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Report

Number: C019/05

Evaluation of management measures for a sustainable plaice fishery in the North Sea

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Commissioned by: Ministry of Agriculture, Nature and Food Quality and
Dutch Fish Product Board
Drs. J. Paardekooper/ Drs. F. Brocken.

Project number: 316.12686.01

Approved by: Drs. E. Jagtman
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Signature: ____________________

Date: May 9, 2005

Number of copies: 25
Number of pages: 90
Number of figures: 30

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1. Summary

Spawning stock biomass (SSB) of plaice decreased substantially since the late 1980s and the most recent stock assessment shows that the stock has been below the precautionary biomass level of 230.000 tons since 1994. In 2003, the European Commission ordered a recovery plan for plaice and in response, the Dutch fishing industry wrote a proposal in 2004 for a sustainable management in which it suggested a series of possible management measures. RIVO was requested to evaluate and quantify the effects of these measures. This report presents the results of the study. The various questions have been grouped under four headings: 1) discards; 2) spatial distribution and growth; 3) mesh size selection; 4) sketch of management options. The main body of the report gives a comprehensive treatment of the main questions, whereas the annex provides further details.

It is concluded that an effective reduction in actual fishing effort, either by a reduction in the number of vessels, by a decrease in the number of fishing days or by a decrease in the fishing efficiency, will provide the best and most rapid contribution to the recovery of the SSB of plaice. The actual rate at which SSB will increase stays uncertain as this rate depends on the numerical strength of future incoming year-classes and on future developments in growth rate. An increase in mesh size from 80 to 100 mm would theoretically rebuild the SSB of plaice substantially, but with this mesh size it will be difficult to continue the fishery for the more slender but highly priced sole.

The effectiveness of effort reduction will depend on the season in which this reduction is mainly applied. In the spawning period, in particular in January and February, the reduction will have the greatest benefit for the adult fish, which is then concentrated on the spawning grounds in the southern and south-eastern part of the North Sea. The vulnerability for exploitation of under-sized plaice is relatively low in this period. Reducing the discarding of under-sized plaice will best be achieved by reducing fishing effort later in the year, especially in the 3rd and 4th quarter when a new year-class recruits from the inshore nursery grounds to the offshore fishing grounds. It is tentatively concluded that effort reductions could best be applied in the period January-February and evenly spread out during the second half of the year.

Effort reduction may become even more effective if accompanied by Real Time Closure's (RTCs, areas that are temporarily closed by the fishing industry to the fishery when high discard percentages are observed in that area). Although the ultimate effect of a RTC is difficult to quantify, RTCs may prevent excessive discarding when high concentrations of under-sized plaice temporarily occur. To be effective RTCs require full compliance by the industry. In the longer term, the development of more selective fishing gear for sole with

a lower by-catch of plaice may make an important improvement in the sustainable exploitation of North Sea plaice. This may be especially relevant if the growth rate of plaice continues to be low as compared to the more productive 1970s and 1980s.

It is known that high-grading occurs from time to time although no quantitative information is available. Theoretically high-grading may result from quota management that restricts the fishery for one species but allows the fishery for another species to continue. Consequently a reduction in fishing effort contributes to lesser high-grading and to a reduced risk that the fisheries management gets trapped in a spiralling down by under-estimating catches, under-estimating stock sizes, assigning TACs that are too low and thus to more high-grading even.

With regard to effort reduction through decommissioning of vessels, it is likely that the least efficient vessels will leave the fishery first. Over the years the fishing efficiency for plaice in the Dutch beam trawl fleet increased by 1% per year due to the upgrading of the engine and to the replacement by new, more efficient vessels. This effect should be taken into account when assessing the fishing efficiency of the remaining fleet after decommissioning.

2. Samenvatting

De paaibiomassa (SSB) van schol is sinds eind jaren ’80 gestaag afgenomen en uit het assessment van 2004 blijkt dat de paaibiomassa zich sinds 1994 onder het voorzorgsniveau van 230.000 ton bevindt. In 2003 heeft de Europese Commissie om een herstelplan voor schol gevraagd en in een reactie daarop heeft de Nederlandse visserijsector in 2004 een voorstel geschreven voor een duurzaam beheer van het scholbestand. In mei 2005 bereidt de platviswerkgroep van de Noordzee Regionale Advies Commissie (RAC) een voorstel voor. Nederland brengt een voorstel in met als inzet dit tot een advies aan de EC uit te werken. Het Ministerie van LNV en het Productschap Vis (PV) hebben afgesproken dat het bestaande scholinitiatief, dat door de kottersector in november 2004 is uitgebracht, hiervoor als basis dient. Het doel is het bestand boven B_{pa} (230.000 ton) te brengen en daar ook te houden. Het RIVO is gevraagd om de voorstellen uit dit initiatief te evalueren om de effecten op het scholbestand in te kunnen schatten. Naast de concrete maatregelen is er een aantal onderzoeksvoorstellen dat verder moet worden uitgewerkt. Dit rapport presenteert de resultaten van die evaluatie. De voorstellen die geëvalueerd zijn, zijn hiervoor gegroepeerd in vier thema’s: 1) discards; 2) ruimtelijke verspreiding en groei; 3) maaswijdte en 4) evaluatie van managementscenario’s. Deze vier thema’s worden in de hoofdtekst besproken, in de bijlagen worden de vragen afzonderlijk beantwoord en worden meer details over gebruikte methodes gegeven.

Een vermindering van de visserij-inspanning, door vermindering van het aantal schepen, het aantal visdagen of een vermindering van de efficiëntie, draagt het beste bij aan een snel herstel van de paaibiomassa van schol boven B_{pa}. De daadwerkelijke snelheid waarmee de paaibiomassa toeneemt kan niet goed voorspeld worden omdat dit afhangt van natuurlijke factoren zoals toekomstige rekrutering en groeisnelheid. Wanneer in de zuidelijke Noordzee (beneden de tonggrens) met 100 mm gevist zou worden in plaats van met de huidige 80 mm, zou de paaibiomassa van schol aanzienlijk stijgen, maar zo’n visserij is praktisch niet haalbaar omdat er met 100 mm te weinig tong gevangen zou worden.

Het daadwerkelijke effect van een inspanningsreductie hangt af van het seizoen waarin deze reductie wordt toegepast. Een reductie in de paaitijd van schol, en dan vooral in de maanden januari en februari, heeft het sterkste positieve effect op volwassen vissen omdat ze dan geconcentreerd zijn op de paaigronden in de zuidelijke en zuidoostelijke Noordzee. Ondermaatse schol heeft in deze periode juist een kleine kans om gevangen te worden in die gebieden. Discarding kan het meest efficiënt verminderd worden door de visserij-inspanning juist later in het jaar te verminderen (3^{e} en 4^{e} kwartaal) wanneer nieuwe jaarklassen zich op de visgronden begeven. Voorlopig concluderen we dat de visserij-

inspanning het beste verminderd kan worden in de maanden januari en februari en gelijkmatig verdeeld over de tweede helft van het jaar.

Een vermindering van de visserij-inspanning heeft een nog groter effect wanneer het gecombineerd wordt met zogeheten *Real Time Closures* (gebieden die tijdelijk door de visserijsector zelf gesloten worden omdat er grote hoeveelheden (>50% van de vangst) discards gevangen worden). Ondanks dat het moeilijk is om het daadwerkelijke effect van RTCs te kwantificeren, denken we dat ze excessief hoge aantallen discards voorkomen wanneer ergens concentraties ondermaatse vis aanwezig zijn. Daarbij is het belangrijk dat de afspraken omtrent de RTCs door de sector goed nageleefd worden. Op de lange termijn kunnen technische ontwikkelingen, waarbij op tong gevist kan worden zonder veel scholdiscards te maken, een belangrijke bijdrage leveren aan een duurzame exploitatie van de scholbestanden. Wanneer de groeisnelheid van schol op het huidige lage niveau blijft (waardoor ondermaatse schol langer blootgesteld is aan discarding) zijn dit soort ontwikkelingen extra belangrijk.

Een afname van de visserij-inspanning heeft ook tot gevolg dat *high-grading* waarschijnlijk afneemt. Van *high-grading* zijn geen kwantitatieve gegevens beschikbaar maar het kan voorkomen wanneer beschikbare quota voor één soort beperkt zijn en voor een andere soort die bijgevangen wordt, niet beperkt zijn. Het voorkomen van *high-grading* is belangrijk om de kans te verkleinen dat de exploitatie van schol in een neergaande spiraal terechtkomt van onderschatten van vangsten, onderschatten van bestanden, het toekennen van te kleine TACs en het stimuleren van *high-grading*.

Wanneer de visserij-inspanning verkleind wordt door het aantal schepen te verminderen, is het waarschijnlijk dat de minst efficiënte schepen het eerste gesaneerd worden. In de afgelopen 14 jaar is de efficiënte van schepen met gemiddeld 1% per jaar toegenomen door modernisering van motoren en door de vervanging door nieuwe, meer efficiënte schepen. Dit effect moet meegewogen worden wanneer de efficiëntie van de vloot opnieuw wordt vastgesteld na een eventuele vermindering van het aantal schepen.

3. Introduction

In 2004, the European Commission asked the North Sea Regional Advisory Council (NSRAC) for advice "on the implementation of a recovery plan for North Sea plaice and a long-term management plan for sole". In January 2005, the Commission reformulated its request, asking the NSRAC for advice on a long-term management strategy for plaice and sole. In response to the Commission's ideas on plaice management, the Dutch fishing industry wrote a proposal for a sustainable management of the plaice fishery[1] with the purpose to bring the stock above B_{pa}. In 2004, the spawning stock biomass of the North Sea plaice stock was estimated at a level of 187.000 tonnes which is between B_{lim} (160.000 tonnes) and B_{pa} (230.000 tonnes; Figure 3.1). In this document, several measures for a sustainable plaice fishery were proposed such as effort reduction, spatial and technical measures. Such measures were also included in the NSRAC's initial advice on management measures for North Sea plaice of November 2004. Based on this document, the Dutch Fish Product Board and the Dutch Ministry of Agriculture and Food Quality formulated several research questions to evaluate the proposed measures. By answering these questions in the present report the proposed measures are evaluated. In addition to the evaluation of management measures, several research proposals were formulated for new research that should resolve caveats in our current knowledge of the plaice stock. Such caveats are, for example, the explanation for changes in growth rate and the spatial distribution of North Sea plaice.

The complete list of 23 research questions and our answers to these questions is presented in Annex 1. The report, however, was set up along four themes in which all these answers are synthesized. These themes are:

1. Discards (Chapter 4);
2. Spatial distribution and growth (Chapter 5);
3. Mesh size experiments (Chapter 6);
4. Evaluation of management scenarios (Chapter 7).

The time available for executing the project was four weeks and therefore, the analysis for the different questions could not be too extended.

The results of this evaluation will, amongst others, be submitted to the NSRAC flatfish working group meeting to assist its discussion on a long-term management strategy for the North Sea flatfish fishery.

[1] PV notitie 2004242/33.1.1.

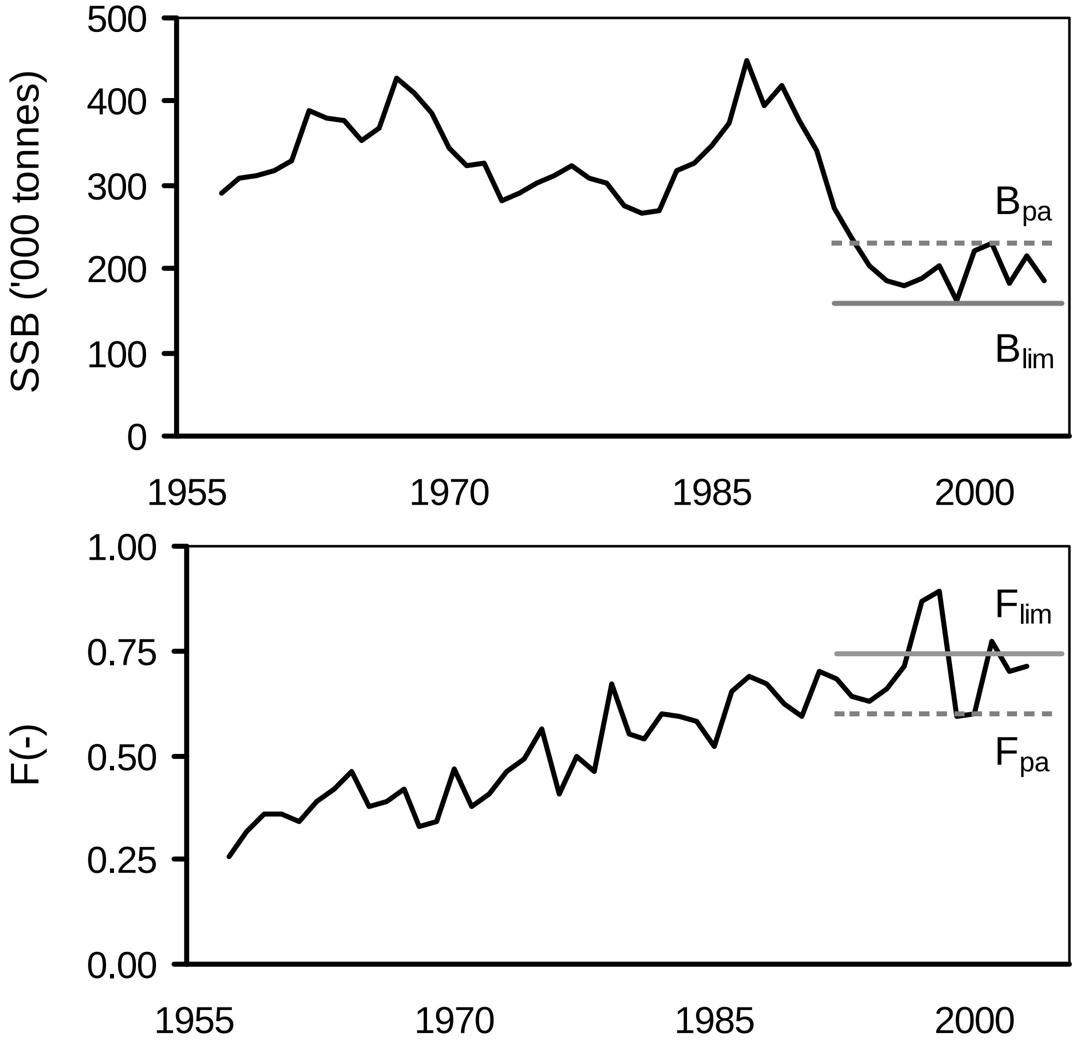

Figure 3.1. *Trends in spawning stock biomass (SSB, upper panel) and fishing mortality (F2-6, lower panel) in North Sea plaice. The horizontal lines indicate the levels of* B_{lim} *and* B_{pa} *and* F_{lim} *and* F_{pa}*.*

4. Theme 1: Discards

In its initial advice on management measures for North Sea plaice of November 2004, the NSRAC concludes that fishing mortality (F) for human consumption (F_{hc}) is further declining, but overall the estimated F is still high, mainly due to discards. In this chapter, we:

1. Analyse discard data collected by the catching industry and compare them with RIVO data;
2. Assess the effect of discarding rates and survival on the outcome of stock assessments;
3. Assess to what extent data from the catching industry can be used in the ICES work;
4. Evaluate the set up of experiments that measure discard survival.

4.1 Analysis of discard data collected by the catching industry and comparison with RIVO data

In the 4th quarter 2004 and the 1st quarter of 2005, seventeen Dutch fishers have sampled their catches in order to determine the percentage of plaice being discarded. On Tuesdays and Thursdays each week, random samples were taken from the unsorted catch at approx. 4:00 pm, and the volume (marketable and discarded plaice separately) determined in a simple bucket. A total number of 288 samples were collected that covered the entire southern North Sea (*Figure 4.1*). During the period of the Dutch fishers sampling programme, three vessels were sampled by the Netherlands Institute for Fisheries Research for discards in a routine sampling programme (Details of this programme are described in Annex 2). During week 50 in 2004 and week 5 and 10 in 2005 two observers from RIVO went onboard a beam trawler, sampling 90% of the hauls for discards and 85% of the hauls for landings. Total discards and landings were collected by weight and converted to total volume. For the discards a ratio of 1 litre to 0.89 kg was used, and for the landings a ratio of 1 litre to 0.83 kg. Results were compared to research samples from the same weeks and areas (119 samples).

The mean percentage of plaice being discarded was 31.8% by volume (34.1% in weight) in the fishers sampling programme and 33.2% (35.6 in weight) in the RIVO programme over the same period. The sheer number of samples of the fishers results in confidence limits as small as 2%: the overall mean is between 30.3% and 33.4% with 95% confidence. The percentages (detailed by week and area) match the RIVO sampling programme perfectly: the 1% difference is well within the confidence limits. Evidently, the fishermen’s sampling results in accurate and reliable data.

For the fishermen's sampling programme, the number of samples per week-trip (2) is low in comparison to typical research sampling (35-40). Since the variation among samples within week-trips is negligible in comparison to that among week-trips, the set-up of a low number of samples taken over a large number of week-trips is statistically preferable. Practical considerations (staff and transport limitations) so far made this statistical preferred set-up unfeasible for the RIVO surveys.

The wide coverage of the fishermen's sampling programme enables for the first time an analysis of spatial and temporal patterns in the discarding process. The observed spatial pattern (*Figure 4.2*) indicates a large variation in discard percentage, ranging from 11 to 50% in volume, while the observed temporal pattern (*Figure 4.3*) shows variation from 16 to 53% in volume. Disregarding the spatial and temporal patterns might therefore lead to serious misjudgement of the overall magnitude of the discarding process.

The current analysis assumed that major variation in discard percentages was related to differences in the fishing and handling processes between ships (*Figure 4.4*). Future extension of the data set will be required to discriminate between this assumption, and the alternative of even larger spatial variation. Meanwhile, however, it will be worthwhile to break the anonymity of the participating fishermen, and consider what technical details might explain the observed inter-ship variation.

Monitoring of the discarding process requires sufficient spatial and temporal coverage and adequate detail in the measurements (e.g. length composition). The fishermen's sampling described here covers the spatial and temporal variation, while typical research sampling yields the required level of detail and ensures the quality of the data. The spatial-temporal pattern of the sampling programme determines the estimated discard percentage that is used in the stock assessment models. Therefore, it is important to pay attention to a representative sampling programme. The combination of both sampling programmes will achieve an adequate result.

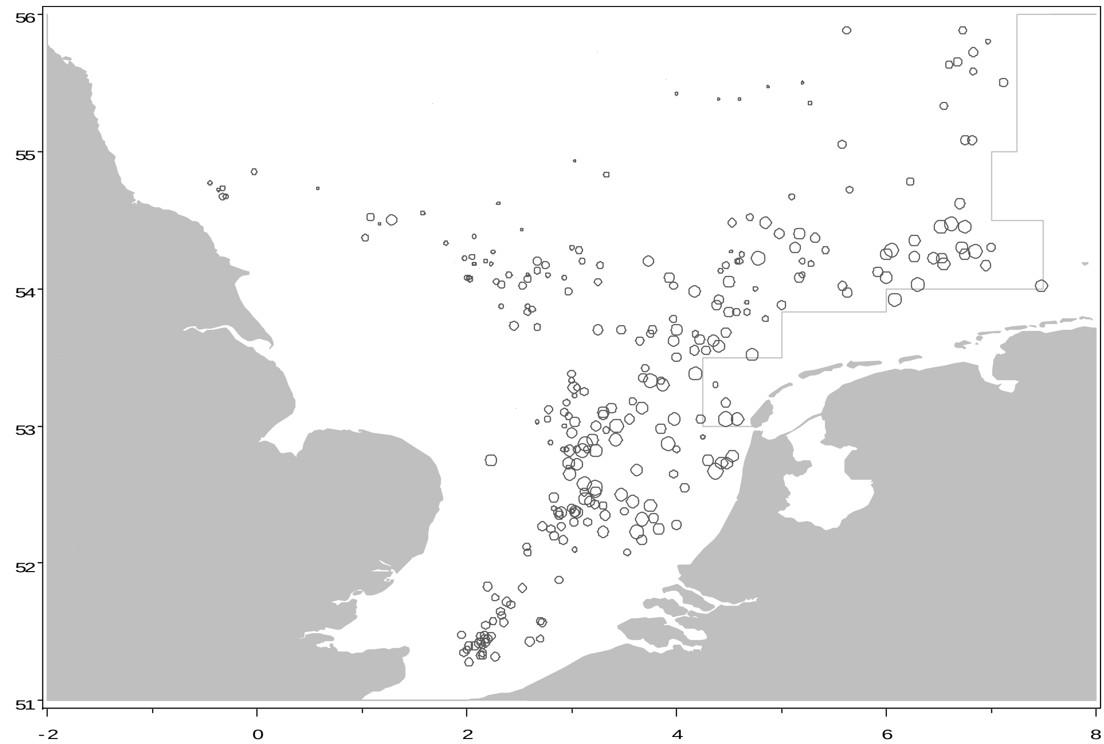

Figure 4.1. *Graphical presentation of the fishermen's discard sampling. Symbols are proportional to the percentage of the catch being discarded. Note that these data are not corrected for the type of fishing gear, or the time of sampling.*

Figure 4.2. *Spatial pattern observed in the discard samples: the discard percentage of the catch volume of an average beam trawler, after correction for the variation between ships, and the week of sampling.*

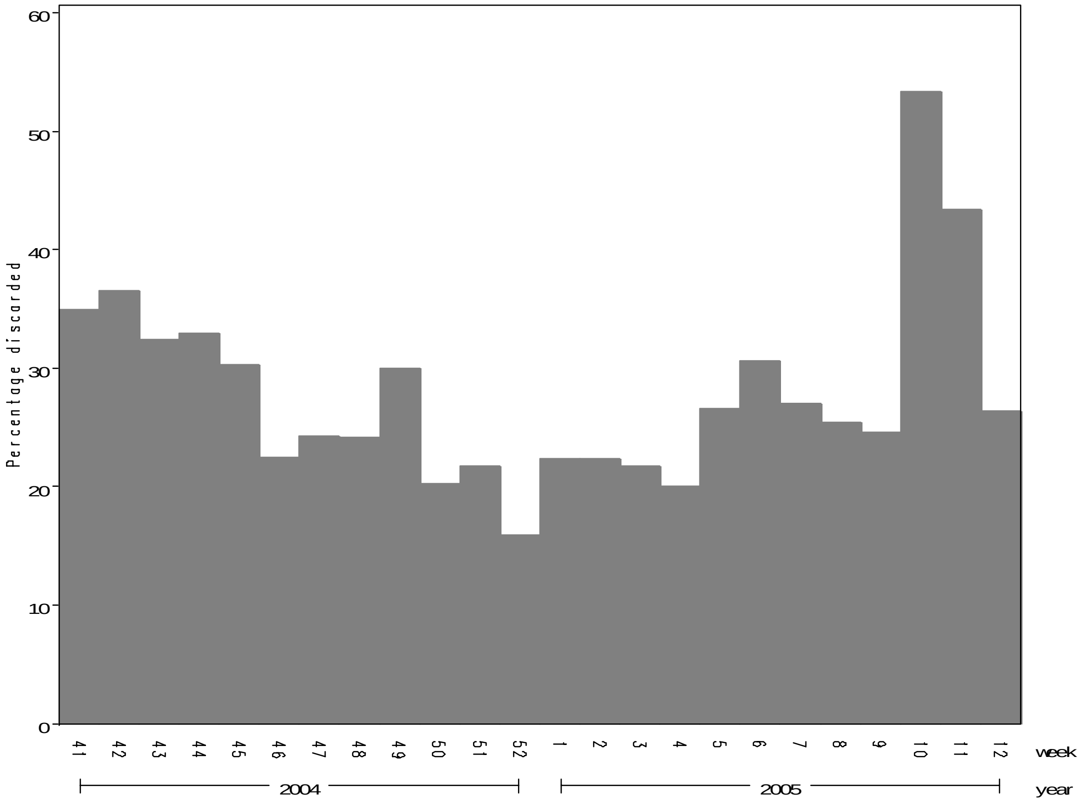

Figure 4.3. *Temporal pattern observed in the discard samples: the discard percentage of the catch volume of an average beam trawler, after correction for the variation between ships, and the area the sample was taken from.*

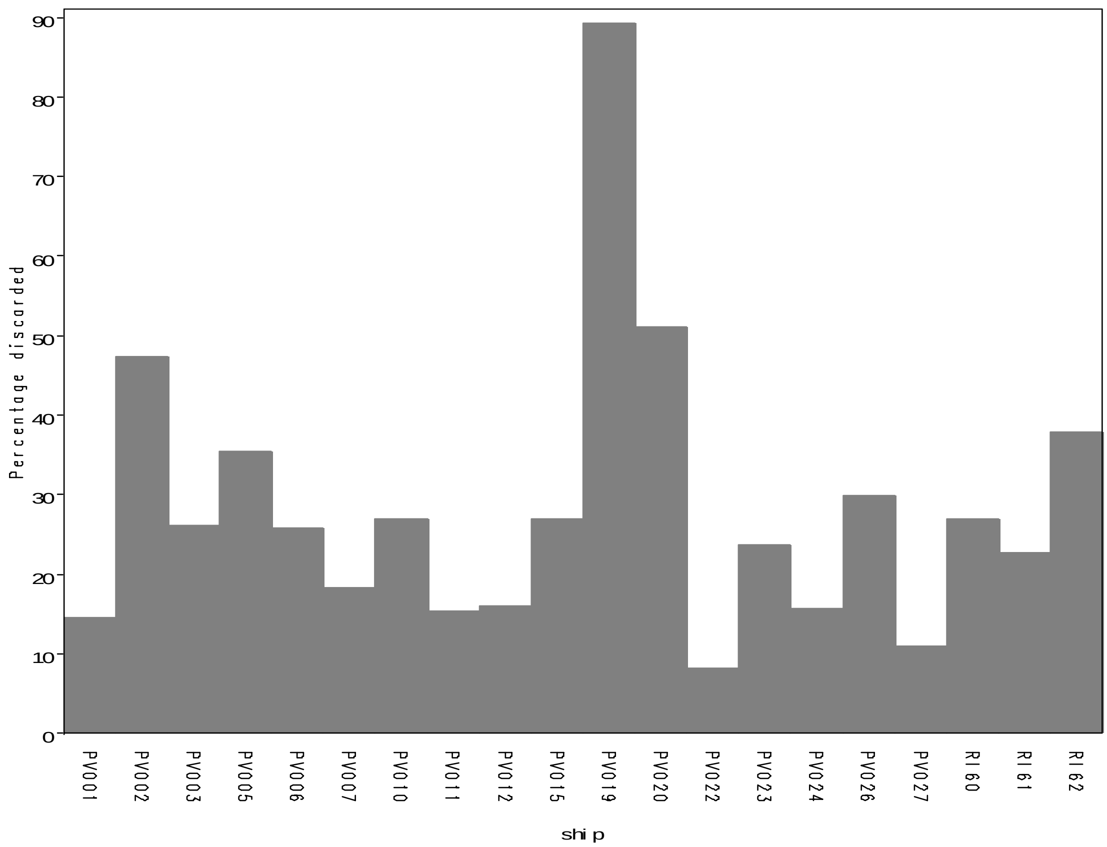

Figure 4.4. *Variation in discard percentages (in volume) observed between ships: the discard percentage per ship, after correction for the variation between areas and over the weeks. The ship codes have been anonymized. The latter three ships are those sampled by RIVO.*

4.2 Assessment of the effect of discarding rates and survival on the outcome of stock assessments

The fishing industry has criticised the accuracy of the stock assessment, and questioned in particular the effect of discard levels on the estimated level of spawning stock biomass and fishing mortality rate. We therefore explored the effect of varying levels of discards on the outcome of the stock assessment. This addresses the question if our current estimate of the spawning stock biomass would be different if discarding levels are different than we assume.

The calculations showed that the effect of discard levels on the stock reconstruction is rather small in comparison to the historical variation in the level of SSB (Figure 4.5). For example, with estimated discard numbers being 30% lower than at present (a multiplier of 0.7) the effect on SSB is negligible and the effect on F small. Similarly, a small effect was found for varying discard survival rates (Figure 4.6). Details of this analysis are presented in Annex 3.

Note that in the stock reconstruction, the estimated SSB *decreases* when discard rate is assumed to be lower. Thus, if the current estimates of the discard rate as used in the assessment were too high, the SSB of plaice would be even lower than we think now. This is an important notion, since it is a counterintuitive one. Intuitively one would think that with lower discarding levels SSB levels would be higher. However, in the case of stock assessment historical SSB levels are reconstructed based on historical catches. In the assessment calculation SSB is simply the sum of the estimated catches (landings + discards) after correction for the natural mortality. Thus, with lower estimates of discards, or a better survival of discards (in this case the discards survive and will not be extracted from the population), the sum of the historical catches, and hence the SSB, will be lower. Note that in the stock assessment (which is a reconstruction), the estimated F will also *decrease* with a *decreasing* discard rate. Thus, if discard rates estimated by the sector would have been lower than those estimated by RIVO, and these rates would have been used in the assessment model, the F of plaice (human consumption + discards) would be lower than we think now.

It is important to appreciate that discard rate and survival only have a modest effect on the stock *reconstruction* (hind cast) but are very determining factors for the future of the plaice stock (forecast). Opposite to the hind cast, a *decrease* in discarding will in the future lead to an *increase* in SSB. The very effect of discarding percentages on a sustainable plaice fishery in the future is illustrated in Figure 4.7. If the ratio of the discard-F to the landings-F stays the same as it is at present (upper panel), the risk to fall below B_{lim} in 2010 exceeds 5% already when fishing takes place at a landings-F of 0.3 and higher (red line). On the other hand, if the ratio of the discard-F to the landings-F is halved compared to what it is at present (lower panel), even fishing at a level of up to a landings-F of 0.4 will still keep the risk of falling below B_{lim} in 2010 below 5% (red line). At the same time (lower picture), the landings in the first three years (blue dotted lines) as well as in 2010 (blue solid lines) will be higher (compared to the upper picture) and the discard percentages (in weight) lower (compared to the upper picture). The lower picture can be interpreted as decreased discarding due to any form of technical measures, but also as increased survival of the discards. In the latter case the percentages represent the percentages of dead discards.

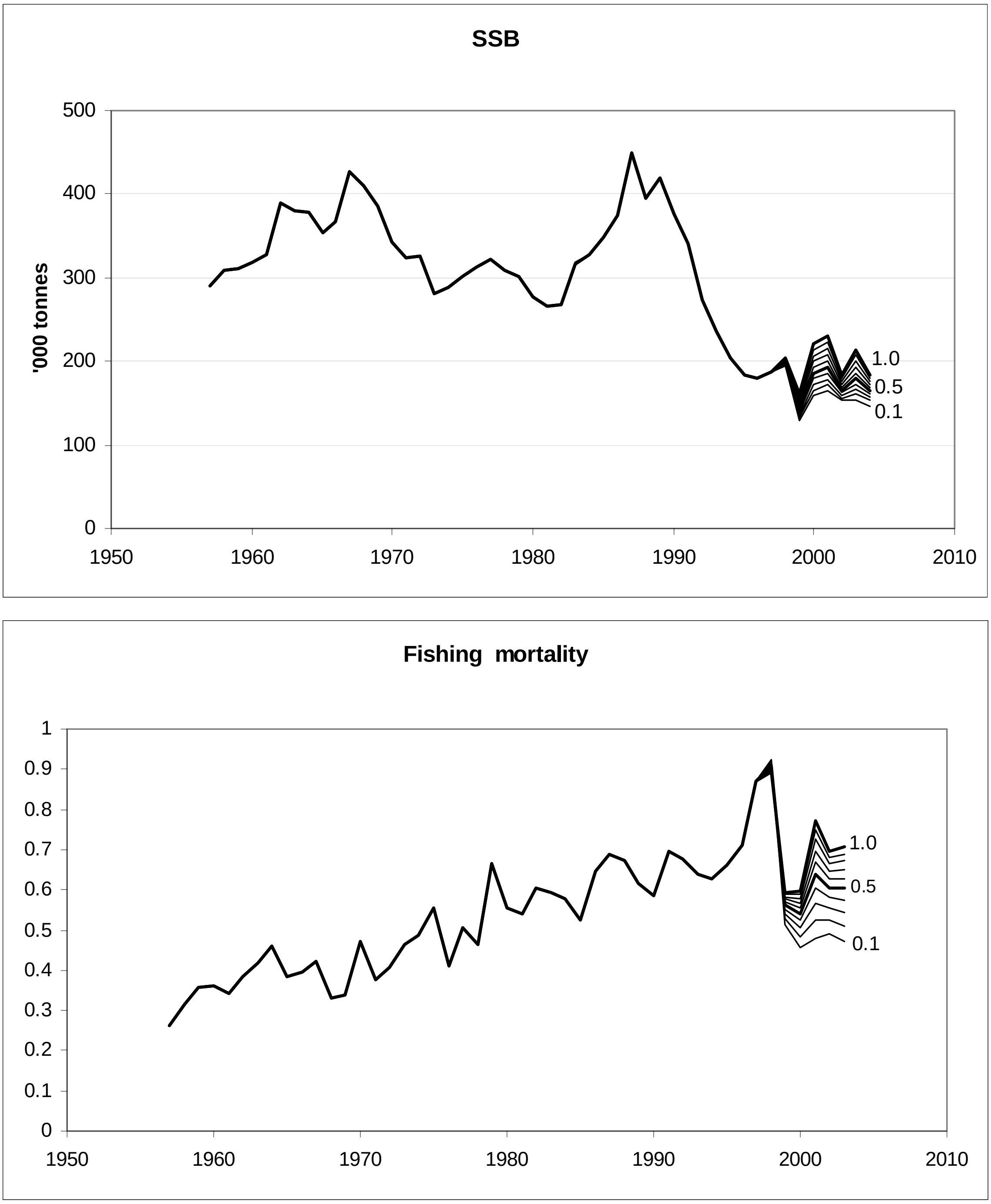

Figure 4.5. *The effect on the outcome of the stock assessment of varying multipliers (0.1 – 1) on the discard numbers at age in 1999-2003. Upper panel: Spawning stock biomass (SSB). Lower panel: Fishing mortality (F).*

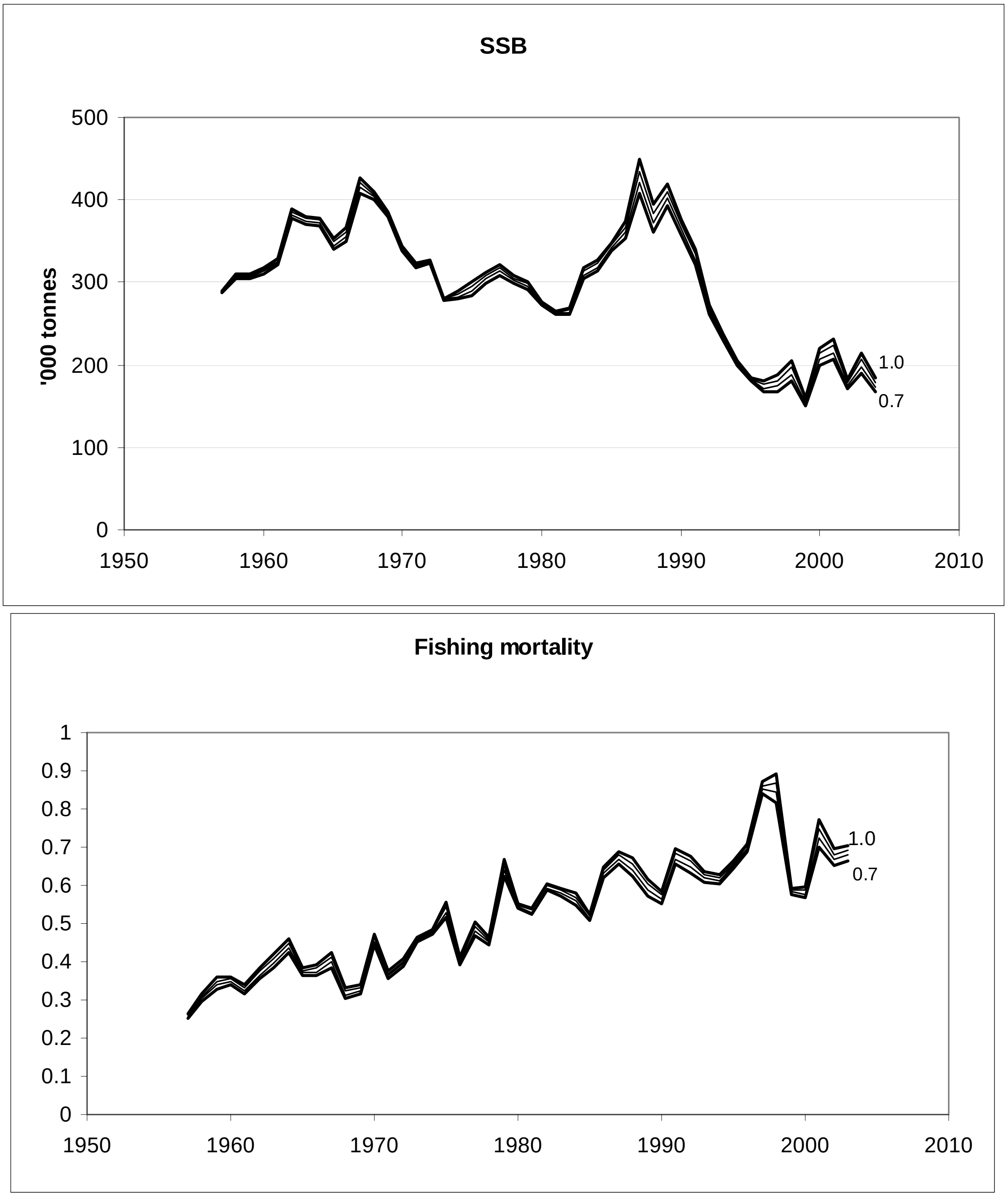

Figure 4.6 *The effect on the outcome of the stock assessment of varying multipliers, in this case to be interpreted as varying discard mortality, (0.7 – 1) on the discard numbers at age over the whole time series. Upper panel: Spawning stock biomass (SSB). Lower panel: Fishing mortality (F).*

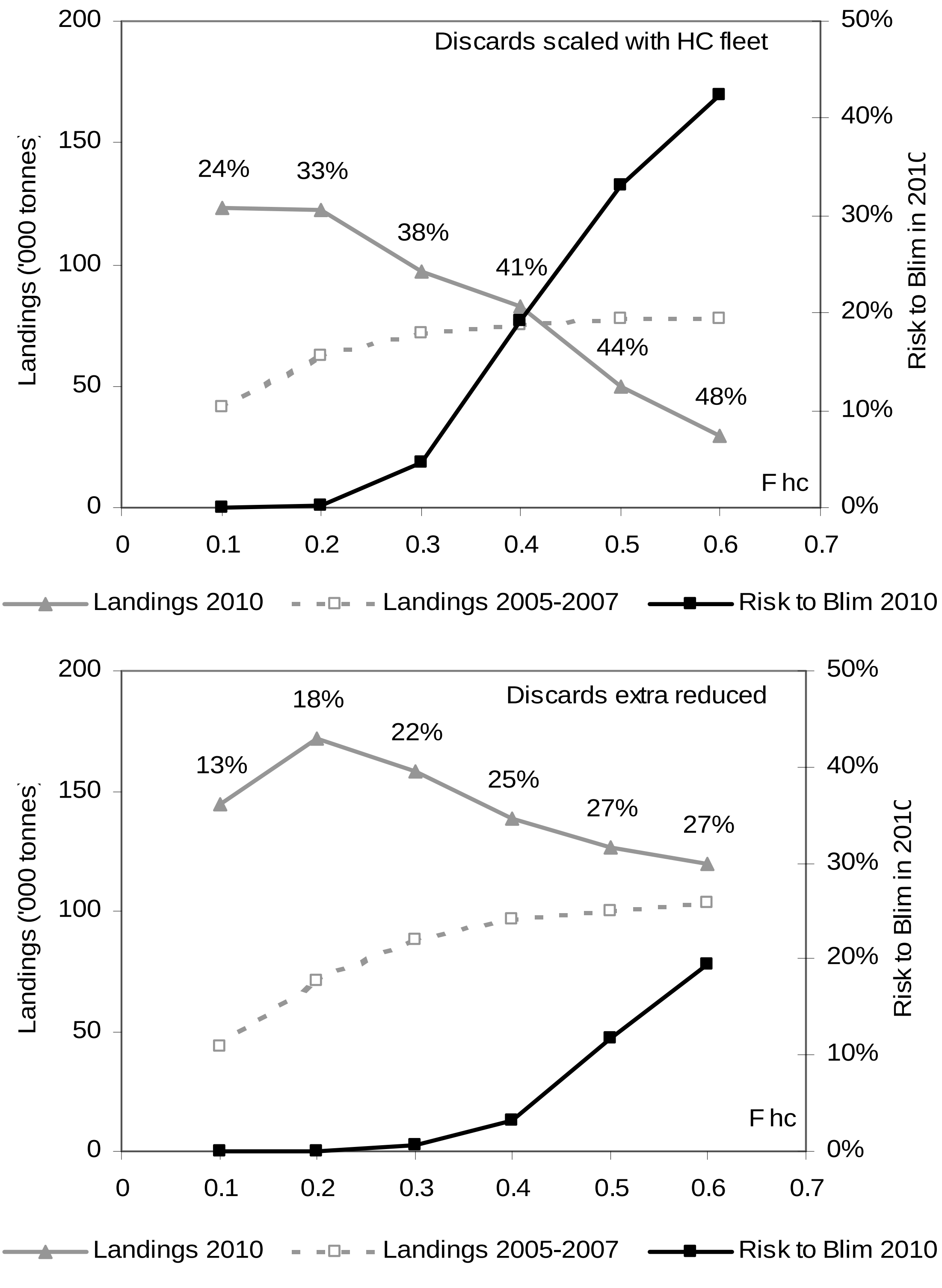

Figure 4.7. *Results of STPR3 analysis for North Sea plaice (see: report of the ICES Ad hoc group on long term management, 12-13 April 2005 Copenhagen). Two scenario's. Top graph: different fishing mortalities for human consumption landings (F_{hc}) where the discards mortality is scaled by the same multiplier as applied to the human consumption fishing mortality. Bottom graph: same, but discard mortality is halved before being multiplied by the multiplication factor. Shown are the risk to B_{lim} (160 000 t) in 2010 (black line), the median of the average landings during the first three years of the simulation (2005-2007, dotted grey line) and during 2010 (solid grey line), and the median of the percentage discards (in weight) in 2010 (percentages on top of the solid line).*

4.3 Assessment to what extent data from the catching industry can be used in the ICES work

The discard data from the fishing industry can in principle be used in the ICES work in two ways. Firstly, the raw information can be presented in the report of the ICES WGNSSK in the form of tables and/or graphs. Secondly, it may be desirable to process the information to make it suitable for use in the stock assessment model. However, in the latter case it is necessary that length measurements be carried out on the sampled discards and that length measurements of the landings are taken or that the landings by market category of the sampled vessel are made available. Only then a suitable procedure can be developed to estimate the age composition of the discards. The uncertainty that arises from including the data from the sector should then also be investigated. More details can be found in Annex 4.

It should be noted that even if the fishing industry would start carrying out length measurements right now, the first full data year that includes these data would be 2006. These data can then first be used in the stock assessment of 2007.

4.4 Evaluation of the set up of experiments that measure discard survival

Survival of plaice and sole discards in the beam trawl fishery has been studied by the Netherlands Institute for Fisheries Research (RIVO) since 1972 (Van Beek *et al.* 1990). The method used, that can be applied onboard commercial vessels, is described in detail in Annex 5. For the current project, the results and methods of these survival studies are discussed (details also in Annex 5). A literature study was carried out in order to investigate what kind of methods are used in survival experiments at other institutes and whether there were possibilities for improvement in our methods (details in Annex 6).

Many survival studies used a similar approach as the RIVO approach. Several aspects that are useful for improvement of our studies were addressed by searching relevant literature. In most experiments the density of fish in the experimental set-up is lower than in the approach used by RIVO. From one study (Millner *et al.* 1993) it appeared that high densities of fish could have a negative effect on survival of fish. In most methods applied water quality is monitored during the experiment as large variation in temperature, salinity and oxygen levels may lead to lower survival. Fish used for experiments are not always separated into groups with different damage levels. We think it is important to make this separation in order to know how severely damaged fish are. Moreover, the separation allows for a stratified selection of fish to be used in the survival experiments which gives a more accurate estimate of the survival rate of the total catch. If fish are put in survival experiments after classifying their damage, it is of less importance if their damage is classified similarly in different experiments. Furthermore, it is recommended to carry out an autopsy on dead fish. Measuring trends in the level of stress hormones during the experiment gives insight in the stress that is caused by the experiment itself. If the experiment causes no additional stress, concentrations of these hormones should decrease and level out. This provides information whether the fish died due to the fishing or due other reasons such as inappropriate experimental conditions. To measure stress hormones, blood samples should be taken which is labour intensive and can be better carried out on board research vessels or in experiments on land.

Two other types of studies were found: experiments at research sites and tagging experiments. When fish under investigation are transported to a research site, the advantage is that the fish can be studied under more controlled conditions. However, disadvantages are that the experiment cannot start immediately after the catch and that it is much more expensive than studies onboard vessels. Tagging experiments can be used to estimate long-term survival. Fish that are tagged are treated similarly to those that are normally caught and discarded. As a control, some fish can be collected under optimal conditions, i.e. through short hauls of 15 minutes and optimal treatment on board. Because survival of these fish is also influenced by the catching and handling process too, these results are not representative for natural mortality rates and the usefulness of this comparison is limited. The fish in these experiments stay in their natural habitat, but many fish are required, it is unknown what happens exactly under water and tagging experiments are expensive.

Conclusions

For estimation of survival in the beam trawl fishery on board of beam trawlers, it is preferable to stick to the method used by Van Beek *et al.* (1990), because this seems the most feasible and least expensive. However, some improvements could be made to the experimental set-up:

- Temperature, oxygen and salinity should be measured;
- The density of fish should be decreased, the optimal number should be determined but as a start we suggest 5 fish per tank;
- The autopsy should be done more thoroughly: did the fish die of the damages by the net, or by the experiment (e.g. lack of oxygen, high variation in temperature).

5. Theme 2: Spatial distribution and growth

5.1 Introduction

The spatial distribution and growth rate of under-sized plaice is highly relevant for the exploitation pattern of the plaice stock. Discard mortality is determined by the level of fishing effort, the distribution of the discard size classes relative to that of the fishery and to the duration of the pre-recruit phase. The latter is directly determined by the growth rate. Changes in the pre-recruit phase alter the period that an individual is exposed to discarding during its life. Recently, significant changes in both the spatial distribution and growth rate of plaice were observed (Van Keeken *et al*. 2004; Rijnsdorp *et al.* 2004). Based on survey data, Van Keeken *et al*. showed that the significant changes in the spatial distribution of plaice were particularly pronounced in the 20-29 cm and the 30-39 cm length classes (minimum landing size of plaice is 27 cm). They could not explain this movement unambiguously but addressed the offshore movement primarily to the increased water temperature in summer (Van Keeken *et al.* 2004). Rijnsdorp *et al*. (2004) showed that length at age increased since the mid 1960s to reach an optimum in the mid 1970s. Since the mid 1980s, length at age decreased to a level intermediate between the low level around 1960 and the high level around 1975. They concluded that the productivity of the southeastern North Sea for flatfish has decreased over the last two decades, possibly in relation to a decrease in the inflow of nutrients and an overall change in the North Sea ecosystem (Rijnsdorp *et al.* 2004).

To reduce discard mortality, a partially closed area was established (Plaice Box) in 1989 in the coastal waters along the continental coast. The North Sea flatfish fisheries generate considerable numbers of discards, especially of plaice in coastal waters, of which the survival is very low. The beam trawl fishery in the Plaice Box was prohibited for vessels larger than 300 HP. From 1989 to 1995 beam trawlers larger than 300 HP were prohibited for part of the year and since 1995 all year round. Smaller beam trawlers (<= 300 HP) were still allowed to fish in the area. Because the Plaice Box encompasses the major nursery grounds of North Sea plaice, it was expected that, at the same rate of exploitation and the same level of larval production and growth rate, the introduction of the Plaice Box would enhance recruitment, yield and spawning stock biomass.

From the evaluation of the Plaice Box it became clear that the effectiveness of the Plaice Box has decreased, because the spatial distribution of young plaice has changed since the box was installed; juvenile growth rate had decreased and juveniles leave the coastal waters at a younger age (Grift *et al*. 2004). Consequently, a smaller proportion of the juveniles is now protected by the box. Whether this development is a reaction to decreased food availability or increased water temperature or other factors is unclear.

The idea of the Plaice Box was that a reduction in fishing effort in the nursery areas of plaice would lead to a better survival of juvenile flatfish and an increase in marketable fish. Both biologists and fishermen expected that the installation of the plaice box would increase the spawning stock biomass and the yield. The box did, however, not show the desired effect: the spawning stock biomass of North Sea plaice varied around the 300 thousand tonnes until 1989, the year in which the Plaice Box was established, after which it declined sharply to below 200 thousand tonnes where it has since remained (Figure 1.1). Fishermen believe that the food availability for plaice has decreased as a result of the reduction in bottom disturbance. This would lead to slower growth rates in young plaice and an earlier movement towards deeper water to look for food. Because of the higher fishing intensity further offshore, the increased risk of discarding would lead to a decrease in survival of young fish. However, changes in growth and dispersal might also be explained well by an increase of water temperature and a decrease in nutrients. The possible positive and negative effects of the Plaice Box are summarized in Figure 5.1.

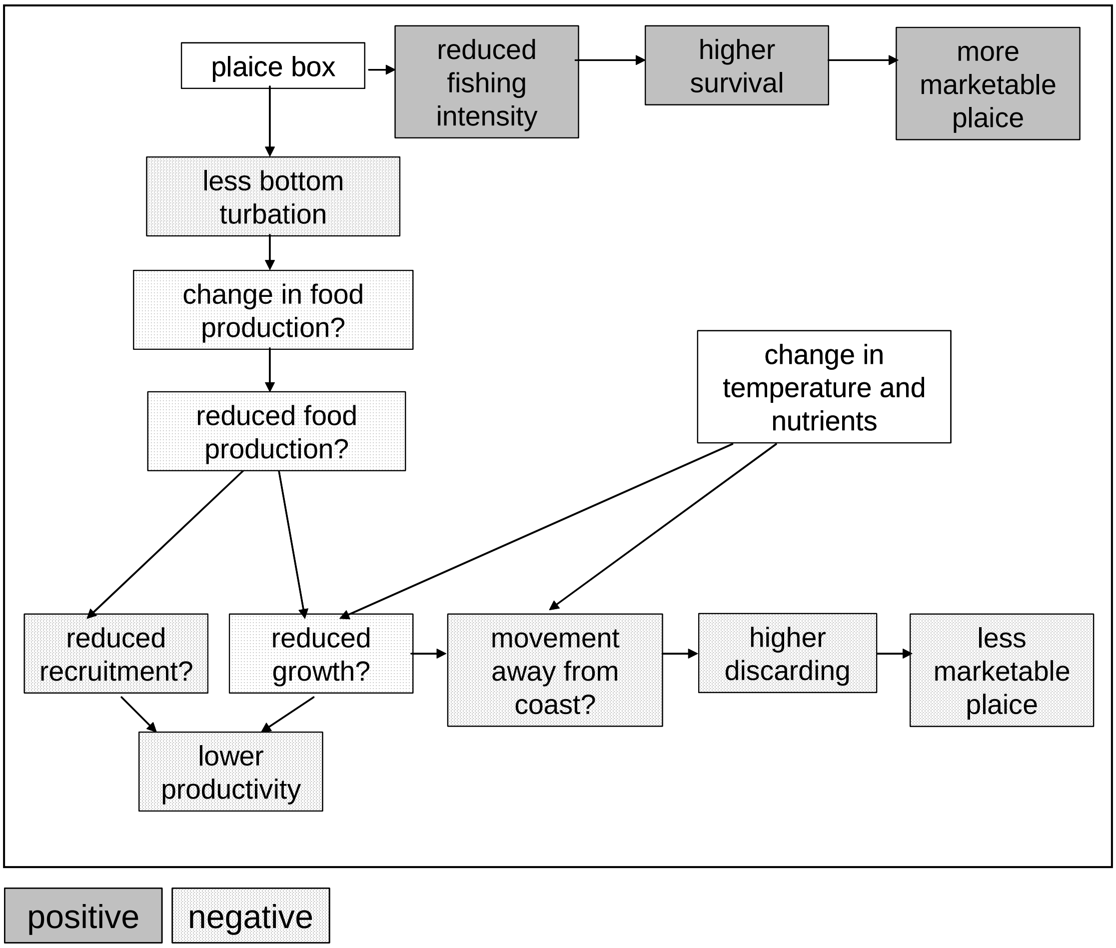

Figure 5.1. Schematic overview of possible positive and negative effects of the Plaice Box.

In this chapter we describe the additional research that should be executed to answer the caveats in knowledge about the changes in spatial distribution and growth rate of North Sea plaice. Also, we describe how questions that remain unanswered after the 2004 evaluation of the Plaice Box could be addressed. Because the research questions about spatial distribution, growth rate and the Plaice Box are so intricately linked (Figure 5.1), they will be described simultaneously. These issues are described in more detail in Annex 9.

5.2 Proposal to measure the effect of the Plaice Box

As was concluded by the 2004 evaluation of the Plaice Box, a good evaluation can only be achieved within an experimental set-up, which allows for the separation of autonomous developments and the partial closure of the area (Grift *et al.* 2004). In such an experimental set-up, some areas should be fished intensively while others should become 'no-take' zones ("chessboard set-up"). Only in this way we ascertain that there are reference areas that can be used to compare developments in the fished areas. Such a set-up provides opportunities to test the effect of a closed area experimentally. Ideally, such a set-up should have been chosen beforehand, but now, 16 years after the box was installed, a similar experiment could be started.

1. Using a chessboard set-up, a possible **negative effect** of the closed area (lower benthic productivity due to the lack of trawling disturbance) can be investigated. Annual surveys of benthic fauna and fish in both fished and non-fished areas are needed. This set-up can also be used to investigate the effect of bottom trawling on food abundance for plaice. In combination with food choice studies of plaice this can provide insight in how diet is influenced by food availability.
2. A set-up to experimentally show a **positive effect** of a closed area (better survival of undersized plaice) is more difficult. This can only be proven if an increase in recruitment originating from the non-fished areas can be shown. Such an increase would occur if survival rates of juveniles in the box would be higher than outside the box. However, the number of settling demersal plaice is highly variable due to variable mortality during the pelagic phase and the pre-recruit demersal phase (discard mortality, predation, diseases). Therefore the critical test for the evaluation would be if the cumulative discard mortality until the time when the cohort reaches the minimum landing size has decreased as a result of closure. Although it is not possible to prove this statistically, indications of a positive effect can however be derived from the set-up mentioned above by comparing densities of juveniles in the different areas.

For these ‘chessboard-like’ studies, an extensive set-up with a large budget (~3-4 M€) is needed. The large budget is mainly caused by the high-resolution sampling programme of benthic fauna. The identification of benthic fauna is very labour-intensive. To cope with inter-annual, natural variation, observations should last at least three years.

5.3 Proposal to explain changes in growth and spatial distribution

In addition to studies on the effectiveness of the Plaice Box, detailed analysis of growth and spatial distribution could provide relevant additional information on the underlying processes. This can be done by:

1. Analyses of existing data on the spatial distribution of plaice and water temperature data. These observational studies that can describe patterns in the spatial distribution of plaice, should be combined with physiological models to explain these patterns (what is the physiological benefit for a plaice of 20 cm to move 1 kilometre to reach an area with a 1° lower ambient temperature);
2. A field study by the fishing industry to the relation between the spatial distribution of plaice (undersized and marketable sized fish) in relation to the water temperature at the fishing ground. A research fleet of fishing vessels record water temperature during every haul and record the catch rate and size distribution of their catch. This idea was also proposed in the so called ‘F-project’ in which the sector cooperates with researchers, it deserves serious follow up. This would result in a large dataset with a high geographic resolution that can be used to investigate effects of temperature on distribution;
3. Derive information from the experimental set-up as mentioned above: distribution of different age classes in fished and non-fished areas;
4. Experimental laboratory studies of the effect of temperature and nutrients on growth could be considered in a later stage to address remaining questions from studies 1-3.

6. Theme 3: Mesh selectivity

Accurate selectivity parameters are important to predict the effect of mesh size measures on the catch composition. Beam trawl selectivity parameters currently used in fisheries research are likely to be outdated. These parameters were estimated in selectivity experiments carried out around 1980. Since those experiments were executed, many technical changes have taken place, which could have led to changes in the selectivity of the nets. It is unknown to which extent the selectivity has decreased. The Dutch beam trawl fleet wants to carry out such experiments and has requested a research proposal. The different options for such selectivity experiments are outlined below whereas more details are presented in Annex 8 and 9.

In order to assess the need for new selectivity experiments, we can start with comparative fishing experiments on board of commercial fishing vessels. If the results from these experiments indicate that selectivity parameters could have changed, new selectivity experiments could be taken into consideration. Because such experiments are rather expensive, there must be good reasons to start them.

Experiments

There are several ways to measure mesh selectivity. The two more simple approaches are: comparison of the catch composition of vessels using different mesh sizes by trip (Annex 8) and; comparison of the catch composition in different mesh sizes in parallel hauls (Annex 9). The most detailed approach is to directly measure the proportion of fish that escapes through the meshes using covered cod-end or brook nets. It depends on the available budget and the desired output which of these experimental set-ups is chosen:

By trip

Size categories of the landings are registered by week for 3 vessels that each fish with different mesh sizes: 80, 90 and 100 mm. This experiment gives a rough idea of the differences in catch composition by trip between different mesh sizes. Possible vessel, area and time effects are not taken in account. The experiment takes at least 5 weeks and fishermen themselves collect the data. Costs will be made for manufacturing nets with different mesh sizes and for data analyses (costs for analyses approx. 6000 euros).

By haul

Length distributions of discarded and landed fish are measured by haul onboard one vessel. This vessel fishes with 2 different mesh sizes at a time: with 80 mm as a reference net on one side and 90, 95, or 100 mm on the other side. After each haul, the length composition of the catches from both sides is measured separately. The number of species under investigation has to be limited to decrease the amount of work. Focus will be on plaice and sole. Information is gained on the catch composition by haul. Effects of vessel characteristics, area or time on the difference in catch composition do not have to be taken in account. The experiment takes 3 weeks, in each week another combination of nets is tested. In each week, at least 20 hauls should be carried out. Costs will be made for manufacturing nets with different mesh sizes and for data analyses (approx. 10000 euros).

Direct measurement of fish escaping through the meshes.
With this approach the fish that escape through the meshes are retained in a wide small meshed cover, or is inferred from the difference in length composition of two cod-ends fixed to a similar front net. This approach is rather costly and is only relevant if there are strong indications that the selectivity parameters of the current fishing gear have changed sufficiently well. This approach is presented in more detail in annex.

Number of observations
In order to give a good estimation of the required number of observations, more information is needed on the variation in catch composition between trips, hauls and starboard/port side of a vessel.

7. Theme 4: Evaluation of management scenarios

In this chapter we will evaluate the effect of seven management scenarios:

1. Real time closures;
2. Effort reduction in the spawning time;
3. Increasing the mesh size;
4. Effort reduction;
5. Efficiency reduction of Euro cutters;
6. Move 30% of the effort below 55° to the North;
7. The integration of several management measures.

Scenarios 1 and 2 were evaluated by analysing existing data. The potential effects of management measures 3-7 were quantified by developing a spatially explicit simulation model. The model, and its results will be described in section 7.3.

7.1 Real time closures

Real Time Closures (RTCs) are imposed when high discard rates of >50% (in terms of weight) are being reported in specific fishing areas. This may occur as undersized plaice temporarily form high concentrations or when a strong year class recruits to the fishing grounds. When these discarding percentages are reported, the area may be closed for vessels fishing on flatfish with mesh sizes of 80 mm and larger for a period of two weeks. The idea of RTCs was implemented by the fishing industry on August 1st 2004 to contribute to the management of North Sea plaice. In 2004, RTCs were established four times during a period between 2 and 4 weeks in an area of approximately the size of one ICES rectangle. The fishermen estimated that in each area, approximately 15-25 vessels were fishing just before the closure. Cooperation to these RTCs is on a fully voluntary basis but during the closure, only one ship was observed in the closed area (it left the area immediately after it was asked to do so).

The effect of Real Time Closures on the overall reduction in discards is difficult to quantify but it can be argued that the RTC will always lead to a reduction in discarding. We used the discard data collected by the fishing industry to estimate its effect, using the observed frequency distribution of discard percentages in the Dutch beam trawl fleet (Figure 7.1). The following assumptions were made:

1) This sample is representative for the fleet;
2) After the RTC has been established, all fishing trips with a discard percentage above 50% are relocated to a nearby fishing ground with a discard percentage of 50%;
3) The observed discard percentage estimates the true percentage without error.

Using these data, we estimate that if Real Time Closures would be implemented in all occasions when discard percentages were >50%, the mean discard percentage in the sampled trips would be reduced by almost 7% from 30% to 28% (in volume).

The effect of the RTC will be strongly affected by the frequency distribution of discard percentage in the fisheries. If undersized plaice are more abundant due to a strong year class, discard percentages >=50% will occur more often and RTCs should be established more frequently. As we assumed that RTCs are imposed in all cases where the discard percentage exceeds 50%, there is full compliance and the observed percentages by the fleet are exact, our estimate can be considered to be a *maximum effect that applies to the current situation* (2004-2005). If there is no full compliance and if RTCs are not imposed in all cases, the effect will be less. Finally, it should be noted that RTCs will be particularly effective to protect a strong year class from excessive discarding, although this may imply that a RTC needs to be established more frequently, for longer time periods and larger areas.

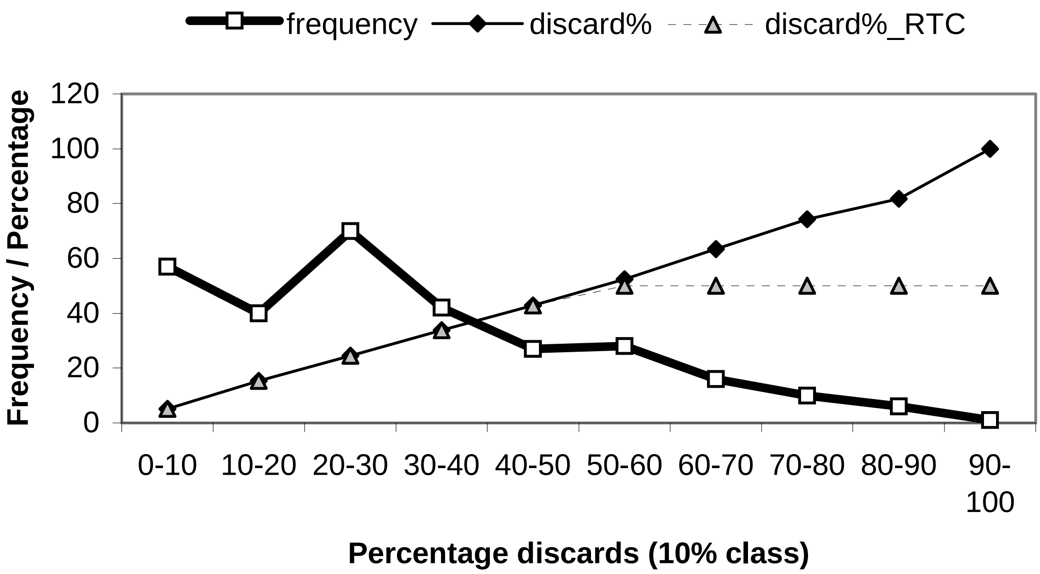

Figure 7.1. *Frequency distribution of reported discard percentage (in volume) in 297 samples of the Dutch beam trawl fleet between October 2004 and April 2005. The thin line with the black diamonds shows the mean discard percentage by 10%-class observed (discard%). The thin line with the grey triangles shows the discard percentage assumed under the Real Time Closure scenario (discard%_RTC). In the RTC scenario, we assumed that vessels with discard percentages >50% would move to near by areas where discarding would be 50 %. From the frequency distributions in the normal and the RTC scenario, the average discard % can be estimated. In this example, the RTC will result in an almost 7% decrease in the mean discard percentage from 30 to 28.*

7.2 Effort reduction in the spawning time

There are two lines of argument that support a positive effect of a reduction in fishing activities during the spawning period of plaice. The first argument builds on the biological insight in the spawning process. If the fishing activities occur on the spawning grounds, mating may get disturbed by the fishing activities leading to less or even unsuccessful reproduction. Recent studies have stressed the importance to include behavioural considerations into fisheries management. It is well established that the older females contribute disproportionally to the next generation because they produce eggs of higher quality, start spawning earlier in the season and spawn more batches of eggs over a longer time period. In addition to the disturbance effect, fishing on the spawning ground may remove adult fish that are about to start spawning. Although it is very difficult to quantify these processes, they all point into the direction of a negative effect of fishing on the production of viable eggs and hence on the effect of fishing on the subsequent recruitment to the stock. For fish stocks that are well below the precautionary level of spawning stock biomass, a reduction of the fishing activities during the spawning time may be particularly important to protect the spawning potential of the adult population.

The second line of argument builds on the catch efficiency of the fishing operations. As plaice is concentrated on the spawning grounds, the mortality rate induced per day at sea peaks (Figure 7.2). Hence, a reduction of the fishing effort in the spawning period will have a strong effect on the reduction of the removal of the adult fish from the population, which are, as we have shown above, more important for the production of viable offspring. From the presence of spawning fish in the commercial landings, we can show that egg production in the southeastern North Sea mainly occurs in January and February, although the majority of the males are already in spawning condition in December (Figure 7.3).

A reduction in fishing effort in the spawning season may reduce the risk of high grading of less valuable fish. However, it should be noted that the protection of the spawning fish by an effort reduction is focussed on the adult fish that are spawning or are about to be spawn. In contrast, economic incentives for discarding less valuable fish are related to fish that have finished spawning.

The biological data thus show that the spawning potential in plaice can best be protected by a reduction in fishing effort in January and February. As the catch efficiency of the fishing operations peaks in January and early February due to the presence of spawning aggregations (Figure 7.4), a reduction in fishing effort in these months will give the largest positive effect.

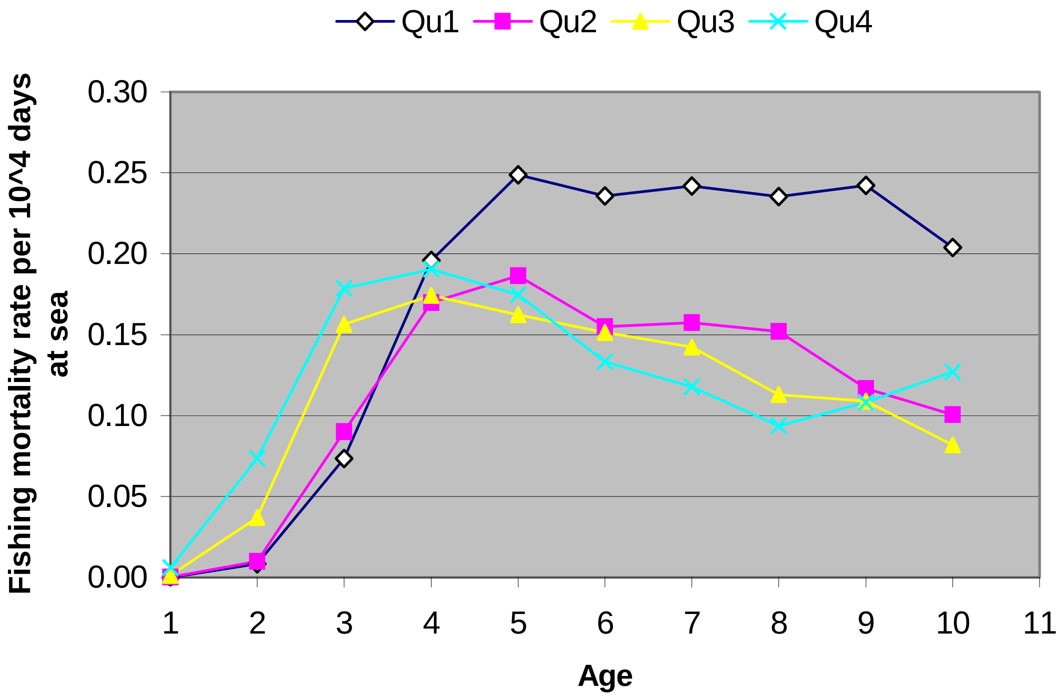

Figure 7.2. *Relationship between the fishing mortality and age for each quarter (Qu1 – Qu4) as estimated by the quarterly VPA of the catch at age data of the landings between 1995-1999. The results are taken from the MSVA (ICES, 1993).*

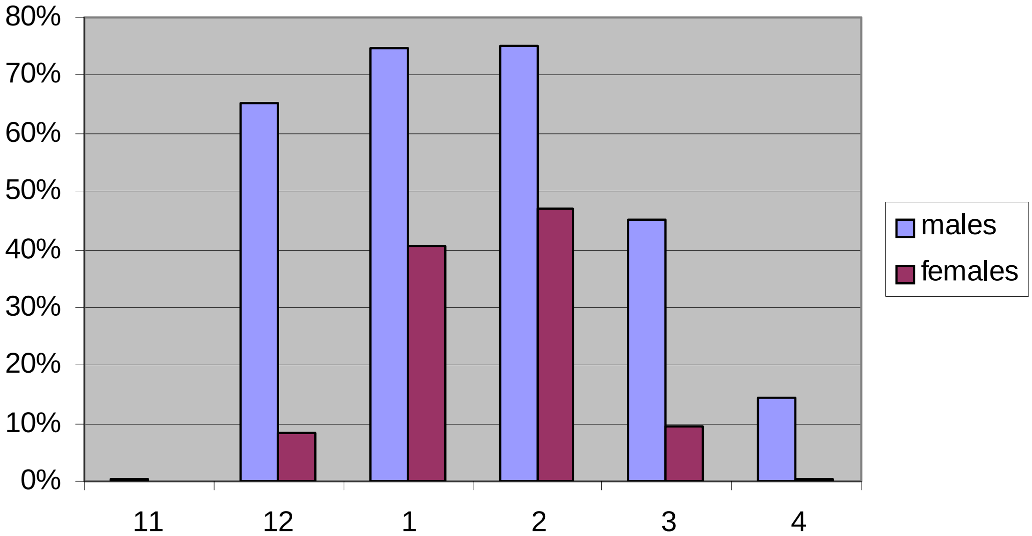

Figure 7.3. *Percentage of spawning fish among adult plaice by month between November (11) and April (4). Data: market samples taken by RIVO between 1995-2002.*

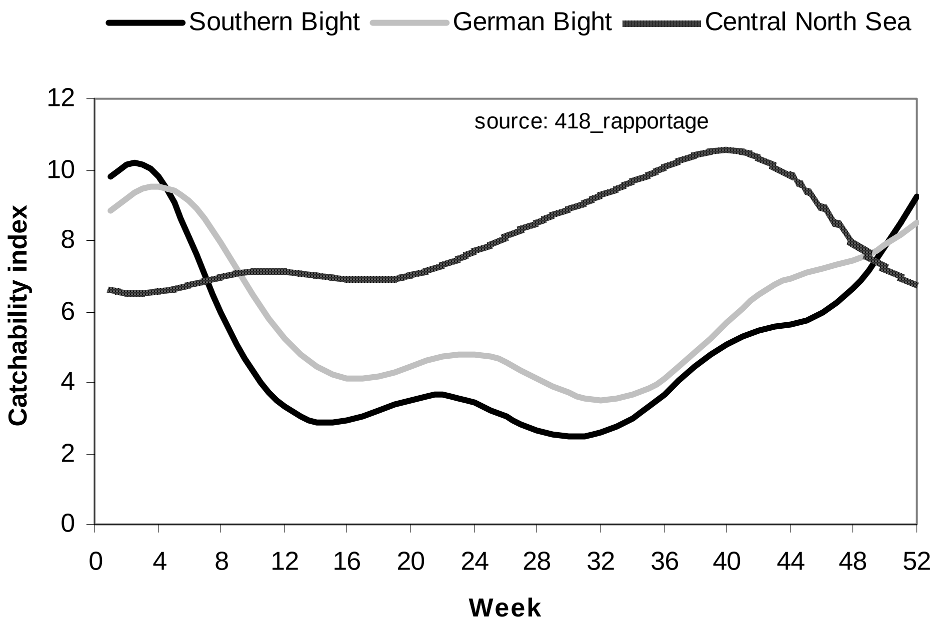

Figure 7.4. *Seasonal trends in the catchability index reflecting the availability of plaice on the fishing grounds in the Southern Bight, the German Bight and the Central North Sea. The peak in the availability in the Southern and German Bight in January reflect the temporary spawning aggregations. Note that these aggregations already disappear between February and March. Source[2].*

7.3 Simulation model

To quantitatively evaluate the potential effect of spatial-temporal management measures such as reductions in effort reduction, changes in the minimum mesh size, or combinations of these, a spatially explicit simulation model was developed. The basic idea of the model is that if both the spatial distribution of plaice and of the fishing effort is known, the catch can be estimated from the selectivity characteristics of the gear and the relative availability of an age group on the fishing grounds (ICES, 1987; Rijnsdorp and Pastoors, 1995). If there is a high overlap in the distribution of the resource and the fishery, a relatively large proportion of the population will be harvested.

The model comprises the basic biological processes of growth and mortality, and has a spatial resolution of ICES rectangles and a temporal resolution of quarters. The plaice population is divided in age classes 1 to 10 and receives each year a constant number of 1-year old recruits. The spatial distribution pattern of each of the age classes was estimated from survey data (age group 1-3) and catch rates from the commercial fisheries (age group >=4) (Figure 7.5). The fishery was modelled using the available effort

[2] Rijnsdorp, Daan & Dekker (2005) Partial fishing mortality per fishing trip: a useful indicator for fishing effort in management of mixed demersal fisheries. RIVO Report C05/XXX.

data of the Dutch beam trawl fleet, distinguishing the fleet of Euro cutters (<=300hp) and large beam trawlers (~2000hp). It was assumed that the Dutch fleet represents the total international fleet. The fishing mortality calculated by the model for 2003 was scaled to the fishing mortality from the VPA including discards. The relative catch efficiency of the Euro cutter fleet, as compared to the fleet of large beam trawlers, was set at 0.77. This conversion factor was taken assuming a log-log relationship of catch efficiency and engine power. Figure 7.6 shows the exploitation pattern from the calibrated simulation model in comparison with that of the VPA. Further details of the model are given in Annex 10 and the issue of efficiency reduction is further discussed in Annex 11.

For the various scenario's we will present the time trends in the landings and the spawning stock biomass over the period 2004 – 2015. It should be noted that *the results of the simulations should be interpreted with caution*. The exact values are strongly dependent on the parameterisation of the model. Landings and stock biomass trends will be very sensitive for the assumption of the incoming recruitment as well as the growth rate and the spatial distribution. Nevertheless, the simulation studies can be used to compare the various scenarios to explore which management measure will contribute to the goal of rebuilding the stock.

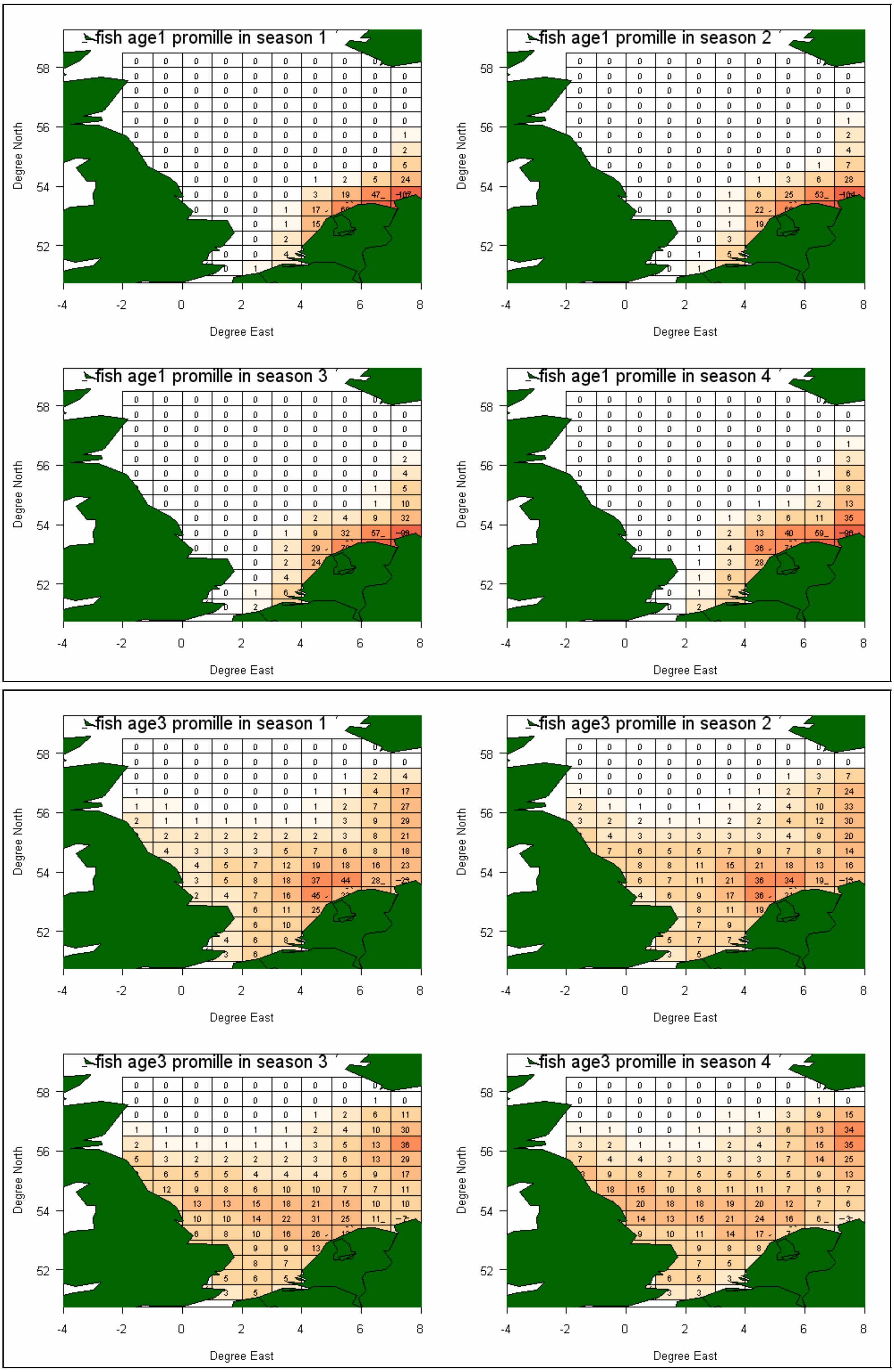

Figure 7.5a *Quarterly distribution patterns of age group 1 (upper panels) and 3 (lower panels) as estimated from the RIVO survey data. The numbers give the proportion (*1000) of the population that is present in an ICES rectangle each quarter.*

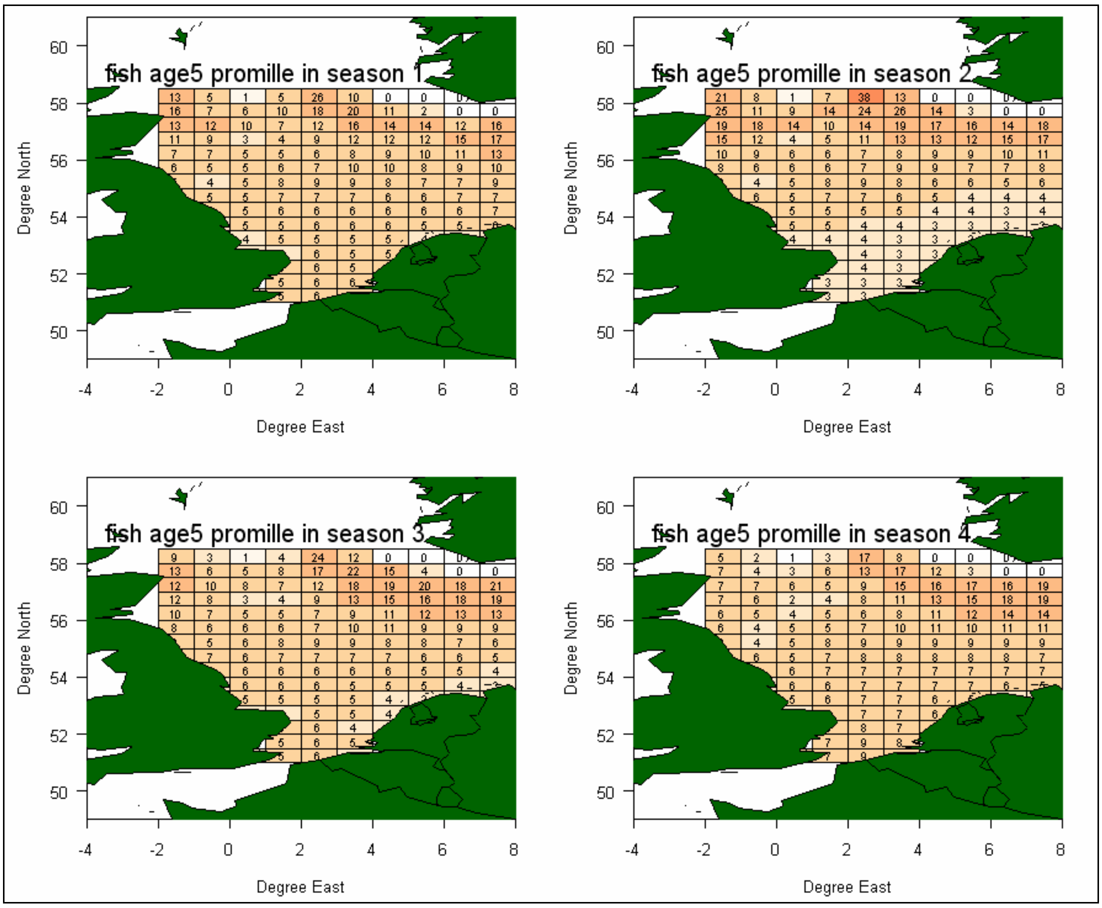

Figure 7.5b *Quarterly distribution patterns of age group 5 as estimated from the catch rates from the Dutch beam trawl fleet. The numbers give the proportion (*1000) of the population that is present in an ICES rectangle in each quarter.*

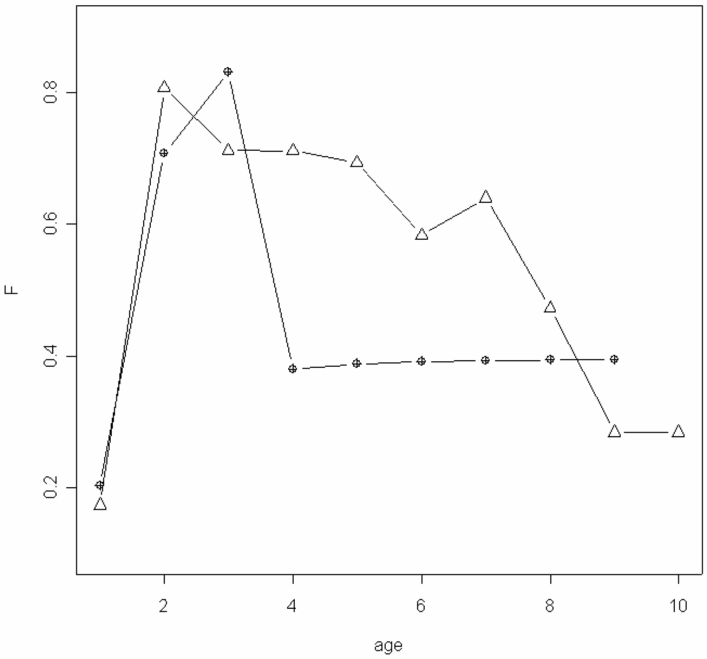

Figure 7.6. *Exploitation pattern from the calibrated standard simulation run (®) and the exploitation pattern estimated by VPA (Δ).*

7.3.1. The status quo run.

All model runs started on January 1st, 2006 with initial population numbers taken from the most recent stock assessment and status quo fishing mortality rates in 2004 and 2005 (ICES, 2004). The status quo run calculated the catch at age given the fishing effort of the two Dutch fleets in 2004, the corresponding exploitation pattern and the resulting development in spawning stock biomass. Comparison of the simulated and VPA exploitation pattern showed a reasonable agreement for the younger age groups 1 to 3 (Figure 7.6). For the older age groups, in particular age groups 4-7, the simulated F was lower than in the VPA. This suggests that the parameterisation of the model, in particular the spatial distribution of the older age groups could be improved. In the current runs, we assume an equal distribution pattern for age groups 4 and older, whereas the distribution of age group 4 and 5 will certainly differ from that of older plaice.

7.3.2. Management scenario's

Scenario #1 – Increasing the mesh size

The first scenario explored the effect of an increase in mesh size applied to the total fleet from 80 mm to 90 mm or 100 mm. In the area north of the 55ºN line[3], the current mesh size of 100 mm was continued.

Figure 7.7 shows that an increase in mesh size will hardly result in a decrease in the landings as compared to the status quo scenario (80 mm). An increase in mesh size will reduce the fishing mortality of the youngest age groups, which dominate the discards. Already one year after the mesh increase, the landings will be higher than with the 80 mm status quo scenario. Discard percentages will be substantially reduced, whereas the SSB shows a substantial increase. With an increase in mesh size to 100 mm SSB will increase to a level above B_{pa} in two years. It should be noted however, that the levels of SSB shown are very sensitive for both growth rate and recruitment level.

[3] Throughout this report we loosely use the 55ºN line to distinguish the fishing area in the north where the minimum mesh size is 100 mm, and the area in the south where the minimum mesh size is 80 mm.

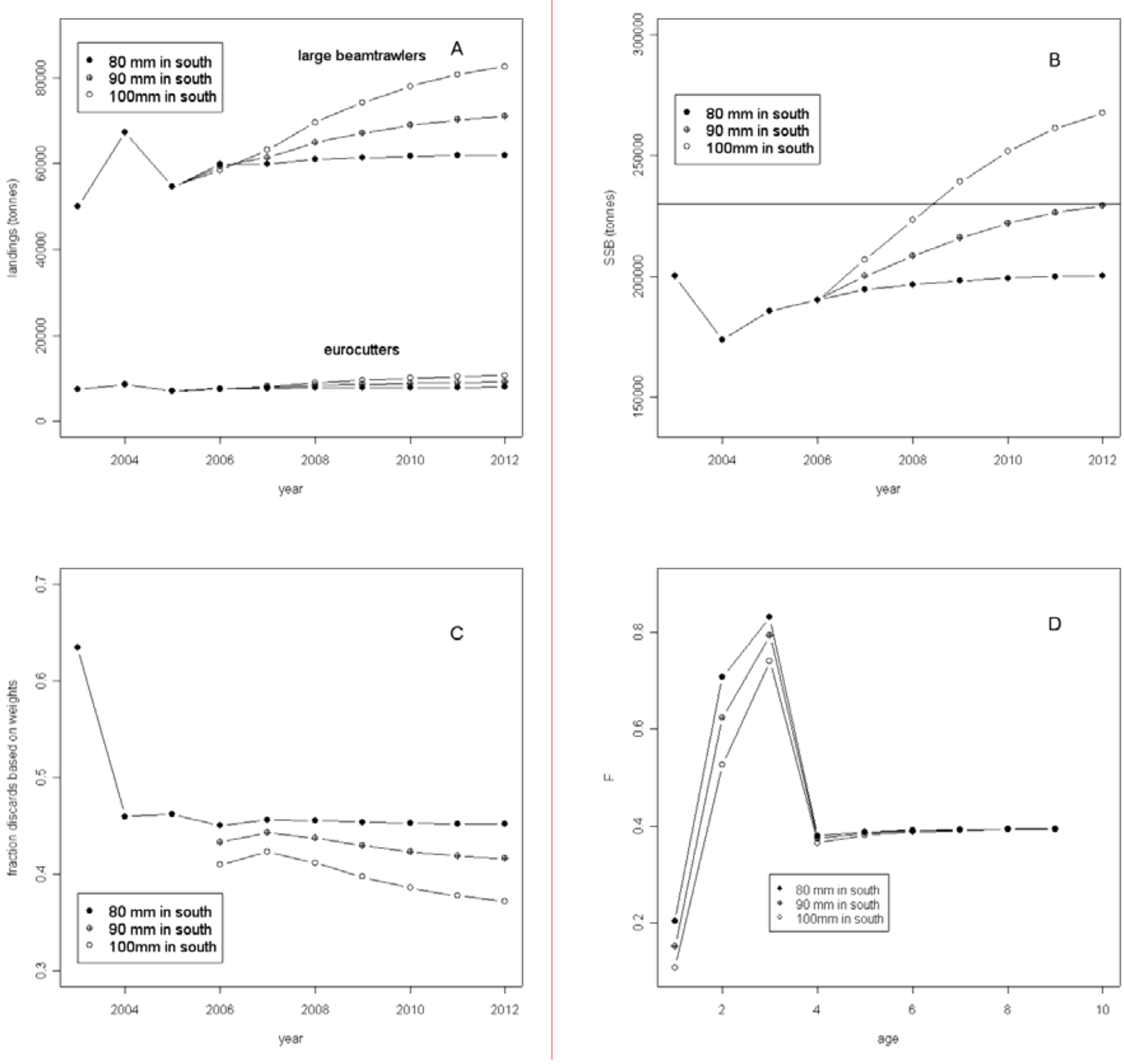

Figure 7.7. *Scenario #1 Mesh size increase from 80 mm to 90 mm or 100 mm. Shown are the trends in (a) landings, (b) spawning stock biomass, (c) discard proportions and (d) the exploitation pattern, at status quo fishing effort when in 2006 the mesh size is increased to 90 mm or 100 mm in the area south of 55ºN. North of the line a 100 mm mesh size is used. The line for the 80 mm scenario shows the status quo simulation (#1).*

Scenario #2 – effort reduction

This scenario explored the effect of a reduction in fishing effort of 10 to 30% in all fleets. Effort reduction was simulated as a reduction in the days at sea and was applied evenly during all quarters of year. The results are shown in Figure 7.8. In this scenario, the landings temporarily drop for 2 years and then increase to a level exceeding the level of the status quo scenario. Discard percentage decreases from about 45% at status quo, to about 35% at a 30% reduction in effort. Already at an effort reduction of 10%, SSB will increase to the precautionary reference level by 2012. With an effort reduction of more than 10%, SSB will increase beyond the B_{pa} level in 2008.

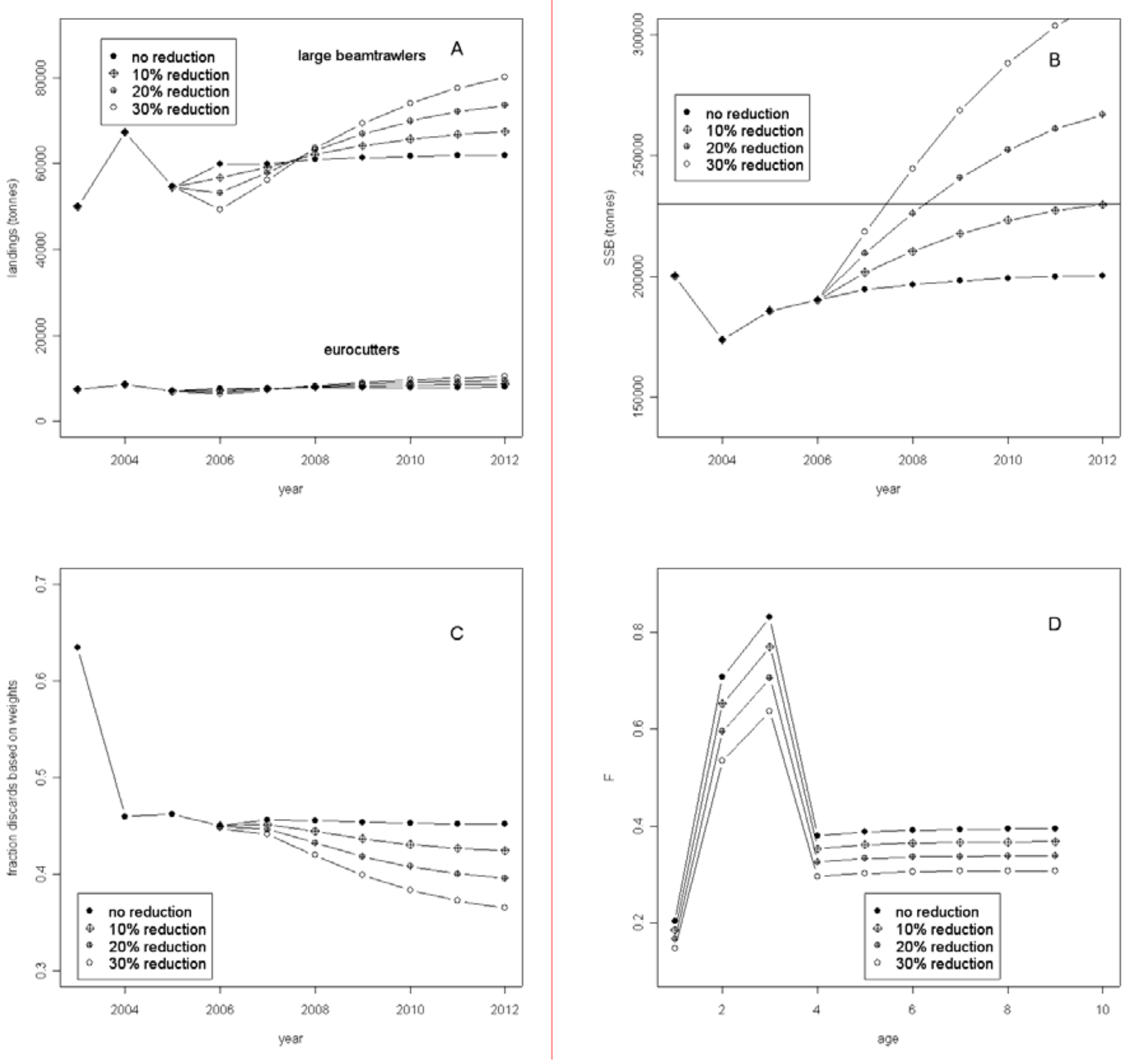

***Figure 7.8**. Scenario #2 showing the effect of an effort reduction by 10%, 20% or 30% in all fleets on the landings (a), spawning stock biomass (b), discard proportions (c) and exploitation patterns (d). The line for the zero reduction shows the status quo scenario #1.*

Scenario #3 - Catch efficiency reduction in the Euro cutter fleet

This scenario explored the effect of a reduction in the catch efficiency of the Euro cutter fleet (Figure 7.9). The results show that a reduction in the catch efficiency of the Euro cutter fleet will result in a modest increase in SSB. The increase in stock size is not sufficient for the Euro cutters to compensate for her decrease in catch efficiency. The landings of the Euro cutters remain slightly below the landings of the status quo scenario. However, a reduction in the catch efficiency of the Euro cutters is beneficial for the large beam trawl fleet as reflected in the increase in landings for this fleet.

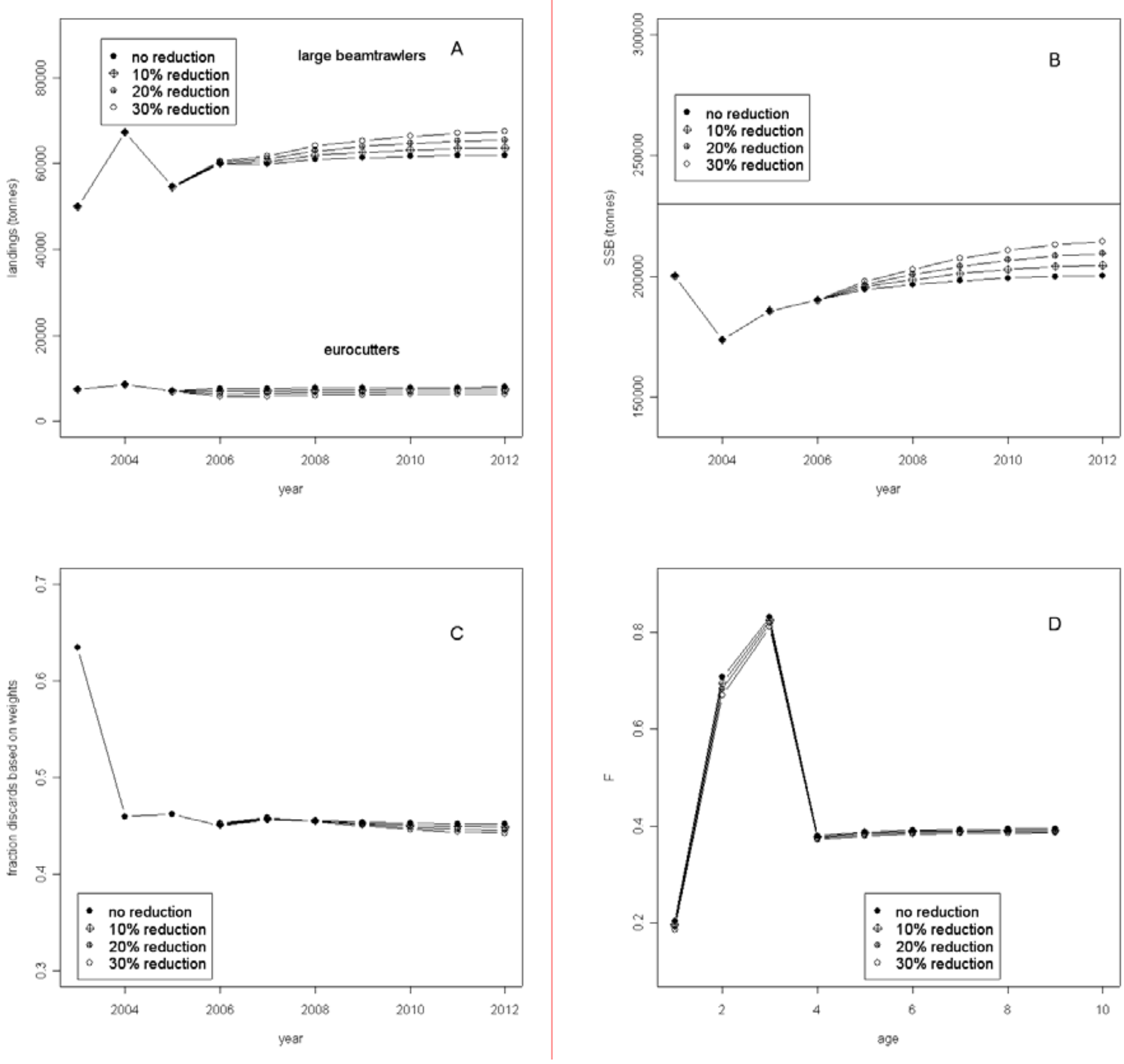

Figure 7.9. *Scenario #3 showing the effect of a reduction in the catch efficiency of the Euro cutter fleet by 10%, 20% and 30% on the landings (a), spawning stock biomass (b), discard proportions (c) and exploitation patterns (d). The line for the zero reduction shows the status quo scenario #1.*

Scenario #4 - Re-allocation of fishing effort to northern fishing grounds

In this scenario, a proportion of the fishing effort was re-allocated from the southern fishing grounds to the area north of the 55ºN to explore whether a reduction in fishing effort in the areas where undersized plaice are abundant would help in rebuilding the spawning stock biomass and still allow a fisheries on the older age groups. In this simulation, the effort that was moved to the northern part also changed from fishing with 80 mm to 100 mm because fishing with 80 mm in the northern part is prohibited.

The results show that the re-allocation does not lead to an increase in SSB. Only when 30% of the effort is re-allocated to the north, the SSB recovers to a level that is similar to that obtained under the status quo scenario. This result is counter-intuitive as it was expected that the reduction of the effort in the areas where the highest number of discards are taken, would have a beneficial effect on the rebuilding of the stock. The explanation of this result lies in the fact that plaice shows a higher abundance in the area north of the 55ºN. Therefore, relocating fishing effort to the north leads to an increase in fishing mortality and therefore to higher landings but a reduction in SSB.

Closer inspection of the exploitation level (Figure 7.10 D) shows that the F does not increase in proportion to the re-allocation percentage. This is likely to be an artifact due to the rather large time steps used in the simulation. The simulation result therefore is likely to give a minimum estimate of the increase in F expected from a re-allocation of effort to the northern fishing grounds.

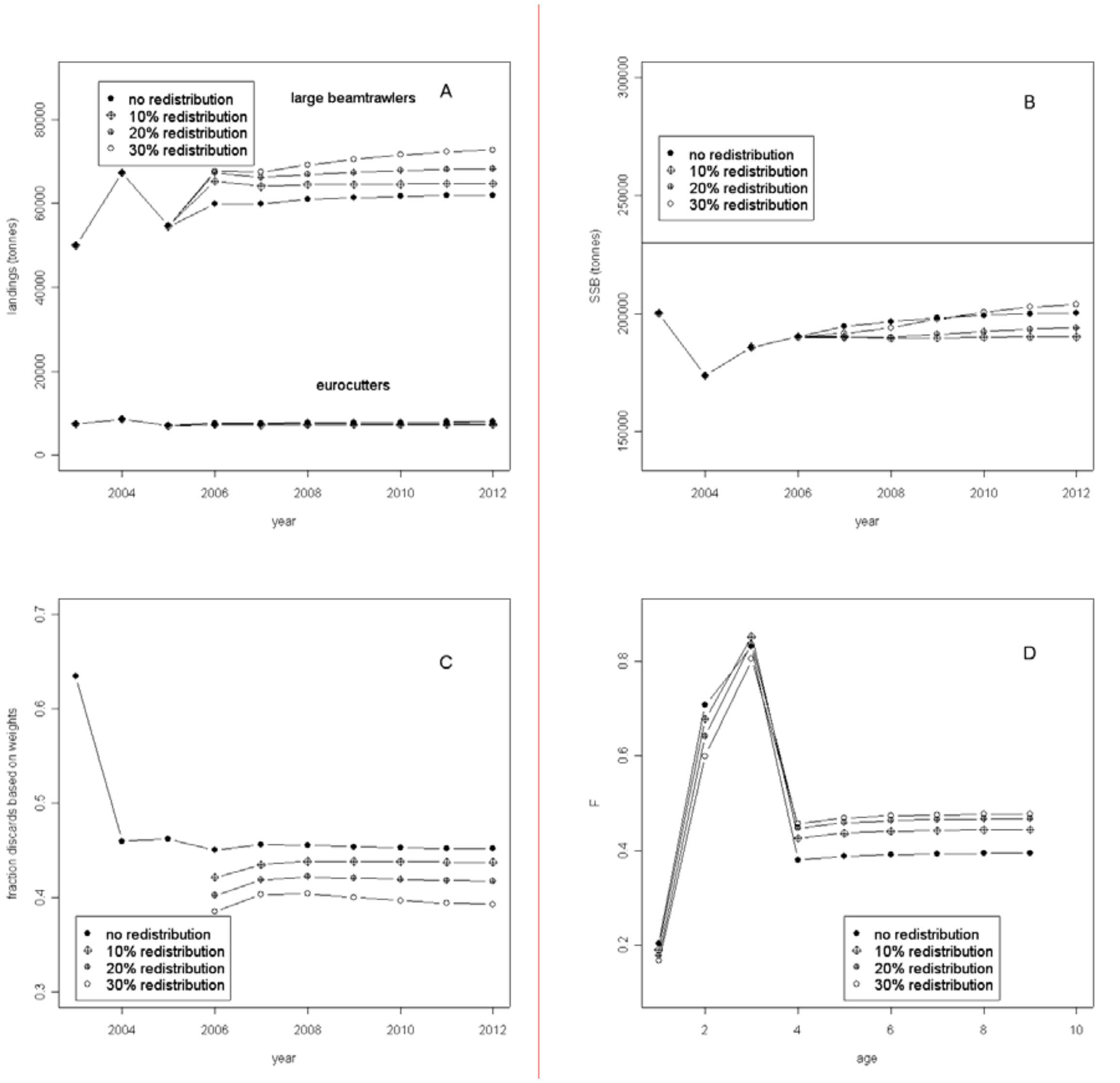

Figure 7.10. *Scenario #4: the effect of re-allocation fishing effort from 2006 onwards from the south to the north by 10%, 20% or 30% on the landings (a), spawning stock biomass (b), discard proportions (c) and exploitation pattern (d).*

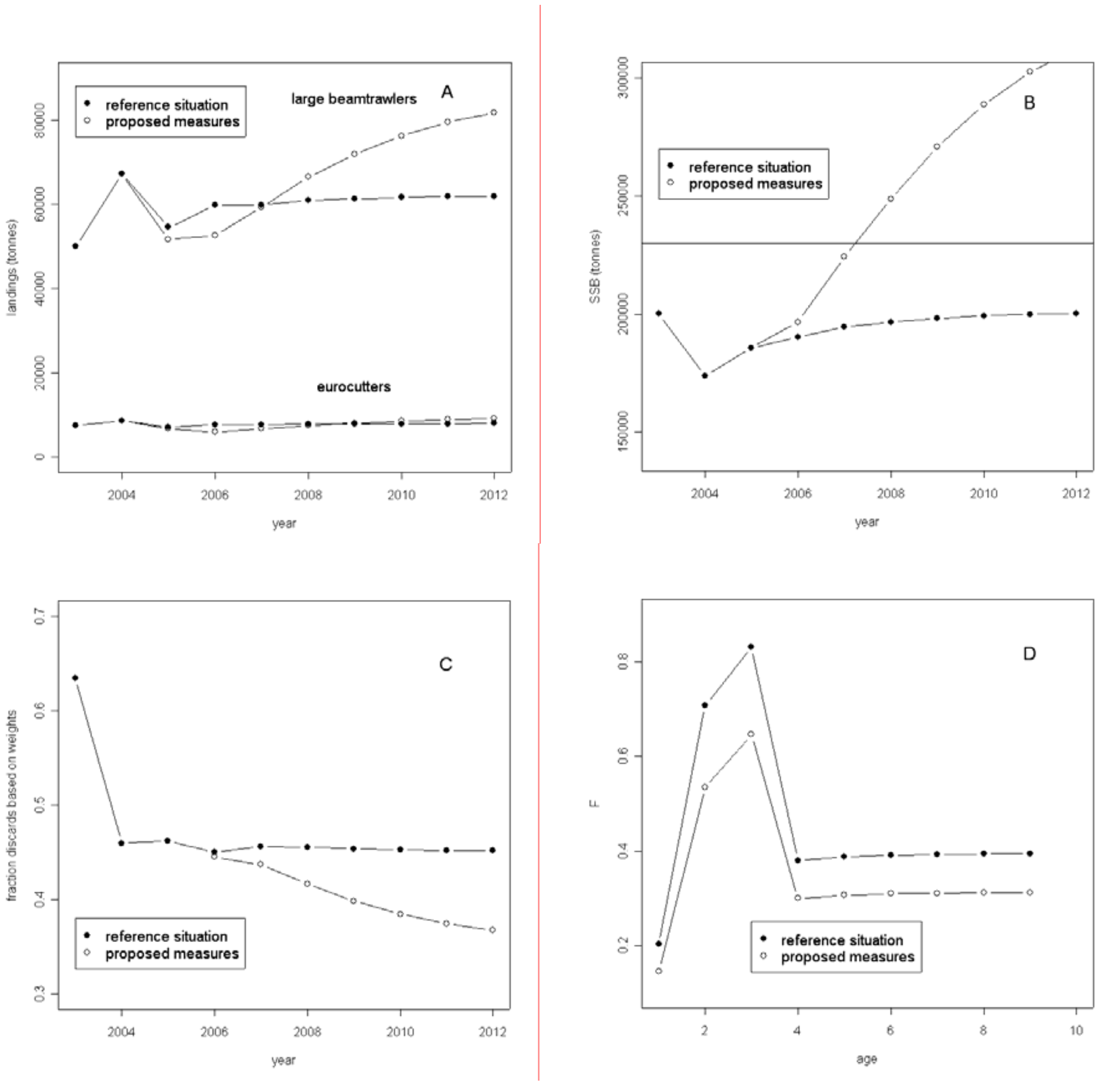

Figure 7.11. *Scenario #5: the effect of a two-step reduction in fishing effort and fishing efficiency (see text) in 2005 and 2006 on the landings (a), spawning stock biomass (b) discard proportions (c) and exploitation pattern (d).*

Scenario #5

This scenario combined several measures that were proposed by the fishing industry:

1) A 10% decrease in days at sea in 2005 as compared to 2004;
2) A further 15% decrease in the days at sea in 2006 reflecting a decommissioning of vessels;
3) A 5% reduction in the fishing efficiency of the fleet of large vessels in 2006, and a 20% reduction in fishing efficiency of the Euro-cutter fleet.

In this scenario, no spatial measures were taken.

Figure 7.11 shows that the landings will remain low in the first year of the management measures, but will subsequently increase. The discard percentage will steadily decrease to a level of 35% and the SSB will increase to a level well above B_{pa} after two years. As in the other simulations, the absolute levels shown should be interpreted with caution as these are fully dependent on the growth rate and recruitment levels assumed in the simulation.

7.4 Synthesis

Comparing the various management scenario's clearly shows that effort reductions (or changes in catch efficiency) and an increase in mesh size will have the largest effect on rebuilding the SSB of plaice. An increase in mesh size to 100 mm, however, will have a dramatic effect on the catch options for sole. Given the selection parameters estimated in the early 1980s, a 100 mm meshed cod-end will start catching sole just below 30cm, and will retain 50% of the soles (with a minimum landing size of 24 cm) of 33 cm! Also, mesh size regulation may be difficult to enforce if there is no support for such a measure in the fishing industry. We therefore conclude that effort reductions provide the most promising approach.

Effort reductions will provide the best contribution to the recovery of the SSB of plaice as it directly translates into a reduction of the fishing mortality of both discards and marketable sized plaice. However, the rate at which SSB will recover is dependent on the realized reduction in fishing effort, as well as on the strength of the incoming recruitment and the future growth rate. As recruitment is highly variable, and growth rate has shown substantial changes over time, no reliable quantitative prediction can be made.

An effort reduction may become even more effective if it is accompanied by Real Time Closures. Although the effect of an RTC is difficult to quantify, it may prevent periods of excessive discarding when dense concentrations of undersized plaice may temporarily occur on certain fishing grounds. Good compliance by the industry is, however important for the effect. On the longer term, the development of more selective fishing gear for sole having a lower by-catch of plaice may give an important contribution to the sustainable exploitation of plaice. This may be especially relevant under the current growth rates of plaice that are lower than in the 1970s and 1980s.

Effort reductions may also help to reduce the risk of high-grading (discarding of marketable sized fish). It is known that high-grading may occur from time to time although no quantitative information is available. High-grading may occur in two situations: 1) over-quota high-grading; 2) economic high-grading. Over-quota high-grading arises if a fishery has exhausted its fishing rights for one species but may continue to fish for other species and only lands the economically most attractive individuals of the one species. Economic high-grading occurs if the least valuable component of the catch, such as lean fish that has finished spawning, is discarded to increase the economic value of the landings. High-grading, in particular over-quota high-grading, is a serious threat to the sustainable management in mixed fisheries, as it may lead to a negative feed back loop of under-estimated catches, under-estimated stock sizes, restrictive TACs, even larger high-grading, etc. Although it is not known to what extent high-grading occurs in the flatfish fisheries in the North Sea and whether this has an effect on the perceived status of the stock, the current management regime that sets annual TACs for individual species will create the conditions under which high-grading will occur. In order to achieve a sustainable flatfish fisheries, it is critical to take account of the risk of high-grading by designing management scenario's that reduce the risk of high-grading in this mixed-species fisheries.

The effect of an effort reduction will depend on the season when it is applied. In the spawning period, in particular in January and February, the reduction in effort will have the greatest benefit for the adult fish, which are concentrated on the spawning grounds in the southern and southeastern North Sea. The number of undersized plaice in this period is relatively low. Reducing the discarding of under-sized plaice will be achieved by reducing fishing effort later in the year, especially in the 3rd and 4th quarter when a new year class recruits from the inshore nursery grounds to the offshore fishing grounds. No detailed data are available to more specifically advice on the periods when fishing effort could be reduced most efficiently to reduce the by-catch of plaice discards. For the moment we therefore conclude that effort reductions could best be applied in the period January-February and evenly spread out over the second half of the year. An alternative would be to spread out the effort reductions evenly over the year.

With regard to the effort reduction through decommissioning of vessels, one should realize that it is likely that the least efficient vessels will leave the fishery. As the fishing efficiency for plaice in the Dutch beam trawl fleet increased by 1.4% and 1.7% per year for the Euro cutter and large vessels, respectively (Annex 11), the effective fishing efficiency of the fleet will not be reduced in proportion to the sum of the administrative engine power of the vessels that has left the fishery. As more than 80% (Euro cutters) and 60% (large vessels) of the increase in efficiency could be ascribed to the upgrading of the engine or the replacement of an old vessel by a new vessel (Table A11.3), the fishing power of a vessel for plaice decreases by about 1% per year relative to a new vessel entering the fleet. This effect should be taken into account to estimate the remaining fishing efficiency of the remaining fleet after decommissioning.

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Annex 1. Detailed answer per research question

Theme	Subject	Question	Question number	Short answer
1. Discards	Analysis of discard data collected by the Dutch fishing industry	Analysis of discard data from the Dutch catching sector over the period from week 41 (2004)- to week 13 (2005).	1.1.a	Data were analysed, no changes in results and conclusions as compared to previous analyses.
		Comparison of discard data from the catching sector with data from RIVO.	1.1.b	No significant difference between discard rates observed by the industry and those by RIVO. Over all, in the period the fishing sector collected data, the discard percentages were 34.1% in weight in the industry data and 35.6% in weight in the RIVO data.
		Quantify the effect of using discard data from the catching sector in the assessment models on F.	1.1.c	The effect of using different discard rates (percentage of the total catch) on the reconstruction of F is limited. In the stock reconstruction, the estimated F of plaice decreases with a decreasing discard rate of plaice. Thus, if discard rates estimated by the sector were lower than those estimated by RIVO, and these rates would be used in the assessment model, we would think that the F of plaice would be lower than we think now. In the future, discard levers are highly important factors determining F.

Theme	Subject	Question	Question number	Short answer
		Quantify the effect of using discard data from the catching sector in the assessment models on SSB.	1.1.d	The effect of using different discard rates (percentage of the total catch) on the reconstruction of the SSB is limited. In the stock reconstruction, the estimated SSB of plaice decreases with a decreasing discard rate of plaice. Thus, if discard rates estimated by the sector were lower than those estimated by RIVO, and these rates would be used in the assessment model, we would think that the SSB of plaice would be lower than we think now. In the future, discard levers are highly important factors determining SSB.
		A short analysis of the necessary steps to include data from the catching sector in the ICES work.	1.1.e	The discard data collected by the catching industry are very valuable and fully complementary to those collected by RIVO. To implement data from the catching industry, length distributions of discards and market categories from the landings are required. Data from the catching sector could be used in the ICES work at the earliest from fall 2006 onwards.
	Techniques for measuring survival rates of discarded plaice	A comparison of techniques for measuring survival rates of discards in the Netherlands and other countries.	1.5.a	Ideally, survival experiments would be executed in controlled tank experiments on land. The RIVO experiments on board could be improved at the following aspects: monitoring water quality in the tanks; put less fish in a tank; execute autopsy on fish; pay attention to set up (light conditions, sediment in tanks).
		Research proposal for a project in which ideas of the catching sector to improve survival rates of discards are collected and tested.	1.5.b	Several ideas from the catching sector were collected. Their ideas for improvement of the survival experiments were in line with the options mentioned in question 1.5.a. Suggestions for the improvement of the survival of fish were: decreasing the handling

Theme	Subject	Question	Question number	Short answer
				time of fish; net adaptations to decrease the exposure of fish to sand, debris, benthic fauna and water; put (more) water in the bins in which the catch is put.
		Assess the effect of different survival rates of discards on estimates of F and SSB.	1.5.c	The effect of using different survival rates on F and SSB is limited. In the stock reconstruction, the estimated F of plaice increases with a decreasing discard mortality rate of plaice, whereas the estimated SSB decreases. Thus, if discard mortality rates estimated by the sector were lower than those estimated by RIVO, and these rates would be used in the assessment model, we would think that the F of plaice would be higher and the SSB would be lower than we think now.
2. Research questions on spatial distribution and growth	Changed spatial distribution of juvenile North Sea plaice	Research proposal for investigating the causes of changes in the spatial distribution and growth rates of North Sea plaice. Assess whether it is possible to include data from fishing vessels	1.3	We propose analysis of existing survey data on the spatial distribution of plaice, in combination with detailed temperature data that was collected during these surveys. These descriptive analyses should be combined with physiological models to explain the effect of temperature on the distribution of plaice. Additional high-resolution data could be collected by the fishing fleet by sampling discards and measuring water temperature. Alternatively (and at higher costs) data could be collected by research vessels.
	Changes in growth rates of North Sea plaice	Research proposal for investigating the causes of changes in the spatial distribution and growth rates of North Sea plaice. Assess whether it is possible to include data from fishing vessels	1.4	Knowledge on factors determining growth rate of plaice should be inferred from research described in question 1.3 and 1.7b. Additional lab experiments should address any caveats left.

Theme	Subject	Question	Question number	Short answer
	Remaining research questions after the evaluation of the Plaice Box	Research proposal to address issues that remained unanswered af the 2004 evaluation of the Plaice Box.	1.7.b	Supposed negative effects of the Plaice Box (decreased food availability due to decreased bottom trawling) can be investigated by experimental research. Six areas in the Plaice Box should be fished with different intensities (none-mediate-intensive, all in duplo) and in each area benthic fauna (=food) and diet of plaice should be investigated intensively ('chessboard' experiment). The research will take ~3 years and cost ~2-3 M€. The positive effects of the Plaice Box are more difficult to prove directly; the survival rates of juvenile plaice in the box should than be investigated which is very difficult. The most efficient way is to infer possible effects from the 'chessboard' experiment.
3. Technical measures	Technical measures	Research proposal for testing the effect of using 90 and 100 mesh sizes on the catch composition (plaice discards, plaice landings, sole landings). Pay attention to the number of trips or hauls that is necessary to be able to draw conclusions.	2.5.a	In an experiment, three beam trawlers, each fishing with different mesh sizes, should fish in the same area at the same time. From the plaice discards, length distributions should be assessed and from the landings, market categories should be registered. The vessels should fish in one area during one day, and than move to another area so four areas per week are covered. Ideally, the experiment would be repeated in different seasons.
	Proposal for mesh size experiments	Assess if selection parameters of fishing gears are still up to date. If not, which experiments are required to estimate new parameters.	2.6.c	The selectivity parameters that are currently used were measured in the 1980s. Due to technical developments, these parameters will not be up to date anymore. From the experiment described in 2.5.a it should become clear whether the parameters should be re-estimated. If so, additional experiments should be executed, for

Theme	Subject	Question	Question number	Short answer
				example cod end cover or trouser net experiments.
4. Evaluation of management scenarios	Real time closures	Assess the effect of RTCs on F and SSB.	1.2	The effect of Real Time Closures on the overall reduction in discards is difficult to quantify. It can be argued that the RTC will always lead to a reduction in discarding. Based on the discard data collected by the catching industry, we estimate that RTCs in the period October 2004-March 2005 could have reduced the overall discard% from 30 to 28% in volume when they would have been implied when discard rates are higher than 50%. This estimate is a maximum estimate.
		Asses the effect of fishing with 90 and 100 mm on F and SSB of plaice and sole.	2.5.b	A mesh increase to 90 mm will rebuild the SSB in a few years towards Bpa. An increase to 100 mm will rebuild SSB above Bpa. The rate at which SSB will recover stays uncertain as this rate depends on the numerical strength of future incoming year-classes and on future developments in growth rate. An increase in mesh size to 100 mm would theoretically rebuild the SSB of plaice substantially, but with this mesh size it will be difficult to continue the fishery for the smaller, more slender but highly-priced sole.
	The effect of an effort reduction during the spawning season	Assess the effect of effort reduction in the spawning season on SSB.	3.1.a	Reduced fishing effort during the spawning season may lead to a lesser disturbance of the spawning process. In addition, a reduction of the fishing effort in the spawning period will have a strong effect on the reduction of the removal of the adult fish from the population, which are, more important for the production of viable offspring. The biological data thus show that the spawning

Theme	Subject	Question	Question number	Short answer
				potential in plaice can best be protected by a reduction in fishing effort in January and February.
		Assess the effect of a general effort reduction on F and SSB.	3.1.b	General effort reductions will have a positive effect on the rebuilding of the SSB. Already a 20% reduction in effort will rebuild SSB above Bpa. The corresponding landings will recover after a 2-year dip to a level that is higher than the landings at status quo effort.
	The effect of a 15% effort reduction	Assess the effect of a fleet reduction by 10, 20, 30, 40 and 50% on F and SSB.	3.2	See previous 3.1b
	The effect of Hp reduction	Assess the effect of a reduction of the efficiency of the Euro cutters.	3.3.a	A reduction in the efficiency of Euro cutters will have a relatively small effect on the rebuilding of the stock towards Bpa. The landings of the Euro cutters will stay below that at status quo, but the landings of the larger beam trawlers will benefit from the reduction in discards made by the Euro cutters.
		Assess the effect of measures on the fishing pressure in the 12-miles zone.	3.3.b	See 3.3.a
	The overall effect of effort reduction	Asses the effect of the integration of management measures.	3.a	An integrated scenario was explored in which the fishing effort was reduced by decommissioning, a reduction of the number of fishing days, and a decrease in the efficiency of the Euro cutters. This scenario gave a quick increase in SSB above Bpa, at the expense of a temporary decrease in the landings.

Theme	Subject	Question	Question number	Short answer
	Alternative measures	Explore alternative management measures.	3.b	A scenario was explored in which a proportion of the fishing effort in the sole area (south of the 55oN) was reallocated to the plaice fishing grounds north of this line. Reallocation resulted in an increase in the overall fishing pressure on paice, and hence resulted in a further decrease in SSB. Only when 30% of the effort was reallocated, SSB gradually recovered to the SSB level at status quo.
	The speed at which Bpa is reached	With the combination of which measures is Bpa reached quickest.	3.c	SSB will recover quickest when the fishing effort is reduced.

Annex 2. Comparison of discard data from the industry and RIVO

(Q 1.1.a, 1.1.b)

Collection of discard data by RIVO

During the period of the PV discards sampling programme, three vessels have been sampled by RIVO for their discards observation programme. During week 50 in 2004 and week 5 and 10 in 2005 two observers from RIVO went onboard a vessel, sampling 90% of the hauls for discards and 85% of the hauls for landings.

For each sampled haul, the landings were recorded by species by weight. Total and sampled volume of discards was recorded. A sub-sample of the discards was taken and all fish were counted and measured. Sampled numbers of plaice discarded at length were raised per haul to total numbers at length and converted to total weight of the plaice discards per haul, using a length-weight key.

Total discards and landings weight per haul were converted to total volume. For the discards a ratio of 1 litre to 0.89 kg was used, derived from observations during three RIVO discards observation trips. For the landings a ratio of 1 ltr to 0.83 kg was used, derived from observations during the RIVO market sampling programme. Discards percentage per haul was eventually calculated as volume discards/volume total catch.

Annex 3. Influence of discard levels and mortality on the assessment

(Q 1.1.c, 1.1.d, 1.5.c)

Introduction

In this section we present sensitivity analyses of the stock assessment to different levels of perceived discard percentages and discard mortalities. The analyses will show how sensitive the estimated values of F (question 1.1.c) and SSB (question 1.1.d) are to variations in the perception of the level of discarding. This makes it easier to judge the consequences of using the discard information from the industry in the stock assessment. Furthermore, the analyses will show how sensitive the reconstruction of F and SSB are to a decrease in the mortality of discards (question 1.5.c). It is important to appreciate that in this chapter, we investigate the effect of discarding on the *reconstruction* of F and SSB estimates, in other words, what is our perception of F and SSB in the past given different discard levels. The effect of discarding on future developments of F and SSB is discussed in other sections (i.e. Chapter 7).

Methods

The stock assessments were carried out as in ICES (2005), with the XSA method and using the data used in the final plaice stock assessment of 2004. The only modifications of the data (see below) that were made were those that pertained to the research questions. The plaice stock assessment of 2004 was the first in which discard estimates were used (ICES). The estimates of discard numbers at age for 1957-1998 were derived by a reconstruction method (Van Keeken *et al.* 2004; ICES 2005), and the estimates for 1999-2003 were derived from observations of the RIVO discard sampling program (Van Keeken and Pastoors 2004).

We investigated two questions. The first question is: what is the effect of varying discard levels on the outcome of the stock assessment? We decided that this question only pertains to the discard level in the period 1999-2003, because this is the period where the estimates were based on RIVO observations, and our client wants to be able to judge the consequences if observations from the industry would have been used. Therefore we modified the estimates of discard numbers at age in the period 1999-2003 by putting a multiplier on these estimates.

The second question is: what is the effect of varying levels of assumed mortality of discards on the outcome of the stock assessment? In this case we modified the estimates of discard numbers at age of the whole time period 1957-2003, by putting a multiplier on these estimates. The assumption here is that the multiplier is the fraction of discards that die.

For the study we used an implementation of XSA in a spreadsheet (Kell *et al.* 2001). We analysed scenarios using different multipliers on discards in recent years (0.1 – 1.0) and using different discards mortality proportions (1.0 – 0.7)

Results

In the first series we assumed no survival of discards. In Figures 1a-d the effect of the multiplier on discard numbers at age for 1999-2003 is shown. The percentage discards (in numbers) decreases with decreasing multiplier from more than 80% to around 30% in the last year (Figure A.1a). The effect on SSB is small: SSB in the last year decreases by less than 50,000 tonnes over the whole range of multipliers (Figure A3.1b). F in the last year decreases by about 0.2 over the whole range of multipliers (Figure A3.1c). The number of recruits in the last year decreases by about 500 millions over the whole range of multipliers (Figure A3.1d).

The second series is similar to the first, but instead we assumed an overall mortality of 0.8 (as opposed to 1.0) of discards. In Figures 2a-b again the effect of the multiplier on discard numbers at age for 1999-2003 is shown. The effects on SSB (Figure A2.2a) and F (Figure A3.2b) are even smaller than with full discard mortality (compare with Figures 1b and 1c respectively).

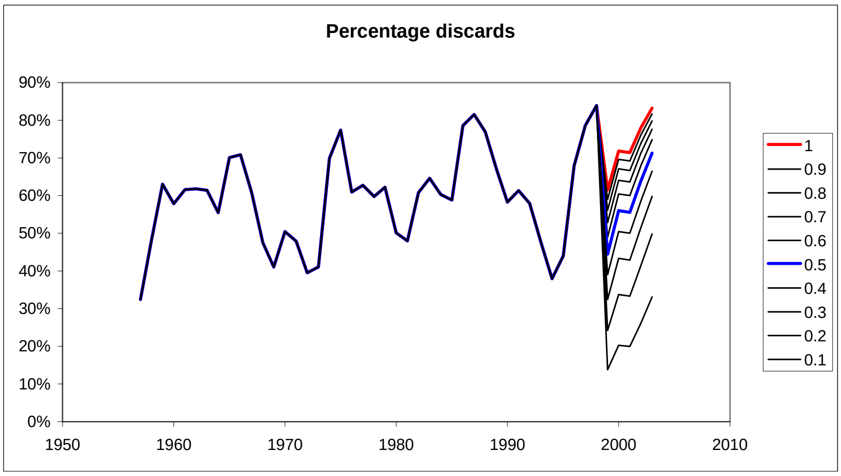
The third series analyses the effect of varying assumptions of discard mortality by using different multipliers on the whole time series. The effect on SSB (Figure A3.3a) and F (Figure A3.3b) is very small: SSB in the last year decreased by less than 20,000 and F in the last year decreased by less than 0.05 over the range of multipliers. The effect on SSB and F in earlier years is generally even smaller.

Conclusions

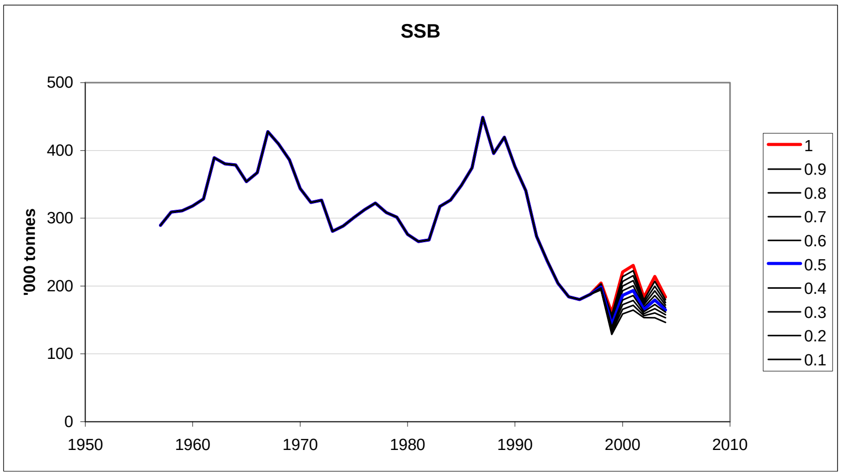
The effect of varying levels of perceived discards on the stock assessment is rather small. For example, with discard estimates being 30% lower than at present (a multiplier of 0.7) the effect on SSB is negligible and the effect on F small. The effect of varying assumptions on discard survival is also small. These results should enable our client to judge the consequences of using the discard information from the industry and of a better survival of discards.

Figure A3.1. *The effect of varying multipliers (0.1 – 1) on the discard numbers at age in 1999-2003 on the outcome of the stock assessment. No survival of discards. A. On the percentage discards (in numbers). B. On SSB. C. On F. D. On the number of recruits.*

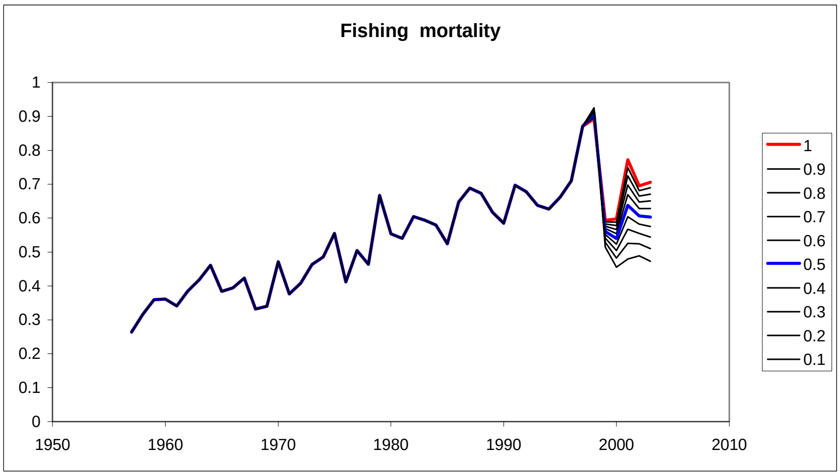
A.



B.



C.


Fishing mortality
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1950
1960
1970
1980
1990
2000
2010
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

D.

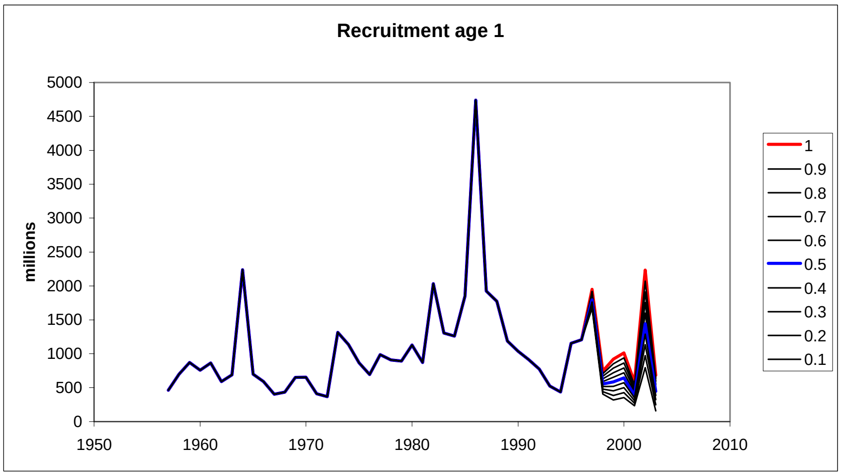
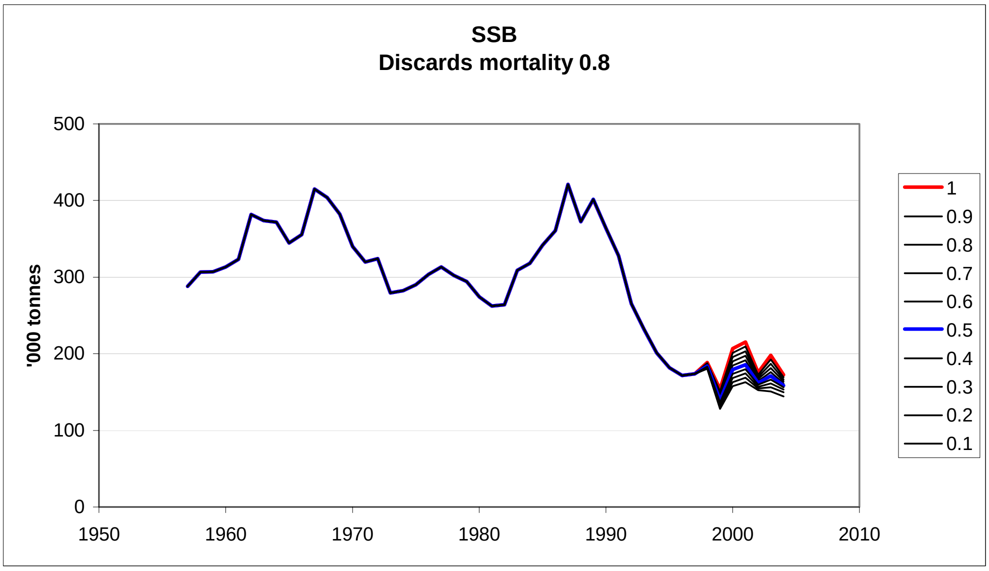

Recruitment age 1
millions
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1950
1960
1970
1980
1990
2000
2010
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

Figure A3.2. *The effect of varying multipliers (0.1 – 1) on the discard numbers at age in 1999-2003 on the outcome of the stock assessment. Mortality of discards 0.8 instead of 1.0. A. On SSB. B. On F.*

A.



B.

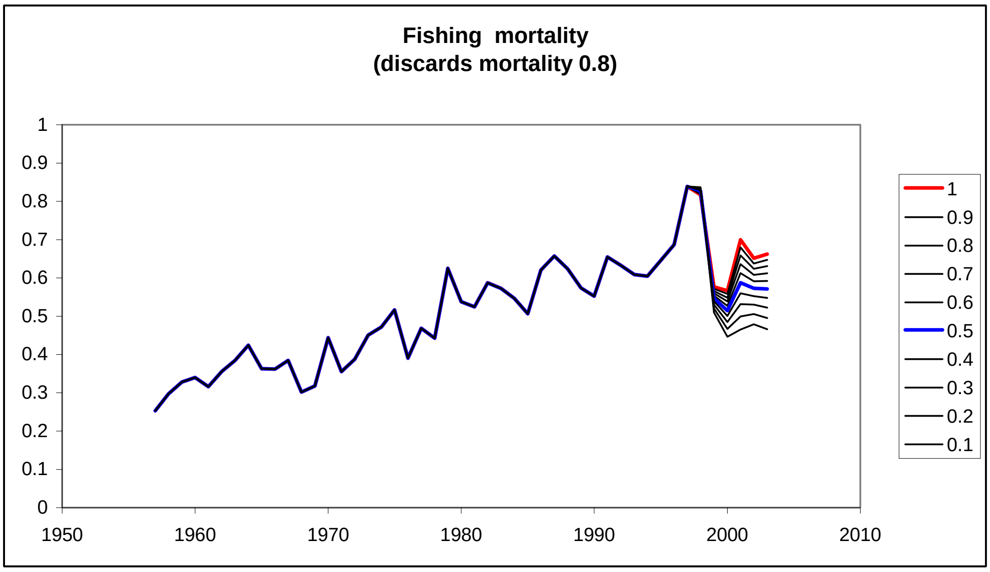
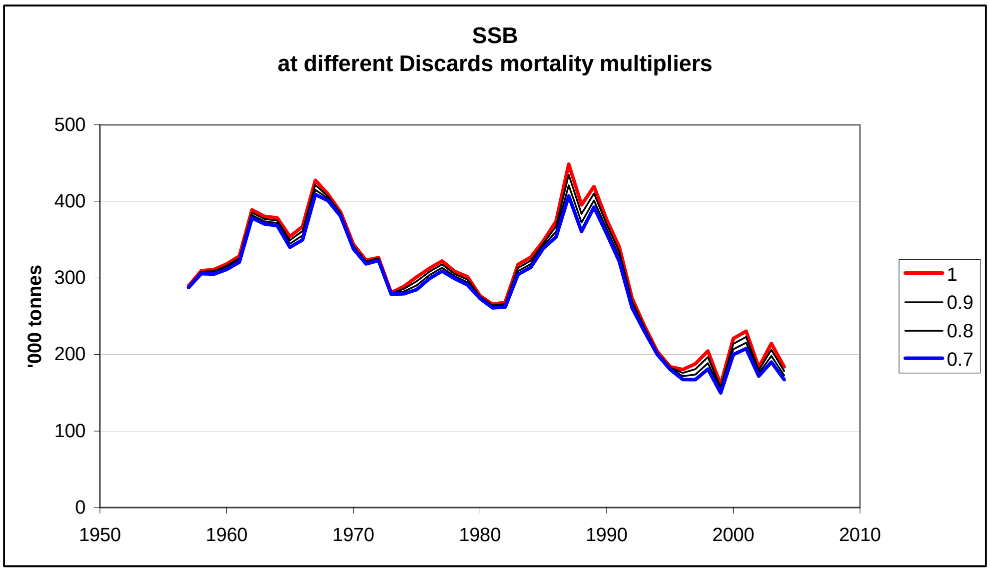
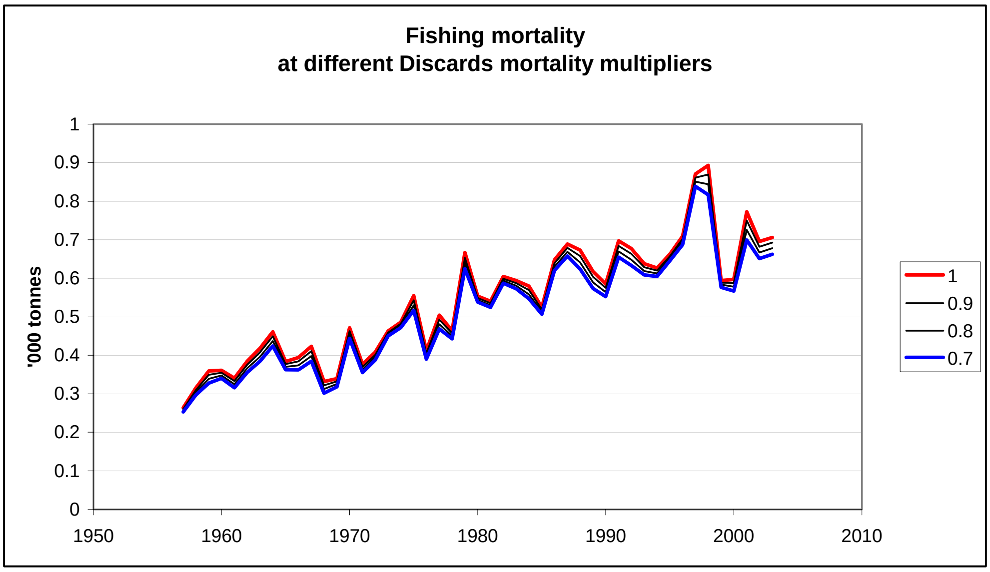


Figure A3.3. *The effect of varying multipliers, in this case to be interpreted as varying mortality, (0.7 – 1) on the discard numbers at age over the whole time series on the outcome of the stock assessment. A. On SSB. B. On F.*

A.



B.



Annex 4. Analysis of the necessary steps to integrate the data from the industry into the ICES work

(Q 1.1.e).

The discard data from the industry could in principle be integrated into the ICES work in two ways:

1. The raw information can be presented in the Working Group report of the ICES WGNSSK in the form of table and/or graphs.
2. The information could be processed into data that are suitable as input in the stock assessment model.

Ad. 1.

The presentation of the raw information in the WG reports is possible without any problems. The report by Dekker and van Keeken (2005) has shown how the information of the industry can be organised. We propose the following graphs for the Working Group report:

a. A graph in which for each sample the percentage of discards (in volume or weight) is plotted against time, with a trend-line. See example Figure A4.1a.
b. A map of the North Sea area, in which for each sample the percentage of discards (in volume weight) is plotted as circles of which the size is proportional to the percentage. See example Figure 4.1.
c. A graph, as 1a, in which the samples of the RIVO are compared with the samples of the industry. See example Figure A4.1b.
d. A graph consisting of two parts. The first part is as 1a; however, in this case the samples are categorized by gear-mesh size combination, and a separate trend-line is given for each of these combinations. The second part displays for each of these gear-mesh size combinations the contribution in the total catch through time; this makes it possible to judge the importance of each of the gear-mesh-size combinations. See example Figure A4.1c. For this type of information, additional discarding data from the sector is required because currently, data from other gear types than the beam trawl are sparse.

Ad 2.

The data that was collected by the industry is not yet suitable for input into the stock assessment models as such, because the models need catch numbers at age as input. If additional data would be collected:

A. The best solution would be that the sampling by the industry is complemented with length measurements of the sampled fish. Ideally, length-frequency distributions would be measured from both landings and discards. Also, LF distributions of discards only can be measured, if from the landings market categories are available. RIVO can than convert these measurements to catch-numbers at age by applying its own age-length keys to the length distributions of the samples from the industry. However, to improve these age-lengths keys, additional samples of otoliths from discards that could be delivered by the sector are welcome.

B. In case the above plan raises objections, the industry should at least carry out length measurements for all samples taken with gear-mesh size combinations other than beam trawl 80 mm. This is because the researchers from RIVO sample almost exclusively the beam trawl 80 mm, and they therefore do not have length data on discards from other gear-mesh size combinations.

- In this case, the length data from the industry for these other gear-mesh size combinations would be raised to numbers at age by the researchers from RIVO using their age-length key.
- For the raising of the discard percentages of the industry from the beam trawl 80 mm the researchers of RIVO will have to use the RIVO data on length or age distribution.
- Whether this is possible, however, depends on whether a useable relationship exists between the age distribution of discards, and the percentage discards (in volume or weight). This would first have to be investigated.
- In the case that a useable relationship is found, a course calculation can simply be made. The discard numbers at age from the industry sampling can be calculated by scaling the discard numbers at age from the RIVO sampling according to the ratio of the percentage discards from the industry sampling to the percentage discards from the RIVO sampling (percentage in volume or weight):

  n-at-age Industry = n-at-age RIVO x (% Industry / % RIVO)

- Because this method is in fact a course extrapolation, the RIVO researchers will also have to carry out further research in order to gain some insight into the degree of uncertainty in the resulting discard numbers at age.

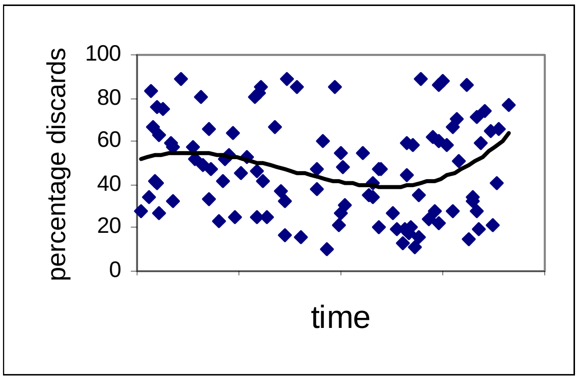


Figure A4.1a. *Discard percentages of sampled trips through the year, plus trend-line. Fictive data!*

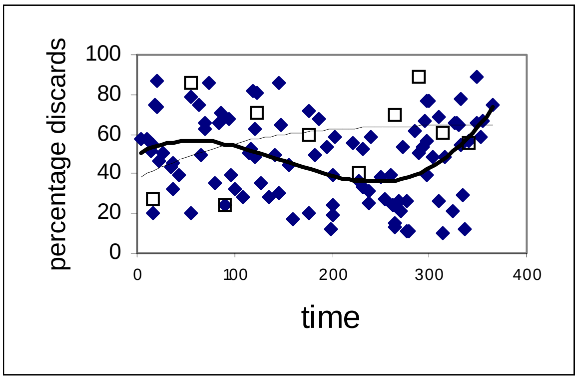


Figure A4.1b. *Discard percentages of sampled trips through the year, plus trend-lines. Closed symbols and thick line represent samples from the industry and open symbols and thin line represent samples from RIVO. Fictive data!*

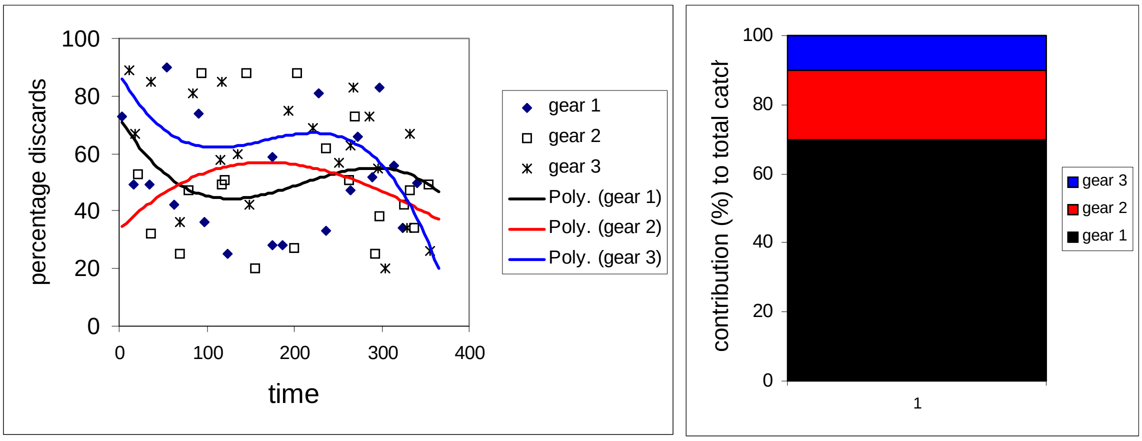


Figure A4.1c. *Left panel: Discard percentages of sampled trips by gear type through the year, plus trend-lines. Right panel: contribution (in %) of each gear type to the total catch. Fictive data!*

Annex 5. Literature analysis discard survival experiments

(Q1.5.a)

Description of the method used by RIVO (Van Beek *et al.* 1990)

Survival experiments with plaice and sole discards were carried out on board commercial beam trawl vessels operating under normal commercial conditions. Additional experiments were carried out with plaice caught with an otter trawl on R.V. 'Tridens'. Discards were sorted from the catch and their condition was classified according the scale given in Table 1.

Table 1. Classification of the condition of flatfish according to the damage

Class	Description
A	Fish lively, no visible signs of loss of scales or mucus
B	Fish less lively, some scratches and some scales missing, mucus layer affected up to 20 %, some small red spots on the blind side
C	Fish lethargic, several scratches and some areas without scales, mucus layers affected up to 50 %, several red spots on the blind side
D	Fish lethargic, head reddish, many scratches and areas without scales, mucus layer affected for mor than 50 %, blind side with many red spots and hemorrhages

From each condition class a random sample was taken and placed in a plastic tank (size: 40x60 cm and 12 cm high) with a maximum of 15 fish per tank. Stacks of about 10 tanks almost filled with seawater were placed in a wooden frame and supplied with continuous flow of fresh seawater (Fig. 1). The tanks were placed on deck in a position where rolling and pitching of the ship were minimal.

On board R.V. 'Tridens' the stacks of tanks were placed in a large closed basin of seawater, with continuous flow. If conditions permitted, the experiments were checked every 12 hours and the dead fish was recorded and removed. The experiment was terminated when all fish had died or at the end of the cruise. In a number of cases the experiment had to be stopped prematurely due to the weather conditions.

Survival experiments were initiated with discards from catches that varied in the gear used (otter or beam trawl), the number of chains in front of the net, haul duration (between 15 and 120 min), fishing speed, total volume of the catch and the engine power of the vessel. Also sea conditions (wind force) and water temperature were considered. The technical information of the experiments is summarized in Table 2. The length range of the discards used in the survival experiments was 20 to 30 cm in plaice and 20 to 28 cm in sole.

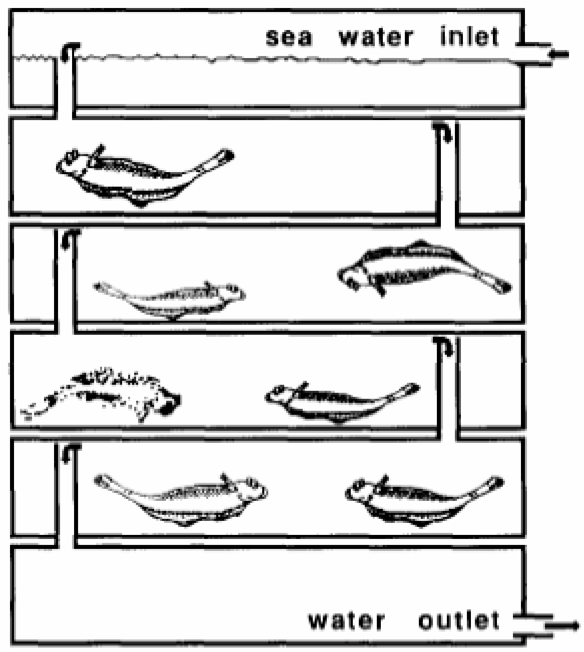


Fig. 1. Experimental set-up used to estimate the survival of flatfish discards.

In addition, the effect of the increasing processing speed on the survival of plaice discards was examined by comparing discard mortality of plaice processed by the tradition al method and of plaice discards processed with a sorting device. By this method the catch is dumped in a water filled container which supplies a conveyer belt along which the catch is sorted and processed. Discards and other unwanted material stay on the conveyer belt and are transported back to sea immediately. In the sorting device used in our experiments, the catch was kept wet with sprinklers throughout their stay on the conveyer belt.

The overall survival of the discards (Si) at experimental time i was calculated from the proportion (P.) and the survival (S i) measured in each condition class (j = _ .. 4) of the'total d scard catch according to:

$$S_i = \sum P_j * S_{i,j}$$

The survival of soles escaped through the meshes was estimated in conjunction with mesh selection experiments on commercial beam trawlers using the covered cod-end technique (Rijnsdorp *et al.* 1981; Van Beek 1982). The survival experiments were set up in pairs, experiment A with soles from the cod-end and experiment B with soles that escaped through the meshes of the cod-end and retained in the cod-end cover. The length range of the fish was 18 to 25 cm. The fish were not classified in condition categories. Further experimental procedures were identical to those applied in plaice.

TABLE 2
Technical information on the survival experiments.

Exp. numb.	horse power	haul duration	total catch × 40kg cod-end	total catch × 40kg cover	number of chains	depth (m)	water temp.	air temp.	weather cond.	date
plaice: otter trawl (fishing speed: 3.5 knots)										
1	600	20	5.0	-	6	25-30	8	8	7	Nov 1972
2	600	60	5.5	-	6	25-30	8	8	5-7	
3	600	60	5.5	-	6	25-30	8	8	7	
4	600	60	5.8	-	6	25-30	8	8	8	
5	600	100	5.8	-	6	25-30	8	8	7	
6	600	100	8.8	-	6	25-30	8	8	8	
7	600	105	8.0	-	6	20-30	6	5-6	-	Feb 1975
8	600	105	8.0	-	6	20-30	6	5-6	-	
plaice: beam trawl (fishing speed: 5.0-5.5 knots)										
9	1200	60	5	-	8	20-30	9-10	-	SW 1-4	Nov-Dec 79
10	1200	60	5	-	15	30-50	9-10	-	SW 1-4	
11	1200	120	10	-	24	20-30	9-10	-	SW 1-4	
12	1200	120	17	-	24	30-50	9-10	-	SW 1-4	
13	1015	110	4	-	24	20-25	12-13	-	W 1-2	May-Jun 81
14	1015	60	1	-	8	20-25	12-13	-	S 2	
15	1235	120	22	-	24	20-30	18	-	Var 2	Sep 1982
16	1235	120	22	-	24	20-30	18	-	Var 2	
17	1235	60	11	-	15	30-40	10	-	3-8	Dec 1982
18	1235	120	23	-	24	30-40	10	-	3-8	
plaice: beam trawl, deck-processing with conveyer belt (fishing speed: 5.0-5.5 knots)										
19	1200	60	5	-	15	20-30	9-10	-	SW 1-4	Nov-Dec 79
20	1200	60	5	-	15	30-50	9-10	-	SW 1-4	
21	1200	120	10	-	15	20-30	9-10	-	SW 1-4	
22	1200	120	17	-	15	30-50	9-10	-	SW 1-4	
23	1235	60	12	-	15	20-30	16	-	7-4	Oct 1982
24	1235	120	22	-	24	20-30	16	-	7-4	
25	1235	120	22	-	15	20-30	16	-	7-4	
26	1235	60	11	-	24	30-40	10	-	3-8	Dec 1982
27	1235	120	23	-	15	30-40	10	-	3-8	
sole: beam trawl (fishing speed: 5.0-5.5 knots)										
28)[1]	1015	120	7.5	5.5	13	~30	-	-	S 1- 2	Aug 1980
29)[1]	1015	120	7.5	5.5	13	~30	-	-	S 1- 2	
30	1015	15	2.0	0.5	12	15-20	17	-	Var 2	Aug 1981
31	1015	60	4.0	1.0	12	15-20	17	-	Var 2	
32	1015	120	7.0	4.0	12	15-20	17	-	Var 2	
33	1310	30	3.0	0.5	16	20-30	16-17	-	W 2-3	Aug-Sep 1981
34	1310	60	4.0	1.5	16	20-30	16-17	-	W 2-3	
35	1310	90	6.0	2.5	16	20-30	16-17	-	W 2-3	
36	1310	60	3.5	3.5	16	20-30	16-17	-	W 2-3	
37	1310	120	7.0	7.0	16	20-30	16-17	-	W 2-3	
38	1310	15	0.5	0.5	16	20-30	16-17	-	W 2-3	

)[1] Irish Sea

Estimating discard survival: a literature review

There are three types of experiments used to estimate discard survival:

1. Experiments onboard commercial vessels
2. Experiments in research facilities
3. Tagging experiments

Experiments onboard commercial vessels

All survival experiments that were carried out onboard vessels, operating under normal commercial conditions, had in principle the same experimental set-up as the RIVO set-up. Fish were kept in plastic tanks supplied with a continuous flow of fresh seawater.

Selection of fish was carried out randomly in the experiments by Revill (Revill *et al.* 2005). Laptikhovsky (Laptikhovsky 2004) divided the rays in his experiment into 4 condition categories, like was done in the RIVO experiment.

The density of animals in a tank varied between experiments. In the RIVO experiment a maximum of 15 specimens of plaice or sole were kept in a tank of 40x60x12 cm (29 liters). Wassenberg & Hill (Wassenberg and Hill 1989) looked at the survival of several fish species and kept at the most 5 specimen in a tank of 50x35x25 cm (43 liters). Fish larger than 20 cm were kept individually in a tank. Revill *et al.* (Revill *et al.* 2005), who examined the survival of dogfish in the Eastern Channel beam trawl fishery, kept 2 specimen in a tank of 40x60x18 cm (33 liters).

The temperature and salinity in the tanks were measured every hour in the experiment by Wassenbarg & Hill (Wassenberg and Hill 1989). In each experiment the seawater was refreshed regularly.

The length of the experiments varied from 200 minutes by Laptikhovsky (Laptikhovsky 2004), 8 hours by Wassenberg & Hill (Wassenberg and Hill 1989), 48 hours by Revill *et al.* (Revill *et al.* 2005) and 96 hours in the RIVO experiment. In each experiment dead animals were removed from the tanks and recorded.

Experiments in research facilities

For experiments in research facilities fish were caught by fishing vessels and transported to the research site. While being transported, the fish were kept in tanks on deck (Wassenberg and Hill 1993; Purbayanto *et al.* 2001; Davis and Ryer 2003; Palsson *et al.* 2003; Parker *et al.* 2003) or in cages in the water swept behind the vessel (Sangster *et al.* 1996). The water in the tanks was refreshed during transport, which took at the most 3 hours.

At the research locations, the fish were kept in plastic tanks (Wassenberg and Hill 1993; Purbayanto *et al.* 2001; Davis and Ryer 2003; Palsson *et al.* 2003; Parker *et al.* 2003; Davis 2005) or in cages in the water (Millner *et al.* 1993; Sangster *et al.* 1996; Palsson *et al.* 2003). Dead specimens were removed daily. The length of the experiments varied between 4 days (Purbayanto *et al.* 2001; Palsson *et al.* 2003; Parker *et al.* 2003) and 60 days (Sangster *et al.* 1996).

The damage level of the fish was recorded in three experiments (Wassenberg and Hill 1993; Purbayanto *et al.* 2001; Davis 2005). In the other experiments no difference was made between more or less damaged fish.

In the experiments by Parker *et al.* (Parker *et al.* 2003) and Davis (Davis 2005) also behaviour of fish was studied. Parker *et al.* studied the stress response by means of blood samples and Davis studied the stress response by visual observations.

Tagging Experiments
For estimating discard survival two tagging experiments were carried out (Millner *et al.* 1993; Kaimmer and Trumble 1998). Millner *et al.* studied the survival of plaice, by comparing the recapture rate of discarded fish and of a control group. Each fish was measured and examined for condition and signs of skin damage. Kaimmer and Trumble investigated the injury, condition and mortality of Pacific halibut. The recapture varied between 5 % (Kaimmer and Trumble 1998) and 40 % (Millner *et al.* 1993).

Synthesis

- Condition categories are not always distinguished

- Stress and mortality are reduced when exposure to air is reduced (Davis and Ryer 2003).

- Stress levels are highest just after the fish are caught. When fish are kept in a tank, the stress level does not increase, but it is higher than normal levels. (Davis and Ryer 2003)

- Density is most often lower than in RIVO experiment. Millner (Millner *et al.* 1993) did two experiments with plaice. In one experiment 10 specimens were kept in a cage of 60x40x20 cm (48 liters), in another 5 specimens per cage. It seemed that reducing the number of specimen in a tank increased the survival chance, because of a decreased chance of cross infections.

- Water quality (temperature, oxygen and salinity) is monitored in all experiments and regulated in some

- Temperature is a very important factor: should be similar to values is natural habitat (Davis and Ryer 2003)

- Length of experiment varies a lot

Comparison of set-ups: advantages and disadvantages with regard to discard survival studies of plaice in the Dutch beam trawl fishery:

1. onboard vs. laboratory

	Advantages	**Disadvantages**
Onboard	- Start immediately after catch - Fish can easily be released after experiment	- Disturbed by movement of the vessel
Laboratory	- Experiment in environment that does not move, easier to reduce stress - more measurements are possible	- Transport to research location takes time and might cause extra stress - Only fish from the last day of catch can be used, just before return to the harbour. Otherwise vessels have to be chartered to fish especially for these experiments - Expensive

2. tank vs. tagging

Tank experiments are useful for estimation of short term survival, while tagging experiments are more informative on long term survival (Millner *et al.* 1993).

	Advantages	**Disadvantages**
Tank	- All processes can be monitored	- Difficult to simulate natural habitat
Tagging	- Fish stay in natural habitat	- Many fish are required - Expensive - Unknown what happens below the water surface

Conclusions

The RIVO method could be adjusted according to some of the experiments mentioned in this study:

- Temperature, oxygen and salinity will be measured
- The density of fish will be decreased to 6 per tank

Adjustments according to other ideas:

- The autopsy will be intensified: did the fish die of the damages by the net, or by the experiment (e.g. lack of oxygen, high variation in temperature)

Annex 6. Suggestions for new discard survival studies

(Q1.5.b)
Survival studies for plaice and sole discards in the beam trawl fishery were carried out by the Netherlands Institute for Fisheries Research (RIVO) between 1972 and 1981 (Van Beek *et al.* 1990).
Recently, new discussions were started about the results of these studies. Mainly the fishing industry had some critical remarks about the method used:

- The density in the tanks used in the experiment was too high, which might have resulted in a decreased survival;
- Damage levels need to be reviewed.
- Vibrations of experimental set-up increases stress and, through that, mortality;
- Temperature and oxygen need to be constant and similar to values in the natural habitat;

By means of these remarks from the industry and a literature study on other survival studies, the experimental approach was critically reviewed.

Review
In the past decades, several survival studies have been carried out in other countries. Some studies used the same experimental set-up as the RIVO; some studies transported the caught fish to fixed research facilities; and other studies used tagging experiments for estimating survival of discards. All methods have their advantages and disadvantages.

For estimation of survival in the beam trawl fishery it is preferable to stick to the method used by Van Beek *et al.*, because this seems the most feasible and least expensive. However, the method itself can be adjusted according to what was found in other studies and according to remarks by the industry.

The original experimental set-up will be used, with the following adjustments:
- Temperature, oxygen and salinity will be measured
- The density of fish will be decreased to 6 per tank
- The autopsy will be done more thoroughly: did the fish die of the damages by the net, or by the experiment (e.g. lack of oxygen, high variation in temperature)

An experiment that would be very interesting to carry out *in addition to the experiment described above* is the more elaborate study where fish are transported to the laboratory shortly after they were caught. This experiment can be used to investigate the long term survival in a better controllable and more stable environment. Water quality will be checked; healthy fish will be joined as a control group; stress parameters will be measured. It is an expensive experiment, but very useful in addition to the onboard experiments.

From the fishing industry several ideas were suggested for improving discard survival. It would be very useful to investigate the effects of the suggested adjustments.

Possible adjustments:

Gear adjustments	- length of the net - length and height of the *bovenpees* - holes in the bottom of the net to get rid of trash and benthos
Fish handling on deck	- reduce exposure time to air - increase amount of water in the boxes

Methodology

The methodology of the traditional experiment is described in the literature analysis. Adjustments are described in the paragraph above.

Annex 7. Spatial distribution and growth

(Q1.3, 1.4, 1.7b)

Background

The evaluation of the Plaice Box that was carried out in 2004 (Grift *et al.* 2004) showed that the evaluation of the effectivity of the box was hampered by:

1. the fact that the specific aims and objectives of the closure were not well defined before closure was put into place
2. the fact that the Plaice Box was only partly closed and for the fisheries that still takes place the fishing effort is only known for part of the fleet
3. relevant, measurable criteria were not developed
4. there was no research program to monitor the effects, over a predetermined time scale
5. the lack of a reference area similar in ecology to the box area
6. other developments in abiotic and biotic variables, unrelated to the Plaice Box took place simultaneously, such as changes in water temperature and food availability
7. fishing effort outside the box increased

Because of the lack of a reference area no distinction could be made between the effect of the closure and other developments. Distribution and growth rate of plaice changed considerably since the closure. Young plaice leave the coastal area (and the box) in an earlier stage in life than they used to, thereby increasing the risk to be caught and discarded. Growth rate was high in the period 1970-1980, increased from 1980 onwards and has stabilised since. Also inter-annual variation in growth rate has increased recently.

There are several possible explanations for the change in distribution and growth rate:

- Change in nutrients. Although the relationship between changes in the environment and the plaice stock seem obvious, it is difficult to relate environmental changes to changes in the recruitment of plaice. There are several steps that might eventually link nutrient levels to the recruitment of plaice (nutrients-primary production-secondary production-growth rate-recruitment). Most of these links are poorly understood. Also links between closely connected levels are difficult to interpret: a decrease in primary production will only lead to a decrease in secondary production if primary production is limiting for secondary production. Moreover, a decrease in secondary production is not always related to food availability for plaice. Secondary production, for instance zoobenthos, is prey for a large variety of organisms, of which plaice only uses a selection, and different organisms may show different reactions to changes in primary production or water temperature.

- Change in water temperature. Different species and sizes groups have different optimum temperatures for growth (Fonds *et al.* 1992). If food is not limited, growth rate will increase with temperature up to a maximum beyond which growth rate will decrease. Small juvenile fish eat more and grow faster at higher temperatures than larger older fish. Large fish grow better in colder conditions. Plaice is a cold-water species, which means that the optimum temperature is relatively low (Fonds *et al.* 1992) In contrast, sole is a warm-water species that is not as sensitive to changes in water temperature (Fonds and Saksena 1977). The difference in change in distribution between plaice and sole supports this hypothesis.
- The idea often stated by fishermen is that the Plaice Box might have had a negative effect is based on the hypothesis that bottom trawling changes the benthic fauna community and increases food availability for plaice. The reduction of trawling activities in the box would thus have decreased food availability, influencing both distribution and growth. It has been shown that bottom trawling has a direct effect on the benthic community, by destroying benthic organisms that become available to scavenging flatfish, and an indirect effect by favouring fast growing pioneer species with a high productivity at the expense of long-lived slow growing species (Rijnsdorp *et al.* 1996). The conclusion of a literature search carried out for the Plaice Box evaluation is that there are many studies that study impact of bottom trawling on benthic communities and productivity. There is no evidence that bottom trawling enhances total ecosystem productivity. However, total ecosystem productivity is not directly related to food availability for plaice. To date there are no studies that quantify the effect of bottom trawling on the food availability for plaice.
- Changes in fish predator populations. Populations of species such as cod have decreased dramatically in the North Sea. If young plaice favour the deeper waters, but were prevented from going there by the presence of potential predators, a decline in predator density might have induced the change in distribution.
- The decrease in abundance of older plaice may have caused the movement of juvenile plaice towards deeper waters. If food competition between age groups or even inter-specific competition with e.g. sole or dab occurs, the distribution of juvenile plaice might be affected.
- The complete disappearance of especially the 1-group plaice from the Wadden Sea might be related to the rapid increase of Cormorants *Phalacrorax carbo* and

common seal *Phoca vitulina* in this area (Reijnders *et al.* 2003, van Roomen *et al.* 2004).

- Prey distribution and preference for food species may have changed. Large annual variation in several benthic species is common and trends were observed recently. For instance *Ensis americanus* increased in the coastal zone, bivalves generally decreased in the Wadden Sea, while polychaetes have increased there (Leopold 1998, Leopold *et al.* 2003).

Research proposal

For each of the hypotheses, proposals for research are presented here. All proposals gain strength if the work is not limited to plaice only, but other flatfish species (e.i. dab, sole) are included as references because of differences and/or similarities in characteristics between species and to take account of possible inter-specific interactions (competition).

Growth rate
To investigate the effects of temperature and food on growth of plaice a review of the literature on the growth physiology of plaice and sole will be conducted to determine the effect of temperature on the maximum growth rate at an excess of food. The physiological data can be synthesized in a model of the energy allocation from Kooyman (2000). Based on the literature review and synthesis, it is possible that additional tank experiments are needed.

Distribution
The description of spatial distribution of young plaice is based on the annual surveys carried out every autumn. However, many studies have shown that the effect of climate change is often expressed in a change in the seasonal phenology and a larger year to year variability. If young plaice move away form the shallower coastal water earlier in year than they used to, they might be missed in the autumn surveys. Also mismatches between food peaks and the reproduction of certain organisms occur (Philippart *et al.* 2003). There are very little data on seasonal migration patterns of flatfish in coastal waters and changes therein in response to the warmer water temperature. Also relationships with developments in prey availability have remained largely unexplored to date. Insight into these processes is crucial to understand why the distribution has changed.
Therefore we propose:

- To ask fishermen to record temperature during every haul and record the size distribution of discarded and marketable fish. This will generate an extensive high resolution dataset to investigate effects of temperature on (changes in) distribution for a future evaluation of the Plaice Box
- To start a local study in especially the coastal areas such as the Wadden Sea, the Delta and along the Dutch coast in which year round patterns of the abundance of young plaice is monitored. To be able to make comparisons other flatfish species must be monitored as well
- To analyse the existing survey data using CTD data. CTD data are collected in a standardized way during all RIVO surveys in recent years. However, to date these data were never used in analyses of distributions. Effects of temperature on distribution can be explored.
- Explore to what extent the disappearance of 1-group plaice from the Wadden sea can be explained by changes in food availability. An integrated analysis of survey data on benthic fauna, shrimp and fish (NIOZ and RIVO surveys) can provide new insights in recent changes in the Wadden Sea ecosystem

The effect of bottom trawling on the food availability for plaice

In all studies of the effect of bottom trawling on benthic fauna the focus has been on changes in benthic communities and to a lesser extent on productivity. Also diet choice in relation to food availability is unknown. Large changes in food choice have been noted since the beginning of the 20th century, but recent information is lacking (Rijnsdorp and Vingerhoed 2001). Do plaice eat what is available or do they have certain preferences? Or do they adjust their diet to changes in food availability? Therefore we propose:

- to set up a large scale experiment in which several predefined areas will be exposed to different trawling intensities. The areas must be comparable in all abiotic parameters such as soil, depth and median grain size. Both composition and productivity of the benthic fauna will be measured annually. All areas will be monitored for at least five consecutive years.
- Diet studies in flatfish species: exploration of existing data. In the recent past stomach contents have been sampled in several studies. In the baseline study for an airport island stomach data have been collected in an area for which detailed information on benthic fauna was available. However due to a premature end of this project these data were never analysed. These data can be used to relate food choice of flatfish to food availability
- Diet studies in flatfish: seasonal and geographical variation. Elaborating on the study mentioned above stomachs will be sampled of flatfish originating from different areas and in different periods. For such a study fish (stomachs) and benthic fauna should be sampled within the same area and period.

- Diet studies: use of new techniques such as isotopes. Analyses of isotopes in fish can show the origin of the food and identify to what level in the food chain it belonged.
- Experimental studies on food choice in flatfish: study food preferences in captivity by offering a wide range of prey items to flatfish of different ages.

Effect of the Plaice Box: introduction of a reference area

In the evaluation of the Plaice Box an experimental set-up was recommended. This allows for the separation of autonomous developments and the closure (with or without fishing) effects. A control area that only differs from the treatment area in fishing intensity should be used.

Therefore we propose to:

- Change the set-up of the Plaice Box so that some areas are completely closed for fishing (including all trawling fisheries, eurocutters and shrimp fisheries) and other areas are opened for fishing. Fishing intensities in the open areas should be monitored. The DFS and SNS surveys can be used to monitor development in fish fauna and epibenthos. An extra survey for benthos should be conducted. Using such a setup it is possible to investigate possible negative effects of the closed area. Therefore annual surveys of benthic fauna and fish in both fished and not fished areas are needed. A setup to show a positive effect of a closed area is more difficult. A positive effect can only be shown if an increase in recruitment originating from the non-fished areas can be shown. However, the number of settling demersal plaice is highly variable due to variable mortality during the pelagic phase and the pre-recruit demersal phase (discard mortality, predation, diseases). Therefore the critical test for the evaluation would be if the cumulative discard mortality until the time when the cohort reaches the minimum landing size has decreased.

Predation by cormorants and seals

To assess the importance of flatfish in diets of predators such as seals and cormorants diet studies are needed. For both species the easiest option is to analyse fish otoliths in regurgitates and droppings. For both groups this has been done in the past by Alterra on an ad-hoc basis (Brasseur *et al.* 2004). However a regular monitoring program in which regurgitates are collected in breeding colonies and on roosts (cormorants) and tidal flats (seals) is lacking. This would yield information on prey choice (species and size) and seasonal changes therein. Therefore we propose to:

- Start a regular monitoring program in which regurgitates of cormorants, to be collected during the breeding season in colonies and outside the breeding season on roost sites, are analysed.

- Start a regular monitoring program in which droppings of seals (harbour and grey) are collected on the tidal flats and analysed

Annex 8. Mesh size experiments

(Q2.5.a)

Objective

Comparison of the difference in beam trawl catch composition between cod-ends with 80, 90, 95 and 100 mm mesh size.

Experimental set-up

There are several ways to measure mesh selectivity. In increasing order of sophistication information can be gathered by a comparison of the catch composition between varying mesh sizes, the comparison of the catch in two different nets in parallel hauls, the measurement of the fraction of the catch that escapes through the meshes. It depends on the available budget and the desired output which of the ways is chosen.

In order to give a good estimation of the required number of observations, more information is needed on the variation in catch composition between trips, hauls and starboard/port side of a vessel. For this document, a rough estimation was made for the length of the experiments and number of hauls needed.

Experiment 1: Comparison of landing composition between vessel

The simplest type of comparison can be done on trip basis. 4 vessels fish each with a different mesh size: 80, 90, 95 or 100 mm. The landing compositions of the vessels are compared for each week. All commercial species can be taken into account. No RIVO personnel has to be onboard, the data can be collected by the fishermen themselves.

This experiment gives a rough idea of the differences in catch composition by trip between different mesh sizes. Possible vessel, area and time effects are not taken in account. Neither is information on selectivity of the nets.

<u>Estimated length of experiment</u>

5 weeks

<u>Expected costs</u>

- Manufacturing of cod-ends (if 80 and 100 mm are available) with 90 mm and 95 mm (P.M.)
- Data analysis and reporting (RIVO, WO 60 hours): ~6000 euros

Experiment 2: Comparison of landings by size class

An experiment that is more labour intensive for the cooperating fishermen, but gives more information as well, is a comparison of mesh sizes by haul onboard one vessel. This vessel fishes with 2 different mesh sizes at a time: with 80 mm as a reference net on one side and 90, 95, or 100 mm on the other side. After each haul, the length composition of the catches from both sides is measured separately. The number of species under investigation has to be limited to decrease the amount of work. Focus will be on plaice and sole.

Using this method, information is gained on the catch composition by haul. Effects of vessel characteristics, area or time on the difference in catch composition do not have to be taken in account. Information on selectivity is not gained by this type of experiment but can be inferred from the difference in the length distribution of the catch.

No RIVO personnel has to be onboard, the data can be collected by the fishermen themselves.

<u>Estimated length of experiment</u>
The vessel fishes 3 weeks, in each week another combination of nets is tested. In each week, at least 20 hauls should be carried out.

<u>Expected costs</u>
- Manufacturing of cod-ends (if 80 and 100 mm are available) with 90 mm and 95 mm (P.M.)
- Data analysis and reporting (RIVO): ~10000 euros

Experiment 3: Comparison of landings by size class, including selectivity

An experiment that is most elaborate and most expensive is a selectivity experiment. One vessel fishes with 2 different mesh sizes at a time: with 80 mm as a reference net on one side and 90, 95, or 100 mm on the other side. Special gear for selectivity measurements is used to measure the percentage of fish in the catch that is retained in the cod-end. In practice two different methods are available for this experiment: 1) the covered cod-end method were the fish that escape through the meshes are caught in a fine meshed cod-end that envelopes the commercial cod-end; 2) a trouser cod end where special nets are used comprising of one legs with different mesh sizes. Each haul, the length composition of the catches from both sides are measured separately, as well as the length distribution of the fish that escaped through the meshes and is collected in a small meshed cod end (coverd cod-end technique only). The number of species under investigation has to be limited to decrease the amount of work. Focus will be on plaice and sole. This experiment has to be carried out in the presence of RIVO personnel.

This experiment gives us the same information as experiment, including suitable data for updating the selectivity ogives.

Estimated length of experiment

The vessel fishes 3 weeks, in each week another combination of nets is tested. In each week, at least 20 hauls should be carried out.

Expected costs

- Manufacturing of cod-ends (if 80 and 100 mm are available) with 90 mm and 95 mm (P.M.)
- Manufacturing of gear selectivity measuring devices (P.M.)
- 2 RIVO co-workers onboard the vessel for 3 weeks (~36000 euro)
- Data analysis and reporting (RIVO, WO 160 hours): 16000 euros

Notes

- Choice of fishing areas: the experiments should be carried out in areas where all size classes are present. This might mean that licenses are required for fishing with < 100 mm above 55° latitude. In Experiment 3 the special gear for selectivity measurements contains meshes < 80 mm, so at least for this type of experiment a special license is required.
- Experiment 3 could also be carried out onboard R.V. Tridens, where the research facilities are better for selectivity experiments. This will bring extra costs (approx. 14.000 euros per day at sea), but then no commercial vessel has to pause its fishing for carrying out the experiments and no license is required.

Annex 9. Selectivity experiments

(Q2.6).

Objective

To find out whether selectivity parameters used in analyses are still up-to-date. If not: describe how they can be updated

Are the selectivity parameters still up-to-date?

Probably, due to changes technical measures and technical developments, the selectivity parameters that are currently used are not up-to-date. It is expected that, in the course of the past decades, L_{50} (the length at which 50% of the fish are retained in the net) has shifted to lower values, i.e. the nets are less selective due to changes in the design and characteristics of twines used. However, it is unknown to what extent L_{50} has shifted. The extend to which the parameters are out-dated, should become clear from the mesh size experiments executed by the fishing industry (see Annex 8).

When the beam trawl selection ogives were determined (Van Beek 1982), the idea was that only mesh size was of great importance in calculating selectivity ogives. In the mean time it was shown by research that more variables have a significant effect on selectivity (Reeves *et al.*, 1992). Other variables that affect selectivity are listed in the table below:

Gear	Variable	Reference
All	Mesh size	
	Mesh thickness	(Ferro and O'Neill, 1994)
	Mesh stiffness	(O'Neil and Xu, 1994)
	Mesh shape	(Reeves et al, 1992)
	Number of meshes around the cod-end	(Reeves et al, 1992)
	Length of the extension piece in front of the cod-end	(Reeves et al, 1992)
Beam Trawl	Beam width	
	Number of chains	
	Presence and features of codend attachments	

In the early 1980s, selection ogives were fitted by eye. At present, computers, software and models are available to calculate selection ogives (Constat, 1995; Millar and Walsh, 1992). In order to be able to calculate selection ogives on a haul-by-haul basis, it is necessary to measure a relatively large number of fish: as a rule of thumb at least 200 individuals per species per haul.

Updating selectivity ogives

Full selectivity experiments are needed to determine changes in selectivity characteristics. In general this should be done by trained scientists as the complexity of data collection and analysis is usually outside the scope of work offered by the industry alone.

Catch comparison experiments can be carried out to investigate how catch composition depends on mesh size: e.g. whether a lower level of discards results from larger mesh sizes. This approach will not generate selection characteristics, but merely comparative data on the effect of mesh size alterations on catch composition categories, e.g. number of fish per species above and below the minimum landing size.

Annex 10. Description of the simulation model

To evaluate the potential effect of spatial-temporal management measures, a spatially explicit simulation model was developed. The basic idea of the model is that if both the spatial distribution of plaice and of the fishing effort is known, the catch can be calculated from the selectivity characteristics of the gear and the relative availability of an age group on the fishing grounds (ICES, 1987; Rijnsdorp and Pastoors, 1995). If there is a high overlap in the distribution of the resource and the fishery, a larger proportion of the population will be harvested. The model comprises the basic biological processes of growth and mortality, and has a spatial resolution of ICES rectangles and a temporal resolution of quarters. The plaice population is divided in age classes 1 to 10. Recruitment occurs at age 1 and can be modelled as a constant number or as a stock-recruitment function with a variance component. Growth follows a von Bertalanffy equation (VBGE). The model comprised of two fleets (Dutch Euro cutters with an engine power of 225-300 hp, Ducth beam trawlers >300 hp). It was assumed that these fleets were representative for the total international fleet. The model was build using the R software environment and allows a tailor made applications. The model could, for instance, be modified to model more fishing fleets and smaller time steps.

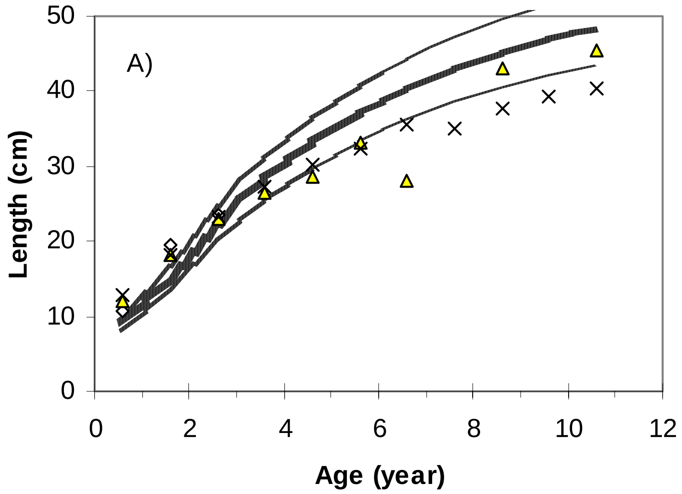
Model parameterisation

Length distribution at age

The growth rate was based on the observed mean length at age of plaice in the autumn survey data of RIVO in the recent years (Figure A10.1). The VBGE parameters were set at: t0=0.1; K=0.2; Linf=55cm. A condition factor of 0.01 was applied to convert the length into a mean weight. Assuming a coefficient of variation of 10%, the length distribution at each time step was estimated. Figure A10.1 shows that there is some discrepancy in the length used in the model and the mean length at age as used in the stock assessment.

Mesh selection

Selectivity parameters for plaice were: selection factor sf=2.2; selection range=10 cm. The selection range chosen was larger than the value estimated for each experiment to take account of the variation in selection factors that are likely to occur among ships. The mesh selection experiments of the early 1980s conducted on board of commercial beam trawlers at different times of the year and different fishing grounds showed a rather wide variation in the estimated selection factor. With the selection parameters, the fraction of each age group that escaped through the meshes can be estimated. The fish that are retained in the net were separated into a discard group (< minimum landing size) and a landing group (>= minimum landing size).



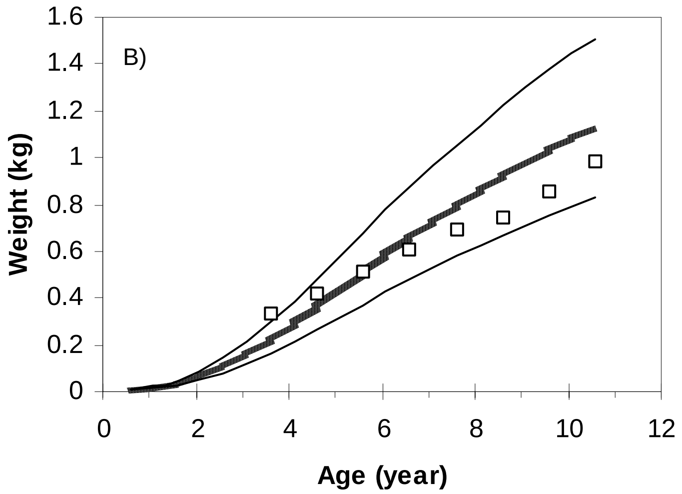


Figure A10.1. *Mean and 95% range of length (A) and mean weight (B) of plaice as used in the simulation (full lines). The simulated length and weights are compared to the length observed in the surveys (DFS - ◊; SNS - Δ; BTS - x) and the catch weight used in the stock assessment (□).*

Distribution

The distribution of age group 0 – 3 was modelled from the densities of plaice measured in the Demersal Young Fish Survey (DFS: age group 1 and 2); Sole Net Survey (SNS: age group 1, 2, and 3); Beam Trawl Survey (BTS: age group 2 and 3), all carried out in the period between mid August and mid October. The surveys all deployed a beam trawl as fishing gear. Catch numbers were converted into the number per hectare.

As plaice progressively move to deeper water from the inshore nursery grounds, the offshore movement was modelled by including depth, distance to the continental coast and age in the model:

$\log Y = Survey*Ageclass + Cohort + \Sigma Depth^n + \Sigma Dist^n + \Sigma Lat^n + \Sigma Lon^n$

$$+Age*(\Sigma Depth^n + \Sigma Dist^n + \Sigma Lat^n + \Sigma Lon^n)$$

Depth, distance, latitude and longitude were included as a taylor series to allow for non-linear relationships between logy and these co-variables. The interaction twerm between Age and depth, distance, latitude and longitude modelled the change in distribution with age. Finaly, the interaction of survey*ageclass took account of the differences in catchability (mesh size, fishing speed) among the surveys. The model explained, including the significant terms only, 4&% of the variance in log catch rate (Table A10.1). With this model the catch rate was predicted for each ICES rectangle at day 15 of February, May, August and November and used as the basis for the relative distribution of the age classes needed for the simulation model. Modelled distributions are shown in Figure 7.5a.

Tabel A10.1 *Results of the genmod analysis of the catch numbers of 0-3 year old plaice per ha as a function of distance to the continental coast, depth, latitude(lat), longitude (lon) and the age. With this model the density of plaice was predicted for each ICES rectangle in each quarter.*

Source	Deviance	NumDF	DenDF	FValue	ProbF	ChiSq	ProbChiSq
Intercept	470951.4						
ageclass*survey	351733.4	14	11355	385.2	0	5392.9	0
cohort	344613.1	9	11355	35.8	0	322.1	5.34E-64
depth	296752.1	1	11355	2165.0	0	2165.0	0
dist	289533.8	1	11355	326.5	0	326.5	5.49E-73
dist*dist	284261.5	1	11355	238.5	0	238.5	8.39E-54
depth*age	278322.3	1	11355	268.7	0	268.7	2.22E-60
depth*depth*age	276586.8	1	11355	78.5	0	78.5	7.98E-19
dist*age	274907.5	1	11355	76.0	0	76.0	2.89E-18
dist*dist*age	270639.6	1	11355	193.1	0	193.1	6.83E-44
lat	268658.2	1	11355	89.6	0	89.6	2.87E-21
lon	266648.7	1	11355	90.9	0	90.9	1.51E-21
lat*lat	257954	1	11355	393.3	0	393.3	1.58E-87
lat*lon	257856.3	1	11355	4.4	0.035513	4.4	0.035491
age*lon	256360.8	1	11355	67.6	2.22E-16	67.6	1.95E-16
age*lat*lon	251020.6	1	11355	241.6	0	241.6	1.79E-54

For the older age classes, the catch rates of the surveys are rather low. Also these age groups will start showing seasonal migrations between the spawning areas in winter and the feeding grounds in summer. Hence, it was decided to estimate the seasonal distribution patterns of the exploited plaice population from the commercial catch rates. In an intermediate step, the catch rates were converted into partial fishing mortality estimates per fishing trip (fpue, Rijnsdorp *et al.*, 2005) and allocated to the ICES rectangle in which most of the week catch was reported. These fpue reflects the probability that plaice is caught during a unit of fishing effort. As such it is an estimate of the relative abundance of plaice on a particular fishing ground. The fpue were then analysed in relation to the engine power of the vessles (lhp), depth latitude, longitude and the seasonal change in distribution (sin + cos). The seasonal pattern was modelled as a taylor series of the periodic function of the day number (radians):

$$\log Y = lhp + \Sigma Depth^n + \Sigma Lat^n + \Sigma Lon^n$$

$$+(\Sigma \sin^n + \Sigma \cos^n)*(\Sigma Depth^n + \Sigma Lat^n + \Sigma Lon^n)$$

Tabel A10.2 *Results of the genmod analysis of fpue as a function of depth, latitude(lat), longitude (lon) and the seasonal pattern (sin cos). With this model the fpue was predicted for each ICES rectangle in each month. The monthly prediction were then averaged to give an estimate of the predicted fpue for each quarter, which reflects the relative abundance of plaice in each ractangle.*

Source	Deviance	Num DF	DenDF	FValue	ProbF	ChiSq	ProbChiSq
Intercept	0.073219						
lhp	0.069986	1	29595	2263.222	0	2263.222	0
depth	0.067463	1	29595	1766.744	0	1766.744	0
depth*depth	0.067428	1	29595	24.89905	6.08E-07	24.89905	6.04E-07
lat	0.067059	1	29595	257.8602	0	257.8602	5.02E-58
lon	0.066696	1	29595	254.7399	0	254.7399	2.41E-57
lat*lat	0.06362	1	29595	2153.358	0	2153.358	0
lon*lon	0.063514	1	29595	74.42866	0	74.42866	6.29E-18
lat*lon	0.063078	1	29595	305.5757	0	305.5757	2.01E-68
lon*lon*lon	0.063076	1	29595	0.998921	0.31758	0.998921	0.317572
depth*depth*sin	0.063071	1	29595	3.948079	0.046934	3.948079	0.046925
lat*sin	0.062884	1	29595	130.6922	0	130.6922	2.89E-30
lat*cos	0.047097	1	29595	11054.44	0	11054.44	0
lon*sin	0.046995	1	29595	71.20256	0	71.20256	3.22E-17
lon*cos	0.046984	1	29595	7.473359	0.006266	7.473359	0.006262
lat*sin*sin	0.04521	1	29595	1242.583	0	1242.583	3.4E-272
lon*sin*sin	0.044877	1	29595	233.2951	0	233.2951	1.14E-52
lat*lat*sin	0.044314	1	29595	393.9425	0	393.9425	1.15E-87
lat*lat*cos	0.043104	1	29595	846.9592	0	846.9592	3.3E-186
lon*lon*sin	0.04304	1	29595	45.43492	1.61E-11	45.43492	1.58E-11
lat*lon*sin	0.042959	1	29595	56.53474	5.67E-14	56.53474	5.52E-14
lat*lon*cos	0.042911	1	29595	33.72976	6.4E-09	33.72976	6.33E-09
lat*lat*sin*sin	0.042452	1	29595	321.2059	0	321.2059	7.91E-72
lat*lon*sin*sin	0.042266	1	29595	130.4229	0	130.4229	3.31E-30

The model with significant terms explained 41% of the variance in log(fpue). With this model, the fpue was predicted for each month in each ICES rectangle for a standard vessel of 2000 hp. The relative abundance was then calculated for each quarter and each ICES rectangle from the monthly predictions. Figure 7.5b shows the resulting distribution pattern. It is noted that the distribution in the 1st quarter does not give a very strong concentration of adult plaice in the Southern Bight, where the main centre of egg production occurs (Harding *et al.*, 1978). This is mainly due to the fact that plaice appears to concentrate in this area mainly in January. From February onwards, the fpue in this area sharply decrease as the plaice start their return migration to the feeding grounds. Nevertheless, the quarterly distribution patterns reflect the seasonal shift from a southern distribution around the spawning and a northern distribution in the feeding period.

The distribution patterns used in the simulation should be considered as a first approximation. In particular the distribution of the age groups >=4 is only a very crude proxy for the distribution of the older age groups. These distribution maps were based on the catch rates of the commercial fisheries and ignored the spatial and seasonal differences in the size distribution. Although this information is available in the sales slips of the landings, the fisheries researchers has no access to this information. If this data would have been available, distribution patterns could have been estimated for the separate age groups. Also, the seasonal and spatial pattern of the recruitment of a new year class could have been quantified.

Annex 11. Trends in fishing efficiency of the Dutch beam trawl fleet

An analysis of the partial fishing mortality generated per day at sea (FpUE) of the fleet of large beam trawlers showed that the efficiency of the fleet has increased since 1990 (Rijnsdorp *et al.*, 2005). The FpUE is the fishing mortality caused by one ship per day at sea. The total fishing mortality is thus the sum of all these partial fishing mortalities. To estimate the trend in efficiency of the Euro cutter fleet, the analysis of the FpUE that was executed by Rijnsdorp *et al.* (2005) was extended to include both the Euro cutter (<=300 hp) and larger cutters (>300 hp). In order to analyse the effect of a time trend in FpUE and the contribution of the vintage of the engine (bjm) and hull (bjc) for the Euro cutter fleet and the fleet of large beam trawlers we took account of the effect of other variables: engine power, fishing areas and seasonal pattern (Table A11.1). All variables showed to have significant effects on the partial fishing mortality (and thus the efficiency of one ship). It is noteworthy that the slope of the log-log regression of FpUE and engine power is less than 1. Hence, there is a less than proportional increase in efficiency with increasing engine power. Thus, if the engine power would be doubled (from e.g. 1000 to 2000 hp), the efficiency would not double. The slope of the relationship for sole (0.74) was steeper than that for plaice (0.54). The results for the Euro cutter fleet are less meaningful as most Euro cutters record an engine power of 300 hp.

The analysis revealed that the efficiency of the euro cutters increased by 7.6% (se = 0.1) for sole and 1.4% (se = 0.2) for plaice over a period of 13 years (1990-2003). For the fleet of large beam trawlers, the corresponding values were: sole = 3.2% (se=0.04); plaice = 1.7% (se=0.04). The positive trend in time was mainly due to the upgrading of the engine and the replacement of an old by a new vessel (Table A11.2). The combined effect of these contributed to more than 80% of the increase in efficiency for sole and more than 60% for plaice.

The effect of the vintage of the engine and the hull on the observed increase in efficiency was explored using data on the oil consumption per unit of administrative engine power from the LEI[4] panel. The oil consumption of the sampled vessels showed a steady increase in both the Euro cutters and the fleet of large beamers (Figure A11.1). No such change was apparent in the vessels that remained unchanged. Comparing the mean value over the last three years with the overall mean of the unchanged vessels suggest an increase in oil consumption of 19% in the Euro cutters and 4% in the large trawlers. The inter annual-variation in the oil consumption within the fleet is likely due to the mutations within the LEI-panel.

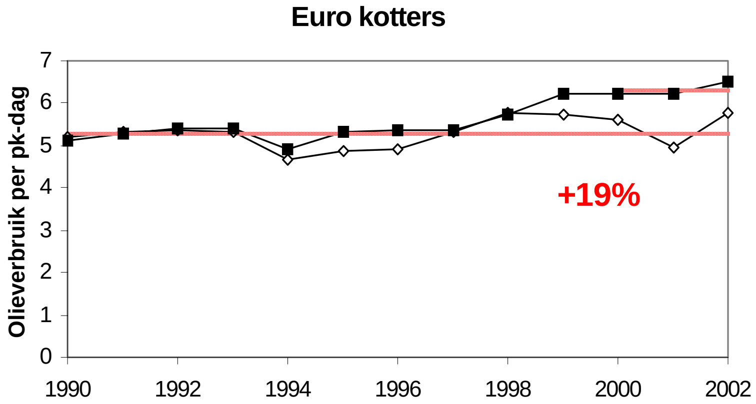
[4] The Netherlands Agricultural Economics Research Institute LEI.

***Table A11.1**. Results of the analysis of covariance of the partial fishing mortality per day at sea (fpue) of individual fishing trips of two fleet classes (large beam trawlers, Euro cutters). The table shows the percentage of the variance in fpue that is explained by the co-variables: fleetclass (euro – large beam trawlers); engine power (lhp); fishing area (area); seasonal pattern (periodic); vintage of the hull (bjc), vintage of the engine (bjm) and the time that a vessel has been in operation.*

	Sole			Plaice		
	%expl	df	P	%expl	df	P
fleetclass	15.0%	1	<0.001	23.3%	1	<0.001
lhp*fleetclass	13.7%	2	<0.001	4.1%	2	<0.001
area*periodic	12.0%	65	<0.001	25.2%	77	<0.001
bjc*fleetclass	2.7%	2	<0.001	0.7%	2	<0.001
bjm*fleetclass	1.0%	2	<0.001	0.03%	2	<0.001
tship2*fleetclass	0.5%	2	<0.001	0.2%	2	<0.001
total	45.0%	109633		53.5%	117879	
error	55.0%	109559		46.5%	117793	

***Table A11.2.** Contribution (%) of the replacement of a vessel by a newer vessel (bjc), the upgrading of the engine (bjm) and the time that a vessel has been in operation (tship2) to the overall increase in efficiency of the Euro cutters and large beam trawlers between 1990-2003.*

	Euro cutters		Large beam trawlers	
	sole	plaice	sole	plaice
bjc	21.2%	71.2%	35.4%	39.3%
bjm	64.0%	11.3%	27.2%	24.0%
tship2	14.8%	17.5%	37.3%	36.7%



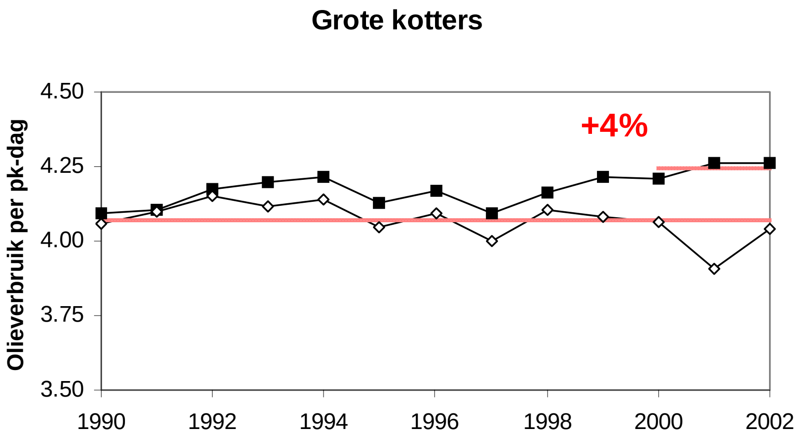


Figure A11.1. *Fuel consumption per hp-day (on the y-axis) for Euro cutters (<=300 hp, upper panel) and large beam trawlers (>300 hp, lower panel) based on the LEI panel data (analysis carried out by Hans van Oostenbrugge, LEI).*