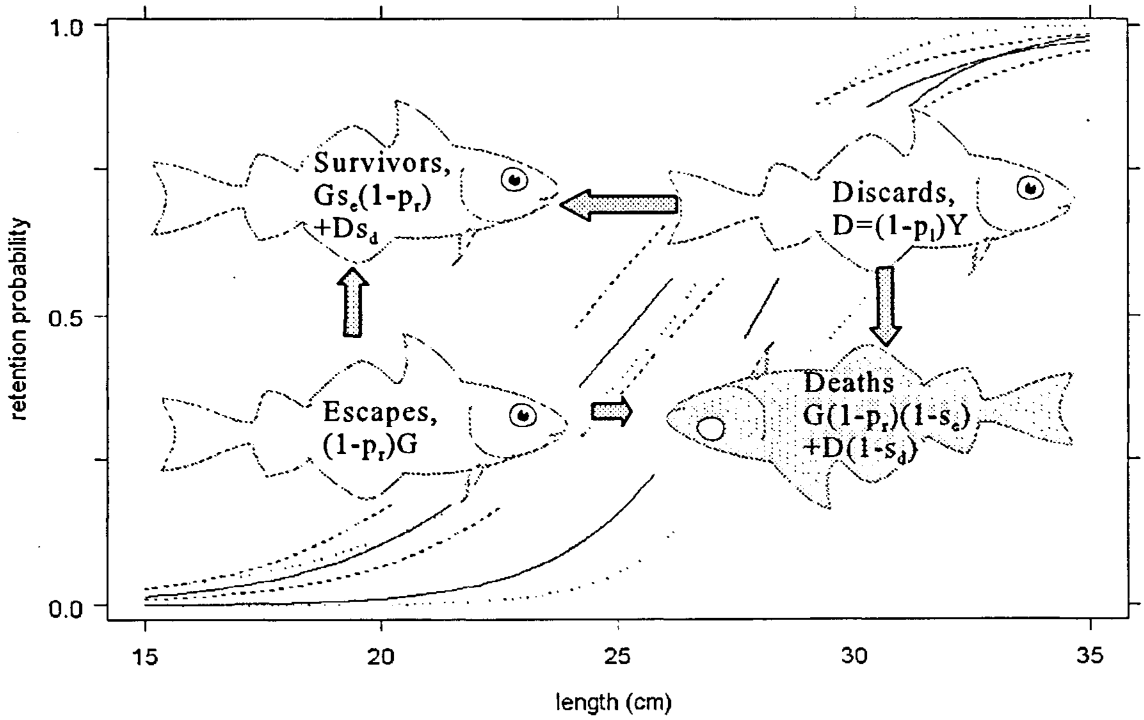
Fisheries Technology
Committee

ICES C.M. 1998/B:6

Report of the

Study Group on the Use of Selectivity and Effort Measurements in Stock Assessment

ICES Headquarters , 9-13 September 1998



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https://doi.org/10.17895/ices.pub.9582

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1. INTRODUCTION

1.1 Participants

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1.2 Terms of reference

The **Study Group on the Use of Selectivity Measurements in Stock Assessment** [SGSEL] will be renamed the **Study Group on the Use of Selectivity and Effort Measurements in Stock Assessment** (Co-Chairmen: Dr R.M. Cook, UK (or his designate) and Dr D.A. Somerton, USA) will meet at ICES Headquarters from 9–13 September 1998 to:

a) validate the selectivity parameters obtained from mesh selection experiments against values obtained from other methods;

b) perform case studies to assess the impact of post-selection mortality data on total fishing mortality;

c) further develop the methodology for combining selectivity parameter estimates for different trials;

d) investigate how information sources such as environmental variables and survey gear performance data or Bayesian priors can be utilised in stock assessment models;

e) evaluate the implications for assessment and management of the stability or trends in catchabilities on varying spatial scales, with an emphasis on the relationship between fishing mortality for select stocks and fleet-based effort.

SGSEL will report to ACFM, the Fisheries Technology and Resource Management Committees at the 1998 Annual Science Conference.

1.3 Overview

The first meeting of the study group concentrated on codend selectivity data and the various issues related to their use in stock assessments. This work has continued and is reported in Sections 2 and 3 of this report. Section 2 deals with recent developments in field experimental data and the establishment of a database for selectivity information.

Section 3 is concerned with the problem of combining estimates of selectivity from field trials into single estimates of selectivity for particular gears or fleets. Statistical methods are described which take into account various sources of variability which arise from sampling using differing vessels under different conditions. The model is then used to obtain for the first time a combined estimate of fleet selectivity for North Sea haddock based in experimental data. This is compared with estimates derived from stock assessment data documented in the first SGSEL report (ICES 1996a). Results of these preliminary analyses suggest that the experimental and stock assessment data provide consistent estimates of selectivity for towed gears fishing for haddock.

While codend selectivity of commercial gears is important in evaluating the management implications of technical measures, the selectivity and catchability of research vessel gears is important in stock assessment. This is of particular concern where survey data are used to scale the assessment to absolute, as opposed to relative, estimates of stock size. A common problem in such analyses is the correlation between the estimates of catchability and natural mortality. Usually there is insufficient information in the data to estimate both quantities in the assessment and at least one value needs to be quantified. Section 4 discusses this problem and how experiments may be used to estimate survey catchability for use in assessments.

Fishing mortality is the only population dynamics variable which managers may aspire to influence in the management of fisheries. Crudely it may be divided into factors which quantify fishing activity and those which quantify the ability of fleets to catch fish. Fishing activity is usually measured in terms of nominal fishing effort, such as days at sea etc. Many factors affect the ability of fleets to catch fish, informally called catchability, and this will include, *inter alia*, fleet capacity, gear type, vessel size and power and season. Recent advice from scientists for some demersal stocks has been to limit fishing effort so as to reduce fishing mortality (ICES 1998a). If such measures are to be successful then the relationship between fishing effort and fishing mortality needs to be identified. In addition, effort data are often important in 'tuning' stock assessments. WD6 discusses some of the problems associated with the use of commercial effort data. Section 5 deals with these issues in relation to the North Sea demersal stocks.

A common assumption made when evaluating the benefits of a mesh size change is that fish which pass through the net without being retained all survive. At face value this means that increasing mesh size may improve the long term yield from a stock. Recent experiments have indicated that not all fish passing through the gear survive. This may have important implications both for the evaluation of mesh sizes and for conventional stock assessment if a significant number of deaths are not accounted for in the calculations. Section 6 reviews the present state of knowledge of the survival of fish which have passed through a codend. Attempts are also made to calculate the impact of this survival on conventional assessments. Preliminary results for North Sea haddock suggest that although the effect may not be large, including the post-selection mortality in the assessment can alter the perception of the state of the stock.

2. SELECTIVITY DATA

Study Contract No. 1991/15 (Wileman, 1991) for the Commission of the European Communities, Directorate General for Fisheries gives a review of available selectivity data, including an extended bibliography and data sheets of codend selectivity measurements for North Sea species. The data are based on species, gear type and author and are given in an aggregated format. Raw data are not included, but summarised data with confidence limits are available. Averaged data corrected to a standard codend. Easy exchange of this data is limited due to the fact that they are only given in printed form.

The methodology of conducting selectivity experiments as given in Pope *et.al.*, 1975 was improved substantially by a task group with members from the Fishing Technology and Fish Behaviour Working Group (FTFB-WG), published as an ICES Cooperative Research Report (Wileman *et al*, 1996). The authors of the manual recommended specifically "the establishment of an international database of gear selectivity measurements obtained using approved methods".

Selectivity data are not held centrally but by individual institutes in widely varying formats. It is therefore difficult to obtain appropriate summaries or subsets of the wide range of available selectivity information. The wish to improve the exchange of selectivity data has been expressed during several meetings of the ICES Working Group on Fishing Technology and Fish Behaviour in recent years.

Following the activities in the Fish Capture Committee, the *Ad Hoc* Group on the ICES Secretariat Databases included in his report the establishment of a selectivity database as one of desired new initiatives. It was listed under item 10 in Chapter 3 "New initiatives and associated databases" (ICES 1995).

Gear designs are continuously evolving which affect size selectivity. Older data on cod-end selectivity do not therefore accurately represent the selectivity of current fleets and the fishing mortality they cause. To reduce fishing mortality a range of devices has been developed (eg rigid sorting grids and square mesh escape panels) and as these are now being adopted in conservation measures, knowledge of their selectivity is also needed.

In 1996 an EU-funded concerted action (van Marlen, 1998) was started. The project aimed at defining the specifications and conditions for developing, using and maintaining a selectivity database.

Participants from institutes in Norway, Sweden, Denmark, Germany, The Netherlands, Belgium, France, Portugal, The United Kingdom, and Greece addressed workers in gear technology and stock assessment to investigate the need for selectivity data and find out the extent of data collected.

There are three categories of participant in a database system: the data owner who supplies the original data; the user who makes requests for data; the host who acts as a central focus and may operate the database. A participant may be a public research institute, a private organisation, an international body (eg ICES) or exceptionally an individual scientist.

The fisheries manager or stock assessment biologist usually needs highly aggregated data at fleet or area level - eg the fishing mortality for sole for the Belgian beam trawl fleet (engine power below 270 hp) in ICES Area IVc. The most appropriate aggregation level for this group is at experiment level where an estimate of the selectivity of a particular codend tested during one experiment (many hauls) is available. These can be aggregated to the desired higher level if information on variance is available.

The gear technologist or stock assessment biologist may want less aggregated data to develop models of selectivity in terms of variables which change every haul - eg the effect of catch size on selectivity of haddock in pair trawls. Here it may be necessary to have estimates of the selectivity of individual hauls made with a particular codend which can then be combined to develop a model. Haul-level information may also be most appropriate for developing models of the effect of variables such as mesh size which do not vary from haul to haul in an experiment.

The statistician may want to undertake more detailed research to develop improved methods of analysis of selectivity data. In this case it is usually essential to have the full original data set comprising the length/frequency distribution of the measured fish and the appropriate raising factors. A comprehensive database including the length-frequency information may also be required by all collectors of selectivity data as a means of long-term storage and to ensure that all relevant information on an experiment is recorded for posterity.

Following a consultation exercise with potential database users, a number of options for the establishment of such a database have been identified. These options are now the subject of a project proposal to develop the database with financial assistance from the EU. At present the contract is under negotiation.

3 FLEET ESTIMATES OF SELECTIVITY

3.1 Methods of combining selectivity data

Annex 1 (also WD2) discusses methods for combining selectivity data from different trips. Typically, selectivity data contain information at a number of different *levels*. With just one trial (with a single codend say), there is information about the selectivity of each haul, and about how selectivity varies between hauls. With several trials, there is additional information about how selectivity varies between codends, or between trips with the same vessel, or between vessels. Such data are known as *hierarchical* or *multilevel* data.

There are many techniques available for modelling hierarchical data; see Goldstein (1995) for example. Broadly, these fall into two types:

- Bayesian methods, and particularly Monte Carlo Markov Chain techniques (eg Spiegelhalter *et al*, 1995). Holtrop (1998) describes in detail how these can be applied to different selectivity data structures.
- Fixed and random effects models (mixed models). These are frequentist in approach. Essentially, fixed effects represent changes in selection due to 'controlled' changes in net configuration, such as mesh size. Random effects represent 'uncontrolled' change in selection, such as variation between hauls, or between trips. The between-haul selectivity model of Fryer (1991) is a simple mixed model.

Experience suggests that both Monte Carlo Markov Chain techniques and mixed models tend to give similar conclusions about gear selectivity (Holtrop, 1998). Often, software considerations dictate which method is used.

Annex 1 gives two stylised examples that show how mixed models can be formulated for selectivity data. The theory is then applied to all the haddock selectivity data collected by FRS Marine Laboratory between 1992 and 1998 (Ferro & Graham, 1998). The data come from 9 vessels, 14 trips, and 58 different test codends. The response variables are the estimated l_{50} and log SR of each test codend, and the explanatory variables are:

- gear — categorical: single trawl, pair trawl, pair seine, twin trawl
- season — categorical: winter, spring, summer
- mesh size — continuous: range 66 - 119 mm
- open meshes round — continuous: range 54-134
- twine thickness — continuous: range 2.9 - 6.4 mm.

The results of the analysis must be regarded as preliminary, for reasons given in Annex 1, but essentially:

- l_{50} increases with mesh size, decreases with open meshes round, and decreases with twine thickness,
- log SR increases with mesh size, and is greater in summer than in winter,
- there is no significant gear effect,
- there is significant variation between-codends and between-trips,
- although selection is bound to vary between vessels, there is no evidence of such variation in the data; this is probably due to the lack of balance in the data, which makes it difficult to tease the between-vessel variation apart from the between-trip variation.

3.2 Estimating fleet selection

Annex 1 describes how fleet selection might be estimated, given the results of a series of selection trials such as those described by Ferro & Graham (1998). Define fleet selection to be

$p_{fleet}(l)$ = prob (fish of length l is retained by a net in the fleet | it enters the net).

Let

$q_{vth}(l)$ = prob (fish of length l enters the net of vessel v on haul h of trip t),

where subscript v runs through all vessels in the fleet, t runs through all trips made by vessel v, and h runs through all hauls made by vessel v on trip t. Further, let

$r_{vth}(l)$ = prob (fish of length l is retained | it enters the net of vessel v on haul h of trip t).

Then fleet selection is given by

$$p_{fleet}(l) = \frac{\sum_{vth} r_{vth}(l)\, q_{vth}(l)}{\sum_{vth} q_{vth}(l)},$$

which is an average, over all the hauls conducted by the fleet, of the retention probabilities at length l, weighted by the 'catchabilities' at length l.

Either a lot of data, or some sweeping assumptions are needed to proceed further. One sensible way forward is to assume that the fleet can be divided into a number of discrete groups, g, each operating with a particular net configuration (eg mesh size, meshes round, etc.). If π_g is the proportion of the catch taken by group g, then we can estimate fleet selection by

$$\hat{p}_{fleet}(l) = \sum_g \pi_g \mathrm{E}[r_g(l)].$$

where E[$r_g(l)$] is the expected retention curve of a net in group g.

The results of the mixed model analysis were used to estimate the fleet selection of Scottish single trawls, pair trawls, and pair seines, on haddock in 1994. It was assumed that:

- all vessels fished with 100 mm mesh, and 100 open meshes round (current regulations)
- 50% of vessels used 6 mm twine, 25% used 5 mm twine, and 25% used 4 mm twine
- 50% of trips occurred in winter and 50% in summer.

Figure 3.1 shows the estimated fleet selection curve (solid line), with approximate pairwise 95% confidence intervals (dashed lines). The selectivity curve has an l_{50} of 26.5 cm and a SR of 5.8 cm.

3.3 Estimates of fleet selection from selectivity trials vs. estimates from other methods

During the meeting, an attempt was made to compare an estimate of fleet selection based on the mixed model analysis in Annex 1, with an estimate obtained using the method of Cook & Reeves (1996). The latter estimates fleet selectivity using conventional stock assessment data, inferring fleet selectivity from the relationship between fishing mortality at age and mean length at age.

Cook & Reeves (1996) give estimates of haddock fishing mortality at age and mean length at age for Scottish single trawls between 1990 and 1994. The data are plotted in Figure 3.2. The relationship between fishing mortality at age f and mean length at age l can be modelled as:

$$f = \frac{K\exp(\alpha + \beta l)}{1 + \exp(\alpha + \beta l)}$$

Here, K simply scales a conventional logistic selection curve. Figure 3.2 shows this function fitted to the data using nonlinear least squares with weights proportional to l^{-2}. The estimated selection parameters, with approximate 95% confidence intervals, are given in Table 3.1. Note from Figure 3.2 that there is no length information between 25.9 and 29.6 cm, the critical length range for estimating l_{50}. Repeating this analysis on a quarterly basis might help.

To obtain comparable estimates from the mixed model analysis requires a breakdown of the fleet between 1990 and 1994. We assumed that

- between 1990 and mid 1992, all vessels fished with 90 mm mesh, and that 25% of vessels used 3.5 mm twine, 50% used 4 mm twine, and 25% used 5 mm twine,
- between mid 1992 and 1994, all vessels fished with 100 mm mesh, and that 25% of vessels used 4 mm twine, 37.5% used 5 mm twine, and 37.5 % used 6 mm twine,
- throughout, all vessels used 100 open meshes round,
- 60% of trips occurred in summer and 40% in winter.

Table 3.1 gives the estimated selection parameters with approximate 95% confidence intervals. These confidence intervals incorporate both uncertainty due to the estimation of the parameters in the mixed model, and uncertainty in the proportions used above. The first component is based on the covariance matrix of the parameter estimates in the mixed model. To get some handle on the second component, we allowed the proportions to vary within a plausible range of values: specifically,

- 1990 - 1992: proportion of vessels using 3.5 mm twine was uniformly distributed between 20 and 30% ie ~ U(20, 30), the proportion using 5 mm twine ~ U(20, 30), and the proportion using 4 mm twine was adjusted accordingly,
- 1992 - 1994: proportion of vessels using 5 mm twine ~ U(32.5, 42.5), the proportion using 6 mm twine ~ U(32.5, 42.5), and the proportion using 4 mm twine was adjusted accordingly,
- proportion of trips in summer ~ U(50, 70).

Figure 3.3 shows the two estimated fleet selection curves, with approximate pointwise 95% confidence limits. The curve based on experimental selectivity data is to the left of that based on conventional fisheries data. Although the 95% confidence intervals do not overlap much, the difference between the two curves is not great, particularly considering all the simplifying assumptions that have gone into both estimates.

Table 3.1

	Fleet selection curve based on			
	conventional fisheries data		experimental selectivity data	
l_{25}	26.0	(24.2, 27.8)	22.6	(21.5, 23.6)
l_{50}	28.0	(26.4, 29.6)	25.5	(24.5, 26.4)
l_{75}	29.9	(27.9, 31.9)	28.4	(27.4, 29.3)

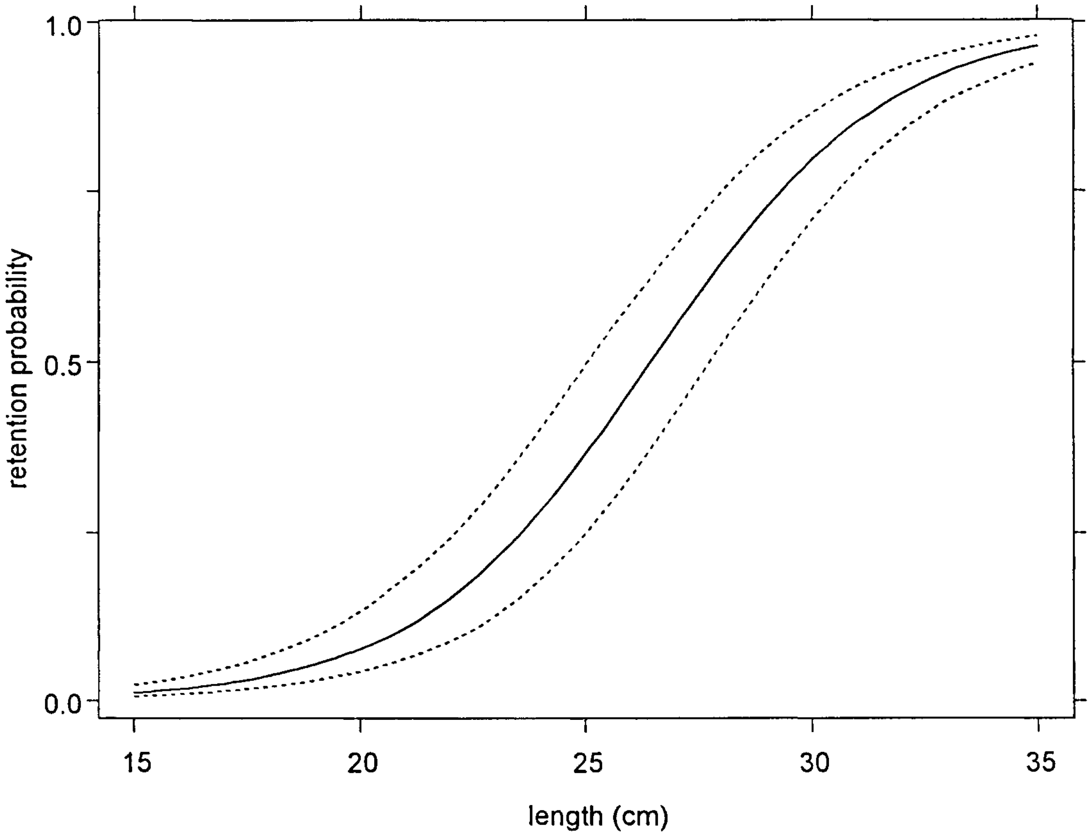


Figure 3.1 Estimated fleet selection of haddock by the Scottish white fish fleet in 1997 (solid line). The dashed lines show approximate pointwise 95% confidence intervals

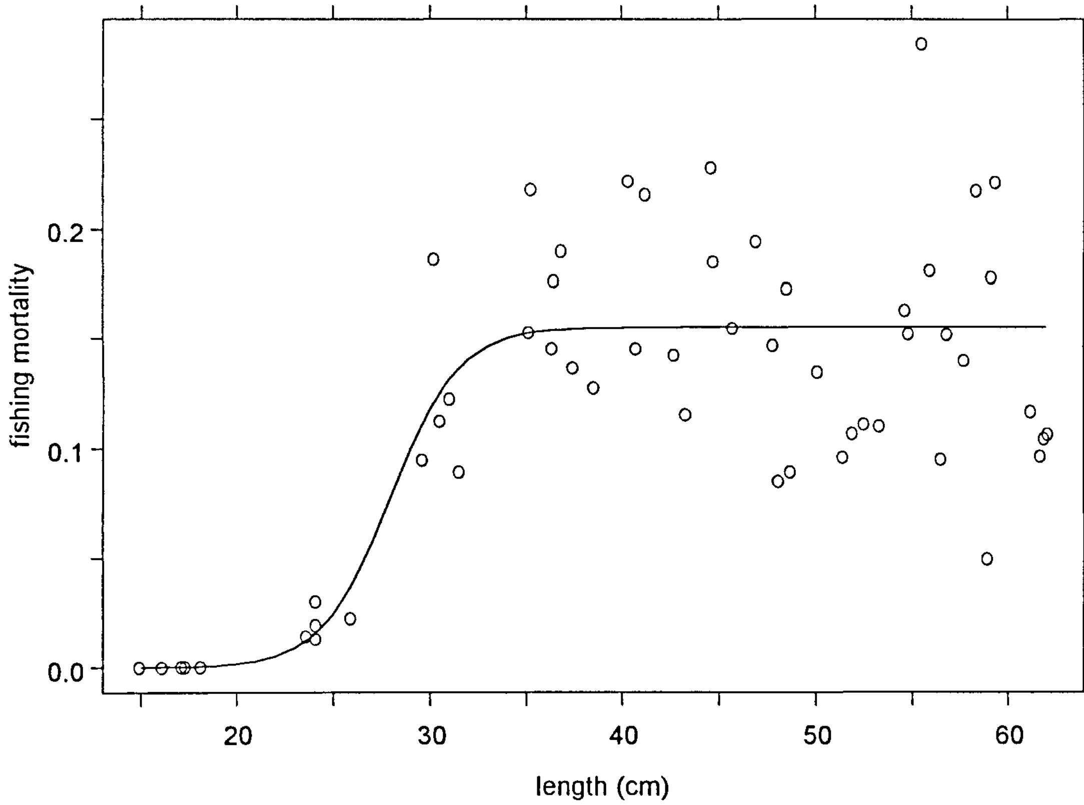


Figure 3.2 Plot of haddock fishing mortality against mean length at age for Scottish single trawls 1990 - 1994. The solid line is the fitted 'selectivity' curve.

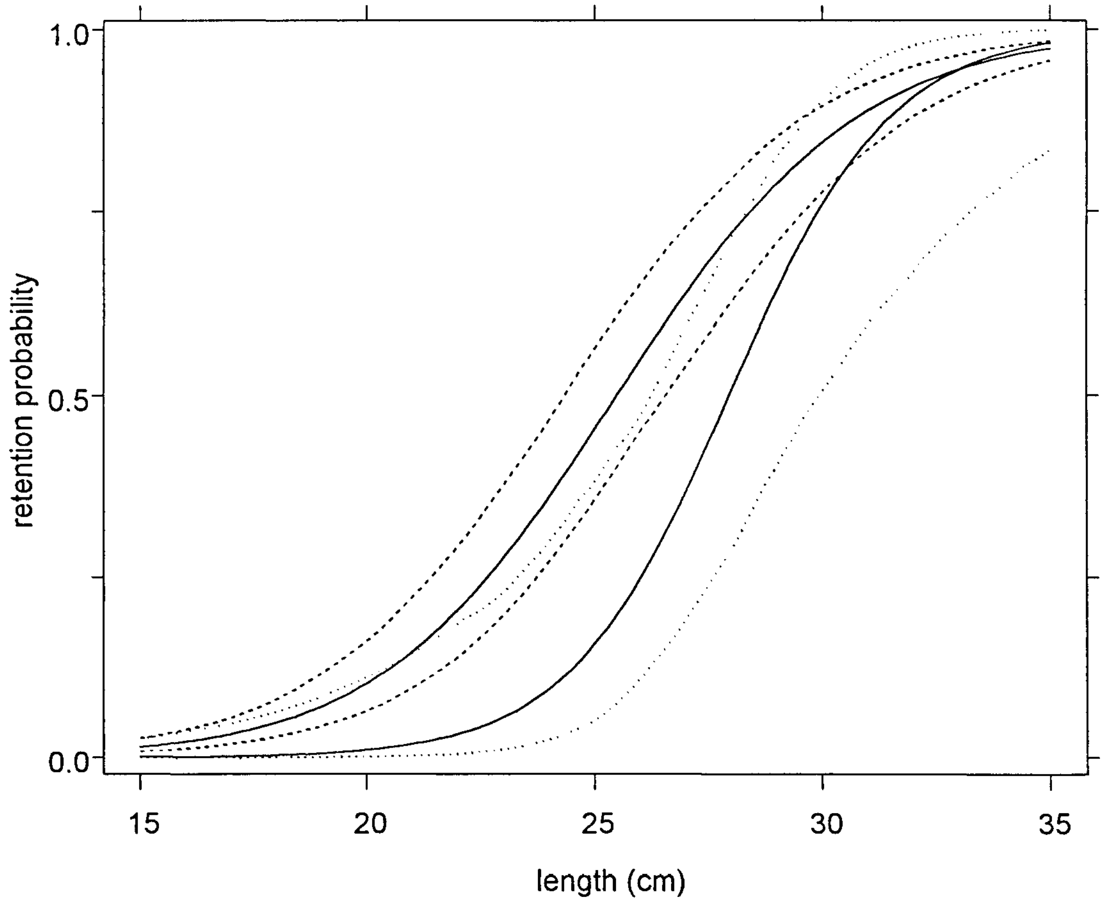


Figure 3.3 Estimated haddock fleet selection curves for Scottish single trawls 1990-1994 (solid lines) pointwise 95% confidence intervals (dashed lines). The left hand curve is derived from experimental s right hand curve is derived from conventional stock assessment data.

4. INCORPORATING ESTIMATES OF SURVEY TRAWL EFFICIENCY INTO STOCK ASSESSMENT MODELS

4.1 Introduction

A simple simulation study reported in Somerton and Hilborn (WD8) was used to demonstrate that a time series of relative abundance data, such as one produced by a research trawl survey, can be insufficient to allow precise estimation of survey trawl catchability and current population size in stock assessment models when the population has not experienced large contrasts in population size due to changes in fishing mortality rate. In such situations, precision in the estimates of current population size may be improved by either fixing the survey catchability parameter in an assessment model at a value determined experimentally or using experimental data to formulate a prior probability distribution on catchability for use in a Bayesian analysis. The report by Somerton and Munro (WD3) describes an approach to estimating the capture efficiency of survey trawls from the data produced by at-sea experiments. The report of Somerton and Thompson (WD4) describes how the experimental estimates of trawl efficiency can then be incorporated into stock assessment models using a Bayesian analysis.

4.2 Estimating survey trawl efficiency

Somerton and Munro (WD3) describe an approach to estimate the capture efficiency of survey trawls based on a theoretical model of the trawl capture process developed by Dickson (1993a). In this model, the fishing width of a trawl, measured from door to door, is partitioned into the net path, or the width swept by the trawl net, and the bridle path, or the width swept by the bridles, sweeps and doors. For cases in which there is neither escapement over the headrope nor escapement out of the trawl path before the passage of the doors, the catch predicted by this model is the sum of the catch of fish initially in the trawl path and the catch of fish herded from the bridle path into the trawl path. Algebraically this is expressed as:

$$N=K_nDW_nL+K_nK_bD(W_d-W_n)L \tag{4.1}$$

Where N = catch in numbers
- D = fish density
- W_n = net width
- W_d = trawl width
- L = tow length
- K_b = bridle efficiency
- K_n = net efficiency

In this expression, the first term represents the part of the catch derived from the net path and the second term represents the part derived from the bridle path. Bridle efficiency, or the proportion of fish within the bridle path herded into the net path, and net efficiency or the proportion of fish passing between the wings of the trawl that are caught, are typically both a function of fish size, but for simplicity a subscript denoting size class has been omitted. Trawl efficiency (K), or the quotient of the catch divided by the number of fish in the trawl path (DWDL) is expressed as:

$$K=K_n\left[\frac{W_n}{W_d}-K_s\left(1-\frac{W_n}{W_d}\right)\right] \quad \textit{where } K_s = \textit{sweep efficiency} \qquad 4.2$$

Thus the problem of estimating trawl efficiency is one of estimating bridle efficiency and net efficiency. This has been done using two distinct types of experimental data (Dickson 1993b).

Net efficiency was estimated by attaching an auxiliary net under the trawl net to capture fish escaping under the footrope, similar to Engås and Godø (1989) and Walsh(1992), then fitting a statistical model to the quotient of the trawl catch to the auxiliary net catch as a function of fish length (Munro and Somerton in prep, Somerton and Otto in prep). Implicit in this approach is the assumption that fish can escape only under the footrope after they have entered the net past the wing tips. For most species this is probably correct because the cod ends of survey trawls are usually lined with sufficiently small mesh to prevent mesh escapement. Experiments using the auxiliary net consisted of trawling repeatedly in one or two localised areas and recording for each tow the number of each species, by size, captured in the trawl and auxiliary nets. Net efficiency by size was then estimated from these data in a two stage process. First an appropriate model relating net efficiency and size was chosen by fitting four models of hierarchically increasing complexity and picking the best or most parsimonious model using likelihood ratio tests (Munro and Somerton in prep). Next, confidence intervals about the predicted value of net efficiency at each size was estimated using bootstrapping (Efron and Tibshirani 1993). As an example of this, for yellowfin sole net efficiency increased with length until a maximum of 0.77 was reached at 31 cm then declined slightly at larger sizes (Figure 4. 1).

Bridle efficiency was estimated by experimentally varying the length of the bridles, similar to Engås and Godø (1989), and modelling the change in catch that accompanies the changes in bridle length similar to Dickson 1993b and Ramm and Xiao (1995). Such an approach is based on the assumption that when net efficiency and fish density are constant for the three bridle lengths within each block, variation in catch is due to variation in the area swept by the bridles. Three bridle lengths (27.3 m, 54.6 m and 81.6 m) were used, in random order, in sufficiently close proximity so that fish density was kept nearly constant. Net width and trawl width were measured on each tow. Bridle efficiency was then estimated from this data by fitting Equation 4.1 to catch, trawl width and net width data. Because the time required to fit the model to each data set was quite lengthy (about 10 minutes on an SGI workstation) variance of the estimate of bridle efficiency was approximated using the asymptotic covariance matrix instead of estimated with a bootstrapping procedure as it was for net efficiency. For 6 of 8 flatfish species examined, tests for variation in bridle efficiency with fish length were not significant, indicating that, for the species and size range examined, herding is not a size dependent process. For the 2 species with significant variation, bridle efficiency decreased with increasing fish length. As an example of this process, for yellowfin sole bridle efficiency was 0.21 (±0.08). The change in the catch with bridle length and the fitted model are shown in Figure 4.2.

The trawl efficiency was computed from the estimates of net efficiency and bridle efficiency using Equation 4.2. Variance of the estimates of trawl efficiency were obtained using the delta method on Equation 4.2 and ignoring all covariance terms. In the future, the fitting procedure will be formulated more efficiently to facilitate the simultaneous bootstrapping of both the herding data and the net efficiency data to estimate variance. Trawl efficiency and its approximate 95% confidence intervals are shown in Figure 4.3.

Estimates of the variance of trawl efficiency are likely too low because, for practical reasons sampling was conducted in small localised areas and may not have captured the spatial variation in trawl efficiency that occurs over the wider geographical area encompassed by the survey. In the future, the process outlined above could be improved in two ways. First, the auxiliary net could be used during the herding experiment so that the data needed to estimate both net efficiency and herding efficiency are collected simultaneously. This would allow estimation of any inherent covariance between the two parameters. Second, the combined herding/escapement experiment could be done periodically over the course of a stock assessment survey, rather than on a special research cruise so that the estimates better reflect the mean and variance over the entire survey area. Together these modifications will allow the procedure to better determine the error associated with the efficiency estimates.

4.3 Incorporating estimates of survey trawl catchability into stock assessment models using Bayesian analysis.

Somerton and Thompson (WD4) describe an approach to incorporate experimentally derived estimates of survey trawl catchability into stock assessment models. In the Northeast Pacific, stock assessment models have became increasingly complex with objective functions often involving several independent time series of relative abundance indices. Such models have a large number of parameters (up to 500) consisting of both those that are usually fixed at a predetermined value (e.g. weight-length parameters, von Bertalanffy parameters, natural mortality, length at maturity and survey catchability) and those that are usually estimated during the process of fitting the model to relative abundance data (e.g. annual recruitment, initial stock size and selectivity parameters). One of the most influential parameters, the catchability of the survey trawl, has been treated as a fixed parameter in some analyses and as an estimated parameter in others. In situations where the time series of survey data was short or where there was little contrast over time in the fishing mortality rate, the relative abundance time series contained too little information to constrain the value of catchability adequately and, consequently, the values of fishery control variables such as Total Allowable Catch or fishing mortality rate. When this occurred, maximum survey catchability was fixed at 1.0, a value based on two assumptions: 1) efficiency of the trawl net is 100% and herding is zero or escapement and herding equally balance, and 2) the survey covers the entire geographical range of the population. Because neither of these assumptions is likely to be true, some stock assessment modelers have considered a different approach. Although catchability could be fixed at a value derived from the trawl efficiency experiments, such values are potentially biased because trawl efficiency may vary spatially and the experiments covered only a small part of the total survey area. As an alternative, catchability could be treated as an estimated parameter in the model but one that is constrained to some degree by the information about its value provided by the efficiency experiments. One method for doing this is based on Bayes' Theorem (Thompson, 1992; Walters and Ludwig, 1994).

To introduce the Bayesian approach to prior information, consider the following overly simplistic and somewhat contrived application of Bayes' Theorem based on a situation in which a population was sampled with a trawl to estimate mean density twice in succession. Although mean density at the time of the second sampling could be based entirely on the second sample, it could be argued that the first sample also contains information that should be incorporated into the estimate. Bayes' Theorem provides a way to include this information. To use Bayes' Theorem we must first define a statistical model of the sampling process, which in this example is the Poisson distribution. From the first sample, we could calculate the Prior probability distribution of the mean as:

$$Prior(M_j) = \frac{\mathcal{L}(data|M_j)}{\sum_j \mathcal{L}(data|M_j)}$$

where $\mathcal{L}(data|M_j)$ is the likelihood of the first sample at the jth value of the mean of the Poisson distribution and the summation in the denominator is over all values of the mean (M is a continuous variable and the notation M_j is intended to indicate that it has been discretised in some way). From the second sample, we again calculate the likelihood of the data at each value of the mean. With these two quantities, the Posterior probability distribution of the mean is then calculated using Bayes Theorem:

$$Posterior(M_j|data) = \frac{\mathcal{L}(data|M_j)Prior(M_j)}{\sum_j \mathcal{L}(data|M_j)Prior(M_j)}$$

This process is shown graphically in Figure 4.4.

Moving from this simplistic example to an actual application in a stock assessment, consider the 1997 assessment of the eastern Bering sea population of Pacific cod. Early attempts at including a Bayesian prior distribution on catchability expanded to include a prior distribution on natural mortality as well because the two parameters are confounded in the stock assessment model that is used (Thompson, 1994). The prior distribution on catchability had a mean of 1.0 and a standard deviation of 0.3. Although the mean is based on the value derived from efficiency experiments (Pacific cod is the only species examined to date at the Alaska Fisheries Science Center that has no detectable escapement from the net used in the survey trawl and no detectable herding), the value for the standard deviation was somewhat subjectively chosen because the estimate for the experimental value was not finalised at the time of analysis. The prior distribution on natural mortality had a mean of 0.37 and a standard deviation of 0. 11. The mean was obtained from a simulation study and the standard deviation was again chosen somewhat subjectively (Table 4. 1). In addition to the mean and standard deviations of the two parameters, they were assumed to have an inherent correlation that was set to -0.5 and a bivariate prior distribution (Figure 4.5, upper panel; Table 4. 1). This assumption was arrived at in a discussion between managers and scientists, although a purely scientific judgement would be that such a correlation is zero. The likelihood of the data (e.g. relative abundance, catch at age, etc.) produced by the stock assessment model was quite different than the prior distribution, with a maximum for catchability at 4.67, which is extremely high, and for natural mortality at 0.04, which is extremely low (Table 4. 1, Figure 4.5). The resulting posterior distribution had a maximum for catchability at 1.66 and for natural mortality at 0. 18, both more realistic values. These values, however, are quite dependent on the values chosen for the standard deviations in the bivariate prior distribution and, at, present, these are just educated guesses.

In future applications of this method, the prior distributions will be based on the observed experimental error even though these estimates of error are likely too low because of the limited geographical coverage of the trawl efficiency experiments. In addition, the experimental procedures will be modified so that much of the spatial, and perhaps temporal, variation is captured.

Table 4.1

Distribution	mean catchability	SD catchability	mean mortality	SD mortality	correlation
Prior	1.00	0.30	0.37	0.11	-0.50
Likelihood	4.67	0.69	0.04	0.03	-0.97
Posterior	1.66	0.26	0.18	0.02	-0.81

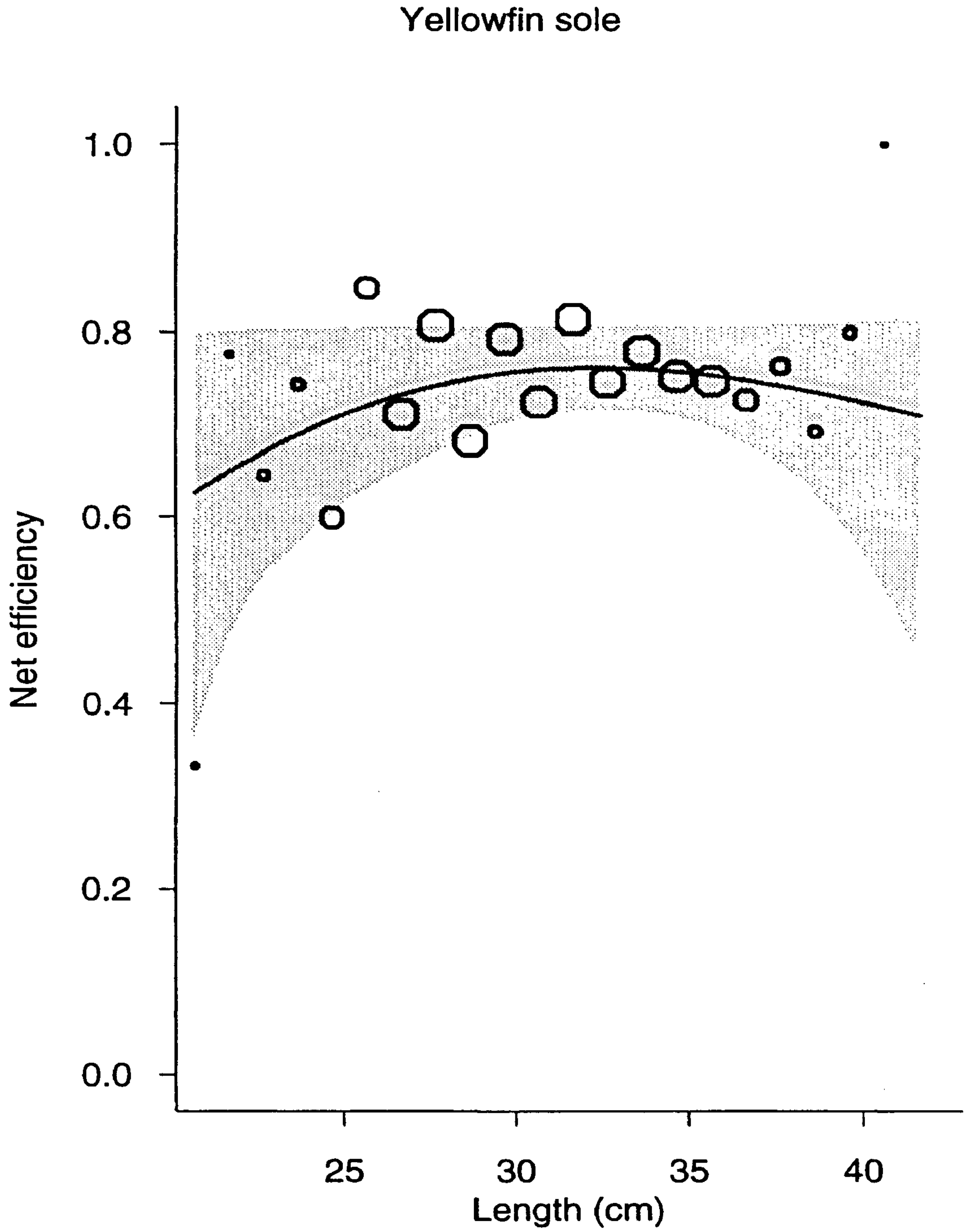


Figure 4.1. Mean net efficiency (solid line) and 95% confidence intervals (shaded area) for yellowfin sole as a function of body length. Sample size at each 1cm interval is proportional to the diameter of the circles. A total of 17 rows and 9717 length measurements were taken for this species.

Yellowfin sole

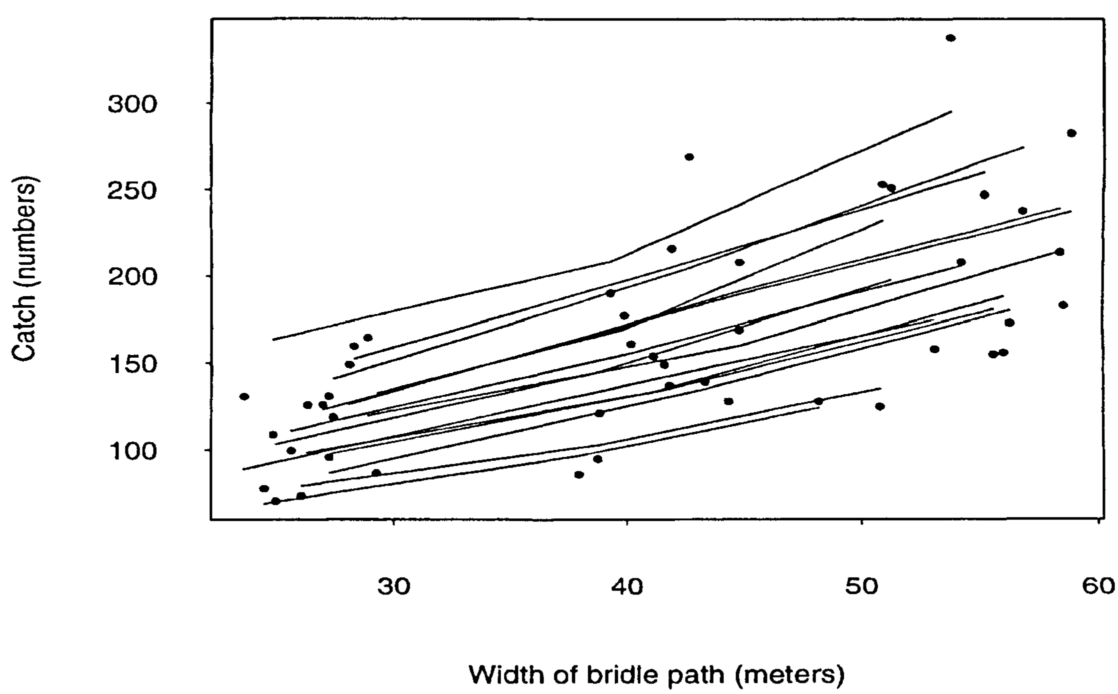


Figure 4.2 Catch of yellowfin sole in numbers and the width of the bridle path in metres is shown for each of the 15 statistical blocks sampled with each of the three bridle lengths. The lines show the fitted herding model (Equation 4.1).

Yellowfin sole

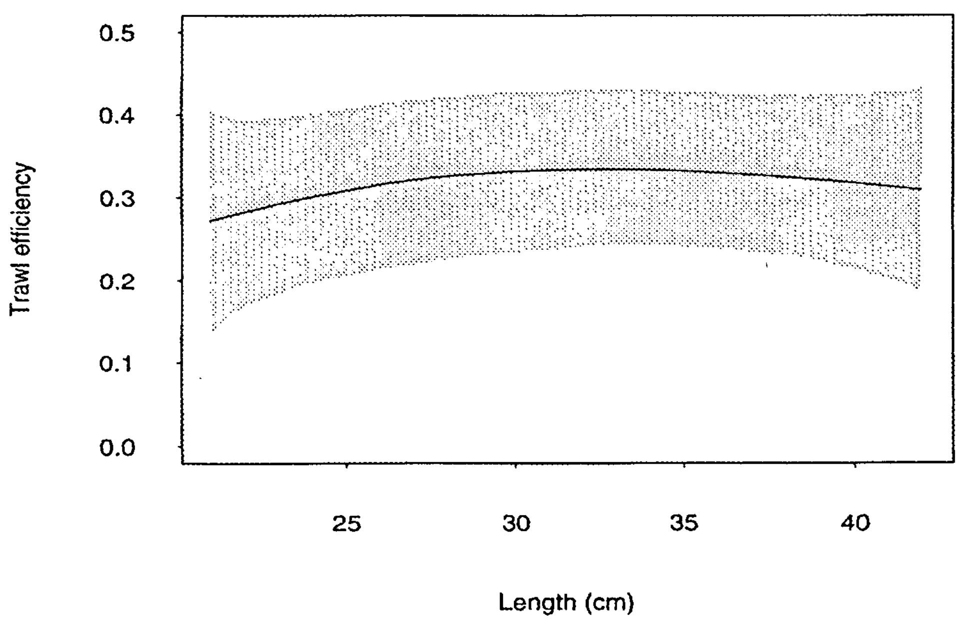


Figure 4.3 Mean trawl efficiency (solid line) and 95% confidence intervals for yellowfin sole as a function of body length.

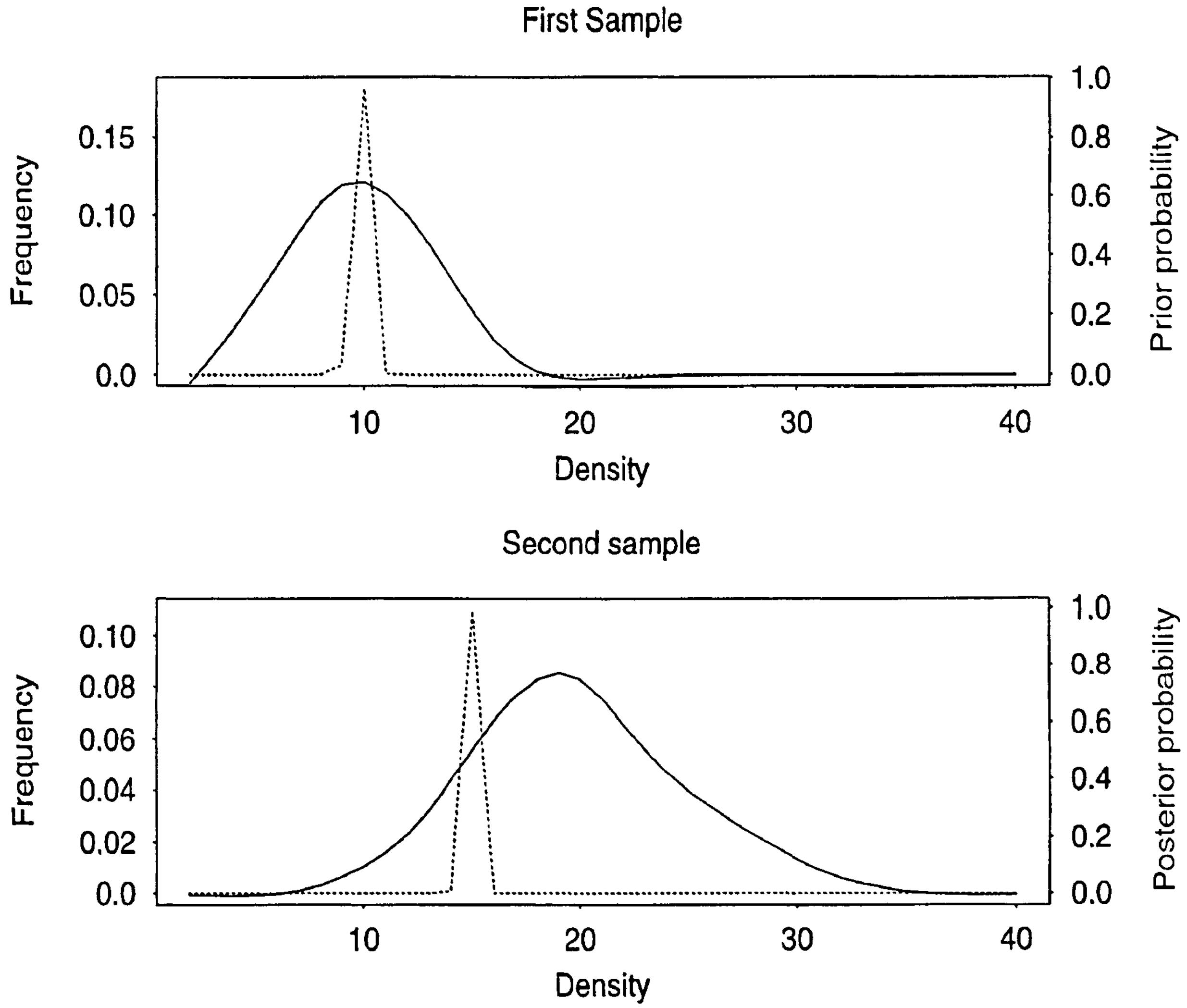


Figure 4.4 The first sample was 100 observations drawn from a Poisson distribution with a mean of 10 (Top panel). A smoothed frequency distribution of this sample is shown with the solid line. The scaled likelihood or probability distribution of the mean is shown with a dashed line. This distribution is then used as the Prior distribution in the next stage. The second sample was 100 observations drawn from a Poisson distribution with a mean of 20 (Lower panel). A smoothed frequency distribution of this sample is shown with a solid line. Applying the Bayesian analysis described in the text produced the Posterior probability distribution shown with a dashed line. The mean of the Posterior was 15. The Posterior mean will depend upon the error in the first and second samples. For example, if the size of the first sample is increased to 200 the mean of the posterior distribution is 13. If instead the sample size of the second sample is increased to 200 the mean of the posterior distribution is 16.

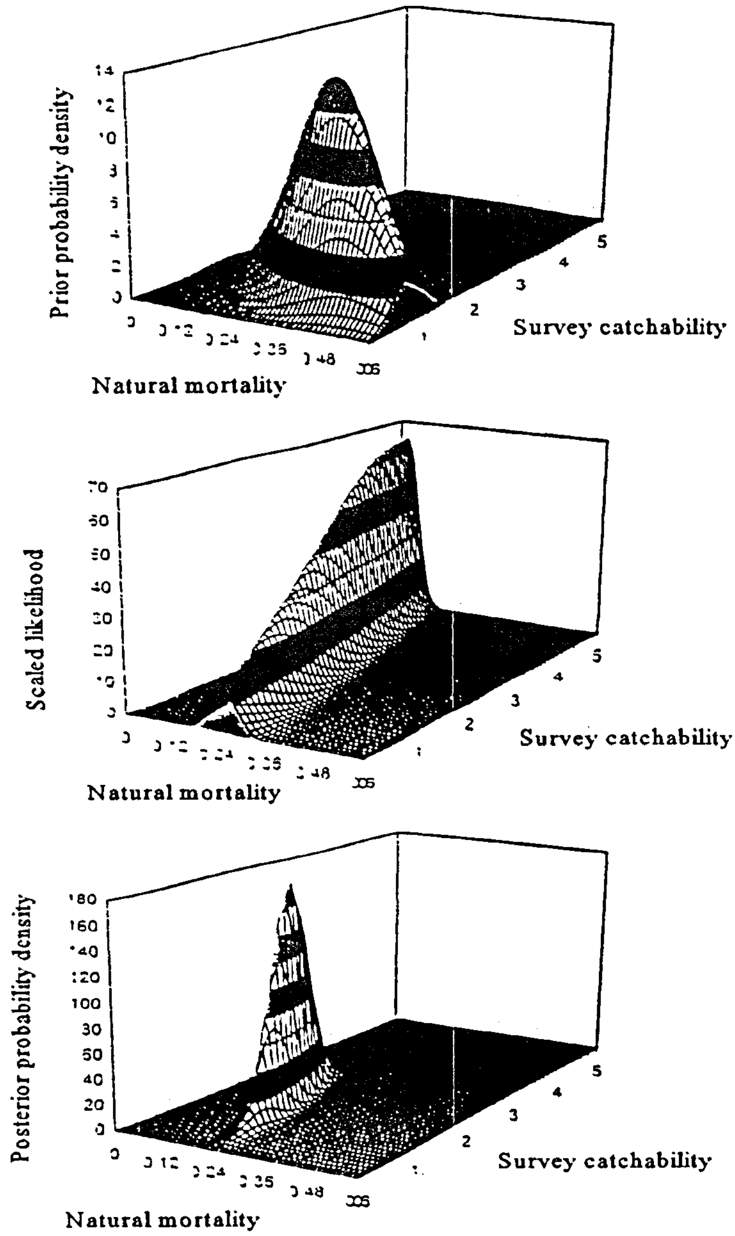


Figure 4.5. Bivariate prior probability distribution for survey catchability and natural mortality used in the 1997 eastern Bering sea Pacific cod stock assessment (upper panel). Bivariate likelihood profile on catchability and natural mortality obtained by fitting the model to relative abundance data without any constraints on the parameters (middle panel). Bivariate posterior probability distribution of catchability and natural mortality calculated by applying Bayes' Theorem (Lower).

5. RELATIONSHIPS BETWEEN FISHING EFFORT AND FISHING

5.1 North Sea roundfish

The relationship between fishing mortality and fishing effort has been examined for four roundfish stocks in the North Sea, ie cod, haddock, whiting and saithe. Annual data were taken from the most recent ICES assessments in ICES (1996b) for a range of gear types. In order the investigate the relationship, total fishing mortality, F, was partitioned into partial fishing mortalities, f, by fleet, I, using the ratio of the fleet catch to the total catch.

The values of f were calculated on an age disaggregated basis for each year. A mean f for each year was then calculated as an average over a standard reference age range as used by ICES (1996b). The mean partial f by fleet was plotted against the nominal fishing effort as used by the working group.

Conventionally the relationship between f and nominal effort, E, is considered to be of the form;

$$f \quad q\,E \tag{5.1.1}$$

where the catchability (q) is assumed to be constant. Catchability expresses a variety of factors which determine the vulnerability of fish to capture. It is likely that q increases with time. Such possible trends have been examined by plotting q against time (t) where q has been estimated from:

$$q_{i,t} = \frac{f_{i,t}}{E_{i,t}} \tag{5.1.2}$$

For a large number of fleets and stocks there was a discernible positive relationship between fishing mortality and nominal effort as expected. The clearest trends were seen where there was a large amount of contrast in the data. Trends in catchability were less well defined. However, there was a tendency for q to increase with time as might be expected.

This initial analysis showed that there is a broad relationship between fishing mortality rate and effort. The question remains to what extent can the observed variations in catchability be explained?

Fishing effort is defined as the product of fishing activity and fishing power (eg Beverton and Holt, 1957). The fishing effort exerted by a fleet is the sum of these products over all fishing units in the fleet. Fishing activity is in units of time. Fishing power is the ability of a fishing unit to catch fish and is a complex function depending on vessel, gear and crew. However, because measures of fishing power may not be available, activity (such as hours fished) has often been used as a substitute for effort and called 'nominal effort'. The consequence is that catchability includes not only the availability and vulnerability of fish but also the power of the fishing gear to catch them. If fishing effort is to be controlled, the relationship with fishing mortality must be established.

5.1.1 Variation in fishing power

When fishing power is relatively constant catchability will reflect only changes in fish availability, as suggested by Cook and Armstrong's analysis (1985) over the period from 1962 to 1982 when there was little gear development. In recent years however, there have been many changes in technical measures and in gear and vessel design which may alter selectivity and fishing efficiency and hence fishing power significantly. To illustrate the scope of such changes the relevant gear and vessel developments in Scotland over the past 40 years are described briefly and the main technical measures on cod-end design applying to the North Sea whitefish fisheries in UK waters given (5.1).

The efficiency of Scottish seine and trawl gear was improved by the introduction of the Decca navigation system in the early 1960's, allowing more precise delineation of clean ground and the exploration of offshore grounds. There have been further improvements to navigation and echosounding systems with the recent development of PC-based plotters and ground discrimination capability. In the 1980's mechanised rope reels became common and allowed greater rope lengths (up to 14 coils of 120 fathoms of rope per side) to be fished, thus increasing the area swept in each set. More recently in the 1990's traditional Scottish seining has declined rapidly in favour of pair seining with two vessels (Galbraith, 1998).

The introduction of high headline whitefish trawls in the late 1970's aimed to increase the catch of higher swimming fish such as haddock. In the early 1980's so-called 'rockhopper' groundgear, on both trawls and seines, gave better protection on rough ground and not only increased the areas available to fishing but also increased the efficiency of the net for catching groundfish. At the same time the pair trawling technique started to be used. From approximately 1990 onwards so-called scraper trawls with very long wings and wide bosom were introduced increasing the catch of high value groundfish such as monks and megrims. Also twin trawls were adopted increasingly in the whitefish and particularly the Nephrops fisheries. Sangster and Breen (1998) show a significant increase in the catch of Nephrops, flatfish and cod particularly. Most new whitefish and Nephrops trawlers built in Scotland now have three main winches, giving them the capability of fishing twin trawls.

In the mid 1970's the need to maintain or increase the lucrative whitefish by-catch in Nephrops trawls may have been the cause of the introduction of dual-purpose fish/prawn nets with higher mouth opening. In 1992 mandatory square mesh panels were introduced in Nephrops trawls to reduce discarding of juvenile whitefish although analysis of discard levels in the succeeding two years did not show that the legislation had a clear effect (Gosden et al., 1995).

Vessel design may also contribute to increasing fishing power. It is now common practice to instal an auxiliary engine to provide power for winches, deck machinery, lighting, etc, thus leaving the main engine to be used entirely for propulsion (English, 1992). Larger trawls or higher towing speeds may then be used. Higher productivity at sea and increased fishing time have resulted from the addition of shelter decks to protect crew while working on deck.

Table 5.1. The main legislation on cod-end design in the UK whitefish fisheries.

	Mesh size increased to:	Meshes round cod-end	Twine thickness
1961	70 mm	No limit - typically 100 open meshes	3.5 mm
1983	80		
1987-88	85	Ballooning of cod-ends - up to 150 meshes	3.5 mm
June 1988	90		3.5 mm
June 1991		Max 100 open meshes by law	Thicker twines start to be used
June 1992	100		5 to 6 mm

5.1.2 Effects on catchability

A more detailed examination of catchability estimates is needed to assess whether the effects of such gear developments and technical measures can be identified. As an initial attempt, quarterly Scottish data on North Sea haddock for four Scottish gears for the period 1974-1995 have been processed as described above using total mortality and landings data from the relevant ICES Assessment Reports (ICES, 1984; 1988; 1997a). More disaggregated data, eg by horsepower band within each gear type, would have been desirable but were not available.

It is clear that there are trends in catchability over time (Figs. 5.1-5.4) for these gear types. An indicator of trends in fish availability during this period is needed in addition to information on technical developments to make a complete analysis. The gears are all used in the mixed whitefish fishery. If trends are seen in all gears then they may be explained by common technical developments or changes to fish availability perhaps. If however, a trend is specific to one gear then it is more likely to be associated with a technical change to that gear.

Most notable are the increases in catchability during the period up to 1979 for all gears and quarters followed by a consistent decrease during the next 3 or 4 years. The pair trawl (Fig. 5.1) exhibits a steady increase in all quarters throughout the period from 1982 to 1995. The seine net values (Fig. 5.2) are relatively constant during the same period and this may indicate the conservative nature of the seine net fleet compared to the pair trawl fleet in which the skippers may be more willing to develop their gears having often only recently taken up pair trawling. The fact that no gears (except the trawl in quarter 1) show any consistent reduction in catchability after the 1979-1982 period despite the regular introductions of further technical measures may also indicate the fisherman's ability to manipulate his gear to maintain catch levels.

5.2 North Sea flatfish

Relationships between fishing effort, fishing mortality, catchability and CPUE for North Sea plaice have been documented in WD 7 (see appendix 2). It was shown that no linear relationship existed between the partial fishing mortality and the effort exerted by the Dutch beamtrawl fleet. The UK beamtrawl fleet, for which a much shorter data-series is available, did show a positive relationship between fishing effort and partial mortality indicating a constant catchability. In the working document it was further shown that differences exist between the CPUE's of individual vessels and that this difference may be attributed to differences in quota restrictions between different groups of vessels. However, this finding needs further work, as the analysis is currently based on a short time series (see section 5.3).

The study group reconsidered the procedures to analyse partial fishing mortalities in relation to explaining variables: availability, selectivity of (commercial) gears, technical developments, technical measures and behavioural changes due to e.g. quota restrictions. Due to the limitation on available time and data, it was not possible to give a full analysis of all potentially relevant variables. Analysis were limited to quarterly evaluations of catchability and evaluation by horsepower category.

Partial fishing mortality was calculated on an age-basis, using the catch at age and fishing mortality at age from ICES (1998b)

$$f_{a,y,q,\imath} = F_{a,y} \frac{C_{a,y,q,\imath}}{C_{a,y}}$$

where

f	partial fishing mortality
F	combined fleets fishing mortality
C	catch in numbers
a	age
y	year
q	quarter
I	fleet

The average partial fishing mortality was calculated as the arithmetic mean (F bar) over the ages 2 - 10 which is common practice for this stock.

Catchability was calculated as in equation 5.1.2 .

Data in sufficient detail was only available for the Dutch beamtrawl fleet and consisted of catches in numbers at age by quarter(1970-1996), effort by quarter for the entire fleet (1970-1982 and 1990-1996) and effort by year and by HP category (1990-1996).

Figures 5.5-5.8 show the results of the quarterly analysis of catchability for both North Sea plaice and sole. For plaice, there is a clear trend in catchability in the first quarter but much less so in the 2^{nd} to 3^{rd} quarters (Figure 5.6). Sole shows the greatest decline in catchability in the second quarter and has comparable values for the other three quarters. It thus appears that for these two flatfish stocks and for the fleet considered, the main reduction in catchability has occurred in the spawning season (plaice 1st quarter, sole 2nd quarter).

Results of the analysis by HP class are presented in Figure 5.9. Unfortunately only data were available for the years 1990 - 1996. Over this short time range no trends in catchability are detectable which indicates that the catchability has not been affected by developments in different HP-groups.

5.3 Further work

A number of likely directions were suggested by the study group in order to bring the analysis of relationships between fishing effort and fishing mortality further. First it is necessary to arrive at exact definitions of the terms fishing effort, fishing activity and fishing power. Using equation 5.1.2 to calculate q means that catchability (an indicator of stock size or availability) is confounded by the technical developments in the fleets. Second it was stressed that the current analysis are severely hampered by a lack of data. For as many fleets as possible the following data should be made available:

i) nominal fishing effort (hours fished, days at sea, hp days at sea) by gear, by quarter, by rectangle and by horsepower category.

ii) catch in numbers or total landings by fleet, by quarter, by rectangle and by HP category

iii) estimates of selection (e.g. L50) by fleet and by quarter

iv) time series of technical measures that have been introduced into the fishery

v) time series of technical innovations that have been introduced into the fishery

vi) time series of available quota by fleet, by HP category and by ICES area.

The analysis of the behaviour of individual vessels and the way fishing behaviour may affect fishing mortality, can only be addressed when detailed data are available on a trip basis. The study group recognizes the needs for these analyses and recommends that further work be developed in this direction (see section 7). A step even further would be possible when not only data by trip but even data by haul would be available. This would enable the catches by haul to be related to the specific unit of effort (haul duration times fishing speed). At RIVO-DLO the so-called 'micro-distribution project', started in 1993, aims to fulfill this need (Rijnsdorp et al, 1998). Small automatic position-registration boxes are placed on a sample of the Dutch cutter vessels (25). Every 6 minutes the position of the vessel is stored on a disk which will later be analysed at the lab. The information on the catch by haul is available from detailed logbooks obtained from the skippers. Unfortunately, no data is available on the discards generated on the trips, which makes the estimation of the composition of the catch impossible.

The study group recommends investigation of assessment-independent stock estimates (both spatial and temporal) using quarterly IBTS data. If it can be assumed that catchability for certain species has been constant over the period when quarterly IBTS data are available (1991-1996), these data can be used to derive absolute stock estimates. If catch data where applied to these stock estimates, all variables would be available to estimate fishing mortality directly, using the Baranov equation:

$$C_t=\frac{F_t}{Z_t}N_t(1-e^{Z_t})$$

This analysis would enable the disentanglement of spatial and temporal patterns in the relationships between fishing effort and fishing mortality and thereby the derivation of catchability estimates that are not influenced by the assessment process itself.

Fig. 5.1. Pair trawl

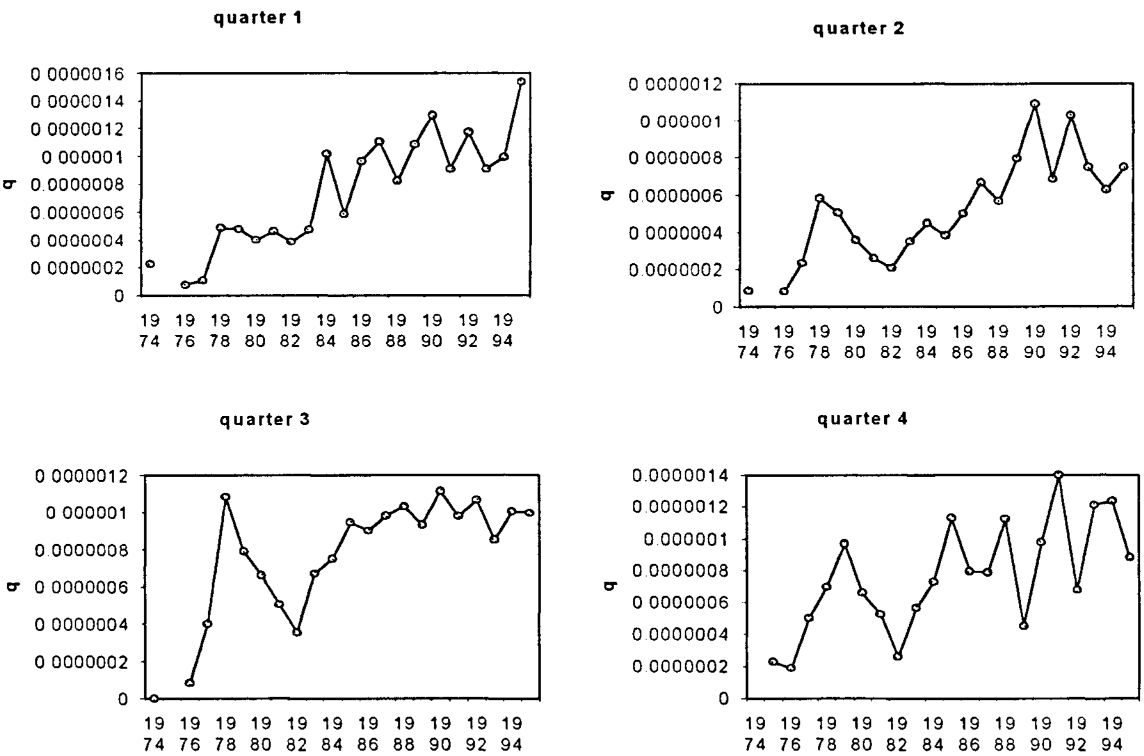


Fig. 5.2. Seine

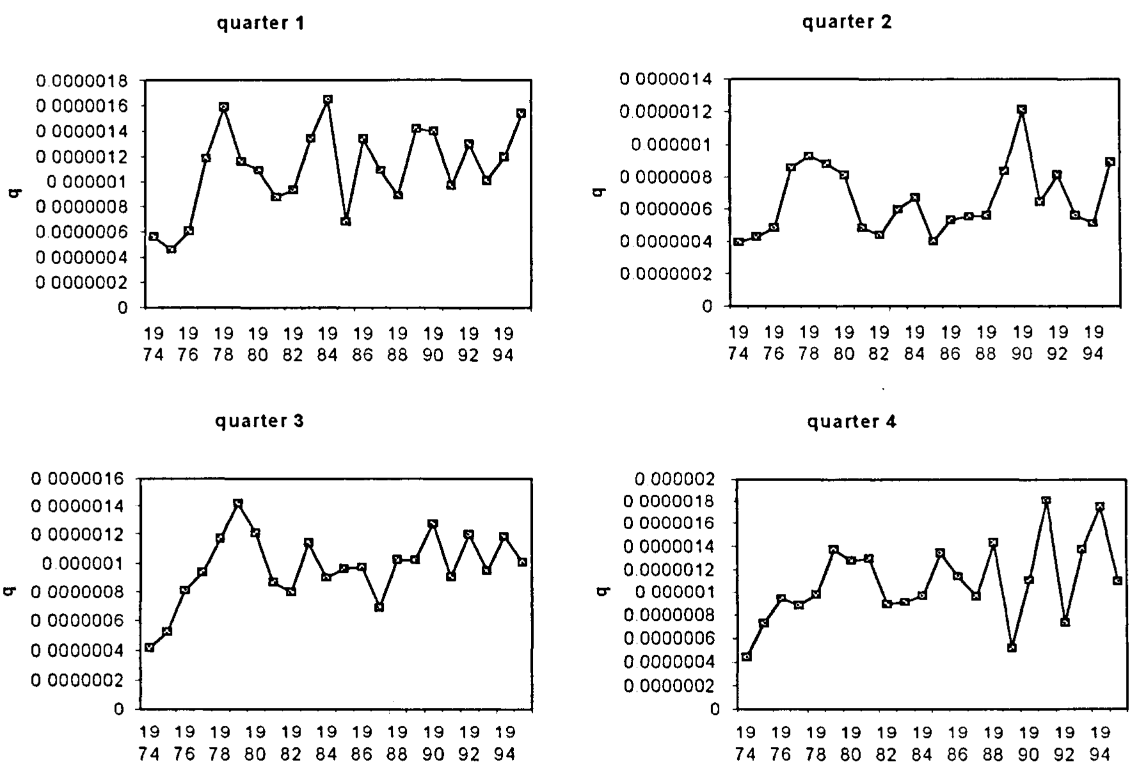


Fig. 5.3. Trawl

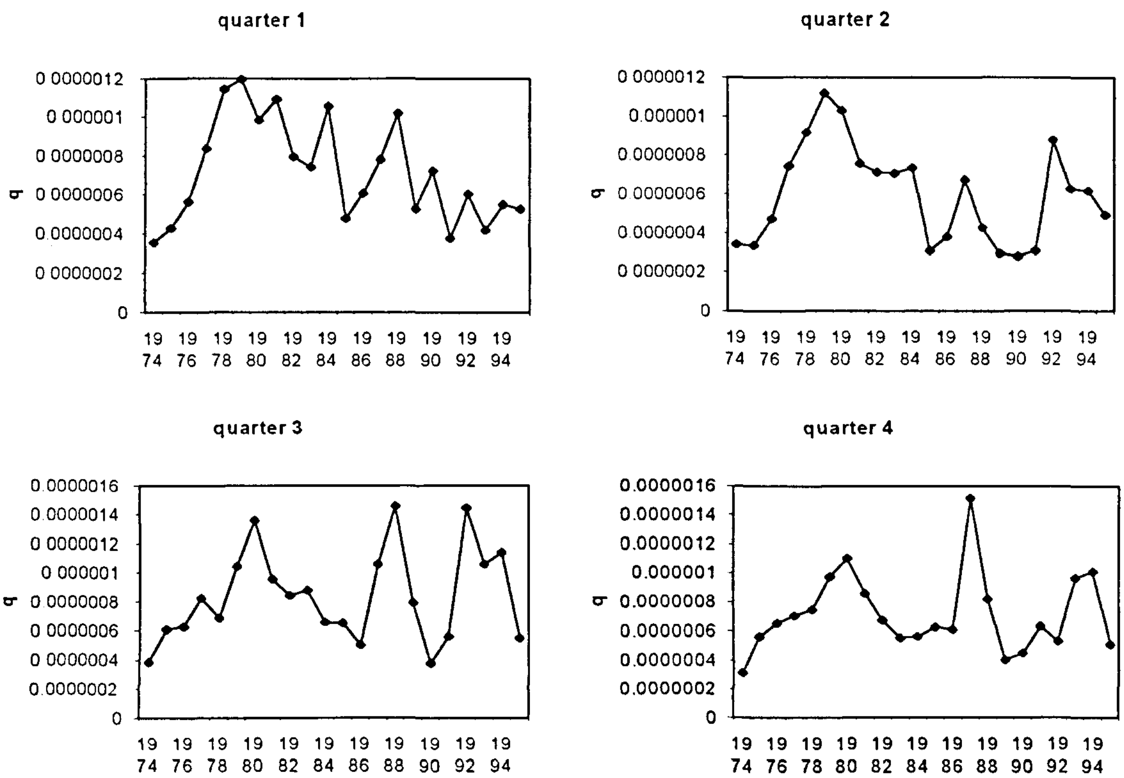


Fig. 5.4. Light trawl

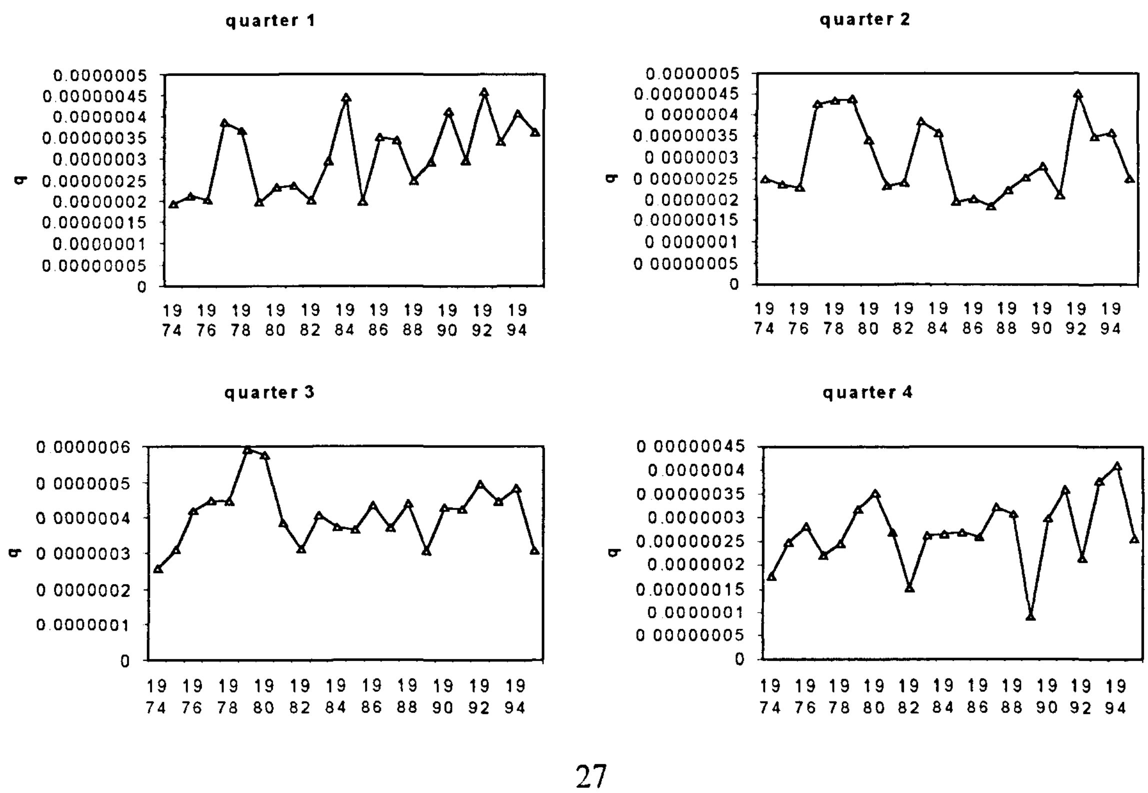
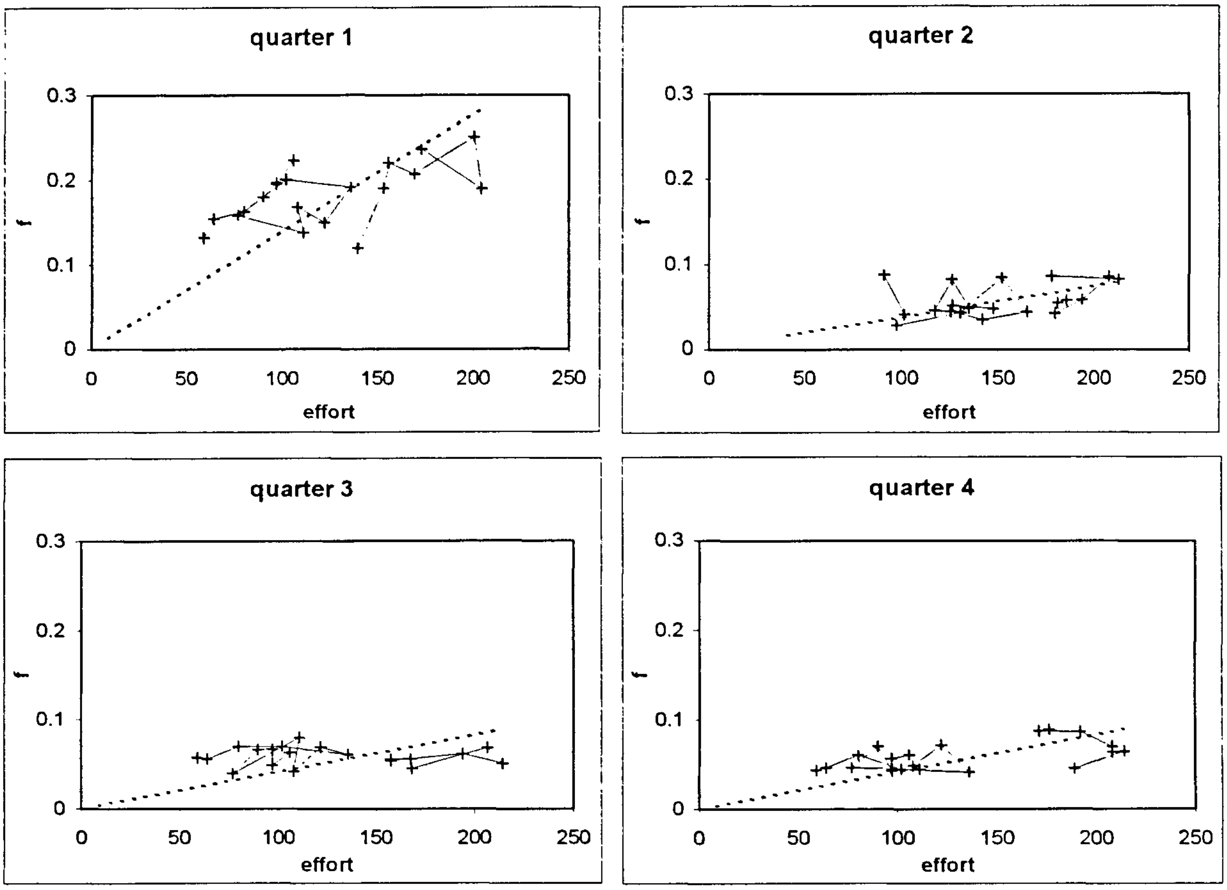
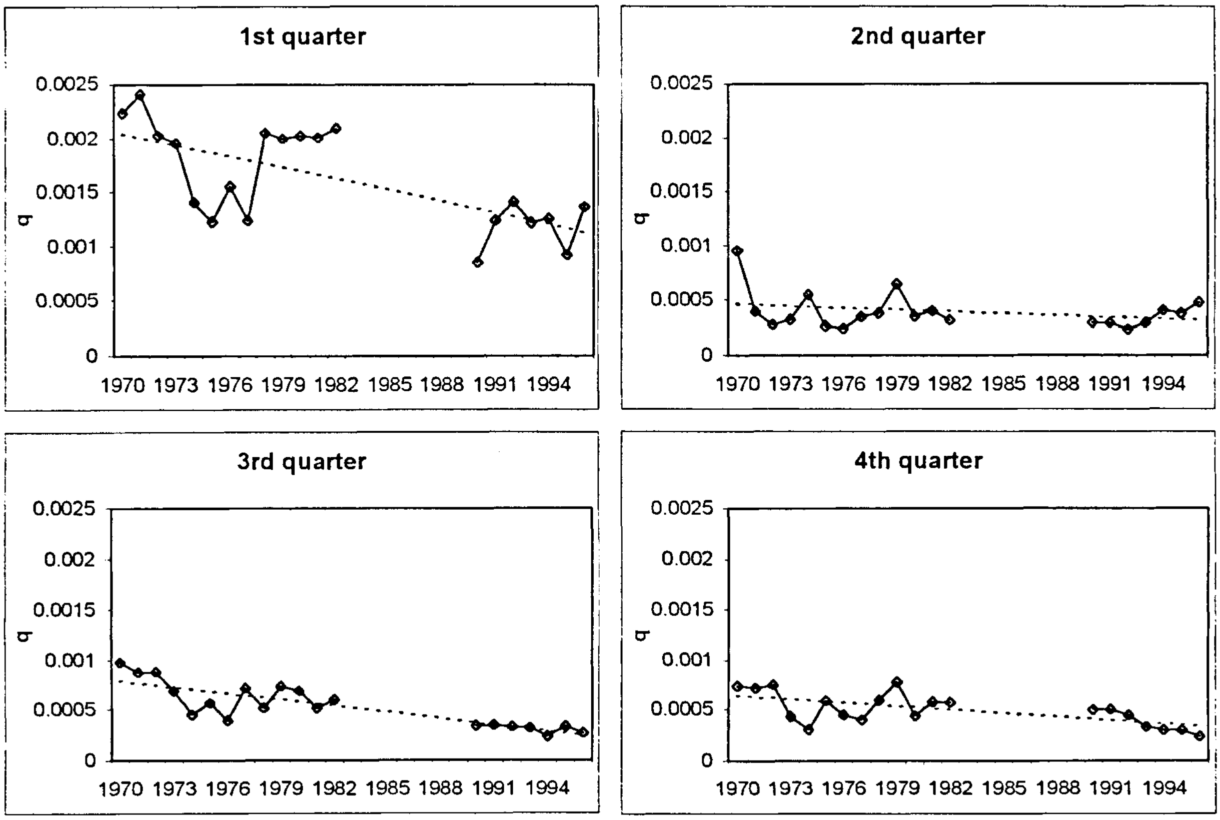


Figure 5.5



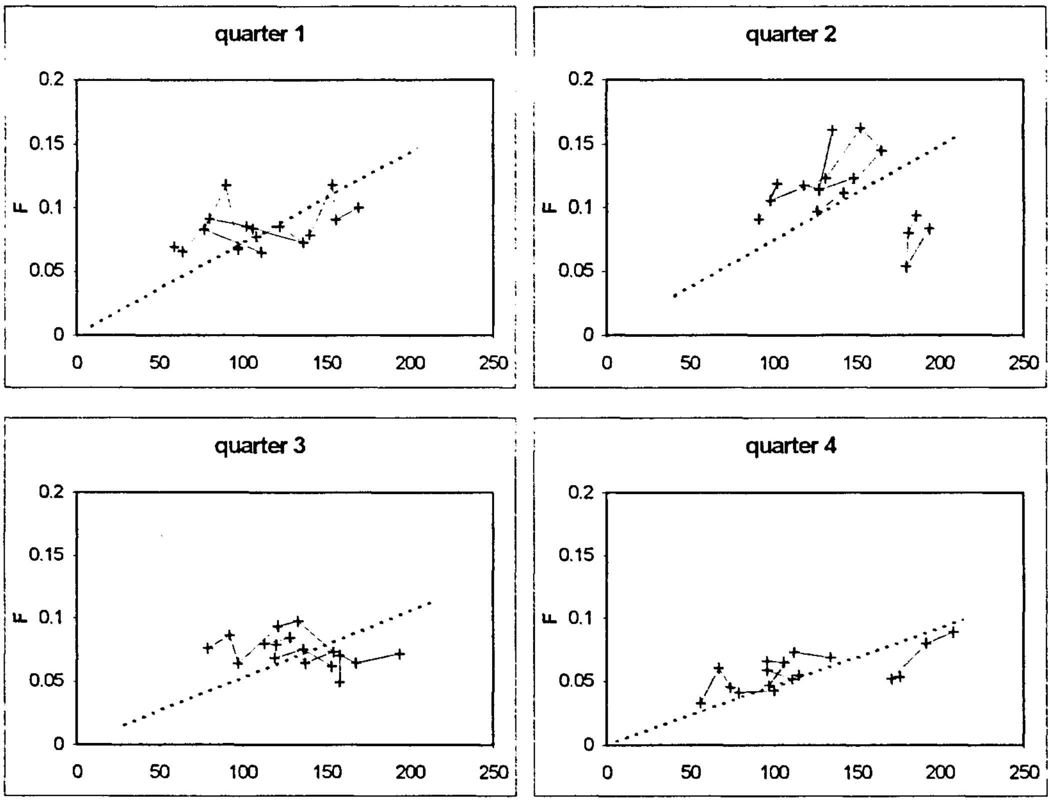
PLAICE partial fishing mortality of the Dutch beamtrawl fleet plotted against fishing effort (unit: 100,000 hpdays) for the four quarters. Data used: 1970-1982 and 1990-1996.

Figure 5.6



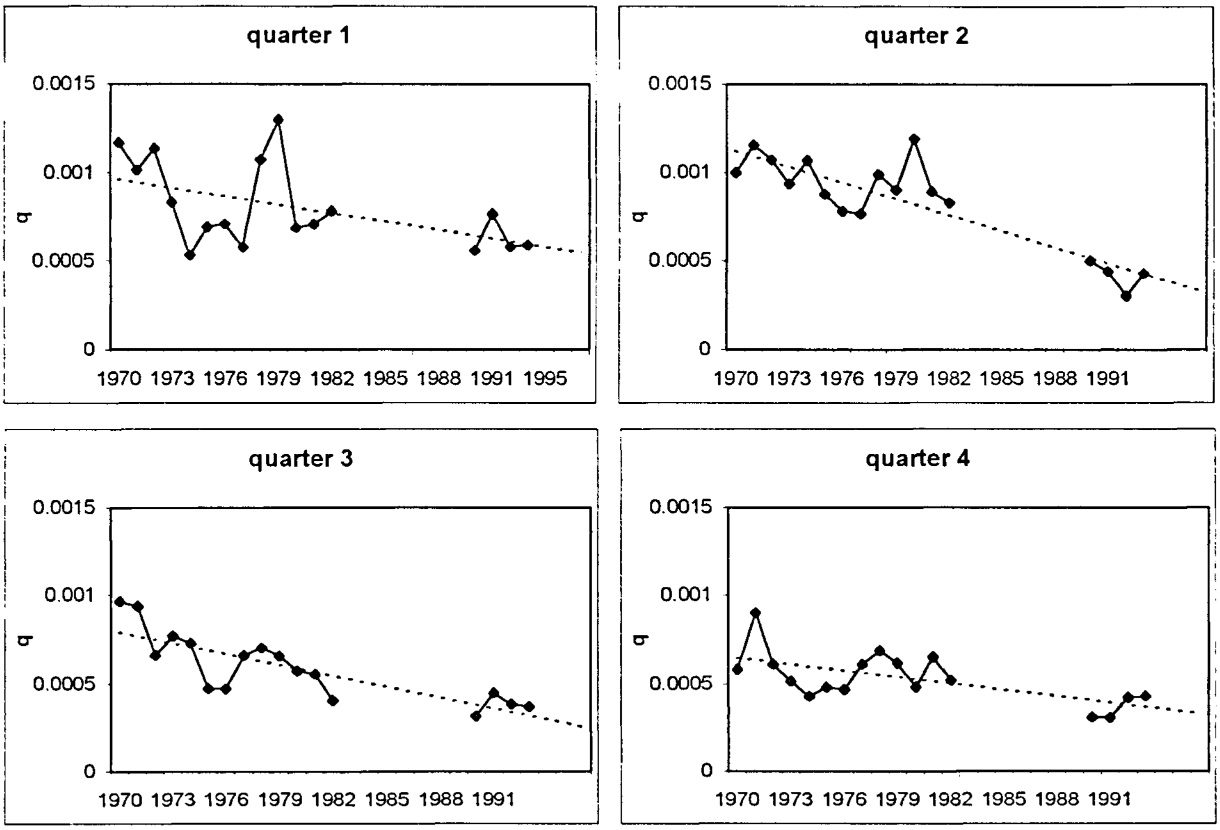
PLAICE catchability of the Dutch beamtrawl fleet plotted againsttime for the four quarters.
Data used: 1970-1982 and 1990-1996.

Figure 5.7



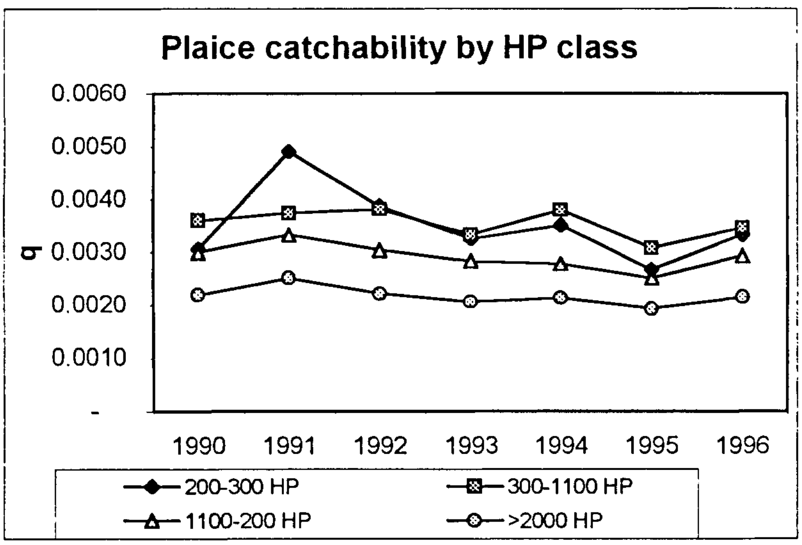
SOLE partial fishing mortality of the Dutch beamtrawl fleet plotted against fishing effort (unit: 100,000 hpdays) for the four quarters. Data used: 1970-1982 and 1990-1996.

Figure 5.8



SOLE catchability of the Dutch beamtrawl fleet plotted againsttime for the four quarters.
Data used: 1970-1982 and 1990-1996.

Figure 5.9



North Sea plaice catchability by HP-class for the Dutch beamtrawl fleet.

6. MORTALITY OF ESCAPING FISH

6.1 Survival experiments

Several experiments have recently been conducted to assess the survival probabilities of fish following escapement through the mesh lumen of commercial trawl cod-ends (Lehmann and Sangster, 1994; Lowry *et.al.*,1996; Sangster *et.al.* 1996; Soldal & Isaksen, 1993 and Suuronen *et.al*, 1995). A comprehensive review of sources of escape mortality is given by Frechet from the proceeding of the ICES sub-group on unaccounted mortality (ICES 1997c). Experimental methodologies between the experiments are similar in nature, and generally involve retaining the escaped fish in a small mesh cover surrounding the cod-end, and transfer to an underwater cage where the fish are monitored and mortalities removed and in some instances post-mortems conducted to assess causes of death (see references for full details).

Earlier development work conducted by Main & Sangster (1988) showed that the survival of young fish was relatively low after escapement. Survival rate, estimated only from numbers of fish at all lengths, was believed to be related to mesh size and catch composition. Based on total numbers of fish escaping, Soldal and Isaksen (1993) suggest that survival of escaping cod ranged between 90 to 100%. Lehmann and Sangster, (1994) from work conducted in 1992, suggest that survival rate for haddock escaping from 90, 100 and 110mm mesh cod-ends to be, on average, 77, 81 and 85% respectively. This was shown to be significant at the 95% level. Work conducted the following year by Lehmann and Sangster (1994), showed survival rates averaged 57, 80, 79 and 86% for fish escaping from cod-ends constructed from 70, 90, 100 and 110mm mesh respectively. The results from 1993 show that there was no significant relation between survival and mesh size. It is also suggested, contrary to the 1992 data, that larger fish had a better probability of survival. Later work by Lowry *et.al.*(1996) supports the findings from 1993, by showing that probability of survival increases with age. The data presented by Lowry *et.al.*(1996), typically indicates that within a particular age cohort, the smaller fish within the cohort are more likely to die, which suggests for example, that the 'heathier' fish, (i.e. faster growing) in the '1'gp cohort have a better survival probability than the 'weaker' fish within the 2-gp. It is generally considered that with the data available at present, that survival rates of '0'-gp haddock are approximately 80%, with survival probability increasing with length, and hence age, with an average of 90 to 95% survival occurring with the older age classes, i.e. 2 and 3 gp.

All survival experiments have been conducted during the summer months when fish are in good physiological condition due to summer feeding and may be better equipped to survive the rigours of the herding, capture and subsequent escape from the fishing gear. As has been shown with selectivity, (ICES 1998c), seasonal variation may also be a significant factor in survival which would require further investigation.

The estimates of survival vary and should be treated with some caution. There are indications that mortality during these trials may also contain an element of experimentally induced mortality. Unpublished results indicate that extended time within the small mesh cover used to retain the escaped fish may induce a certain level of stress or fatigue within some individuals. To quantify this, although great advancement has been made in experimental design, more development work is required in cover design and experimental techniques to reduce experimental effects on the results.

It should be considered that the values expressed here are 'worst case' due to the possible effects mentioned above. However, consideration must be given to the fact that following escape into the small mesh cover and subsequent entry to the holding cages, the individual fish are protected from post escape predation. It is possible that, under commercial conditions, the process of escape and the resulting initial stress and damage sustained may reduce the individual fishes ability to escape predation. These factors require further investigation.

6.2 Estimation of mortality due to passage through fishing gears

6.2.1 Methods

The last report of the SGSEL (ICES, 1997b) outlined a method for the estimation of the mortality rate due to fishing resulting from the passage of fish through the fishing gear. A full description of the method is given in Annex 3 and is outlined below.

The method requires as input estimates of:

a) age specific survival of fish escaping from the gear,
b) age specific survival of fish discarded and
c) the age selectivity of the gear.

The underlying principle of the method is to make a correction to the observed catch for the additional deaths occurring from discarding and passage through the gear. Given corrected catches it is possible to estimate the total mortality due to fishing by using conventional stock assessment methods which solve the Baranov catch equation. The correction factor, U, which is applied to the observed catch, Y, is:

$$U=1-s_d\ (1-p_l)+(1-p_r)(1-s_e)/p_r \qquad (6.2.1)$$

where s_d is the survival rate of discards, s_e is the survival rate of escapes, p_l is the proportion of the catch which is landed, and p_r is the proportion of fish which are retained by the gear. The total deaths due to fishing, the removals R, is then simply given by UY.

The quantity, Y, is the total catch retained by the gear and will include the landings, L, and any fish which are discarded, D. It is commonly the case that estimates of catch are limited to landings only. In this case, the landings will have to be corrected for discards before applying the correction in equation 6.2.1. For some fisheries observations are made on both landings and discards in which case it is not necessary to know p_l and the removals may be calculated directly from:

$$R=L+D(1-s_d)+(D+L)(1-p_r)(1-s_e)/p_r \qquad (6.2.2)$$

Given estimates of R, it is then straightforward to apply conventional stock assessment catch at age methods to calculate fishing mortality, F′, by solving the equation:

$$R_a = \frac{F'_a}{Z_a} N_a (1 - e^{Z_a}) \qquad (6.2.3)$$

where N is the population number, Z is the total mortality and a is a subscript for age. An estimate of the mortality caused by passage through the gear, the escape mortality, F_e, is then :

$$F_e = F'(R - Y)/R \qquad (6.2.4)$$

6.2.2. Escape mortality estimates for North Sea haddock

The method described above have been used to obtain estimate of the escape mortality, F_u. A full description of the results is given in Annex 3. Based on assumptions about escape survival and gear selectivity, assessments were performed which indicated that the escape mortality was largest at age 2 where it accounted for about 40% of the total fishing mortality. Above age 4 the effect of escape mortality is negligible.

By including the additional deaths due to passage through the gear, the overall mortality estimates increase but by about 20% and there is a concomitant increase in the population size estimates. If the assumptions made about survival are realistic then it implies present assessments under-estimate both stock size and fishing mortality. Comparisons of the estimate of F_{max} made under the assumption of some escape mortality with conventional assessments suggest that a more pessimistic view of the state of the stock emerges. This is because including post escape mortality leads to lower estimates of F_{max} and a higher estimate of fishing mortality. However the long term stock trends are little affected.

At present experiments on the survival of fish which escape the gear do not give a clear picture of the appropriate values to use in the calculations performed here. In order to investigate the effect of changes in the assumption of survival rates a sensitivity analysis was performed. Survival ogives for fish escaping the gear were described by an age based symmetric curve analogous to a typical gear selectivity ogive. These were defined by two parameters, EA50, the age at which 50% of fish survive and, ESR, the age range over which survival increases from 25%-75%. The escape mortality was calculated for values of EA50 and ESR of 2,4 and 4. Curves with low values of these parameters will have steeper slopes and lie to the left of curves with higher values.

Table 6.2.1 shows the results of the sensitivity analysis. Estimates of mean fishing mortality over the ages 1-3 are shown for the escape mortality and the total fishing mortality. The effect of EA50 is the greatest, with the escape mortality increasing by approximately 50% as EA50 increases. The magnitude of the effect on total fishing mortality is very much smaller, however. The 'selection range' effect is smaller and in most cases the estimated mortality decreases as ESR increases.

Figure 6.2.1 shows the escape mortality for three different survival ogives. These range from 'steep left shifted ogives' to 'flatter right shifted' ogives. The steep left shifted curves give more sharply peaked exploitation patterns with lower maxima than the flatter right shifted curves.

6.2.3 Conclusions

The analysis presented here is preliminary and is highly dependent on the assumption made about the survival of fish escaping from the gear but is probably indicative of the likely size of the effect. If correct it implies that present assessments have a small bias on the estimate of stock size and fishing mortality rate for the youngest age classes. Taking account of escape mortality also gives a slightly more pessimistic state of the stock in relation to yield per recruit criteria. It is important that more work is directed towards improving the estimates of the survival ogives so that more reliable estimates of fishing mortality can be made.

All of the analysis presented in the example is age based, primarily because much of the stock assessment data are most easily accessible in this form. However is has to be recognised that both gear selectivity and post selection survival will be heavily influenced by fish size not age alone. The analysis would be improved if size was included in the analytical methods.

Table 6.2.1. Calculated mean fishing mortality over ages 1-3 for different survival rate ogives for North sea haddock.

Escape mortality

		Age Range, ESR		
		2	3	4
EA50	2	0.196	0.200	0.202
	3	0.270	0.254	0.244
	4	0.315	0.293	0.277

Total fishing mortality

		Age Range, ESR		
		2	3	4
EA50	2	0.798	0.78	0.785
	3	0.831	0.814	0.804
	4	0.841	0.828	0.817

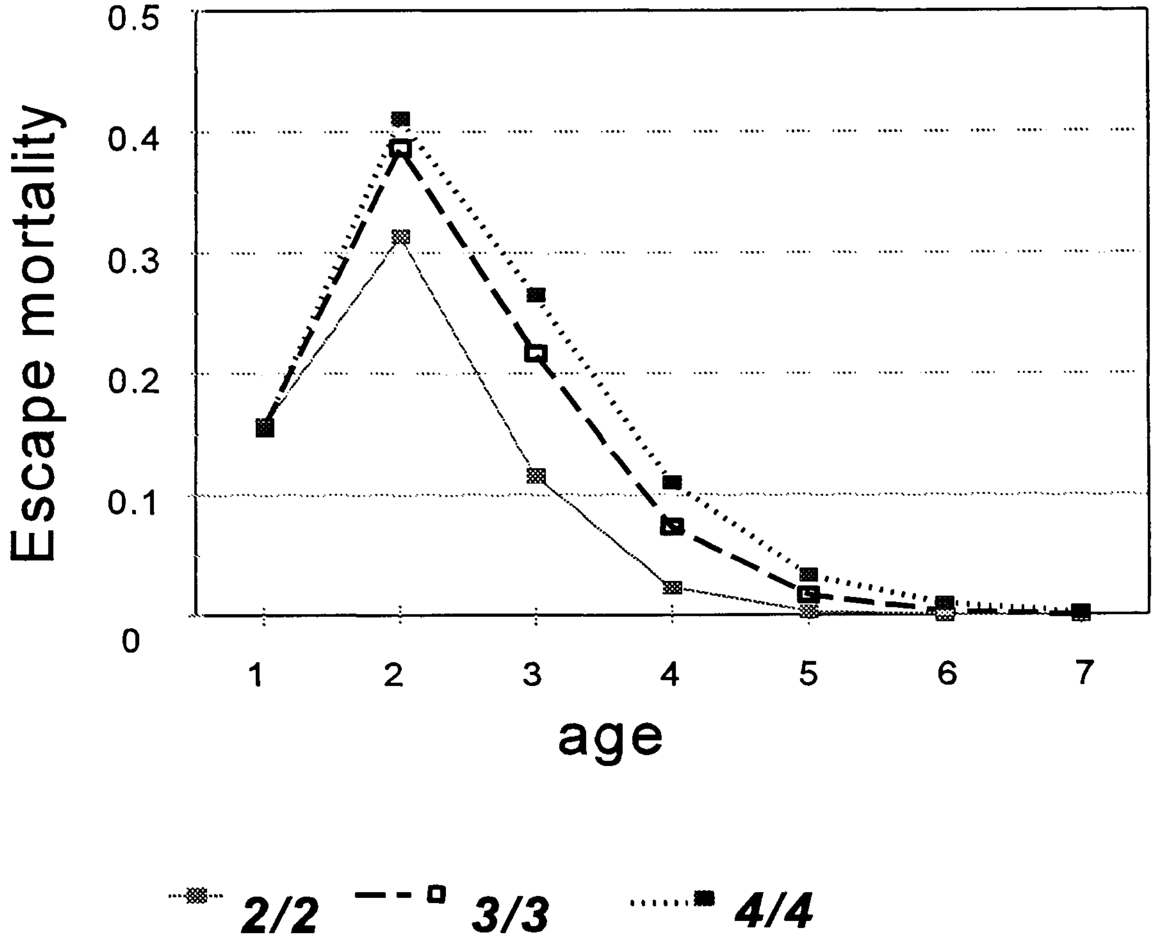


Figure 6.2.1. Escape mortality at age calculated from three assumptions about escape survival. In the legend, 2/2 refers to an ogive with EA50=2, ESR=2 etc.

7. RECOMMENDATIONS

7.1 Scientific recommendations

Bearing in mind the work presented in the report, SGSEL recommends that:

The analysis of the Scottish haddock selectivity data set should be completed. In particular the analysis should use individual haul data, and model L50 and selection range as a bivariate response. This should lead to improved estimates of the model parameters and variance components.(Section 3.1)

Methods for using experimental selectivity data to estimate fleet selection should be further developed. In particular ways of weighting the contribution of different components of the fleet should be investigated. Appropriate weighting factors relating catch rates, fishing activity and gear usage need to be compiled.(Section 3.1)

The methodology for estimating fleet selection from experimental selectivity data should be applied to a wide range of fleets and species. The resulting estimates of fleet selection should be compared to estimates from other methods.(Section 3.2)

Systematic attempts are made to estimate the catchability of research vessel sampling gears and to estimate the relative age or size catchability of the relevant target species.(Section 4)

Further studies be undertaken to investigate the relationship between fishing effort and fishing mortality. Current units to express fishing effort (typically horsepower days, hours fished) are inadequate to describe the actual effective fishing effort of fishing fleets which consists of both fishing activities and fishing power. To understand this relationship between fishing effort and fishing mortality more detailed analysis is needed, taking account of the variation over time of the following variables, which may influence fishing effort:
* selectivity
* technical measures
* technical developments in fishing vessels, fishing gears and fishing operations
* quota restrictions

(Section 5.3)

The quarterly IBTS data (1991-1996) be used to provide assessment independent estimates of stock size and it's spatial distribution for a number of demersal stocks in the North Sea. It further recommends that these stock estimates be used in conjunction with commercial catch at age, to estimate fishing mortality at age by fleet, by area and by quarter. Quarterly IBTS data (1991-1996) can be used to derive stock-assessment independent estimates of number and spatial distribution of fish. In order to scale the abundance indices of the IBTS survey, fixed catchabilities would have to assumed. If these data are used in conjunction with commercial catches by fleet, the fishing mortalities by fleet can be calculated directly using the familiar Baranov equation. Thus assessment independent estimates of fishing mortality by age, fleet, area and quarter would be available which would enable a more detailed insight into the relationships between fishing effort and fishing mortality in different periods and different spatial areas. (Section 5.3)

Further work is undertaken to obtain reliable estimates of the survival of fish which escape from fishing gears. This is necessary for a wider variety of species and gears. (Section 6.1)

Estimates of escape mortality are obtained from a wider range of species and stocks. These estimates need to be used to evaluate the significance of escape mortality in fish stock assessment.(Section 6.2)

The effect of escape mortality on the evaluation of changes in mesh size is investigated. This will require knowledge of how escape mortality changes with mesh size.(Section 6.2)

7.2 Future of the study group

SGSEL has now had two meetings and produced three reports and it is appropriate to review its future. One of the objectives in setting up the group was to bring together experts in the field of fishing technology, stock assessment and statistics to work on topics of common interest. The final meeting of SGSEL was successful in bringing these disciplines together and useful progress has been made on the main terms of reference which probably would not have occurred without the establishment of the group. Participants found the mixture of expertise a particularly valuable forum for scientific progress. While the balance of expertise in the group was appropriate, the number of participants has been relatively small and this has limited the amount of progress which can be made. Unless active steps are taken to increase participation it will be difficult to make significant further progress.

Members of the group felt that it is important to establish a forum where fishing technologists and stock assessment scientists can work together to improve the exchange of information and ideas.

SGSEL therefore recommends that the Fishing Technology and Resource Management Committee engage in a dialogue to identify the most appropriate and productive forum for continuing the work of the study group.

One possibility is to establish a more broadly based study group which could deal with a wider range of issues related to technical conservation measures in fishery management.

8. WORKING DOCUMENTS

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WD2: Fryer, R. J. , Ferro, R. S. T. and Graham, N. Combining selectivity data from different trials.

WD3: Somerton, D. A. and Munro, P. Estimating the capture efficiency of survey trawls.

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WD5: Cook, R. M. Relationship between fishing effort and fishing mortality for North Sea roundfish.

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Annex 1

COMBINING SELECTIVITY DATA FROM DIFFERENT TRIALS

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Introduction

How can we combine selectivity data from different trials? In a sense, the answer is straightforward. Selectivity data are just one example of hierarchical (or multilevel) data, with several hauls made with the same codend, several codends tested on the same trip, several trips made with the same vessel, and several vessels used from a fleet. As such, we have available all the techniques developed for modelling hierarchical data (eg Goldstein, 1995). Unfortunately, this is rather like saying we can use regression for modelling the relationship between dependent and explanatory variables, a statement which fails to acknowledge the many types of regression analysis available. As with regression, an appropriate hierarchical model depends crucially on the available data, the way they were collected, their distribution, and the relationships between different measurements.

Here, we use a couple of stylised examples to describe some of the concepts necessary for modelling hierarchical data. We then illustrate the theory using selectivity data collected by the FRS Marine Laboratory between 1992 and 1998 (Ferro & Graham, 1998). Finally, we consider how these data might be used to estimate 'fleet selectivity'.

Simple hierarchical models have been used routinely in selectivity work for some time. For example, the between-haul selectivity model of Fryer (1991) is a hierarchical model with two levels: the data collected on each haul (within-haul information), and variation in selectivity between hauls (between-haul information). Fryer (1996) extends this model to include a third level, with variation in selectivity between-vessels. Both these papers adopt a frequentist approach, using likelihood methods for estimation and inference, and we do the same here. An alternative that works well with hierarchical data, is to use Bayesian methods and particularly Monte Carlo Markov Chain techniques (Spiegelhalter *et al*, 1995). Holtrop (1998) describes in detail how these can be applied to different selectivity data structures.

Theory

Basic assumptions

- We have selectivity data from several hauls, and are interested in modelling these data in some way.

- The selectivity of each haul can be summarised by a vector of parameters η. For example, if each haul has a logistic selectivity curve, with retention probability p related to length l by

$$\log\left(\frac{p}{1-p}\right) = \alpha + \beta l,$$

  then we might take $\eta = (\alpha, \beta)^T$. Note, however, that the choice of summary parameters is flexible. With a logistic selectivity curve, we could consider any transformation of $(\alpha, \beta)^T$, such as $(l_{50}, SR)^T$, provided the transformed parameters satisfy the various modelling assumptions below.

- For each haul, we have an estimate of η, denoted $\hat{\eta}$. Let R be the variance of $\hat{\eta}$, assumed known, so that approximately

$$\hat{\eta} \sim N(\eta, R).$$

  We shall call R the *within-haul* variation associated with $\hat{\eta}$.

Case 1

Suppose we have conducted several selectivity trials with the same test codend. Further, suppose some trials were conducted on different trips using the same vessel, and that some trials used different vessels chosen at random from the fleet. Let $\hat{\eta}_{vth}$ be the estimated selectivity of haul h on trip t of vessel v, and let R_{vth} be the associated variance.

We wish to combine these data to estimate the selectivity of any vessel in the fleet that uses the test codend.

The first step is to partition the sources of variation in the data into *fixed* and *random effects*. Loosely, fixed effects describe the effect of explanatory variables, whether continuous or categorical, that are of specific interest in the selectivity trials. A typical example would be the effect of mesh size. Random effects describe variation that originates because we have taken samples from some larger homogeneous population of interest. The variation in selectivity between hauls made with the same codend (on the same trip using the same vessel) is a typical example of a random effect.

Here, there are no fixed effects associated with the codend, since the codend is always the same. For simplicity, we shall also assume that there is no auxiliary information that can be included as a fixed effect, such as codend catch bulk, time of year, or size of vessel. The fixed part of the model therefore just consists of the parameters needed to describe mean selectivity. We write this as fixed ~ 1.

However, there are four random effects to consider. These have a nested structure, and are:

- within-haul variation,
- between-haul (within-trip) variation,
- between-trip (within-vessel) variation,
- between-vessel variation.

We write the random part of the model as random ~ vessel / trip / haul / within-haul.

The full model can be written explicitly as

$$\hat{\eta}_{vth} = \eta + \epsilon_v + \epsilon_{vt} + \epsilon_{vth} + \omega_{vth}$$

where

- η is the mean selectivity,
- ϵ_v is the random effect associated with vessel v,
- ϵ_{vt} is the random effect associated with trip t of vessel v,
- ϵ_{vth} is the random effect associated with haul h of trip t of vessel v,
- ω_{vth} is the within-haul random effect associated with haul h of trip t of vessel v.

Let's assume the random effects are mutually independent and normally distributed with variances Σ_v, Σ_t, Σ_h, R_{vth} respectively. We can then estimate η and its standard error by residual maximum likelihood (REML); see Robinson (1987) for an accessible account. REML also estimates the variance components Σ_v, Σ_t, Σ_h, and standard likelihood ratio tests can be used to assess the significance of each component. Remember that the within-haul variance matrices R_{vth} are assumed known (see above).

Case 2

Now suppose that each trial investigated several codends, each varying in mesh size. Let m_{vtc} be the mesh size used with codend c on trip t using vessel v. Further, let $\hat{\eta}_{vtch}$ be the estimated selectivity of haul h with codend c on trip t of vessel v, and let R_{vtch} be the associated variance.

Mesh size must now be incorporated as a fixed effect. If we assume that $\hat{\eta}_{vtch}$ varies linearly with mesh size, we can write the fixed part of the model as fixed ~ mesh size.

The random part of the model is now random ~ vessel / trip / codend / haul / within-haul. This is basically the same as before, except that we have introduced an additional random effect to model any between-codend (within-trip) variation that is not accounted for by the mesh size effect (ie any lack of fit about the linear model in mesh size).

The full model can be written explicitly as

$$\hat{\eta}_{vtch} = \eta + m_{vtc}\alpha + \epsilon_v + \epsilon_{vt} + \epsilon_{vtc} + \epsilon_{vtch} + \omega_{vtch}$$

where α is the vector of parameters measuring the mesh size effect.

REML can again be used to estimate the parameters η and α, their standard errors, and the variance components. The significance of the fixed effects can be assessed by either Wald statistics or likelihood-based tests.

An implicit assumption above is that the mesh size effect α is the same on each trip of each vessel. But what if this is not so? A sensible approach is then to assume that the mesh size effect has itself some distribution, varying between trips and/or between vessels about some mean value. The fixed part of the model remains the same. The random part now has two additional terms: variation in the mesh size effect between trips within vessels, and variation in the mesh size effect between vessels. This can be written random ~ vessel / trip / codend / haul / within-haul + vessel / trip / mesh size. The full model can be written explicitly as

$$\hat{\eta}_{vtch} = \eta + m_{vtc}(\alpha + \delta_v + \delta_{vt}) + \epsilon_v + \epsilon_{vt} + \epsilon_{vtc} + \epsilon_{vtch} + \omega_{vtch}$$

where δ_v and δ_{vt} are the two new random effects.

Computational stuff

We have blithely said that REML can be used to estimate these selectivity models. However, this usually involves writing your own software. The models are actually special cases of the Laird Ware model (1982), and Jones (1993) discusses issues of estimation and inference. However, an important difference here is that the within-haul variances R are assumed known, necessitating modifications to most model fitting algorithms. In the example below, the selectivity parameters were only available on a univariate basis, and were fitted using GENSTAT, a package that has particularly good REML facilities. However, even here, some tweaking and brow beating was required.

Example

We illustrate using the haddock selectivity data presented in Ferro & Graham (1998). The data come from 14 selectivity trips between 1992 and 1998, with a total of 58 different test codends. The data are currently only available aggregated by codend (ie no individual haul data). For each codend, we have estimates of l_{50} and log SR, and of the variances of these estimates. However, covariances are not available, so we will model l_{50} and log SR separately. (Note that the R variances here measure within-codend variation, rather than within-haul variation).

The explanatory variables are:

- gear — categorical: single trawl, pair trawl, pair seine, twin trawl
- season — categorical: winter, spring, summer
- mesh size — continuous: range 66 - 119 mm
- open meshes round — continuous: range 54-134
- twine thickness — continuous: range 2.9 - 6.4 mm.

Only one codend was used on a twin trawl, and only two codends were used in spring, so for simplicity, we omit these data.

Modelling l_{50}

Figure A1.1a shows the estimates of l_{50} for each codend plotted against mesh size by season and gear. The plotting symbols (a - n) differentiate selectivity trips. Trips b & c were conducted on the same vessel, as were trips d & e, and trips f, g, h & I. The thin vertical lines around each point are ± 2 standard errors based on the within-codend variances. An unweighted straight line has been fitted to the data in each panel. Figures A1.1b & A1.1c show similar plots for meshes round and twine thickness.

Note that:

- winter data were only collected on single trawls,
- the greatest contrast in meshes round comes from trip l,
- there are only three codends with thick twine.

The data give no reason to doubt the various normality assumptions, so we consider the (very) full model:

> fixed ~ season + gear + mesh size + meshes round + twine thickness +
> season . mesh size + season . meshes round + season . twine thickness +
> gear . mesh size + gear . meshes round,
>
> random ~ vessel / trip / codend / within-codend + vessel / trip / mesh size + vessel / trip / meshes round + vessel / trip / twine thickness.

The fixed model incorporates all two level interactions with gear and season, other than gear . season and gear . twine thickness for which there is minimal information. The random model allows the effects of mesh size, meshes round, and twine thickness to vary between trips and between vessels.

This model is clearly over-parameterised. We simplified the model using various likelihood tests and Wald statistics, giving:

> fixed ~ mesh size + meshes round + twine thickness
>
> random ~ trip / codend / within-codend.

Here are the estimates of the fixed effects and variance components. We also give approximate standard errors, although these are very crude for the variance components.

effect	estimate	standard error
mesh size	0.351	0.021
meshes round	-0.102	0.019
twine thickness	-1.53	0.41
component		
between trip	3.30	1.55
between codend	0.74	0.37

Note that the analysis is, to a certain extent, incomplete, since there are various issues that need to be investigated further. In particular:

- The trip and vessel variance components are somewhat confounded. For example, the variation between the data marked l and k in Figure A1.1 could be due to either between-trip or between-vessel variability, or some combination of the two. The between-trip variance is significant here, but this result is greatly influenced by trip d. If we remove trip d, the between-trip component becomes non-significant, and the between-vessel component becomes important.
- There is marginal evidence of an interaction with gear, particularly involving meshes round. For simplicity, we ignore this here. However, if we remove trip d, the interaction can not be ignored. It turns out that the meshes round effect is greatly influenced by the data from trip l, and if we remove this trip (as well as trip d), the meshes round effect disappears altogether. This is an inevitable consequence of trying to combine data from several trials, each with their own specific objectives.
- Working on the haul level, if possible, might help to clarify things here. For example, the catches in trip d were exceptionally high, and this effect might be modelled using codend bulk as an additional explanatory variable.
- We have cheated a little. There are two data points associated with trip b. We have treated these as two different codends tested on the same trip. In fact, they should be two different trips with exactly the same codend. But this posed software problems.

Modelling log *SR*

Figure A1.2 shows selection range plotted against mesh size on a log scale. Similar plots against meshes round and twine thickness reveal nothing of interest, and are not shown here. Modelling log *SR* along similar lines to before, we arrived at:

fixed ~ season + mesh size,

random ~ trip / codend / within-codend.

The estimates of the fixed effects and the variance components are below. The season effect is the difference between log *SR* in summer and in winter (so log *SR* is greater in summer). Again, the between-trip and between-vessel variance components are confounded. Here, we could have retained either one at the expense of the other. However, we plumped for the between-trip component for consistency with the l_{50} model.

effect	estimate	standard error
mesh size	0.0129	0.0022
season	0.39	0.11

component		
between trip	0.023	0.013
between codend	0.013	0.006

Fleet selectivity

The models above can easily be used to predict the expected l_{50} and log SR of any vessel in the fleet, given the mesh size, meshes round, twine thickness, and season. But for stock assessment purposes, we need to average these predictions in some sensible way across the different net configurations in the fleet, and seasons of the year. Unfortunately, it is not sufficient to simply calculate a weighted average of the predicted values of l_{50} and log SR. For example, Figure A1.3 shows two selection curves (solid lines) with different l_{50}s but common SR. The dashed line is the average retention probability at each length. Clearly, the SR of the average curve is much greater than that of the two individual curves.

Let's consider fleet selectivity defined to be:

$$p_{fleet}(l) = \text{prob (fish of length } l \text{ is retained by a net in the fleet} \mid \text{it enters the net)}.$$

Let

$$q_{vth}(l) = \text{prob (fish of length } l \text{ enters the net of vessel } v \text{ on haul } h \text{ of trip } t),$$

where the subscripts v now run through all vessels in the fleet, the subscripts t run through all trips made by vessel v, and so on. (We will assume each vessel only uses a single codend through the year). Further, let

$$r_{vth}(l) = \text{prob (fish of length } l \text{ is retained} \mid \text{it enters the net of vessel } v \text{ on haul } h \text{ of trip } t).$$

Then

$$p_{fleet}(l) = \frac{\sum_{vth} r_{vth}(l)\, q_{vth}(l)}{\sum_{vth} q_{vth}(l)}.$$

This is just an average, over all the hauls conducted by the fleet, of the retention probabilities at length l, weighted by the 'catchabilities' at length l.

To proceed we need to make some sweeping assumptions. First, assume that the catchabilities are of the form

$$q_{vth}(l) = q_{vth}\,\lambda_l$$

where λ_l is a measure of the availability of length l fish. Then

$$p_f(l) = \frac{\sum_{vth} r_{vth}(l)\, q_{vth}}{\sum_{vth} q_{vth}}.$$

One possibility here would be to allow the q_{vth} to have some distribution about some mean vessel-specific catchability q_v, say. This might be important if selectivity was related to catch bulk. But for simplicity we will assume that $q_{vth} = q_v$ = constant. This gives

$$p_f(l) = \frac{\sum_v q_v \sum_{th} r_{vth}(l)}{\sum_v q_v H_v},$$

where H_v is the total number of hauls by vessel v.

Clearly, we do not observe the retention curves $r_{vth}(l)$. Instead, we can use the expected selection curve for each haul to estimate fleet selectivity by

$$\hat{p}_{fleet}(l) = \frac{\sum_v q_v \sum_{th} \mathrm{E}[r_{vth}(l)]}{\sum_v q_v H_v}.$$

Finally, suppose we can divide the fleet into discrete groups g each operating with a particular net configuration (eg mesh size, meshes round, etc.). If π_g is the proportion of the catch taken by group g, then the estimate of fleet selection simplifies to

$$\hat{p}_{fleet}(l) = \sum_g \pi_g \mathrm{E}[r_g(l)],$$

where E[$r_g(l)$] is the expected retention curve of a net in group g.

Note that the retention probabilities $r(l)$ are nonlinear transformations of the selectivity parameters l_{50} and log SR, which we can make explicit by writing $r(l) = r(l, l_{50}, \log SR)$. But the same nonlinear relationship can not necessarily be used for calculating expectations; ie

$$\mathrm{E}[r(l)] \neq r(l, \mathrm{E}[l_{50}], \mathrm{E}[\log SR]).$$

A simple way round this is to simulate the joint distribution of l_{50} and log SR, and hence the distribution of $r(l)$.

Example

As there are no significant gear effects, lets consider a turbo-fleet consisting of all single trawls, pair trawls, and pair seines. Current regulations impose a minimum mesh size of 100 mm, and a maximum of 100 open meshes round. Most boats adhere to these minimum and maximum values respectively, so we will take these as fixed. Since a nominal mesh size of 100 mm is equivalent to a measured mesh size of about 95 mm, we shall use 95 mm for making predictions.

At present, twine thickness is not regulated. Our best hunch is that about 50% of vessels use 6 mm twine, 25% use 5 mm twine, and 25% use 4 mm twine. Again, these nominal twine thicknesses correspond to measured values of about of 5.4, 4.5, and 3.5 mm respectively.

Assume that 50% of trips occur in winter and 50% in summer.

We thus have 6 groups to consider, corresponding to the various possible combinations of 6, 5, 4 mm twine, and winter, summer fishing. Assuming the proportions π_g are simply determined by the number of vessels fishing in each group, we have

$$\hat{p}_{fleet}(l) = \frac{1}{8}\mathrm{E}[2r_{w6}(l) + 2r_{s6}(l) + r_{w5}(l) + r_{s5}(l) + r_{w4}(l) + r_{s4}(l)]$$

where eg r_{w6} is a retention curve chosen at random from a vessel fishing in winter with nominal 6 mm twine.

To estimate the expected retention curves, we take Var[l_{50}] = 3.30 + 0.74 = 4.04 and Var[log *SR*] = 0.023 + 0.013 = 0.036, using the estimated variance components above. We do not have estimates of between-haul variation, so the variances of l_{50} and log *SR* are underestimated.

Figure A1.4 shows the expected retention curves of vessels fishing in winter with the three different twine thicknesses (dotted lines) and in summer (dashed lines). The solid line is the weighted average of these curves and gives the estimate of fleet selectivity. Fleet selection has an estimated l_{50} of 26.5 cm and a *SR* of 5.8 cm.

Four final thoughts:

- fleet selectivity needs to be converted from length to age,
- the precision of the estimated fleet selection curve in Figure A1.4 should be evaluated,
- the joint distribution of l_{50} and log *SR* should be used to estimate fleet selection, rather than treating them as independent as we have done here,
- between-haul variation needs to be included in the estimation of the expected retention curves.

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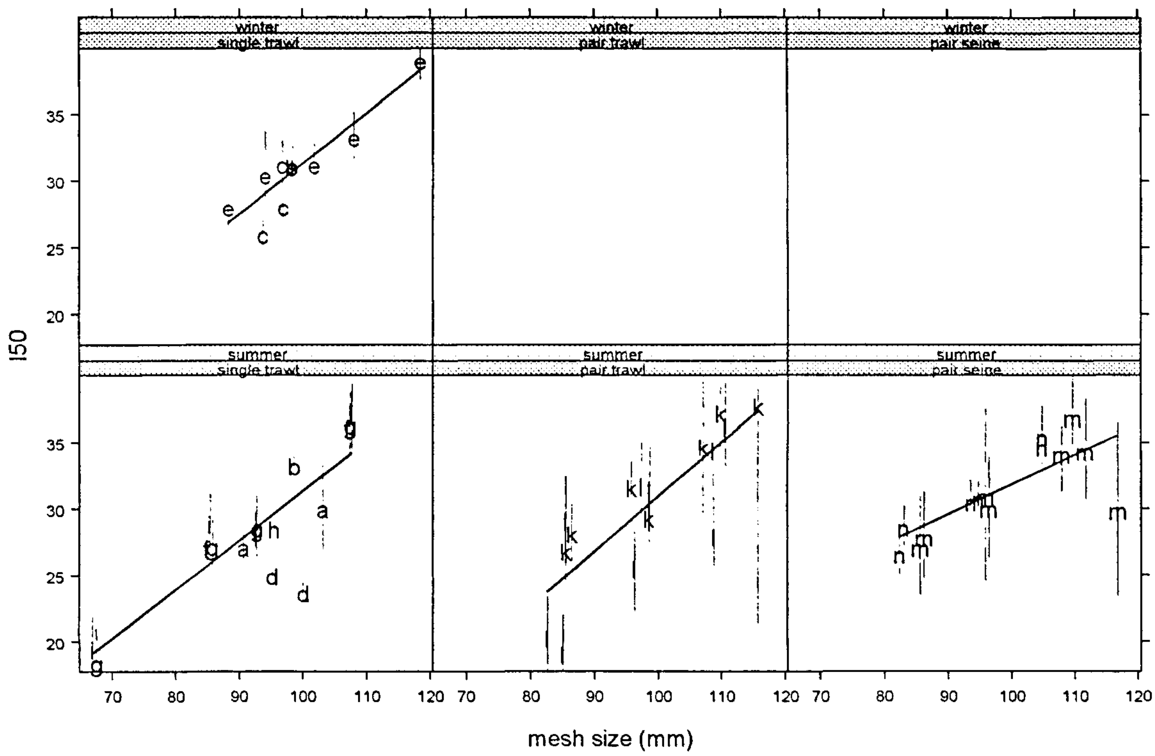

Figure A1.1a Estimates of l50 plotted against mesh size by gear and season

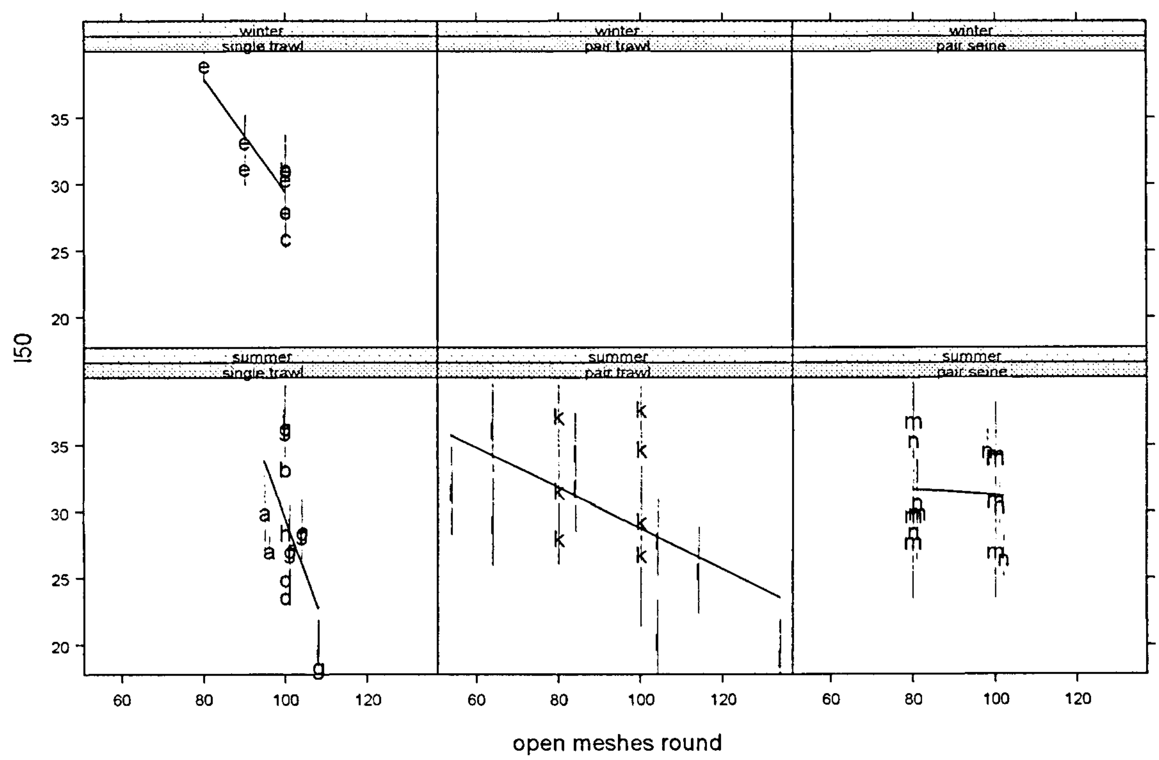

Figure A1.1b Estimates of l50 plotted against open meshes round by gear and season

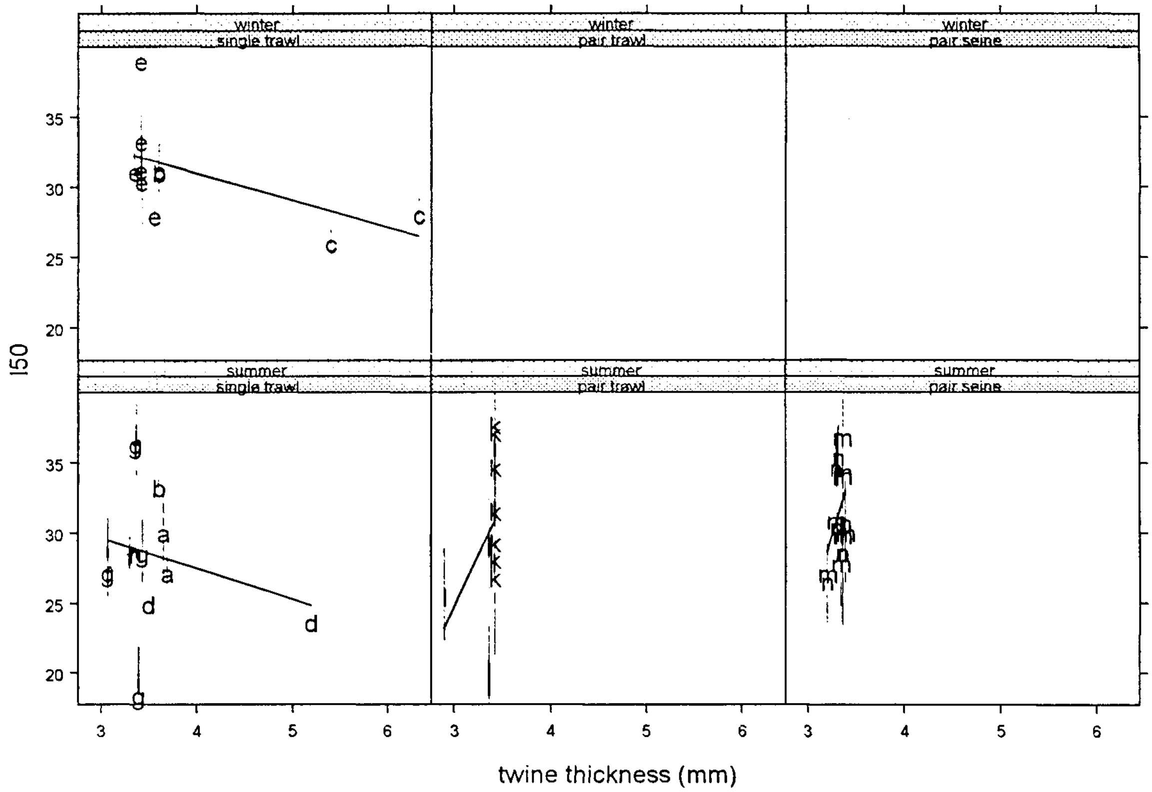

Figure A1.1c Estimates of l50 plotted against twine thickness by gear and season

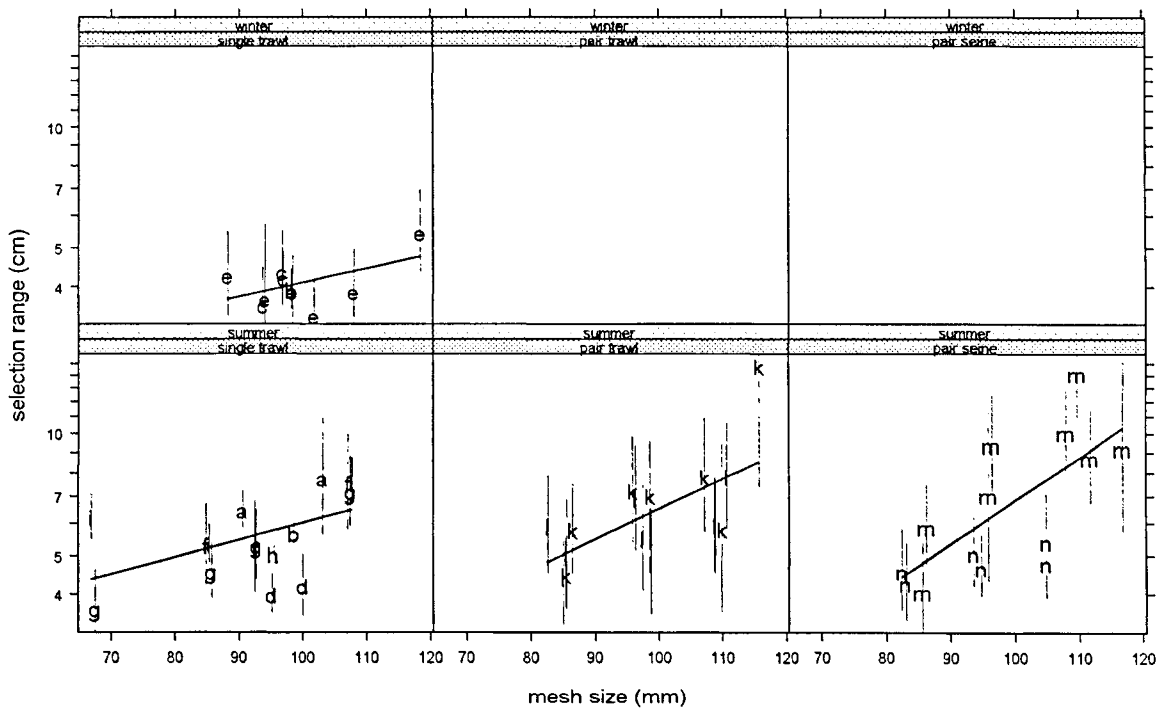

Figure A1 2 Estimates of log SR plotted against mesh size by gear and season

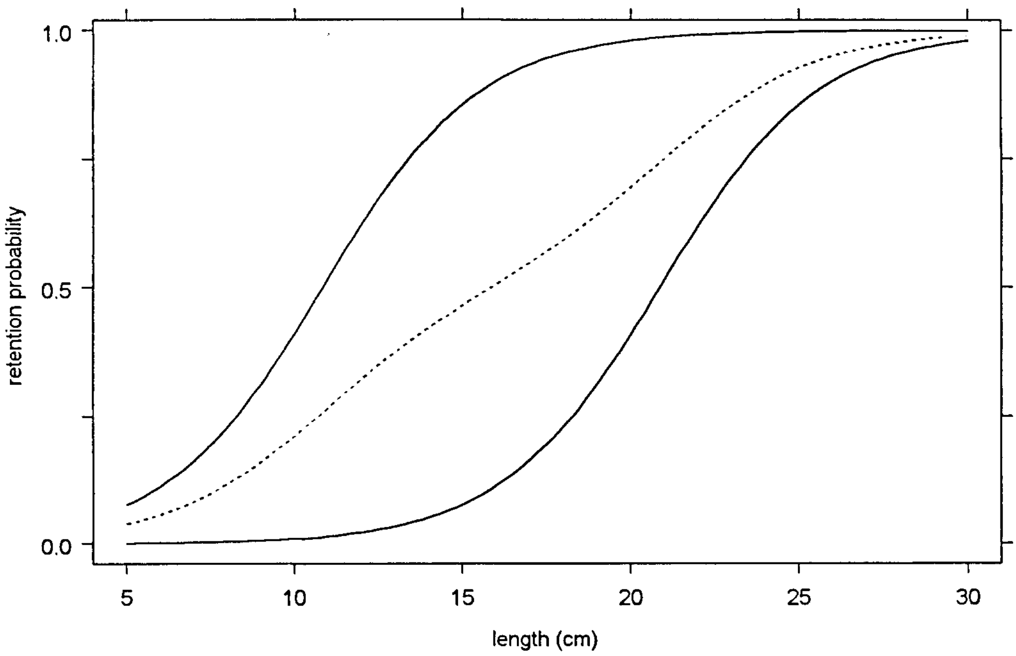

Figure A1.3 The solid lines show two logistic selection curves with the same SR. The dashed line is the average of the two curves and has a much greater SR.

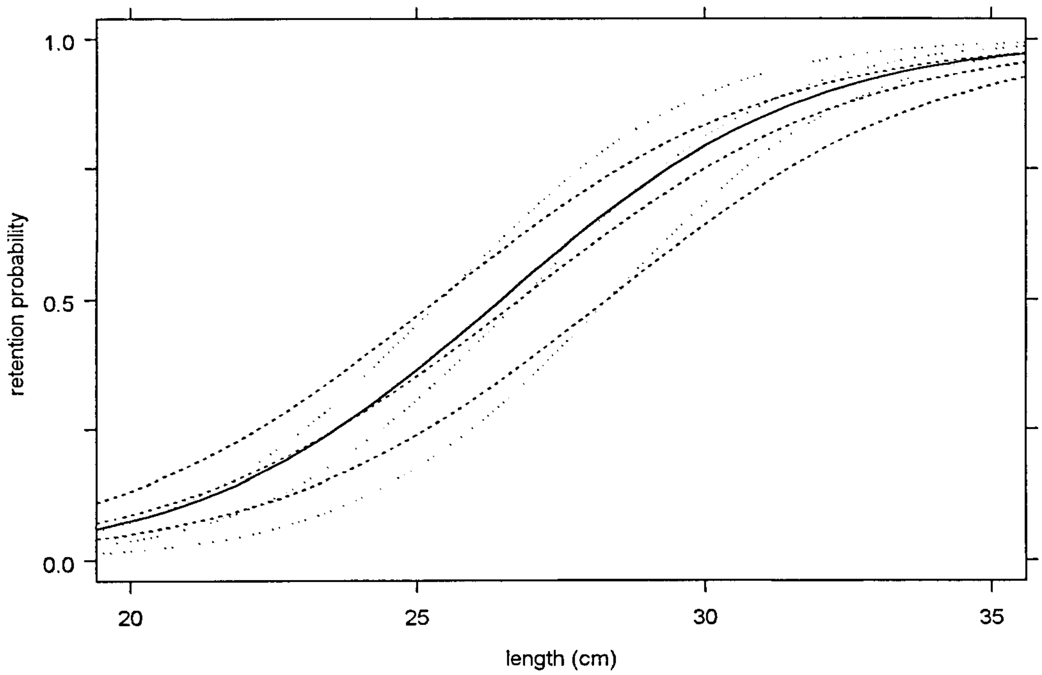

Figure A1.4 The dotted (dashed) lines show the expected retention curves when fishing in winter (summer) with nominal 4, 5, 6 mm twine (right to left). The solid line is the estimated fleet selection curve.

Annex 2

TRENDS IN EFFORT, FISHING MORTALITY, CATCHABILITY AND CPUE IN THE NORTH SEA PLAICE FISHERY

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1 Introduction

The flatfish fisheries in the North Sea is mainly conducted by beam trawlers fishing for a mixed bag of sole and plaice with a bycatch of other flatfish species and roundfish species. The fisheries is managed by single species quota. Although sole is a more southerly species than plaice, they largely share a common distribution area. Therefore, changing the TAC on one species may affect the fishing pattern for the whole fishery and may lead to processes like avoidance or discarding.

The method used for assessing the demersal North Sea stocks is Extended Survivors Analysis XSA (Shepherd, 1992; Darby and Flatman, 1994). In general, virtual population analysis methods are methods whereby a stock's historical population structure is reconstructed from the total catch data given a particular level of natural mortality. To do so, the numbers at age (or fishing mortality at age) in the last year and age have to be found since the method iterates backwards down a cohort. In XSA these are found from the relationship between catch per unit effort (CPUE), abundance and year class strength.

Two models for the relationship between CPUE indices and population abundance are used in XSA. For the fully recruited ages of all fleets, fleet catchabilities are assumed to be constant with respect to time. For the recruiting ages, catchabilities are assumed proportional to year class abundance (Darby and Flatman, 1994). Trends in catchability may therefor seriously affect the results of the analysis (Mohn & Cook, 1993).

A second important assumption underlying the XSA analysis, is that the catch per unit of effort (CPUE) is an indicator for the developments in the stock. This relationship is however not straight forward, since a number of processes may affect this relationship (Gulland, 1964). For the commercial tuning fleets used in the assessments of plaice and sole (i.e. Dutch beam trawl fleet and UK beam trawl fleet) these processes may be changes in targetting and changes in fleet catchability due to different mesh sizes or management regulations.

In this paper we will investigate the assumptions on constant catchability and CPUE as indicator of stock size for plaice and sole. Partial fishing mortalities are calculated and compared to effort developments for different fleets to assess the relationships between fishing effort and fishing mortality. For the Dutch beamtrawl fleet also the relationships between capacity and effort will be commented upon. A comparison will be made between the CPUE of individual Dutch beamtrawl vessels to the so-called 'flag-vessels' so that estimates can be made of the relationships between targetting and quota availability. The effects of assumptions on CPUE in the assessment procedure will be evaluated.

2 Material and methods

2.1 Catch in numbers

Total international catch in numbers for plaice and sole were taken from the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES 1998). Yearly and quarterly catch data for the Dutch beamtrawl fleet and the UK beamtrawl fleet were obtained from the RIVO-DLO database and from the CEFAS database.

2.2 effort and price data

Effort data on the Dutch beam trawl fleet is available from the mandatory logbook database (VIRIS) for the years 1990-1997. The database contains information by trip and by ICES rectangle (30x30 nm) for all vessels fishing under a Dutch registration. Since 1995, the database is extended to include foreign vessels landing in the Netherlands.
The database is maintained by the Dutch ministry for Agriculture, Nature and Fishery with the primary aim to control quota. For research purposes, an extraction of the database is generated with relevant variables like vessel characteristics, landings by species and days at sea (Van Beek et al, 1998).

The value of the landings per trip was calculated by using average prices per month and per species (LEI-DLO, pers. comm).

Only those records were used where the ICES rectangle had been denoted. Other selection criteria were:

- use of beam trawl gear, and
- catches for plaice and (combined) larger than zero.

In total 88137 trips were analysed between 1990 and 1997 divided over 137929 records.

The database contains the number of days-at-sea (DAS) per trip. If more than one rectangle was visited during a trip, the total trip-time was subdivided across the rectangles according to the proportion of the total value of the demersal landings (plaice, sole, cod, whiting) in each rectangle.

$$E_{t,i}=E_t \frac{V_{t,i}}{\sum_i V_{t,i}}$$

Where

$E_{t,i}$ is effort in trip t and rectangle i.
$V_{t,i}$ is value of the landings from trip t and rectangle i.

Effort is expressed as days-at-sea or as HP days. Days at sea were not corrected for the number of hours fishing per day.

To correct effort series for diminishing productivity of engine power, LEI-DLO has made available a standardized effort series. Standardization is achieved by expressing the average productivity of 'un-changed' vessels (i.e. vessels were no investments are made that may change the productivity) in various HP-groups as an index (SHPD; standardized horse power days).

Aggregated effort data on the UK beamtrawl fleet was made available by CEFAS which also supplied detailed data on the so-called flag-vessels.

2.3 capacity

Capacity of the Dutch fleet is assembled by LEI-DLO and takes account of landing rights of vessels to ascertain the number of 'sailing cutters'. These are multiplied by the engine power of the vessels to arrive at the capacity of the Dutch fleet. Alternatively, capacity may also be expressed in standardized units, following the same procedures as above.

2.4 fishing mortality

Total international fishing mortality of plaice and sole is assessed in the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES 1998). No recent international effort series is available for the North Sea demersal fishery. In order to explore the relationships between fishing effort and fishing mortality, partial fishing mortalities by fleet and by age are calculated as:

$$f_{partial} = f * C_{fleet}/C_{total}$$

where

- f is total fishing mortality by age
- C_{fleet} is the catch in numbers at age by a certain fleet
- C_{total} is the total international catch in numbers at age.

The arithmetic average partial fishing mortality for a certain fleet and over a certain range of ages is used as an index of the fishing mortality generated by that fleet (Murawski & Finn, 1986; Rocha et al, 1992).

2.5 catchability

Catchability is estimated in a linear relationship between fishing effort and fishing mortality:

$$f = q . E$$

Where

- f = total (partial) instantaneous fishing mortality coefficient by fleet
- q = catchability coefficient
- E = effort (e.g. days-at-sea, Hp-days)

Regression lines were forced through the origin. Residuals from the model fit were plotted against fishing effort to inspect trends in catchabilities.

2.6 comparing individual vessel CPUE

Data on Dutch beamtrawl vessels were taken from the Dutch logbook information (VIRIS) which was available from 1990 to the first half of 1997 for the Dutch fleet. Data on landings by foreign vessels in the Netherlands were available for the years 1995 to mid 1997. Only trips with beamtrawl gear were selected for analysis. Trips where the summed catch of plaice and sole was less than the summed catch of all other species were discarded.

A second analysis was performed using data on flag vessels sailing under the UK flag and compared to the Dutch vessels. The UK flag data consisted of the years 1990 - 1996 and was based on fishing effort in days at sea.

The North Sea was subdivided into 7 areas (Figure A2. 1) reflecting the important fishing locations. Areas 1 to 3 signify the plaice box. Area 7 is the northern North Sea north of 55 deg. N where a meshsize of 100 mm is obligatory and where traditional plaice fishing grounds are found. The areas 4 to 6 are the central and southern North Sea where plaice and sole are caught in a mixed fishery. Vessels were grouped in two groups:

1. *Eurocutters*. Vessels with an engine power between 260 and 300 HP (about 160 Dutch vessels and 30 flag-vessels)
2. *Large vessels*. Vessels with an engine of more than 300 HP (about 210 Dutch vessels and 40 flag-vessels)

An ANOVA model was estimated to evaluate the impacts of different variables on the log CPUE:

$$logCPUE = constant + b_1 logH + b_{2,i,j} month_i * area_j + b_{3,i,j,k} flag_i * month_j * year_k$$

Where:

CPUE	Catch of plaice or sole divided by the days-at-sea
HP	Engine power of the vessel (continuous variable)
Month	January, February, ..., December
Area	Areas as given in Figure A2. 1.
Flag	Boolean; has value 0 if it is a Dutch beamtrawler and 1 if it is a flag vessel
month*area	The model is estimated for all months and all areas (12*7=84 coefficients)
flag*month*year	All groups, all months, and all years (gives 72 coefficients (2*12*3))

CPUE was expressed as catch per day-at-sea where days-at-sea were based on the total time away from port. Alternatively HP days were used as a measure of effort.

The variable *month*area* represents the period- and location effect. The coefficients of the *flag*month*year* variable indicate the differences in CPUE between Dutch beamtrawl vessels and flag vessels over time after filtering out the vessel category, period, and location effect. The relative (percentual) difference in CPUE can be calculated using the differences of the coefficients of flag*month*year:

$$\%diff = \frac{e^{b_{NL}}}{e^{b_{flag}}} - 1$$

A negative percentual difference indicates a higher CPUE for flag-vessels, a positive difference a higher CPUE for Dutch beamtrawl vessels.

2.7 assessing the effects of trends in catchability

Trends in catchability may affect results of stock assessment procedures. Two simple XSA runs are compared: one with only the NL beamtrawl index and the other with only the UK beamtrawl index for tuning. All other settings are the same as used in the assessment WG (ICES, 1998).

3 Results

3.1 Effort

Developments in fishing effort of the Dutch beamtrawl fleet are shown in Figure A2. 2. Two units are used to express effort: horsepower days (HPD) and standardized horsepower days (SHPD). The Dutch beamtrawl fleet started to develop in de mid 1960s. After an increase in the late 1970s, effort levels have remained relatively stable since the mid 1980s. The UK beamtrawl fleet started to develop in the mid 1980s (Figure A2. 3) and gradually replaced the traditional Seine fishery. An important part of the UK beamtrawl fleet consists of so-called flag-vessels, vessels sailing under the UK flag but with a Dutch owner and captain and a predominantly Dutch crew (Figure A2. 3).

3.2 Capacity

Total capacity for the Dutch beamtrawl fleet increased in the 1970s and 1980s. In the late 1980s the total capacity started to decrease, probably due to decommissioning programs (1987-1991 and 1992-1996). Figure A2. 4 shows the relationship between capacity and fishing effort for the Dutch beamtrawl fleet. When effort and capacity are expressed in normalized horsepower days, the recent years (1989-1996) show a stable effort level at declining capacity levels, which indicates no direct positive relationship between capacity and effort. When both variables are expressed as standardized horsepower units, the above mentioned phenomenon is less clear.

3.3 CPUE

Trends in CPUE for the Dutch fleet and UK fleets are shown in Figure A2. 5 and Figure A2. 6. In the calculation of the Dutch CPUE, it was assumed that all Dutch landings were taken in the beamtrawl fishery. This assumption is valid for the more recent years when the plaice and sole landings were predominantly taken by the beamtrawl fleet (up to 99% of the landings). In earlier years this assumption may be questioned.

If CPUE is taken as an indication of stock trends, the Dutch CPUE indicates a much stronger decline in the plaice stock, than the UK beamtrawl fleet or the UK flag vessel fleet. The difference in CPUE between fleets is further addressed in paragraph 3.6.

3.4 Partial fishing mortality

Partial fishing mortalities for the Dutch and the UK fleet are shown in Figure A2. 7. Relationships between fishing effort and partial fishing mortality are shown in Figure A2. 8. A strong decrease in partial fishing mortality generated by the Dutch beamtrawl fleet is visible with no observable relationship to the effort development. Estimation of a constant catchability parameter base on Dutch beamtrawl index is rather dubious, whereas the UK beamtrawl fleet seems to conform well to the assumption of linear catchability.

3.5 Trends in catchability

Trends in residuals of the fitted catchabilities against the effort, are shown in Figure A2. 9 and. A strong trend appears in the Dutch data series when effort is expressed as normalized horsepower days. If effort is expressed in standardized horsepower days no discernable trend remains. Residuals of the Dutch fleet are an order of magnitude larger than the residuals of the UK fleet.

3.6 Individual vessel CPUE

ANOVA analysis were performed on individual vessel CPUE for Dutch vessels as compared to foreign flag vessels landing in the Netherlands (1995-1997). Figure A2. 10 shows the percentual differences in CPUE for the large cutters (> 300 HP) and the Eurocutters (260-300 HP). All flag vessels have higher CPUE's for plaice and the difference between Dutch vessels and flag vessels seems to increase.

Additional ANOVA analyses were performed to compare the CPUE of Dutch beamtrawl vessels and UK flag-vessels. Results for vessels larger than 300 HP are presented in Figure A2. 11. In the years 1991 and 1992, higher CPUE's where realized by Dutch vessels. In 1993 to 1996 flag vessels were more efficient in catching plaice. The tendency for flag vessels to be more efficient seems to increase over the last years.

3.7 Assessments

Results of two example XSA assessments, one using only the NL CPUE series and the other using only the UK CPUE series for tuning, are presented in Figure A2. 12. The SSB difference between the 'UK assessment' over the 'NL assessment' is up to 29% in 1996.

4 Discussion

4.1 CPUE trends

Some trends in CPUE may well be disconnected from the developments of stocks. Processes like targetting (Biseau, 1998) or changes in the effectiveness in effort (REF) are likely causes of these processes. Furthermore, mesh size regulations and closed areas are likely to affect CPUE.

4.2 Capacity, effort and mortality

For management purposes the relationships between fleet capacity, effort and the generated fishing mortality are important. If fishing mortality is closely linked to fishing effort - the underlying hypothesis in many VPA models - then to reduce fishing mortality one has to reduce fishing effort. In the same manner, if fishing effort would be linked to the capacity of a fleet, this would enable the definition of capacity levels that would generate a certain agreed target fishing mortality. These relationships are however not as straightforward as mentioned above. Fishing capacity is like a wallet of money: one knows that one can spend it, but it is not yet sure what it is going to be spend on. Suppose, a certain capacity X is converted to an effort Y directed at species A. If for example quota on that species would be restricted, the same capacity X could rather be directed at species B, thereby creating a higher fishing mortality on species B and a lower fishing mortality on species A. Any fixed relationships between capacity, effort and fishing mortality are thus only to expected in periods when fishing patterns are stable.

A better insight into the relationship between fishing effort and fishing mortality may be obtained by using an independent index for the spatial distribution of the population, and then applying the known effort and catch distributions from the various fleets to estimate fishing mortality by fleet and area. For North Sea flatfish the quarterly IBTS data (1991-1996) are a suitable candidate to estimate the (relative) distributions of fish over rectangles.

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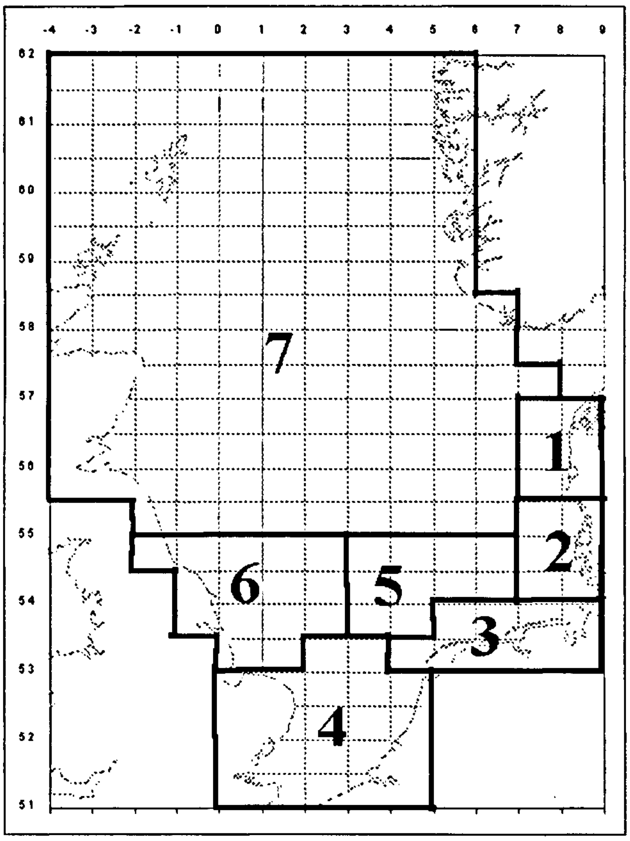

Figure A2. 1 Map of areas in the analysis
7 areas are distinguished in the analysis of CPUE.

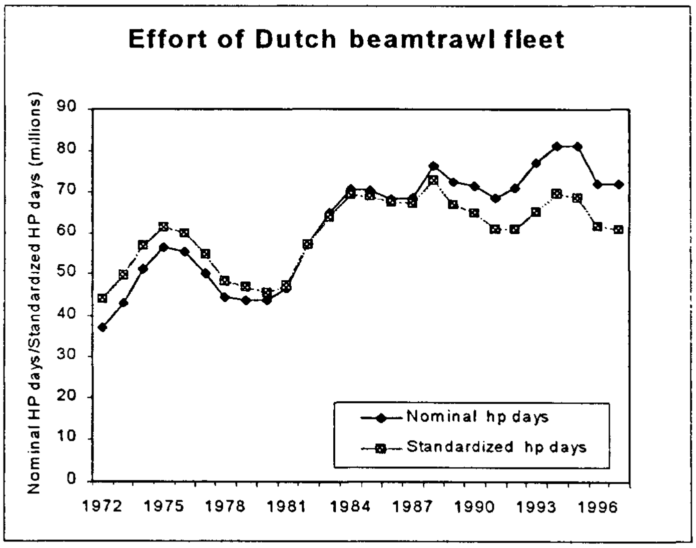

Figure A2. 2 NL beamtrawl fleet effort
Effort of the Dutch beamtrawl fleet in days-at-sea (DAS), HP days (HPD) and standardized HP days (SHPD).

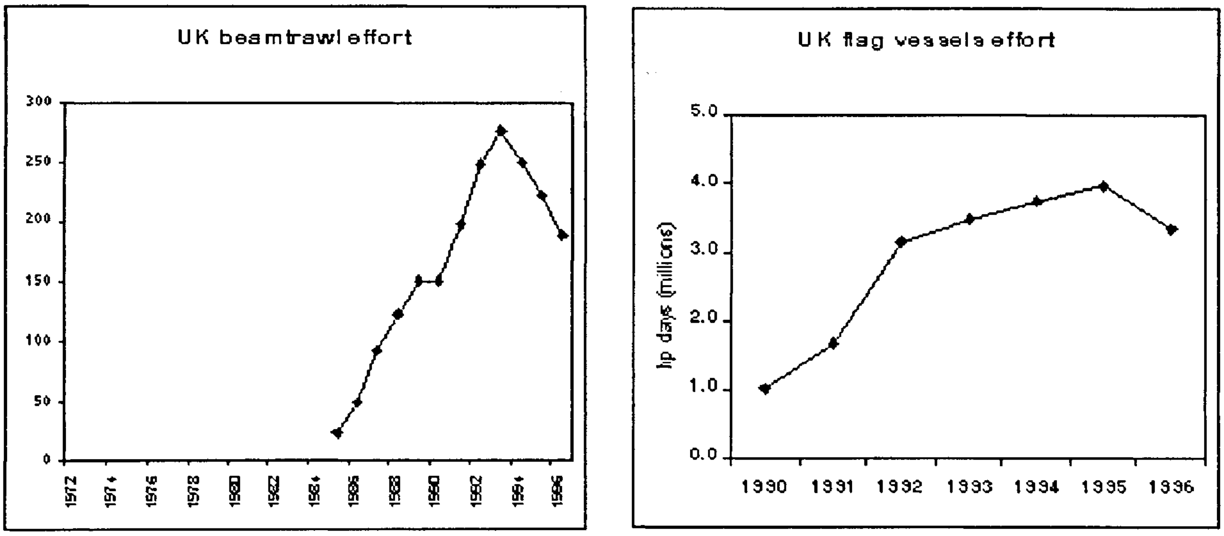

Figure A2. 3 UK beamtrawl effort and UK flag vessel effort
Effort of the UK beamtrawl fleet in HP hours (left) and UK flag vessels in HP days (right)

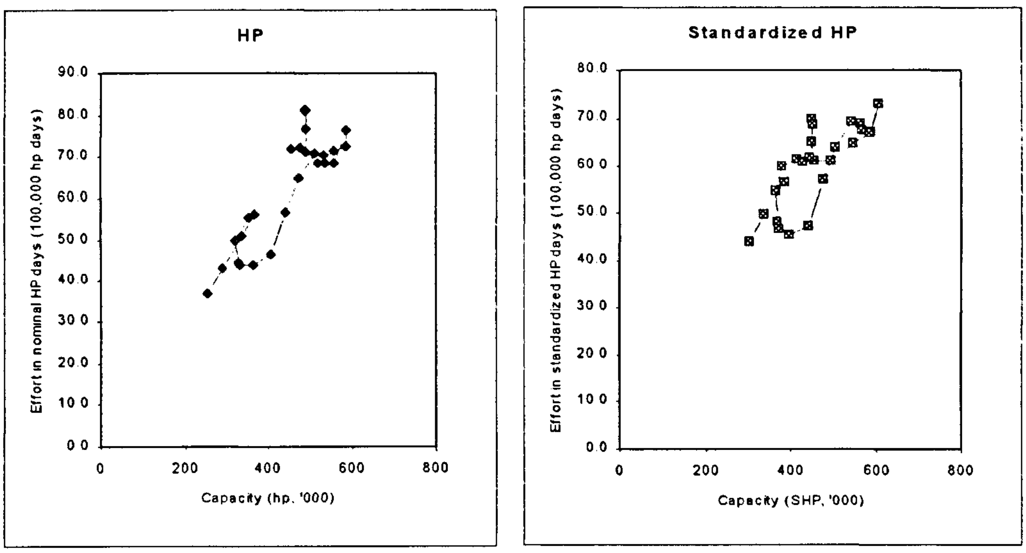

Figure A2. 4 Effort vs Capacity for the NL beamtrawl fleet
Effort vs capacity for the NL beamtrawl fleet expressed in horsepower units (HP, HPD) and standardized horsepower units (SHP, SHPD).

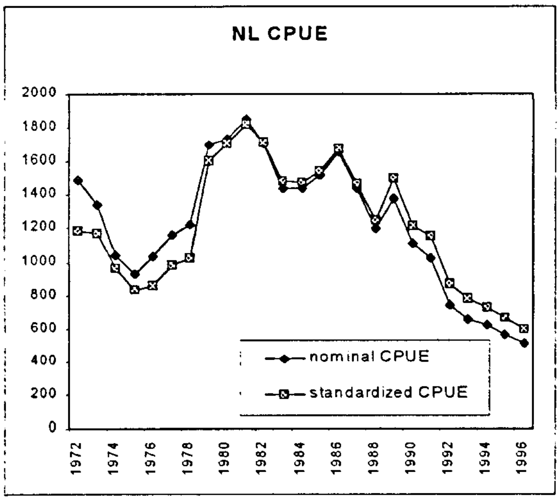

Figure A2. 5 NL plaice CPUE
NL plaice CPUE in catch per HP day (nominal CPUE) and Standardized HP day (standardized CPUE). Units: ??

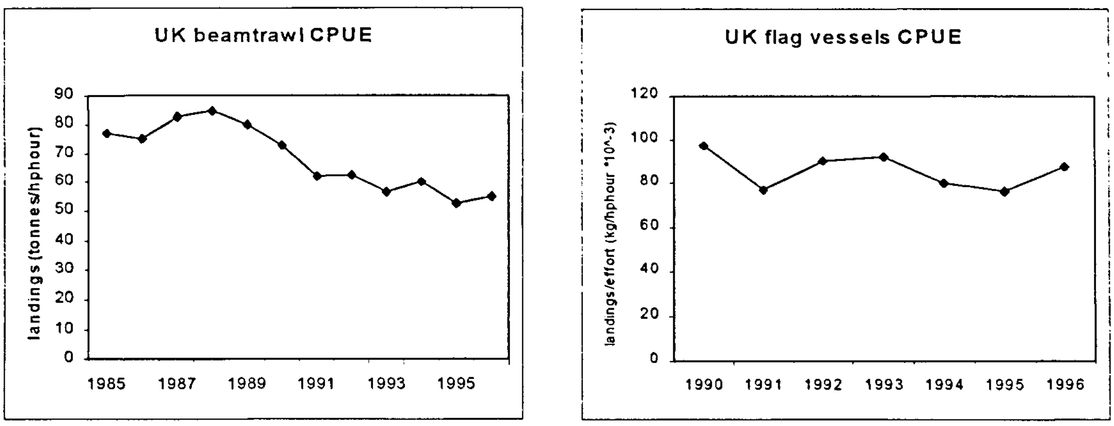

Figure A2. 6 UK plaice CPUE
UK plaice CPUE (left) and UK flag vessels CPUE (right) in landings per HP hour

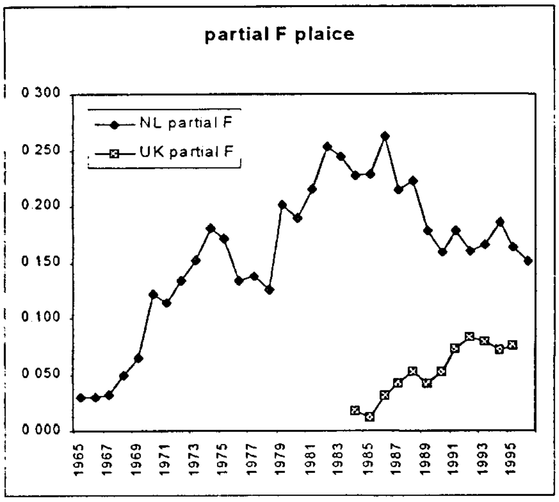

Figure A2. 7 Partial fishing mortality plaice
Partial plaice fishing mortalities generated by the NL beamtrawl fleet and the UK beamtrawl fleet.

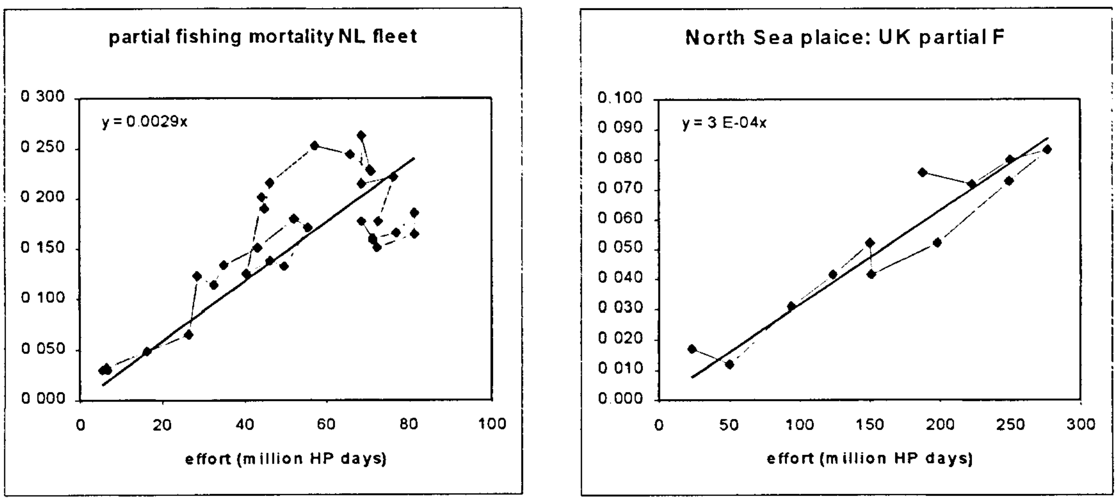

Figure A2. 8 Partial fishing mortality North Sea plaice plotted against effort.
Partial fishing mortality generated by the NL and UK beamtrawl fleet. Estimates of total fishing mortality derived from ICES (1998). Partial fishing mortality calculated over as the arithmetic average over the ages 2 - 10.

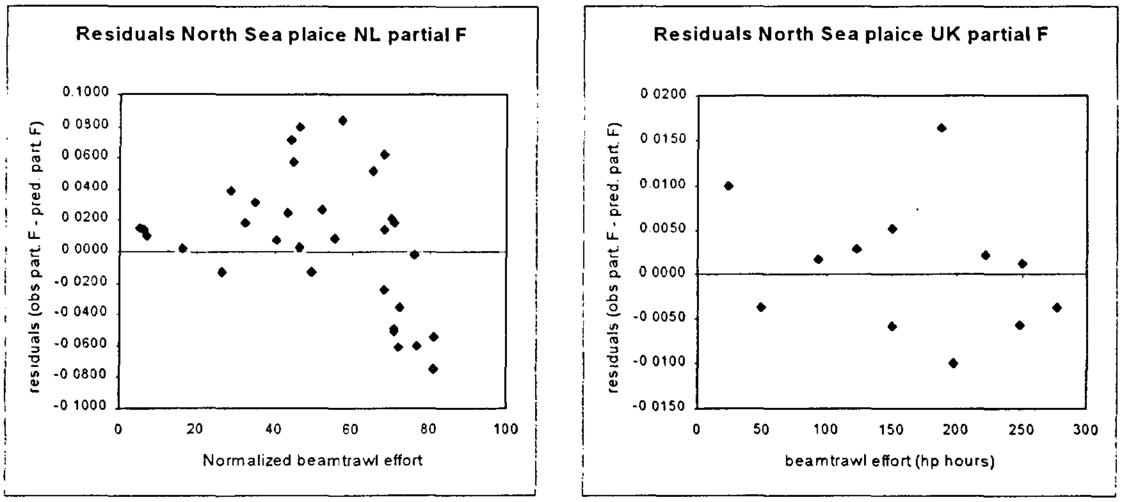

Figure A2. 9 Residuals of catchability estimates; NL and UK fleet
Residuals of the model fit (F=q*E) against beam trawl effort for the Dutch fleet (left) and the UK fleet (right).

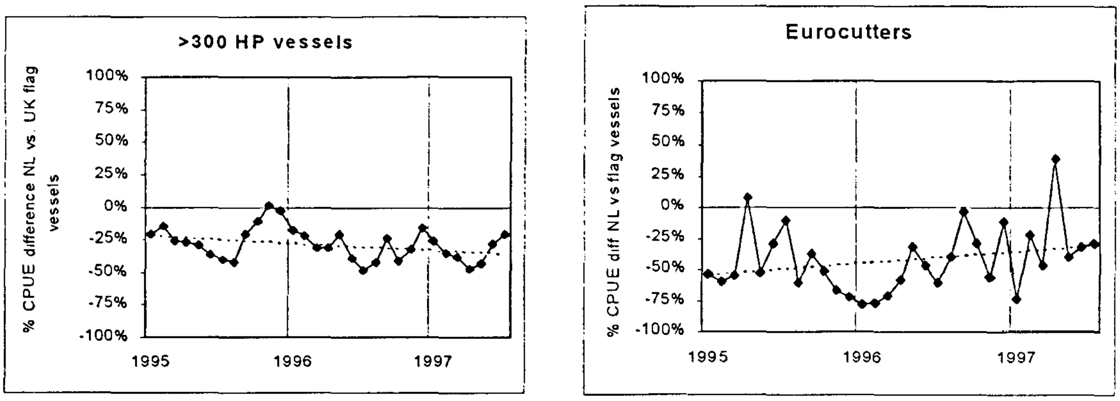

Figure A2. 10 Comparing Individual vessel CPUE; all flag vessels
Relative differences in plaice CPUE of NL vessels and flag-vessels in the period 1995 to mid 1997. Results from ANOVA model described in the text. A negative percentual difference indicates a lower CPUE for NL vessels.

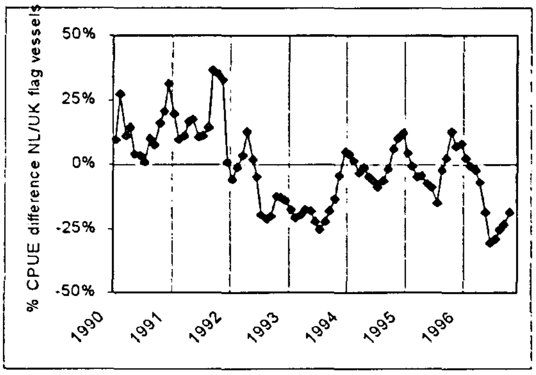

Figure A2. 11 Comparing Individual vessel CPUE; UK flag vessels only

Relative differences in plaice CPUE of NL vessels and UK flag-vessels (>300 HP) in the period 1990 to 1996. Results from ANOVA model described in the text. A negative percentual difference indicates a lower CPUE for NL vessels.

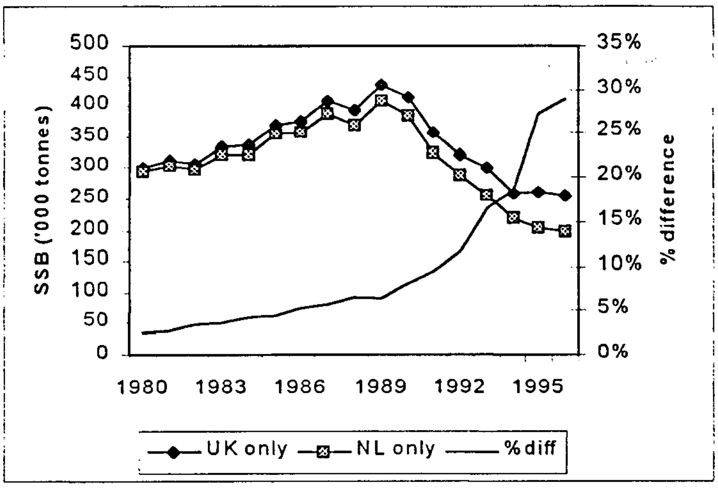

Figure A2. 12 Plaice SSB when tuned with either NL of UK CPUE only
SSB results from XSA tuned with either the NL fleet only or the UK fleet only. Percentage difference of UK tuned XSA to NL tuned XSA indicated on the right hand axis.

Annex 3

THE ESTIMATION OF MORTALITY DUE TO PASSAGE THROUGH FISHING GEARS

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Introduction

Traditional stock assessments within ICES assume that all fish passing through a towed gear survive. Experiments in recent years have shown that at least some fish do not survive the rigours of the capture process even if they ultimately escape from the gear. Some experiments indicate that this survival may be low depending on the size and age of the fish. If the survival is low there may be important implications for current assessments since they will tend to underestimate fishing mortality and stock size. Furthermore, such assessments may result in biassed estimates of biological reference points and misleading calculations on the benefits of changes in mesh size.

To date experiments on survival have been limited to examining the proportion of fish which die after escaping from the gear. In order to make use of this information in the assessment arena, these data need to be translated into a mortality rate. This paper proposes a simple method for such a calculation and illustrates its use in North Sea haddock assessments.

Theory

The following analysis is based on a method proposed by Mesnil (1996). A schematic diagram of the theory is given in Figure A3. 1.

Let G be the number of fish entering the codend. Of these a proportion p_r are retained and brought aboard. If the number of fish brought aboard is Y, then;

$$Y=p_r G \tag{1}$$

Now suppose that of these Y fish a proportion p_l are retained and landed while the remainder are discarded. The landings, L and the discards, D, can be expressed as;

$$L=p_l Y \tag{2}$$

and

$$D=(1-p_l)Y \tag{3}$$

Suppose that some of the fish which pass through the codend do not survive. If survival rate of these escaping fish is s_e, then the unseen deaths of fish which passed through the codend and subsequently died is given by;

$$G(1-p_r)(1-s_e) \tag{4}$$

or

$$Y(1-p_r)(1-s_e)/p_r \tag{5}$$

Of the fish which are discarded, some may survive. Let this survival rate be s_d. This means some of the catch Y is returned to the sea alive. We wish to know the total number of fish which die due to fishing. These are called the removals, R, and is the sum of the landings, the discards which do not survive and the codend escapees which die, ie;

$$R=L+D(1-s_d)+G(1-p_r)(1-s_e) \tag{6}$$

Substituting for L and D using the expressions above, and re- arranging leads to the formula for R;

$$R=Y(1-s_d\ (1-p_l)+(1-p_r)(1-s_e)/p_r) \tag{7}$$

and writing

$$U=(1-s_d\ (1-p_l)+(1-p_r)(1-s_e)/p_r) \tag{8}$$

we have:

$$R=UY \tag{9}$$

where U is a correction factor to convert the fish observed on deck (but before discarding) into total removals due to fishing. An important limitation is that U can only be calculated for those length groups of fish which are actually measured on deck, since C is never observed. However, the method should provide a bias correction for most of the length range.

Estimation of escape mortality

There is a well established theory of catch at age analysis for the transformation of estimates of catch (or landings) at age into estimates of fishing mortality, F, and population numbers in the sea, N (eg Darby and Flatman, 1994). This theory is based on solving the Baranov catch equation;

$$C_a=\frac{F_a}{Z_a}N_a(1-e^{Z_a}) \tag{10}$$

where C is the catch in number, Z is the total mortality and a is the subscript for age. In normal usage, C refers to the landings or landings plus discards and F is the mortality rate resulting from C. If C is an under estimate of the number of deaths due to fishing then the use of equation **(10)** will lead to biassed estimates of fishing mortality. This problem can be rectified by correcting the catch using equation (9) and leads to the analogous equation:

$$R_a = \frac{F_a'}{Z_a} N_a (1 - e^{Z_a}) \qquad \textbf{(11)}$$

where F′ is the total mortality due to fishing including that caused by passage through the gear. This equation can be used in the normal catch at age analysis in order to calculate Z and N. Given Z and N, equation **(10)** can be used to calculate F. The unaccounted mortality, or escape mortality due to passage through the gear, F_e, is then simply:

$$F_{ea} = F_a' - F_a \qquad \textbf{(12)}$$

In order to make use of the theory outlined above within the framework of conventional catch at age analysis it is necessary to be able to estimate U_a and correct the observed catch to obtain an estimate of the removals. This in turn requires estimates of p_r, p_l, s_e and s_d. For convenience these can be modelled as age dependent ogives using standard two parameter curves typically used to describe cod-end selectivity. Thus we have ogives defined as follows:

for gear selectivity;

$$p_{ra} = \frac{1}{1 + 3^{2(GA_{50} - a)/GSR}} \qquad \textbf{(13)}$$

for proportion of catch landed;

$$p_{la} = \frac{1}{1 + 3^{2(LA_{50} - a)/LSR}} \qquad \textbf{(14)}$$

for proportion of escapees surviving;

$$s_{ea} = \frac{1}{1 + 3^{2(EA_{50} - a)/ESR}} \qquad \textbf{(15)}$$

and for the proportion of discards surviving;

$$s_{da} = \frac{1}{1 + 3^{2(DA_{50} - a)/DSR}} \qquad \textbf{(16)}$$

In each case the A_{50} parameter is the age where the proportion is 0.5 and SR is the parameter corresponding to the age range over which the proportion increases from 0.25 to 0.75. Estimates of these parameters will usually have to be obtained from independent field measurements.

An example: North Sea haddock

For illustration the model described above has been used to make a preliminary estimate of the escape mortality rate for North Sea haddock mainly because more of the required data exist for this stock than any other. The essential inputs required are the standard stock assessment data and parameter estimates for equations **(13)** to **(16)**. For the illustration presented here guesstimates of the relevant parameters were made as follows (Table A3. 1).

Gear selectivity. Since most haddock are caught in seines and trawls by Scottish

Table A3.1. Parameter values used to specify ogives.

Gear selection	GA50	2	GSR	3
Catch retention	LA50	2	LSR	1
Escape survival	EA50	2.7	ESR	3
Discard survival	DA50	20	DSR	1

vessels, selectivity parameters were loosely chosen on the basis of Scottish experimental data. These suggest a GA_{50} of about age 2 with a range of three years.

Catch retention. Approximations to the parameters were obtained by examining the age compositions of Scottish landings with those of the discards age compositions.

Escape survival. Examination of Scottish survival data from field experiments was used to get a rough idea of survival at age.

Discard survival. It was assumed that no discarded fish survive. Parameters were chosen to give a zero proportion at all ages.

The ogives defined in this way are shown in Figure A3. 2.

Input catch data which correspond to landings were obtained from the ICES stock assessment database. These data were used in conjunction with parameters in Table 1 to construct a removals matrix and perform a conventional VPA. The VPA was initiated using standard ICES working group inputs. The starting values of F used in this way will of course be biassed because they are based on analyses which do not take into account gear related deaths. However, the convergence rate of the VPA is rapid and the calculated Fs for the historical period should be unaffected by this problem.

For comparative purposes two analyses were performed. Firstly a run was made using the parameter values given in Table 1. This run assumes that some of the fish passing through the gear die. Secondly a run was made making the conventional assumption that all fish escaping from the gear survive. This run is close to the typical ICES assessment.

Results

Figure A3. 3 shows the estimated fishing mortalities by age from the two analyses. Not surprisingly the mortality on young fish increases when it is assumed gear escapes are subject to mortality. This mortality peaks at age 2 and represents about 40% of the mortality due to fishing at that age. The total mortality between the two runs is not as large as might be expected on the basis of the calculated escape mortality. The difference age 2 is only about 20%.

Figure A3. 4 shows the difference in the estimates of the number of age 1 fish between the two runs. As expected, when it is assumed that some escapes die, the population number increases. However, there are no important differences in the trends.

Taking account of gear deaths has an impact on the fishing mortality pattern by age. This might be expected to affect the calculation of equilibrium yield and certain related biological reference points.

A yield per recruit analysis was performed on each of the two runs to investigate this. Figures A3. 5 and A3. 6 show the results obtained. Including the effects of gear deaths leads to lower estimates of Fmax and a more "peaked" yield per recruit curve. The value of the maximum yield per recruit is also lower when gear deaths are included. However, this does not mean that average yields would be lower because the average value of recruitment is higher in this analysis.

Discussion and conclusions

The analysis in this paper has been performed primarily for illustration and improved parameter estimates for escape survival would be required before the results can be taken seriously. On the assumption that the chosen parameter values are reasonably realistic then some tentative conclusions can be made:

1. Escape mortality can be moderate for the youngest fish and suggests that conventional estimates of F at the younger ages may be biassed downward by about 20%.

2. For haddock, at least, the inclusion of gear related deaths in the assessment does not make a major change to the perception of the state of the stock either in terms of stock trends or conventional biological reference points.

An important analysis which needs to be done is to investigate how escape survival affects traditional mesh assessments. It might be expected that such an analysis would show that increasing the mesh size in a fishery has smaller beneficial effects than otherwise expected. In order to perform such an analysis, the effect of increasing mesh size on survival needs to be quantified.

References

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Darby, C.D. and Flatman, S. 1994. Virtual Population Analysis: version 3.1 (windows/Dos) user guide. MAFF Information Technology Series No. 1. Directorate of Fisheries Research, Lowestoft, 85pp.

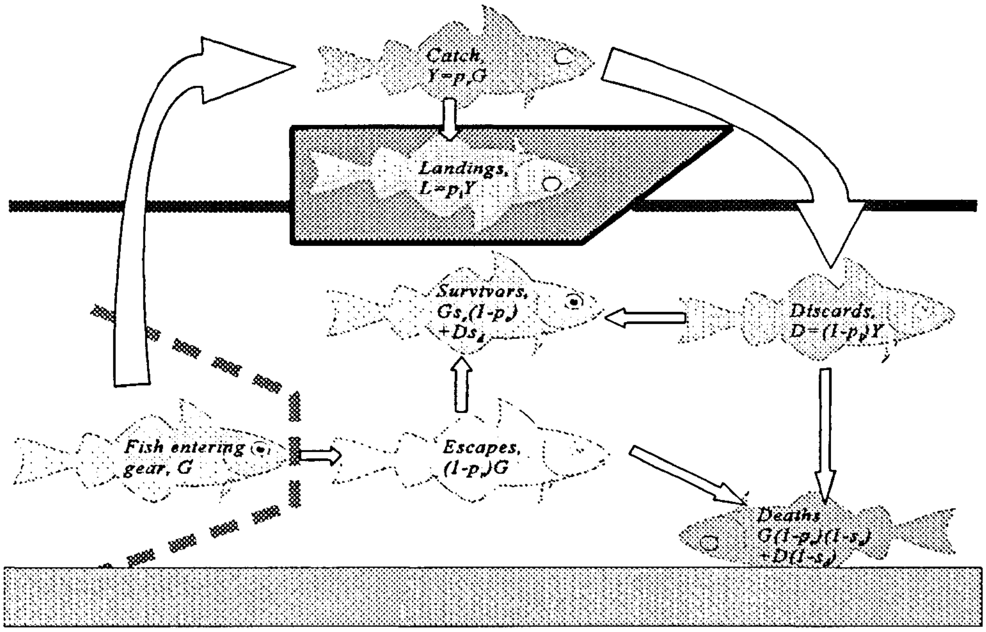

Figure A3. 1. Diagram showing the fate of fish after entering a fishing gear and how these may be partitioned between survivors and deaths. In order to calculate unbiassed estimates of fishing mortality, all deaths resulting from fishing activity must be accounted for.

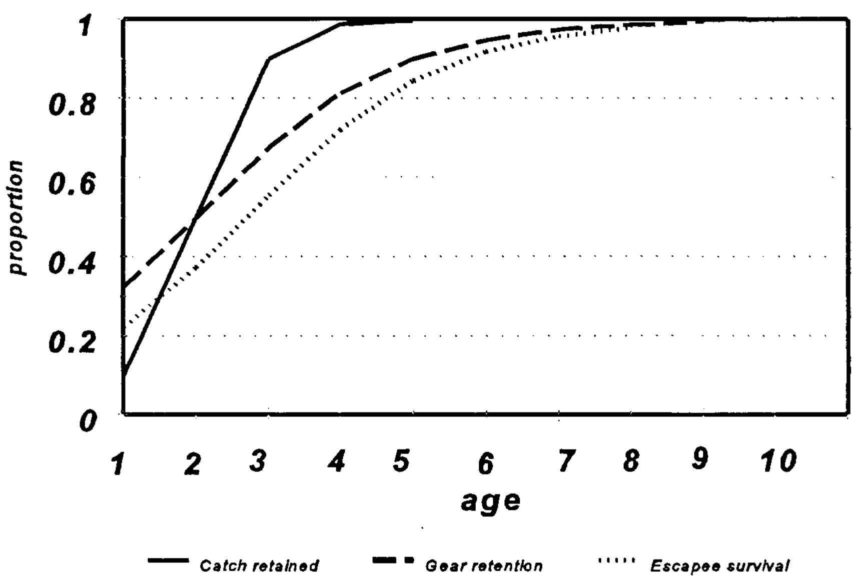

Fig.A3. 2. Ogives giving (a) the proportion of the catch retained as landings, (b) the proportion of fish entering the gear which are retained and (c) the proportion of fish escaping the gear which survive.

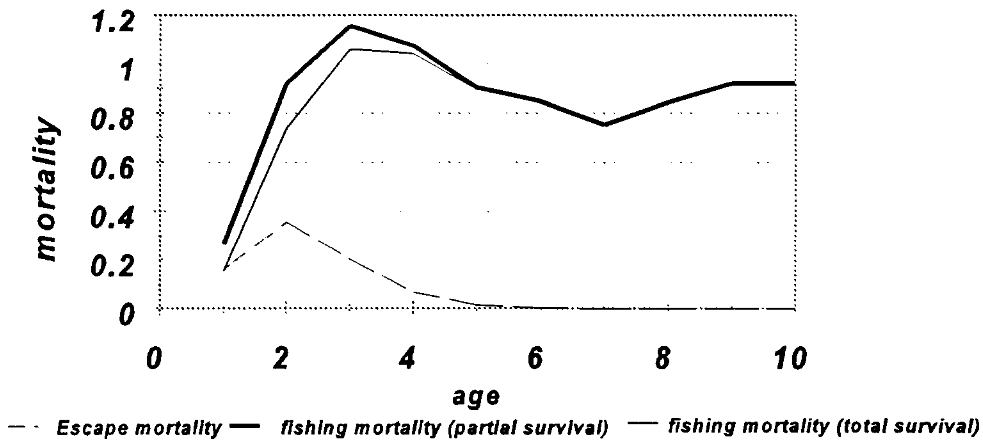

Fig. A3. 3. Estimates of fishing mortality.

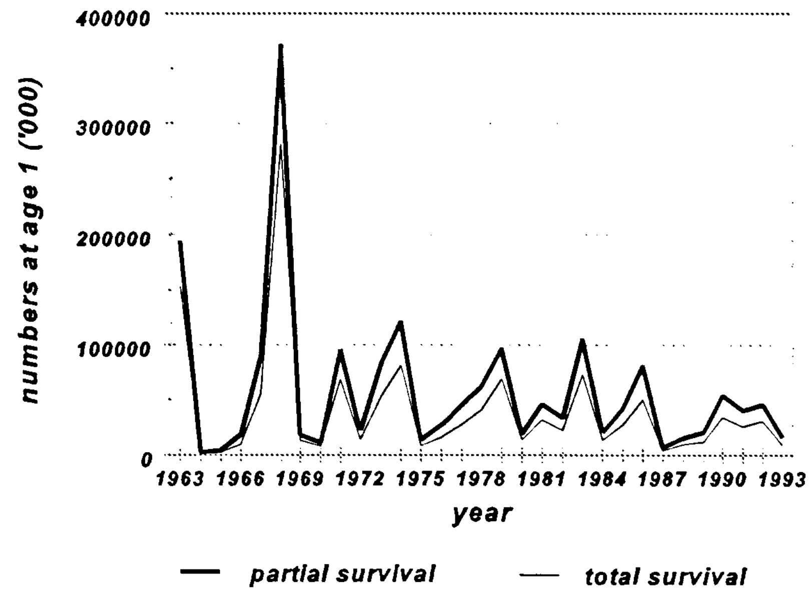

Fig. A3.4. Trends in recruitment at age 1 estimated from the two runs.

Fig. A3.5 North Sea Haddock: Yield per Recruit (partial survival)

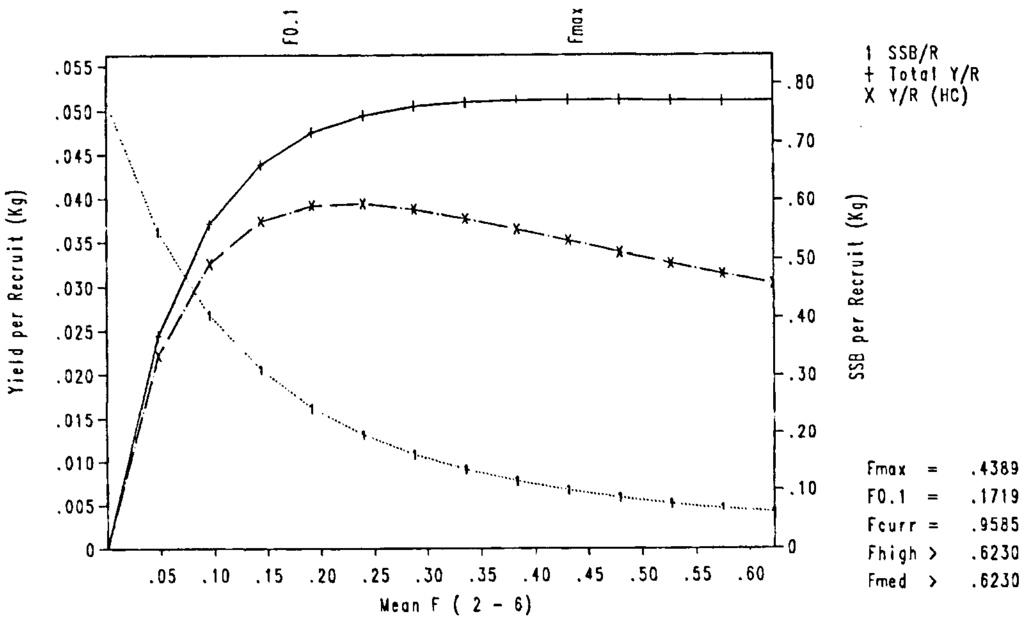

Fig. A3.6 North Sea Haddock: Yield per Recruit (total survival)