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An evaluation of MTAC – a program for the calculation of catch forecasts taking the mixed nature of the fisheries into account

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Summary

The International Council for the Exploration of the Sea (ICES) has traditionally given fishery management advice on a stock-by-stock basis, usually in the form of a catch forecast by stock. This approach is potentially problematic since it disregards technical interactions, i.e. cases where more than one species is caught by the same gear in the same area, and different fleets catch differing proportions of the various species. Ignoring this mixed-species aspect of the fishery may lead to a situation where, for instance, the quota for one species is exhausted early in the season, but boats continue fishing and catching that species because quota are not yet exhausted for other species in the fishery. The MTAC program has been developed to generate stock-based advice that accounts for such technical interactions.

The European Commission aims to use a mixed species based approach for their TAC proposals for, *e.g.*, the demersal stocks of the North Sea. These stocks are very important for the Dutch beam trawl fishery. Therefore, it is a concern to LNV that the working and the merits and limitations of the MTAC program are understood. It was decided that an evaluation of MTAC is undertaken. This report presents this evaluation.

The MTAC program calculates Mixed Species catch forecasts (MS-TACs) for each individual species fished in a given area, taking into account the mixed nature of the fisheries, under the objective to approach set targets (such as, *e.g.*, single species advice) as closely as possible. The resulting MS-TACs can be seen as a compromise that aims to resolve the conflict that arises when fleets have depleted their quota for some species but not for others while these species are unavoidably caught together. MTAC can give fleet based advice in the form of fleet based effort or catch forecasts.

The MTAC program needs some inputs that reflect political choices.

- A political choice (called the **p-option**) has to be made whether to reduce effort of all fleets (1) equally, or (2) proportional to the species catch within the fleet's total catch, or (3) proportional to the fleet's catch of a species as a proportion of the total species catch.
- A political choice has to be made on **decision weights** for each species, which determine relative priority of each species for how closely the target has to be approached in the compromise.
- A political choice (called the **q-option**) has to be made on whether to modify the decision weights according to the fleets' species compositions.

In all three cases, results vary widely depending on the choices made.

A thorough check of the MTAC program showed that the program correctly does what it is described to do. Scenario runs illustrate the consequences of the inputs such as the set targets, the chosen p- and q-options, and the chosen decision weights. Also these consequences can be logically understood. This illustration should help the MTAC users to make their choices *a priori*. The outcome of MTAC is sensitive to uncertainty with respect to stock status, *e.g*. population size at the start of the TAC year. Uncertainty in one stock may affect results for another stock if strong technical interactions between the two exist.

The evaluation of the MTAC program indicates certain drawbacks to its use. The resulting MS-TACs do not necessarily conform to the precautionary approach. In other words, MTAC may generate forecasts such that SSB will fall below B_{pa} or F_{pa} will be exceeded. An alternative program, called SMP[1], can guarantee outcomes such that set limit points are not exceeded or undershot; but this program has not been tested nor evaluated. The use of MTAC for fleet based advice confronts the users with the political consequences of imposing heavy restrictions on some fleets and more lenient restrictions on others. This issue relates to the fact that the use of MTAC is not consistent with the concept of relative stability.

[1] Short-term Multi-fleet Prediction

Also its use for fleet based advice appears unacceptable when, owing to discarding and/or underreporting, catch data are incomplete for certain fleets, because the advice will be biased and those fleets would suffer less from restrictions than fleets that report all catches. In response to the above points, MTAC experts have claimed that the program has not been designed for fleet based advice, but for aggregated TAC advice. However, this contradicts the logical design of the program, and ignoring the fleet based output is illogical. Moreover, using it only for calculating aggregated MS-TACs does not resolve the conflict the program was meant to resolve. The conclusion is that MTAC is a tool for calculating fleet based effort or catch forecasts.

It can be concluded that MTAC is a transparent model that might be a fine tool for calculating fleet based effort or catch forecasts, as long as catch data are complete and fleets keep fishing the same array of species in the same proportions. However, effective use depends on management being prepared to alleviate the present restrictions imposed by the precautionary approach and to ignore political problems associated with differentially penalising fleets.

Samenvatting

Traditioneel geeft ICES (International Council for the Exploration of the Sea) visserijbeheersadviezen op basis van individuele visbestanden, meestal in de vorm van vangstvoorspellingen per bestand. Deze benadering is mogelijk problematisch, omdat ze technische interacties negeert. Technische interacties bestaan wanneer meerdere soorten gevangen worden door een vloot binnen hetzelfde gebied, en verschillende vloten verschillende vangstsamenstellingen van die soorten hebben. Het negeren van die technische interacties kan tot gevolg hebben dat, bijvoorbeeld, het quotum voor één soort al vroeg in het jaar uitgeput is, maar dat schepen doorgaan met vissen omdat het quotum voor een andere soort nog niet uitgeput is, en de eerste soort blijven vangen als onvermijdelijke bijvangst. Het MTAC programma is ontwikkeld om advies per visbestand te genereren dat rekening houdt met die technische interacties.

De Europese Commissie is van plan om deze gemengde visserijbenadering te gebruiken voor de TAC voorstellen voor, bijvoorbeeld, de demersale visbestanden van de Noordzee. Deze bestanden zijn erg belangrijk voor de Nederlandse boomkorvisserij. Het is daarom van belang voor LNV om de werking van het MTAC programma en haar merites en tekortkomingen te begrijpen. Daarom is besloten het MTAC programma te evalueren. Dit rapport doet verslag van deze evaluatie.

Het MTAC programma berekent "Mixed Species" vangstvoorspellingen (MS-TACs) voor elke soort die in een bepaald gebied bevist wordt, rekening houdend met de gemengde aard van de visserijen, met als doel zo dicht mogelijk gekozen "targets" te benaderen. Een "target" kan het traditionele advies zijn. De resulterende MS-TACs kunnen gezien worden als een compromis dat de bedoeling heeft het conflict teniet te doen dat ontstaat als vloten hun quota voor sommige soorten uitgeput hebben terwijl ze nog door blijven vissen op soorten waarvoor de quota nog niet uitgeput zijn, terwijl deze soorten onvermijdelijk samen gevangen worden. MTAC kan advies op vlootbasis genereren in de vorm van vloot-specifiek effort advies of vloot-specifieke vangstvoorspellingen.

Het MTAC programma vraagt om enkele inputs die politieke keuzes vertegenwoordigen.

- Een politieke keuze (die de **p-optie** genoemd wordt) moet gemaakt worden of de effort van de vloten gereduceerd moet worden ofwel (1) voor alle vloten gelijk, ofwel (2) in verhouding tot de vangst van een soort door die vloot als fractie van de totale vangst door die vloot, ofwel (3) in verhouding tot de vangst van een soort door die vloot als fractie van de internationale vangst van die soort.
- Een politieke keuze moet gemaakt worden voor "**decision weights**" (prioriteiten) die aan de afzonderlijke soorten toegekend worden. Deze "decision weights" zijn een maat voor hoe

belangrijk het voor die soort gevonden wordt dat de "target" voor die soort zo dicht mogelijk benaderd wordt in het uiteindelijke compromis.
- Een politieke keuze (die de **q-optie** genoemd wordt) moet gemaakt worden over het wel of niet modificeren van de "decision weights" op basis van de soortensamenstellingen van de vangsten van de vloten.

In alle drie gevallen verschillen de uitkomsten van het model sterk al naar gelang de gemaakte keuzes.

Het MTAC programma is gecontroleerd en getest, en er kan geconcludeerd worden dat MTAC correct de berekeningen uitvoert die in de beschrijving van het programma gesteld worden. Er zijn scenario's gedraaid die illustreren wat de consequenties zijn van de inputs, zoals de gestelde "targets", de gekozen p- en q-opties, en de gekozen "decision weights". Deze consequenties zijn tevens logisch verklaarbaar. Deze illustratie zou MTAC-gebruikers moeten kunnen helpen om hun keuzes *a priori* te maken.

De uitkomsten van MTAC zijn echter gevoelig voor onzekerheden in de toestand van de visbestanden, bijvoorbeeld de populatiegrootte aan het begin van het TAC-jaar. Onzekerheid in het ene visbestand kan de resultaten beïnvloeden voor een ander visbestand als er sterke technische interacties tussen beide soorten bestaan.

De evaluatie van het MTAC programma toont aan dat er enkele bezwaren kleven aan het gebruik ervan. De resulterende MS-TACs voldoen niet noodzakelijkerwijs aan de voorzorgsbenadering. Met andere woorden, MTAC kan vangstvoorspellingen genereren waarbij B_{pa} onderschreden zal worden of F_{pa} overschreden zal worden. Een alternatief programma, SMP[1] genaamd, kan uitkomsten genereren waarbij ingestelde limietwaarden niet onder- of overschreden worden, maar dat programma is nog niet getest noch geëvalueerd. Het gebruik van MTAC voor vloot-gebaseerd advies confonteert de gebruiker met de politieke consequenties van het opleggen van zware beperkingen aan sommige vloten en minder zware beperkingen aan andere vloten. Hieraan gerelateerd is het feit dat het gebruik van MTAC niet consistent is met het concept van de relatieve stabiliteit. Ook lijkt het gebruik van MTAC voor vloot-gebaseerd advies onacceptabel wanneer vanwege discarding en/of underrapportage de vangstgegevens voor bepaalde vloten onvolledig zijn, omdat het advies dan een "bias" zal vertonen en die vloten minder getroffen zounden worden door beperkingen dan vloten die alle vangsten rapporteren. Als weerwoord op bovengenoemde punten hebben MTAC-experts geclaimd dat MTAC niet ontworpen is voor vloot-gebaseerd advies, maar voor geaggregeerd TAC-advies. Dit is echter in tegenspraak met de logica van het programma omdat de berekeningen gebaseerd zijn op vloot-specifieke vangstvoorspellingen. Het is onlogisch de vloot-gebaseerde output te negeren. Bovendien lost het gebruik van slechts de geaggregeerde MS-TACs niet het conflict op waarvan het de bedoeling was dat MTAC dat zou doen. Geconcludeerd moet worden dat MTAC een gereedschap is voor het berekenen van vloot-specifieke effort of vloot-specifieke vangstvoorspellingen.

De conclusie is dat MTAC een transparant model is dat een goed gereedschap zou kunnen zijn voor het berekenen van vloot-specifieke effort of vloot-specifieke vangstvoorspellingen als de invoergegevens compleet zouden zijn, en de vloten dezelfde soorten in dezelfde verhoudingen zouden blijven bevissen. De effectiviteit van het gebruik van MTAC hangt echter wel af van de bereidheid van het beheer om de beperkingen opgelegd door de voorzorgsbenadering los te laten, en de politieke problemen verbonden aan het verschillend inperken van vloten te negeren.

[1] Short-term Multi-fleet Prediction

1. Introduction

1.1 Why develop software for the calculation of Mixed Species TACs?

ICES has traditionally given fishery management advice on a stock by stock basis. Advice for each stock is usually given in the form of a catch forecast for next year, which can be interpreted as an advice for next year's Total Allowable Catch (TAC) for that stock. The TAC is the total catch allowed to be taken from that stock by all fleets combined that are fishing that stock. This approach has long been recognised as being potentially problematic since it disregards technical interactions, i.e. cases where more than one species is caught in the same area, and different fleets catch differing proportions of the various species. Ignoring this mixed-species aspect of the fishery may lead to a situation where, for instance, the quota for one species is exhausted early in the season, while boats continue fishing and catching that species because quota are not yet exhausted for other species in the fishery. As a result, the quota regulations would not provide an effective constraint of fishing mortality on species for which the quota are first exhausted. Alternatively, the managers might wish to close the fishery once the quota for one species is reached, but that could result in loss of fishing opportunities on other stocks that might be in a better state.

To account for mixed-species fisheries, it would be desirable to develop approaches of giving advice on a fleet or fishery basis. Such approaches would take time to develop and to implement, but an intermediate step would be an approach that takes the current, stock-based, advice as a starting point, and then uses additional fleet information to generate advice that accounts for the technical interactions. The MTAC program has been developed for such an intermediate approach (Vinther *et al.* 2003). A short history of the MTAC model is presented in section 1.3.

1.2 Why evaluate MTAC in the context of the research program “bestek 6c”?

By the end of 2002 it became apparent that the European Commission aims to use a mixed species based approach for adjusting their TAC proposals as soon as possible. It appeared that the available data on the demersal stocks of the North Sea were most close to being suitable for such an approach. These stocks are very important for the Dutch beam trawl fishery. The Dutch Ministry of Agriculture, Nature and Food Quality (LNV) as well as the RIVO-scientists were concerned that methodological assumptions underlying the mixed species approach were poorly understood and that merits and limitations of the MTAC software were still in need of testing. Sensitivity analyses of the first version of the MTAC model had shown that the outcome could not be fully understood and that there were problems with the numerical instability of the model Pastoors and Kraak 2002; ICES 2003a).

The LNV policy questions that were the basis of the research program "Improving Assessment Models" (“bestek 6c, verbetering rekenmodel”) which started in 2002, contained a focus on the mismatch of single species quota for species that are unavoidably caught together in mixed fisheries. Given the close linkage between those questions and the goals of the MTAC model, it was decided to re-allocate some resources within that research program for the evaluation and further development of MTAC. Due to this re-allocation, RIVO-scientists have been able to participate in the further development of MTAC and the analysis of its merits and limitations.

In this report I present the outcome of that study. In section 2 a detailed description is given of what the MTAC model exactly does. In section 3 the behaviour of the model is illustrated. The effects of the choices that can be made by the MTAC user will be shown by presenting the outcomes of runs with different settings on semi-fictive data sets. In section 4 the merits and limitations of MTAC are discussed. Finally, in section 5 the conclusions of the study are presented.

1.3 A short history of the development of MTAC – the role of RIVO scientists

The European Commission (EC) requested that a study group of the STECF[1] subgroup SGRST[2] would meet in October 2002, to develop a model and to collect the necessary data, for the calculation of catch forecasts that take into account the mixed nature of the fisheries and that are based on the catch advice by ACFM (STECF 2002). The aim was to develop a model that would generate mutually compatible Mixed Species TACs (MS-TACs) that would allow approximately proportional exhaustion of the quota for the various species by individual fleets, instead of TACs that lead to continued fishing after the quota for the first species has been exhausted and thus to unavoidable by-catch of that species. The Netherlands Institute for Fisheries Research (RIVO[3]) sent Sarah Kraak to participate in that meeting.

Prior to the meeting of the 2002 STECF/SGRST study group, the Danish Institute for Fisheries Research (DIFRES) had started on the development of the computer program MTAC, according to the technical specifications provided by the EC. The MTAC program was further developed at the meeting, where it was used to run a number of scenarios requested by the EC on data for the North Sea. Because these data were not complete (*e.g.* data from the *Nephrops* fisheries and data on discards were lacking and age-disaggregated data were not available at the fishery level), the group stated that the results should not be used for advice. On the last day of that meeting MTAC was still being modified.

In November and December 2002 Martin Pastoors and Sarah Kraak carried out sensitivity analyses with MTAC and demonstrated that the outcomes of MTAC could not be fully understood (Pastoors and Kraak 2002). Furthermore, they showed that the MTAC approach is not consistent with the principle of relative stability (Kraak and Pastoors 2002).

In February 2003 the ICES Study Group SGDFF[4] met for the first time (ICES 2003a) with the aim of further developing the Mixed Fisheries approach within ICES. Martin Pastoors and Sarah Kraak contributed the above mentioned discussion documents (WD2 and WD3 in ICES 2003a). Sensitivity analyses carried out during that meeting demonstrated again that the working of MTAC was not entirely understood and numerically unstable. A few other existing approaches to mixed fisheries forecasts were also evaluated in that meeting. One of them was a new model, which was implemented in the program SMP[5] (WD4 in ICES 2003a). Besides exploring and investigating software for the calculation of mixed fishery based catch forecasts, the Study Group formulated recommendations concerning fleet definitions and a data format for the collection of the required international disaggregated data.

At the Assessment Working Group WGNSSK[6] in September 2003 (ICES 2003b) a revised version of MTAC was presented (Vinther *et al.* 2003). Sensitivity analyses carried out during the meeting demonstrated that the revised version no longer suffered from numerical instability. In other words, all outcomes could be explained by the input data and the optional settings of the model (this is extensively illustrated in section 3). A revised version of the alternative software SMP was also presented (SMP will be briefly discussed in section 4).

In September/October 2003 I meticulously screened the program-code for errors. It was concluded that the revised program does not contain any errors and that it does the calculations that were initially specified by the European Commission for the STECF/SGRST

[1] Scientific, Technical, and Economic Committee for Fisheries
[2] Subgroup on Resource Status
[3] RIVO is part of the Animal Sciences Group of Wageningen University and Research Centre
[4] Study Group on the Development of Fishery-based Forecasts
[5] Short-term Multi-fleet Prediction
[6] Working Group on the assessment of demersal stocks in the North Sea and Skagerrak

meeting in 2002 (section 3 in STECF 2002) and that are described by Vinther *et al.* 2003 after the revision of the program.

The ICES Advisory Committee on Fisheries Management (ACFM) evaluated the MTAC approach in October 2003. ACFM concluded that the approach is not suitable for advice as long as the data sets used are so incomplete (ICES 2003c). They argued that, *e.g.*, the lack of discard data could lead to advice that would 'favour' fleets that would underreport or discard, e.g., cod compared to fleets catching fewer cod but reporting more.

The STECF/SGRST study group met again in October 2003 (STECF 2003a). The group responded to the arguments of ACFM (above) by stating that MTAC should indeed not be used for fleet based advice (and that it had not been intended to do so), but only for aggregated stock based advice while taking the mixed nature of the fisheries into account. The arguments of ACFM and STECF/SGRST on this issue are further discussed in section 4. MTAC was run on data for the North Sea and on data for the Irish Sea according to scenarios requested by the EC.
Sensitivity analyses were were carried out with the North Sea data to demonstrate to what extent the outcomes are sensitive to the uncertainty of the input data and to the choices of the optional settings by the user. Similar analyses will be presented in section 3.

In January 2004 the ICES Study Group SGDFF met again. This group evaluated the use of MTAC. The group concluded that there are some practical objections against the use of MTAC. The first objection was that MTAC generates outcomes that are not consistent with relative stability; the group thought that it was therefore unlikely that MTAC-generated advice would be applied. The second objection was that MTAC is based on the assumption that fleets will not adjust their fishing strategy in response to management measures; this assumption is unrealistic. The group therefore decided that MTAC should either not be used or should be developed further to accomodate the objections raised above.

2. Description of the MTAC model

A technical description of MTAC is given by Vinther *et al.* (2003). Although we leave out many technical details here, the reader must bear in mind that the program is quite complex and that, therefore, even a non-technical account will not be easy-reading.

The Software MTAC is written in the statistical package “R”. “R” is freeware available from the internet (http://cran.r-project.org). The R-package must be installed to run MTAC.

MTAC uses the Single Species advice for the species (stocks) as a basis to generate Mixed-Species forecasts. For each species either a Single Species TAC (SS-TAC) or a F-multiplier (the factor with which *status quo* fishing mortality has to be multiplied) must be used as input into MTAC. Instead of the ACFM advice the MTAC-user can specify his/her own target catch or target F-multiplier for the TAC year.

The final WG[1] assessment of each stock is used to derive the *status quo* fishing mortality at age. The stock numbers at age at the start of the TAC year must also be available. To derive these stock numbers at age an assumption for the current year[2] is necessary, which may be either a *status quo* F assumption or a TAC constraint. In addition, historical catch data for each

[1] Working Group, for example the WGNSSK

[2] The current or intermediate year in a catch forecast refers to the year (y) in which the forecast is carried out. If data is available up year y-1, then the assessment is carried out in year y and the catch forecast is given for year y+1. In year y it is not yet known what the catch in that year will be, so the catch has to be assumed in order to calculate the population size at the beginning of the forecast year (y+1).

of the species by each of the fleets considered must be available. These can be catch composition data of the previous year, or an average of several previous years (usually three years). If for a species fleet-specific age-disaggregated catch data are not available for a given fleet, MTAC will estimate these from the fleet catches and the fleet-aggregated catch at age data for that species.

MTAC then calculates for each of the species a preliminary catch forecast per fleet, based on the fleet-specific partial *status quo* F multiplied with **species specific fleet factors**. The partial *status quo* Fs are derived from the historical catch data. The species specific fleet factors are calculated by an iterative process, such that the sum of the forecasted fleet catches approaches the SS-TAC as closely as possible. In principle this objective can be reached by an infinite number of combinations of species specific fleet factors; therefore a political choice has to be made by the MTAC-user about how these fleet factors should relate to the fleets' historical catches. Several options for this choice are available in the MTAC program.
The MTAC-user has to set one of the so-called "**p-options**", according to rationales explained below.

- p=0. When this option is chosen, each of the fleets will get the same species specific fleet factor. In this case, each of the fleets will have to reduce (or increase) their partial *status quo* F to the same extent, regardless of the historical catch of the considered species by that fleet.
- p=1. When this option is chosen, a fleet's species specific fleet factor becomes lower if the historic proportion of the species considered in the total catch (in weight) of that particular fleet was higher. In this case, fleets targeting the species will be more affected by required reductions in fishing mortality than fleets that catch the species as an incidental by-catch. This option does not take into account whether the fleets take large or small proportions of the total international catch of a species.
- p=2. When this option is chosen, a fleet's species specific fleet factor becomes lower if the fleet historically has taken a larger proportion of the total international catch of the considered species in weight. In this case, fleets that take a large portion of the international catch of that species will be more affected by required reductions in fishing mortality than fleets that catch only small numbers of that species. This option does not take into account whether the fleet targets that species or takes it as an incidental by-catch.
- p=3. When this option is chosen, the MTAC-user can specify manually, through an extra input file, the species specific fleet factors relative to each other. In this case, the MTAC-user can decide how much each fleet will be affected by required reductions in fishing mortality.

In case fishing mortality on a species is allowed to increase, all fleets profit equally.

The difference between the options p=1 and p=2 is critical, because the implications can be quite different, as is shown in section 3.1.

The species specific fleet factors can be interpreted as multipliers with which the fleets' partial *status quo* Fs have to be multiplied. In other words, they can be interpreted as effort multipliers with which the fleets have to multiply their *status quo* effort. (For example, a factor of 0.5 implies a reduction of effort by half.) However, the species specific fleet factors may conflict with each other among different species within a fleet. It could be the case, for example, that a fleet would have to reduce her effort by 80% for one species and by 20% for another species. This is the conflict that MTAC is designed to resolve.

Therefore, MTAC finally calculates one overall **fleet factor** for each fleet, which is a weighted average of the species specific fleet factors for that fleet. The weighting is done by **decision weights** specified by the MTAC-user (as a political choice), which reflect how important it is to closely approach the SS-TAC of that species in the final compromise. The MTAC-user can choose values for the decision weights by any rationale desired. For example, decision weights can be chosen to reflect how far the current SSB of the stock is removed from B_{pa} (*e.g.*

decision weights equal the ratio B_{pa}/SSB). In that case, a species would get more weight in the final compromise if the current SSB is further below B_{pa}.

Moreover, the MTAC-user can choose whether the weighting considers, in addition to the above mentioned decision weight, the relative contribution of a species in a fleet's total catch in weight (this being a political choice). To this end, the MTAC-user has to set one of the so-called "**q-options**", explained below.

- q=0. When this option is chosen, the relative contribution in the catch is not considered. Only the specified decision weights are used in the weighting procedure.
- q=1. When this option is chosen, the decision weights are multiplied by the proportion of the catch of a species within the fleet's catch in weight. These products are then used as weighting factors in averaging the species specific fleet factors to arrive at one fleet factor for that fleet.

In this case, a species specific fleet factor weighs more heavily in the final average fleet factor if the fleet targets that species than if the fleet takes that species as an incidental by-catch.

Finally, MTAC calculates for each of the species a catch forecast per fleet, using the weighted fleet factors. For each species, these catch forecasts are then summed over the fleets, to arrive at an aggregated Mixed Species TAC (MS-TAC) and an implied F-multiplier (MS-F-mult) for each species.

The output of MTAC displays for each species the aggregated MS-TAC, the MS-F-multiplier and the ratio between the MS-TAC and the SS-TAC (MS-TAC/SS-TAC). If the MS-TAC/SS-TAC ratio is larger than 1, then the MS-TAC is larger than the SS-TAC.

The weighted fleet factors are usually not displayed as output (the reasons for which will be discussed in section 4), but they can be. These fleet factors represent fleet specific effort changes, which give rise to the aggregated forecasted catches (the MS-TACs). In principle, MTAC can give as additional output catch forecasts per fleet (tentatively called "fleet quota"), based on these fleet factors.

It should be noted that making the various choices about the trade-offs to arrive at compromise MS-TACs is not a scientific issue. Rather, there is a strong political element in here that requires managers to decide to what extent they want fishing opportunities for less heavily exploited species to be affected by the need to take severe conservation measures for others. Although scientists can explore the consequences of the different options, the ultimate decision must be taken by the responsible authorities. Therefore, we call these options here explicitly 'political choices'.

Summarizing:

- Input data necessary for MTAC:
  - Population numbers-at-age at the start of the TAC year by species (derived from the WG assessment based on a current year assumption);
  - *Status quo* F-at-age by species (derived from the WG assessment);
  - M-at-age by species (as in the WG assessment);
  - Historical weights-at-age in the catch by species, and, if available, by fleet;
  - Historical catch-at-age in numbers by species, and, if available, by fleet;
  - For fleets for which age-disaggregated data are not available, historical catch in weight by species and fleet.
- Input of political choices:
  - Setting of the p-option, specifying how the species specific fleet factors should relate to each other (*e.g.* fleets are affected in proportion to their catch of the species relative to the fleet's total catch or relative to the international species' catch);

- Choosing the decision weights for the species, specifying the relative importance of approaching the SS-TAC for each species;
- Setting of the q-option, specifying whether the weighting for the final fleet factors should be in proportion to the species catch within the fleet's catch.

- Output:
  A typical MTAC output table looks as follows.

```
         Fsq  SS_F_mult.  SS_TAC  MS_F_mult  MS_TAC  MS_TAC/SS_TAC  Decision_w
AAA    0.613    0.200       27      0.692      56          2.11        0.9
BBB    0.327    1.000      163      0.745     128          0.78        0.1
...
...
More species can be present.
```

- AAA and BBB represent species names;
- Fsq: the input *status quo* F;
- SS_F_mult: the input Single Species F-multiplier, given or implied by the advice or the target;
- SS_TAC: the input Single Species TAC, given or implied by the advice or the target;
- MS_F_mult: the Mixed Species F-multiplier implied by the output Mixed Species TAC;
- MS_TAC: the output Mixed Species TAC (catch forecast):
- MS_TAC/SS_TAC: the ratio of the output Mixed Species TAC to the input Single Species TAC;
- Decision w: the input decision weight.

The set of fleet factors by fleet are not included in the standard output. These can be interpreted as fleet specific effort multipliers.

Technical note: I as well as the author of MTAC are aware of the fact that the approach would be better if the iterative process searching for catch forecasts that match the SS-TACs as closely as possible would encompass the weighted averaging of the fleet specific fleet factors, instead of what the current program does, namely calculating these averages after the iterative process has taken place. However, attempts that were made to this effect led to the program suffering from numerical instability. This was, in fact, the cause of the problems with the first version of MTAC, which gave rise to outcomes that could not be fully explained.

3. Analyses of the behaviour of the model

In this section the outcomes are presented of runs of various scenarios with semi-fictive data sets. The data sets are based on real data from the North Sea, but the data sets are sometimes incomplete. For the purpose of this section this is not a problem, because it merely aims to explain how the model responds to the various settings and data that have to be chosen by the MTAC user. This will help the reader to become a deliberate MTAC user. As was noted in section 2, MTAC requires several types of input of political choices:

- Setting of the p-option, specifying how the species specific fleet factors should relate to each other (e.g. fleets are affected in proportion to their catch of the species relative to the fleet's catch or relative to the international species' catch);
- Setting of the q-option, specifying whether the weighting for the final fleet factors should be in proportion to the species catch within the fleet's catch;
- Choosing the decision weights for the species, specifying the relative importance of approaching the SS-TAC for each species.

In section 3.1 the outcomes are compared of all combinations of different p- and q-settings, and it is explained how these settings affect the outcomes under a range of decision weights and targets F-multipliers. Hereby I illustrate the influences of the choice of decision weights and the choice of targets and how these interact with the choice of p- and q-settings.. In section 3.2 the outcomes are compared when different sets of decision weights are used, to illustrate how these affect the results. Whereas section 3.1 focuses on the effects on the fleet factors, section 3.2 focuses on the effects on the aggregated MS-TACs. These sections help the MTAC user to make the political choices for optional settings because it illustrates the consequences of these choices. In section 3.3 the outcomes are compared of runs where different input data were used, to illustrate how uncertainty of stock status affects the outcome. All the analyses are repetitions of analyses performed at the WGNSSK meeting in September 2003 (ICES 2003b) and at the STECF/SGRST meeting in October 2003 (STECF 2003a).

3.1 The effects of different settings of p- and q-options, different decision weights, and different target F-multipliers, on the resulting fleet factors

In this section the effects of the different options that can be chosen in MTAC will be illustrated. In addition, the effects of the chosen decision weights, and the effects of the set targets on the outcomes will be shown. For this exercise a data set was chosen that is suitable for illustration only, with nine fleets (A to I) fishing six species (cod, haddock, plaice, sole, saithe, whiting). The four figures below show respectively the historical catch[1] weight by species, the historical catch weight by species and fleet, the historical catch composition of the fleets, and the historical distribution of species catches over the fleets.

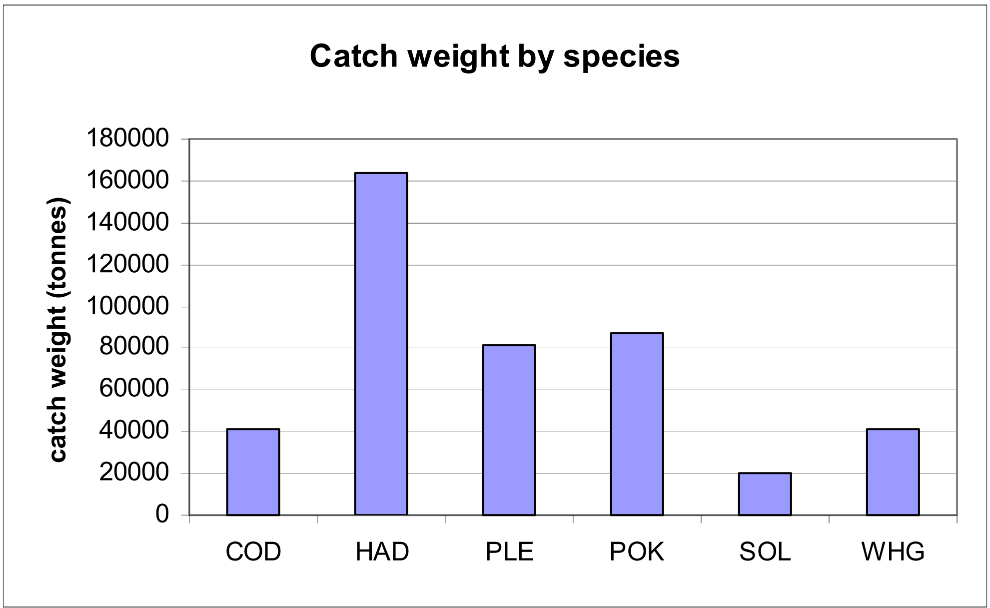


Figure 3.1.1

[1] The model assumes that the true catches (landings plus discards) are known. Because the purpose of these analyses is to illustrate the behaviour of the model, we assume that in all analyses of section 3 'catch' indeed includes discards.

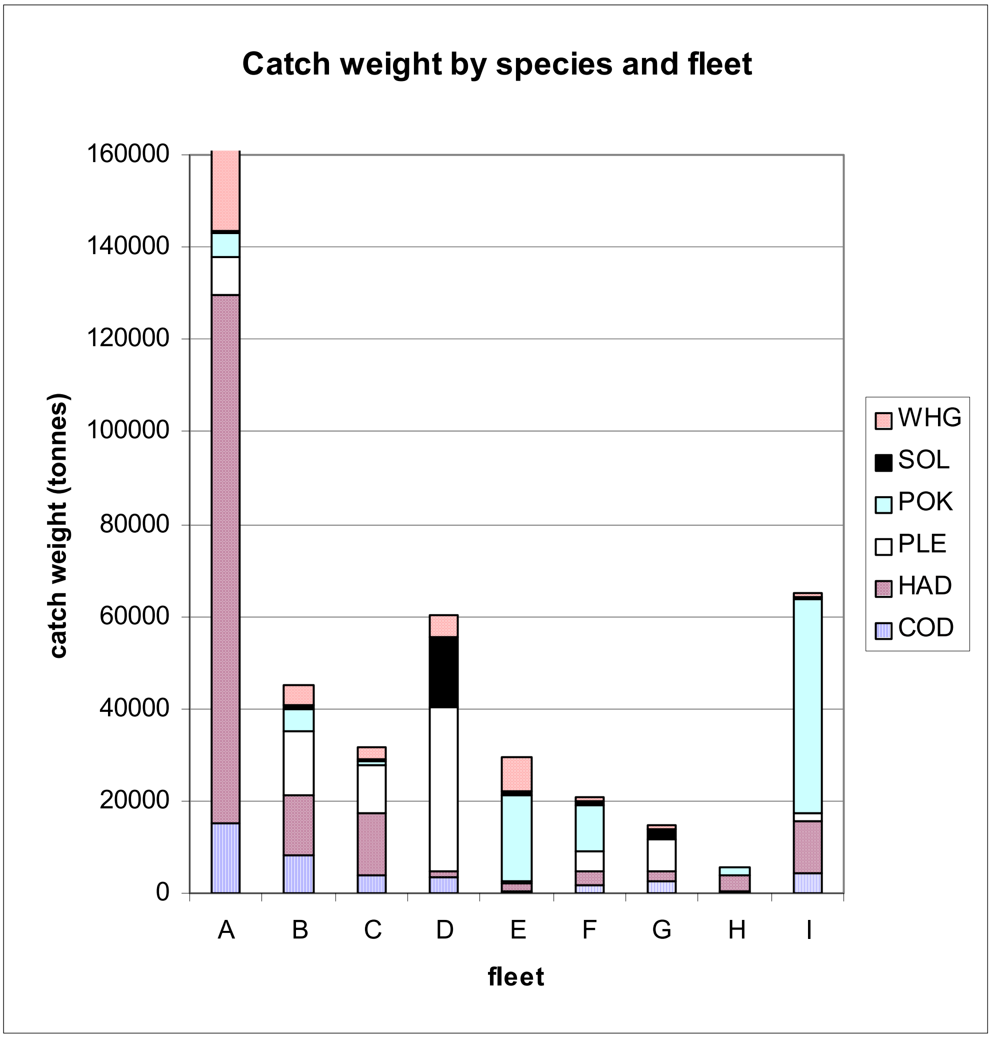


Figure 3.1.2

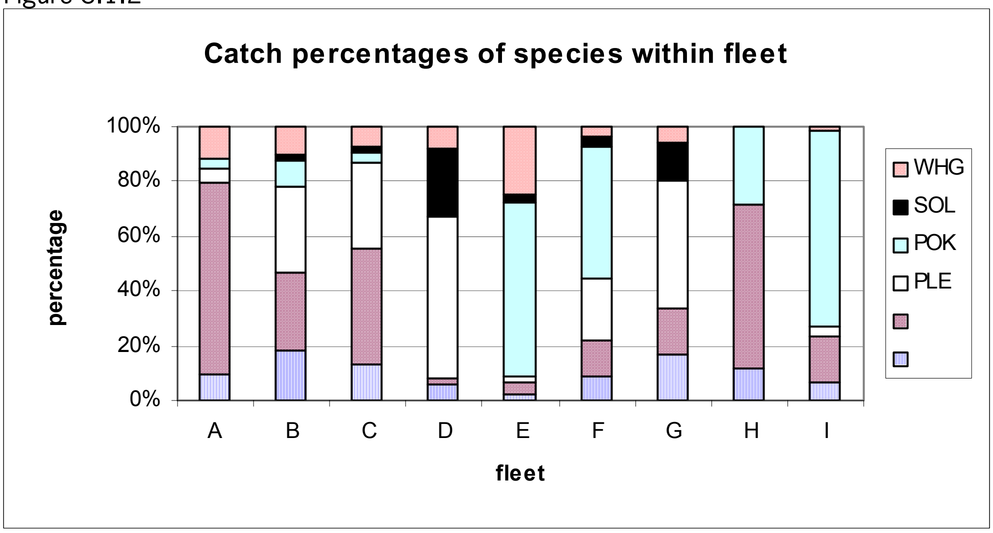


Figure 3.1.3

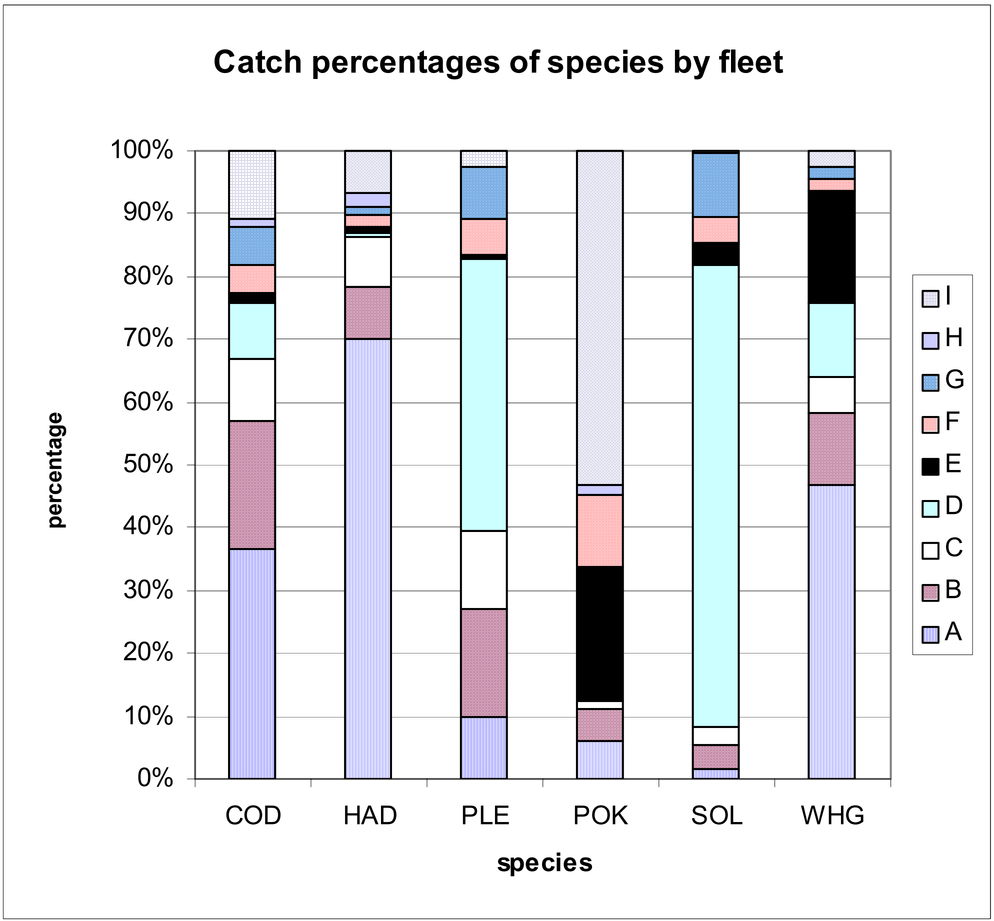


Figure 3.1.4

From figures 3.1.3 and 3.1.4 the following points can be noted for a better understanding of the outcomes of the MTAC runs:

- Fleet A takes the largest proportion of the international cod catch.
- Fleets E and H take the smallest proportion of the international cod catch; however, the two fleets contrast in that their respective cod catches represent a higher proportion of the total catch of fleet H than of the total catch of fleet E.
- Fleets D and I are quite similar with respect to their share in the international cod catch and the proportion of cod in their total catch, but are highly contrasting in that fleet D takes no saithe whereas fleet I catches mainly saithe.

The scenario that is investigated is the one that was proposed by the EC at the 2002 STECF/SGRST meeting (STECF 2002)[1]:

Scenario:

species	**Target F-multiplier**
COD (cod)	0.0 if not stated otherwise
HAD (haddock)	0.60
PLE (plaice)	0.60
POK (saithe)	1.0
SOL (sole)	0.77
WHG (whiting)	0.60

The main characteristics of this scenario are:

[1] For all runs the “estimate catch at age from total catch and selectivity” option is switched off because catch at age data are available for all fleets.

- that F on cod must be reduced to 0 (or an other low value),
- that F on saithe does not have to be reduced at all,
- and that F on the other species must be reduced to an intermediate extent.

MTAC contains three options for weighting the species specific fleet effort reduction (p-options) and an option for modifying the decision weights through multiplication by a fleet target factor (q-option) (see section 2). The p-options are:

- p=0: Equal for all fleets.
- p=1: Proportional to the catch of the species within the total catch of the fleet.
- p=2: Proportional to the fleet's catch of the species as a fraction of the total catch of that species.

The q-option can be switched off (q=0) or on (q=1).

All six combinations of options p and q are run. In addition, the influence of the decision weight assigned to cod relative to the other species is explored by running MTAC with all six combinations of options while the decision weight on cod varies from 2 to 40 while the decision weights for all other species are kept at 1. The influence of the value of the target F-multiplier on cod is explored, by running MTAC with all six combinations of options while the target F-multiplier for cod varies from 0.1 to 1 (other F-multipliers as in the scenario given above) with decision weights of 40 for cod versus 1 for all other species.

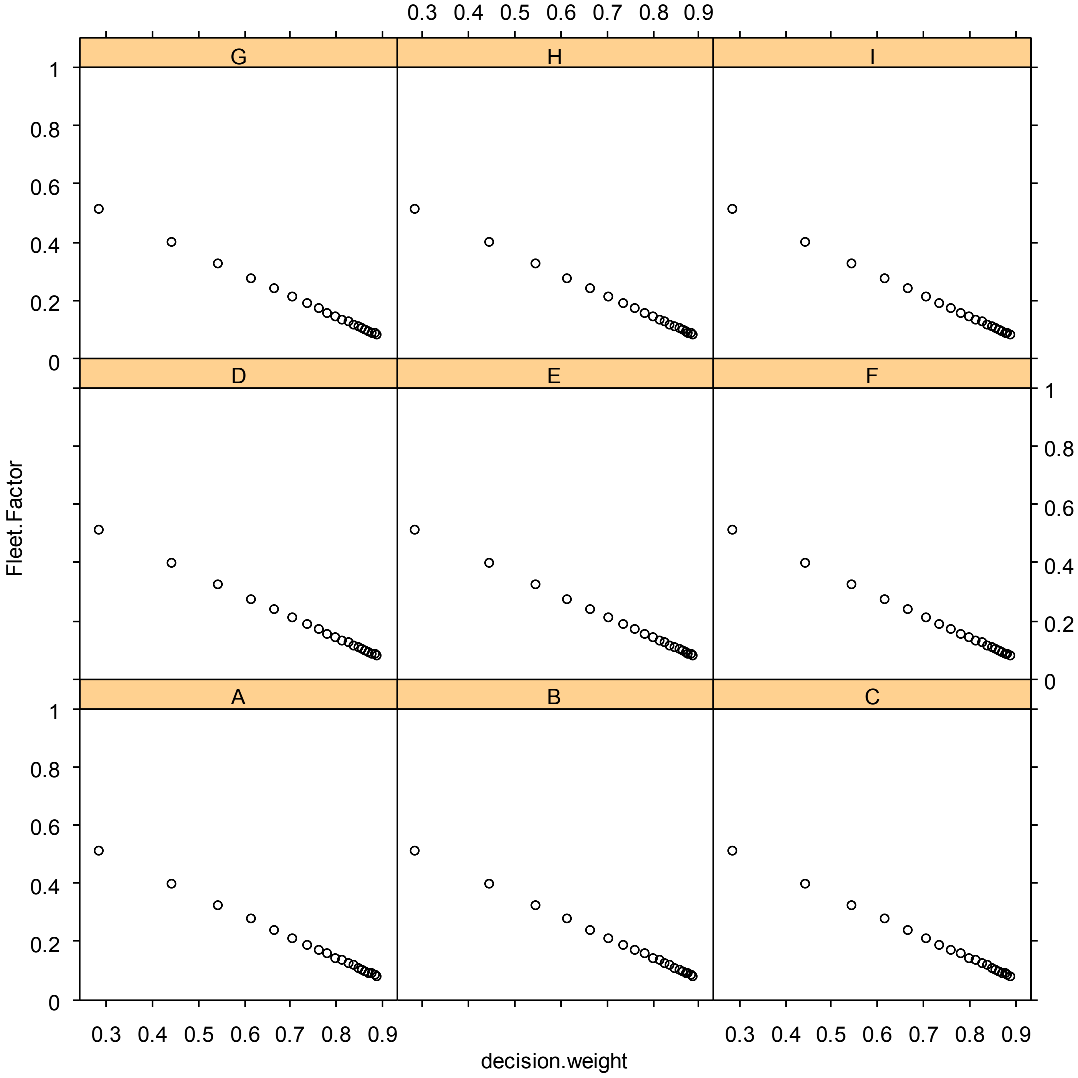
3.1.1 Results

Figures are presented for each of the six combinations of p and q-options, firstly with varying decision weights (cases 1-6), and then with varying target F-multipliers for cod (cases 7-12). Each figure consists of nine graphs representing the nine example fleets. The dots represent the outcomes of the runs: the fleet factor (fleet effort reduction multiplier) on the y-axis, and the varying decision weight on cod[1] or varying target F-multiplier for cod respectively on the x-axis.

[1] The values on the x-axis are actually the decision weights on cod as a fraction of the sum of the decision weights of all species. For example, a decision weight of 2 for cod would translate to a value of 2/7 = 0.29 on the x-axis and a decision weight for cod of 40 would translate to a value of 40/45 = 0.89 on the x-axis.

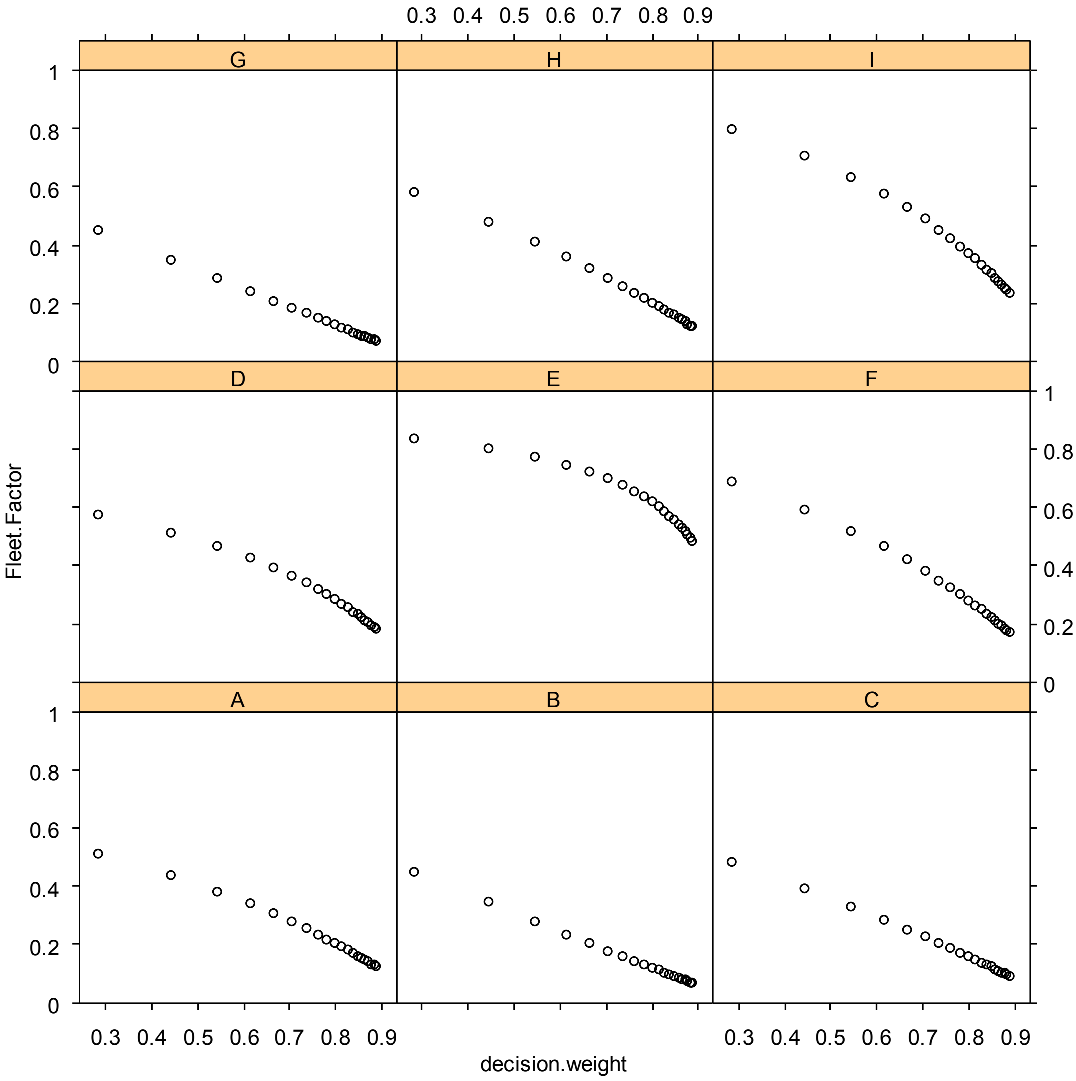
1. p=0, q=0, decision weights on cod vary

The outcome of this run is straightforward. The fleet factors (y-axis) can be interpreted as fleet effort reduction factors. All fleets have to reduce effort equally (p=0). The resulting effort reduction is a compromise between the different targets for the different species (*e.g.* reduction to 0 for cod and no reduction for saithe). The compromise is the same for all fleets regardless of their catch compositions (because q is set at q=0). The decision weight for cod represents the importance that is given (as a political decision) to approaching the target set for cod relative to the other targets. If banning all fishing on cod has high priority (on the right hand side of the x-axis), then all fleets that historically catch some cod must reduce effort to a very low level. With lower priority given to conserving cod (on the left hand side of the x-axis), the fleets' effort reduction is more moderate.



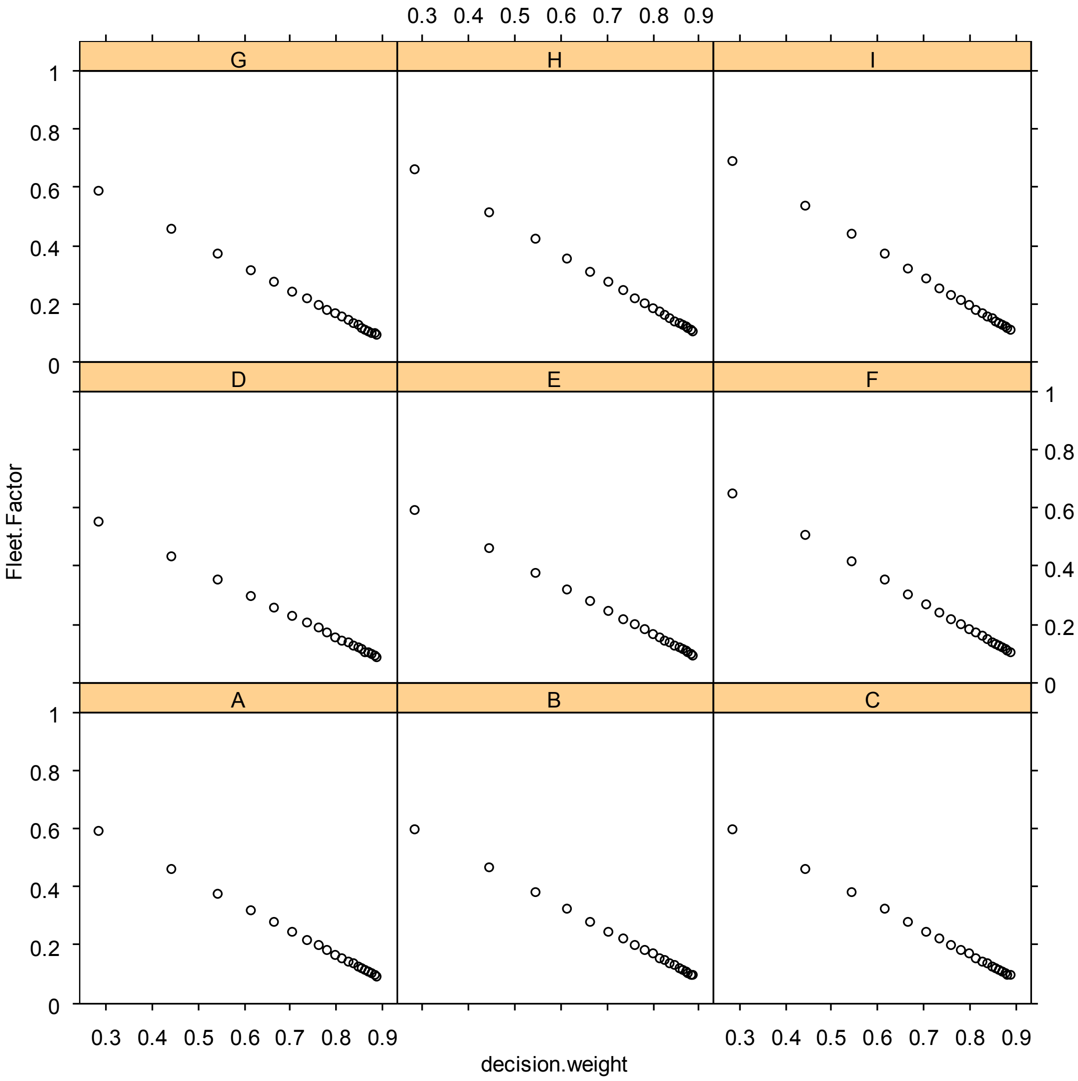
2. p=0, q=1, decision weights on cod vary

Here the species' decision weights used to calculate each fleet factor are modified by a fleet target factor, reflecting the proportion of a species in a fleet's catch (q=1). This choice favours fleets E and I, because due to the low proportion of cod in their catch the requirement to reduce fishing mortality on cod does not press very heavily on these fleets. Fleet E suffers the least from restricting cod fishing mortality, and only when decision weight is quite high, because it has the lowest proportion of cod in its catch. Although both fleets D and I have similar cod proportions in their catch composition, fleet I is favoured much more strongly because it heavily targets saithe, for which fishing mortality does not have to be reduced.



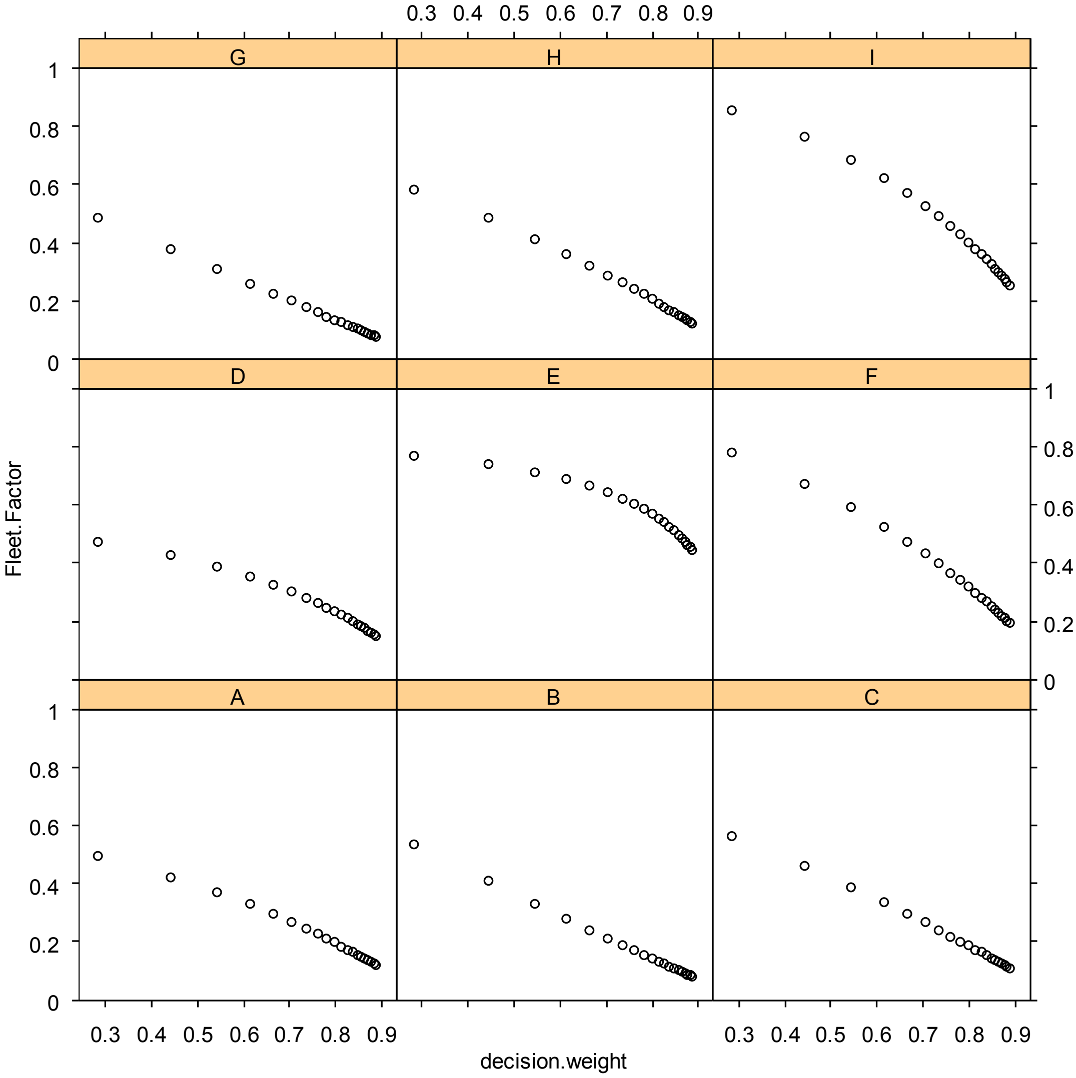
3. p=1, q=0, decision weights on cod vary

Choosing the option of reducing species-specific fleet effort in proportion to the species' proportions in the fleets' catches (q=1) differentiates only slightly between the fleets, and gives most of them a slight advantage at low decision weight.



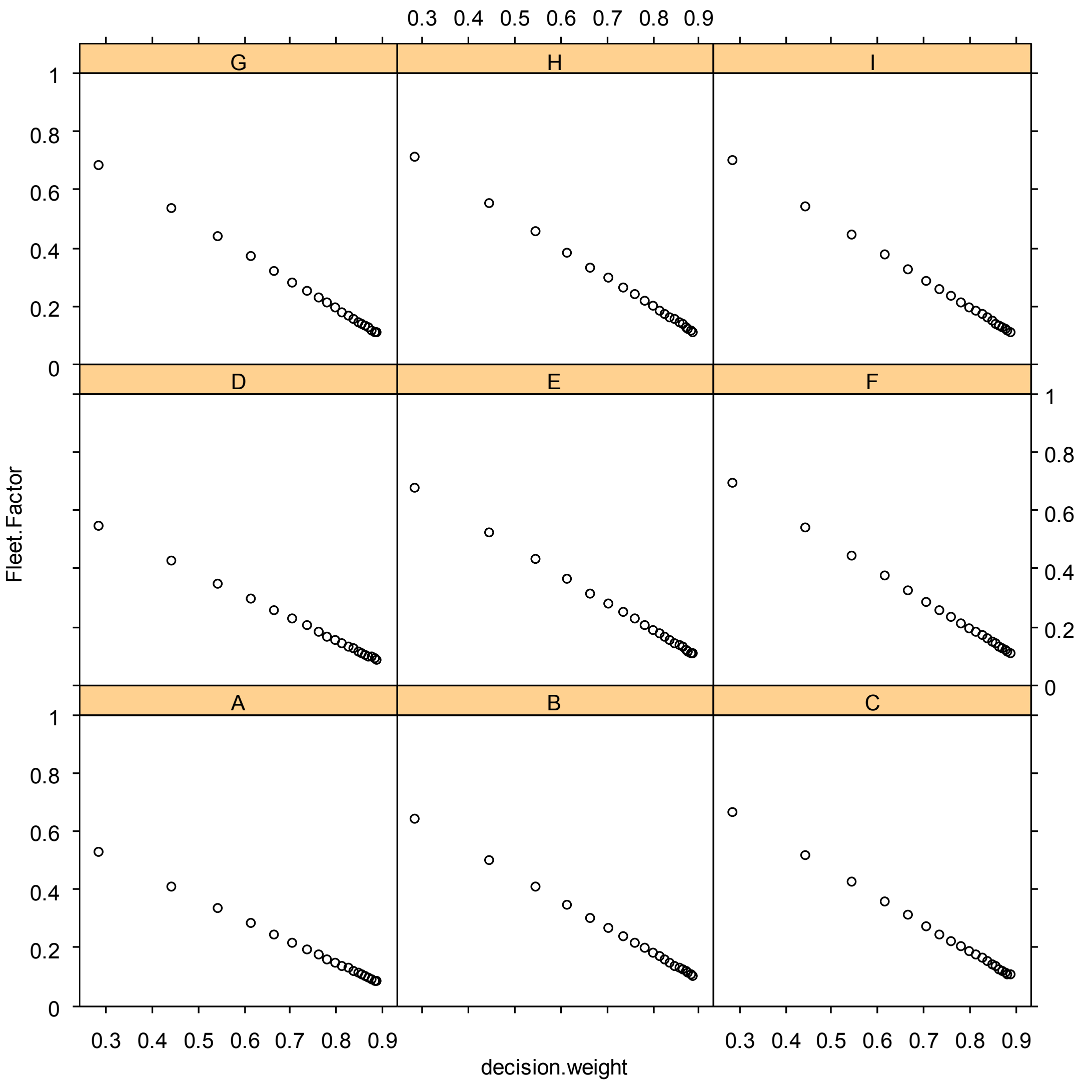
4. p=1, q=1, decision weights on cod vary

Again, modification of the decision weight by fleet target factors (q=1) favours fleets E and I.



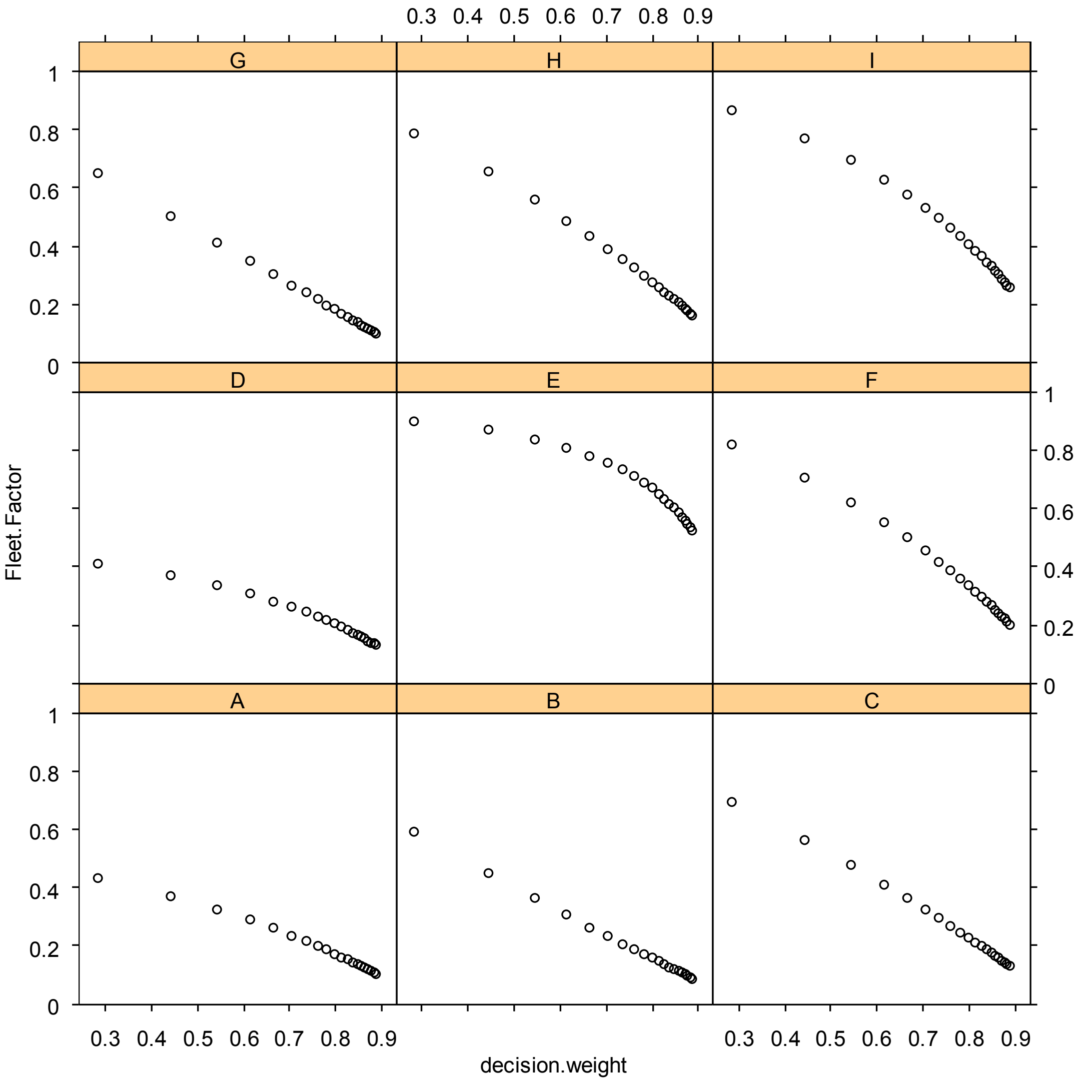
5. p=2, q=0, decision weights on cod vary

Choosing the option of reducing species-specific fleet effort in proportion to the fleets' contribution to the total catch of that species (p=2) also differentiates only slightly between the fleets, and slightly favours all fleets except fleet A which takes most of the cod.



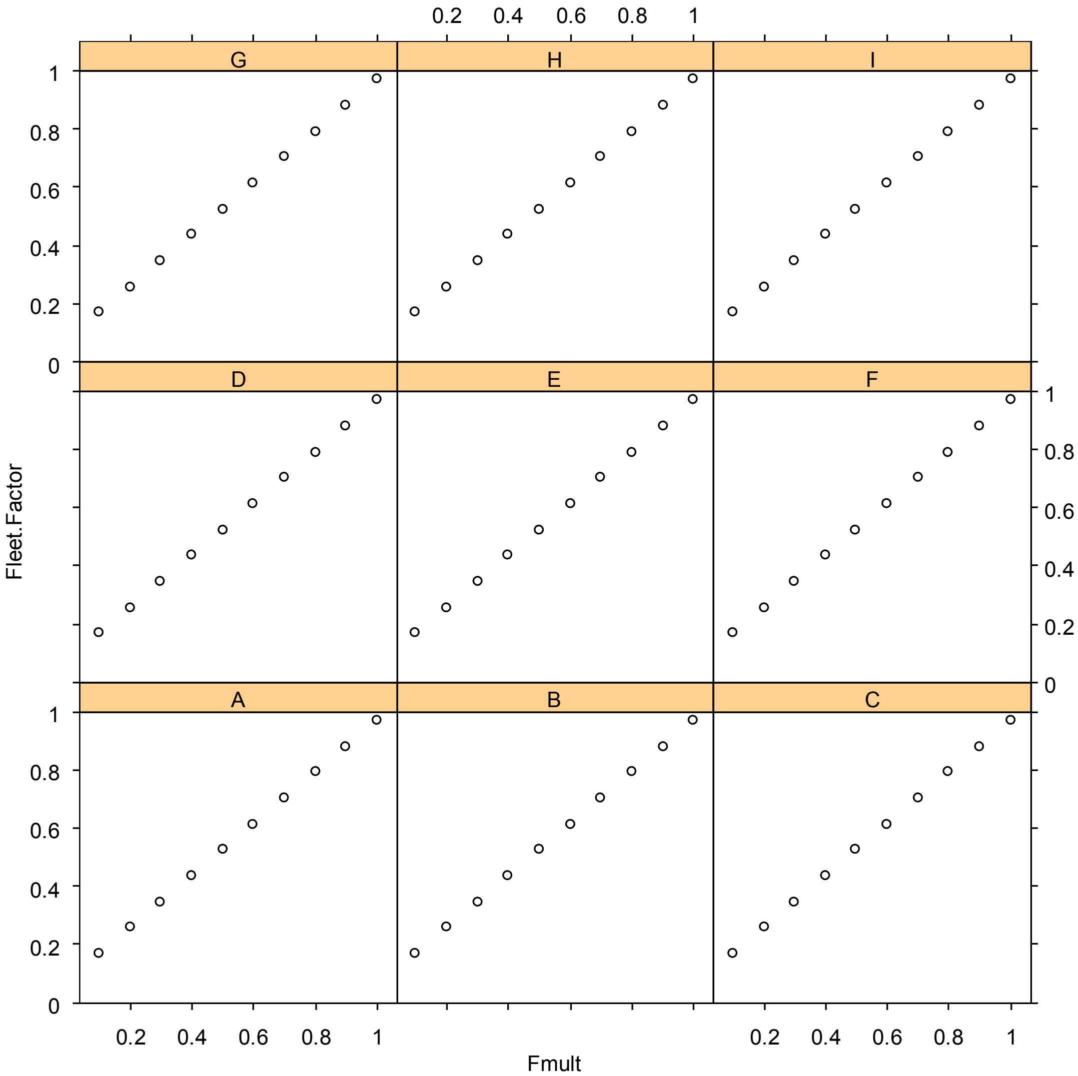
6. p=2, q=1, decision weights on cod vary

Choosing the option of reducing species-specific fleet effort in proportion to the fleets' contribution to the total catch of that species (p=2) in combination with the modification of the decision weights by fleet target factors (q=1) differentiates most between the fleets. This differentiation appears to be driven as much by the distribution of saithe catches as by the distribution of cod catches. Fleets that suffer take a high proportion of cod and/or take a low proportion of saithe. Similarly, fleets that benefit take little cod and/or target saithe. Note that this effect comes about because the fishing mortality for saithe does not have to be reduced whereas the fishing mortality for cod has to be reduced to 0. Reduction of fishing mortality for the other species is intermediate.



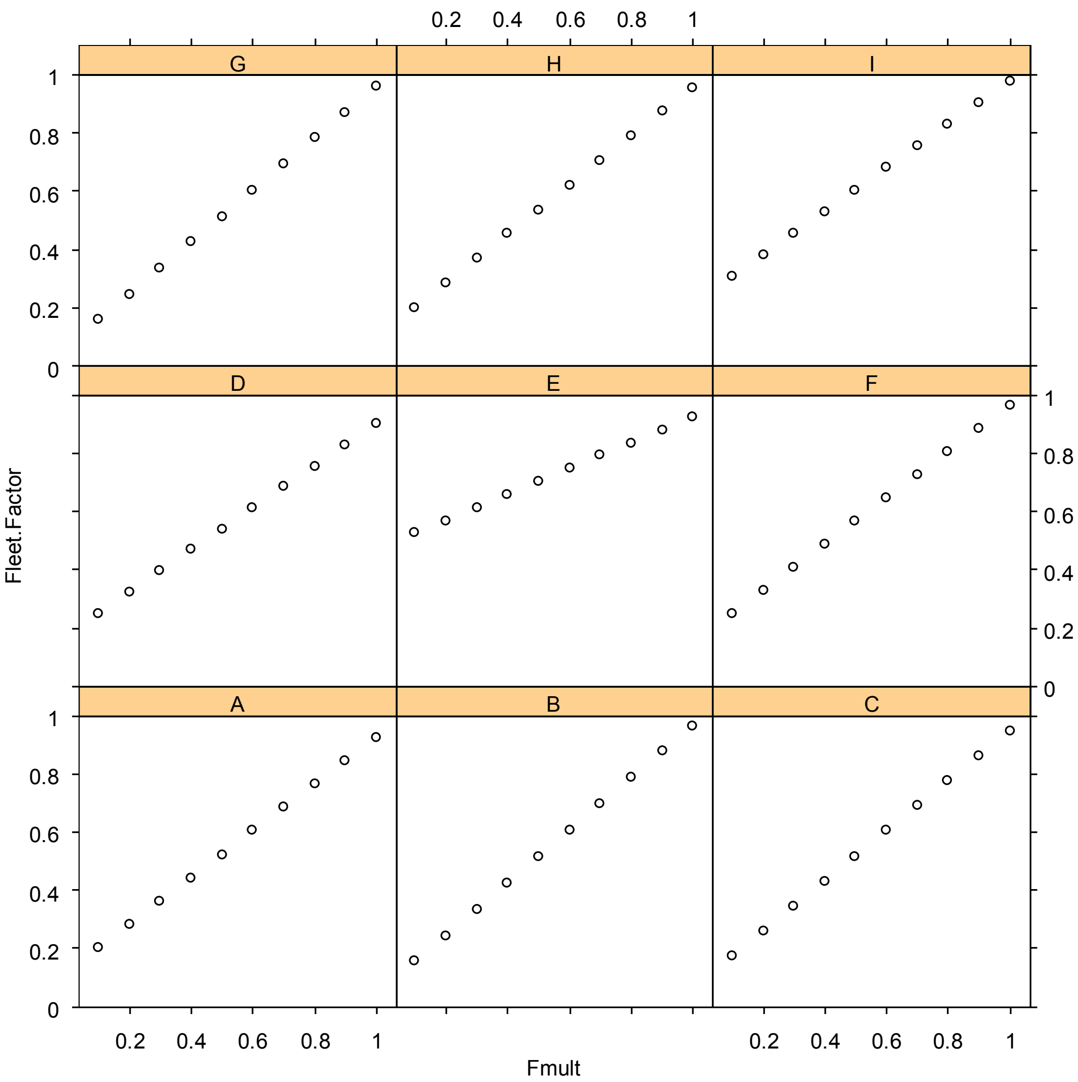
7. p=0, q=0, target F-multiplier for cod varies

The outcome of this run is straightforward: all fleets have to reduce effort equally. Their level of effort linearly increases with the level of the chosen target F-multiplier for cod (on which the decision weight is large).



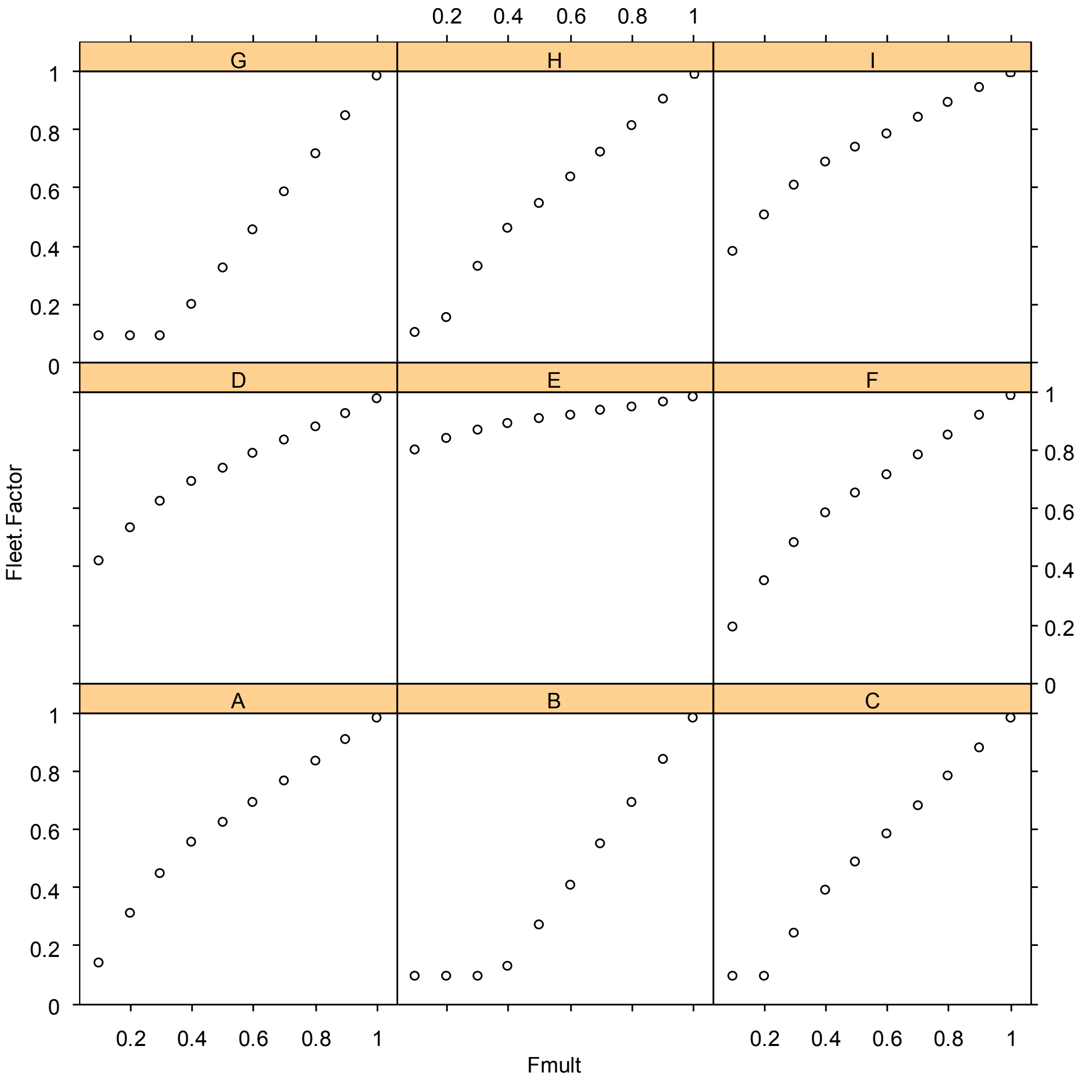
8. p=0, q=1, target F-multiplier for cod varies

Fleets, such as fleet E, that historically take little cod (in terms of proportion within the fleets' catch) suffer less from the requirement to restrict cod fishing mortality.



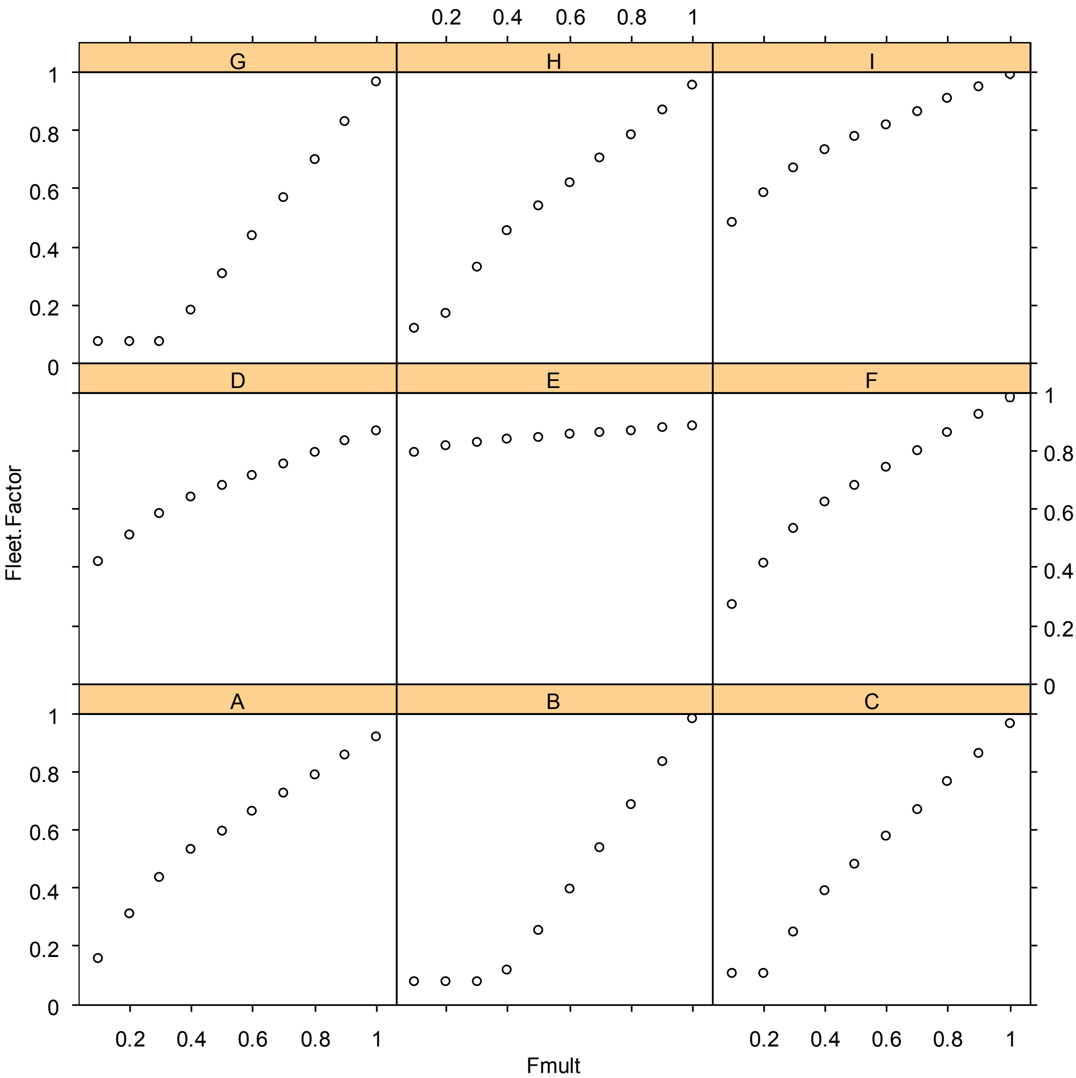
9. p=1, q=0, target F-multiplier for cod varies

When species-specific fleet effort has to be reduced in proportion to the species composition within the fleet, fleets such as fleet E suffer little due to their low proportion of cod in their catch. Fleets such as fleets B, C and G, which have a high proportion of cod in their catches, have to limit their effort when the target F-multiplier for cod is low, but can gradually increase their effort at higher F-multipliers. Note that the plateaus at low F-multipliers for these fleets are due to the fact that species-specific fleet effort cannot be below zero.



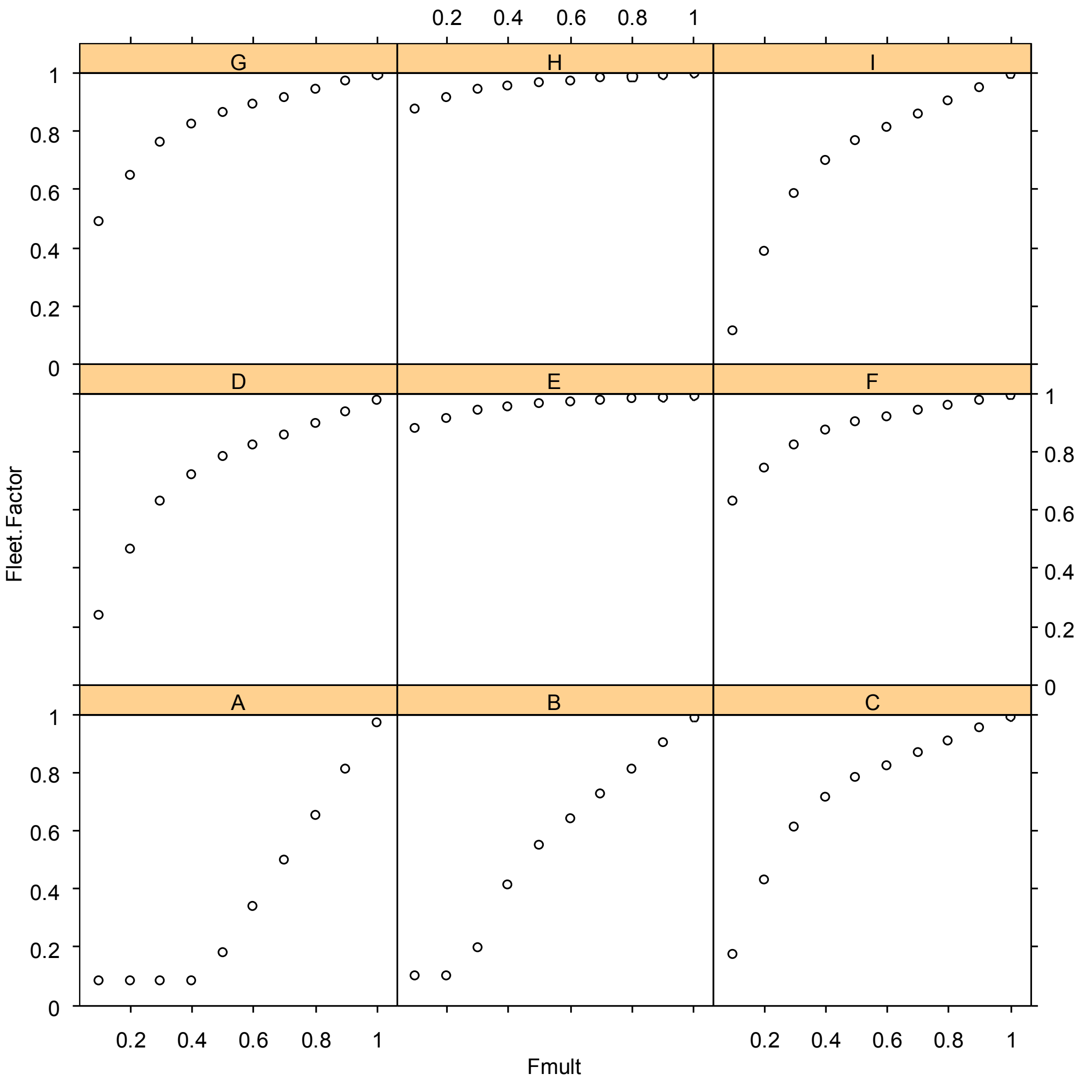
10. p=1, q=1, target F-multiplier for cod varies

Modification of the decision weights by fleet target factors does not bring about much change, except that most fleets seem to suffer a bit more at the highest target F-multipliers for cod.

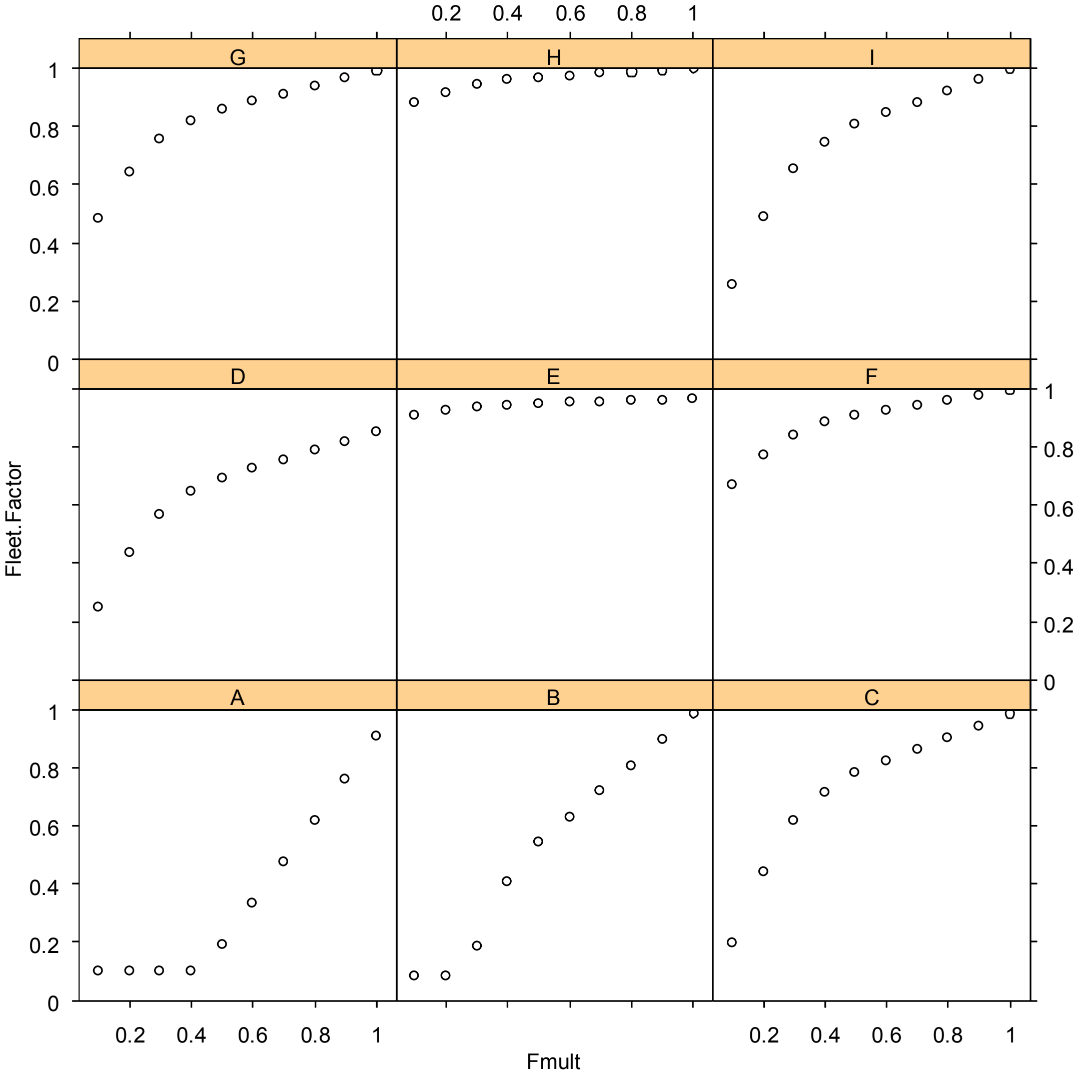


11. p=2, q=0, target F-multiplier for cod varies

The contrast between the p-option chosen here (species-specific fleet effort reduction in proportion to the proportion of a species' total catch taken by a fleet) and the previous p-option (species-specific fleet effort reduction in proportion to the proportion of a species within a fleet's total catch) is quite clear. In the present setting fleets such as G and H are favoured compared to the previous setting because they contribute little to the total cod catch (although within these fleets' catches cod represents a high proportion as compared to the other fleets, which is the reason why they are not favoured in the previous setting). Similarly, fleet A, taking a very high proportion of total cod catch, suffers more in this setting than in the previous one.



12. p=2, q=1, target F-multiplier for cod varies
Modification of the decision weights by fleet target factors does not bring about much change.



3.1.2. Conclusions

The exercise of varying decision weights on cod on the x-axis of the figures (1-6) illustrates how the priority given to, *e.g.*, conserving cod influences the resulting compromise between the different targets for the different species. It also highlights the difference between choosing to modify the decision weights by fleet target factors or not (q=1 or q=0 respectively). The choice of such modification (q=1) differentiates well between the fleets according to whether they target cod or not. The effects of choosing different p-options are not apparent in this analysis.

The exercise of varying the target F-multiplier for cod on the x-axis (7-12) firstly shows that when the target cod fishing mortality is lower the resulting compromise is also lower. Furthermore, it illustrates the difference between reducing species-specific fleet effort equally, or in proportion to the fraction of a fleet's species catch within the fleet's catch or within the total catch of that species (p=0, p=1or p=2 respectively). Choosing between these options allows managers to either ‘penalize’ fleets when the proportion of cod within the fleet’s catch is high, or when they take a high proportion of the total international cod catch. The effects of choosing different q-options are not apparent in this analysis.

3.2 The effects of decision weights on the resulting MS-TACs

In this section the effects of the choice of decision weights for each species on the resulting MS-TACs are investigated. This is a sensitivity analysis of the model and therefore the data and results are only used for that purpose; they are not meant to convey information on the true dynamics of the North Sea system. The input data used in this analysis are based on the assessments and intermediate year scenarios presented by WGNSSK 2003 (ICES 2003b).

The decision weights for plaice and cod are equal and range from 0 to 0.5; the other fish species receive an equal share of 1 minus the sum of the decision weights of plaice and cod.

The single species target F-multipliers used were as in the scenario table below. The exact values are not relevant for the purpose of this section, which is illustrating the effects of decision weights. It suffices to note that the targets restrict fishing mortality on cod and plaice, but not on the other species.

Target scenario[1]:

	Target catch or target F
Cod	0.35* C_{sq}
Haddock	C_{sq}
Whiting	C_{sq}
Plaice	0.6* C_{sq}
Sole	F_{pa}
Saithe	F_{pa}
Nephrops	F_{sq}

3.2.1. Results.

Figure 3.2.1 below illustrates how the MS-TACs are influenced by the decision weights. MS-TACs are presented by open dots and SS-TACs by closed dots (constant).

1 C_{sq} = Status quo catch (landings)

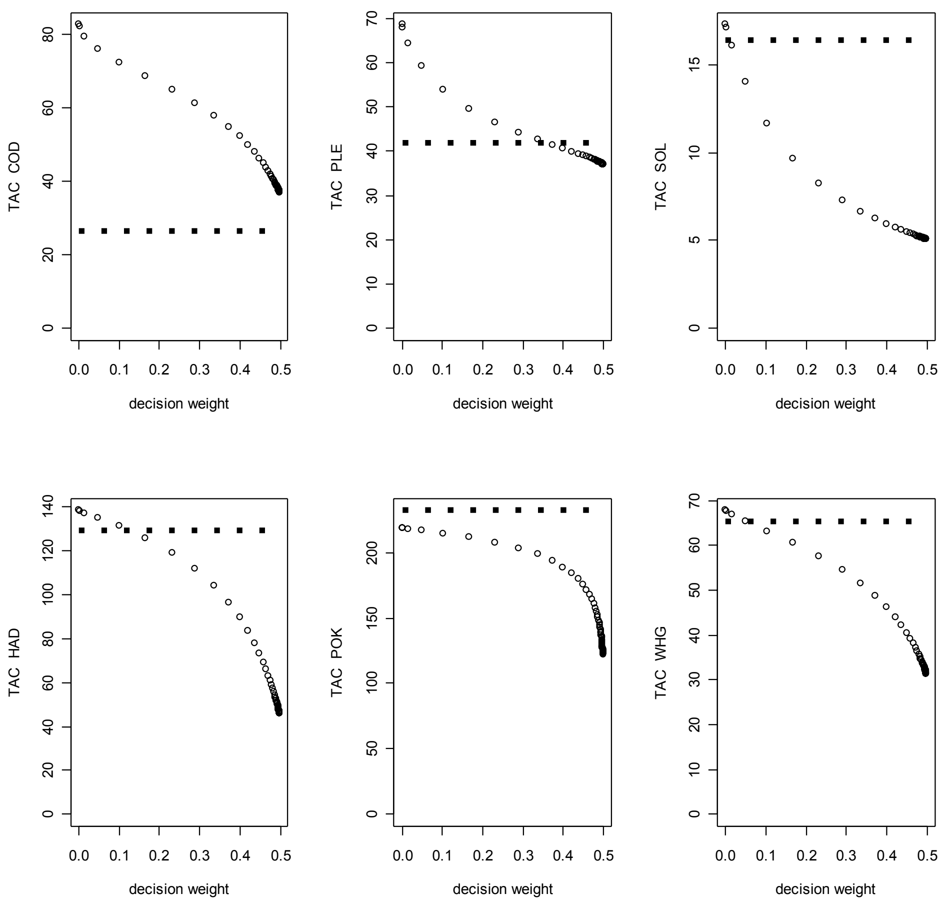


Figure 3.2.1

3.2.2. Discussion and conclusion

The compromises calculated by MTAC tend to result in MS-TACs for cod and plaice higher than their SS-TACs, and therefore not restrictive enough, and MS-TACs for the other species lower than their SS-TACs, and therefore more restrictive than desired.. This is indeed the nature of the very conflict entailed in mixed fisheries that MTAC aims to resolve (*i.e.*, find a compromise to). Putting more weight on cod and plaice results in outcomes where the targets for cod and plaice are more closely approached (their MS-TACs become closer to their SS-TACs) at the expense of becoming unnecessarily restrictive for the other species (their MS-TACs become more removed away downward from their SS-TACs). This analysis illustrates that managers can choose how to resolve the mixed fishery conflict by the choice of decision weights. This is a political decision, not a scientific one.

In an analyis carried out at the STECF/SGRST meeting of 2003 (STECF 2003a) it was found that results may differ strongly between scenarios with decision weights for some species set at 0 and scenarios with these decision weights set at very low values, such as 0.01. For example, if for a particular species the target F is higher than the *status quo* F, this target will play no role in the calculation of a compromise with the decision weight for that species set at 0. The result will be that even fleets that catch almost no other species than this particular one, will still have to reduce their effort because it catches a small proportion of a species with a lower target and a high decision weight. With a non-zero but small decision weight set for the non-endangered species, the compromise will result in higher fleet factors for the fleets that almost exclusively target that species. The study group therefore recommended that, if it is a political choice not to give any priority to achieving the target for a particular species, it is best to give this species a very low but non-zero decision weight, such as 0.01.

3.3 The effects of uncertainty in the input data concerning stock status on the resulting MS-TACs

In this section it is investigated how MTAC responds to uncertainties in input data concerning terminal population sizes and intermediate year assumptions. Again, this is a sensitivity analysis of the model and the data used should therefore be regarded as an arbitrary dataset with no reference to reality (the same data set is used as in section 3.2).

The estimate of fishing mortality at age in the intermediate year determines the population size assumed at the start of the TAC year, which is the population to which the MTAC model is applied. Uncertainty in the intermediate year (2003) estimate of fishing mortality at age (F_{2003}) was examined for two species, namely cod and haddock. For cod, three scenarios were chosen based on the scenarios investigated by WGNSSK (ICES 2003b).

- F_{2003} equal to F_{2002}.
- F_{2003} equal to the average of the last 3 years (F_{sq}).
- F_{2003} corresponding to the TAC for 2003 (F_{TAC}), which implies an F-multiplier of about 0.3 on F_{2002}.

For haddock, four scenarios were examined.

- F_{2003} equal to F_{2002}.
- F_{2003} equal to the average of the last 3 years (F_{sq}).
- F_{2003} equal to 0.3 times F_{2002} (The estimated effect of both decommissioning and days at sea regulations in 2003 combined is a 70% reduction in effort).
- F_{2003} equal to 0.3 times the average of the last 3 years (F_{sq}) (The estimated effect of both decommissioning and days at sea regulations in 2003 combined is a 70% reduction in effort).

All combinations of these scenarios were examined giving a total of 12 scenarios, which are summarised in the table below.

scenario	COD	HAD
1	F_{sq}	F_{2002}
2	F_{2002}	F_{2002}
3	F_{TAC}	F_{2002}
4	F_{sq}	F_{sq}
5	F_{2002}	F_{sq}
6	F_{tac}	F_{sq}
7	F_{sq}	$F_{2002 * 0.3}$
8	F_{2002}	$F_{2002 * 0.3}$
9	F_{tac}	$F_{2002 * 0.3}$
10	F_{sq}	$F_{sq * 0.3}$
11	F_{2002}	$F_{sq * 0.3}$
12	F_{tac}	$F_{sq * 0.3}$

A function for the "objective" determination of the decision weights was devised[1]. This function is simply the ratio of B_{pa} to SSB_{2003} such that a stock below B_{pa} would receive more weight than a stock above B_{pa}. A modification to this function was also considered using the square of the ratio of B_{pa} to SSB, forcing more contrast into the decision weights. Decision weights are given in the table below. Use of the two decision weight options in conjunction with the 12 scenarios detailed above gave rise to 24 runs.

[1] The function is only "objective" to the extent that the decision weights of the respective species are not arbitrarily chosen, but instead according to a systematic rule. It remains a political decision what rule to choose.

Species	B_{pa}	SSB 1 Jan 2003[1]		B_{pa}/SSB	(B_{pa}/SSB)^2
COD	150000	52700	WGNSSK	2.846	8.101
HAD	140000	348200	ACFM	0.402	0.162
WHG	315000	236000	WGNSSK	1.335	1.782
POK	200000	364000	ACFM	0.549	0.302
SOL	35000	29000	ACFM	1.207	1.457
PLE	300000	152000	ACFM	1.974	3.895

Stock numbers at the start of 2004 and fishing mortality at age came from the short term forecast runs obtained from WGNSSK (ICES 2003b). Fleet specific stock weights at age came from the mixed fishery database for 2002 (STECF 2003a) and are not therefore the same as used by WGNSSK 2003. The single species target F-multipliers used were as in section 3.2.

3.3.1. Results

Summary results of the 12 scenarios with the respective weighting functions are given in the figures below. The values for each species are the ratios MS-TAC/SS-TAC for each scenario. Ratios bigger than 1 represent situations where the resulting MS-TAC is higher than the target (not restrictive enough), whereas ratios smaller than 1 represent situations where the resulting MS-TAC is lower than the target (unnecessarily restrictive).

1 The source of the estimates of SSB is either the 2003 WGNSSK report (ICES 2003b), which was not accepted by ACFM, or the 2003 ACFM report (ICES 2003c).

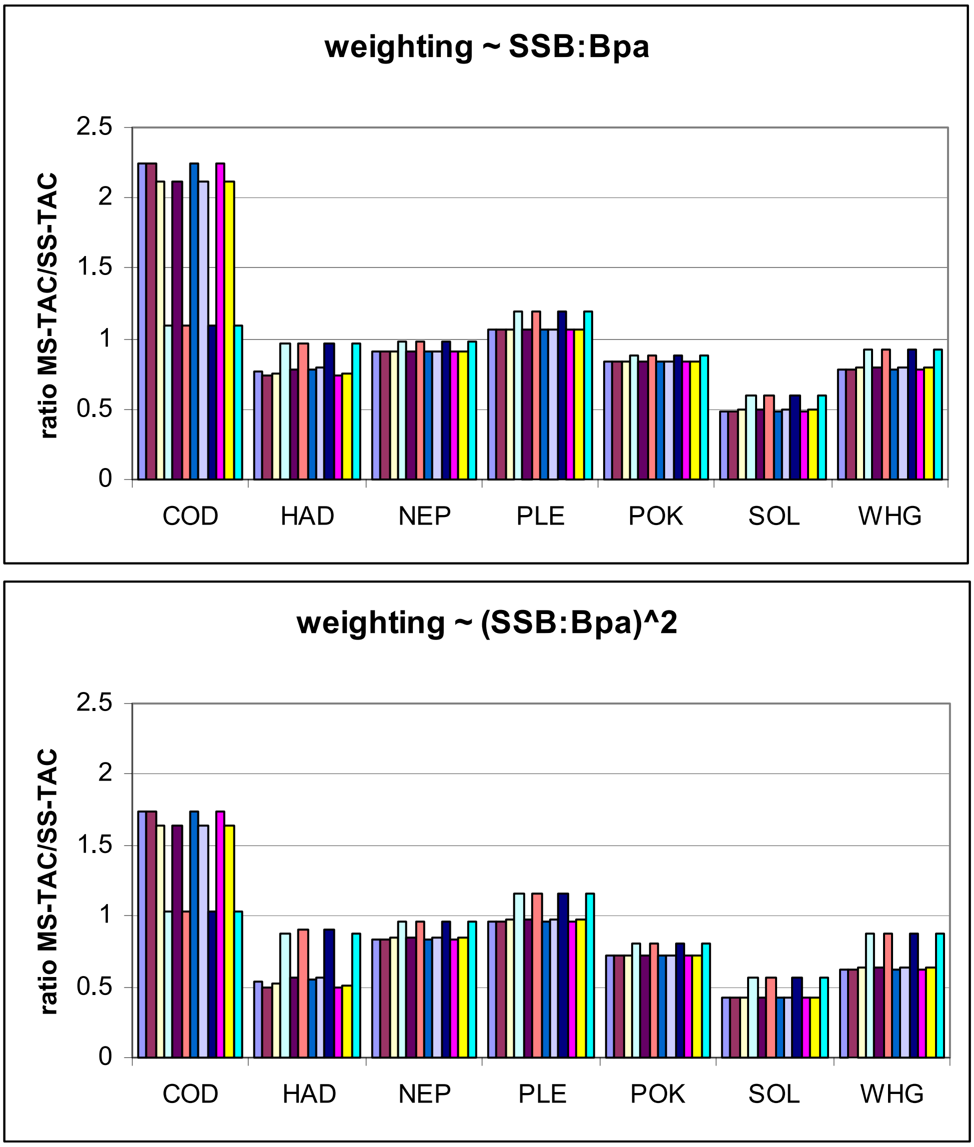


Figure 3.3.1. Each colour refers to one of the 12 scenarios described above.

The ratios MS-TAC/SS-TAC appear to flip between two or three levels for each species depending on the scenario and is a result of the distribution of catch within fleets. Changing the decision weight model to the squared function increases the decision weight on cod and allows MTAC to get the cod MS-TAC closer to the cod SS-TAC thus implying lower MS-TACs on the other species. The TACs for saithe are relatively unaffected by the scenario assumptions and decision weighting model, which is a function of their relatively clean (reported) catch composition.

3.3.2. Discussion.

The scenarios presented here have simplified the implications of intermediate year assumptions. Changes in exploitation pattern due to new technical measures will not affect all fleets in the same way, hence fleet/gear specific selectivities should be derived for input to the model. In the same manner, fleet specific catch weights at age should also be derived. The results presented here may therefore be considered a lower bound on model variability in response to input uncertainty.

3.3.3. Conclusion.

These results highlight that the MTAC method is sensitive to uncertainties in the stock status. The fact that model output changes in response to model input is obviously not surprising, but the key point here is that uncertainty in the status of one or two stocks has implications for the entire species assemblage.

4. Discussion

The purpose of MTAC was to find a compromise between TACs for different species that are caught together in the same fisheries. Whatever political choices are made in the setting of p- and q-options and the decision weights, the results will always be a compromise in the sense that the resulting MS-TACs will be too high for some species and too low for other species. Therefore, the MTAC approach does not adhere strictly to the precautionary approach: with MS-TACs higher than the target, fishing mortality will exceed F_{pa} and/or SSB will fall below B_{pa}. As was shown in the semi-fictive example in section 3.3, even with high decision weight on cod (based on this stock's SSB being far below B_{pa}), the resulting MS-TAC for cod exceeds the precautionary target to a very large extent. This can be seen as a major drawback of this approach.

An alternative approach to MTAC has been presented at several meetings (ICES 2003a, ICES 2003b, STECF 2003a). The SMP-approach tries to find fleet effort reduction factors and corresponding aggregated catch forecasts, in such a way that set limits for SSB and fishing mortality are not violated. If the user sets as respective limits B_{pa} and F_{pa}, the program's outcome is guaranteed to conform to the precautionary approach. The solution depends on the political choice of decision weights (which are differently defined than in MTAC) and the program maximises the forecasted catches, given the decision weights and the set limits. If it is a political choice to give highest priority to conforming to the precautionary approach, SMP is preferable over MTAC. However, the SMP approach is not yet ready for use, since the algorithm and its implementation have not yet been scrutinised by experts, and it has not yet been extensively tested.

The design of MTAC implies that its purpose is to give fleet based advice. It generates fleet factors, which can be interpreted as effort reduction factors, and it can generate corresponding catch forecasts per fleet. This way, policy makers could restrict effort on a fleet basis, or give quota to individual fleets. However, the policy makers will then have to find the political basis for the assignment of heavy restrictions to some fleets and more lenient restrictions to others. Yet, these restrictions are extremely dependent upon the choice of policy settings (of p and q and the decision weights). At present, the TACs are split in national quota based on the relative stability principle. Relative stability does not address the allocation of quota to fleets within a country, but only the allocation of quota between countries. Most outcomes of MTAC do not closely correspond to relative stability (Kraak and Pastoors 2002). The response of the expert group to this potential problem has been to declare that MTAC's purpose is not to give fleet based advice, but – as an intermediate approach – aggregated TAC advice (TACs per species aggregated over fleets; STECF 2003a). However, this statement does not hold for several reasons:

- It contradicts the explicit design of MTAC that is based on fleet factors.
- It contradicts the use of p=1 or p=2 options, which are devised to determine rules according to which effort reduction has to be allocated to fleets.
- It contradicts using the q-option q=1, which weights the species specific fleet factors according to a species' contribution in a fleet's catch.
- If the aggregated catch forecasts given by MTAC with p≠0 and q≠0 would be implemented as TACs for the respective species while ignoring the fleet factors, and these TACs would be allocated according to, *e.g.*, relative stability, the problems entailed in mixed fisheries would remain unsolved. That is to say, the quota would then not be depleted synchronously, leading to overquota fishing and/or the foregoing of catches of target species for which the quota has not yet been exhausted. Using MTAC with p≠0 and q≠0 for aggregated TAC advice on the pretence that it takes the mixed nature of the fisheries into account is nonsense.

Only the use of MTAC with p=0 and q=0 (leading to all fleet factors being equal) for aggregated TAC advice would correspond to the stated purpose of arriving at quota that will be depleted synchronously, even if allocated according to relative stability. However, in this case all fleets would have to suffer equally from the requirement to preserve the endangered species, *e.g.*, cod, and the TACs for the non-endangered species, such as saithe, would correspondingly be very low. Even fleets catching very small proportions of cod, but targeting for example saithe, would have to reduce their effort to a great extent (see the first scenario in section 3.1). Using MTAC with p=0 and q=0 would forego MTAC's sophisticated ability of fine-tuning through differentiating between the fleets (illustrated in section 3.5.1). Through this ability fishing mortality on endangered species can be constrained while keeping fishing opportunities on other species open.

I believe that **if** MTAC is to be used, it should be used for fleet based advice. In that case, policy makers should devise a set of rules according to which effort or catches should be allocated to individual fleets. An advanced version of MTAC could be envisaged that incorporates these rules. For example, an additional objective within the program could be that it minimises the difference between the outcome and relative stability, or any other policy rule. However, at the SGDFF meeting in 2004 (ICES 2004) it was concluded that due to program-technical reasons related to the optimisation procedure this is not possible.

The criticism of ACFM (ICES 2003c) that MTAC should not be used for fleet based advice because of incomplete data has also been raised by STECF (STECF 2003b). ACFM argued that, *e.g.*, the lack of discard data could lead to advice such that fleets catching a lot of cod but underreporting or discarding those catches would have to reduce their effort to a smaller extent than fleets catching fewer cod but reporting more (ICES 2003c). Incomplete data are of course also a problem for aggregated TAC advice. However, in the case of fleet based advice, the possibility of unjustly penalising individual fleets as a consequence of biased data seems unacceptable. The 2003 STECF/SGRST study group recognised that effort should be directed to getting more complete data sets, but, as was mentioned above, also stated that MTAC is intended for aggregated TAC advice only, and that therefore the lack of data does not do more harm than with traditional TAC advice. I find that MTAC should not be viewed as a tool for aggregated TAC advice only, because its algorithm is based on fleet factors. The SMP approach suffers from the same problem. The best solution seems to be to focus on getting better data.

Another criticism by ACFM (ICES 2003c) is that the fishery definitions are very course, and this concern is shared by STECF (STECF 2003b). Considerable scientific effort is currently being directed towards improving fishery definitions (e.g. the EU funded TECTAC project). As long as the "fleets" used in MTAC are rather homogeneous units with respect to their catch compositions MTAC will perform well. A further requirement, if MTAC is to be used for fleet based advice, is that these "fleets" should be manageable as units.

This report highlights that the MTAC method is sensitive to uncertainties in the stock status. The fact that model output changes in response to model input is obviously not surprising, but the key point here is that uncertainty in the status of one or two stocks has implications for other stocks, especially those stocks for which strong technical interactions exist with the uncertain stocks. Uncertainty in stock status is of course to a large extent a data problem, but it may also be due to limitations in the assessment models themselves.

Both MTAC and SMP work under the explicit assumption that historical catch compositions of the fleets will stay the same in the TAC year. This simplification is unrealistic, because it is likely that fleets will change their effort allocation, *e.g.* their spatial distribution of effort, and their species targeting in response to management decisions that entail large changes in TACs or allowable effort. This concern was also expressed by STECF (STECF 2003b). Scientific research will have to work towards predicting these responses and incorporating them in catch forecast models. Several scientific projects are currently ongoing (*e.g.* TECTAC) or about to start (*e.g.* COMMIT) that aim to quantify the relationships between management and fleet behaviour. However, these projects have not yet delivered useable forecasts of fishermen behaviour that could be applied in mixed fisheries forecast models.

As was noted at the end of section 2, MTAC would technically be better if the averaging of the fleet factors were done within the minimalisation procedure, because then the differences between the MS-TACs and the SS-TACs would be minimised to a smaller level.

The MTAC user may be bewildered by the wide range of outcomes that can be generated depending on political choices of options and decision weights. The risk exists that MTAC users will "play around with the buttons" until an acceptable outcome is reached. Therefore, it is important that the MTAC user determines the choices of optional settings and decision weights *a priori* (*i.e.*, before running MTAC), based on explicitly stated general policy rules. I hope that this report gives insight in the meaning of the p- and q- options and the decision weights, such that it helps managers to make these choices *a priori*.

Given these serious drawbacks of MTAC, its merits should be mentioned. The MTAC program could be a fine tool for calculating fleet based effort or catch forecasts, if it could be permitted to exceed respectively undershoot the precautionary approach reference points, and if it could be permitted to ignore relative stability and any political problems associated with penalizing some fleets more than others, and if the data were complete, and if historical catch compositions would remain stable. As such, the program works very well, and, despite its complexity, it is very transparent (to those people who give some effort to understanding it and are not overwhelmed by its complexity). The program does exactly what is said it does in the technical description (Vinther *et al.* 2003).

5. Conclusions

- The MTAC program calculates MS-TACs for each individual species fished in a given area, taking into account the mixed nature of the fisheries, under the objective to approach set targets (such as, *e.g.*, single species advice) as closely as possible.

- The resulting MS-TACs can be seen as a compromise that aims to resolve the conflict that arises when fleets have depleted their quota for some species but not for others while these species are unavoidably caught together.

- MTAC calculates these MS-TACs by first determining fleet factors, which are fleet fishing mortality or fleet effort multipliers. From these multipliers catch forecasts by fleet are derived, which when summed over the fleets add up to the MS-TACs.

- The MTAC program needs some inputs that reflect political choices.

- A political choice has to be made whether to reduce effort of all fleets (1) equally, or (2) proportionally to the species catch within the fleet's total catch, or (3) proportionally to the fleet's catch of a species as a proportion of the total species catch. This feature is called the p-option. Results vary widely depending on this choice.

- A political choice has to be made on decision weights for each species, which determine relative priority of each species for how closely the target has to be approached in the compromise. Results vary widely depending on this choice.

- A political choice has to be made on whether to modify the decision weights according to the fleets' species compositions. This feature is called the q-option. Results vary widely depending on this choice.

- The MTAC program was checked, and it is concluded that MTAC correctly does what it is described to do.

- Scenario runs illustrate the consequences of the inputs such as the set targets, the chosen p- and q-options, and the chosen decision weights. These consequences can be logically understood. This illustration will help the MTAC user to make these choices *a priori*.

- The outcome of MTAC is sensitive to uncertainty with respect to stock status, *e.g*. population size at the start of the TAC year. Uncertainty in one stock may affect results for another stock if strong technical interactions between the two exist.

- The MTAC program was evaluated, and it was found that certain drawbacks exist to its use.

- The resulting MS-TACs do not necessarily conform to the precautionary approach. In other words, MTAC may generate forecasts such that SSB will fall below B_{pa} or F_{pa} will be exceeded.

- The use of MTAC for fleet based advice confronts us with the political consequences of the assignment of heavy restrictions to some fleets and more lenient restrictions to others. This issue relates to the fact that the use of MTAC is not consistent with relative stability.

- The use of MTAC for fleet based advice is unacceptable when, due to incompleteness of the data, the advice is biased such that fleets that discard or underreport suffer less from restrictions than fleets that report all catches.

- In response to the two above points, MTAC's experts have claimed that MTAC is not designed for fleet based advice, but for aggregated TAC advice. However, the program is logically designed to calculate fleet based forecasts. Ignoring the fleet based output is illogical, and using only the aggregated MS-TACs does not resolve the conflict the program was meant to resolve. The conclusion is that MTAC is a tool for calculating fleet based effort or catch forecasts.

- MTAC operates under the unrealistic assumption that the historical catch compositions of the fleets will remain constant in the TAC year.

- MTAC is a transparent model which could be a fine tool for calculating fleet based effort or catch forecasts, if it could be permitted to ignore the precautionary approach and any political problems associated with differentially penalising fleets, and if the data were complete and historical catch compositions would remain stable.

6. References

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