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REPORT OF THE STUDY GROUP ON THE USE OF SELECTIVITY MEASUREMENTS IN STOCK ASSESSMENT

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1.2 **Terms of Reference**

A study Group on the use of Selectivity Measurements in Stock Assessment will be established under the chairmanship of Dr R. M. Cook (UK) and will meet in Woods Hole, USA from 19-20 April, 1996 to:

a) Evaluate whether selectivity parameters obtained under experimental conditions are good predictors of the selectivity of commercial fleets using the same nominal mesh size;

b) suggest ways in which experimentally obtained selectivity parameters can be translated into whole fleet selectivity estimates;

c) consider ways in which estimates of selectivity parameters obtained in different experiments on the same nominal mesh size can be used to derive a unified estimate.

1.3 **Background**

Stock assessments, which evaluate the effect of a mesh change in a fishery, use selectivity data obtained from experiments conducted under controlled conditions. For practical reasons such experiments are limited to a few vessels in a small range of conditions. In performing the assessment, the assumption is made that experimental estimates of selectivity are representative of whole fleets operating under commercial conditions. It is unlikely that this assumption is correct and this may have a potentially important effect on any assessment. Therefore, there is need to determine the extent to which fleet selectivity differs from parameters estimated experimentally and to investigate methods which can predict fleet selectivity from such experiments. In addition, experiments examining the same nominal cod-end mesh size often give differing selectivity estimates. These differences should be resolved to determine whether they are due to imprecision in the estimates, due to natural variation in selectivity between experiments or are simply inconsistent. An exploratory analysis is required in order to identify the most promising way forward.

1.4 **Procedure for measuring cod-end selectivity**

There are five different approved methods of measuring cod-end selectivity. These are fully described in a forthcoming ICES Cooperative Research Report (Wileman *et al.*, 1996).

The first and most widely used method is the covered cod-end method. The test cod-end is totally enclosed by a small mesh cover which is fitted with semi-rigid hoops to hold it clear of the cod-end. The sum of the catches in the test cod-end and cover give an estimate of the population entering the cod-end. The cover extends well behind the cod-end to minimise the effect of the cover catch on the flow in the test cod-end and on the escape behaviour of the fish.

The remaining four methods - twin trawl, trouser trawl, parallel and alternate haul - all fall into the category of "paired gears" where the population entering the cod-end is not measured directly but estimated by towing a separate small mesh cod-end attached to the paired gear. In the twin trawl case, a vessel tows two trawls side by side which are as nearly identical as practical except for their cod-ends. One trawl has the test cod-end and the other the small mesh cod-end. The trouser trawl is divided down its centre-line by a vertical panel extending from the trawl mouth to the cod-end mouth. The aft sections of the trawl may be redesigned such that two cod-ends of similar dimensions (the test and small mesh cod-ends) may be attached. In the parallel haul method two vessels of similar specification tow alongside each other towing similar trawls except that the test cod-end is attached to one and the small mesh cod-end to the other. In the alternate haul technique one vessel tows its trawl alternately on successive hauls with the test cod-end and a small mesh cod-end.

Many old data sets prior to 1991 using the covered cod-end method may provide biassed selection parameters because hoops were not fitted and it is likely that selection was inhibited by the masking effect of the test cod-end meshes by the small mesh cover meshes.

Measurements are taken to determine accurately the length/frequency of the target species in the test cod-end and small mesh cover or cod-end, sub-sampling if catches are large. Measurements are also taken of cod-end mesh opening (inside knot measurement) and total catch weight. Mesh size measurements are made with the ICES gauge in order to achieve standardisation between data sets. These measurements will not correspond to those obtained with the wedge gauge usually used by fishery inspectors for enforcement purposes. For example in the North Sea, measurements made with the ICES gauge with 4 kg tension should be increased by approximately 4% to give the equivalent measurement for the EU wedge gauge with 5 kg hanging weight as prescribed in the legislation.

A mathematical model for the selection curve (probability of retention in the test cod-end of a fish of given length entering the cod-end) is fitted to the data. A modern data analysis method would first determine the parameters describing the selection curve for each haul, fitting to the numbers of fish actually measured (rather than the raised numbers after taking account of sub-sampling). The final model of the selection of a cod-end would be characterised by the mean selectivity parameters over the hauls during which it was used and their haul-to-haul variance.

In recent years selectivity measurements have primarily been carried out either

- to determine the effects of gear design parameters such as mesh size, cod-end circumference, cod-end length and twine thickness upon selectivity,

- to determine whether innovative new designs of cod-end have different selection properties to those of conventional commercial cod-ends.

1.5 **The use of selectivity data**

There is a practical question of how to use selectivity data in assessments. It is worth briefly considering one of the most common methods for evaluating the effect of a mesh size change on an exploited stock. In essence all that is done is to re-calculate a new set of age dependent fishing mortalities based on the new mesh size using the formula;

$$F_{new}=F_{old}\left(\frac{s_{new}}{s_{old}}\right) \qquad \textbf{(1)}$$

where "old" and "new" refer to the old and new mesh sizes. The parameters, *s*, are calculated directly from selectivity ogives derived from experiments. The new fishing mortalities can then be used in any assessment model.

Equation (1) implicitly makes the assumption that the ratio of the Ss is representative of whole fleets whereas in general the estimates come from controlled experiments which consider cod-end selectivity. It should also be noted that usually equation (1) is applied to age based data while in reality, selection operates on size. Thus there are questions of whether the appropriate parameter estimates are used in assessments and whether age based calculations are satisfactory approximations to an essentially size based process.

2 A REVIEW OF THE USE OF SELECTIVITY MEASUREMENTS IN ASSESSMENTS

2.1 **Introduction.**

This short review by Reeves (WD2) is concerned with the use of data in the selectivity of fishing gears in the context of fish stock assessment. This can be taken to imply a narrower context where the fisheries concerned are generally managed on the basis of annual stock assessments, and the management also involves some form of regulation of gear characteristics. The review is biassed towards the fisheries of the North Atlantic.

2.2 **Mesh Assessment**

2.2.1 Theory and Methodology

The main use of selectivity data in a stock-assessment context is in the area of mesh assessment, that is the assessment of the effects of changes in the selectivity of fishing gear on the short and long term yields from a fishery. Much of the theoretical basis for this is first laid-out by Beverton and Holt (1957) who then go on to discuss the potential regulation of the North Sea demersal fisheries, and investigate the effects of a 15% reduction in effort and an increase in mesh size from 70 mm to 80mm. They focus particularly on plaice and haddock, and their calculations use selectivity data for these two species. Other references from the same era address similar problems but tend not to use actual selectivity data. In particular, Gulland (1957) considers the effects of assuming knife-edge selection rather than a selectivity ogive, and Jones (1961) uses hypothetical selectivity curves for two gill nets. In later papers Jones (1984a) also discusses the role of mesh size regulation in fisheries management and (Jones, 1984b) reviews methods of performing assessments using length data and discusses the methodology for performing a mesh assessment in with such data. Cadima (1968) gives a worked example of a mesh assessment using data for Faeroese haddock.

Using traditional Beverton-Holt models, Hoydal *et al* (1982) develop a model to estimate the effective mesh sizes used by different fleets fishing the same stock. The model can then be used to investigate the effects of changing the mesh sizes of the various fleets. The procedure estimates a value for L_{50} using the observed length-distribution of the commercial catches, and values for the selection factor and the 'steepness' of the selectivity curve (i.e. L_{75}/L_{50}) which are assumed to have been previously determined by selectivity trials. The steepness of the selectivity curve is assumed to remain constant with mesh size, implying that the slope of the selectivity curve decreases as mesh size increases. This paper draws on earlier work by Hoydal (1977) and Sparre (1980) as well as unpublished work by K P Anderson. Mesnil and Shepherd (1990) develop a similar model which more explicitly deals with multi-fleet, multi-species fisheries, and uses both length and age data. Information about the distribution of length at age is used to allow the effects of a change in gear selectivity to be modelled. The paper also reviews methods of converting length compositions into age compositions. Conversion between length at age can also lead to problems in estimating mean weight at age. Macer (1991) discusses biases which can occur in this situation.

2.2.2 Mesh Assessment in practice.

The most straightforward application of mesh assessment is to estimate the short and long-term consequences of a proposed change in mesh size in a fishery. In this form, mesh assessment is a fairly routine part of stock assessment. For instance, van Beek (1982) notes that the ICES Flatfish Working Group carried out mesh assessments on North Sea sole in 1968, 1974 and 1981. Thus, rather than attempt to list every example of a mesh assessment to be found in the literature, the text below gives just a few selected examples, with the emphasis on the North Atlantic. Bennett (1984) reviews the data available and previous mesh assessments for demersal stocks in the Irish and Celtic Seas, and investigates various mesh assessment techniques in this context. Waldron *et al* (1985) estimate the potential effects of a proposed change in minimum mesh size from 120mm to 130mm in the groundfish fishery off southern Nova Scotia. Caramelo (1988) uses the method of Jones (1984b) to investigate the effects of a change in mesh size on the stocks of *Nephrops norvegicus* in Portuguese waters, and Trujillo *et al* (1991) use the model developed by Mesnil and Shepherd (1990) to do a multi-species, multi-fleet mesh assessment for the fisheries of the Iberian Peninsula (ICES areas VIIIc and IXa). The 1990 ICES Roundfish Working Group (Anon. 1991) use the selectivity models of Reeves *et al* (1992) to perform mesh assessments for the roundfish stocks of the North Sea and west of Scotland. These take account of variations in selectivity with other aspects of cod-end construction as well as mesh size.

As well as this simplest form of mesh assessment, similar techniques can also be used to estimate the optimum mesh size for use in particular fishery. This can be of particular importance in tropical fisheries where a large number of species are involved. Such fisheries are beyond the scope of this review (but see e.g. Sainsbury, 1984), but such considerations can also apply in even single-species fisheries. Blinov (1986a) devises a method for determining the optimum mesh size in the Arcto-Norwegian cod fishery, and also applies the method to redfish in the North Atlantic (Blinov, 1986b). Macer (1982) estimates what mesh sizes would be optimal for cod, haddock and whiting in the North Sea if these stock were fishes as single-species fisheries, and determination of the theoretical optimum mesh size also forms part of the Irish and Celtic Sea review of Bennett (1984).

Basic mesh assessment methodology can also be incorporated into broader investigations of fisheries and their exploitation. The mesh assessment performed by Suuronen *et al* (1992) for herring in the Baltic, considers variation in natural mortality and growth as well as mesh size, and Schweigert *et al* (1984) investigate the potential change in roe yield of a change in gillnet mesh size in a herring roe fishery, and thus consider variation in roe yield with length and age, as well as mesh size. Hylen and Rørvik (1983) investigate the use of a modified version of the model of Hoydal *et al* (1982) to estimate the maturity ogive for Arctic Cod. Murawski (1984) uses selectivity data in a multi-species, multi-fleet yield-per-recruit model, with particular reference to the mixed-species trawl fisheries of the Georges Bank. Pikitch (1987) uses a similar model to investigate the effects of various management policies, including different mesh sizes, on the Oregon flatfish fishery. The study by Doubleday *et al* (1984) on the deep water redfish fishery in the North-west Atlantic, allows for variation in partial recruitment with sex and depth by applying mesh selection ogives to survey length compositions from different depths. These results are then used to estimate yield per recruit. Huson *et al* (1984) extend the study to consider the effects of depth and mesh size on the financial performance of part of the redfish fleet by translating the effects of mesh size on catch rate, size of fish in the catch, and long term catches into financial terms.

2.3 **Other Applications.**

2.3.1 Selectivity and the estimation of discards.

Casey (1993) uses selectivity data to infer discard data for the mixed demersal fisheries of the Irish Sea. The available landings-at-age data are corrected to catches-at-age using selectivity ogives for each fleet and species, and information about the distribution of length at age for each species. Discards are then inferred assuming a discard ogive centred on the minimum landing size and applying this to the catch-at-age data. McBride (1991) corrects length compositions of landings of Barents Sea cod to total catch using survey length compositions and a selectivity ogive in order to estimate discards. In this case however, the selectivity ogive used, does not seem to correspond to the gear in use in the fishery, so the results are of questionable value.

2.3.2 Selectivity in virtual population analysis

Although estimation of selectivity-at-age forms a part of some VPA-type models (e.g. Doubleday, 1976), selectivity data are not routinely used in the fitting of such models. Deriso *et al* (1985) consider a range of different catch-at-age models, of which only the relatively simple Relative Abundance Analysis can explicitly use selectivity data. The Catch at Size Analysis of Sullivan *et al* (1985) is a length-based assessment technique which uses a modification of the selectivity-at-age function used by Deriso *et al* (1985), and which allows the user to specify selectivity parameters if these are known.

3. SUMMARY OF PRESENTATIONS AND WORKING DOCUMENTS

3.1 **Recent Scottish Cod-end Selectivity Estimates**

In WD1 Ferro describes recent results from selectivity experiments carried out in Scotland. In 1991 improved methods of measuring cod-end selectivity were introduced at the Marine Laboratory. Semi-rigid hoops were attached to the cod-end cover to hold the cover away from the cod-end. The twin trawl method was also used occasionally.

During the five years from 1991 to 1996, a series of selection trials have been undertaken on commercial fishing vessels (engine power from approx 300 to 900 hp) using these two methods on a range of different gear types - single boat trawls, pair trawls and a pair seine. The aim has been not only to determine the selection characteristics of typical commercial gears but also to assess the effect of cod-end design (eg meshes round the cod-end circumference, twine thickness, lifting bag) and other factors (eg season) on selection. No experiment during this time however, has investigated the variation of extension length.

Each cod-end was tested for three or more hauls (usually four or five, occasionally over 10) and the results combined, taking account of between-haul variance (Fryer, 1991) to give a mean selectivity for each cod-end. The 50% retention length and selection range for each cod-end were obtained. In some cases the experiment was designed so that a range of mesh sizes and number of meshes round the cod-end were tested and a model of selectivity was developed with these quantities as variables. In these cases the derived model has been used to determine the selection parameters for each cod-end tested.

The results for three species are available, although sufficient cod were found only during one pair seine and two pair trawl trips.

Mesh sizes were measured using the ICES gauge with a 4 kg spring. The ICES gauge is considered to give readings which are approximately 4% lower than the standard EU wedge gauge with a 5 kg weight hanging on it. Hence selection factors equivalent to the wedge gauge are obtained by multiplying by a factor of 0.96.

Most cod-ends are made of 3.5 to 4 mm double polyethylene twine. Two cases with thicker twine are included. The number of open meshes round the cod-end circumference was varied in some trials. The meshes gathered in the selvedge are not included. Hence 120 total meshes round the circumference means 100 open meshes approximately.

Haddock

(a) 50% retention length

There is a clear increase in 50% retention length (L50) with mesh size and L50 reduces with an increase in meshes round the cod-end circumference. The thick twine cases show poor selection. There is little evidence of a gear type effect.

(b) Selection range

There is no clear relation between selection range and either meshes round or mesh size or gear type.

Whiting

(a) 50% retention length

A variation with mesh size and meshes round is evident but no systematic differences between gear type.

(b) Selection range

There is an apparent difference between selection ranges for single and pair boat cod-ends - the latter being higher. However, it is possible that this is an artefact of the choice of models for the pair boat data sets. Meshes round were varied only in the pair boat experiments and no significant relation between selection parameters and meshes round was found.

For the single boat data alone for cod-ends with 100 open meshes round, a variation with mesh size is evident.

Cod

(a) 50% retention length

A variation with mesh size and meshes round was found.

(b) Selection range

The selection ranges for all cod-ends are well scattered for these mesh sizes and for these gear types.

The selection factors (based on both ICES and wedge gauge mesh measurements) and mean selection ranges for cod-ends with 100 open meshes in circumference (excluding the meshes in the selvedge) are given below:

	Selection factor		Selection
	ICES Gauge	Wedge Gauge	range (cm)
Cod	3.40	3.26	7.35
Haddock	2.99	2.87	6.31
Whiting	3.46	3.32	6.95

The estimates based on wedge gauge mesh sizes are more appropriate for calculating the fishing mortality of commercial fleets.

There is little justification for taking individual selection ranges for each species. In the past a mean selection range of 7 has been taken for all gears and all these three round fish species.

3.2 **Estimation of Selectivity Parameters from Stock Assessments**

A working document by Cook (WD3 and annex 1) describes a simple method for estimating the selectivity parameters, L50 and L25, for fishing fleets using conventional stock assessment data. Fishing mortality rates at age for two Scottish fleets, demersal seiners and trawlers, and three stocks, cod, haddock and whiting, were partitioned from the international fishing mortality rate matrix obtained from the standard ICES assessments. Given certain assumptions, the fishing mortality rate at age can be equated to the gear selectivity at age. This in turn can be rescaled to selectivity at length by relating the fishing mortality at age to the mean length at age. Selectivity curves were then fitted to the fishing mortality at length to estimate the selectivity parameters. The parameters calculated in this way should be estimates of whole fleet, whole gear selectivity and can be compared with the values obtained under experimental conditions.

In the paper the selectivity parameter estimates from the assessment data are compared to the experimentally calculated values obtained from the so-called "Armstrong model" (Reeves *et al* 1992). The agreement between the two methods appears to be very close. However, the assumption of 100 meshes in total around the cod-end is probably too low and 120 meshes would be more realistic. This means that the values obtained from the Armstrong model are too large and should be revised downwards. This would imply that the selectivity of commercial gears is much better than would be predicted from experiments on cod-ends of the same mesh size. This is somewhat counter-intuitive.

The experimentally derived selectivity estimates used in the Armstrong model were based on the covered cod-end technique which is known to be biased (Section 1.4). More recent experiments using the hooped cod-end method reported by Ferro (WD1) give more up to date estimates of the selectivity parameters for trawls. These estimates are in close agreement with the values obtained from the assessment data and are given in the Table below.

	L50		L25	
Species	**Assess**	**Expt**	**Assess**	**Expt**
Cod	32.8	32.6	29.9	29.0
Haddock	28.6	28.7	26.1	25.5
Whiting	30.1	33.2	27.9	29.7

This very preliminary analysis would suggest that the experimental values, even though derived from a few vessels, give good estimates of the required parameters. The agreement is surprisingly close given the simplifying assumptions in calculating the assessment based values and the fact that the two methods do not really measure the same thing. It would be worth extending this analysis to other stocks and fleets to see whether this apparent agreement is more than fortuitous.

Fleet - gear specific selectivities have also been derived for both cod stocks present in the Gulf of St. Lawrence (Fréchet et Chouinard, 1987). The fishing mortalities were partitioned into various fishing gear categories. For the northern part of the Gulf (3Pn,4RS cod) selection patterns were calculated for traps, gillnets, longlines and otter-trawls. For the southern stock (4T 4Vn January to April) the gear specific selectivities were calculated for the fixed and mobile gear components only.

The resulting partial recruitment vectors were used to derive fishable biomass for each gear sector. Length based selectivity curves could be calculated by either using average length at age or the age-length key and would thus allow to calculate standard selectivity parameters like L25, L50 and L75.

3.3 **Combining several estimates of Selectivity Parameters**

WD4 (Annex 2) discussed ways of combining selectivity estimates from several experimental trials to obtain either:

- an improved estimate of the selectivity of an experimental cod-end,
- an estimate of "fleet selectivity", where the trials have been carried out on different vessels.

The problem is similar to that of combining selectivity estimates from several hauls to estimate the selectivity of a cod-end. Methods for the latter are well established (eg Fryer, 1991; Millar, 1993; Wileman et a*l*, 1996, Chapter 6) and can be adapted to combine estimates over trials.

The WD showed how a fixed and random effects model for combining selectivity estimates over hauls, could be modified to combine selectivity estimates over trials. The essential difference is that between-haul variation in selectivity is replaced by between-trial variation. The method was applied to a small data set of trials conducted on single trawls with 100 mm mesh.

Issues concerning the estimation of fleet selectivity were discussed. These included:

- Effects that might be important: eg,
    - random effects such as between-vessel, -trip, and -haul variation,
    - fixed effects such as horse-power and season.
- Possible definitions of fleet selectivity: eg
    - the mean selectivity curve from a (super-population) distribution that describes how selectivity varies between vessels,
    - the average of the (realised)

selectivity parameters for each vessel in the fleet,
- a weighted average of the selectivity parameters for each vessel in the fleet, with weights related to the catch of each vessel.

-Sampling implications: eg,
- vessels chosen for other experimental purposes could probably be used, as long as there was no systematic bias in the way they were chosen (such as only small boats),
- a sampling programme designed to estimate fleet selectivity might choose vessels at (stratified) random, or with probability proportional to catch.

It was noted that the term "vessel selectivity" can be ambiguous, since a vessel might fish with several nets, each with quite different selectivities. The selectivity of the vessel would then be some composite of the selectivities of these nets.

3.4 Estimation of Selectivity Parameters from Tagging Data

Cod selectivity in commercial fishing gears, both static and towed gears was estimated from tagging data using generalized linear models (Myers and Hoenig; 1996). Use of tagging data gives a direct estimate of selectivity in oppose to common indirect methods where selectivity is derived from VPA or catch rate comparisons with two gears. A change in otter trawl selectivity was demonstrated, implying that the assumption of constant selectivity over time, as used in assessment models, was violated. This type of analysis requires an extensive tagging database.

3.5 Estimation of selectivity Parameters using Research Vessel Data

Length compositions of cod, haddock and whiting were compared for commercial catches and groundfish surveys in the northern North Sea (roundfish area 1) in 1991 (Macer, WD5). The commercial data were quarterly length compositions for landings and discards for all Scottish gears. The survey data were obtained from the International Young Fish Survey (quarter 1) and the English groundfish surveys (quarters 2-4). These surveys were carried out with the GOV trawl, except for the third quarter, when a Granton trawl was used. A small mesh liner was used in all surveys and all data were in 1 cm groups. Each length composition was normalised to the numbers caught over length groups 30-45 cm for cod and haddock and 33-42 cm for whiting (lengths that should have been fully selected and well represented in the catches). Because they were erratic at the extremes of the ranges, the survey data were smoothed by taking running 5 cm means. Selection ratios were calculated for each length group as the ratio of the normalised commercial catch to the normalised survey catch.

The ratios for cod were very variable especially for quarters 1 and 2; for quarters 3 and 4 the mean selection length was around 26 cm. The variability probably reflects high variability in the discard data, as well as the fact that small cod are less common in the northern North Sea than they are in the south. The haddock data, which were less variable, indicated selection lengths of 26 cm (quarter 2), 28 cm (quarter 1) and 31 cm (quarters 3 & 4). The catch ratios for whiting were noisy, especially for quarter 1, probably because of low catchability in the survey. Mean selection lengths ranged from 23 cm (quarter 4) to 29 cm (quarter 3).

Reported experimental results indicated a selection factor of about 3, which implied a mean selection length of 27 cm for the minimum mesh size of 90 mm in force in the North Sea in 1991. This was in reasonable accord with the values obtained from the standardised catch ratios. However, there were clearly problems with variability in the data (due, for example, to escapement of small cod below the footrope of the survey trawl) and these were likely to preclude accurate assessments of mean selection length by this method. Because of the difficulties of estimating discards, it was concluded that experimental methods were likely to provide more accurate estimates.

4. FUTURE WORK

4.1 **Introduction**

At this short preliminary meeting it was not possible to undertake any substantial work other than to review the working papers prepared beforehand. These working documents served to illustrate the areas of work which might be worth pursuing in future. Following discussion a number of possible topics for further work were identified which could be taken forward at possible subsequent meetings. These topics were selected on the basis of priorities in developing better selectivity assessments, data availability and the appropriateness to the range of expertise among the participants. The four main topics for further work are discussed below.

4.2 **Estimates of selectivity parameters**

Usually the selectivity parameters used in assessments are taken from controlled experiments obtained from a very small number of sample vessels and gears. It is desirable to try to validate these estimates against values obtained from other methods. Working document WD3 (annex 1) describes on way of obtaining selectivity estimates from conventional stock assessments such as VPA. It is also possible to make selectivity estimates from research vessel data (see section 3.5, Macer WD5) and from tagging data (Myers and Hoenig, in press). The Study group felt that it would be fruitful to make a more comprehensive comparison of selectivity parameters obtained from different methods. This would help validate experimental values used.

In order to carry out such a comparison it is necessary to have data both from selectivity experiments, conventional stock assessments and research vessel data. A number of potential data sets were identified which include:

a) North Sea cod, haddock, whiting, sole and plaice for otter and beam trawls,

b) Barents Sea cod and haddock for trawls

c) Cod in the Scotia/Fundy area for trawls

There may be in addition data for gill nets for cod and sole in the North Sea.

It is proposed that data for these stocks and fleets could be assembled prior to analysis at a future meeting using methodology of the type described in WD3 and WD5.

4.3. **Quality of selectivity assessments**

Most of the analyses done to evaluate the effect of increases in mesh size or comparable increases in gear selectivity are based on modifying the fishing mortality exploitation pattern at age using experimental values for the change in selectivity at length. This process makes many assumptions most of which have not been investigated. Furthermore, assessments of this type rarely make any attempt to estimate the precision of the predictions or to quantify uncertainties as a result of uncertainty in the model parameters. For example, natural mortality is rarely known, yet is likely to have an important effect on yield calculations.

In addition, while mesh size has a large effect on selectivity, other factors, such as cod-end diameter also affect selectivity yet it is not known how important this factor is in the overall selectivity assessment. There is a need, therefore, to investigate the magnitude of the effect of these covariates on selectivity assessments.

WD4, which considers ways of combining selectivity estimates, discusses the possible stochastic variation of selectivity curves by individual vessels or fleets. This variability is due to the selection process and is not estimation error. It may have an important effect on the way in which selectivity assessments are performed.

The Study Group discussed these problems and felt they were important enough to merit investigation. The work required, however, is very considerable since it would involve a substantial number of simulation studies. It is suggested that such studies should be encouraged but may not prove suitable for active investigation during a study group meeting.

4.4 **Survival studies**

Recent studies on survival of fish that escape trawl cod-ends have been conducted both in Scotland and USA over a few years and have shown consistent results. On the west coast of Scotland both length and age based information is available on survival of haddock and whiting. On the east cost of USA, cod, american plaice and yellowtail flounder were studied.

In its progress report, the study group on unaccounted mortality has provided preliminary formulations to include the post-escapement mortality into VPA based assessments.

It is therefore recommended that case studies using available information be conducted in order to assess the impact of including post selection data on fishing mortality.

4.5 **Combination of parameter estimates**

WD4 describes methodology for combining parameter estimates and gives a worked example. However this theory and its application need to be developed further.

Methods for combining selectivity estimates over trials would be applied to larger data sets where available. These would aim to:

- obtain improved estimates for various cod-ends,
- estimate the differences in selectivities between gears, (to see if these are important for assessment purposes),
- estimate between-vessel, and -trip variation in selectivity.

5. CONCLUSIONS

The justification for the study group meeting pointed out the need to have the participation of gear technologists, stock assessment scientists and statisticians. Probably due the timing and location of the meeting, stock assessment expertise was under-represented and the success of any future meetings of the study group will depend on increased participation of assessment biologists. However, the group identified important areas of work which can be pursued since both data and methods are available. Furthermore, the group provides an valuable opportunity for various disciplines to co-operate and exchange ideas and expertise. The group felt that it would be worthwhile having one more meeting of perhaps 5-7 days, probably in Europe in order to pursue the work identified in section 4.

6. WORKING DOCUMENTS

WD1; Ferro, R.S.T. A Summary of Recent Scottish Cod-end Selectivity Data for Haddock, Whiting and Cod.

WD2; Reeves, S.A. Review: The Use of Selectivity Data in Stock Assessment.

WD3; Cook, R.M. and Reeves, S.A. A Comparison of the Selectivity Parameters of Scottish Demersal Seines and Trawls Estimated from Commercial Catch Data and Designed Experiments.

WD4; Fryer, R. J. Estimating Fleet Selectivity from Vessel Selectivity.

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Annex 1

Working paper to Study Group on the Use of Selectivity Measurements in Stock Assessment, April 1996.

A COMPARISON OF THE SELECTIVITY PARAMETERS OF SCOTTISH DEMERSAL SEINES AND TRAWLS ESTIMATED FROM COMMERCIAL CATCH DATA AND DESIGNED EXPERIMENTS

by

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Introduction

Fishing mortality rate is a fundamental parameter used in fish stock assessment and fisheries management. It quantifies the degree of exploitation exerted on fish stocks and is one of the few quantities amenable to modification by managers. In order to modify the mortality rate in pursuit of a management objective, there must be components of it which can be controlled. Usually this can be done by trying to regulate the size of first capture of the fish or the total amount of fishing effort deployed by exploiting vessels.

Fisheries scientists are regularly asked to investigate the effects of increases in mesh size or gear changes which have a similar effect such as the use of square mesh panels. These measures effectively alter the fishing mortality rate by increasing the size at first capture. In order to undertake such calculations, it is necessary to quantify the selectivity of existing gears and that of the proposed modified gear. Assessment scientists, who are called upon to perform these analyses, usually make use of selectivity parameters obtained under controlled experimental conditions. Such experiments are, by necessity, small in scale and it can be argued that the selectivity parameter estimates thus obtained are not representative of whole gears or fleets. If this is the case then the assessment of the effects of mesh size changes may be mis-leading. Clearly, there is a need to establish that selectivity parameters calculated from small scale experiments are adequate for the purpose of broader calculations involving assumptions about the performance of whole fleets.

The paper considers the problem of whole fleet selectivity, in particular the selectivity parameters for Scottish demersal trawls and seines. These are calculated from fishing mortality rates of North Sea cod, haddock and whiting and compared to those obtained experimentally and reported in Reeves *et al* (1992). The analysis shows that the estimated selectivity from the two methods is surprisingly similar.

Exploitation Pattern Models

Typically, fishing mortality in a particular stock is size dependent because most fishing gears allow increasing numbers of smaller fish to escape. This effect is related to the so called selectivity of the gear. Selectivity is one component of the "catchability" of fish. Simply expressed, for a size class, l, fishing mortality rate, F, can be written as the product of a catchability term, q, and fishing effort, E;

$$F_l=q_lE \qquad (1)$$

All other factors being constant, q will be directly proportional to the size selectivity of the gear, i.e;

$$q_l=Qg(l) \qquad (2)$$

where Q is a proportionality constant and the term $g(l)$ is the gear selection curve. It is an undefined function which predicts the proportion of fish of length l retained in the gear. Substituting (2) into (1) we obtain;

$$F_l=Kg(l) \qquad (3)$$

where K is the product QE. Equation (3) shows that for constant K, the fishing mortality rate is proportional to the selectivity of the gear. On the assumption of a constant K, therefore, the size dependent fishing mortality rate is also a measure of the gear selectivity. If the form of the gear selection curve is specified it should be possible to estimate its parameters given estimates of F_l. Selectivity parameters calculated in this way will be estimates based on the actual operation of exploiting fleets. They can be compared to selectivity parameters calculated from controlled experiments.

For towed gears such as trawls and seines, gear selectivity is typically regarded as being sigmoid with respect to the length of fish. The proportion of fish entering the gear which is retained, p_l, can be described by a simple two parameter model of the form;

$$p_l=\frac{1}{1+A_0e^{-A_1l}} \qquad (4)$$

This curve produces the typical selectivity curve with an upper asymptote equal to one. If we set $g(l)=p_l$ then equation (3) becomes;

$$F_l=\frac{K}{1+A_0e^{-A_1l}} \qquad (5)$$

The expression, which is the same shape as equation (4) has an upper asymptote, K, which is the maximum value of fishing mortality rate is plotted in Figure 1a. The conventional selectivity parameters, *L50* and *L25* can then be simply defined as the lengths which satisfy equation (5) for the conditions, $F_l=K/2$ and $F_l=K/4$;

Typically fishing mortality rate does increase with increasing size of fish and the rising part of the curve in Figure 1a is qualitatively descriptive of many exploitation patterns. However, is it frequently observed that estimated exploitation patterns pass through a maximum at intermediate lengths and then decline for the largest fish. The reasons for this could be due to a variety of factors such as size directivity by fishing vessels or the migration of larger fish to inaccessible areas. For descriptive purposes it might be regarded as "deselection" where larger fish, for one reason or another, are less available to the gear. The reduction in availability, a, of fish to the gear with size might be modelled as;

$$a_l=\frac{1}{1+(B_0l)^{B_1}} \qquad (6)$$

Now an exploitation pattern incorporating both size selection and deselection can be written down as;

$$F_l=Kp_la_l \qquad (7)$$

An example of a curve of this type is

given in Figure 1b. This curve incorporates most of the properties needed to describe typical exploitation patterns seen for seines and trawls. However, the definition of the conventional selectivity parameters is less straight forward for this expression since the curve has a maximum at a point denoted by F^*, l^*. At this point it is necessary to make a strong assumption that the curve to the left of the maximum is largely determined by gear selectivity and that correspondingly the effects of deselection in this size range are small. If this assumption is reasonable then the selectivity parameters can be defined as the lengths which satisfy the condition that $F_l=F^*/2$ and $F_l=F^*/4$.

Data

Estimates of fishing mortality rates for haddock and whiting were obtained from standard ICES assessments reported in Anon (1996). For cod the fishing mortality rates were taken from Anon (1993). Although this is a non-standard assessment, it was necessary to use an assessment which included estimates of discards to obtain unbiased fishing mortality rate estimates. This is particularly important since the size groups of fish below the fully selected size range are seriously affected by discarding.

The assessments referred to above provide fishing mortality rates by age group of fish. In order to relate these to size, mean length at age in the catch was obtained from the Scottish biological sampling programme (Armstrong and Hall 1987). This programme provides estimates of size at age from length frequency samples taken at major landing sites and from measurements by on board observers of fish discarded at sea. The data on fishing mortality rate and mean length are given in Tables 1-3.

Methods

In the case of haddock and whiting, selectivity parameters were estimated from the fleet partial fishing mortalities obtained by partitioning the total fishing mortality rate using the ratio of the fleet catch to the total catch, ie;

$$F(fleet)=F(total)*\frac{catch(fleet)}{catch(total)}$$

The model was fitted to data for the years 1990-1994.

For cod, fleet data were not available and the selectivity parameters were estimated from the total fishing mortality. The assessment for this stock only includes data up to 1992, and, as a result, the model was fitted to data for 1990-1992.

The conventional selectivity parameters, *L50* and *L25* were estimated using model (5) for whiting and (7) for cod and haddock. This was done by fitting the models using least squares to the fishing mortalities obtained from conventional assessments. Since larger fish are scarcer and hence less frequently sampled, a weighting procedure was applied to correct for higher variances at these sizes. Thus for an observed fishing mortality F', the model was fitted by minimising the sum of squares:

$$\sum \frac{1}{l}\left(F_l'-F_l\right)^2 \qquad \textbf{(9)}$$

After fitting the model, *L50* and *L25* were calculated from the fitted curve. In the case of whiting using equation (5) the selectivity parameters can be calculated directly from;

$$L50=\frac{1}{A_1}\log(A_0)$$

$$L25 = \frac{1}{A_1}\log\left(\frac{A_0}{3}\right)$$

For cod and haddock the maximum of the fitted curve, F^*, was determined by numerical search and then equation (7) was solved for l at $F^*/2$ and $F^*/4$ using a non linear root finder.

Results

Figures 2-4 show the fishing mortality rates by fleet for each stock plotted against mean length. These plots show the accelerating rise in mortality rate as length increases followed by a slower rise to a maximum. For cod and haddock, the exploitation pattern passes through a maximum and then declines. The whiting data also show a rise with length but at the highest lengths, the data become very scattered and the simplest assumption is that an asymptote is reached.

Also shown on the plots is the fitted curve. The models are able to track the trends in the data and appear to be an adequate means of removing noise in the mortality estimates.

Table 4 and Fig. 5 show the estimated selectivity parameters obtained after fitting the models to the data. They can be compared to the estimates obtained from Reeves et al (1992) for a nominal 100mm mesh, the mesh size presently in use in the North Sea for demersal trawls and seines.

Discussion

An important assumption made in the analysis here is that mean length at age is a good proxy for the typical length corresponding to the calculated fishing mortality rate. Notwithstanding this assumption, the agreement between the selectivity parameters estimated from the two independent data sets and methods is striking. At face value this suggests that the average fleet selectivity corresponds very closely to the expected selectivity predicted from the nominal mesh size.

The largest disparity between the estimates occurs for whiting with trawls. Inspection of figure 2a shows that the fitted model lies above most of the data points to the right of the L50 and appears to be heavily influenced by three very large values of fishing mortality. This would imply that the estimated selectivity parameters are lower than would otherwise be expected and that the two methods are actually in closer agreement.

A problem with the analysis presented here is the characteristically dome shaped exploitation patterns for cod and haddock. Whatever the underlying cause, the declining limb of the curve is an indication that not all size ranges in the fish population are equally available to the gear. It is therefore difficult to distinguish between the effects of selection and deselection. The assumption made here is that the deselection effects are small over the size ranges where most fish are not fully retained within the codend. This assumption needs to be supported to improve confidence in the results.

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Table 1. Partial F by fleet and associated mean length for haddock for the years 1990-1994.

Trawl		**Seine**	
F	Mean length	F	Mean length
0	14.9	0.0007	12.7
0	16.1	0.0002	17.2
0.0001	17.1	0.0001	17.3
0.0001	17.3	0.0001	18
0.0001	18.1	0.0002	18.7
0.014	23.6	0.0359	22.6
0.0131	24.1	0.0209	22.7
0.03	24.1	0.0422	23.2
0.0192	24.1	0.0449	26.3
0.0223	25.9	0.0674	26.4
0.0947	29.6	0.2415	28.7
0.1863	30.2	0.2552	29.7
0.1124	30.5	0.4491	30.2
0.1222	31	0.1866	31.1
0.0893	31.5	0.3022	31.9
0.1526	35.1	0.5182	34.2
0.2178	35.2	0.3333	35.3
0.1453	36.3	0.3131	35.3
0.1761	36.4	0.458	35.7
0.1897	36.8	0.4125	36.1
0.1362	37.4	0.3023	36.5
0.1271	38.5	0.3665	38.7
0.2215	40.3	0.3345	40
0.1453	40.7	0.3298	40.2
0.2154	41.2	0.3354	40.5
0.1424	42.7	0.3028	42.1
0.1152	43.3	0.2309	42.3
0.2275	44.6	0.2301	43.2
0.1849	44.7	0.239	43.7
0.1546	45.7	0.1527	45
0.1939	46.9	0.209	45.6
0.1468	47.8	0.197	46.2
0.085	48.1	0.2008	46.5
0.1726	48.5	0.1998	46.7
0.0891	48.7	0.1797	46.8
0.1343	50.1	0.1626	49.6
0.0957	51.4	0.1631	50.1
0.1067	51.9	0.1652	50.2
0.1109	52.5	0.1472	50.2
0.11	53.3	0.1236	50.8
0.1629	54.6	0.1633	52.5
0.152	54.8	0.1086	52.6
0.2842	55.5	0.1761	53.5
0.1809	55.9	0.2046	54.7
0.095	56.5	0.1411	54.7
0.1517	56.8	0.1008	58.3
0.1398	57.7	0.2463	58.7
0.2171	58.3	0.1382	59
0.0495	58.9	0.2228	59.1
0.1777	59.1	0.164	59.2
0.2208	59.3		
0.1165	61.2		
0.0963	61.7		
0.1044	61.9		
0.1065	62.1		

Table 2. Partial F by fleet and associated mean length for whiting for the years 1990-1994.

Trawl		**Seine**	
F	Mean Length	F	Mean Length
0.0001	13.1	0	11.6
0.0001	14.3	0.0001	11.7
0.0001	14.7	0.0001	15.6
0.0002	16.3	0	16.2
0.0002	16.7	0.0001	18.7
0.0033	21.1	0.0146	20.1
0.0154	22	0.0126	21.1
0.0079	22	0.0071	22.5
0.0032	22.2	0.0074	23.2
0.0127	23.5	0.0108	24.5
0.0377	26	0.1329	24.6
0.0312	26.7	0.0741	26.6
0.0305	26.7	0.1178	26.7
0.0479	27.4	0.0416	27.2
0.0331	27.7	0.0444	27.6
0.0615	29.1	0.1763	28.8
0.0551	30.5	0.1966	29.3
0.0764	30.8	0.1448	30.5
0.0798	30.8	0.3431	30.6
0.0694	30.9	0.1372	30.7
0.1045	31.4	0.1206	30.9
0.1037	32.3	0.5537	31.1
0.0796	32.3	0.2611	31.4
0.1305	33	0.1881	31.9
0.4544	33	0.3921	31.9
0.1301	33.1	0.3889	33.2
0.0992	33.4	0.1806	33.4
0.2163	33.6	0.2654	33.5
0.113	33.7	0.245	33.6
0.1187	33.8	0.2145	33.6
0.1848	34	0.4036	33.7
0.0884	34.8	0.2216	33.9
0.1528	35.3	1.0401	33.9
0.0995	35.3	0.2408	34.3
0.1466	35.3	0.365	34.4
0.1882	35.5	0.2988	34.7
0.1451	35.6	0.3515	35.3
0.1889	37.2	0.2688	35.3
0.4708	37.6	0.5848	35.7
0.0833	38	0.1457	35.7
0.4252	38.3	0.2689	35.8
0.2556	39	0.3229	36.1
0.1634	39.2	0.3679	36.5
0.2445	40	0.2235	37
0.0479	40.2	0.206	39.2
0.2967	41.1	0.2583	39.4
0.0637	41.6	0.8154	45.8
0.0811	44	0.4743	48
0.1928	47	0.0018	55.5
0.007	55.5		

Table 3. *F* for all gears and associated mean length for cod for the years 1990-1992.

F	Mean Length
0.0002	21.5
0.0007	21.6
0.439	31.5
0.37	31.8
0.4591	32.5
1.2921	39.2
1.0271	40
0.9803	45.5
0.8619	54.5
1.0077	56.6
0.9499	60.4
0.8931	69.7
0.9102	70.5
0.7329	72.1
1.044	81
0.801	82.4
0.7372	82.9
0.9245	90.6
0.5411	91.4
0.8634	91.7
0.6011	98.5
0.9126	98.5
0.9679	98.9
0.6659	100.7
0.3899	102.8
0.4409	104.5
0.6507	105.6
0.7802	106.5
0.4387	108.2
1.9138	108.5
0.7136	110
0.8105	113.6

Table 4. Selectivity parameters estimated from analysing the fishing mortality at length from conventional stock assessments compared with equivalent estimates obtained form selectivity experiments. The experimental values are estimates using the *Reeves et al* model assuming 100mm mesh, 100 meshes around the codend and an extension length of 9 metres.

		L50 (cm)		L25 (cm)	
Species	Gear	Assessment	Experiment	Assessment	Experiment
Haddock	seine	28.7	26.1	25.6	23.1
	trawl	28.6	28.1	26.1	25.6
Whiting	seine	29.1	29.2	26.5	26.6
	trawl	30.7	34.6	27.9	31.5
Cod	all	32.8	33.5	29.9	28.8

Fig. 1. Exploitation curves used to estimate selectivity parameters

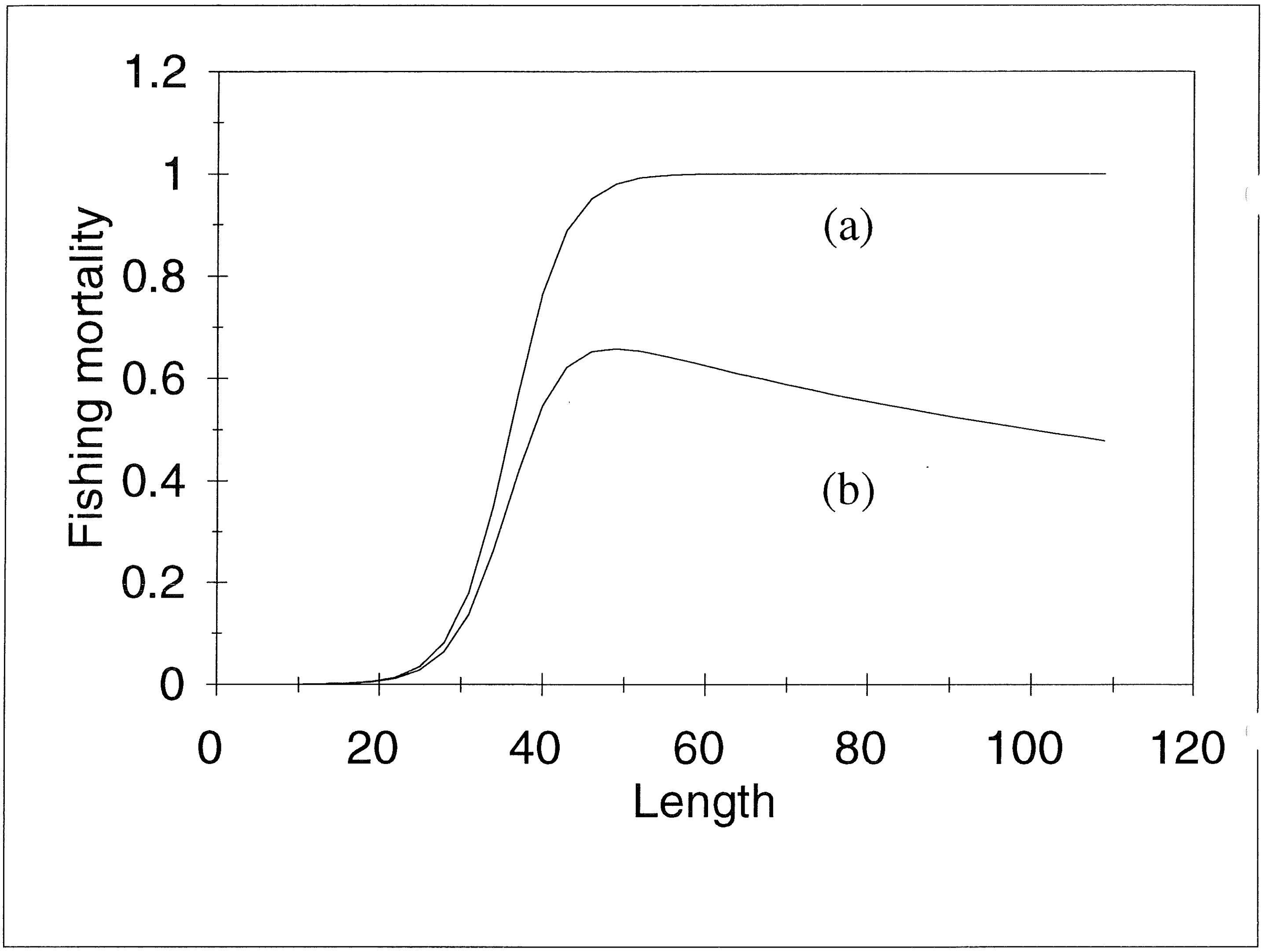
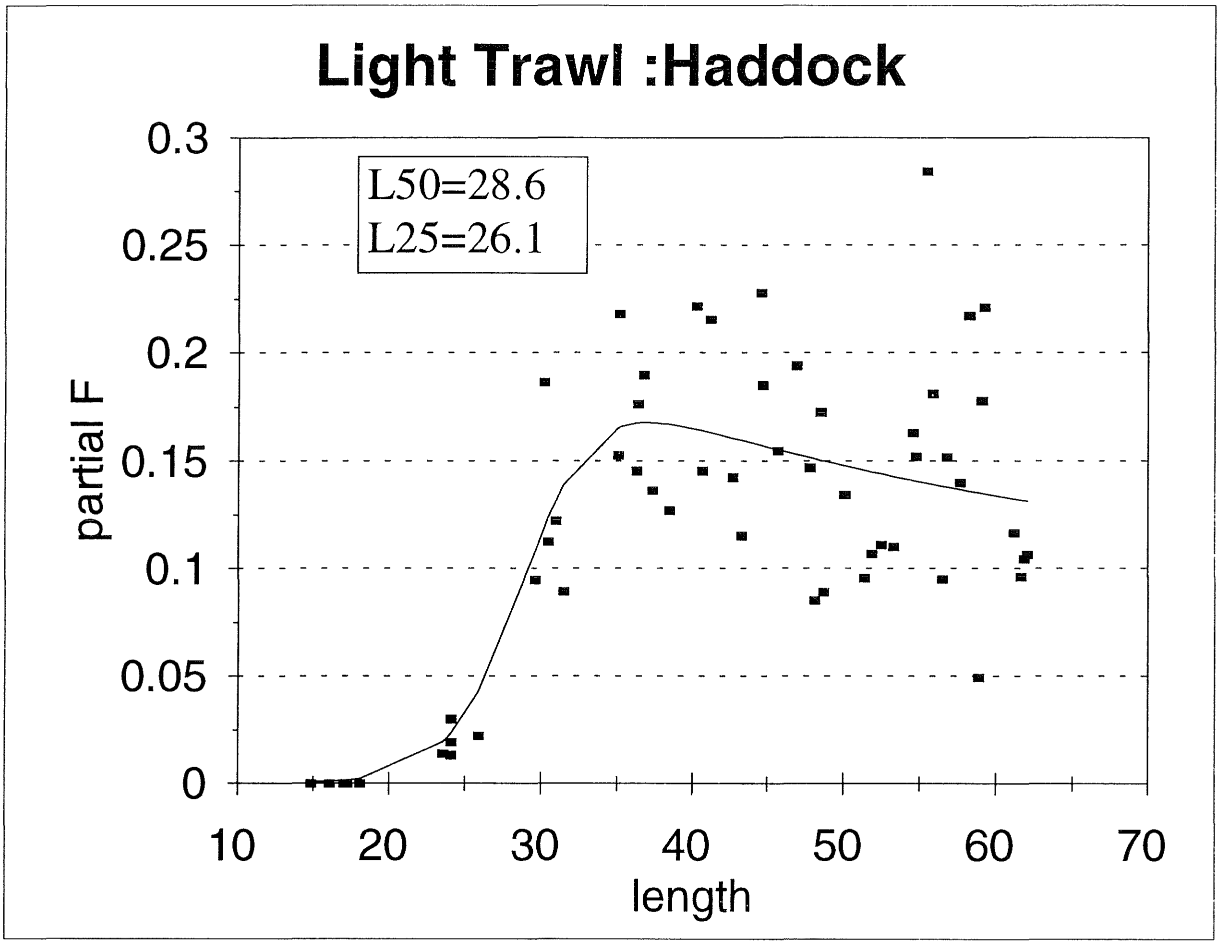


Fig. 2. Selectivity curves for North Sea Haddock



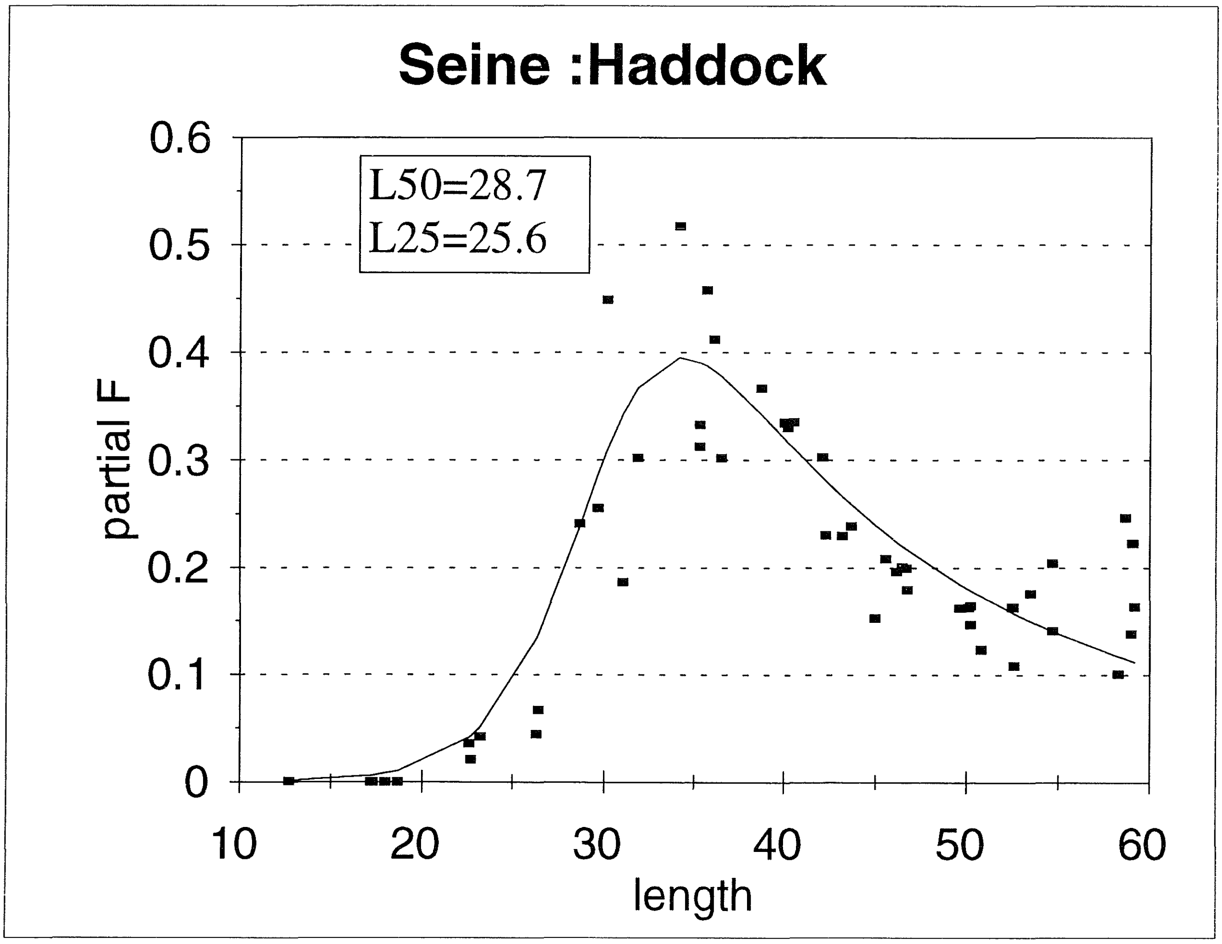
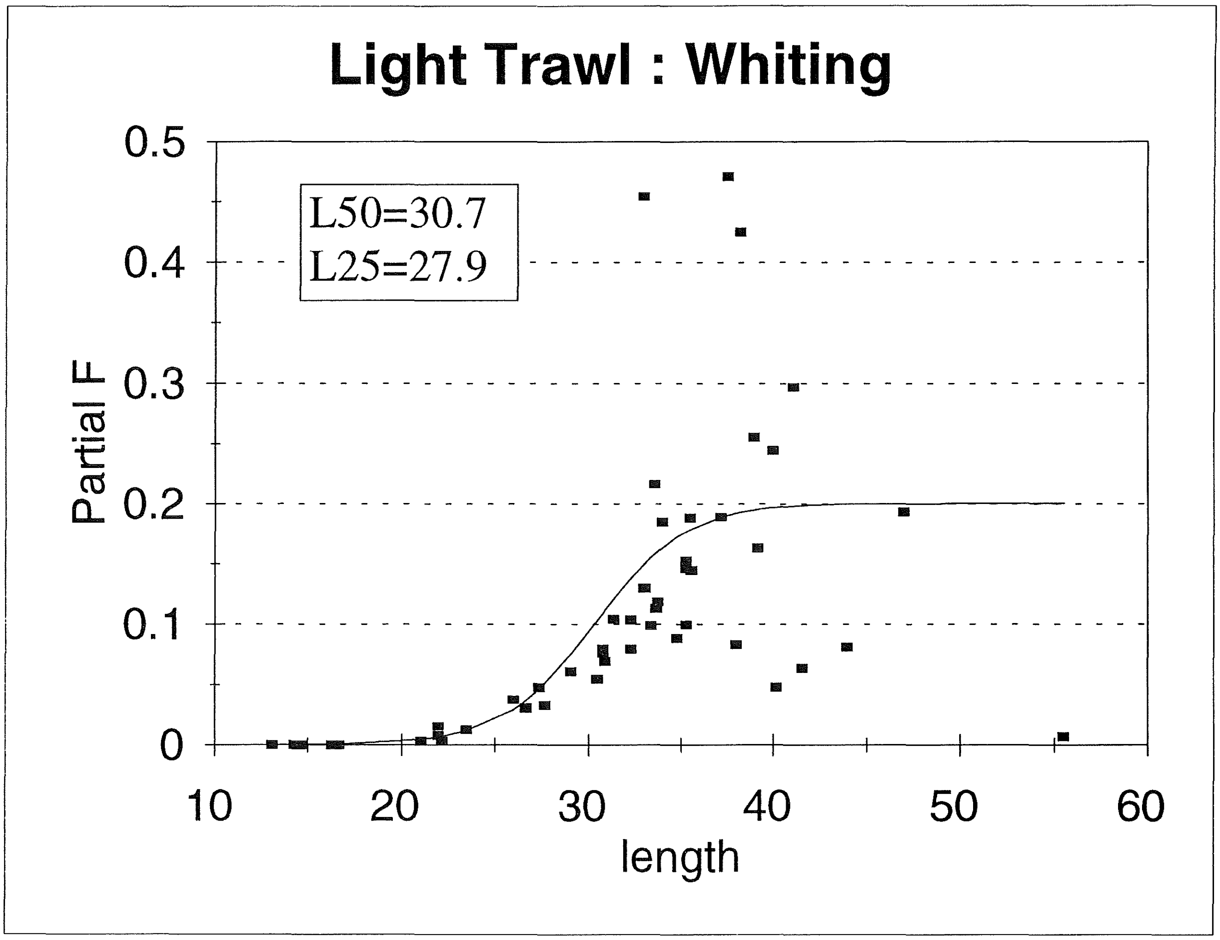


Fig. 3. Selectivity curves for North Sea Whiting



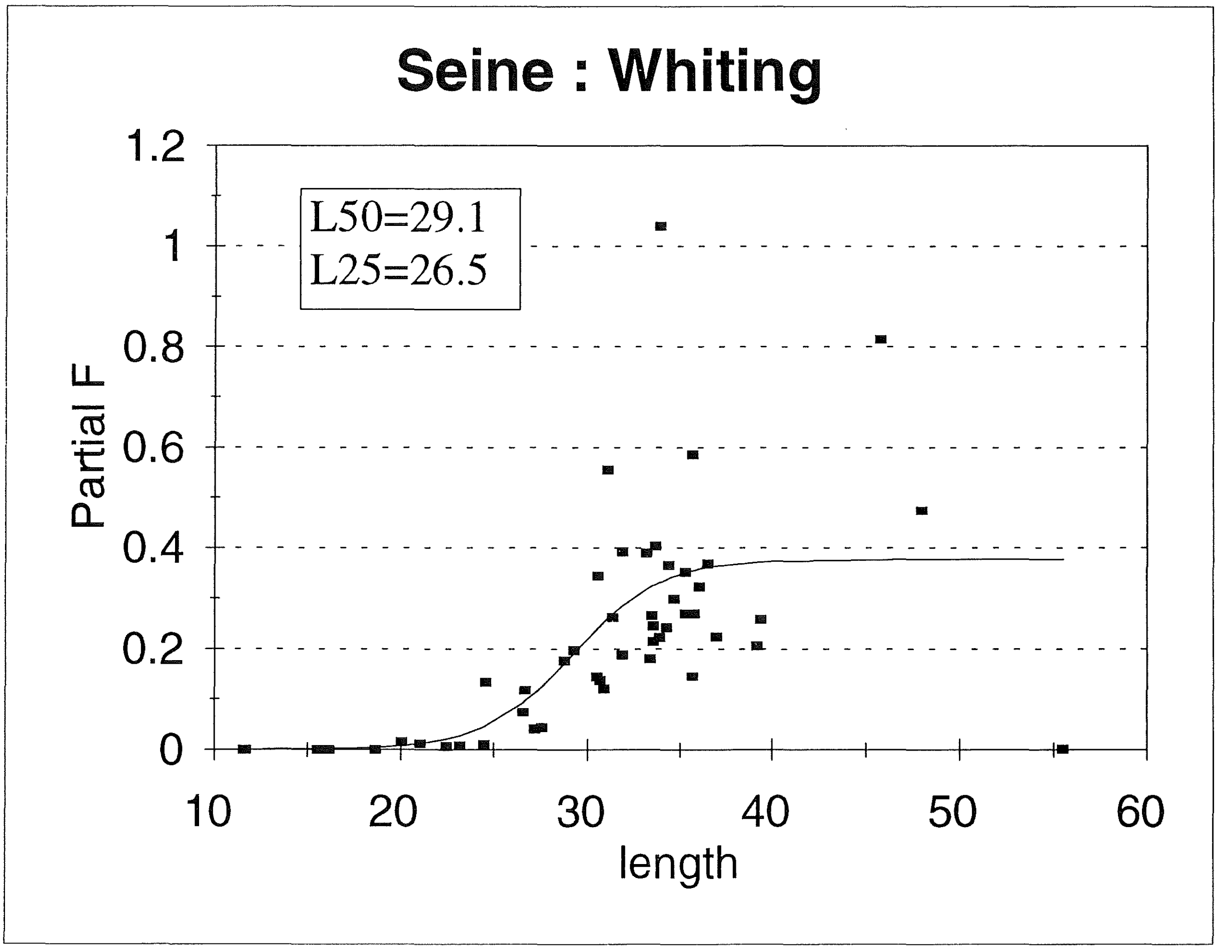


Fig. 4. Selectivity curves for North Sea Cod

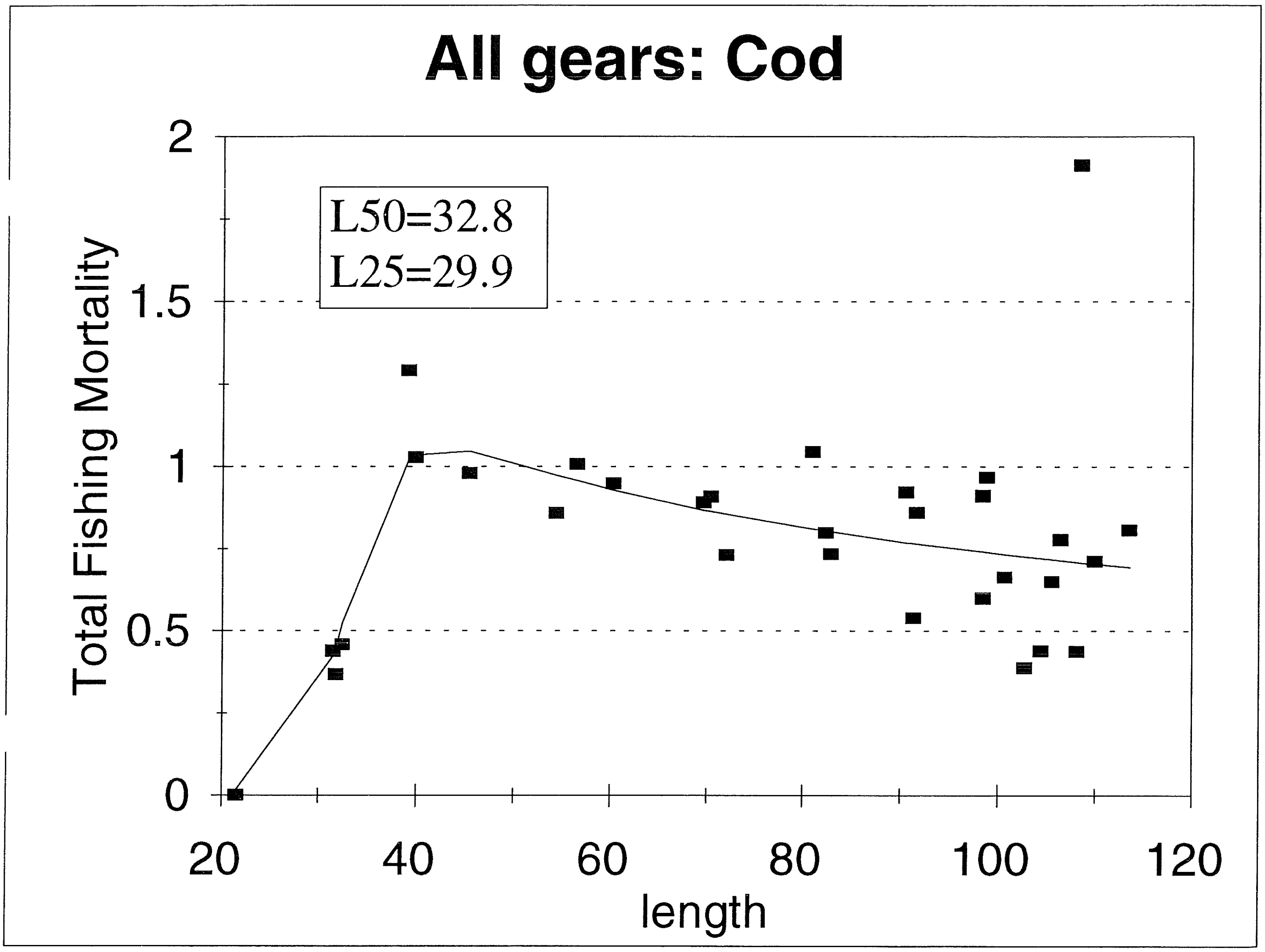
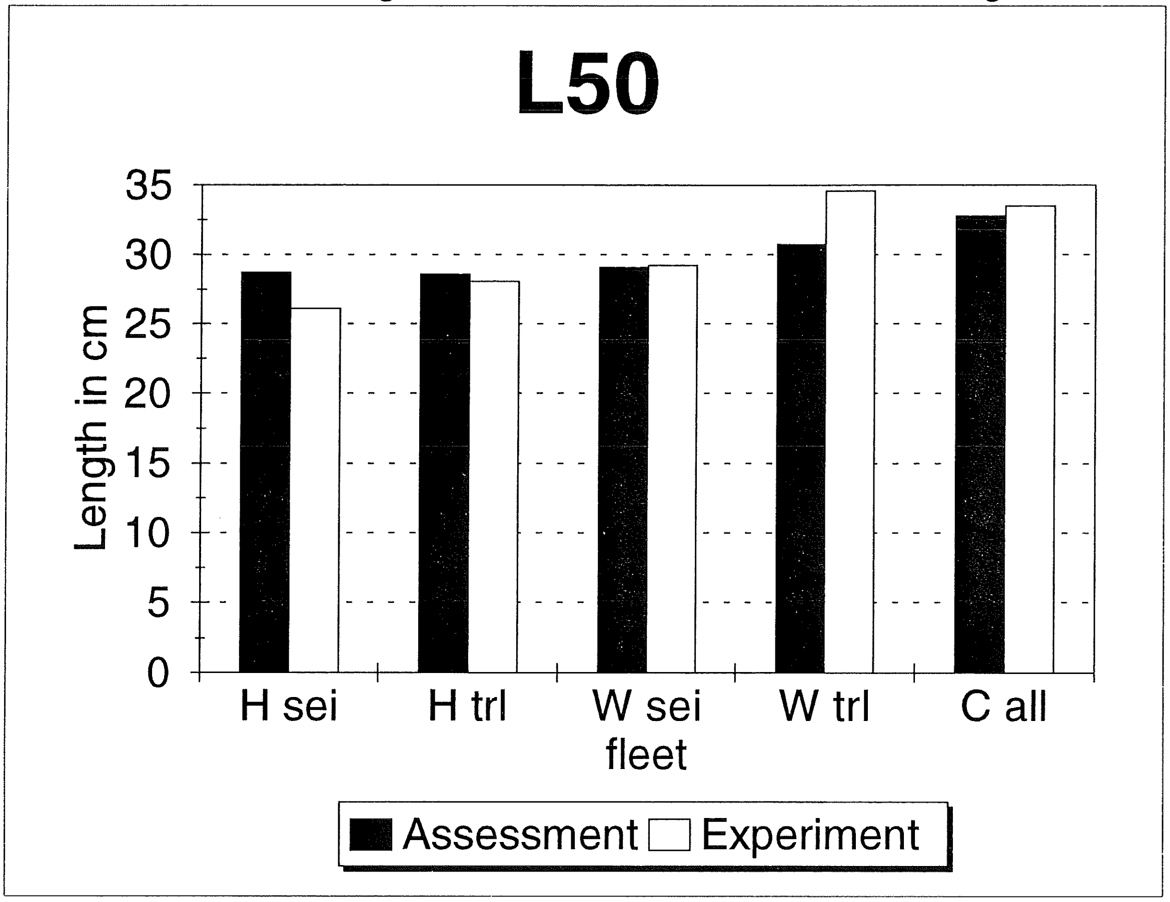
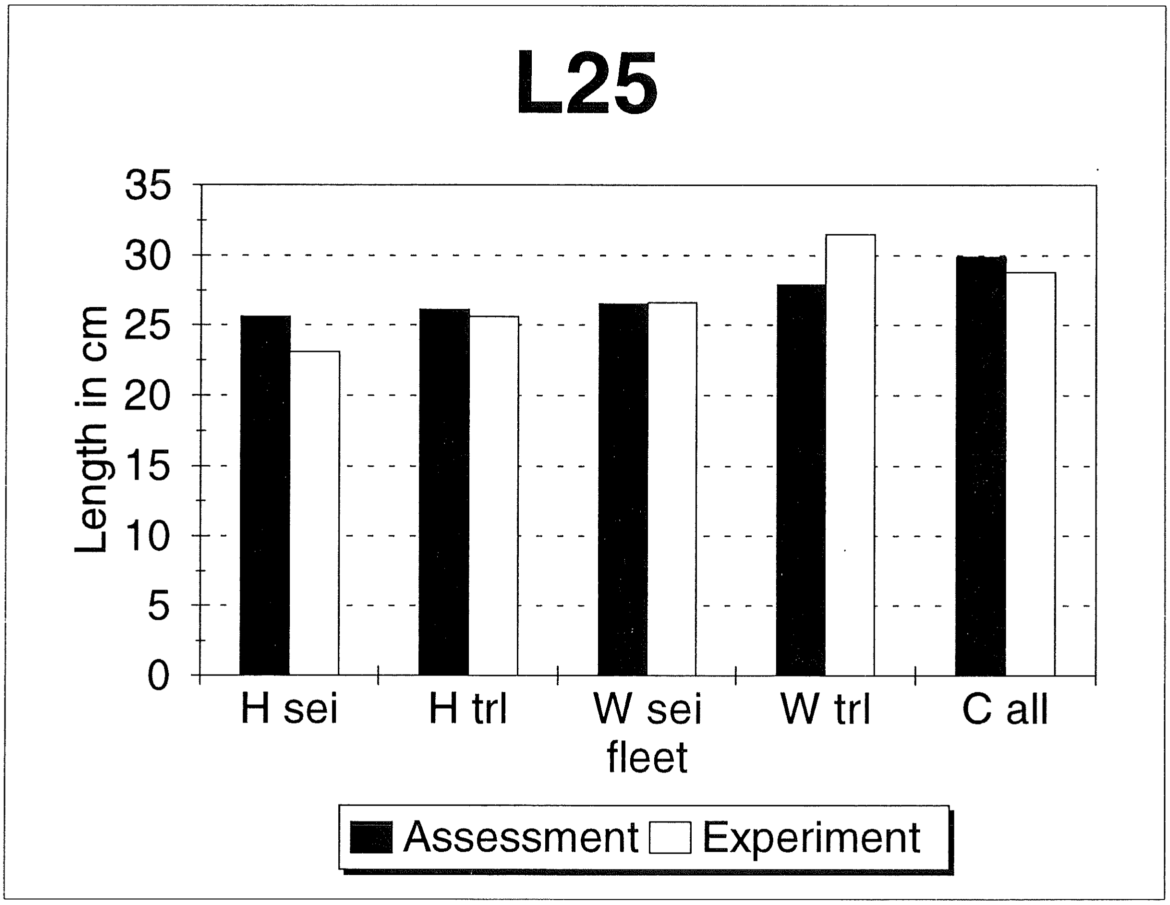


Fig. 5. L50 and L25 plotted for each stock and fleet.
H=Haddock, W=Whiting, C=Cod, sei=seine, trl=trawl, all=all gears





Annex 2

Working document for the Study Group on the Use of Selectivity Measurements in Stock Assessment, April 1996.

Estimating fleet selectivity from vessel selectivity

Rob Fryer

Introduction

Supposing we have estimates of the selectivity of several vessels, how do we estimate the selectivity of the fleet? This seemingly innocent question opens up a Pandora's box of statistical solutions, which depend on:
- what we mean by fleet selectivity,
- the size of the fleet compared to the number of vessels sampled
- the form of the vessel selectivity curves
- the available data.

One way forward is to note that estimating fleet selectivity from several vessels is, in many ways, a similar problem to estimating vessel selectivity from several hauls. In both situations, there are several selectivity curves that have to be combined in some way. We might therefore adapt methods for estimating vessel selectivity to those for estimating fleet selectivity. Here, I show how a fixed and random effects model for estimating vessel selectivity (Fryer, 1991) can be adapted to estimate fleet selectivity. I first give the theory, then an example, and finally discuss the limitations of the method, and other issues in estimating fleet selectivity.

I use the term *selectivity* loosely throughout, to avoid having to distinguish between *e.g.* cod-end selectivity and whole gear selectivity. Clearly though, estimates of vessel cod-end selectivity only provide estimates of fleet cod-end selectivity, and so on.

Theory

I only give cursory details here. For more information, see Fryer (1991).

Sampling

- We have selectivity estimates for n vessels.
- The number of vessels sampled, n, is small compared to the size of the fleet, N.
- The vessels are chosen at random.

Vessel selectivity

- Each vessel i has a logistic selectivity curve with parameters $\nu_i = (\alpha_i, \beta_i)^T$, so that retention probability p is related to length l by

$$\log\left(\frac{p}{1-p}\right) = \alpha_i + \beta_i l.$$

- We have estimates of ν_i, denoted $\hat{\nu}_i$, and an associated variance matrix R_i, with

$$\hat{\nu}_i \sim N_2(\nu_i, R_i).$$

Fleet selectivity

• The selectivity ν_i of a vessel chosen at random from the fleet varies about a fleet selectivity curve, ν_F say, according to

$$\nu_i \sim N_2(\nu_F, D),$$

where D is the between-vessel variation in selectivity. Thus

$$\hat{\nu}_i \sim N_2(\nu_F,\ D + R_i).$$

Estimation

Fleet selectivity ν_F, and the between-vessel variance D, can be estimated by either maximum likelihood, or residual maximum likelihood. The estimation process is a special case of that described in Appendix B of Fryer (1991), where the design matrices X_i are set equal to the 2×2 identity matrix.

Example

I demonstrate the theory using haddock selectivity estimates from five trials with single boat trawls, all with nominal 100 mm mesh (Dick Ferro, pers. com.). Four of the trials were conducted with the same vessel (I think), so there are clearly problems in using these as independent estimates of fleet selectivity. Nevertheless, this is the largest data set I could find involving different trips with the same gear type, and will serve to illustrate the method. The data are given in Table 1.

I estimated ν_F in two ways from these data:

• using only the Solstice data, so here ν_F really represents the average selectivity of Solstice, and D measures the between-trip variation in selectivity,

• using all the data.

Parameter estimates are given in Table 2. However, the sample sizes are small, so these estimates should not be over-interpreted.

Comments

Vessel selectivity

• Sometimes, we will not have estimates of ν_i, but of the transformed parameters $\theta_i = (l_{50i}, SR_i)^T$. This might just be because the parameters are reported in this way, in which case we can simply transform the θ_i back to ν_i. However, it might be because a logistic selectivity curve is not appropriate. We might then apply the model to the θ_i by assuming that

$$\hat{\theta}_i \sim N_2(\theta_F,\ D' + R_i'),$$

where $\hat{\theta}_i$ is the estimate of θ_i, R_i' is the corresponding variance matrix (on the θ scale), θ_F is the fleet l_{50} and SR, and D' is the between-vessel variance (on the θ scale). But we might have to consider other transformations to satisfy the normality assumptions, such as $(l_{50i}, \log SR_i)^T$. Also, although we would have estimates of the fleet l_{50} and SR, we would not be able to convert these into a selectivity curve, because we would have no idea what an appropriate curve would be.

• Non-parametric selectivity curves are being used increasingly frequently (*e.g.* Millar, 1993). It would be straightforward to estimate a non-parametric fleet selectivity curve (by either isotonic regression, or some smoothing technique, with bootstrap confidence intervals). However, the raw data, or at least the estimated selectivity curve by haul for each vessel would be required.

- It is simple to adapt the fixed and random effects model to cope with different parametric selectivity curves, such as Richards curves, or where several summary statistics are reported, such as $(l_{25i}, l_{50i}, l_{75i})^T$. The latter would be useful for dealing with non-parametric selectivity curves, if the raw data are not available.

Data requirements

- A crucial data requirement is the variance matrix R_i. This means that we require both the variances of the selectivity parameter estimators, and the correlation between them.

Sampling stuff

- The more vessels the better, since this reduces the variance of $\hat{\nu}_F$ and provides more degrees of freedom for estimating D. How many vessels are sufficient? That depends on D, R_i, and how precise an estimator of ν_F is required.

- If the number of sampled vessels n is not small compared to the number of vessels in the fleet N, then some finite sampling correction would be needed. There might need to be a shift of emphasis from estimating some super-population parameter ν_F to estimating the realised selectivity of the fleet

$$\frac{1}{N}\sum_{i=1}^{N}\nu_i.$$

However, this is not necessarily straightforward due to the sometimes considerable measurement error associated with $\hat{\nu}_i$. Further, this might not be viable since recent experiments suggest that selectivity of a particular vessel changes with season (Dick Ferro, pers. com.), and maybe by trip, so that ν_i is itself a mixture of fixed and random effects (see later).

- To date, vessels are not selected at random. However, provided they are not selected in any systematic way (*e.g.* only small vessels) it shouldn't matter too much.

Variance components

- In principle, the theory can be extended to model data by haul. If $\hat{\nu}_{ij}$ are the estimated selectivity parameters for haul j of vessel i, with variance matrix R_{ij}, then we might consider

$$\hat{\nu}_{ij} \sim N_2(\nu_F, D_v + D_h + R_{ij}),$$

where D_v is the between-vessel variance and D_h is the between-haul variance (here, assumed constant between-vessels). The additional complexity of such an approach might not give much benefit for estimating ν_F. However, it would be essential for designing an efficient sampling scheme to estimate ν_F, since it would allow the efficient allocation of resources both between- and within-vessels.

- If the selectivity of a vessel varies with season and / or trip, then either the sampling scheme would have to be designed with these effects in mind, or these effects would have to be incorporated in the selectivity model in some way. Extending the notation above, if $\hat{\nu}_{ikj}$ are the estimated selectivity parameters for haul j, trip t, vessel i, then we could have

$$\hat{\nu}_{ikj} \sim N_2(\nu_F(\text{season}), D_v + D_t + D_h + R_{ikj}),$$

where D_t is the between-trip variance.

This would be a more sensible way of modelling the data presented earlier, had there been selectivity estimates for more than two vessels.

Fleet selectivity

• I have only considered an 'unweighted' selectivity curve, in which each vessel in the fleet is treated equally. It might be more sensible to estimate the average selectivity of the fleet, weighted by *e.g.* the annual catch of the vessel C_i. This might then involve estimating

$$\frac{\sum_{i=1}^{N} C_i \nu_i}{\sum_{i=1}^{N} C_i}.$$

References

Fryer, R.J., 1991. A model of between-haul variation in selectivity. ICES J. Mar. Sci., 48:281-290.

Millar, R. B., 1993. Incorporation of between-haul variation using bootstrapping and nonparametric estimation of selection curves. Fish. Bull., 91: 564-572.

Table 1

vessel	hauls	$\hat{\nu}$	R	comments
Solstice_1	6	$\begin{pmatrix} -10.66 \\ 0.367 \end{pmatrix}$	$\begin{pmatrix} 0.50922 & \\ -0.01757 & 0.00061 \end{pmatrix}$	100 open meshes round.
Solstice_2	23	$\begin{pmatrix} -12.30 \\ 0.429 \end{pmatrix}$	$\begin{pmatrix} 0.18294 & \\ -0.00630 & 0.00023 \end{pmatrix}$	100 open meshes, various covers and tow durations.
Solstice_3?	4	$\begin{pmatrix} -12.06 \\ 0.426 \end{pmatrix}$	$\begin{pmatrix} 2.22582 & \\ -0.09406 & 0.00398 \end{pmatrix}$	1992 EU survival experiment
Solstice_4?	5	$\begin{pmatrix} -11.88 \\ 0.419 \end{pmatrix}$	$\begin{pmatrix} 1.40803 & \\ -0.05678 & 0.00252 \end{pmatrix}$	1993 EU survival experiment
Aalskere	12	$\begin{pmatrix} -16.86 \\ 0.547 \end{pmatrix}$	$\begin{pmatrix} 0.78347 & \\ -0.02403 & 0.00075 \end{pmatrix}$	98.6 mm measured mesh size, 100 open meshes.

Table 2

	$\hat{\nu}_F$	$\mathrm{Var}\,\hat{\nu}_F$	D
Solstice data	$\begin{pmatrix} -11.37 \\ 0.395 \end{pmatrix}$	$\begin{pmatrix} 0.22418 & \\ -0.00876 & 0.00035 \end{pmatrix}$	$\begin{pmatrix} 0.5452 & \\ -0.0214 & 0.0008 \end{pmatrix}$
All data	$\begin{pmatrix} -12.58 \\ 0.430 \end{pmatrix}$	$\begin{pmatrix} 1.12753 & \\ -0.03209 & 0.00093 \end{pmatrix}$	$\begin{pmatrix} 5.0604 & \\ -0.1406 & 0.0039 \end{pmatrix}$

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