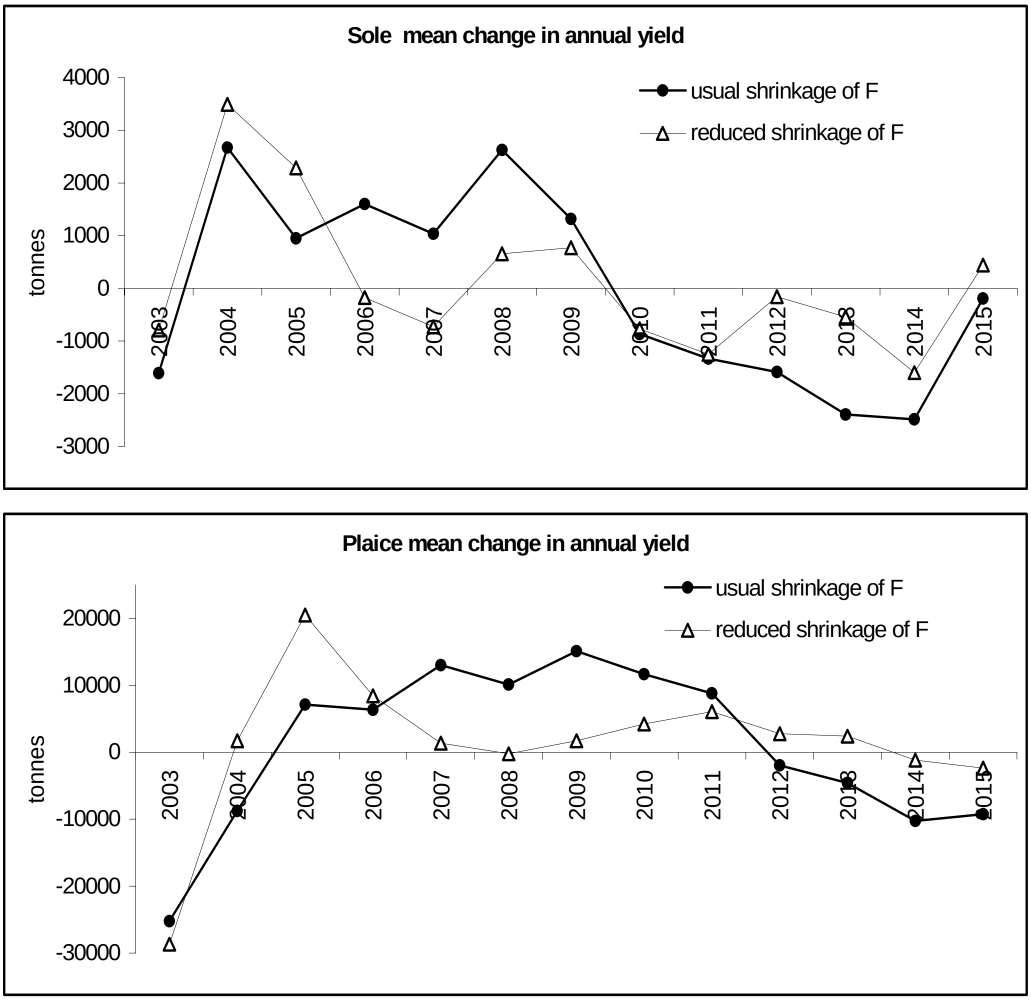


Figure 3.1.5. Scenario O. A comparison of the mean change in annual yield (catch in tonnes) for sole and plaice produced by the simulation operating model from 10 Monte Carlo runs in the projection period. Shrinkage on fishing mortality (F) set at 0.5 for 5 years (usual) and 2.0 for 3 years (reduced).

3.2 Scenario 1 Single species TAC management, with interaction between sole and plaice

In this scenario, advice is given as single species TACs. It is assumed that fishing continues until the sole TAC is depleted and then stops, and that this may consequently result in under- or over-exploitation of the plaice TAC. The plaice catch is calculated from the effort needed to deplete the sole TAC. In this scenario over-quota plaice catch is not reported.

3.2.1 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 3.2.1). Due to the problems caused by the shrinkage of F, as in scenario 0, 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 3.2.1). 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 3.2.2). 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*).

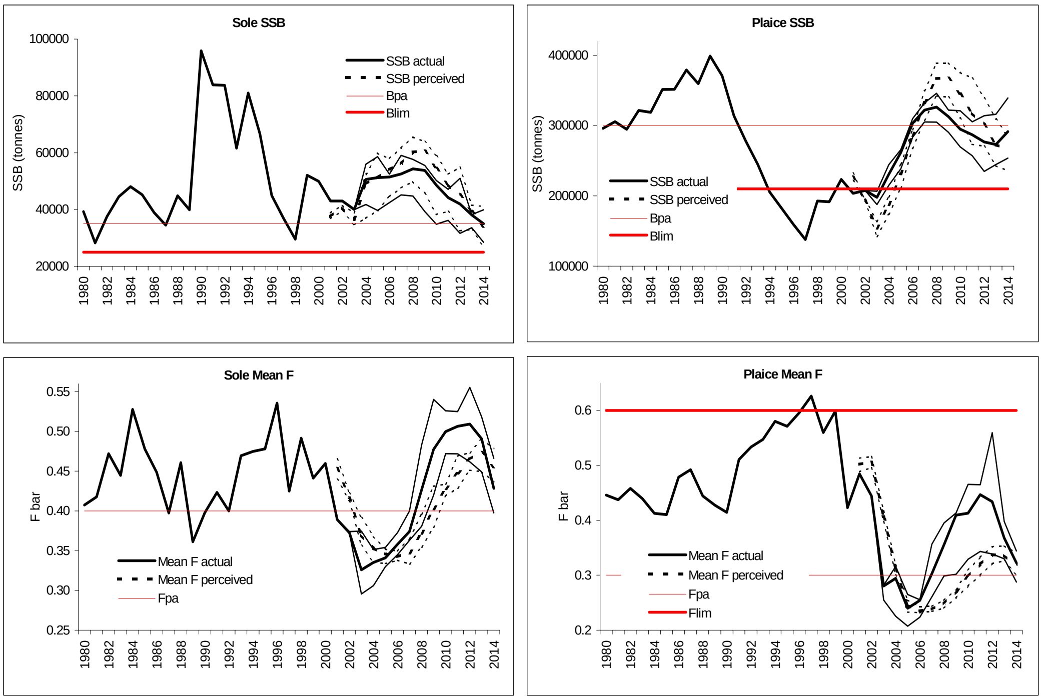


Figure 3.2.1. Scenario 1. Sole and plaice population characteristics from 1980 to the end of the projection period. Solid lines denote the "true" (actual) population, dotted lines denote the perceived population. In the projected part of the simulation the average of 10 Monte Carlo runs of the model 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. Shrinkage on fishing mortality (F) as in the current XSA assessments (0.5 for 5 years).

Throughout the whole simulation period over-quota fishing of plaice occurs in at least some Monte Carlo runs (Figure 3.2.3), resulting in the perceived plaice yield being lower than the "true" plaice yield (Figure 3.2.4). 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 3.2.3 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.

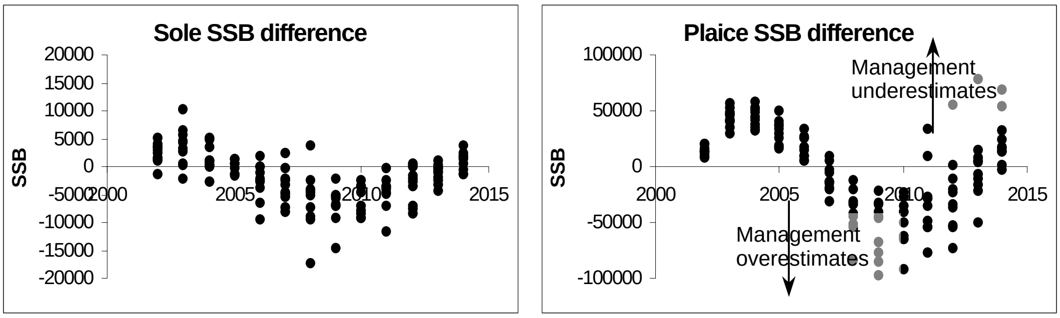


Figure 3.2.2. Scenario 1. The difference between "true" and perceived estimates of SSB, for each Monte Carlo run for sole and plaice during the projected part of the simulation. Positive values mean that the perceived population is under estimated compared to the "true" population. Variability in the Monte Carlo runs comes from recruitment and sampling error. Shrinkage on fishing mortality (F) as in the current XSA assessments (0.5 for 5 years).

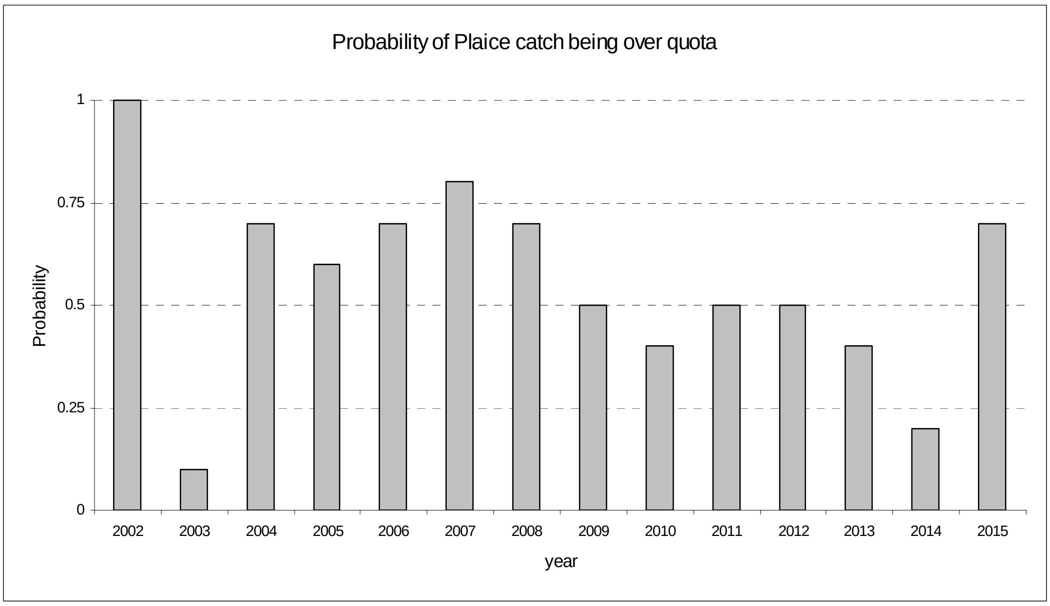
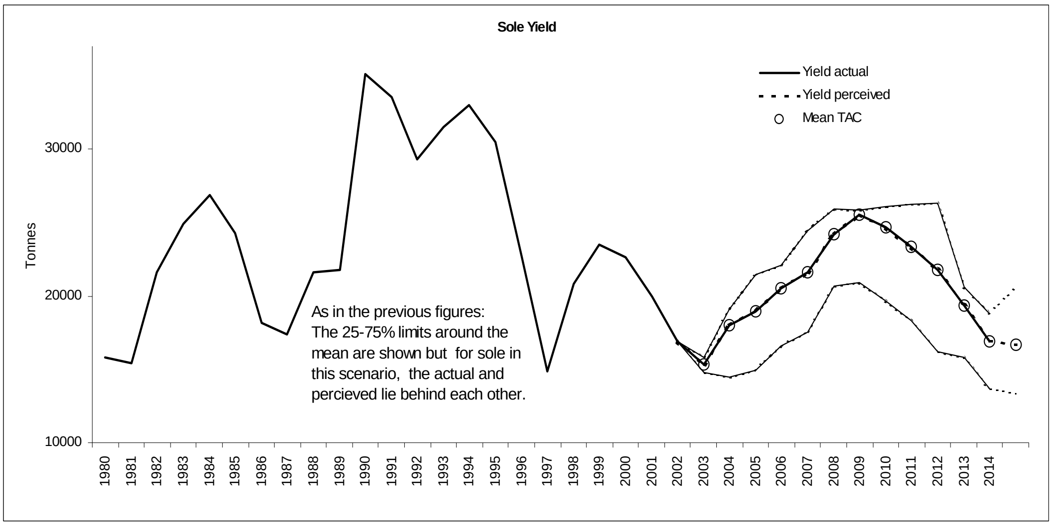


Figure 3.2.3. Scenario 1. The probability that the plaice catch will be over quota and discarding or un-official landings will occur in the projection part of the simulation.



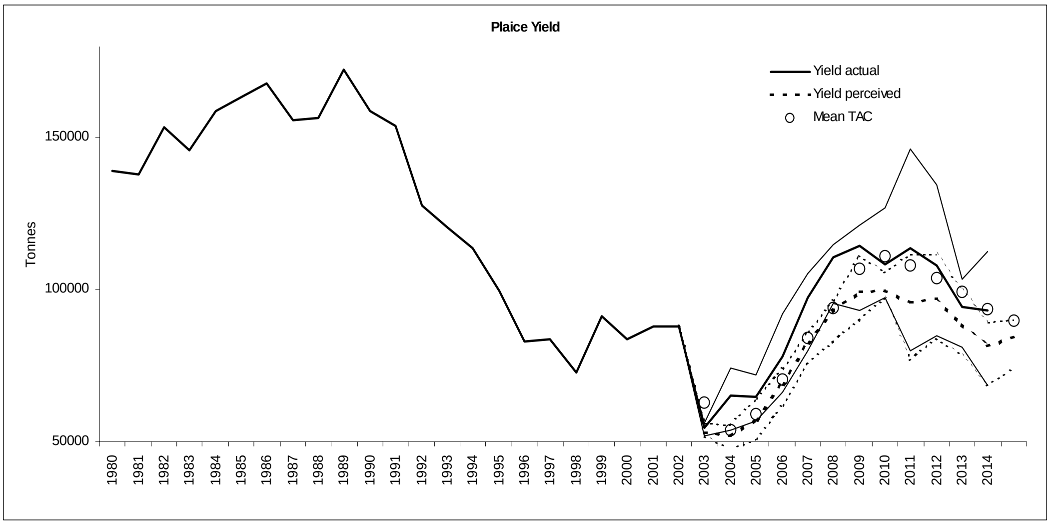


Figure 3.2.4. Scenario 1. The yield (catch) of sole and plaice from 1980 to the end of the projection period. Solid lines denote the “true” catch, dotted lines denote the perceived catch. In the projected part of the simulation the average of 10 Monte Carlo runs of the model is shown bounded by the central 50% range of the estimates (i.e. the 2 central quartiles). The mean TAC from the Monte Carlo runs is show by the circles.

3.2.2. Economy

Figure 3.2.5 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.

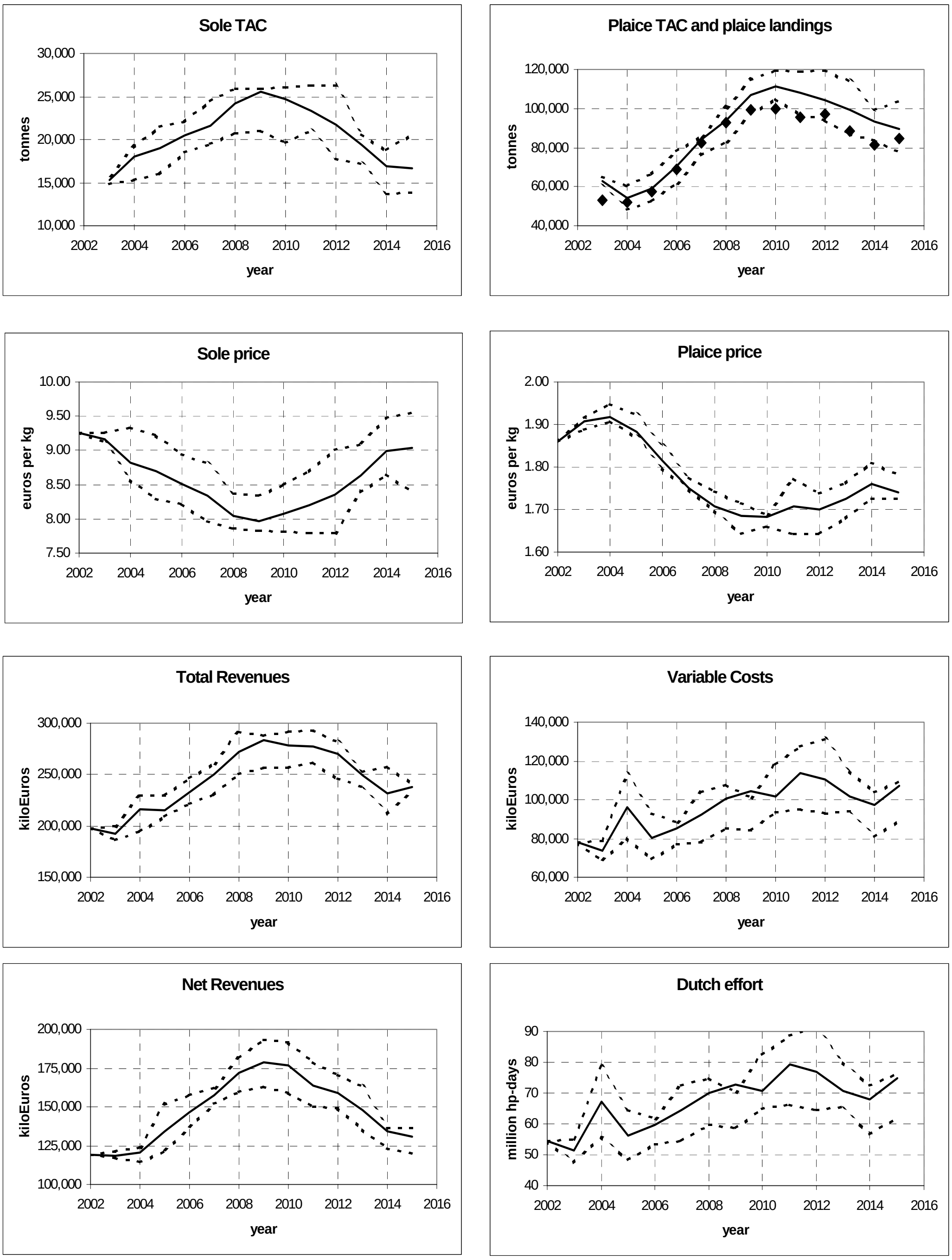


Figure 3.2.5. Scenario 1. Sole TAC, plaice TAC (and landings), sole price, plaice price, total revenues, variable costs, net revenues, and Dutch effort. Solid lines: mean; stippled lines: upper and lower quartiles; diamonds: mean landings.

3.3 Scenario 2 Effort management

In this scenario, advice is given as allowable fishing effort. This effort is the lowest of two estimates, either the predicted effort needed to fish the forecasted catch (equivalent to the TAC) for sole, or the predicted 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. Absolute compliance with the management is assumed. All the catch is landed.

3.3.1 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 3.3.1), which is the case in scenario 1 (cf. Figure 3.2.1). The decline in sole is due again to the underestimation of F (Figure 3.3.1). 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 3.2.1 and 3.4.1 respectively).

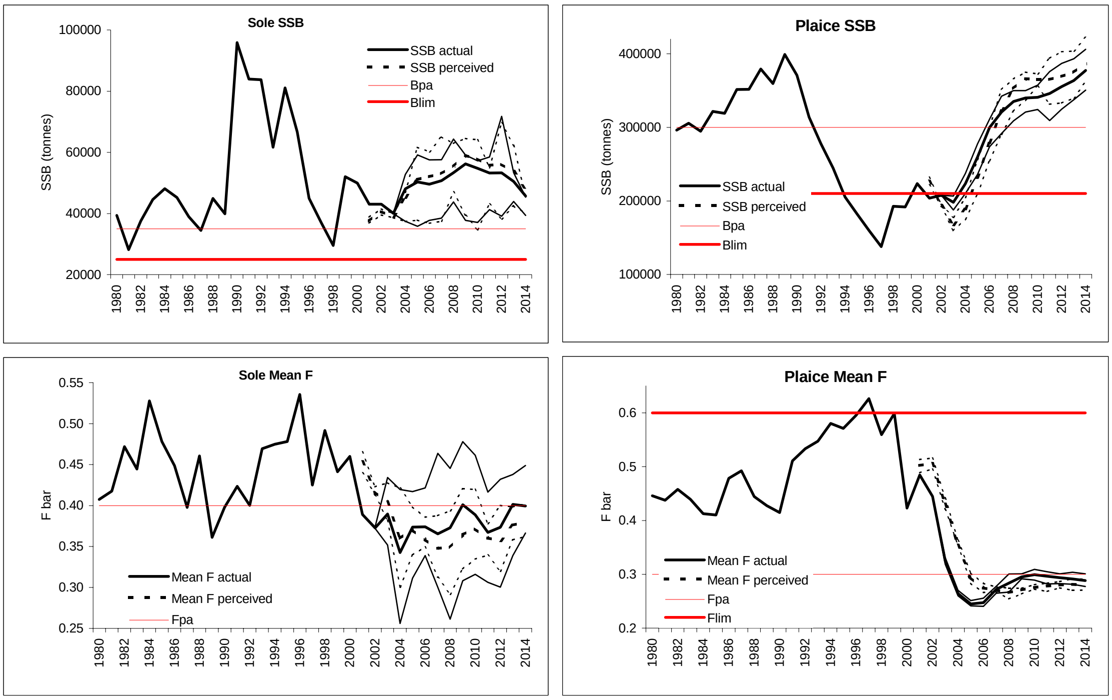


Figure 3.3.1. Scenario 2. Sole and plaice population characteristics from 1980 to the end of the projection period. Solid lines denote the "true" (actual) population, dotted lines denote the perceived population. In the projected part of the simulation the average of 10 Monte Carlo runs of the model 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. Shrinkage on fishing mortality (F) as in the current XSA assessments (0.5 for 5 years).

In this scenario the effort restriction is sometimes determined by the plaice assessment (Figure 3.3.2), 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 3.3.2). 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 3.3.3). 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.

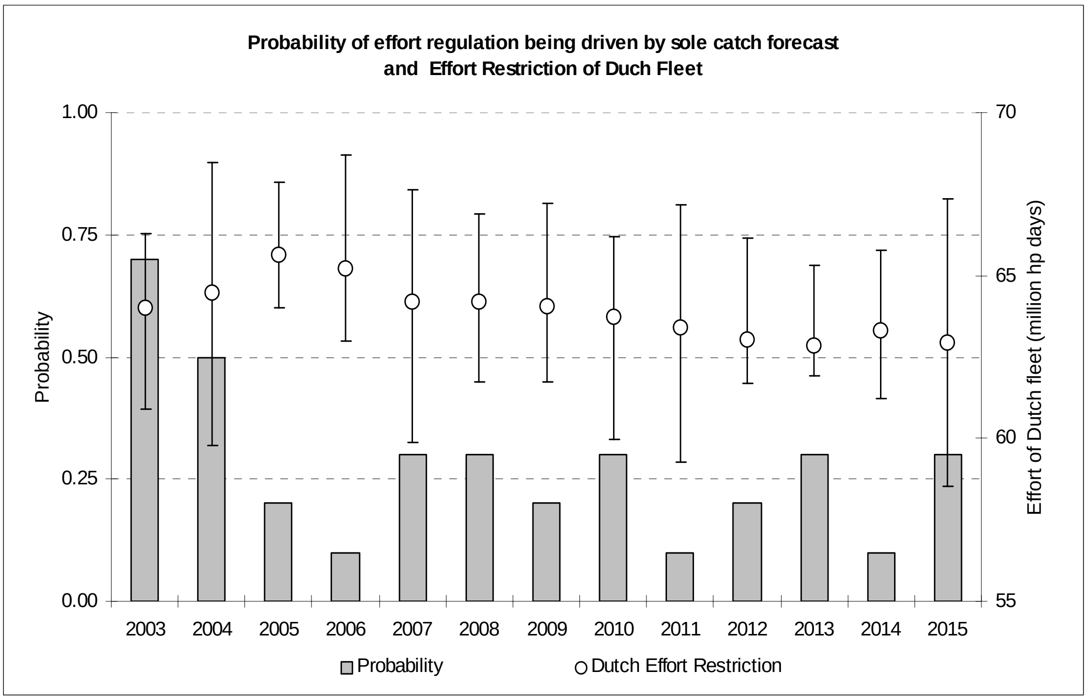
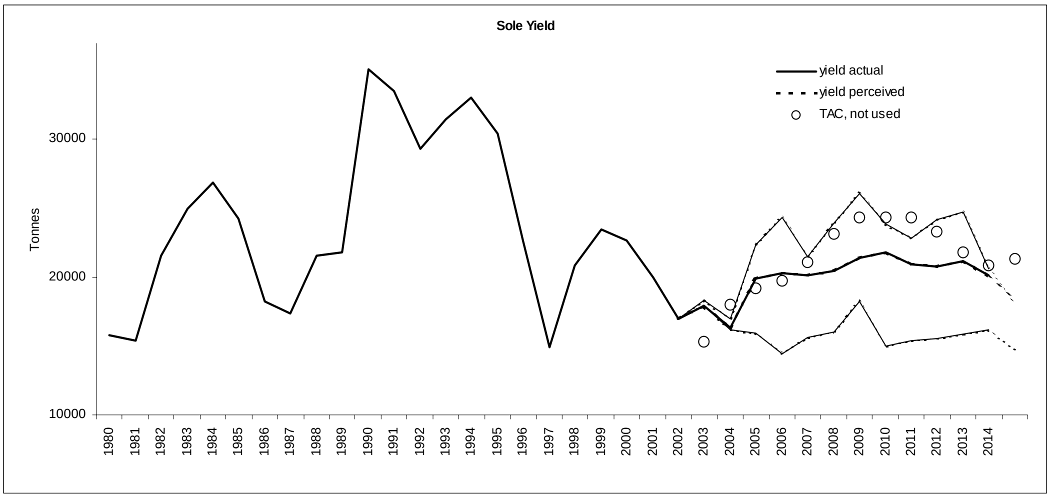


Figure 3.3.2. Scenario 2. The probability that the sole catch forecast will determine the effort restrictions (bars) and the allowable effort for the Dutch fleet (circles) in the projection part of the simulation. Error bars around the circles denote the 25% and 75% percentiles of the Monte Carlo runs.



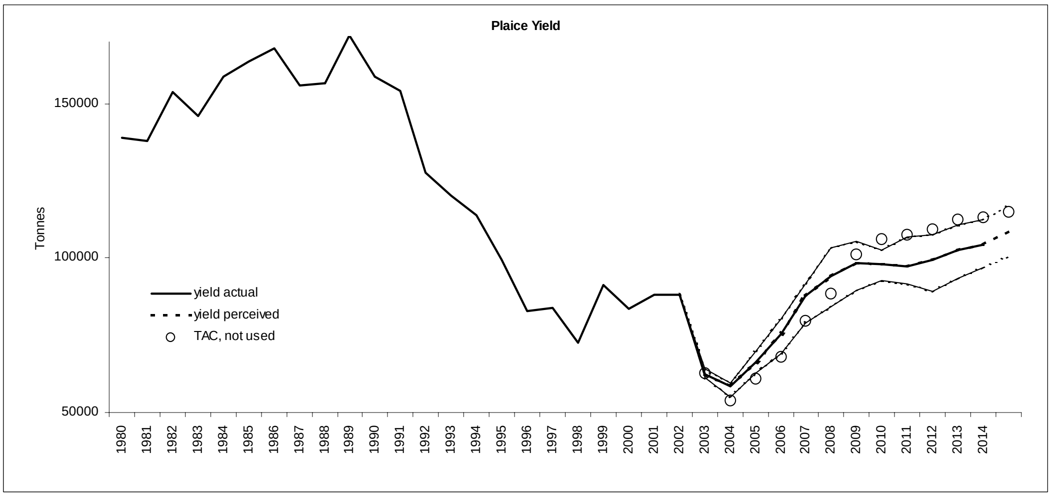


Figure 3.3.3. Scenario 2. The yield (catch) of sole and plaice from 1980 to the end of the projection period. Solid lines denote the "true" catch, dotted lines denote the perceived catch. In the projected part of the simulation the average of 10 Monte Carlo runs of the model is shown bounded by the central 50% range of the estimates (i.e. the 2 central quartiles). The mean TAC from the Monte Carlo runs is shown by the circles.

3.3.2 Economy

Figure 3.3.4 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 3.2.5 and 3.4.3). 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 3.2.5 and 3.4.3), this scenario generates net revenues that remain almost stable and only decrease at a very slow rate at the end of the time series.

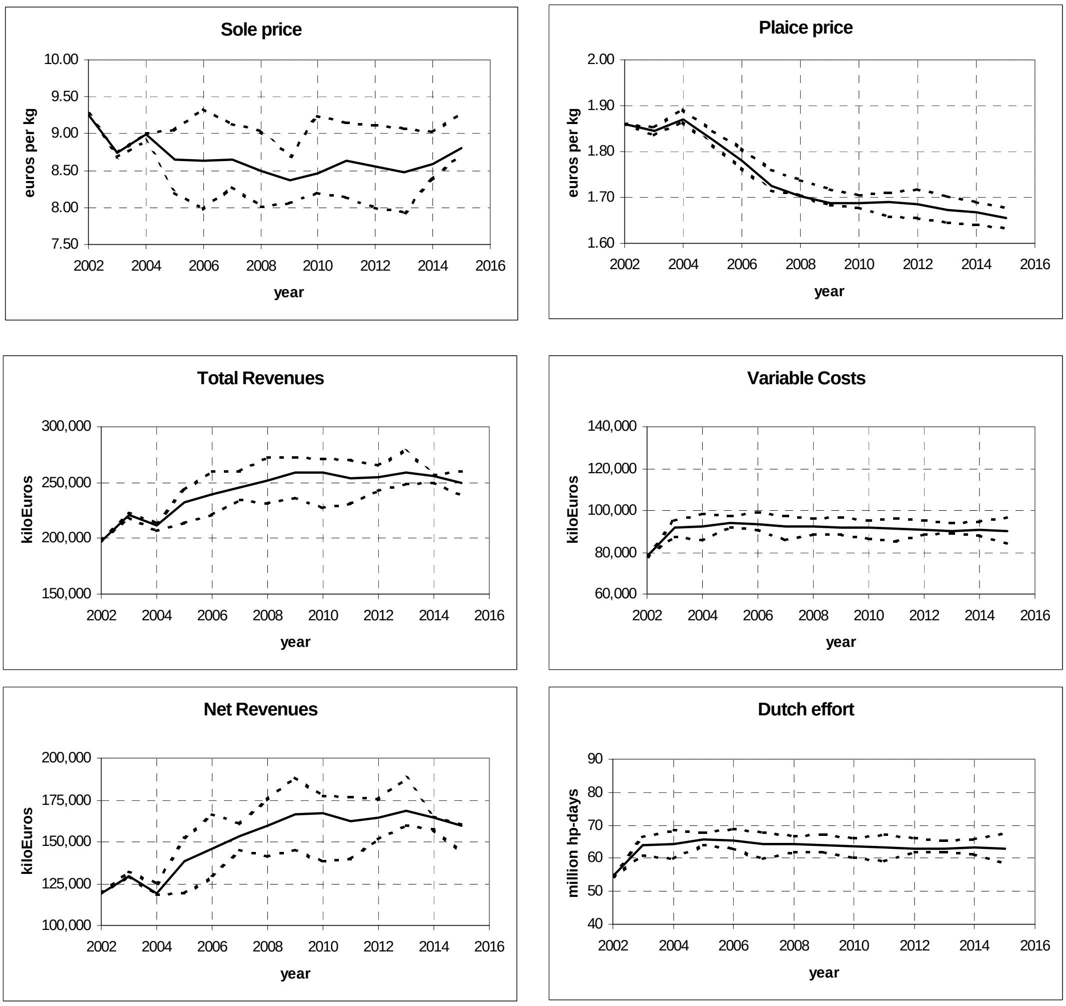


Figure 3.3.4. Scenario 2. Effort management; high shrinkage over 5 years. Sole price, plaice price, total revenues, variable costs, net revenues, and Dutch effort. Solid lines: mean; stippled lines: upper and lower quartiles.

3.4 Scenario 3 Multi-species management

In this scenario the advice is given in the form of one TAC for both species (MS-TAC), which is derived from the sum of the two catch forecasts (equivalent to the single species TACs). The "true" fishing effort needed to deplete the MS-TAC is calculated, and subsequently the sole and plaice catches taken with that effort are calculated. Absolute compliance with the management is assumed. All the catch is landed.

3.4.1 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 3.4.1). 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.

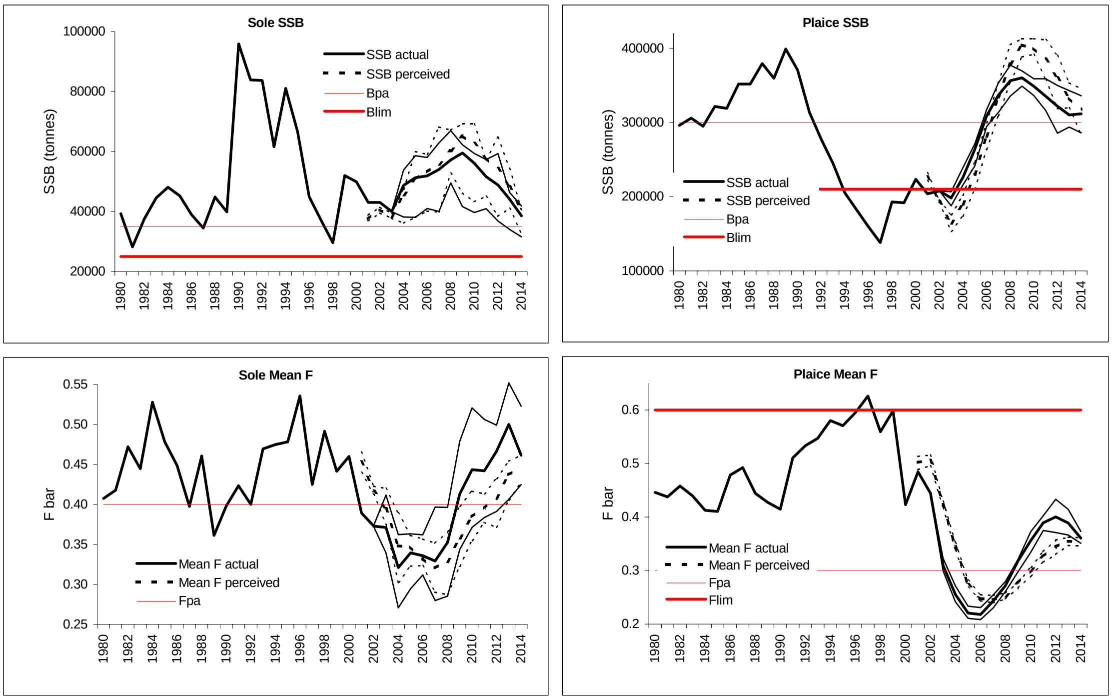


Figure 3.4.1. Scenario 3. Sole and plaice population characteristics from 1980 to the end of the projection period. Solid lines denote the "true" (actual) population, dotted lines denote the perceived population. In the projected part of the simulation the average of 10 Monte Carlo runs of the model 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. Shrinkage on fishing mortality (F) as in the current XSA assessments (0.5 for 5 years).

The total multi-species catch initially increases and slightly declines again after 2011 (Figure 3.4.2). 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.

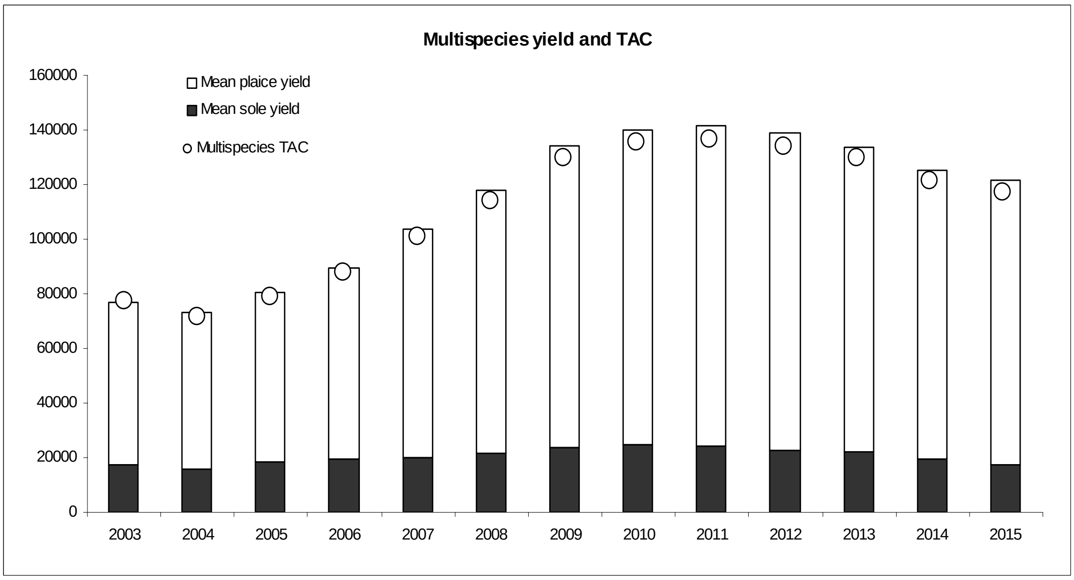


Figure 3.4.2. Scenario 3. The mean yield (in tonnes) of plaice and sole from 10 Monte Carlo runs of scenario 3 during the projected period of the simulation. The multi-species TAC is also overlaid. Shrinkage on fishing mortality (F) as in the current XSA assessments (0.5 for 5 years).

3.4.2 Economy

Figure 3.4.3 indicates that the sole prices 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).

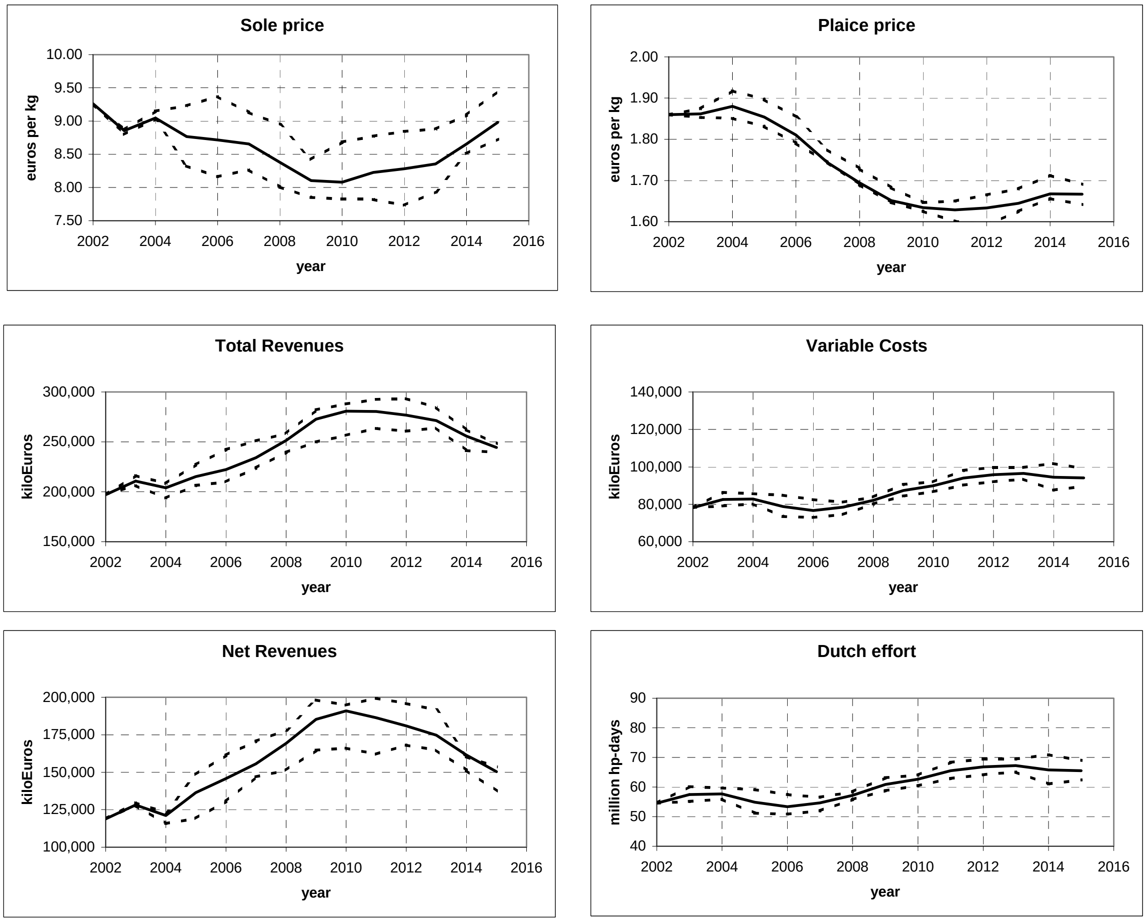


Figure 3.4.3. Scenario 3. Sole price, plaice price, total revenues, variable costs, net revenues, and Dutch effort. Solid lines: mean; stippled lines: upper and lower quartiles.

3.5. Comparative evaluation of the three scenarios.

Tables 3.5.1, 3.5.2, and 3.5.3 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 3.5.1). 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 3.5.1) 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 3.5.2). 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 3.5.3). 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 3.5.1. Biological evaluation criteria.

	criteria	scenario 1	scenario 2	scenario 3	units
		Single species TAC	Effort restriction	Multi-species TAC	
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 3.5.2. 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 3.5.3. 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. Then the effect of shrinkage will be discussed. 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 (discarding low priced grades in order to land more high-priced grades of a species) 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 in the OM are available in the MP. In reality this is of course not the case. Furthermore, it was assumed that the “true” catch in the OM is available in the MP, 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 2.

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 (recruitment and CPUE sampling).

4.2 Shrinkage

For many demersal stocks the use of shrinkage of F towards the recent mean is a common practice. Scenario 0 has shown that if F has a strong trend, the assumptions about the use of shrinkage are inappropriate. Shepherd (1999) commented that the use of shrinking F to the recent mean may cause conflict with strong signals in the surveys, and may cause a bias towards the mean, particularly if the catch data are inaccurate. To some extent this conclusion misses the point that even if the catch is well sampled and there are no strong signals in surveys, the use of shrinking F may introduce a bias towards the mean. In scenario 0, this bias formed a cyclical instability as the perception of the stock was always out of phase with the actual state of the stock.

Whether this instability matters in terms of management is another issue. After (or during) a period with a strong trend in F, the introduction of the bias will result in a period of "catch up" as the stock fluctuates between periods of being over-exploited and then under-exploited in relation to fixed reference points. Management by target reference points will be difficult and retrospective bias will be inherent in the assessment method. The degree to which advice will change between years, will vary by the rate of change in F from the mean. Stability in advice, perception of the state of the stock, and the allocation of quota will all be affected by this bias and it may undermine the advice itself (by causing large retrospective change). Stability will be difficult to achieve, and as strong declines are often associated with recovery plans or other conservative measures, assessing the impact or success of such plans would be made even more difficult if shrinkage of F to the mean was applied.

4.3 Comparison of the three scenarios

To begin with, 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, 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). As was explained in section 4.2, 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.

4.4 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 (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 (2001)).

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 in the MP. The model then calculates the catches that the fishery will take under that effort restriction in the OM. MTAC would calculate a weighted average of the two efforts and calculate catches that can be taken with that effort in the MP and these catches would then be taken in the OM. 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 are 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 (0.4 and 0.3 respectively), 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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Annex 1. Model coefficients

Scenario 1

E^0	Fishing effort (mln. hp-days) in baseline (year 2002)	53.569
L_s^0	Landings (tonnes) sole in baseline.	10611
L_p^0	Landings (tonnes) plaice in baseline	26977
P_s^0	Price of sole in base line (Euros per kg)	9.26
P_p^0	Price of plaice in base line (Euros per kg)	1.86
R_o^0	Gross Earnings other species (not sole and plaice) in base line (kEuros)	46385
SSB_i	Index of SSB of sole and plaice	Input from stock assessment
E	Estimation of fishing effort (mln. hp-days)	
C_i	Catches of sole and plaice	Output to biological sub-model
P_i	Estimation of sole and plaice	
R_o	Estimation of other gross earnings than from plaice and sole (kEuros)	
R_T	Estimation of total gross earnings (landings value) (kEuros)	
C_v	Estimation of effort related variable costs (kEuros)	
R_N	Estimation of net earnings (kEuros)	
α_0	coefficient	0.0009786
β_0	coefficient	1.177
α_p	coefficient	916.432
β_p	coefficient	0.8496
α_c	coefficient	-1.629
β_c	coefficient	1.4355
e_s	Price flexibility of sole	-0.3
e_p	Price flexibility of plaice	-0.2

Scenario 2

E^0	Fishing effort (mln. hp-days) in baseline	53.346
L_s^0	Fishermen go for maximum net earnings per unit quota value for plaice and sole. Ultimately, effort is limited by sole quota.	10611
L_p^0	Landings (tonnes) sole and plaice in baseline	26668
P_s^0	Price of sole in base line (Euros per kg)	9.26
P_p^0	Price of plaice in base line (Euros per kg)	1.86
R_o^0	Gross Earnings other species (not sole and plaice) in base line (kEuros)	46385
SSB_i	Index of SSB of sole and plaice	Input from stock assessment
E	Estimation of fishing effort (mln. hp-days)	
C_i	Estimation of catches of sole and plaice	Output to biological sub-model
P_i	Estimation of sole and plaice	
R_o	Estimation of other gross earnings than from plaice and sole (kEuros)	
R_T	Estimation of total gross earnings (landings value) (kEuros)	
C_v	Estimation of effort related variable costs (kEuros)	
R_N	Estimation of net earnings (kEuros)	
α_0^s	coefficient	0.00011698
β_0^s	Coefficient	1.4057
α_0^p	coefficient	0.00001882
β_0^p	Coefficient	1.4578
α_s	coefficient	628.637
β_s	coefficient	0.7105
α_p	coefficient	1747.43
β_p	coefficient	0.6853
α_c	coefficient	0.4715
β_c	coefficient	1.4021
e_s	Price flexibility of sole	-0.3
e_p	Price flexibility of plaice	-0.2

Scenario 3

E^0	Fishing effort (mln. hp-days) in baseline	54.520
L_p^0	Landings (tonnes) plaice in baseline	26690
L_S^0	Landings sole (tonnes) baseline	10917
P_s^0	Price of sole in base line (Euros per kg)	9.26
P_p^0	Price of plaice in base line (Euros per kg)	1.86
R_o^0	Gross Earnings other species (not sole and plaice) in base line (kEuros)	46385
SSB_i	Index of SSB of sole and plaice	Input from stock assessment
Q_{sp}^0	Quota (plaice and sole together) in baseline.	37564
Q_{sp}	Sum of quota sole and plaice	Input from stock assessment
E	Estimation of fishing effort (mln. hp-days)	
C_i	Catches of sole and plaice	Output to biological sub-model
P_i	Estimation of sole and plaice	
R_o	Estimation of other gross earnings than from plaice and sole (kEuros)	
R_T	Estimation of total gross earnings (landings value) (kEuros)	
C_v	Estimation of effort related variable costs (kEuros)	
R_N	Estimation of net earnings (kEuros)	
α_0	coefficient	0.00250207
β_0	Coefficient	0.9483
α_s	coefficient	504.894
β_s	coefficient	0.7687
α_p	coefficient	225.736
β_p	coefficient	1.1936
e_S	Price flexibility of sole	-0.3
e_p	Price flexibility of plaice	-0.2

Appendix 1. Analysis of Variance: summary of results

1. Analysis of variance of the whole fleet

Tests of Between-Subjects

Dependent Variable:

Sourc	Type I of	df	Mean	F	Sig
Corrected	524751 [a]	60	8702.3	9.95	.00
Interce	209706.	1	209706.	239.8	.00
PKGRO	235545.	5	47109.1	53.87	.00
VISTU	126310.	2	63155.0	72.22	.00
V	41056.9	1	3732.4	4.26	.00
VISTUIG *	106866.	6	17811.0	20.36	.00
VISTUIG *	88309.4	2	4014.0	4.59	.00
PKGROEP *	17023.8	6	2837.3	3.24	.00
SCHI	463240	55	8407.2	9.61	.00
Erro	409483	468	874.4		
Tot	955206	528			
Corrected	934235	528			

a. R Squared = .562 (Adjusted R Squared

2. Analysis of variance for hp-groups

Tests of Between-Subjects Effects

Dependent Variable: Netrespkdag

PKGROEP	Source	Type I Sum of Squares	df	Mean Square	F	Sig.
>2000pk	Corrected Model	607.188[a]	68	8.929	30.274	.000
	Intercept	944.379	1	944.379	3201.857	.000
	VISTUIG	27.691	1	27.691	93.885	.000
	V9	210.317	11	19.120	64.824	.000
	VISTUIG * V9	.186	2	9.309E-02	.316	.729
	PKDAG_T	3.001	1	3.001	10.176	.002
	SCHIP	365.993	53	6.906	23.413	.000
	Error	166.645	565	.295		
	Total	1718.213	634			
	Corrected Total	773.834	633			
0-260pk	Corrected Model	5061141.5[b]	263	19243.884	5.098	.000
	Intercept	414947.950	1	414947.950	109.934	.000
	VISTUIG	233166.043	2	116583.021	30.887	.000
	V9	124604.387	11	11327.672	3.001	.001
	VISTUIG * V9	105830.578	22	4810.481	1.274	.178
	PKDAG_T	14199.940	1	14199.940	3.762	.053
	SCHIP	4583340.5	227	20190.927	5.349	.000
	Error	4000976.7	1060	3774.506		
	Total	9477066.2	1324			
	Corrected Total	9062118.2	1323			
1501-2000pk	Corrected Model	738.795[c]	98	7.539	27.928	.000
	Intercept	1600.308	1	1600.308	5928.560	.000
	VISTUIG	50.058	1	50.058	185.445	.000
	V9	369.071	11	33.552	124.298	.000
	VISTUIG * V9	10.119	5	2.024	7.497	.000
	PKDAG_T	23.296	1	23.296	86.302	.000
	SCHIP	286.251	80	3.578	13.256	.000
	Error	224.583	832	.270		
	Total	2563.686	931			
	Corrected Total	963.378	930			
261-300pk	Corrected Model	21890.617[d]	203	107.836	10.254	.000
	Intercept	27472.774	1	27472.774	2612.356	.000
	VISTUIG	1279.602	2	639.801	60.838	.000
	V9	4493.482	11	408.498	38.844	.000
	VISTUIG * V9	2830.191	22	128.645	12.233	.000
	PKDAG_T	546.835	1	546.835	51.998	.000
	SCHIP	12740.507	167	76.290	7.254	.000
	Error	19749.935	1878	10.516		
	Total	69113.326	2082			
	Corrected Total	41640.552	2081			
301-800pk	Corrected Model	574.644[e]	32	17.958	4.957	.000
	Intercept	145.440	1	145.440	40.150	.000
	VISTUIG	16.036	1	16.036	4.427	.037
	V9	170.649	11	15.514	4.283	.000
	VISTUIG * V9	37.386	7	5.341	1.474	.181
	PKDAG_T	27.998	1	27.998	7.729	.006
	SCHIP	322.575	12	26.881	7.421	.000
	Error	492.649	136	3.622		
	Total	1212.733	169			
	Corrected Total	1067.293	168			
801-1500pk	Corrected Model	154.004[f]	35	4.400	5.228	.000
	Intercept	141.502	1	141.502	168.114	.000
	VISTUIG	50.556	1	50.556	60.064	.000
	V9	27.557	11	2.505	2.976	.002
	VISTUIG * V9	22.274	11	2.025	2.406	.010
	PKDAG_T	.209	1	.209	.248	.619
	SCHIP	53.407	11	4.855	5.768	.000
	Error	93.430	111	.842		
	Total	388.936	147			
	Corrected Total	247.433	146			

a. R Squared = .785 (Adjusted R Squared = .759)

b. R Squared = .558 (Adjusted R Squared = .449)

c. R Squared = .767 (Adjusted R Squared = .739)

d. R Squared = .526 (Adjusted R Squared = .474)

e. R Squared = .538 (Adjusted R Squared = .430)

f. R Squared = .622 (Adjusted R Squared = .503)

Appendix 2. 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.
    - o 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 (2004) for 1995-2002.
    - o 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.
    - o 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.
    - o 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.
    - o 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.