Northwest Atlantic Fisheries Organization

Serial No. N2302 NAFO SCR Doc. 93/109

SCIENTIFIC COUNCIL MEETING - SEPTEMBER 1993

[1]Estimating Discards Using Selectivity Data: the Effects of Mesh Size Changes in the Mixed Demersal Fisheries in the Irish Sea.

by

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Gear Selectivity/Technical Interactions Symposium

Abstract

A model is described to predict the numbers at age of fish discarded in fisheries for which only landings at age are known. The model assumes a knowledge of the distribution of length within each age group in the population, and uses mesh selection characteristics, and an inferred discarding practice, to derive the proportions of each age group discarded and landed. Mesh selectivity and discarding practice, in terms of proportions of the catch discarded and landed, are described using a logistic fit to the proportions of the population entering the net that are caught, discarded and landed. The application of the model is illustrated using data from the mixed demersal fisheries in the Irish Sea, and the effects of mesh size and effort changes on catch predictions are examined.

Introduction

Catches of finfish in the Irish Sea are dominated by four main species; the common sole (*Solea solea* (Linnaeus, 1758)), plaice (*Pleuronectes platessa* Linnaeus, 1758), cod (*Gadus morhua* Linnaeus, 1758) and whiting (*Merlangius merlangus* (Linnaeus, 1758)). The demersal fishery for these species in the Irish Sea is prosecuted by 3 main fleets, each using a different gear type; beam trawlers, otter trawlers and *Nephrops* trawlers. Each fleet targets a different group of species; beam trawlers target flatfish, otter trawlers target gadiods and as the name suggests, *Nephrops* trawlers target Norway lobster (*Nephrops norvegicus* (Linnaeus, 1758)). However, all three main fleets catch each of the four main finfish species in varying amounts.

Annual single species assessments for each of these stocks are carried out by the International Council for the Exploration of the Sea (ICES). The methodology used is tuned Virtual Population Analysis (VPA), which is based on fitting a time series of catch per unit of effort at age data (CPUE), to catches at age from the fishery (Pope and Shepherd, 1988). Reliable estimates of catch at age data are fundamental to VPA. Catches from the fishery comprise both landings and discards, the latter being fish which are caught but are not landed for sale. In some fisheries discards are monitored on a regular basis, but the collection of such data is extremely costly, both in time and money. For the Irish Sea fisheries, landings are routinely monitored and sampled for age composition, but information on the numbers of fish discarded is generally lacking, and for each of these main species, with the exception of whiting, no estimates of discards are available. For whiting, discarding is monitored only in the fishery which targets Norway lobster. The proportions of each age group discarded in this fishery are applied to the other fisheries' landings of *Nephrops* to give estimates of catches of whiting. As a result, ICES assessments for Irish Sea stocks using VPA, have largely been carried out using landings data alone, and as discarding may account for a significant proportion of the fishing mortality (F) on certain age groups of some species, the estimates of F and the initial population sizes of such age groups will be in error.

This paper sets out to describe a method of estimating the likely level of discarding in fisheries for which no observed discard data are available. The method is illustrated using data from the mixed fishery for sole, plaice, cod and whiting in the Irish Sea. Estimates of discards are made using a selectivity model, and the revised catch at age data are used to provide alternative assessments using VPA. In all assessments and predictions presented here, it has been assumed that all discarded fish die, and that all fish escaping the meshes survive. The results are compared with those carried out by ICES and short-term, multiple-species, multiple-fleet catch predictions involving mesh size changes, are presented. The long term effect of mesh size changes, in terms of yield per recruit are also examined.

Methods and Data

The Model

The model utilises landings at age data from the fishery for each species, together with species-specific mesh selectivity parameters, and assumes that the distributions of length at age in the population is known or can be inferred.

Distribution of length at age in the population

The distribution of length within each age group in the population for a given time period (e.g. year, month, season) may be obtained by direct observation from research vessel surveys or may be described as normal distributions with mean length at age μ_a, and standard deviation σ_a. Writing the normal density function:

$$\phi a(l) = \frac{1}{\sigma a\sqrt{2\pi}} e\left[-\frac{1}{2}\left\{\frac{(\bar{l}-\mu a)}{\sigma a}\right\}^2\right] \qquad 1$$

The proportion of the population of age a in the length range $(l, l+\Delta l)$ is given approximately by

$$Pa(l) = \phi a(\bar{l}) \times \Delta l \qquad 2$$

where $\bar{l}$ is the mean length in the l'th length group.

In practice, $\bar{l} = l + \frac{1}{2}\Delta l$,

and we set $Pa(l) = 0$ for $\bar{l} \notin (\mu a \pm 3\sigma a)$

Mesh selectivity

For a given species, the proportions of each length group of fish entering the net which are retained by a given mesh may be described using a logistic curve defined using species-specific selection factors (L_{50} and L_{25}) as follows:

$$Sa(l) = \{[3^{\{(L_{50}-\bar{l})/(L_{50}-L_{25})\}}] + 1\}^{-1} \qquad 3$$

where $Sa(l)$ is the proportion of population at age a in length group (l) entering the net that is retained by the meshes

L_{50} is the the length at which 50% of the fish entering the net are retained by the meshes

L_{25} is the length at which 25% of the fish entering the net are retained by the meshes

Estimating catch at age

Given the length distribution at age in the sea, and the selection characteristics of the gears used to exploit the population, and assuming all age/length groups are equally succeptible to exploitation i.e. available for capture, the proportion of each age group entering the gears that is caught (Pc_a)*is simply the sum over all lengths within an age group*, of the product of the proportions at length retained by the mesh, and the proportions at length available for capture (P(*l*,*a*)), as follows:

$$Pc_a = \sum Sa(l) \times P(l,a) \qquad 4$$

Discarding practice.

For some species and fisheries, there are data available on discarding practice. In such cases, the proportions at each length retained and discarded is usually based on observations made at sea. In the absence of any information on the discarding practice, we assume that the primary reason for discarding fish which are caught, is to comply with minimum landing size regulations. For some species, particularly those with a high market value, virtually all fish above the legal minimum landing size will be retained for sale, whereas those below the minimum permissible landing size will not appear in the declared landings. Whether such fish are returned to the sea, or landed illegally, they still account for unknown fishing mortality and, in principle, should be included in any assessment. In practice, it is unlikely that the sorting procedure on board vessels will result in knife-edge discarding at the minimum landing size; some undersized fish will be landed to the market and invariably some oversize fish will be discarded. As a result we have assumed that a sorting ogive may be used to describe the discarding practice, in the same way as for mesh selection as follows:

$$PL(l) = \left\{\left[3^{(DL_{50}-\bar{l})/(DL_{50}-DL_{25})}\right]+1\right\}^{-1} \qquad 5$$

where $PL(l)$ is the proportion of the catch of length group (l) that is retained and landed

DL_{50} - denotes the length at which 50% of the fish caught are retained and landed and is assumed to be the minimum landing size.

$$DL_{25} = \frac{1}{2}(0.1 \times DL_{50})$$

and denotes the length at which 25% of the fish caught are retained and landed

The proportion of fish at length (l), which are caught and discarded (PD(l)) is then given by

$$PD(l) = 1 - PL(l) \qquad 6$$

Estimating Catch numbers.

Using equations 3, 5 and 6, we can estimate the proportions of each age group caught, that are landed and discarded. The proportion of the catch of each age group that is landed ($PL(a)$), is the sum over all length groups within that age group, of the product of the proportion at each length retained by the gearsof those entering the net and the proportion at each length landed. Hence:

$$PL(a) = \sum Sa(l) \times PL(l) \qquad 7$$

and the number caught ($CN_{(a)}$) are related to the number landed ($NL_{(a)}$) as follows:

$$CN(a) = NL(a) \times \frac{1}{PL(a)} \qquad 8$$

The number discarded at age is given by

$$DN(a) = CN(a) - NL(a) \qquad 9$$

Hence for a species, given the landings in number at age, the mesh selectivity parameters and an estimate of discarding practice, it is possible to derive estimates of the catch in numbers at age (Equation 8, via 7, 5 and 3).

Alternatively, if the distribution of numbers of length at age of the landings is known (NL(l,a), the catch at age data may be estimated by multiplying the landings numbers at length by the reciprocal of the proportions landed at length ($PL_{(l)}$) from equation 5, and summing over all length groups within each age group; i.e.

$$CN(a) = \sum (NL(l,a) / PL(l))$$

It also follows that if the length distributions of the catch at age data are known, then landings and discards at each length and age may be estimated using the respective proportions landed and discarded from equations 5 and 6.

Calculation of mean weight at age in the catches.

In addition to providing estimates of the proportions of the catch landed and discarded, the mean weight of landings, discards and catch may also be calculated. Mean weight at age in the catch ($\overline{W}C_{(a)}$)is calculated using:

$$\overline{W}C(a) = \frac{\sum Sa(l) \times W(\bar{l})}{\sum Sa(l)}$$

where $W(\bar{l})$ = mean weight of length group l.

Similarly mean weight at age in the landings ($\overline{W}L(a)$)is obtained from:

$$\overline{W}L(a) = \frac{\sum PL(l) \times Sa(l) \times W(\bar{l})}{\sum PL(l) \times Sa(l)}$$

and mean weight at age of discards ($\overline{W}D(a)$) is

$$\overline{W}D(a) = \frac{\sum PD(l) \times Sa(l) \times W(\bar{l})}{\sum PD(l) \times Sa(l)}$$

Effect of changes in mesh size

In all assessments and predictions carried out, all discards are assumed to die and all escapees from the nets are assumed to survive. Given fishing mortality at age (exploitation pattern) by fleet, for mesh sizes currently in use, new exploitation patterns may be calculated for a change in mesh size. This may be done using the selectivity model to estimate the proportions of each age group that enter the net that are caught for the new mesh size(equation 4). Dividing the new proportion caught at age by the proportions caught at age using the current mesh, we obtain a selection ratio which is applied to the fishing mortality at age for the current mesh to give an exploitation pattern for the new mesh size. In a multiple fleet fishery, where each fleet may be using a different mesh size, the effects on the fishing mortality rate generated by different fleets changing to new mesh sizes may be modelled.

Application of the model

All basic data for the assessments and predictions relate to years prior to and including 1989. For each species, landings at age from the Irish Sea fisheries were obtained from the 1990 Report of the ICES Irish Sea and Bristol Channel Working Group (Anon., 1990). International landings at age data for 1989 were partitioned into landings at age by fleet according to estimates provided by working group members. Where fleet disaggregated landings numbers at age were not available, estimates were derived using the landings at age composition for the most similar fleet, and raised to the relevant landings weight. Since estimates of fleet disaggregated landings at age data were available for 1989 only, the relative proportions of each age group caught by the different fleets were then used to partition the international landings at age data for years prior to 1989.

The 1989 landings at age data were converted to catches at age using the results of the selectivity model described above, where distribution of length at age in the sea for each stock was described as follows:

For age groups considered to be fully selected by the Irish Sea fleets, mean length at age in the population was calculated from mean weights at age in the catches given in Anon. (1990) and converted to length using published length-weight relationships (Bedford *et al.*, 1989). Normal distributions of length at age were described using the normal disrtibution function described above (equation 2), setting standard deviation of length at age equal to 10% of mean length. For partially selected age groups, mean and standard deviation of length at age were obtained from English research vessel sampling in the Irish Sea (D. J. Symonds, *pers. comm.*), and distribution of length at age was described using these parameters and the normal distribution function. The assumed mean lengths at age in the populations used are given in Table 1.

Proportions of each age group of each species species enterning the nets that are caught by each fleet were estimated using the estimated distributions of length at age in the population derived from means and standard deviations given in Table 1, together with mesh sizes in use in 1989 and appropriate selectivity parameters(Table 2). Selectivity parameters are those given by Wileman (1988). The distribution of size at age in the populations is assumed to remain constant from year to year, hence the proportions of each age group entering the nets that are caught also remains constant. Similarly constant proportions of those fish caught are assumed to be landed and discarded. Using the assumed discarding practice for each species, proportions landed and discarded were calculated.

For each year that landings by age data were available, the numbers at age landed by species were raised to numbers caught using equation 8. These data were then used as input to VPA. Fleet data used to tune each of the VPA's was also treated in the same way, with the landings numbers being raised by the appropriate proportions landed for the mesh size used by the tuning fleets. Whiting were treated rather differently since estimates of discards were included in the VPA input tables in the ICES report (Anon., 1990). The catch at age data were first converted to landings at age by subtracting the estimated discards provided in the ICES report from the catches. New estimates of discards were then calculated using the results of the selectivity model.

For each stock, with the exception of whiting, VPA using the revised catch at age data, was carried out in exactly the same way as in the ICES assessments. For whiting the input catch at age range was reduced to exclude 0-group catches, and two assessments were made; one using the catch estimates provided in the ICES report, and a second using the revised catch estimates resulting from the selectivity model. This was necessary since no 0-group whiting are reported as being landed in the ICES report and as a result, no estimate of catch can be made using the selectivity model.

Long-term catch predictions were carried out to compare the results of the revised assessments with those made by ICES, and to investigate the long term effects of mesh size changes. The predictions were expressed in terms of yield-per-recruit (Beverton and Holt, 1957).However, the application of the yield-per-recruit method was modified to take into account changes in mean weight in the catches associated with changes in mesh size, and to permit the yield to be expressed both in terms of landings and discards. For each stock, predictions were made using both the ICES assessment result and the revised assessment result. In each case, stock in numbers and fishing mortality at age in the starting year (1990) were derived from the relevant VPA.

For consistency in making comparisons, in each case, numbers of recruits were taken as the geometric mean recruitment between the 1st year included in the assessment up to 1987. Stock size of the next oldest age group was assumed to be the geometric mean recruitment reduced by the total mortality rate on the recruiting age group. Stock sizes for all other age groups were taken directly from VPA. Fishing mortalities at age were the mean values over the period 1987-1989, scaled to the reference fishing mortality over a specified age range in 1989. These values were partitioned into fishing mortalities at age by fleet using the respective catches at age in 1989. Furthermore these were also partitioned into fishing mortality due to landings and to discards, using the relevant proportions landed and discarded by each fleet.

Predictions involving increases in minimum mesh size to 80mm and 90mm for all fleets were considered. For each mesh size change, the total fishing mortalities at age by fleet (landings mortality + discard mortality) were reduced by the appropriate selection ratios for different mesh sizes. These new mortalities were then partitioned into landings and discards mortalities on the basis of the new estimates of the proportions of the catches landed and discarded. The fishing mortality rates were then summed across fleets to give new total mortality rates for landings and discards.

Short-term catch predictions were carried out using a multiple species, multiple fleet prediction programme (MSFP; B. Mesnil, *pers. comm.*). The starting parameters were the same as for the yield-per-recruit analyses, except that predictions involving the effects of mesh changes are only compared to predictions carried out using the results of the revised assessments. The predictions were carried forward on an annual basis from the years 1990 to 2000, assuming geometric mean recruitment at the start of each year. Predictions for each species included estimates of fishing mortality for six fleets. The three "real" fleets were given exploitation patterns corresponding to fishing mortality at age for landings, and three "ghost" fleets which accounted for the fishing mortality due to discards. In this way, the landings and discards could be modelled separately.

Results

Estimates of the proportions at age of each species landed and discarded for mesh sizes in use in 1989 from the mesh selection model are given in Table 3. Corresponding values for all fleets using 80mm and 90mm mesh sizes are given in Table 4. The results of applying the selection model to data for cod indicated that no discarding of cod of age 1 to 7 should occur with a minimum landing size of 35cm. Consequently the ICES assessment was not revised.

Assessments

The results of the VPA runs using the revised catch at age data from the selectivity model together with those of the ICES assessments are illustrated in Figures 1 to 3. Results for cod are not presented since these remain unchanged from the original ICES assessment (Anon., 1990). Presentation of the results has been restricted to comparisons between trends in mean fishing mortality over specific age ranges (reference F), spawning stock biomass (SSB), recruitment and mean fishing mortality at age over the period 1987-1989 (mean F). For sole (Figure 1) and whiting (Figure 3) the trends in reference F, SSB and recruitment are essentially the same for both the ICES and the revised assessment, each being slightly higher in the revised assessment. The results for plaice (Figure 2) are similar, except that recruitment for the years 1977 and 1989 appear significantly higher in the revised assessment than in the ICES assessment. The 1989 values for recruitment are of course poorly defined in the VPA, which may explain this discrepancy. The 1977 value is a result of the extermely high catch numbers of 1 year old plaice in that year (an order of magnitude greater than the next highest observed catches of 1-groups), which was not reflected in the catch of the 1976 year class as 2 year olds in 1978. Examination of the mean exploitation patterns for each species indicates that for sole (Figure 1d), the effect of including discard estimates in the assessment is relatively small, but that mean fishing mortality on age 2 to 4 is slightly increased. For whiting, (Figure 3d), it appears that mean F on age group 1 is increased in the revised assessment wheras, for age group 2, there appears to be a slight reduction in mean F compared to the ICES assessment. The results of the revised VPA on the mean exploitation pattern for plaice (Figure 2d) are rather more dramatic. Mean F on ages 1 to 3 are significantly increased, reflecting the high level of discarding predicted by the selectivity model.

Long-term yield

Comparisons of yield-per-recruit analyses between the results of the ICES assessments and the revised assessments were carried out using the mean exploitation patterns generated by each assessment. Mean F at age for landings, discards and catch estimated by the selectivity model, by species and fleet are given in Table 5. Associated mean weights at age estimated by the model are given in Table 6. Note that in this model, mean weights in the catches are unaffected by levels of F, and are determined only by mesh selectivity. Input exploitation patterns and mean weights at age for each species derived from the ICES assessment are given in Anon.(1990). The results are presented in Figures 4 to 7. With the exception of plaice, the long term SSB-per-recruit curves are largely unaffected. For plaice (Figure 5), the results indicate that the effect of including discards in the assessment would be to approximately half the long term SSB-per-recruit at levels of F corresponding to the 1989 value. Yield-per-recruit for all species is expressed in terms of landings.The results indicate that for sole and whiting (Figures 4 and 6),predictions of long-term landings at 1989 levels of F increased under the exploitation pattern, generated by the revised assessment. For whiting, this may be explained by the fact that fishing mortality on age 2 is reduced in the revised assessment compared to the ICES assessment, and the estimated mean weights at age in the landings from the selectivity model are greater than those used for the ICES prediction. However in the case of sole, the observed increase in landings at 1989 levels of F are wholly due to the difference in mean weights at age used, since fishing mortality on ages 2 to 4 are greater for the assessment including discard estimates.

The results for plaice in terms of landings are the most dramatic. Compared to the ICES assessment, results of the yield-per-recruit analysis, using the revised assessment results in landings of only 40% of the ICES prediction. In addition the shapes of the two yield curves are markedly different; the ICES curve being relatively flat-topped wheras the revised curve indicates that the 1989 level of fishing is some 70% greater than that required to achieve maximum yield. Furthermore maximum sustainable yield would be about double that estimated for the 1989 fishing level. This is largely due to the low proportion of fish of age group 1 that are predicted to be landed by the model (0.01), and also because of the extended selection range for this species.

It is worth considering however, that the differences in yield per recruit for plaice will not be reflected in the absolute long-term yield, since the revised assessment predicts averagely higher recruitment than the ICES assessment. The same will also be true for sole and whiting although the overall effects will be reduced in absolute terms, since the predicted level of discards is less for these species.

The long term effects of increasing minimum mesh size from those used in 1989, to 80mm and 90mm for all fleets was examined. The calculated selection ratios applied to the mean exploitation patterns from the revised VPA for 1989 mesh sizes to give new exploitation patterns are given in Table 7. The resulting exploitation patterns by species and fleet for mesh increases to 80mm and 90 mm are given in Tables 8 and 9 respectively. The associated mean weights age in the catches are given in Table 10. Comparative analyses were only carried out using the results of the assessments based on estimated catches using the selectivity model. The results for sole, plaice and whiting are presented in Figures 8 to10. Similar data for cod are not included since the predicted effects of increasing mesh sizes up to 90mm on the exploitation pattern for this species are negligible.

For sole (Figure 8), the yield curves are rather flat-topped. For 1989 mesh sizes, and for uniform 80mm mesh sizes for all fleets, maximum sustainble yield in terms of landings-per-recruit would be achieved with a reduction in overall level of fishing by about 20%. If 80mm mesh sizes were used by all fleets, maximum sustainable yield would be achieved at a slightly higher level of F than with 1989 mesh sizes, although in both cases the increase in yield would be small. Increasing minimum mesh sizes for all fleets to 90mm , would result in a long-term increase in landings by approximately

10% at the 1989 level of fishing, with a corresponding 30% increase in spawning stock biomass. The results also indicate that if all fleets adopted a 90mm mesh size, a doubling of the fishing mortality rate would achieve no increase in yield to that predicted for the 1989 fishing level. Increasing the mesh size to 80 mm for all fleets is predicted to have little effect on the size of the spawning stock.

Results for plaice (Figure 9), indicate that for all mesh sizes investigated maximum sustainable yield would be achieved at a level of fishing at approximately 40% of the 1989 level, but that the size of the spawning stock is similar whatever the mesh size used, over the limited range investigated. Increases in mesh size to 80mm and 90mm for all fleets is predicted to give increases in landings of 5% and 20% respectively, at the 1989 fishing level. Any increases in fishing effort are predicted to result in reduced landings in the long term, and spawning stock biomass will also decline.

The results for whiting (Figure 10) indicate much larger changes than those observed for sole and plaice, with mesh increases to 80mm and 90mm indicating increases in yield of approximately 35% and 90%, with corresponding increases in spawning stock biomass of about 180% and 335% respectively at the 1989 fishing level. The yield curves also indicate that fishing effort should be reduced to between 20% and 40% of the 1989 level, depending on the assumed mesh size, in order to achieve maximum sustainable yield.

Short-term yield.

Short-term annual catch predictions simulating the effects of different mesh size changes were carried out using the same input data as for long term predictions except that fishing mortalities and mean weights at age for landings and discards were treated separately by fleet (Tables 5, 6, 8, 9, and 10), and input stock numbers at age were derived from the revised VPA's only.Since such an analysis generates a large volume of results, the results expressed only for all fleets combined to illustrate the effects to the fishery as a whole. The results are given in Tables 11a-c, and the projected landings are plotted in Figure 11. It is important to remember that these results show comparisons between predictions made using the results of the revised assessments including discards together with exploitation patterns for different mesh sizes generated using the selectivity model.

From Table 11 and Figure 11, it can be seen that for all species except sole, the predicted landings assuming the 1989 mesh size exploitation patterns are basically constant from 1994 onwards. This is simply a result of the analyses being carried out assuming constant recruitment. For sole (Figure 11a), landings are predicted to progressively decline from 1990 until 1998, due to good year classes passing through the fishery, and stabilise therafter assuming constant geometric mean recruitment. For whiting (Figure 11b), landings are predicted to remain at about the 1990 level in all years. For plaice, assuming 1989 mesh sizes (Figure 11c),landings will decline to about 80% of the 1990 level by 1994, and with constant recruitment will remain at that level thereafter.

Increasing the minimum mesh size to 80mm for all fleets results in immediate reduction in landings for whiting and sole(Figures 11a and 11b). No changes are expected for plaice and cod. For whiting, the loss in landings is of the order of 15% compared to the 1989 exploitation pattern prediction,wheras for sole it is about 2%. The losses of whiting in 1990 are predicted to be converted to gains by 1991, whereas the sole landings do not reach their predicted level under the 1989 exploitation regime until one year later. An increase in mesh size to 90mm, predictably results in even bigger losses in landings of sole and whiting in 1990 (23% and 39% respectively), and although the whiting landings recover by 1991, landings of sole remain lower than the level predicted using the 1989 exploitation pattern until 1993. For sole (Figure 11a), the level of landings for all fleets combined, using a 90mm mesh, are greater after 1993, than those predicted using the exploitation patterns generated using 1989 mesh sizes and a uniform mesh sizes of 80mm for all fleets. Since no change in exploitation pattern is predicted for cod for mesh size up to 90mm, the predicted landings for each mesh size regime remain the same.

Discussion

A model to predict the likely level of discarding in fisheries for which no observed discard data are available has been described and applied to the mixed demersal fisheries in the Irish Sea. The model, is relatively simple but is dependent on a number of parameters. Firstly, the model assumes that the distribution of size at age in the population available for capture is known. Secondly, that species-specific gear selectivity parameters are available. These parameters are fundamental to predicting the proportions of fish entering the net that are caught. Thirdly, in order to use the model to predict the proportion of the catches that are landed and discarded, assumptions about the discarding practices must be made. In this paper we have assumed that discarding takes place primarily in order to comply with minimum landing size regulations and that, the discarding practice can be described as a logistic function about a mean discarding length equivalent to the minimum landing size and a discarding range corresponding to 10% of the mean; as a result, some undersized fish will be considered as landings and some fish above the minimum landing size will be discarded. Such assumptions may not be wholly appropriate for some species, especially those species which command a high price on landing. Furthermore, we know that discarding takes place for a variety of reasons other than to comply with minimum landing size regulations and that no account of such discarding has been taken into account in this analysis.

In this paper we have dealt with only annual catch at age data and the estimated discards were calculated using annual landings at age data from the fishery. Clearly there is scope for improvement here, since it would be more appropriate to take into account factors such as spatial and seasonal distribution of the stocks and fisheries, and in particular the seasonal distribution of different age groups of fish in relation to fleet activity. In addition, for all species, and in particular, fast-growing species, the size at age in the population throughout the year will change and may also vary between years. Furthermore, the model does not incorporate any size selection accounting (see Horwood, 1993). Hence ,in this analysis, size at age in the available population remains constant. This assumption not only affects the proportions of fish caught, landed and discarded but will also affect the predicted mean weights of landings and discards.

Nevertheless, the application of the model to the Irish Sea fisheries has given some insight into the possible level of discarding. The magnitude of the numbers of fish discarded may not be precise because of the problems outlined above, but discarding of some catches undoubtedly takes place, and is not accounted for in some assessments. Although there are no data to compare the predicted discard levels of sole, plaice and cod, some discard estimates for whiting in the Irish Sea are available. It is interesting to compare the whiting assessments made by ICES with those carried out in this paper. In terms of mean fishing mortality (Figure 3d), both assessments produce similar exploitation patterns.

The general results of the revised assessments are that, including estimates of discards in assessments results in increased fishing mortality rates and increases in stock in number for partially selected age groups. This is perhaps not surprising, but what is not obvious, is what effect the changed exploitation patterns and stock number increases will have on our perception of the current exploitation rates and on catch predictions. The results presented here are rather speculative because of the problems outlined above, however while the magnitude of the perceived differences in the assessments and predictions may be questioned, the qualitative effects of the results merit consideration. Such points were addressed by the ICES Working Group on Methods of Fish Stock Assessments in 1985 and an overview of assessment calculations in relation to discards is included in the report of that meeting (Anon., 1985).

Perhaps the most striking results in this paper are the differences in yield-per-recruit analyses carried out for plaice, comparing the results of the ICES assessment with that obtained including estimates of discards (Figure 5). The perceived differences in the yield-per-recruit curves are due to the changes in the exploitation patterns generated by including estimates of discards in the VPA, with the major source of fishing mortality on the youngest ages being attributable to discarding. As pointed out earlier, if long-term yield (yield-per-recruit x mean recruitment) is considered, there will be a compensatory effect due to increases recruitment generated by the assessment which includes discards, and the overall differences in yield will be less.

These results highlight the sensitivity of the model to estimates of mean length at age in the population and its reliance on the selectivity parameters used to estimate the proportions caught. A further drawback is also highlighted; the assumption that all age groups are equally available for capture. In practice, although plaice discards are likely to be high at certain times of the year and in certain areas, fishing effort may not be directed equally at all age groups at all times of the year and seasonal discard rates may be quite different. This is especially true for 1-group plaice since their growth rate is relatively high and discarding of this age group in January may be vastly different to that in December. This is also true in the case of North Sea haddock, where it has been necessary to carry out seasonal catch predictions in order to take into account differential discarding rates of 0- and 1-group individuals (C. T. Macer and R. A. Ayres, unpublished data). It is also important to remember that, in these analyses, all discards are assumed to die.

The results of mesh size changes conform with general expectations. The qualitative effects of mesh size increases are rather obvious; any increase in mesh size results in short-term losses in catches in number of partially selected age groups, which will usually result in a reduction in yield to the fishery. At the same time an increase in mesh size will also reduce the proportion of the catch that is discarded, providing that the main reason for discarding is to comply with minimum landing size regulations. However, the reduction in numbers of fish caught will be partly offset by the increase in mean weight of fish of partially selected age groups caught, since an increase in mesh will result in larger fish of each age group being retained by the meshes. This may be an important factor to consider when modelling the effects of changes in mesh size, although it is not incorporated in the standard yield-per-recruit analysis of Beverton and Holt (1957), in which mean weights at age in the catches is assumed to remain constant. However, the net effect of this is probably to underestimate yield in the long term and the relative shape of the yield curve may also be affected

The quantities of interest to fishermen and to fishery managers, of the effects of increases in mesh size, are what are the magnitude of the short-term losses and how long does the fishery have to wait in order to reap the benefits of an improvement in exploitation pattern? The results of the annual catch predictions show that for two of the species examined, sole and whiting, the immediate effects are a reduction in landings relative to the prediction involving no change in mesh, and that the losses are regained over a time period spanning between 1 and 4 years. There are no immediate losses predicted for plaice but relative gains are accrued within 2 years. For cod, the results indicate that there are no effects on landings or on the stock for mesh size increases up to 90mm. These results indicate the problems of managing a mixed species fishery using mesh size regulations in isolation. For example, while an increase in mesh size to 90mm for all fleets would not affect the landings of cod, the short-term losses for sole (an immediate 20% reduction in landings), a species with a high unit price, may be unacceptable to the fishery.

With the increase in interest in the use of technical measures including mesh size changes to manage stocks in the north-east Atlantic, such problems will need to be addressed by assessment scientists and fishery managers. The results presented in this paper, indicate that for some species, discarding could be a significant source of fishing mortality on some age groups and that their inclusion in assessments and predictions may be important, since it can affect the perception of appropriate management strategies. However, discard data are difficult and expensive to collect but the approach used here shows that much can be done with validation of simple models to predict discards. If the parameters required for such models can be adequately defined, it may be possible to use an approch such as the one presented here as an alternative to wholesale discard monitoring programmes.

Acknowledgements.

I am grateful to numerous colleagues in Lowestoft and elsewhere who assisted in the collation and processing of data for this study. In particular, S. Warnes, W. A. Dawson and the members of the 1990 Irish Sea and Bristol Channel Working Group, notably, R. Briggs, P. Connolly and S. Flatman. D. J. Symonds, M. R. Vince, P. A. Large and M. J. Boon were also kind enough to spare their time to direct me to appropriate data sets. I thank J. W. Horwood and B. W. Jones, for their encouragement and constructive comments on the manuscript, and C.T. Macer for helpful discussions and comment.

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POPLEN.XLS

Table 1.
Mean and standard deviations of length at age (cm) in the populations used in the selectivity model. Values are only presented for the age ranges used in the assessment.

Species	sole		plaice		whiting		cod	
Age	mean	s. dev.	mean	s. dev.	mean	s. dev.	mean	s. dev.
1			17.28	1.86	22.85		44.18	4.42
2	19.05	1.78	22.44	2.30	30.53	3.05	61.75	6.17
3	22.52	3.05	26.94	3.15	36.70	3.67	75.15	7.52
4	25.46	2.97	30.86	3.09	41.65	4.16	85.38	8.54
5	27.93	2.79	34.29	3.43	45.62	4.56	93.20	9.32
6	30.02	3.00	37.29	3.73	48.81	4.88	99.16	9.92
7	31.78	3.18	39.90	3.99	51.37	5.14	103.71	10.37
8	33.26	3.33	42.18	4.22	53.42	5.34		
9	34.52	3.45	44.17	4.42				
10	35.57	3.56						

Table 2.

Minimum landings sizes, selectivity parameters and length weight relationshop for each species.

Species	sole	plaice	cod	whiting
MLS (cm)	24	25	35	27
Selection factor	3.2	2.2	3.1	3.3
Selection range	4.7	3.0	6.3	8.5
Length weight relationship				
a	0.009	0.0123	0.0124	0.004
b	3.034	2.97	2.96	3.21

PROPLA89.XLS

Table 3.
Estimated proportions of each species caught that are landed and discarded by fleet

Proportions of catch landed

species	sole			plaice			whiting			cod		
fleet	beam	otter	nephrops	beam	otter	nephrops	beam	otter	nephrops	beam	otter	nephrops
age												
1				0.01	0.01	0.00	0.33	0.32	0.30	1	1	1
2	0.43	0.40	0.37	0.20	0.20	0.20	0.97	0.96	0.96	1	1	1
3	0.79	0.76	0.72	0.73	0.72	0.72	1	1	1	1	1	1
4	0.91	0.90	0.87	0.95	0.95	0.95	1	1	1	1	1	1
5	0.96	0.95	0.94	0.99	0.99	0.99	1	1	1	1	1	1
6	0.98	0.98	0.97	1	1	1	1	1	1	1	1	1
7	0.99	0.99	0.99	1	1	1	1	1	1	1	1	1
8	1	0.99	0.99	1	1	1	1	1	1			
9	1	1	1	1	1	1						
10	1	1	1									

Proportions of catch discarded

species	sole			plaice			whiting			cod		
fleet	beam	otter	nephrops	beam	otter	nephrops	beam	otter	nephrops	beam	otter	nephrops
age												
1				0.99	0.99	1.00	0.67	0.68	0.70	0	0	0
2	0.57	0.60	0.63	0.80	0.80	0.80	0.03	0.04	0.04	0	0	0
3	0.21	0.24	0.28	0.27	0.28	0.28	0	0	0	0	0	0
4	0.09	0.10	0.13	0.05	0.05	0.05	0	0	0	0	0	0
5	0.04	0.05	0.06	0.01	0.01	0.01	0	0	0	0	0	0
6	0.02	0.02	0.03	0	0	0	0	0	0	0	0	0
7	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0
8	0	0.01	0.01	0	0	0	0	0	0			
9	0	0	0	0	0	0						
10	0	0	0									

PROPLD.XLS

Table 4.
Proportions of the catches landed and discarded for mesh sizes of 80mm and 90mm

Proportions of catch landed

species	sole		plaice		whiting		cod	
mesh size	80mm	90mm	80mm	90mm	80mm	90mm	80mm	90mm
age								
1			0.01	0.01	0.34	0.36	1	1
2	0.43	0.47	0.20	0.23	0.97	0.97	1	1
3	0.79	0.85	0.73	0.74	1	1	1	1
4	0.91	0.95	0.95	0.95	1	1	1	1
5	0.96	0.98	0.99	0.99	1	1	1	1
6	0.98	0.99	1	1	1	1	1	1
7	0.99	1	1	1	1	1	1	1
8	1	1	1	1	1	1		
9	1	1	1	1				
10	1	1						

Proportions of catch discarded

species	sole		plaice		whiting		cod	
mesh size	80mm	90mm	80mm	90mm	80mm	90mm	80mm	90mm
age								
1			0.99	0.99	0.67	0.64	0	0
2	0.57	0.53	0.80	0.77	0.03	0.03	0	0
3	0.21	0.15	0.27	0.26	0	0	0	0
4	0.09	0.05	0.05	0.05	0	0	0	0
5	0.04	0.02	0.01	0.01	0	0	0	0
6	0.02	0.01	0	0	0	0	0	0
7	0.01	0	0	0	0	0	0	0
8	0	0	0	0	0	0		
9	0	0	0	0				
10	0	0						

Table 5.
Estimated exploitation patterns (fishing mortality at age) based on mesh selectivity model.
Data are presented by fleet for mesh sizes in use in 1989.
Fishing mortalities are unweighted arithmetic mean values for the period 1987-89,
scaled to the mean value over the specified age range for 1989 from VPA.

Fishing mortality due to landings

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.000	0.001	0.000	0.001
2	0.006	0.005	0.001	0.012	0.025	0.105	0.010	0.140
3	0.056	0.024	0.004	0.084	0.155	0.420	0.046	0.621
4	0.179	0.051	0.012	0.242	0.284	0.561	0.069	0.914
5	0.259	0.050	0.012	0.321	0.246	0.462	0.060	0.768
6	0.328	0.057	0.014	0.399	0.287	0.441	0.068	0.796
7	0.308	0.089	0.023	0.420	0.205	0.278	0.038	0.521
8	0.346	0.091	0.024	0.461	0.162	0.282	0.045	0.489
9	0.360	0.062	0.009	0.431	0.178	0.269	0.041	0.488
10	0.286	0.114	0.031	0.431				

Fishing mortality due to discards

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.024	0.085	0.024	0.133
2	0.009	0.007	0.001	0.017	0.102	0.418	0.043	0.563
3	0.015	0.008	0.001	0.024	0.057	0.163	0.018	0.238
4	0.018	0.006	0.002	0.026	0.015	0.030	0.003	0.048
5	0.011	0.003	0.001	0.015	0.002	0.005	0.000	0.007
6	0.007	0.001	0.000	0.008	0.000	0.000	0.000	0.000
7	0.003	0.001	0.000	0.004	0.000	0.000	0.000	0.000
8	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000				

Fishing mortality due to catches

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.024	0.086	0.024	0.134
2	0.015	0.012	0.002	0.029	0.127	0.523	0.053	0.703
3	0.071	0.032	0.005	0.108	0.212	0.583	0.064	0.859
4	0.197	0.057	0.014	0.268	0.299	0.591	0.072	0.962
5	0.270	0.053	0.013	0.336	0.248	0.467	0.060	0.775
6	0.335	0.058	0.014	0.407	0.287	0.441	0.068	0.796
7	0.311	0.090	0.023	0.424	0.205	0.278	0.038	0.521
8	0.346	0.092	0.024	0.462	0.162	0.282	0.045	0.489
9	0.360	0.062	0.009	0.431	0.178	0.269	0.041	0.488
10	0.286	0.114	0.031	0.431				
Mean F(89)				0.348				0.734
Age ranges for mean F				3-9				3-8

Table 5 continued.

Fishing mortality due to landings

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.001	0.154	0.091	0.246	0.041	0.341	0.028	0.410
2	0.020	0.688	0.412	1.120	0.074	0.765	0.061	0.900
3	0.020	0.876	0.582	1.478	0.067	0.982	0.141	1.190
4	0.009	0.958	0.723	1.690	0.075	1.032	0.153	1.260
5	0.007	0.768	0.500	1.275	0.090	0.939	0.132	1.161
6	0.009	0.794	0.507	1.310	0.041	1.011	0.147	1.199
7	0.000	0.960	0.734	1.694	0.018	1.065	0.117	1.200
8	0.000	0.873	0.821	1.694				
9								
10								

Fishing mortality due to discards

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.002	0.328	0.207	0.537	0.000	0.000	0.000	0.000
2	0.001	0.027	0.018	0.046	0.000	0.000	0.000	0.000
3	0.000	0.001	0.001	0.002	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000				
9								
10								

Fishing mortality due to catches

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.003	0.482	0.298	0.783	0.041	0.341	0.028	0.410
2	0.021	0.715	0.430	1.166	0.074	0.765	0.061	0.900
3	0.020	0.877	0.583	1.480	0.067	0.982	0.141	1.190
4	0.009	0.958	0.723	1.690	0.075	1.032	0.153	1.260
5	0.007	0.768	0.500	1.275	0.090	0.939	0.132	1.161
6	0.009	0.794	0.507	1.310	0.041	1.011	0.147	1.199
7	0.000	0.960	0.734	1.694	0.018	1.065	0.117	1.200
8	0.000	0.873	0.821	1.694				
9								
10								
Mean F(89)				1.384				1.142
Age ranges for mean F				2-6				2-6

WTABS.XLS

Table 6.

Mean weights at age in the catches (kg) by fleet assuming 1989 mesh sizes
Mesh sizes assumed : beam trawl, 80mm: otter trawl, 75mm; Nephrops trawl, 70mm.

Mean weights at age of landings

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.094	0.092	0.091	0.092
2	0.150	0.147	0.145	0.147	0.172	0.172	0.172	0.172
3	0.198	0.193	0.190	0.194	0.247	0.247	0.247	0.247
4	0.232	0.227	0.223	0.227	0.345	0.345	0.345	0.345
5	0.267	0.261	0.258	0.262	0.461	0.461	0.461	0.461
6	0.300	0.295	0.292	0.296	0.590	0.590	0.590	0.590
7	0.333	0.329	0.326	0.329	0.720	0.720	0.720	0.720
8	0.367	0.363	0.360	0.363	0.850	0.850	0.850	0.850
9	0.399	0.395	0.393	0.396	0.976	0.976	0.976	0.976
10	0.429	0.426	0.424	0.426				

Mean weights at age of discards

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.069	0.067	0.064	0.067
2	0.120	0.118	0.115	0.118	0.123	0.121	0.120	0.121
3	0.140	0.136	0.133	0.136	0.162	0.161	0.161	0.161
4	0.148	0.145	0.141	0.145	0.183	0.181	0.181	0.182
5	0.154	0.151	0.148	0.151	0.191	0.191	0.191	0.191
6	0.157	0.155	0.152	0.155	0.196	0.196	0.196	0.196
7	0.160	0.157	0.155	0.157	0.204	0.204	0.204	0.204
8	0.161	0.159	0.157	0.159	0.211	0.211	0.211	0.211
9	0.163	0.160	0.158	0.160	0.232	0.231	0.231	0.231
10	0.164	0.162	0.160	0.162				

Mean weights at age of catches

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.069	0.067	0.064	0.067
2	0.133	0.130	0.126	0.130	0.133	0.131	0.131	0.132
3	0.186	0.179	0.174	0.180	0.224	0.224	0.223	0.224
4	0.225	0.218	0.212	0.218	0.337	0.337	0.337	0.337
5	0.263	0.256	0.251	0.257	0.459	0.459	0.459	0.459
6	0.298	0.291	0.288	0.292	0.589	0.589	0.589	0.589
7	0.332	0.327	0.324	0.328	0.720	0.720	0.720	0.720
8	0.366	0.361	0.359	0.362	0.850	0.850	0.850	0.850
9	0.398	0.395	0.392	0.395	0.976	0.976	0.976	0.976
10	0.428	0.425	0.423	0.425				

Table 6 continued.

Mean weights at age of landings

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.134	0.132	0.131	0.132	0.947	0.946	0.946	0.946
2	0.260	0.257	0.255	0.257	2.547	2.547	2.547	2.547
3	0.447	0.444	0.441	0.444	4.555	4.555	4.555	4.555
4	0.661	0.659	0.658	0.659	6.647	6.647	6.647	6.647
5	0.881	0.880	0.879	0.880	8.615	8.615	8.615	8.615
6	1.092	1.091	1.091	1.091	10.350	10.350	10.350	10.350
7	1.286	1.285	1.285	1.285	13.696	13.696	13.696	13.696
8	1.457	1.457	1.456	1.457				
9								
10								

Mean weights at age of discards

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.094	0.093	0.092	0.093	0.226	0.226	0.226	0.226
2	0.133	0.132	0.131	0.132				
3	0.143	0.142	0.142	0.142				
4	0.152	0.152	0.152	0.152				
5	0.167	0.167	0.167	0.167				
6								
7								
8								
9								
10								

Mean weights at age of catches

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.107	0.105	0.104	0.105	0.947	0.946	0.946	0.946
2	0.256	0.253	0.250	0.253	2.547	2.547	2.547	2.547
3	0.446	0.443	0.441	0.443	4.555	4.555	4.555	4.555
4	0.661	0.658	0.658	0.659	6.647	6.647	6.647	6.647
5	0.881	0.879	0.879	0.880	8.615	8.615	8.615	8.615
6	1.092	1.091	1.091	1.091	10.350	10.350	10.350	10.350
7	1.286	1.285	1.285	1.285	13.696	13.696	13.696	13.696
8	1.457	1.457	1.457	1.457				
9								
10								

Table 7.
Calculated selection ratios for changes in mesh size for each Species by fleet.
Fishing mortality at age by fleet is reduced by the appropriate Selection ratio
to give new exploitation patterns for the new mesh size

Selection ratios for 80mm mesh

Species	sole			plaice			whiting			cod		
fleet	beam	otter	Nephrops	beam	otter	Nephrops	beam	otter	Nephrops	beam	otter	Nephrops
age												
1	1			1	0.75	0.62	1	0.67	0.45	1	1	1
2	1	0.62	0.43	1	0.96	0.96	1	0.77	0.62	1	1	1
3	1	0.75	0.62	1	1	0.99	1	0.91	0.85	1	1	1
4	1	0.83	0.73	1	1	1	1	0.97	0.95	1	1	1
5	1	0.89	0.82	1	1	1	1	0.99	0.98	1	1	1
6	1	0.92	0.88	1	1	1	1	1	0.99	1	1	1
7	1	0.94	0.91	1	1	1	1	1	1	1	1	1
8	1	0.96	0.94	1	1	1	1	1	1			
9	1	0.97	0.95	1	1	1						
10	1	0.98	0.97									

Selection ratios for 90mm mesh

Species	sole			plaice			whiting			cod		
fleet	beam	otter	Nephrops	beam	otter	Nephrops	beam	otter	Nephrops	beam	otter	Nephrops
age												
1				0.42	0.32	0.26	0.54	0.29	0.20	0.99	0.99	0.99
2	0.30	0.19	0.13	0.85	0.82	0.80	0.76	0.41	0.33	1	1	1
3	0.43	0.33	0.27	0.98	0.98	0.97	0.91	0.69	0.65	1	1	1
4	0.55	0.46	0.40	1	1	1	0.96	0.88	0.86	1	1	1
5	0.65	0.58	0.54	1	1	1	0.98	0.95	0.95	1	1	1
6	0.73	0.67	0.64	1	1	1	0.99	0.98	0.98	1	1	1
7	0.79	0.75	0.73	1	1	1	1	0.99	0.99	1	1	1
8	0.84	0.81	0.79	1	1	1	1	0.99	0.99			
9	0.88	0.85	0.84	1	1	1						
10	0.90	0.88	0.87									

FTABS80.XLS

Table 8.
Estimated exploitation patterns (fishing mortality at age) based on selectivity model.
All fleets are assumed to use 80mm mesh

Fishing mortality due to landings

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1								
2	0.006	0.003	0.000	0.010	0.025	0.100	0.010	0.136
3	0.056	0.019	0.002	0.077	0.155	0.426	0.046	0.627
4	0.179	0.043	0.009	0.232	0.284	0.561	0.068	0.914
5	0.259	0.045	0.010	0.315	0.246	0.462	0.059	0.767
6	0.328	0.052	0.012	0.393	0.287	0.441	0.068	0.796
7	0.308	0.084	0.021	0.412	0.205	0.278	0.038	0.521
8	0.346	0.088	0.023	0.457	0.162	0.282	0.045	0.489
9	0.360	0.060	0.009	0.429	0.178	0.269	0.041	0.488
10	0.286	0.112	0.030	0.428				

Fishing mortality due to discards

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.024	0.064	0.015	0.102
2	0.009	0.004	0.000	0.013	0.102	0.402	0.041	0.544
3	0.015	0.005	0.001	0.021	0.057	0.157	0.017	0.232
4	0.018	0.004	0.001	0.023	0.015	0.030	0.004	0.048
5	0.011	0.002	0.000	0.013	0.002	0.005	0.001	0.008
6	0.007	0.001	0.000	0.008	0.000	0.000	0.000	0.000
7	0.003	0.001	0.000	0.004	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000				

Fishing mortality due to catches

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.000	0.000	0.000	0.000	0.024	0.064	0.015	0.102
2	0.015	0.007	0.001	0.023	0.127	0.502	0.051	0.680
3	0.071	0.024	0.003	0.098	0.212	0.583	0.063	0.858
4	0.197	0.047	0.010	0.255	0.299	0.591	0.072	0.962
5	0.270	0.047	0.011	0.328	0.248	0.467	0.060	0.775
6	0.335	0.053	0.012	0.401	0.287	0.441	0.068	0.796
7	0.311	0.085	0.021	0.417	0.205	0.278	0.038	0.521
8	0.346	0.088	0.023	0.457	0.162	0.282	0.045	0.489
9	0.360	0.060	0.009	0.429	0.178	0.269	0.041	0.488
10	0.286	0.112	0.030	0.428				
Mean F(89)				0.340				0.734
Age ranges for mean F				3-9				3-8

FTABS80.XLS

Table 8 continued.

Fishing mortality due to landings

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.001	0.108	0.045	0.153	0.041	0.341	0.028	0.410
2	0.020	0.532	0.258	0.810	0.074	0.765	0.061	0.900
3	0.020	0.798	0.496	1.314	0.067	0.982	0.141	1.190
4	0.009	0.929	0.687	1.625	0.075	1.032	0.153	1.260
5	0.007	0.760	0.490	1.257	0.090	0.939	0.132	1.161
6	0.009	0.794	0.502	1.305	0.041	1.011	0.147	1.199
7	0.000	0.960	0.734	1.694	0.018	1.065	0.117	1.200
8	0.000	0.873	0.821	1.694				
9	0.000	0.000	0.000					
10	0.000	0.000	0.000					

Fishing mortality due to discards

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.002	0.213	0.089	0.305	0.000	0.000	0.000	0.000
2	0.001	0.019	0.009	0.028	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000				
9								
10								

Fishing mortality due to catches

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.003	0.321	0.134	0.458	0.041	0.341	0.028	0.410
2	0.021	0.551	0.267	0.838	0.074	0.765	0.061	0.900
3	0.020	0.798	0.496	1.314	0.067	0.982	0.141	1.190
4	0.009	0.929	0.687	1.625	0.075	1.032	0.153	1.260
5	0.007	0.760	0.490	1.257	0.090	0.939	0.132	1.161
6	0.009	0.794	0.502	1.305	0.041	1.011	0.147	1.199
7	0.000	0.960	0.734	1.694	0.018	1.065	0.117	1.200
8	0.000	0.873	0.821	1.694				
9								
10								
Mean F(89)				1.268				1.142
Age ranges for mean F				2-6				2-6

FTABS90.XLS

Table 9.
Estimated exploitation patterns (fishing mortality at age) based on selectivity model.
All fleets are assumed to use 90mm mesh

Fishing mortality due to landings

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.000	0.000	0.000	0.000
2	0.002	0.001	0.000	0.003	0.025	0.099	0.010	0.133
3	0.026	0.009	0.001	0.036	0.154	0.423	0.046	0.622
4	0.103	0.025	0.005	0.133	0.284	0.561	0.068	0.914
5	0.172	0.030	0.007	0.209	0.246	0.462	0.059	0.767
6	0.242	0.038	0.009	0.289	0.287	0.441	0.068	0.796
7	0.246	0.068	0.017	0.330	0.205	0.278	0.038	0.521
8	0.291	0.075	0.019	0.384	0.162	0.282	0.045	0.489
9	0.317	0.053	0.008	0.377	0.178	0.269	0.041	0.488
10	0.257	0.100	0.027	0.385				

Fishing mortality due to discards

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.010	0.027	0.006	0.043
2	0.002	0.001	0.000	0.004	0.083	0.330	0.033	0.446
3	0.005	0.002	0.000	0.006	0.054	0.149	0.016	0.219
4	0.005	0.001	0.000	0.007	0.015	0.030	0.004	0.048
5	0.004	0.001	0.000	0.004	0.002	0.005	0.001	0.008
6	0.002	0.000	0.000	0.003	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000				

Fishing mortality due to catches

Species	sole				plaice			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1					0.010	0.028	0.006	0.044
2	0.005	0.002	0.000	0.007	0.108	0.429	0.042	0.579
3	0.031	0.011	0.001	0.042	0.208	0.571	0.062	0.841
4	0.108	0.026	0.006	0.140	0.299	0.591	0.072	0.962
5	0.176	0.031	0.007	0.213	0.248	0.467	0.060	0.775
6	0.245	0.039	0.009	0.292	0.287	0.441	0.068	0.796
7	0.246	0.068	0.017	0.330	0.205	0.278	0.038	0.521
8	0.291	0.075	0.019	0.384	0.162	0.282	0.045	0.489
9	0.317	0.053	0.008	0.377	0.178	0.269	0.041	0.488
10	0.257	0.100	0.027	0.385				
Mean F(89)				0.254				0.731
Age ranges for mean F				3-9				3-8

FTABS90.XLS

Table 9 continued.

Fishing mortality due to landings

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.001	0.050	0.021	0.072	0.041	0.338	0.028	0.406
2	0.015	0.284	0.138	0.437	0.074	0.765	0.061	0.900
3	0.018	0.605	0.379	1.002	0.067	0.982	0.141	1.190
4	0.009	0.843	0.622	1.473	0.075	1.032	0.153	1.260
5	0.007	0.730	0.475	1.211	0.090	0.939	0.132	1.161
6	0.009	0.778	0.497	1.284	0.041	1.011	0.147	1.199
7	0.000	0.950	0.727	1.677	0.018	1.065	0.117	1.200
8	0.000	0.864	0.813	1.677				
9								
10								

Fishing mortality due to discards

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.001	0.089	0.038	0.129	0.000	0.000	0.000	0.000
2	0.000	0.009	0.004	0.014	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000				
9								
10								

Fishing mortality due to catches

Species	whiting				cod			
fleet	beam	otter	Nephrops	all fleets	beam	otter	Nephrops	all fleets
age								
1	0.002	0.140	0.060	0.201	0.041	0.338	0.028	0.406
2	0.016	0.293	0.142	0.451	0.074	0.765	0.061	0.900
3	0.018	0.605	0.379	1.002	0.067	0.982	0.141	1.190
4	0.009	0.843	0.622	1.473	0.075	1.032	0.153	1.260
5	0.007	0.730	0.475	1.211	0.090	0.939	0.132	1.161
6	0.009	0.778	0.497	1.284	0.041	1.011	0.147	1.199
7	0.000	0.950	0.727	1.677	0.018	1.065	0.117	1.200
8	0.000	0.864	0.813	1.677				
9								
10								
Mean F(89)				1.084				1.142
Age ranges for mean F				2-6				2-6

WTAB8090.XLS

Table 10.
Mean weights at age in the catches (kg) by fleet for mesh sizes of 80mm and 90mm

Mean weights at age of landings

Species	sole		plaice		whiting		cod	
mesh size	80mm	90mm	80mm	90mm	80mm	90mm	80mm	90mm
age								
1			0.094	0.100	0.134	0.136	0.947	0.949
2	0.150	0.154	0.172	0.174	0.260	0.269	2.547	2.547
3	0.198	0.210	0.247	0.248	0.447	0.456	4.555	4.555
4	0.232	0.248	0.345	0.345	0.661	0.667	6.647	6.647
5	0.267	0.284	0.461	0.462	0.881	0.885	8.615	8.615
6	0.300	0.317	0.590	0.590	1.092	1.095	10.350	10.350
7	0.333	0.350	0.720	0.720	1.286	1.288	13.696	13.696
8	0.367	0.382	0.850	0.850	1.457	1.459		
9	0.399	0.413	0.976	0.976				
10	0.429	0.441						

Mean weights at age of discards

Species	sole		plaice		whiting		cod	
mesh size	80mm	90mm	80mm	90mm	80mm	90mm	80mm	90mm
age								
1			0.069	0.075	0.094	0.095	0.226	0.226
2	0.120	0.122	0.123	0.128	0.133	0.135		
3	0.140	0.143	0.162	0.164	0.143	0.144		
4	0.148	0.152	0.182	0.183	0.152	0.153		
5	0.154	0.158	0.191	0.192	0.167	0.167		
6	0.157	0.161	0.196	0.197				
7	0.160	0.163	0.204	0.204				
8	0.161	0.165	0.211	0.211				
9	0.163	0.166	0.232	0.231				
10	0.164	0.167						

Mean weights at age of catches

Species	sole		plaice		whiting		cod	
mesh size	80mm	90mm	80mm	90mm	80mm	90mm	80mm	90mm
age								
1			0.069	0.075	0.107	0.110	0.947	0.946
2	0.133	0.137	0.133	0.138	0.256	0.265	2.547	2.547
3	0.186	0.200	0.224	0.226	0.446	0.455	4.555	4.555
4	0.225	0.243	0.337	0.338	0.661	0.667	6.647	6.647
5	0.263	0.281	0.459	0.460	0.881	0.885	8.615	8.615
6	0.298	0.316	0.589	0.589	1.092	1.095	10.350	10.350
7	0.332	0.349	0.720	0.720	1.286	1.289	13.696	13.696
8	0.366	0.381	0.850	0.850	1.457	1.459		
9	0.398	0.412	0.976	0.976				
10	0.428	0.441						

Table 11. Results of short-term catch predictions for different mesh sizes

a. Catch prediction for 1989 mesh sizes

	year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
sole	landings	1.89	1.75	1.66	1.56	1.51	1.48	1.46	1.45	1.43	1.43	1.43
	discards	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	SSB	6.97	6.63	6.37	6.22	6.1	6.03	5.99	5.97	5.95	5.94	5.94
plaice	landings	3.31	2.94	2.8	2.72	2.68	2.66	2.65	2.64	2.64	2.64	2.64
	discards	1.53	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
	SSB	4.24	3.98	3.83	3.76	3.72	3.69	3.68	3.67	3.67	3.67	3.66
whiting	landings	16.43	17.74	18.26	18.32	18.34	18.35	18.36	18.36	18.36	18.36	18.36
	discards	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01
	SSB	12.25	12.57	12.64	12.66	12.67	12.67	12.67	12.67	12.67	12.67	12.67
cod	landings	12.22	10.16	10.42	10.88	11.04	11.1	11.11	11.12	11.12	11.12	11.12
	discards	0	0	0	0	0	0	0	0	0	0	0
	SSB	5.99	5.36	5.76	5.96	6.02	6.04	6.05	6.05	6.05	6.05	6.05
all species	landings	33.85	32.59	33.14	33.48	33.57	33.59	33.58	33.57	33.55	33.55	33.55
	discards	6.61	6.62	6.61	6.61	6.61	6.61	6.61	6.61	6.61	6.61	6.61

Table 11. (continued)

b. Catch prediction for 80mm mesh all fleets

	year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
sole	landings	1.85	1.74	1.65	1.58	1.53	1.5	1.48	1.47	1.46	1.46	1.46
	discards	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	SSB	7.03	6.74	6.52	6.38	6.28	6.22	6.18	6.16	6.15	6.14	6.14
plaice	landings	3.31	2.97	2.88	2.82	2.81	2.8	2.78	2.78	2.78	2.78	2.78
	discards	1.47	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
	SSB	4.28	4.08	3.98	3.93	3.9	3.88	3.87	3.86	3.86	3.86	3.86
whiting	landings	13.99	19.91	23.5	24.57	24.79	24.86	24.87	24.89	24.89	24.89	24.89
	discards	3.33	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38
	SSB	16.7	19.44	20.32	20.56	20.63	20.65	20.66	20.66	20.66	20.66	20.66
cod	landings	12.22	10.16	10.42	10.88	11.04	11.1	11.11	11.12	11.12	11.12	11.12
	discards	0	0	0	0	0	0	0	0	0	0	0
	SSB	5.99	5.36	5.76	5.96	6.02	6.04	6.05	6.05	6.05	6.05	6.05
all species	landings	31.37	34.78	38.45	39.85	40.17	40.26	40.24	40.26	40.25	40.25	40.25
	discards	4.86	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96

Table 11. (continued)

c. Catch prediction for 90mm mesh all fleets

	year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
sole	landings	1.46	1.51	1.56	1.56	1.57	1.57	1.58	1.58	1.58	1.58	1.58
	discards	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	SSB	7.61	7.72	7.76	7.8	7.8	7.81	7.82	7.82	7.82	7.82	7.82
plaice	landings	3.32	3.13	3.19	3.23	3.26	3.27	3.27	3.27	3.27	3.27	3.27
	discards	1.25	1.38	1.4	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
	SSB	4.44	4.46	4.51	4.52	4.52	4.52	4.52	4.52	4.52	4.52	4.52
whiting	landings	10.09	19.45	28.85	32.93	33.9	34.2	34.29	34.3	34.3	34.3	34.3
	discards	1.6	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
	SSB	22.43	30.46	33.9	34.95	35.28	35.37	35.39	35.39	35.39	35.39	35.39
cod	landings	12.22	10.16	10.42	10.88	11.04	11.1	11.11	11.12	11.12	11.12	11.12
	discards	0	0	0	0	0	0	0	0	0	0	0
	SSB	5.99	5.36	5.76	5.96	6.02	6.04	6.05	6.05	6.05	6.05	6.05
all species	landings	27.09	34.25	44.02	48.6	49.77	50.14	50.25	50.27	50.27	50.27	50.27
	discards	2.87	3.04	3.07	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08

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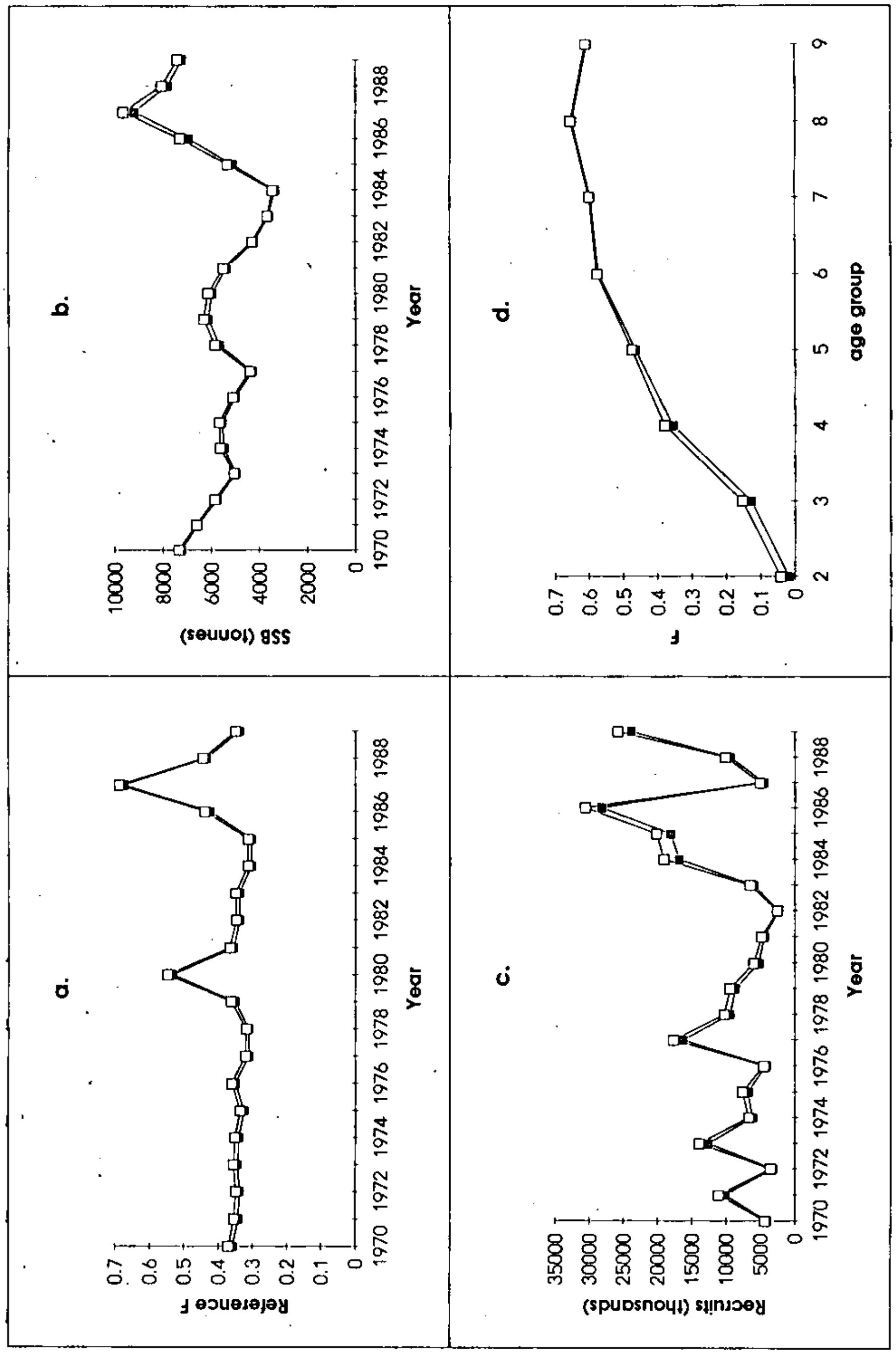

Figure 1

Figure 1. Selected results of assessments for sole. a. Trends in reference mean fishing mortality on age groups 3-9 inclusive. b. Trends in spawning stock biomass (SSB). c. Trends in recruitment (age 2). d. Mean fishing mortality at age (1987-1989). Solid squares indicate results of ICES assessment. Open squares indicate results of revised assessment including estimated discards.

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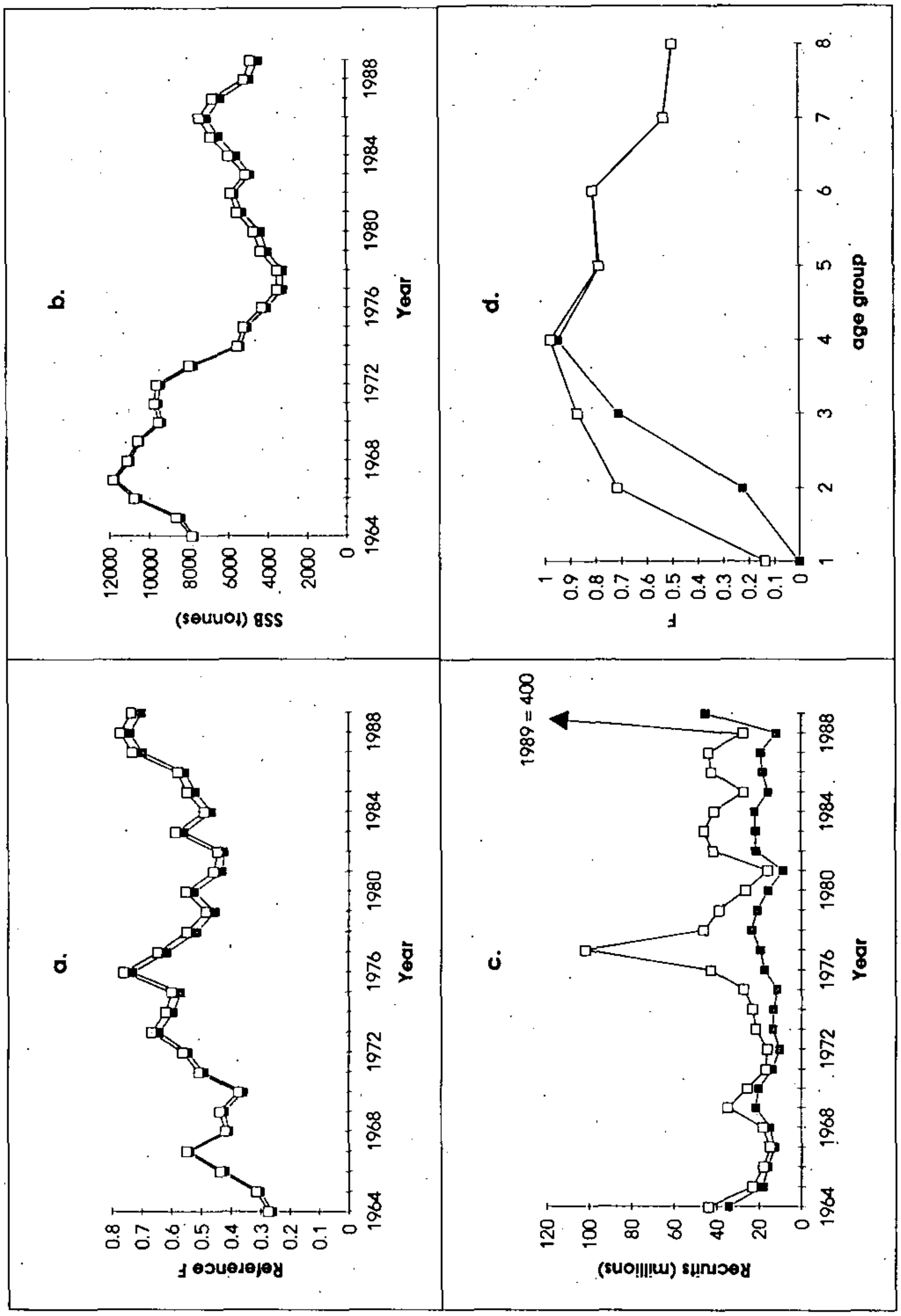

Figure 2

Figure 2. Selected results of assessments for plaice. a. Trends in reference mean fishing mortality on age groups 3-8 inclusive. b. Trends in spawning stock biomass (SSB). c. Trends in recruitment (age 1). d. Mean fishing mortality at age (1987-1989). Solid square indicate results of ICES assessment. Open squares indicate results of revised assessment including estimated discards.

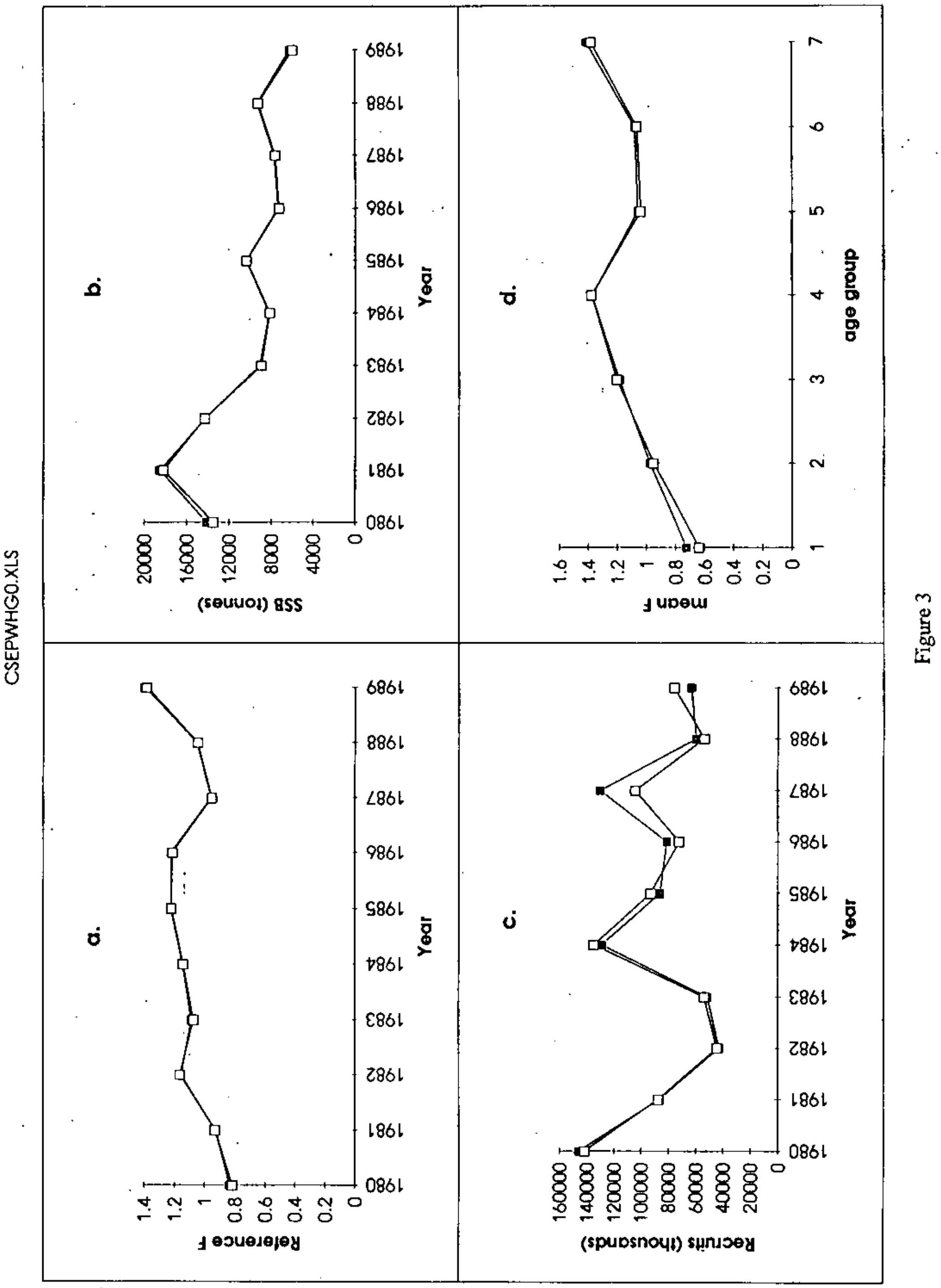

Figure 3. Selected results of assessments for whiting. a. Trends in reference mean fishing mortality on age groups 2-6 inclusive. b. Trends in spawning stock biomass (SSB). c. Trends in recruitment (age 1). d. Mean fishing mortality at age (1987-1989). Solid square indicate results of ICES assessment. Open squares indicate results of revised assessment including estimated discards.

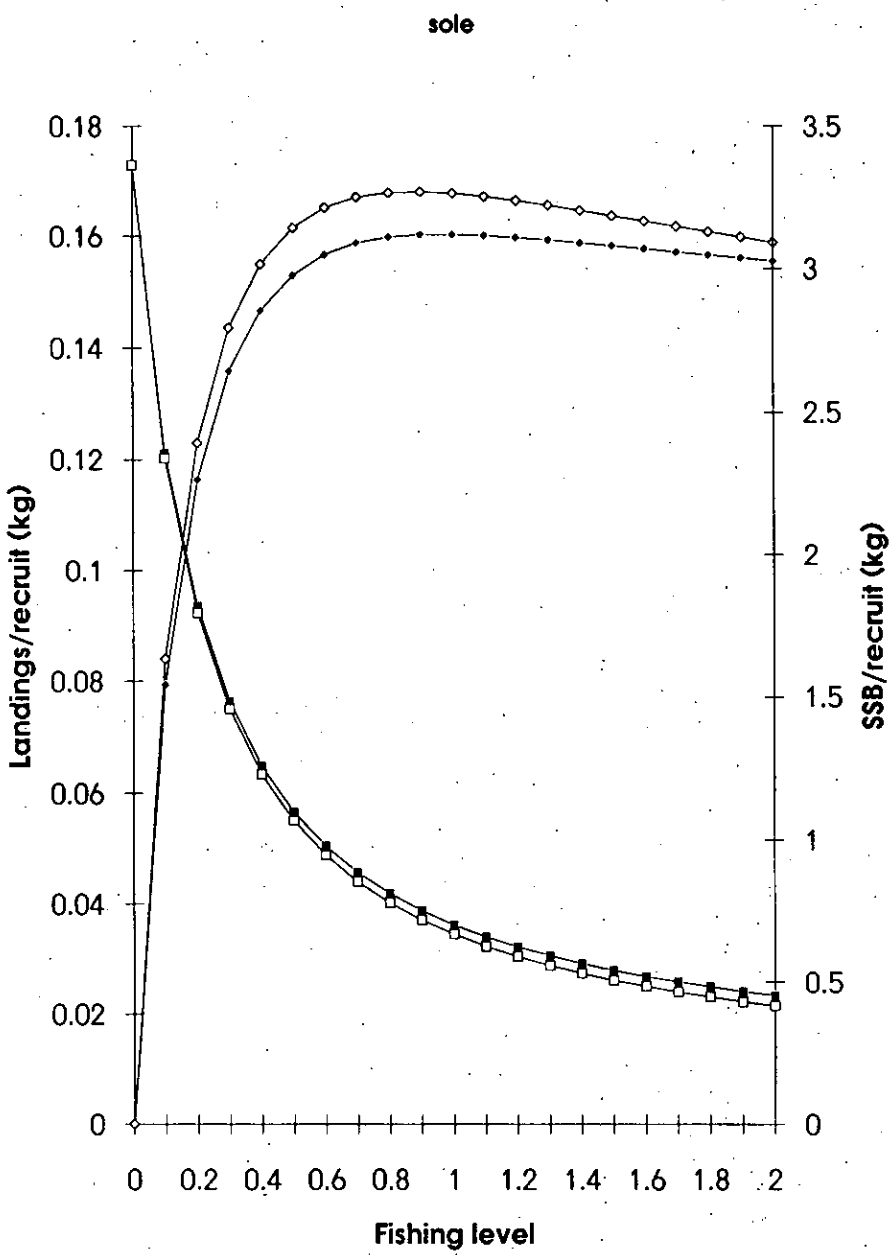

Figure 4. Yield and spawning stock biomass per-recruit analysis results for sole. Fishing level expresses reference fishing mortality relative to the 1989 level from VPA. Closed diamonds indicate landings predicted from the ICES assessment; open diamonds indicate landings predicted from the revised assessment including estimated discards; closed squares indicate spawning stock biomass predicted from the ICES assessment; open squares indicate spawning stock biomass predicted from the revised assessment including estimated discards.

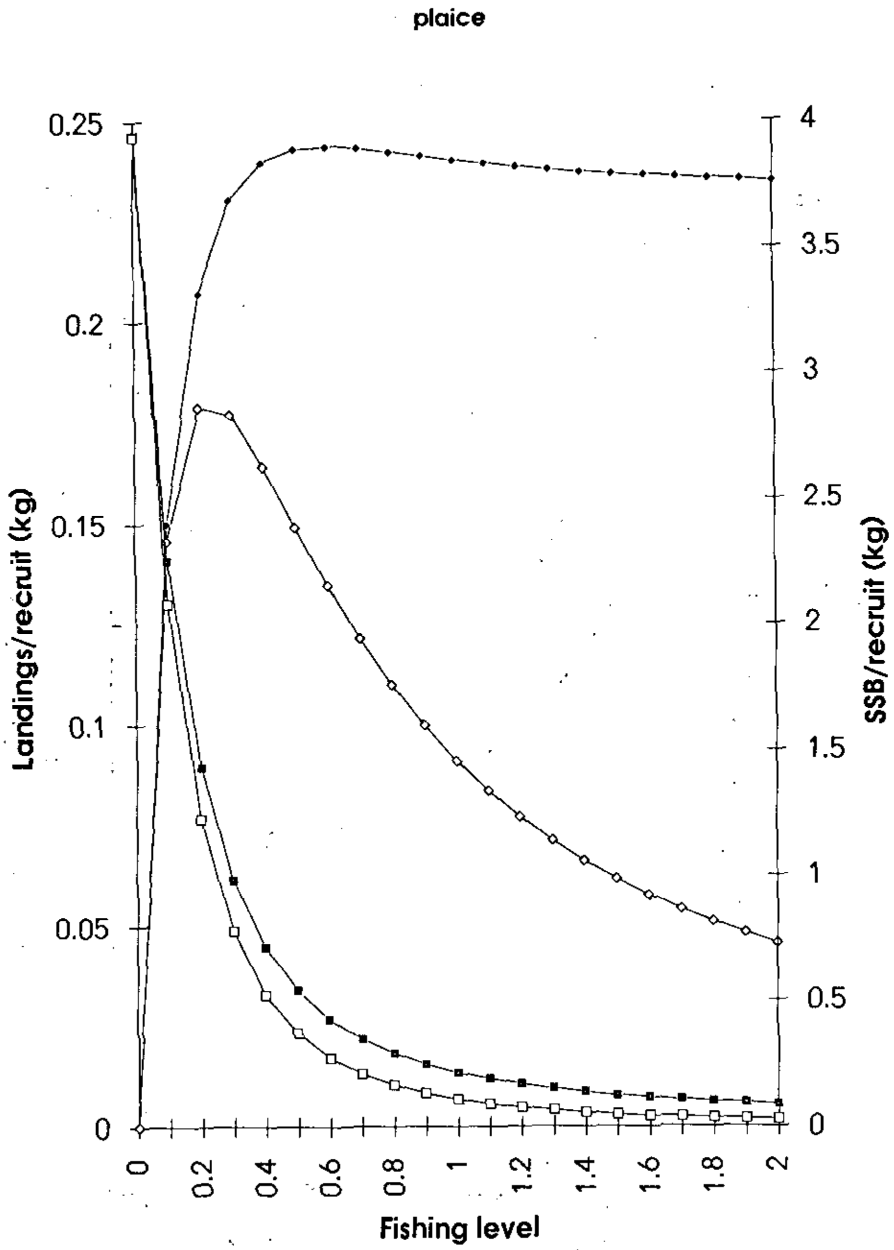

Figure 5. Yield and spawning stock biomass per-recruit analysis results for plaice. Fishing level expresses reference fishing mortality relative to the 1989 level from VPA. Closed diamonds indicate landings predicted from the ICES assessment; open diamonds indicate landings predicted from the revised assessment including estimated discards; closed squares indicate spawning stock biomass predicted from the ICES assessment; open squares indicate spawning stock biomass predicted from the revised assessment including estimated discards.

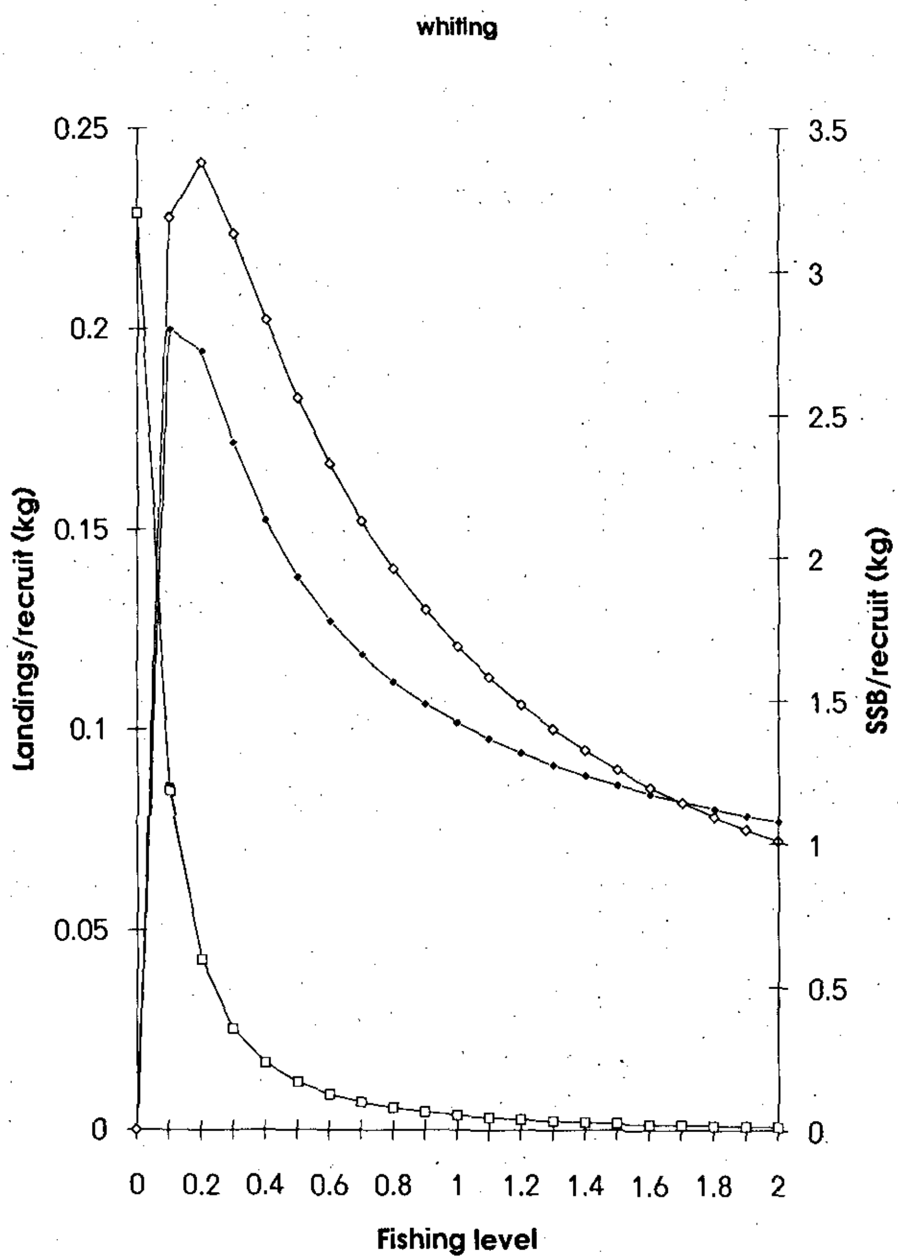

Figure 6 Yield and spawning stock biomass per-recruit analysis results for whiting. Fishing level expresses reference fishing mortality relative to the 1989 level from VPA. Closed diamonds indicate landings predicted from the ICES assessment; open diamonds indicate landings predicted from the revised assessment including estimated discards; closed squares indicate spawning stock biomass predicted from the ICES assessment; open squares indicate spawning stock biomass predicted from the revised assessment including estimated discards.

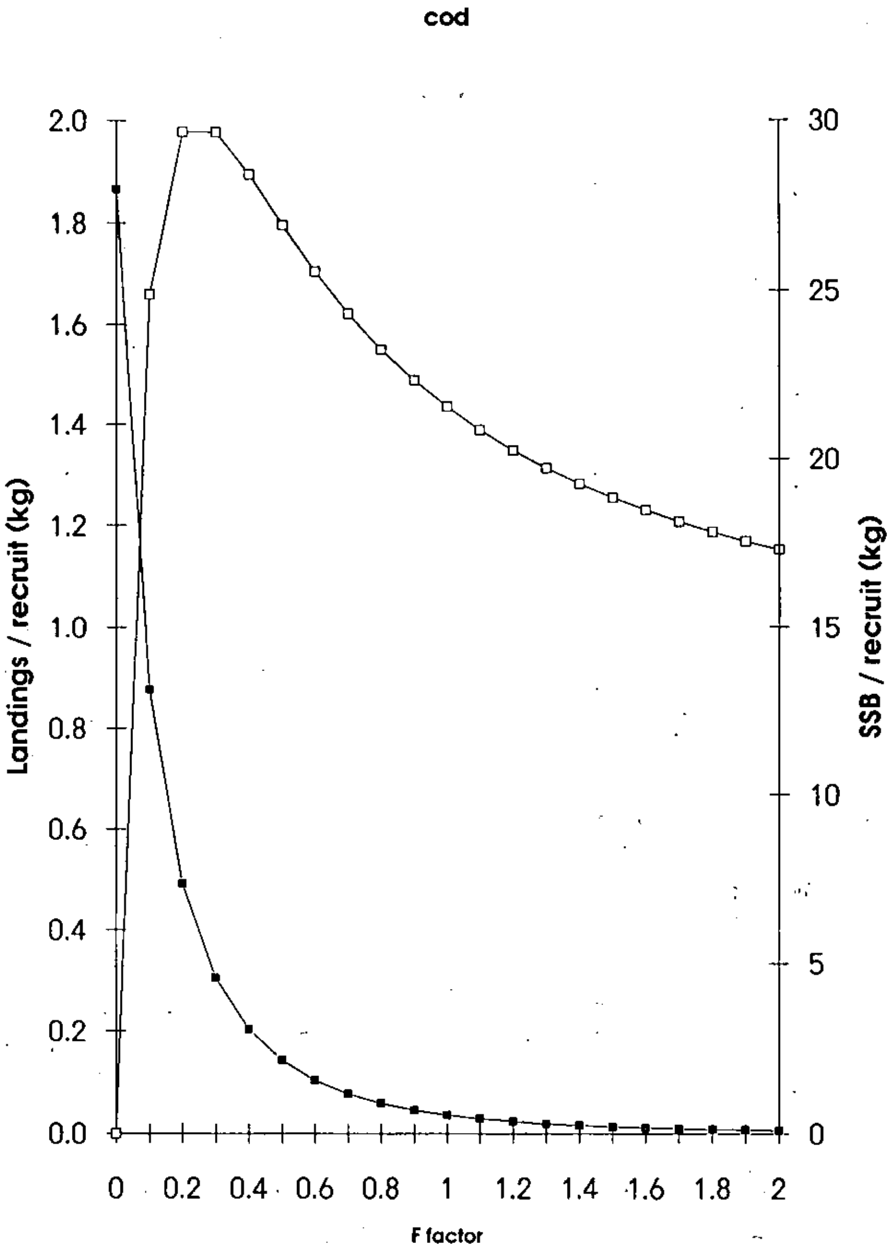

Figure 7. Yield and spawning stock biomass per-recruit analysis results for cod. Fishing level expresses reference fishing mortality relative to the 1989 level from VPA. Results are shown for the ICES assessment only, Open squares indicate landings; closed squares indicate spawning stock biomass.

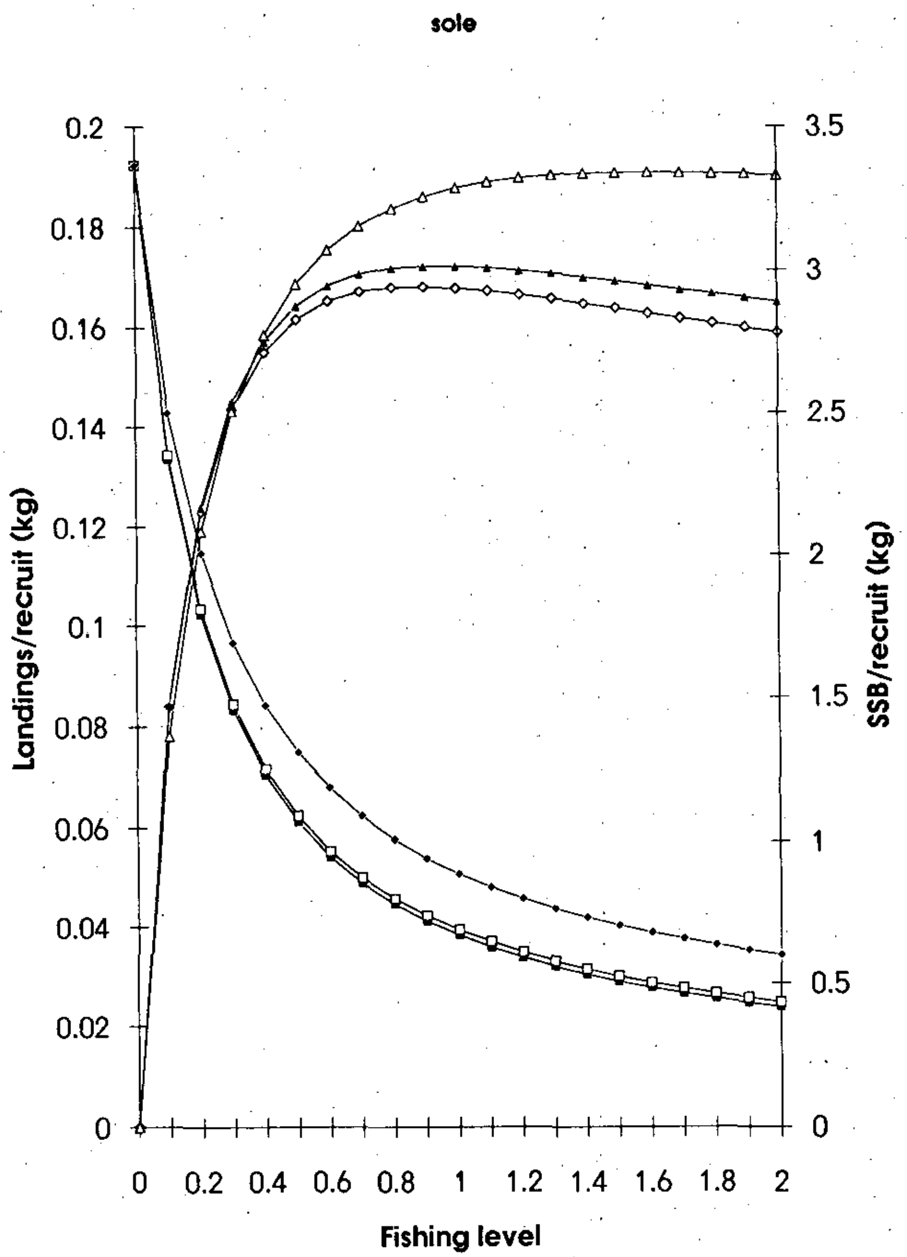

Figure 8. Yield and spawning stock biomass-per-recruit analysis results for sole using different exploitation patterns. Open diamonds, closed triangles and open triangles indicate landings and closed squares, open squares and closed diamonds indicate spawing stock biomass for the 1989, 80mm and 90mm exploitation patterns respectively.

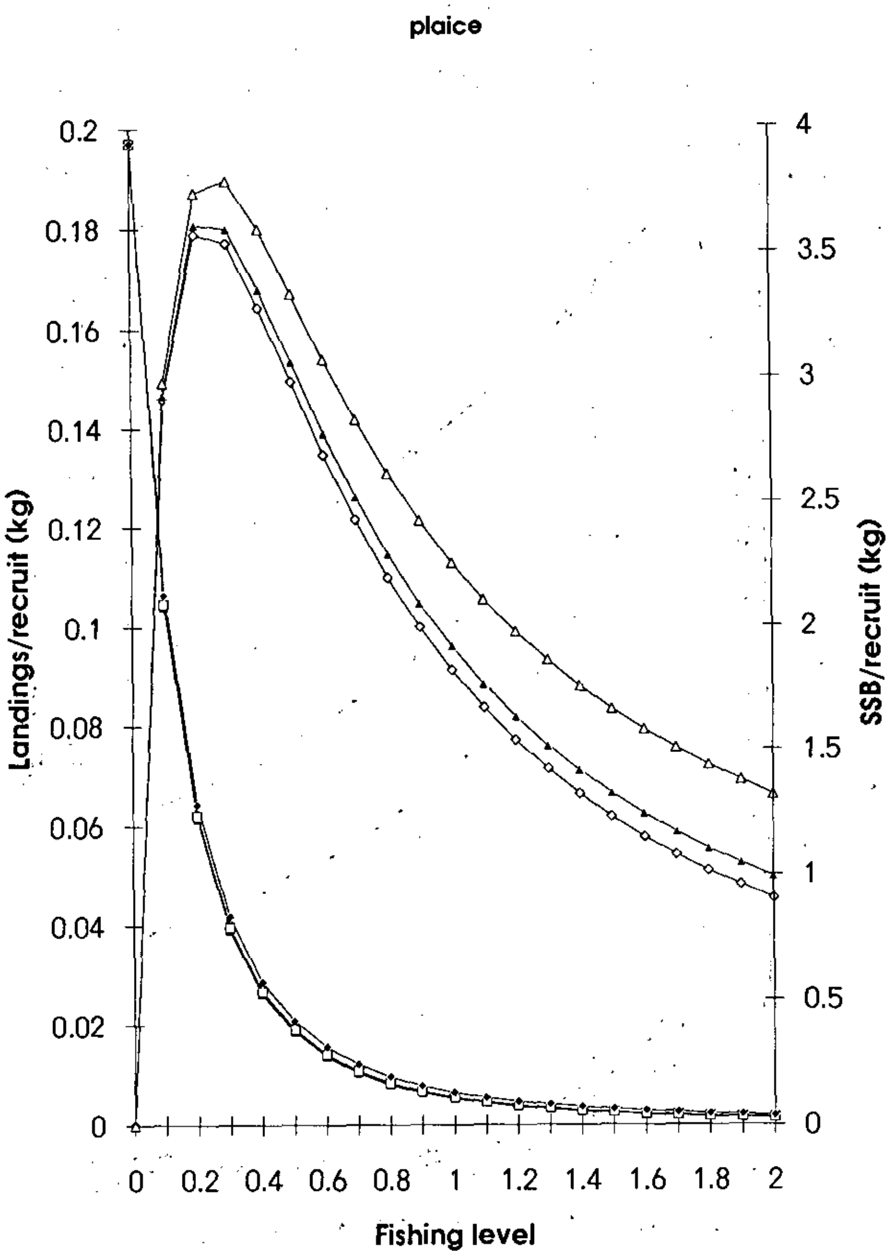

Figure 9. Yield and spawning stock biomass-per-recruit analysis results for plaice using different exploitation patterns. Open diamonds, closed triangles and open triangles indicate landings and closed squares, open squares and closed diamonds indicate spawing stock biomass for the 1989, 80mm and 90mm exploitation patterns respectively.

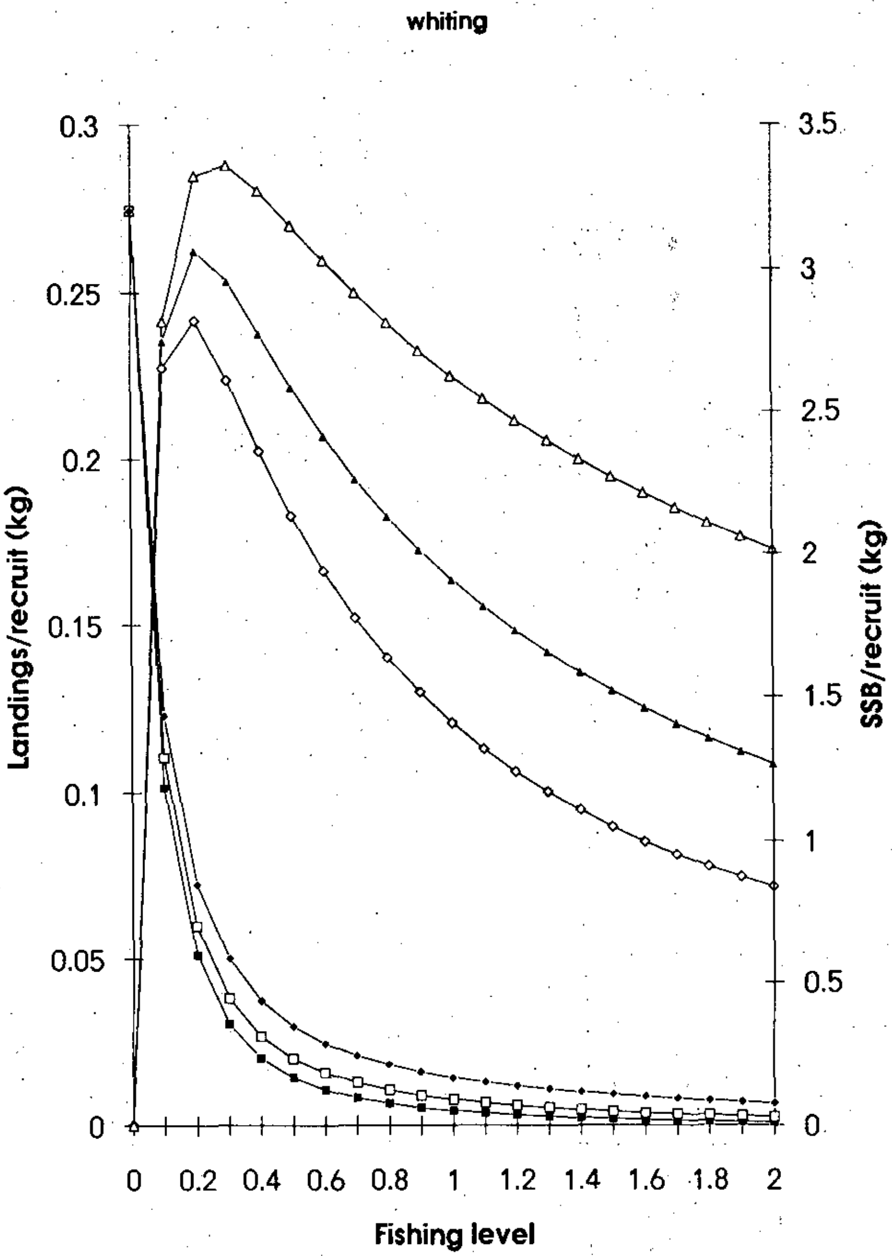

Figure 10. Yield and spawning stock biomass-per-recruit analysis results for whiting using different exploitation patterns. Open diamonds, closed triangles and open triangles indicate landings and closed squares, open squares and closed diamonds indicate spawing stock biomass for the 1989, 80mm and 90mm exploitation patterns respectively.

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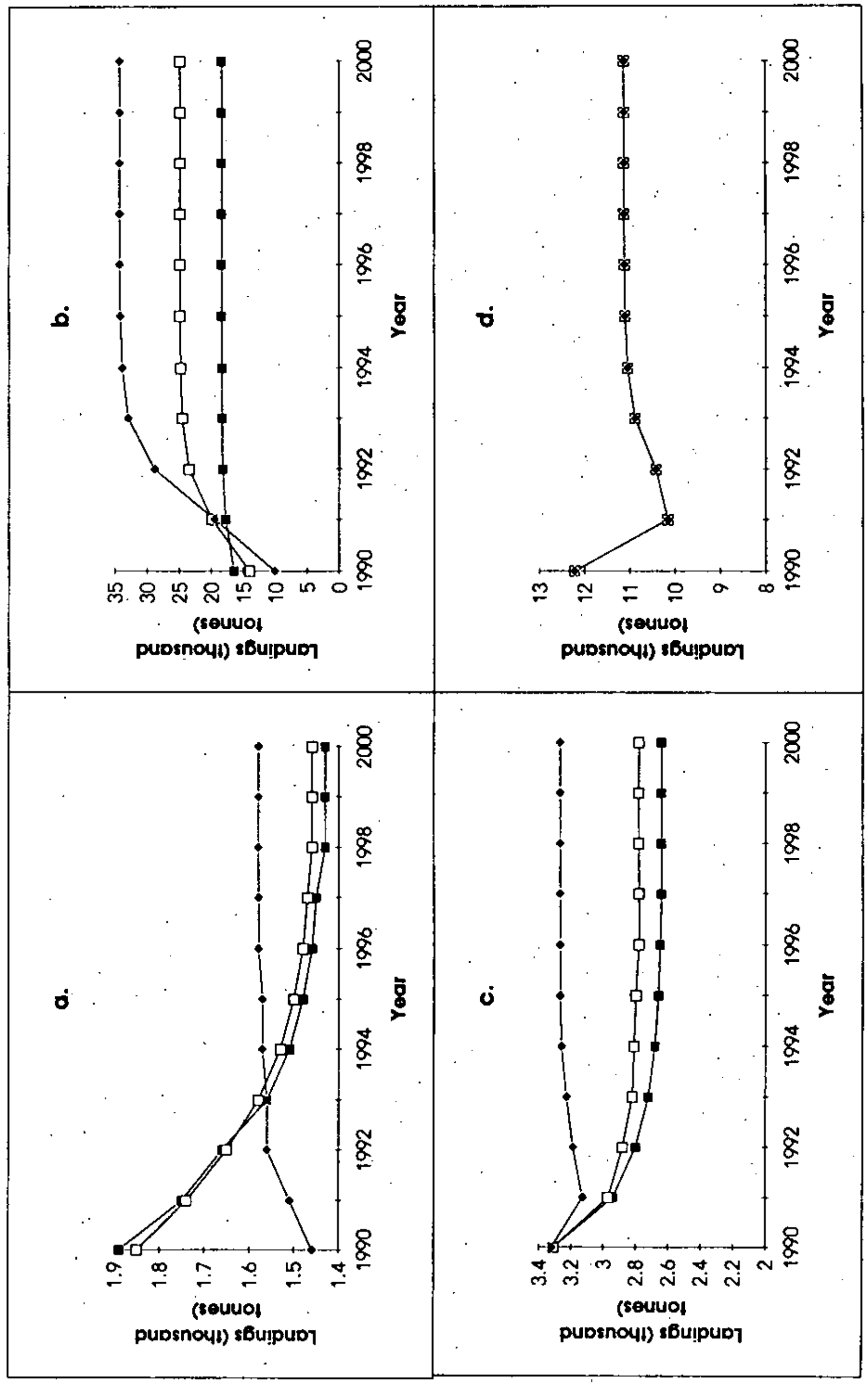

Figure 11

Figure 11: Annual catch predictions for a. sole; b. whiting; c. plaice; d. cod, assuming different exploitation patterns. Closed squares, open squares and closed diamonds indicate results for the 1989, 80mm and 90mm exploitation patterns respectively.