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REPORT OF THE AD HOC WORKING GROUP ON THE USE OF EFFORT DATA IN ASSESSMENTS

Copenhagen, 2-6 March 1981

x) General Secretary
ICES,
Palægade 2-4
DK-1261 Copenhagen K
Denmark.

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1. PARTICIPANTS AND TERMS OF REFERENCE

1.1 Participants

D W Armstrong	Scotland
F van Beek	Netherlands
R De Clerck	Belgium
N Daan	Netherlands
H Eirîksson	Iceland
H Farrugio	France
S Gavaris	Canada
D de G Griffith	Ireland
T Helgason	Iceland
R Houghton	England
K Hoydal	Denmark
T Jakobsen	Norway
H Lassen	Denmark
A Laurec	France
J J Maguire	Canada
R Mohn	Canada
A Nielsen	Denmark
J Shepherd (Chairman)	England
P Sparre	Denmark
Ø Ulltang	Norway
Cl. de Verdelhan	France

1.2 Terms of Reference

"To evaluate the use of effort data in determining fishing mortality levels, and the effect of mixed fisheries, technical interactions and quota systems on the data. The problem of determining input fishing mortality coefficients for virtual population analysis should be specially examined".

2. INTRODUCTION

The Working Group discussed its terms of reference and agreed that the principle problem was to make some progress in the use of effort data for the determination of fishing mortality and (equivalently) stock size in the most recent years, which had not so far been a very successful procedure. They recognised that there were other methods available, notably the use of egg and larval surveys, acoustic surveys, groundfish surveys and tagging experiments, and that these might be more successful in some cases. Nevertheless, in many situations none of these alternatives are available, and there is still a great need to improve methods for the use of effort data.

The Group agreed that although effort data may also be useful when allowing for technical interactions in multispecies assessments, they would concentrate their effort on the principle problem. They also recognised that although the definition and determination of fishing power was clearly of the very greatest importance for the successful use of effort data, these aspects have already been much studied (e.g. FAO Fisheries Techn.Paper No.155) and that they would not be able to add much in the time available. They therefore agreed to concentrate on the use of effort data, rather than their definition and acquisition. They recognised, however, that there is no comprehensive summary of what effort data exist and what are available (not necessarily the same thing), since data reported (for example to ICES on STATLANT 27B forms) may not be the best available. They therefore adopted a standard form on which to collect information for an "ICES Catalogue of Effort Data". The first collection of information on this form is given as Appendix A to this report.

The Working Group first discussed the need for additional information to supplement that on catch at age data, and had a fairly extended discussion on the inability of either traditional VPA or more recent variants to estimate fishing mortality in the most recent year. The results of this discussion are reported in Section 3. The success or failure of some previous attempts to use effort data to resolve the problem was discussed (see Section 4), and some general observations on the analysis and use of effort data were made (Section 5). This discussion, especially of the results reported in Section 5.3 suggested that the principle problem is that different fleets exploit different age ranges. The time series of stock abundance at age is highly stochastic, since it is dominated by fluctuations of recruitment, and a similar series appears for each age, progressively logged in time as the fish became older. Cpue time series from different fleets are, therefore, essentially different moving averages of the recruitment time series, logged by different amounts. The presence of even quite small logs (e.g. one year) rapidly destroys any correlation when similar but highly variable time series are compared. Thus it is very important that cpue for a particular fleet should be compared with an estimate of stock abundance which takes proper account of the level of exploitation at age. This suggested one approach to re-interpretation of cpue data, and the results of work along these lines are reported in Section 6.2. Another approach is to unscramble the moving averages by analysing cpue for individual age groups, and the results of this work are reported in Section 6.1. Further discussion indicated that disaggregated cpue data are probably best analysed using multiplicative models, and an attempt was made to apply this approach to Faroese data (Section 6.3). Finally, since it seemed that the exact nature of estimators of fishing mortality or stock abundance which one used may be very important, an attempt was made to compare the efficacy of various estimators using simulated data (for which the true answer is known).

The Working Group's conclusions and recommendations are given in Section 7, a short bibliography in Section 8, and a summary of notation in Section 9. The catalogue of effort data appears in Appendix A.

3. VPA AND EFFORT DATA

A proper assessment of a fish stock requires a reliable estimate of fishing mortality (or, equivalently, stock size) in the most recent year. If such information were available from independent evidence, a VPA would not be essential to the assessment. Since catch at age data for the most recent year may be imperfect, a VPA which enables historic information to be used as a background for the current situation is often valuable. However, as discussed below, catch at age data contain no information about natural mortality or fishing mortality in the most recent year, and thus the use of VPA cannot assist in finding a solution to the principle problems in preparing a reliable assessment. Virtual Population Analysis, VPA, is nevertheless the most used method for stock assessment and hence forecasting. In the light of the terms of reference of this Working Group it therefore seems appropriate to deal with relations between VPA and effort measurements.

VPA is used to interprete data about catch numbers at age in terms of fishing mortality and population numbers. Since more independent parameters are being estimated than there are data points, some external information is needed. Generally, assumptions are made about fishing mortality or population number for the oldest age of each year class for which a (reliable) catch number is available. Furthermore, a value for natural mortality must be assumed. These assumptions are usually made in such a way that the results show as consistent an exploitation pattern as possible.

There has been work on mathematical approaches to this estimation problem by Pope and Shepherd (working paper), Nielsen (unpubl.), and Gudmundsson.

The fishing mortalities F_{ya} are written as

$$F_{ya} = \hat{F}_y \cdot S_a$$

where $S_a = 1$ for some reference age and the selection coefficients S_a are assumed to be independent of time, and $\hat{F}_y$ is an overall measure of fishing mortality in a particular year.

Work to date shows that such separable VPA models alone do not resolve the problem of underestimation. Pope and Shepherd conclude that external information is needed about three parameters; namely for terminal values of $\hat{F}_y$ (y = latest year), S_a (a = maximal age) and the natural mortality. Others, like Gudmundsson and Nielsen, have observed that natural mortality cannot be estimated and although, formally speaking, the fishing mortalities can be uniquely estimated within their models the variance of the fishing mortalities increase with time and are considerable for the latest year.

Thus it seems to be generally acknowledged that catch at age numbers alone do not give sufficient information. However, if it can be demonstrated that proportionality of fishing mortality to fishing effort is a reliable assumption, the development of compound models which utilise this relationship internally can be envisaged. Such models would provide an alternative to that of Shepherd and Pope, who recommend running VPAs for a range of assumptions, and selecting among them on the basis of external information. Work in this field is actively in progress, but no methods are currently available for routine use.

In any case, such compound models only provide another means of utilising external information such as effort data, and emphasize the necessity for such data for the correct interpretation of catches at age.

4. PAST EXPERIENCE

4.1 Past Experience - North Sea Roundfish

At its meetings in 1979 and 1980, the North Sea Roundfish Working Group attempted to demonstrate correlations between a measure of total international fishing effort and a measure of total international F for all ages. Catch per unit effort indices relative to an arbitrary year were calculated for each fleet for which relevant data were available. Thus

$$\gamma_{yf} = ypue_{yf}/ypue_{*f}$$

An overall value of relative catch per effort for all fleets for which data were available was calculated by weighting by catch weight:

$$\Gamma_{y.} = (\Sigma_f \gamma_{yf} Y_{yf}) / (\Sigma_f Y_{yf})$$

An index of the relative fishing effort for the total international fleet was then obtained by weighting by catch weight:

$$\hat{E}_y = \hat{Y}_y / ((\Sigma_f Y_{*f}) \Gamma_y)$$

where $\hat{E}$ = total international effort index

$\hat{Y}_y$ = total international weight landed in year y.

The total international F for all ages was calculated as a mean value weighted by stock number over what appeared to be an appropriate range of ages.

In no case was a significant correlation established between F and fishing effort.

4.2 Past Experience - NE Arctic Fisheries

In the past, data on effort or catch per unit effort have been used extensively in assessment of the North-East Arctic cod stock. For various age groups or components of the stock regression analysis has been used to calibrate the VPA, either by a regression of catch rates against stock size from VPA or fishing effort against fishing mortality from VPA. Data from various fleets have been used and the results compared.

The data from the NE Arctic have demonstrated the dangers of using catch per unit of effort data without having additional information from for example fishing or acoustic surveys on changes in fish distribution from year to year. Extreme hydrographic conditions in 1978/79 had the effect of concentrating the stock. This could be demonstrated from the results of acoustic surveys. Without correcting for this concentration cpue data led to unrealistically low estimates of fishing mortality in 1978 and 1979, and the NE Arctic Fisheries Working Group concluded that the cpue data from 1978 and 1979 could not be used for assessment purposes.

4.3 North Sea Flatfish

For determining the level of the terminal F values in the North Sea sole assessment beam trawl cpue data of the Netherlands on yearly basis corrected for mean fishing power and fishing speed of the fleet and United Kingdom winter fishery cpue were available for the years 1962-79. The Dutch beam trawl cpue reflects on a mixed fishery for sole and plaice, concentrated on sole. The United Kingdom trawl fishery provides a by-catch cpue. Both indices correlate quite well together, excluding the 1963 values (n = 18, r = 0.88).

The unweighted mean F on age groups 2-7 were plotted against two indices of international effort, one based on the Dutch and one based on the United Kingdom cpue for males and females separately. From the eye-fitted curves through the points the F_{2-7} for 1979 were derived. The F values from the plot based on the Dutch cpue and the corresponding values for the United Kingdom plot were averaged and used for the VPA. The exploitation pattern was calculated from the smoothed average F at age for 1972 to 1975 from the trial VPA.

The correlation between the Dutch and the United Kingdom cpue is remarkable, because the United Kingdom trawl fishery is a consistent fishery on species other than sole, while the Dutch beam trawl fishery is a mixed fishery mostly directed on sole, but in years (mainly the most recent years) when sole catch rates are low, increasingly direct their effort at plaice.

Another difference between the two fleets is that in the period 1962-79 the United Kingdom fleet kept operating in the same area, while the Dutch fleet could expand their fishing area by increasing their mobility with more powerful engined vessels in periods when sole catch rates on nearby fishing grounds were low. The above consideration can explain a non-linear trend in the relation between effort and F for the Dutch fleet, but not for the United Kingdom fleet.

Outside the Working Group, regressions were carried out between a cpue for the two fleets and a biomass from the VPA. Both correlations were significant ($r = 0.88$ for United Kingdom "winter" index for 19 df and $r = 0.89$ for the Netherlands index for 14 df). These results were given in the discussion paper to the 1980 Flatfish Working Group and to the present Working Group (Houghton, discussion paper).

The log-log regressions have slopes which are significantly greater than 1, indicating that there has been a downward trend in apparent catchability as the stock has declined. This could also be interpreted as a bias in the effort data (effort over-corrected for fishing power for example) or as a bias in the VPA (incorrect M).

For the North Sea plaice, no significant correlation exists with a combined effort using the γ method and the mean F derived from the VPA. A better result was obtained from an index of combined English motor trawl catch per effort corrected for the Lowestoft mean annual horse power. The English fleet has a directed fishery on plaice and its cpue gives a significant correlation with spawning stock biomass.

An international effort index was obtained by dividing the United Kingdom cpue by the total catch. This index correlated significantly with the mean female F from last year's VPA, though not with the male F. This effort index has been used to determine the input F level for the most recent VPA.

4.4 Experience in the NAFO Area

Catch rate and effort data are used in assessments done for NAFO in two major ways, as input for general production models and to calibrate analytical models. The raw data are operated on, generally by using some form of multiplicative model, to obtain relative annual values prior to such application.

The typical approach used to calibrate analytical models with effort or catch rate data has been regression analysis. No preference has been given to either catch rate vs biomass or effort vs fishing mortality. In fact, several attempts are generally made using various weightings, various age groups or other modifications. Most workers are satisfied with finding a descriptive relationship and are not concerned with the functional realism of the models. Although this approach can be criticized it is not entirely without merit.

The previous discussion has assumed the use of "total" values. Some recent attempts to calibrate each age of the analytical model with effort data were unsuccessful.

Frequent failure to achieve satisfactory calibration and suspicion about the quality of reported effort data have led to implementation of surveys. In general, commercial catch rate and effort data are resorted to only when attempts with survey data are unsuccessful.

4.5 Irish Sea:

4.5.1 Cod and plaice

One year old cod recruit to the fishery during the last quarter of the year and are known to congregate in discrete areas. The Irish Sea and Bristol Channel Working Group has used a correlation of United Kingdom cpue of 1 year olds in the 4th quarter with the number of 1 year olds in the stock (from VPA, year classes 1967-75) to estimate the number of 1 year olds in the latest years; the correlation was very good ($r = 0.933$ for 8 degrees of freedom). Input Fs were adjusted so that the stock of 1 year olds derived from the VPA agreed with this estimate.

A corresponding procedure for Irish Sea plaice did not give such a good correlation ($r = 0.420$ for 9 degrees of freedom), and it has been used for indicative purposes only.

4.5.2 Recent analysis of English and Welsh data for the Irish Sea

A working paper submitted by Brander describes recent work on English and Welsh data for the Irish Sea. Using a correction for fishing power and analysis of variance (i.e. linear additive model, which is probably less suitable than a multiplicative model) he demonstrates that all effects (seasonal, spatial and annual) are significant. A simple annual average cpue index (using aggregation to avoid empty cells) and weighting for the areas of the regions was constructed. This being the average of disaggregated catch/effort ratios, rather than the ratio of aggregate catch and effort, differs significantly from estimations often used previously by Assessment Working Groups. A good correlation of this index was obtained for cod ($r = 0.83$) and plaice (0.82) using yearly average biomass estimates. A poor correlation for sole ($r = 0.01$) was due to clustering of data points, and for whiting ($r = 0.40$) almost certainly, because of failure to allow for discards which are very important for this species.

The results obtained by Brander are very encouraging, as they are a very substantial advance on results from previous attempts. They suggest that the use of linear (and therefore probably multiplicative) models for cpue data is likely to yield useful results, where disaggregated data are available.

4.6 Celtic Sea and Irish Sea Sole

The Celtic Sea and Irish Sea sole fishery is mainly a directed fishery carried out almost entirely during the spawning season. Therefore fishing is concentrated on high sole densities in a rather limited geographical area. The Irish Sea and Bristol Channel Working Group used effort and cpue data on several occasions and these data were very important as the data set is rather short (1970-79). Most of these data were derived from the Belgian fishery accounting for about 80% of the catches in the Celtic Sea and for about 50% in the Irish Sea. In both areas three main regressions were used:

1) The index of effort (total catch/Belgian cpue) was in good agreement with the weighted mean F values from the VPA. On this basis the input Fs were determined by the most recent trend in effort.

2) The Belgian cpue (kg/hr fishing corrected for hp) of the second quarter against total stock biomass showed a good correlation (r = 0.79). Also the United Kingdom otter trawl cpue data (undirected fishery) were in good agreement.

3) Due to the lack of pre-recruit estimates in these areas, the geometric mean regression of 3 year old soles from the VPA and the cpue of 3 year old soles in the Belgian beam trawl showed satisfactory correlations: r = 0.98 (males) and 0.97 (females) for the Celtic Sea and r = 0.48 (males) and r = 0.68 (females) for the Irish Sea.

5. GENERAL OBSERVATIONS

5.1 Disaggregation and Multiplicative Models

5.1.1 The use of disaggregated data

Within the idealistic scheme of homogeneous exploited population, homogeneous fishing fleet and constant fishing intensity (in time), relationships between cpue and biomass, or fishing mortality and fishing effort, are simple and equivalent. The situation becomes more critical when

- the catchability is changing from age group to age group for a given year,
- different fleets showing different fishing powers exist,
- the catchability or the fishing intensity is changing within the years,
- the fish are distributed over several areas with a low mixing rate.

Assuming the adequate disaggregated information exist, two questions appear:

a) is it possible to get a satisfactory index of overall yearly abundance?

b) is it possible to define an overall fishing effort that could be simply related to fishing mortality?

The second problem is not dealt with in this paragraph. Since most attempts to define an overall fishing effort rely upon the division of total catch by some index of abundance, the first problem has first to be solved, although some remaining difficulties would deserve a discussion. Note that since fishing power may vary with the age of the fish, it would be desirable to standardise for fishing power on an age-specific basis.

The remaining problems are related to fishing power, and heterogeneity in space and in time (within a year).

If the only problem comes from fishing power, a simple standardisation can be made by direct comparison of the cpue of the different fleets. If the only problem comes from the existence of several areas, it is also possible to obtain overall indices of abundances by weighted sums or averages of cpue in the different areas. However, one has to assume either

(i) that the vulnerability remains the same from area to area, in which case each local cpue should be weighted by the corresponding area, or

(ii) that the ratio of partial abundance in any area to total abundance remains constant in which case any weighting can give a reasonable if not optimum relative index.

An important problem remains: it is necessary to have cpue in <u>all</u> areas. If empty cells exist, and especially if they change from year to year, the only possible way is the second one, and more sophisticated data processing will be necessary.

The existence of seasonal variations will cause similar problems. If cpue exist for all seasons, any weighted average can be used, as long as the weights do not change from year to year. As soon as empty cells appear, those simple averages will become dangerous if not useless (Laurec & Le Gall, 1975). Spatial and temporal variations can of course be combined into a spatio-seasonal pattern, which includes interactions (seasonal changes of spatial distribution).

If the different problems are combined, they cannot be solved separately. For standardisation calculations, the relative cpue can be used only when the vessels have fished under the same conditions, ideally at the same place and at the same moment. This is a first major reason for using a precise mathematical model describing and combining the different influences on cpue of fishing power, spatial and seasonal effects, and annual abundance. Another reason is associated with the existence of empty cells. Simple averages over non-empty cells can lead to bias in time, so the fitting of a specific multiplicative model becomes a much preferable procedure.

5.1.2 <u>Application of multiplicative models</u>

Catch rate data are often available on a disaggregated level, at least by month, fleet and area. It would be desirable to extract the annual signal prior to any aggregation in order to avoid masking significant distributional and seasonal effects. Using a mathematical model, it is possible to separate the influence on catch rate (U) of such factors (see e.g. Robson, 1966).

Previous experience has shown that multiplicative models are more satisfactory than additive ones. This leads to the use of logarithmic transformations to give linear models. The general model can be expressed as

$$\mathrm{Log}\,U = \mathrm{Log}\,U_{*} + \Sigma_i\, G_i + \epsilon$$

the G_i being factors determined by the particular situation (spatial and seasonal etc.).

It appears that the more "useful" of these models rely upon the inclusion of categories for fleets and a limited number of time-area strata.

$$\text{Log } U^{i}_{fsy} = \text{Log } U_{*} + \text{Log } P_f + \text{Log } Q_s + \text{Log } A_y + \epsilon^{i}_{fsy}$$

U^{i}_{fsy} is the catch rate for fleet f, in time-area stratum s during year y. Several observations may be made, i being the corresponding index. P_f is the relative fishing power for fleet f, a particular fleet f_o being chosen as a reference ($P_{f_o} = 1$). Q_s is a "corrective" factor for differences in the time-area strata, a particular stratum s_o being chosen as a reference ($Q_{s_o} = 1$). A_y is an index of abundance for year y, a particular year y_o being chosen as a reference ($A_{y_o} = 1$).

An abundance index series for some standard fleet f_i and some standard time-area stratum s_j is defined by

$$U_{*} \; P_{fi} \; Q_{sj} \; A_{yk}$$

for all k.

ϵ^{i}_{fsy} is a residual following a normal distribution with mean zero, a variance that can be considered as constant, or related to different factors (catch, effort...). The different ϵ^{i}_{fsy} have to be considered as stochastically independent if any statistical inference is to be made. Such an inference is particularly important for estimating untransformed fishing powers and abundance indices. In order to get unbiased estimates, the variance of the logarithmetic estimate has to be estimated (Gavaris, 1980).

This model does not take into account possible interactions between the P_f, Q_s and A_y (Francis, 1974). For instance, interaction between A_y and P_f could correspond to saturation problems. Between P_f and Q_s this would correspond to changes of relative fishing power from stratum to stratum.

Interaction between years and Q_s are also neglected. This means that the spatial distribution and seasonal pattern is the same from year to year. This hypothesis cannot be avoided, as well as the hypothesis of "no interaction" between year and fishing powers (Laurec, 1979). Such interactions would make it impossible to perform comparison from year to year. <u>This is a general rule.</u>

If the categories which are used generally include fleet, spatial and temporal dimensions, it is important then to consider the level of disaggregation necessary in these dimensions in order to apply the model successfully.

For fleets, data may be available for individual boats or only for fleet totals. Although differences may exist between boats in a fleet, it is more likely that these will be random if the fleet is homogeneous. It is advisable therefore to group the boats into relatively homogeneous fleet categories. Advantages of this procedure are that fewer parameters need to be estimated, and if the fleet is relatively homogeneous there will be more information used in estimating each parameter, resulting in smaller variances.

Spatial and temporal dimensions are by nature continuous and some approximate discrete categories must be constructed. Obviously, years must be one of the temporal dimensions since annual values are desired. Some seasonal breakdown would be advisable with the possibility of collapsing these categories to a smaller number after examination of the estimated "powers". Spatial categories should be included if it is suspected that the area can be broken down into habitats which are of variable preference to the species of interest. If not, inclusion of spatial categories could justifiably be omitted. The inclusion of spatial categories may require that spatial temporal interactions be included in the model. A large degree of such interaction could be evidence that the area cannot be decomposed into preferred habitats.

Although the minimally required level of disaggregation is the categories which will be used in the model, more detailed information may be available. For example, although fleets might be used as categories, data for individual boats may be available. In this situation, no general advice can be given as to whether the data should be used as they are or whether the totals for the fleet should be used. The decision process involves an examination of the residuals for the particular data set, since the level of aggregation used will affect the skewness of the distribution. The level of aggregation which will most likely result in a log normal distribution should be used to minimise any bias in the results. The absence of zeroes is in this respect highly desirable. If this cannot be achieved, several approaches can be used: use of delta distribution, elimination (combined with separate examination of the proportion of zeroes), addition of a constant before transformation.

Finally, it should be noticed that such calculations can obviously be performed for cpue in weights or number, over all ages or for a given age or size range.

If application of the multiplicative model to individual ages is too tedious, it may be possible to obtain satisfactory results with the following approximate method. Compute an effort series for aggregated ages, partition the effort into the fleet components for which an age distribution is available, divide the catch at age for each of these fleets by the corresponding effort (possibly correcting for exploitation pattern) and finally add the cpue arrays for the different fleets.

5.2 The Importance of Appropriate Estimators

The failure of some previous attempts to utilise effort data is quite possibly due to the use of inappropriate estimates of stock size or fishing mortality. Often quantities easily available from standard Working Group procedures have been used, such as spawning stock biomass, or mean fishing mortality weighted by stock numbers.

Clearly, the biomass of an age group which is absent from the catch cannot influence catch per unit effort. The biomass estimate to be used for correlation with cpue should therefore include age groups only in proportion to the extent that they are fully exploited by the fishery in question. One may therefore define the exploited biomass as

$$\hat{B} = \sum_a N_a W_a \frac{F_a}{F_{f*}}$$

where F_a is the partial fishing mortality in the fishery in question and F_{f*} is a reference value averaged over a suitable range of fully exploited ages (see Section 6.2.2). Clearly, if the age composition of the catch is different from that assumed (as may occur with total or spawning stock estimates) the correspondence with cpue will be degraded. This will be particularly noticeable if recruitment is highly variable, since the estimates will not only be quantitatively in error, but a lag will be introduced between the cpue and biomass time series. The presence of even a small lag (one or two years) may easily destroy the correlation between highly stochastic time series. This effect should be minimised by the use of $\hat{B}$.

A similar effect will occur if weighted mean fishing mortality is used. If the selection pattern is approximately constant, and fishing mortality is proportional to effort, the arithmetic mean fishing mortality (over any age range) should be highly correlated with effort. The weighted mean fishing mortality, however, is biased in favour of any large year classes, and the bias shifts from year to year. This also introduces a lag and quantitative error in the computation. Furthermore, it is self-evident that total international fishing mortality will not in general correlate well with effort from a small part of the total fishery; partial fishing mortality for the fishery in question must be used.

Finally, the construction of "indexes of total international effort", by dividing total international catch by cpue from a small part of the fishery, is unlikely to be successful, unless the age composition of this part of the catch is representative of the total. Otherwise, recruitment fluctuations will again introduce a lag in the time series and degrade the correlation. The success of this method for the North Sea flatfish using Dutch beam trawl and English trawl data is presumably highly dependent on their accurate reflection of the age composition of the stock.

All these considerations indicate that great care must be taken in analysing effort data to ensure that appropriate estimates of the various quantities are used. Unless this is done, success is very unlikely, since fluctuations of recruitment are always with us.

5.3 Possibilities for Analysing North Sea Roundfish Data

The North Sea cod data on cpue in the Roundfish Working Group reports, which failed to yield a usable relationship between effort and fishing mortality, were re-examined. First, the fleet cpue data were plotted as time series on a logarithmic scale along with the relative cpue (aggregated over fleets) and the VPA biomass (Figure 5.3.1). The fleets cpue show different trends although there are similarities in the sequence and coincidence of peaks and troughs. It is known that each fleet exploits a different part of the stock and that they take different age compositions. The RCPUE and total biomass trends are also similar, except that the peaks or troughs in the biomass occur 1 or 2 years later than those in RCPUE.

It seemed reasonable to infer that there was an age effect which caused the lag between RCPUE and biomass, and so the fleet cpue's were compared (by age) with the biomasses for 3 age ranges (0-2, 3-5, 6-12 years) as well as the total (0-12). These values are shown as time series in Figure 5.3.2 and were obtained from the 1980 Working Group VPA. It was striking that the cpue of each fleet appeared to be in phase with the trend in biomass of particular age ranges. The most striking were the correspondences between the Netherlands and Belgian cpue and the 0-2 year old biomasses. Correspondences can be detected between the cpue of the other fleets and other age ranges.

It became clear that a biomass measure was required (from VPA) which was appropriate (in age terms) to the RCPUE index. Pope at Lowestoft had suggested the use of "exploitable biomass", which we define as:

$$\hat{B}_{y\bullet} = \sum_{a=1}^{A} N_{ya} \cdot W_{ya} \cdot S_{ya}$$

where S_{ya} is the relative fishing mortality at age referred to some reference level within the year. We now refer to this as "total exploited biomass" to distinguish it from the "partial exploited biomass" which is appropriate to a particular fleet.

$\hat{B}_{y}$ was calculated for North Sea cod using the arithmetic mean F over all ages in the stock as a reference value for the relative F calculation. The results are plotted as a time series in Figure 5.3.3, which also shows total biomass (0-12) and RCPUE. Regressions were calculated between ln RCPUE and ln B or ln B_y, and the results are shown in Figure 5.3.4. The correlation with exploited biomass is considerably higher than that with total biomass, demonstrating that the difference in age structure between the total stock and that exploited by the fleets generates a lag which is removed by the calculation of exploited biomass.

5.4 Fishing Mortality vs Effort or Cpue vs Biomass

Let $\bar{N}$ be the average stock number of some age group and $\bar{W}$ the average body weight of that age group. Then

$$\bar{N} = N_o \, (1-e^{-Z})/Z$$

where N_o is the number at the beginning of the year, and Z is the total mortality.

If E stands for effort and F for fishing mortality, the two models may be expressed:

$$\text{F vs E : } F \propto E \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\text{cpue vs B : } \bar{W}\,\bar{N} \propto Y/E \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

where

$$Y = F\,\bar{N}\,\bar{W} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

is the catch in weight. These simple equations neglect the problem of aggregating dissimilar effort data (see Section 5.1) and should be regarded as idealisations. From a formal point of view the two models are identical, which is easily seen by inserting Eq (3) into Eq (2).

The real difference lies in the nature of the observations needed to perform the two regressions. The observations for the cpue vs B - regressions are expected to show a larger variation, because the variation in year class strengths is reflected in Y-observations. This may not be the case for the F vs E - regression, so in order to demonstrate a regressional relationship, the cpue vs B - regression is expected to be preferable. On the other hand, variations in effort may not be reflected in the cpue vs B - regression, so the utility, as far as regression concerns, is dependent on the actual data in use.

Another point is that past experience shows that the F vs E - regressions should be made only on disaggregated data. That is, the Fs and Es should be partial quantities, so that each partial F (or E) accounts for a fleet consisting of fairly uniform vessels (equal gear tape, fishing grounds, fishing periods, fishing performance, etc.). But for the estimation of final Fs in the VPA one needs an aggregated estimate of total-F. So far, the aggregation of partial effort estimates has turned out to be problematic, resulting in failure of demonstrating a regressional relationship between E and F. These difficulties may lie in non-proportional changes in fishing power of the various fleets.

Of course the same problems appear in the cpue vs B-regression, but the "stochastic noise" caused by variability in fishing power is less dominant due to the larger spread of observations.

Thus, neither of the two models is obviously preferable to the other, and consequently it is recommended that both should be tried, whenever possible. For schooling fish the utilisation of cpue and E-observations is highly questionable, since a tacit assumption behind the two models is that the fish spread evenly over the entire area, independent of stock size.

5.5 Effect of Mixed Fisheries

5.5.1 Effect of mixed fisheries on effort data

If proportions of species caught in a mixed fishery remain constant, the derivation of catch per unit effort for all species can be achieved in the same way as for directed fisheries. By-catches may be more representative random samples than catches of species for which the fishery is directed, but problems may arise if the fishery shifts to a new target species during a period of study. If that happens in some years but not in others, the fishing power exerted by the effort may vary and cpue for the various years may become incomparable. To tackle the problem of shift in target species, the effort data could be corrected for directivity, but how a correction factor could be defined is not obvious. A reason for a shift in directivity might also be that the quota of the initial target species is fished up (see Section 5.6), so these problems are interrelated.

5.5.2 Assessment of mixed fisheries

A principle reason for thinking about mixed fishery assessments is to work out sets of single-species TACs which are not in conflict with one another. One then needs a matrix of consequent partial fishing mortalities on all ages of other species generated in the fishery by the fleets considered.

Formally this may be expressed

$$F_{yfsa} = F_{yfj*} \cdot S_{fsa}$$

where F_{yfsa} is the fishing mortality on by-catch species s age group a in year y exerted by fleet f the target species (or reference species) of which is j. F_{yfj*} is the fishing mortality of the target species for some reference age group (denoted *). S_{fsa} is the relative partial fishing mortality, i.e. the fishing mortality on the by-catch species age group a, created by a fishing mortality of 1.0 on the reference age group of the target species. The relative partial fishing mortalities can be estimated only if estimates of fishing mortalities for all species are available.

To perform a multispecies/multifleet prognosis taking mixed fisheries' effects into consideration is easily done by running the traditional forecast procedure in parallel for all species and letting the partial Fs on by-catch species be determined by the equation above. Similarly, long-term sustainable yield models (incorporating stock/recruitment relationships) utilise the same data.

A definition of a combined MSY-concept accounting for landings of all species assessed is required, if one wishes to optimise a mixed fishery. In principle, such a goal function may be written:

$$\sum_y \sum_f \sum_s \sum_a Y_{yfsa} \cdot V_{yfsa}$$

where V_{yfsa} stands for the "value" (returns) of one tonne of species s age group a landed by fleet f in year y. Giving all Vs the value of 1.0 would imply that the goal was to maximise the total biomass landed. This choice of V would not be reasonable in all cases, e.g.

it would not be sensible to assign the same value to an industrial by-catch as to a landing for human consumption. Progress is going on in the development of aggregated yield evaluation models (Shepherd, pers.comm.; Sparre, 1980), but the application of optimisation techniques is likely to be highly controversial.

To avoid inconsistent quotas, TACs might be set only for the species mainly taken as target species. Precautionary TACs for the by-catch species could then be derived from the target species TACs, by aid of the mixed fisheries model described above. However, if the aim of the management were to protect a by-catch (e.g., industrial by-catch of herring in the sprat fishery) the TAC for the target species would need to be calibrated to produce the desired catch of the more valuable by-catch.

5.6 The Effect of Quotas on Landings and Effort Data Series

The ideal set of quotas for regulation of all fish stocks within a geographical area should be such that

a) No quota is exceeded before any of the others and no quota fails to be met during the period to which it applies;

b) The fishermen consciously attempt to adhere to the quotas.

Even given the ideal set of quotas, there is the possibility that landings data series can be corrupted. For example, it may be the case with a rather restrictive quota on a particular species the fishermen may decide to land the quota as large fish whereas until the quota was implemented landings consisted of both large and small fish.

At present, however, no ideal set of quotas exist. This may result in two major effects.

1) Discarding may increase as the quota for a particular species is approached or after it has been met;

2) Fishermen consciously misreport their landings and/or the location where they were fishing.

Both of these effects can obviously corrupt a series of landings and/or effort statistics. The level of discarding can be assessed by setting up an appropriate sampling programme but correcting for conscious misreporting of landings/effort data is very difficult.

When quota management schemes are in operation, a further corruption may sometimes occur, if catches are limited to a certain quantity per day, or week, etc. In this case effort data at the level which is controlled (e.g. days) clearly become unreliable; effort data at a higher level of discrimination (e.g. hours fished) should not be seriously affected, however.

6. DEVELOPMENTS

6.1 Use of Cpue Indices Combined over Fleets

6.1.1 Estimation of combined cpue indices

As mentioned in Section 4.1, the North Sea Roundfish Working Group failed to demonstrate a correlation between fishing mortality rates from VPA and the age group aggregated index of effort. It was therefore decided to try alternative methods and the most promising one appeared to be to correlate cpue with stock numbers from VPA. As pointed out in Section 5.2, the interpretation of age group aggregated estimates is difficult, and to avoid that problem the basic calculations were made on individual age groups.

Let C_{yfa} be the number caught (landing + discard) of age group a by fleet f in year.

E_{yf} is the effort exerted by fleet f in year y. (In the present case E was not corrected for fishing power.)

Then catch per unit becomes

$$CPUE_{yfa} = C_{yfa}/E_{yf}$$

Because the effort for the various fleets are expressed in incomparable units cpue was converted to relative values, i.e.

$$\gamma_{yfa} = CPUE_{yfa}/CPUE_{*fa}$$

where * stands for some (arbitrarily chosen) reference year.

The relative cpue for all fleets combined was derived by the sum of the γ weighted by the numbers caught, i.e.

$$\Gamma_{ya} = \frac{\sum_f \gamma_{yfa} \cdot C_{yfa}}{\sum_f C_{yfa}}$$

Finally, these figures were scaled and logarithms were taken.

$$\Gamma'_{ya} = \log_{10} \left(\Gamma_{ya}/\max_y \left\{\Gamma_{ya}\right\}\right)$$

To explain why an age group aggregated cpue index is difficult to interpret we examine the mathematical expression for it:

$$\Gamma_{y..} = \sum_a \sum_f \frac{CPUE_{yfa}}{CPUE_{*fa}} \cdot \frac{C_{yfa}}{C_{y..}}$$

Obviously the values of the Γ's are dependent on the choice of the reference year (*). If the relative values of the Γ's were independent of the reference, the expression would still be useful, but as this is not the case it is impossible to give the Γ's a consistent interpretation. The difficulty arises in part because of the arbitrariness of the reference year. If aggregate measures are needed the basic data must be handled in a different way.

6.1.2 Use of combined cpue indices to estimate terminal Fs

Let $N_{y1a}, N_{y1+1,a} \cdots N_{y2,a}$ be stock numbers derived from VPA. The time series, year y1 to year y2 does not include the most recent year for which VPA results are considered uncertain.

From a plot of $\log_{10}(N_{y,a})$ against Γ'_{ya} a predictive regression may be made. From the regression and effort observations, estimates of N_{ya} for the most recent years are obtained.

The Fs for the most recent years may then be calibrated so that the number caught and the N-estimates correspond to each other. If only the last year is excluded from the regression analysis, the Fs could be chosen so that a perfect agreement between C and F is achieved. If more than one recent year are excluded, some fitting procedure must be applied, e.g. one could choose the Fs which minimise

$$\sum_{\substack{y \\ \text{(for recent} \\ \text{years)}}} \left(N_{ya}^{\text{VPA}} - N_{ya}^{\text{Predicted}}\right)^2$$

6.1.3 An example: North Sea haddock

Regressions of Γ'_{ya} on $\log(N_{ya}^{VPA})$ were made for North Sea haddock for the years 1963-78. (See Figure 6.1.1.)

Four fleets were considered: Scottish trawl, Scottish "other", English trawl, English "other". As an example input data for the calculation of relative catch per unit effort for the year 1964 is shown in Table 6.1.1.

The aggregated cpue indices (Γ_{ya}) are shown in Table 6.1.2. Table 6.1.3 gives the Γ'_{ya} values together with the $\log(N_{ya}^{VPA})$ values. Predictive and geometric functional regressions were performed and the results are shown in Table 6.1.3. Figure 6.1.1 gives a graphical presentation of the ten geometric regressions.

Input Cs do not include discards, which we decided that they should. Initially we made the calculations on landings, and due to lack of time the calculations were not redone with total catches.

6.1.4 Discussion

It is possible that the use of the age composition on both sides of the regression equation may introduce a spurious correlation. The Working Group was unable to resolve this question and the matter requires further consideration. However, the results of the regressions for North Sea haddock seem to be very promising. For ages >2 all correlation coefficients exceed 0.82. It is thus recommended that the North Sea Roundfish Working Group consider the procedure described for the three roundfish stocks. Cpue should be preferably derived from total catch and not from landings only, as was done in the present application.

6.2 Disaggregated CPUE and Biomass

6.2.1 Introduction

Section 6.1 relates to the calculation of aggregated cpue data (over fleets) and its relationship to stock abundance from VPA. This section deals with an alternative procedure of comparing the fleet cpue indices with appropriate partial exploited biomasses. These are, again, calculated from VPA but are obtained by using the catch numbers-at-age of the fleet in question. Whereas the aggregated cpue method potentially provides a single time series of cpue for comparison with a comparable series of exploited biomass from each VPA, the disaggregated method provides time series of partial exploited biomasses (PEBs) for each fleet from one VPA. This method therefore introduces the additional problem of choosing a single VPA from potentially different estimates of the terminal fishing mortalities obtained from the correlation between the fleet cpue's and PEBs. A further, and probably minor, problem in normal circumstances is the need to have the age compositions appropriate to each cpue index which one wishes to use. These were not available in each case in the North Sea Roundfish data and the Effort Working Group had to compare the cpue data with possibly inappropriate PEBs since only aggregated age compositions were available in the majority of cases for the North Sea cod, which was the example chosen. It should be noted that it is not necessary to include discards in the yields as long as the landed age composition is available for the appropriate fleet.

6.2.2. Definition of PEB

A VPA is required with the input total age compositions and stock weights-at-age as well as the age compositions for the fleets for which one has cpue data. The required parameters are defined in Section 9. They are as follows:

$$T_{yfa};\quad C_{y \cdot a};\quad W_{y.a};\quad L_y;\quad N_{ya};\quad F_{ya}$$

We define the partial fishing mortality at age as:

$$F_{yfa} = F_{ya} \cdot T_{yfa}/C_{y \cdot a}$$

and the relative partial fishing mortality at age as:

$$S_{yfa} = F_{yfa} / \bar{F}_{yf*}$$

where $\bar{F}_{yf*}$ is a reference fishing mortality which may be selected in various ways (the implications of these choices have not yet been fully explored). It may be chosen as the fishing mortality on the age for which it is maximum, as that on an age which is highly represented in the catch, or as an average over some range of fully exploited ages. The last choice is used here, so

$$\bar{F}_{yf*} = \sum_{a=a_1}^{a_2} F_{yfa} / (a_2 - a_1 + 1)$$

For North Sea cod we have used $a_1 = 2$, $a_2 = 8$.

The partial exploited biomasses (PEBs) are then

$$B_{yf} = \sum_a N_{ya} \cdot W_{y \cdot a} \cdot S_{yfa}$$

Each value of potential exploited biomass is of the same order of magnitude as the total exploited biomass in the same year and the deviation from it is a reflection of the part of the total biomass which is exploited by the fleet in question.

6.2.3 Theoretical relationship between PEB and CPUE for one fleet

If fishing effort E_{yf} is known for fleet f in year y, the cpue will be $Y_{yf}/E_{yf} = U_{yf}$. From the partial fishing effort and the partial fishing mortality at age (F_{yfa}) one can deduce the partial catchability:

$$q_{yfa} = F_{yfa} / E_{yf}$$

It can be shown that:

$$U_{yf}/B_{yf.} = \frac{1}{A_2 - A_1 + 1} \sum_{a=A_1}^{A_2} q_{yfa} = \bar{q}_{yf}$$

$\bar{q}_{yf}$ is an average catchability for year y and fleet f. If it does not change from year to year the ratio between $U_{yf.}$ and B_{yf} is constant.

If it changes, the situation becomes more difficult. However, if it changes with partial exploited biomass within a simple relationship such as

$$\bar{q} = \alpha \; B_{yf.}{}^{\beta}$$

where α and β are constants, the situation can be dealt with. One may write:

$$U_{yf} = B_{yf.} \cdot \bar{q}_{yf}$$

$$= B_{yf.} (\alpha \; B_{yf.}{}^{\beta})$$

$$\therefore \quad U_{yf} = \alpha \; B_{yf.}{}^{(\beta+1)}$$

If, however, there is any change of $\bar{q}_{yf}$ with time, this would create a different problem which may be resolved, perhaps, by modelling the trend in q against environmental variables. These conclusions also apply to the other models of relating cpue to total stock number or total biomass; however, the present model (fleets separate, ages combined) includes the additional assumption that the shape of the relative q_a with age does not vary with time. This is probably a reasonable assumption since the shape will be determined by fish behaviour rather than that of the fleet.

6.2.4 Application to North Sea cod

A new VPA was prepared based on the new Roundfish Working Group data base; the input terminal F values were derived from the 1980 Working Group Report VPA. This should not create a problem in the subsequent analysis, because the eventual aim was to correlate cpue with PEB from the historic data which will be only moderately influenced by the input F values. The VPA input data were available for the years 1963-78. An M of 0.2 was assumed. Stock weights at age were not available and so a set was calculated from the catch weights at age for discards and human consumption landings in the VPA data files. A weighted mean (by catch number in each fishery) was calculated. Empty cells were filled by using the average weight at age for that age group over the time series.

The following age composition data were available in the new data base:

Scotland - Trawl Scotland - Other gears England - All gears	1963-78
Belgium - All gears Netherlands - All gears	1968-78

Also available were age compositions for France - trawl, Denmark - all gears for a number of years but only a small amount of cpue data were available for these fleets.

Cpue data were available as follows (from Anon., 1979b and Anon., 1980d):

Scotland - Trawl Scotland - Seine Scotland - Light trawl	Total catch/total effort; no fishing power correction
England - Trawl England - Seine England - Pair trawl	Total catch/total effort; effort in ton-hrs (i.e. over-corrected)
Belgium - Otter trawl Belgium - Danish seine	
Netherlands - Otter trawl Netherlands - Beam trawl Netherlands - Pair trawl	Total catch/total effort; no fishing power correction

These data have been plotted in Figure 5.3.1.

As discussed earlier, it was thought unreasonable to aggregate these data and therefore the comparison of PEB with cpue was made between the national PEBs and each of that nation's cpue indices.

The calculations were carried out on a TI-59 programmable calculator (with printer) and the whole calculation for cod took about 9 hours. It is, therefore, recommended, that a suitable computer program be made available on the ICES machine if it is intended that these calculations shall be carried out in the Assessment Working Groups.

The program also produced the reference partial fishing mortality in each year for each fleet ($\bar{F}_{yf*}$) and the relative partial fishing mortalities for each age and year = (S_{yfa}). It was therefore possible to compare partial F and national effort as well as cpue and PEB.

6.2.5 Results for North Sea cod

The time series of PEBs is shown in Table 6.2.1 and the PEBs have been plotted as time series in Figure 6.2.1 for comparison with Figure 5.3.1, which shows the cpue data. The trends may be compared with those in Figure 5.3.2 in which the age groups are identified; it appears that each fleet is concentrating on younger fish.

Regressions were performed on the logarithms of cpue and PEB of appropriate data sets. The log transformation allows one to test the constancy of q, at least in relation to the biomass level since

$$\ln (Y_{yf} / E_{yf}) = \ln \alpha + (\beta + 1) \ln B_{yf}.$$

which incorporates the empirical function $Y/E = \alpha B^{\beta}$, so that when $\beta = 0$ the catchability is constant with biomass and is equal to α.

The regression data have been plotted in Figures 6.2.2 - 6.2.5, and the results of the analysis have been summarised in Table 6.2.2. The results are encouraging, bearing in mind the inappropriateness of the data sets available. Four of the eleven regressions were significant with $P < 0.05$, which is considerably more than one would expect by chance. Appropriate age composition data are available in the national laboratories, and one would expect that better correlations would be obtained for at least some fleets if these data were used, especially if the time series of cpue data were extended as well. The negative correlation for English pair trawl for which 10 data points were available perhaps suggests that the data are not accurate. The lack of correlation with the Scottish seine data needs further investigation.

6.3 Analysis of Faroese Data

6.3.1 Faroese longline data used to calibrate a VPA of cod in ICES Sub-division Vb_1

A VPA was run using the same input fishing mortality rates for 1980 as used for 1979 in last year's assessment.

The partial fishing mortality rates for the Faroese longline fleet were then calculated from the equation

$$F_{LL} = \frac{C_{LL}}{C_{TOT}} F_{TOT}$$

for each age. F_{TOT} is the F estimated from VPA.

Ages 6-8 are considered subject to full exploitation so the mean of these three ages was calculated as a measure of fishing mortality. Partial Fs for longline and total F calculated for the same ages are shown in Table 6.3.1 together with effort estimates as million of hooks operated.

In Figure 6.3.1 the logarithms of partial F values from the VPA are shown plotted against the logarithms of the associated values of fishing effort. There is a definite correlation but the estimate of partial F in 1980 lies well above any line drawn through the points.

A new VPA was run then to bring the 1980 point more in line. This new VPA affects the 1978, 1979 and 1980 point. It moves the 1979 and 1978 away from the line and brings the 1980 point almost to the line.

Without going into any discussion of the special features of longline at the Faroes, this seems to indicate a possibility of calibrating a VPA if data are available for one of the major fleets.

This can of course be tried for several fleets and compared.

6.3.2 Application of multiplicative models to Faroese data

The specific model

$$\log U^{i}_{fsy} = \log U_{*} + \log P_{f} + \log Q_{s} + \log A_{y} + \epsilon$$

was applied to the Faroese data for cod.

Ten fleets corresponding to the P_f's were included and only time (months) was used for the time-area strata (Q_s). Data were available for 1975-80. Three attempts were made with the model to examine the effect on the results:

a) with individual haul data excluding zeroes

b) with individual haul data + 1

c) with monthly totals excluding zeroes.

The results showed that for this stock the monthly totals fit the model better. It is likely that the individual haul data are even more skewed than the log normal distribution can accommodate. Nevertheless, the relative abundance, seasonal pattern and fishing powers maintained approximately the same relationships in all attempts indicating that for obtaining an index, the method is relatively robust.

The seasonal pattern (Figure 6.3.2) is in accord with general knowledge of the biology of this species, i.e. the catch rates are highest during March which is the spawning period. The annual relative abundance also appears to confirm the external information which has indicated a general decline since 1975 with a slight increase in 1980 (Figure 6.3.3). The correlation between the longline series (Figure 6.3.4) and the abundance index is very good (Figure 6.3.5) considering that the longline fleet may be exploiting a different component of the stock (the longline data were not used in the multiplicative model so that these measures are independent). The correlation between the estimate of exploited biomass from the VPA runs was also good (Figure 6.3.6).

It should be pointed out that even the best trial of the multiplicative model accounted for only about 35% of the variation in the data; however, weighting the observations would result in considerable improvement but time limits prevented such a trial.

In addition, it may be possible to segregate the stock area into several units of different preference for cod. As a first attempt time-area interaction may be excluded.

6.4 Analysis of Simulated Data

6.4.1 Introduction

Various indices of fishing mortality and catch per unit effort were correlated to effort and biomass using simulated data. The object of these correlations was to indicate which measures perform best with perfect, noisy and biased data. An index of effort combining YPUEs into an aggregated value, recently introduced to the North Sea Roundfish Working Group, and an index of biomass discussed by the Working Group, the exploited biomass, were included with the more traditional approaches. Results show that both of these methods usually perform better than the traditional indices.

6.4.2 Methods

The modelled fishery comprised two fleets with catches from 7 ages compiled for 20 years

$$C_{yfa} \qquad \begin{array}{l} y = 1,20 \\ f = 1,2 \\ a = 1,7 \end{array}$$

Each fleet had its own catchability coefficient, "q", selectivity and effort patterns. A reasonable starting population was taken from a cod cohort analysis (Rivard, 1980).

$$F_{y \cdot a} = q_1 \, E_{y1} \, S_{1a} + q_2 \, E_{y2} \, S_{2a}$$

$$N_{y+1 \, \cdot \, a+1} = N_{y \cdot a} \; e^{-(F_{y \cdot a} + M)}$$

$$C_{y \cdot a} = \frac{F_{y \cdot a}}{F_{y \cdot a} + M} \; N_{y \cdot a} \left(1 - e^{-(F_{y \cdot a} + M)}\right)$$

The catch was then partitioned according to the ratios of the fishing mortalities generated by each fleet:

$$C_{yfa} = \frac{F_{yfa}}{F_{y \cdot a}} \; C_{y \cdot a}$$

Recruitments were randomly generated from a flat distribution to vary over one order of magnitude, from 1 000 to 10 000 fish. The simulation parameters are given in the Appendix to Table 6.4.1.

Statistics from the modelled fishing mortalities and biomasses were compared via correlation analysis to indices from the catch and effort data from each fleet. The indices of fishing mortalities were:

$\bar{F}_y$	average F_y over all ages
$\bar{F}_{we}$	average F_y weighted by catches
$\bar{F}_{wn}$	average F_y weighted by numbers
$\bar{F}_p$	annual F estimated by Paloheimo's method

$$F_p = \ln \frac{N_{y+1 \, \cdot \, a+1}}{N_{y \cdot a}} - M$$

Three biomass indices were developed from the numbers at age after multiplication by weights at age (constant over the 20 years). These biomasses, calculated for mid-year, were:

B_{tot}	total biomass
B_{ss}	spawning biomass
B_{exp}	exploited biomass (using F_{max} as the reference)

Three simulations were made; the first with perfect data, the second with 20% variation added to both catch and effort data and in the third the catchabilities were function of time. The catchability of the first fleet increased at 2.5% per year while the catchability of the second fleet dropped discontinuously from 0.0003 to 0.0001 between year 10 and 11.

6.4.3 Results and discussion

The population parameters (catch numbers, population numbers, fishing mortalities at age and biomasses) are given in Table 6.4.1, while Table 6.4.2 shows the results of the three simulations. The r^2 for the various correlations for the "perfect" data are given in column 1. Correlations of unity are seen for:

- average F versus effort as defined from aggregated effort
- average F versus effort as defined by the total catch divided by $YPUE_{y1}$.
- $YPUE_y$ •. versus exploited biomass
- $YPUE_{y1}$ • versus exploited biomass

The good fit with the data from fleet 1 is not surprising since it is the major sector in the fishery.

Weighting Fs by numbers or catch greatly decreases the correlation. The same is true of the Fs derived from successive numbers in the population (Paloheimo's method). Paloheimo's F correlated very well with $\bar{F}_{wn}$(r^2 = .98).

The addition of noise to the catch and effort data seriously decreased the correlations, as expected. As only one run was made with random variation, the resultant r^2 may not equal the expected values. As expected, however, the better methods for the pure data were also generally better here.

The last three columns are the results from the simulations with time dependent q's. Again the correlations decreased significantly. The YPUE versus biomass were more resistant to degradation than the F vs E relationships. It has been suggested that this is due to the larger dynamic range of the biomass ($\approx$ 3) than that of the fishing mortalities ($\approx$ 2).

It is realised that simulations could be made more sophisticated (stochastic averaging, perform VPA on noisy catches, etc.), but it is felt that this study gives clear indications of the dangers of using some of the currently accepted methods.

6.4.4 More simulations

Three more runs were carried out to answer the questions:

1) what will be the effect of increasing the dynamic range of the fishing mortality, and
2) what will be the effect of selectivities changing with time.

A first run was made to give a basis for comparison with the more dynamic effort with constant catchability and selectivities over time (the first column of Table 6.4.3). The second column has varying catchability and the effects of this biasing are reflected by the results in the second column. The dynamic ranges were approximately three for both the average F and the total biomass. As was seen in the earlier runs, the regressions of cpue vs B performed better than did the F vs Es. However, increasing the dynamic range of the effort improved the robustness of the F vs E correlation.

In the third run the q's were held constant but the selectivities changed over time. The selectivities of the first run increased for the lower age classes to twice their initial values over the twenty-year period. Generally, the YPUE vs biomass correlations were resistant to this biasing, especially those using B_{exp}. A few regressions increased compared to the "pure" run, this may be an artefact of the particular values used.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Catch at age data (and thus virtual population analysis) contain no information about fishing mortality in the most recent year. A reliable stock assessment can only be carried out if there is independent information which may be used to deduce current fishing mortality (or, equivalently, stock size). An updated VPA, on the other hand, is not absolutely necessary, though one may be desirable.

7.2 Independent information from various sources may be useful. Examples are egg or larval surveys, acoustic surveys, groundfish surveys, and tagging experiments. Commercial effort data are valuable but are not obviously preferable to these other types of information. It would be unwise to rely on an analysis of effort data unless this is known to be of good quality. If effort data are known to be unreliable, another type of independent information should be sought.

7.3 The Working Group has found that effort data can be used to estimate fishing mortality and population size in several fish stocks. If the analysis fails for non-schooling species this is more likely to be caused by the use of inappropriate estimates than by a failure of the basic method. The successful analysis of effort data demands a detailed and thorough understanding of the basic data, and great care in the selection of appropriate procedures.

7.4 The Working Group advises that the responsibility for the collection and use of effort data must therefore remain the responsibility of the normal Assessment Working Groups, who alone possess the specialist knowledge of the stocks required.

7.5 It is unlikely to be feasible to analyse very detailed (disaggregated) effort data in the Assessment Working Group environment in the immediate future. Such data would more appropriately be analysed in Working Group members' own institutes, where computer programs and file structures can be harmonised. The Working Group recommends that the ACFM Study Group on Standard Computer Programs for Assessment Working Groups should be requested to consider, in consultation with ICES staff, what computer processing facilities for disaggregated data could be provided at ICES in the longer term, and what file structures would be desirable (STATLANT 27B format may be appropriate).

7.6 Moderately aggregated data may appropriately be analysed in the Assessment Working Group environment. Members of Assessment Working Groups should make strenuous efforts to ensure that age compositions are available at the same level of aggregation as any catch and effort data brought to Working Group meetings, since it is very difficult to utilise the effort data unless this information is available, and the labour of utilising the data is much increased unless this preparatory work is done.

7.7 From their examination of certain examples where the application of effort data has been unsuccessful in the past, the Working Group found that this was primarily caused by the use of inappropriate methods. Great care is required to select appropriate measures of fishing mortality for comparison with effort, and of biomass for comparison with yield per unit effort. Simple comparison of aggregated cpue with spawning stock or total biomass is unlikely to succeed. Disaggregation by age clarifies the comparisons considerably, and greatly increases the range of cpue data especially, and should be used whenever possible. Estimations which combine several age groups (e.g. simple catch weight!) confound the normally strong signal from variable recruitment and require especial care.

7.8 The Working Group considers that with careful attention to detail and to the use of appropriate estimators of quantities such as fishing mortality and stock abundance, the use of effort data can be made much more successful than in the past. In general, the use of weighted average fishing mortality, and total or spawning stock biomasses should be avoided.

7.9 The comparison of fishing mortality with effort, and of yield per unit effort with biomass are not entirely equivalent. The former exhibits a signal primarily due to changes of effort, whilst the latter responds primarily to fluctuations of recruitment. Which is most useful depends on the case in question, and the Working Group recommends that both should be used in parallel.

7.10 The Working Group experimented with several methods of analysis of effort data which appeared to be promising, namely:

a) the use of compound indices of catch per unit effort constructed from data from several fleets, for separate ages, for comparison with estimates of population at age;

b) the comparison of disaggregated yield per unit effort indices with partial exploited biomass estimates, and partial fishing mortality with disaggregated cpue;

c) the application of multiplicative models to highly disaggregated yield per unit effort data, in order to extract a best estimate of the annual signal, taking account of other factors;

d) the examination of the efficacy of various methods of analysis on simulated data, both with and without the presence of noise.

7.11 With the imperfect data available, method (a) was found to be most successful. The simulation studies (d) suggested that a cpue index aggregated over ages should also correlate well with aggregate exploited biomass, as also observed for North Sea cod (Section 5.3). Method (b) performed less well, though it was still superior to many previous attempts to utilise effort data. The Working Group felt that the poorer performance was probably due to the incomplete data available (proper age compositions were not available for all fleets), and that good results would be obtained with better data.

Method (c) successfully identified a strong annual signal, but it is not clear with which estimate of stock abundance it should be compared although it correlates well with exploited biomass. Use of the method on more aggregated data for which age compositions are available would be worth investigating.

Simulation studies (d) indicated that comparison of compound cpue indices with exploitable biomass was a good and robust procedure, as was comparison of arithmetic mean fishing mortality with effort. Use of spawning stock or total biomass, construction of "effort" measures using cpue from a small component of the catch, and use of weighted mean fishing mortality (using catch or - especially - population numbers)were unsatisfactory, and would probably fail to detect a relationship even when it was present.

7.12 Age composition data are necessary for the correct interpretation of effort data. The inadequacies of VPA as an assessment tool do not therefore justify any relaxation of efforts to improve the collection of samples for age composition analysis.

7.13 The Working Group found that exploited biomass seems in practice to be an appropriate estimator of stock size, but it may no longer be a valid estimator when selection at age changes. Some theoretical justification was presented ((Section 6.2.3) that this is indeed so for partial exploited biomass. Further investigation of the basis of this quantity, especially the selection of reference fishing mortality and its use is desirable.

7.14 It is in some cases desirable that catch per unit effort data and fishing mortalities should be based on catch data including discards (see Sections 6.1.3 and 6.2.1). There are practical difficulties in achieving this, since discard data are usually collected on a different basis to landings data. Methods for including discard data, or allowing for their omission, need to be further investigated.

7.15 The difficulties of analysing large amounts of data in a Working Group are very great. For real progress to be made on these methods, it is essential that a method be found for circulating, collating, and analysing the data before the Working Group meets.

7.16 The Working Group stresses that the investigations carried out are only <u>examples</u> of the sorts of calculations which can be performed. They are in part based on inadequate data and the detailed results should not be used for assessment purposes. The Group recommends that members of Assessment Working Groups should undertake further investigation of the methods used.

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9. NOTATION

Symbols

q	catchability coefficient (in $F = qE$)
Y	yield in weight (including discards)
L	landings in weight (excluding discards)
W	weight of an individual fish
B	biomass
P	relative fishing power of a fishing boat or fleet
E	fishing effort
U	yield or landings per unit of effort (see abbreviations)
C	catch in numbers of fish (including discards)
T	landed catch in numbers of fish
N	stock in numbers of fish
A	abundance effect in the linear model
Q	"corrective" factor for differences in time-area strata in the linear model
G	factors in the linear model
V	value of a quantity of fish
F	instantaneous fishing mortality
Z	instantaneous total mortality
M	instantaneous natural mortality
S	selection coefficient defined as the relative fishing mortality (over age)
γ	relative catch rate (over years) for one fleet
Γ	relative catch rate over years for several fleets combined

(Note: " ^ " over a symbol has been used in various ways and its use is defined in the relevant section.)

Suffices (others occur and are defined locally)

y	years
f	fleets
a	ages
s	species or time-area strata in the linear model
$*$	denotes a reference year, fleet, age or species
$\cdot$	denotes a summation over a suffix

Abbreviations

VPA	Virtual Population Analysis
CPUE	catch per unit effort either with catch equal to yield or landings or numbers of fish as defined in the text
YPUE	yield per unit effort (including discards)
LPUE	landings per unit effort (excluding discards)
PEB	partial exploited biomass
RCPUE	relative CPUE over years averaged across fleets weighted in various ways
TAC	total allowable catch
NAFO	Northwest Atlantic Fisheries Organisation
WG	Working Group

Table 6.1.1. Example of input data and calculation of relative CPUE for year 1964. Data are number at age of North Sea haddock landed in 1964 by Scottish trawlers. The reference year is 1978.

Age	$C_{1964,1,a}$	$CPUE_{1964,1,a}$	Relative $CPUE_{1964,1,a}$	Reference: $CPUE_{1978,1,a}$
1	0	0	0	4.548
2	44 147	228.741	7.195	31.793
3	8 810	45.648	3.532	12.926
4	784	4.062	0.036	114.007
5	630	3.264	0.254	12.837
6	566	2.933	2.459	1.193
7	22	0.114	0.046	2.459
8	22	0.114	0.252	0.452
9	44	0.228	1.924	0.119
10	1	0.005	0.349	0.015
Effort	193			

Table 6.1.2. Values of Γ_{ya} for North Sea haddock.

Age	1963	1964	1965	1966	1967	1968	1969	1970
1	1.611	0.002	0.144	1.329	3.606	0.692	0.003	0.054
2	1.545	3.141	0.025	0.059	0.469	2.471	3.380	0.306
3	0.502	2.738	8.281	0.194	0.115	0.553	2.899	17.757
4	0.072	0.078	0.153	1.475	0.018	0.015	0.020	0.165
5	0.448	0.321	0.417	0.427	11.488	0.307	0.087	0.060
6	0.292	1.594	1.973	0.693	1.235	30.533	1.256	0.311
7	0.262	0.217	0.287	0.355	0.035	0.065	3.299	0.051
8	1.179	0.386	0.215	0.200	0.286	0.082	0.226	5.663
9	0.491	1.487	0.876	0.595	0.287	0.063	0.058	0.138
10	2.757	2.882	3.670	3.110	2.091	0.229	0.470	0.571

Age	1971	1972	1973	1974	1975	1976	1977	1978
1	1.639	0.625	0.321	1.355	1.131	0.131	0.629	1.000
2	0.456	3.100	2.359	0.635	2.488	3.204	0.639	1.000
3	0.593	1.096	6.012	6.335	1.032	5.306	11.961	1.000
4	1.669	0.137	0.034	0.290	0.570	0.073	0.438	1.000
5	0.673	11.426	0.305	0.134	1.186	2.795	0.578	1.000
6	0.208	2.103	21.613	0.780	0.409	3.789	5.801	1.000
7	0.043	0.063	0.430	3.864	0.166	0.081	0.774	1.000
8	0.252	0.065	0.279	0.454	5.131	0.154	0.373	1.000
9	8.285	0.309	0.170	0.209	2.630	5.690	0.318	1.000
10	9.929	26.758	8.512	2.210	3.043	4.379	19.369	1.000

Table 6.1.3. Values of log (N_{ya}^{VPA}) and Γ'_{ya} for age groups 1-10 for North Sea haddock. Results of predictive regression ($y = a+bx$) and geometric regression ($y = u+vx$), $y = \log N$, $x = \Gamma'$

Year / Age Group	I		II		III		IV		V		VI		VII		VIII		IX		X	
	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'
1963	9.739	-0.350	8.724	-0.340	7.674	-1.548	7.423	-1.365	7.023	-1.409	6.158	-2.019	6.098	-1.169	6.018	-0.681	5.111	-1.227	4.591	-0.987
1964	7.774	-3.162	9.597	-0.032	8.353	-0.812	7.262	-1.332	6.993	-1.554	6.554	-1.282	5.865	-1.250	5.651	-1.167	5.549	-0.746	4.732	-0.968
1965	8.513	-1.398	7.591	-2.130	9.258	-0.331	7.778	-1.037	6.841	-1.440	6.522	-1.190	5.912	-1.130	5.534	-1.420	5.201	-0.976	4.940	-0.863
1966	8.904	-0.434	7.551	-1.757	7.341	-1.961	8.907	-0.054	7.204	-1.430	6.198	-1.644	5.993	-1.036	5.428	-1.451	5.265	-1.144	4.699	-0.935
1967	9.338	0	7.982	-0.857	7.182	-2.188	7.115	-1.963	8.478	0	6.634	-1.393	5.566	-2.048	5.436	-1.296	4.869	-1.461	4.851	-1.107
1968	10.097	-0.717	8.912	-0.136	7.525	-1.507	6.906	-2.054	6.873	-1.573	7.953	0	6.136	-1.776	5.045	-1.841	4.531	-2.117	4.041	-2.068
1969	8.656	-3.063	9.845	0	8.596	-0.787	7.058	-1.931	6.683	-2.119	6.588	-1.386	7.516	-0.069	5.918	-1.400	4.732	-2.155	4.176	-1.755
1970	8.523	-1.822	8.553	-1.043	9.452	0	7.922	-1.005	6.449	-2.280	6.257	-1.991	5.977	-1.884	6.993	0	5.698	-1.778	4.380	-1.671
1971	9.345	-0.342	8.074	-0.870	7.955	-1.476	8.860	0	7.283	-1.232	6.100	-2.168	5.631	-1.949	5.737	-1.351	6.443	0	5.537	-0.431
1972	9.360	-0.761	8.957	-0.038	7.750	-1.210	7.499	-1.084	8.386	-0.002	6.819	-1.162	5.794	-1.785	5.253	-1.939	5.500	-1.428	5.939	0
1973	8.713	-1.051	9.056	-0.156	8.539	-0.470	7.077	-1.696	6.892	-1.576	7.795	-0.150	6.358	-0.954	5.534	-1.307	5.068	-1.687	5.369	-0.497
1974	9.567	-0.425	8.391	-0.726	8.763	-0.448	7.954	-0.760	6.637	-1.933	6.397	-1.593	7.222	0	5.884	-1.096	5.270	-1.597	4.839	-1.083
1975	9.582	-0.503	9.059	-0.133	8.037	-1.236	8.316	-0.466	7.443	-0.986	6.283	-1.873	5.940	-1.366	6.631	-0.043	5.617	-0.498	5.121	-0.944
1976	8.564	-1.440	9.253	-0.023	8.480	-0.525	7.283	-1.358	7.671	-0.614	6.900	-0.906	5.858	-1.679	5.262	-1.566	6.069	-0.163	5.053	-0.786
1977	8.809	-0.758	8.245	-0.723	8.825	-0.172	7.792	-0.581	6.854	-1.298	7.055	-0.721	6.354	-0.698	5.626	-1.182	4.954	-1.416	5.548	-0.140
1978	8.996	-0.557	8.479	-0.529	7.687	-1.249	8.300	-0.222	7.196	-1.060	6.368	-1.485	6.596	-0.587	5.922	-0.753	5.386	-0.918	4.716	-1.427
r	0.746		0.890		0.954		0.958		0.967		0.968		0.897		0.942		0.820		0.954	
a	9.521		9.190		9.201		8.665		8.285		7.774		7.092		6.725		6.093		5.759	
b	0.469		0.925		0.992		0.898		0.861		0.848		0.756		0.852		0.633		0.869	
$\bar{x}$	-1.049		-0.593		-0.995		-1.057		-1.282		-1.312		-1.211		-1.153		-1.207		-0.979	
$\bar{y}$	9.030		8.642		8.214		7.716		7.182		6.661		6.176		5.742		5.329		4.908	
u	9.689		9.258		9.249		8.707		8.323		7.810		7.197		6.785		6.261		5.800	
v	0.629		1.039		1.040		0.937		0.890		0.876		0.843		0.904		0.772		0.911	

Table 6.2.1. North Sea cod. Partial exploited biomasses (PEBs).

Year/Fleet	Scotland Trawl	Scotland Other Gears	England All Gears	Belgium All Gears	Netherlands All Gears
1963	416.4	423.6	235.6	-	-
1964	473.6	466.9	244.7	-	-
1965	504.2	499.9	406.1	-	-
1966	661.5	602.6	570.1	-	-
1967	584.8	664.4	577.3	-	-
1968	667.0	745.1	666.9	566.5	915.9
1969	286.1	507.8	512.4	415.6	494.9
1970	488.1	529.0	482.0	633.6	650.4
1971	543.2	715.2	577.3	1 102.0	1 099.1
1972	576.4	856.0	539.9	1 239.0	1 096.0
1973	432.9	488.3	332.3	420.6	535.8
1974	341.5	468.1	362.2	457.9	515.3
1975	304.7	496.9	389.2	421.2	579.6
1976	393.1	587.1	463.0	647.8	641.1
1977	399.7	640.0	529.4	169.0	992.8
1978	313.9	516.6	391.5	856.3	1 332.6

Table 6.2.2. Results of regression analysis on log PEB and log CPUE for various fleets and North Sea cod. The equation is $\ln (Y_{yf}/E_{yf}) = \ln x + (\beta + 1) \ln B_{yf}$.

PEB Fleet	CPUE Fleet	Period	n	r	β+1	Significance Level
SCO TRA	SCO MT	1970-75	6	0.378	0.597	ns
SCO TRA	SCO LT	1970-75	6	0.439	0.667	ns
SCO OTH	SCO S	1963-75	13	0.456	1.628	ns
ENG ALL	ENG MT	1963-75	13	0.780	1.493	**
ENG ALL	ENG S	1963-75	13	0.878	0.980	**
ENG ALL	ENG PT	1966-75	10	-0.620	-5.183	ns
BEL ALL	BEL OT	1971-75	5	0.910	0.972	**
BEL ALL	BEL DS	1973-75	3	-0.118	-3.666	ns
NET ALL	NET OT	1968-75	8	0.745	1.413	*
NET ALL	NET BT	1968-75	8	0.650	1.063	ns
NET ALL	NET PT	1968-75	8	0.596	0.922	ns

Table 6.3.1. Basic data for Figure 6.3.1. Faroese longline boats 1973-80. Cod in Sub-division Vb_1.

Year	Effort Mill. Hooks	Total F from VPA		Partial F Longline	
		1 Run	2 Run	1 Run	2 Run
1973	27	0.386	-	0.067	-
1974	25	0.392	-	0.065	-
1975	30	0.373	-	0.055	-
1976	49	0.539	-	0.153	-
1977	62	0.985	0.978	0.329	0.326
1978	52	0.553	0.452	0.145	0.137
1979	45	0.558	0.447	0.115	0.101
1980	41	0.490	0.375	0.145	0.109

Table 6.4.1.

Catch

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	11	8	4	4	1	5	4	2	1	6	5	3	2	6	1	1	1	2	4	4
2	773	1 421	1 088	520	495	117	667	521	293	182	847	702	390	341	827	197	210	111	235	619
3	596	883	1 642	1 273	615	592	142	811	644	366	230	1 075	977	591	501	1 189	278	290	151	314
4	482	575	878	1 680	1 340	666	660	162	959	782	456	294	1 514	1 476	849	694	1 588	357	361	181
5	205	128	160	256	515	431	224	231	60	371	316	193	139	775	706	384	296	642	137	131
6	87	53	35	46	77	162	142	77	84	23	148	132	90	70	361	311	160	117	241	49
7	37	23	15	10	14	24	53	49	28	32	9	62	62	46	33	159	130	63	44	86
1+	2 192	3 092	3 822	3 788	3 056	1 998	1 893	1 853	2 070	1 763	2 012	2 461	3 175	3 304	3 278	2 935	2 662	1 583	1 173	1 383

Numbers

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	10 000	8 000	4 000	4 000	1 000	6 000	5 000	3 000	2 000	10 000	9 000	5 000	4 000	9 000	2 000	2 000	1 000	2 000	5 000	4 000
2	4 270	8 177	6 542	3 271	3 271	818	4 903	4 090	2 454	1 636	8 182	7 364	4 091	3 273	7 363	1 636	1 636	818	1 636	4 090
3	1 820	2 800	5 416	4 377	2 210	2 233	564	3 417	2 879	1 745	1 175	5 935	5 396	2 998	2 372	5 283	1 162	1 151	570	1 128
4	780	956	1 500	2 961	2 441	1 258	1 296	334	2 068	1 778	1 099	755	3 892	3 538	1 923	1 491	3 256	702	681	331
5	330	211	272	448	930	806	437	473	129	838	757	492	355	1 831	1 577	815	602	1 249	256	237
6	140	88	59	80	139	303	276	157	181	52	354	337	230	166	806	661	325	228	450	88
7	60	37	25	17	25	45	104	100	60	73	22	158	157	108	73	338	263	123	82	155
1+	17 400	20 270	17 814	15 155	10 017	11 463	12 585	11 571	9 772	16 122	20 589	20 041	18 122	20 914	16 115	12 225	8 244	6 271	8 676	10 027

Biomass

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	16 848	13 479	6 740	6 740	1 685	10 110	8 425	5 055	3 370	16 852	15 167	8 427	6 741	15 167	3 370	3 370	1 685	3 370	8 425	6 740
2	19 263	37 064	29 791	14 966	15 037	3 777	22 770	19 075	11 500	7 703	38 701	34 998	19 444	15 475	34 650	7 663	7 627	3 795	7 555	18 798
3	11 808	18 330	35 777	29 172	14 867	15 154	3 862	23 642	20 105	12 298	8 358	42 608	38 735	21 302	16 700	36 856	8 034	7 881	3 866	7 585
4	4 786	5 982	9 579	19 289	16 229	8 536	8 981	2 367	14 977	13 153	8 310	5 835	30 065	26 696	14 200	10 780	23 043	4 866	4 625	2 198
5	2 254	1 469	1 930	3 250	6 881	6 087	3 366	3 740	1 039	6 910	6 381	4 239	3 062	15 369	12 955	6 557	4 736	9 632	1 935	1 750
6	1 057	679	465	643	1 138	2 534	2 357	1 376	1 517	472	3 304	3 208	2 192	1 542	7 325	5 875	2 829	1 944	3 762	719
7	483	307	207	149	217	404	946	929	574	709	218	1 601	1 599	1 065	709	3 203	2 444	1 120	732	1 348
1+	73 642	99 591	112 290	103 470	79 943	63 863	66 296	71 345	70 301	74 628	98 868	123 477	130 140	126 480	117 892	99 579	72 589	46 346	41 325	49 963

Fishing Mortality

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2	0.222	0.212	0.202	0.192	0.182	0.172	0.162	0.151	0.141	0.131	0.121	0.111	0.111	0.122	0.132	0.142	0.152	0.162	0.172	0.182
3	0.444	0.424	0.404	0.384	0.364	0.344	0.324	0.302	0.282	0.262	0.242	0.222	0.222	0.244	0.264	0.284	0.304	0.324	0.344	0.364
4	1.108	1.058	1.008	0.958	0.908	0.858	0.808	0.754	0.704	0.654	0.604	0.554	0.554	0.608	0.658	0.708	0.758	0.808	0.858	0.908
5	1.120	1.070	1.020	0.970	0.920	0.870	0.820	0.760	0.710	0.660	0.610	0.560	0.560	0.620	0.670	0.720	0.770	0.820	0.870	0.920
6	1.120	1.070	1.020	0.970	0.920	0.870	0.820	0.760	0.710	0.660	0.610	0.560	0.560	0.620	0.670	0.720	0.770	0.820	0.870	0.920
7	1.120	1.070	1.020	0.970	0.920	0.870	0.820	0.760	0.710	0.660	0.610	0.560	0.560	0.620	0.670	0.720	0.770	0.820	0.870	0.920
1+	0.734	0.701	0.668	0.635	0.602	0.569	0.536	0.498	0.465	0.433	0.400	0.367	0.367	0.405	0.438	0.471	0.504	0.536	0.569	0.602

<u>Appendix to Table 6.4.1</u>. Simulation parameters.

Starting population and selectivities:

Age	Number	Weight	Selectivity 1	Selectivity 2
1	10 000	1.86	.001	.005
2	4 270	5.53	.2	.1
3	1 820	8.80	.4	.2
4	780	11.0	1	.4
5	330	12.3	1	1
6	140	13.6	1	1
7	60	14.5	1	1

Constant catchability coefficients: $q_1 = 0.001$
$q_2 = 0.0002$

Effort:

Year	E_1	E_2	q_1 Variable	q_2 Variable
1960	1 100	100	.001	.0003
1961	1 050	100	.00102	.0003
1962	1 000	100	.00105	.0003
1963	950	100	.00108	.0003
1964	900	100	.00110	.0003
1965	850	100	.00113	.0003
1966	800	100	.00116	.0003
1967	750	50	.00119	.0003
1968	700	50	.00122	.0003
1969	650	50	.00125	.0003
1970	600	50	.00128	.0001
1971	550	50	.00131	.0001
1972	550	50	.00134	.0001
1973	600	100	.00138	.0001
1974	650	100	.00141	.0001
1975	700	100	.00145	.0001
1976	750	100	.00148	.0001
1977	800	100	.00152	.0001
1978	850	100	.00156	.0001
1979	900	100	.00160	.0001

Table 6.4.2. Parameters of the equation relating effort to fishing mortality and biomass to catch per unit effort for pure data, data with noise and data with changes in "q".

Relationship	Pure Data r^2	Data with Random Noise (20%) r^2	Change in "q" (No Noise) r^2
$\bar{F}$ vs E (Total catch/$Cpue_1$)	1.000	.393	.447
$\bar{F}$ vs E (Total catch/$Cpue_2$)	.810	.464	.236
F_p vs E (Gamma)	.024	.000	.002
$\bar{F}$ vs E (Gamma)	1.000	.397	.536
$\bar{F}_{wc}$ vs E (Gamma)	.318	.107	.075
$\bar{F}_{wn}$ vs E (Gamma)	.044	.003	.006
$\bar{F}_{wc}$ vs E (Total catch/$Cpue_1$)	.320	.109	.058
$\bar{F}_{wn}$ vs E (Total catch/$Cpue_1$)	.044	.003	.002
Cpue vs Exploited biomass	1.000	.746	.943
Cpue vs Spawning stock biomass	.902	.680	.836
Cpue vs Total biomass	.638	.440	.537
$Cpue_1$ vs Exploited biomass	1.000	.745	.923
$Cpue_2$ vs Exploited biomass	.907	.443	.115

Table 6.4.3. Coefficients of determination (r^2) for wider dynamic range of effort and change in selectivity and "q".

Relationship	Pure Data	Change in "q"	Change in "s"
$\bar{F}$ vs E_1	1.000	.789	.988
$\bar{F}$ vs E_2	.929	.231	.888
F_p vs E (Gamma)	.133	.080	.086
$\bar{F}$ vs E (Gamma)	1.000	.895	.984
$\bar{F}_{wc}$ vs E (Gamma)	.560	.349	.613
$\bar{F}_{wn}$ vs E (Gamma)	.195	.119	.156
$\bar{F}_{wc}$ vs E_1	.567	.292	.628
$\bar{F}_{wn}$ vs E_2	.197	.084	.163
Ypue vs B_{exp}	1.000	.987	1.000
Ypue vs B_{ss}	.909	.879	.874
Ypue vs B_t	.742	.670	.732
$Ypue_1$ vs B_{exp}	1.000	.974	1.000
$Ypue_2$ vs B_{exp}	.942	.155	.962

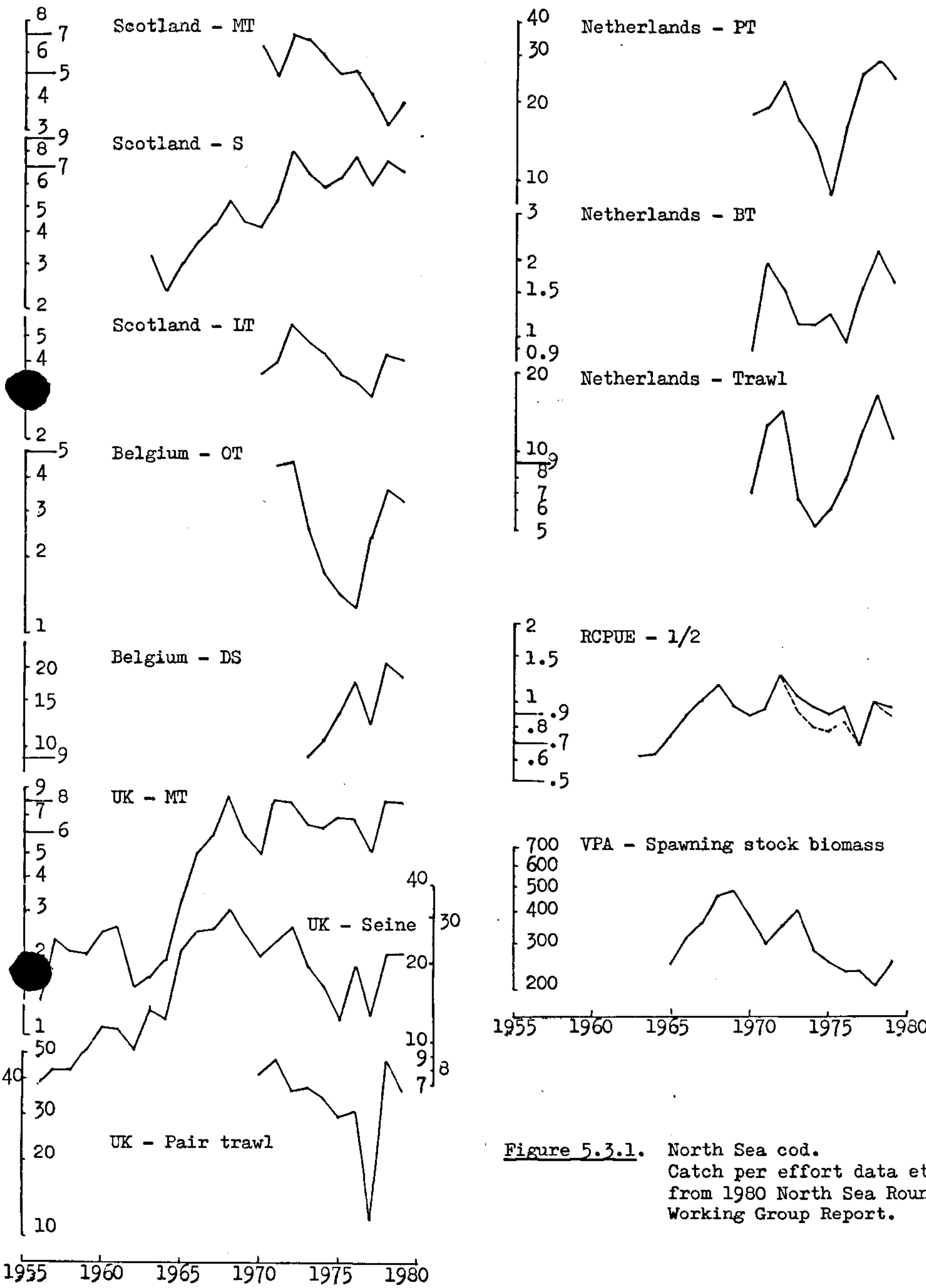


Figure 5.3.1. North Sea cod.
Catch per effort data etc.
from 1980 North Sea Roundfish
Working Group Report.

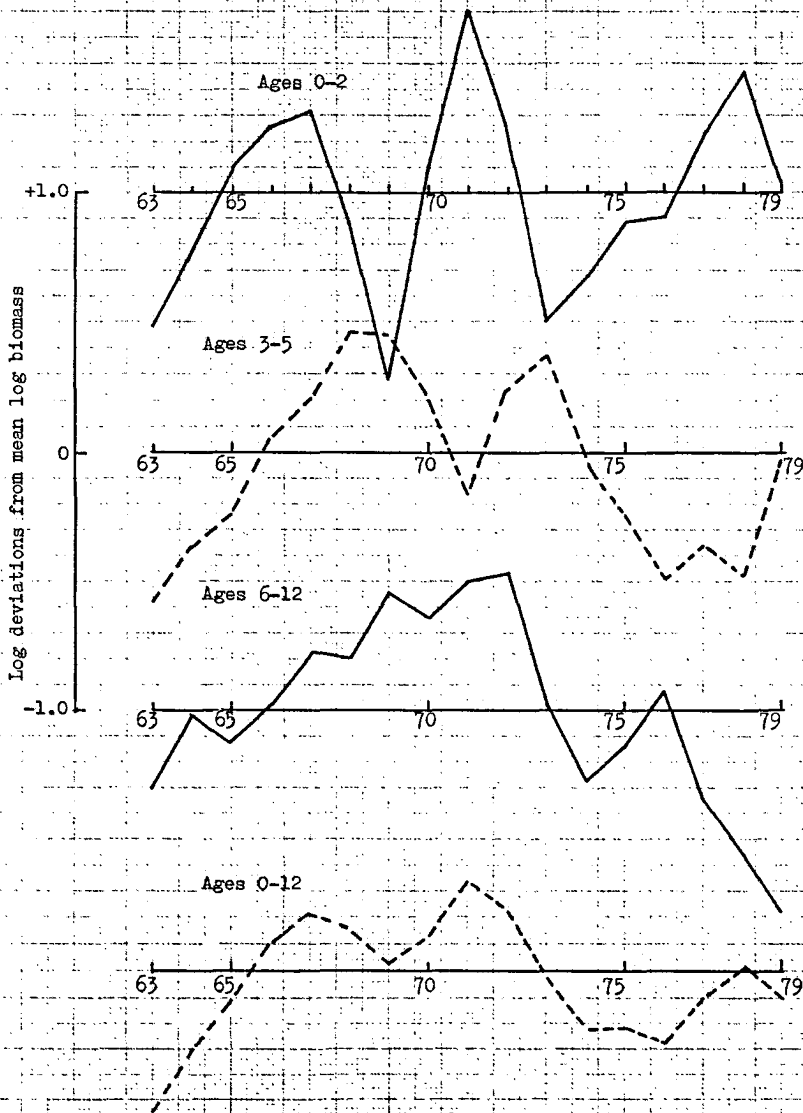


Figure 5.3.2. North Sea cod.
Biomass from VPA for various age ranges.
Beginning of year values. 1980 Working Group Report.

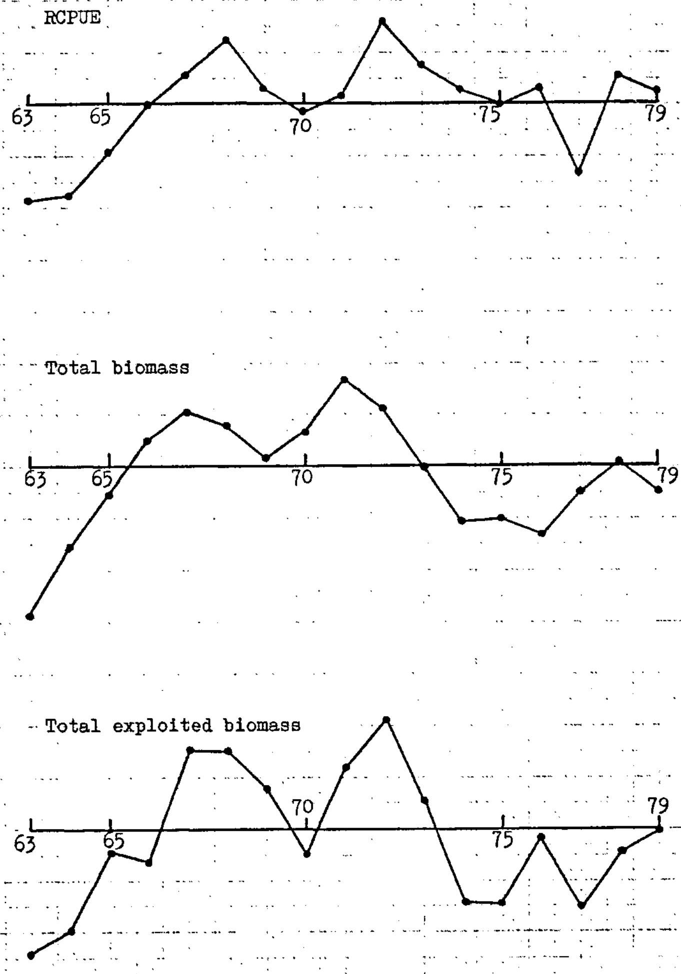
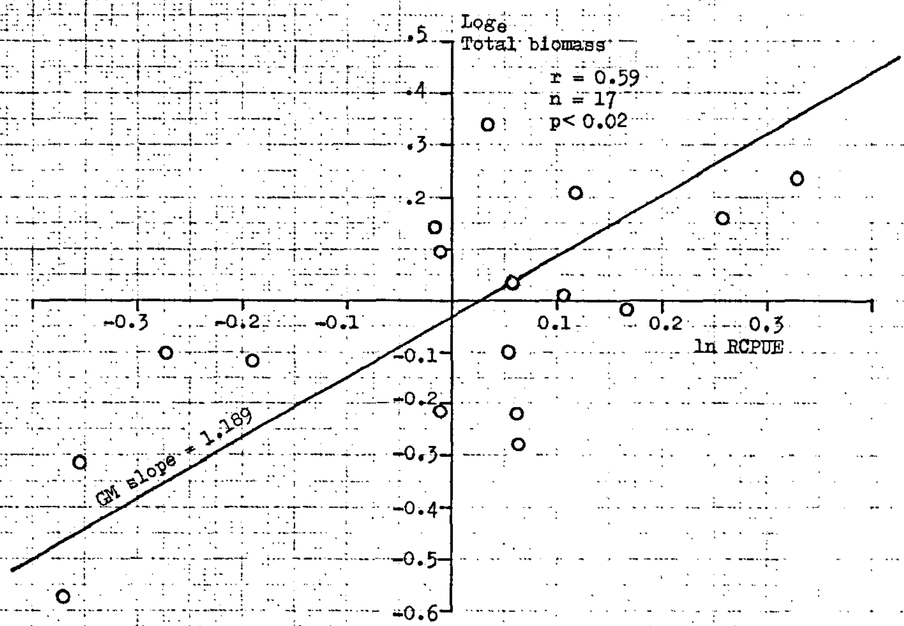


Figure 5.3.3. North Sea cod, ln RCPUE, ln B and ln TEB from 1980 Working Group Report.



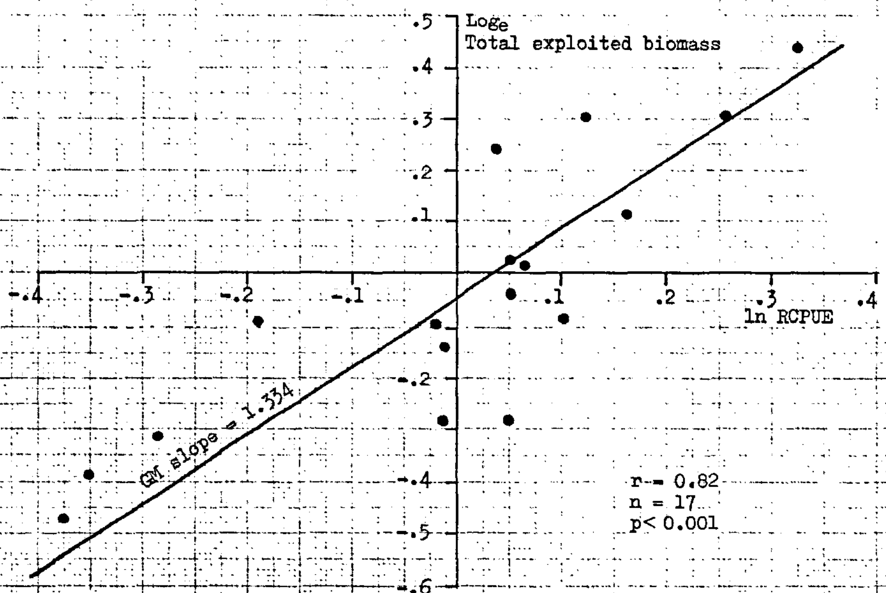


Figure 5.3.4. North Sea cod. Regression of ln B and ln TEB on ln RCPUE. 1980 Working Group Report.

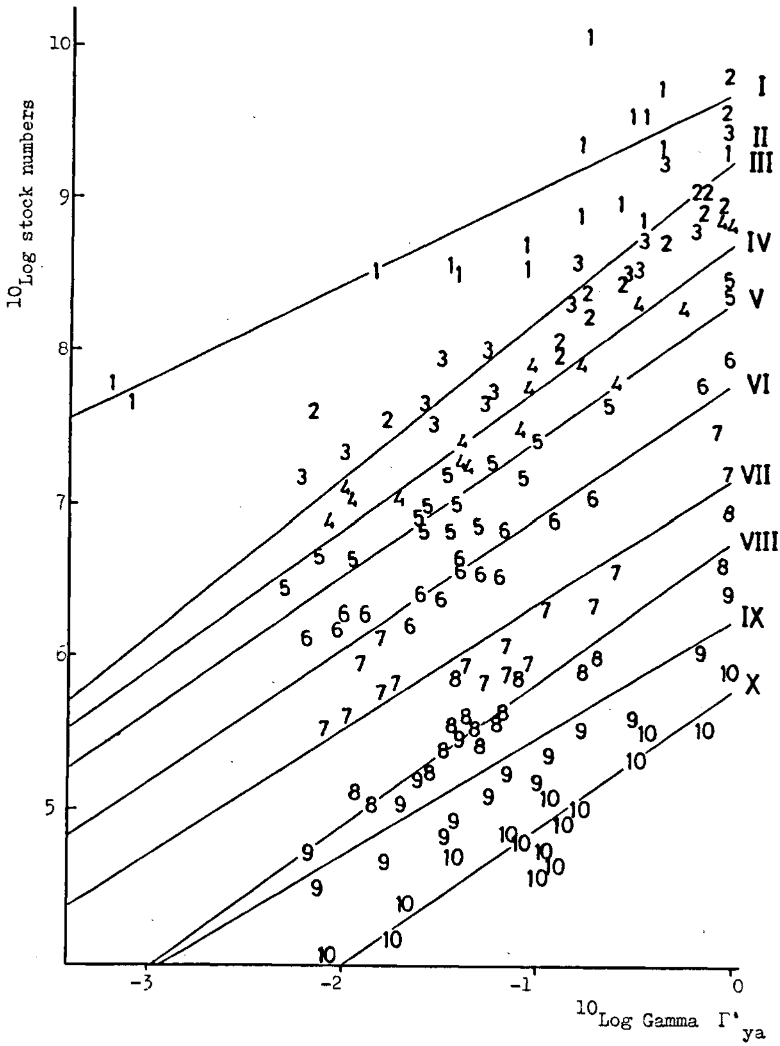


Figure 6.1.1. Γ'_{ya} vs Log (N_{ya}^{VPA}) for North Sea haddock for ages 1 to 10.

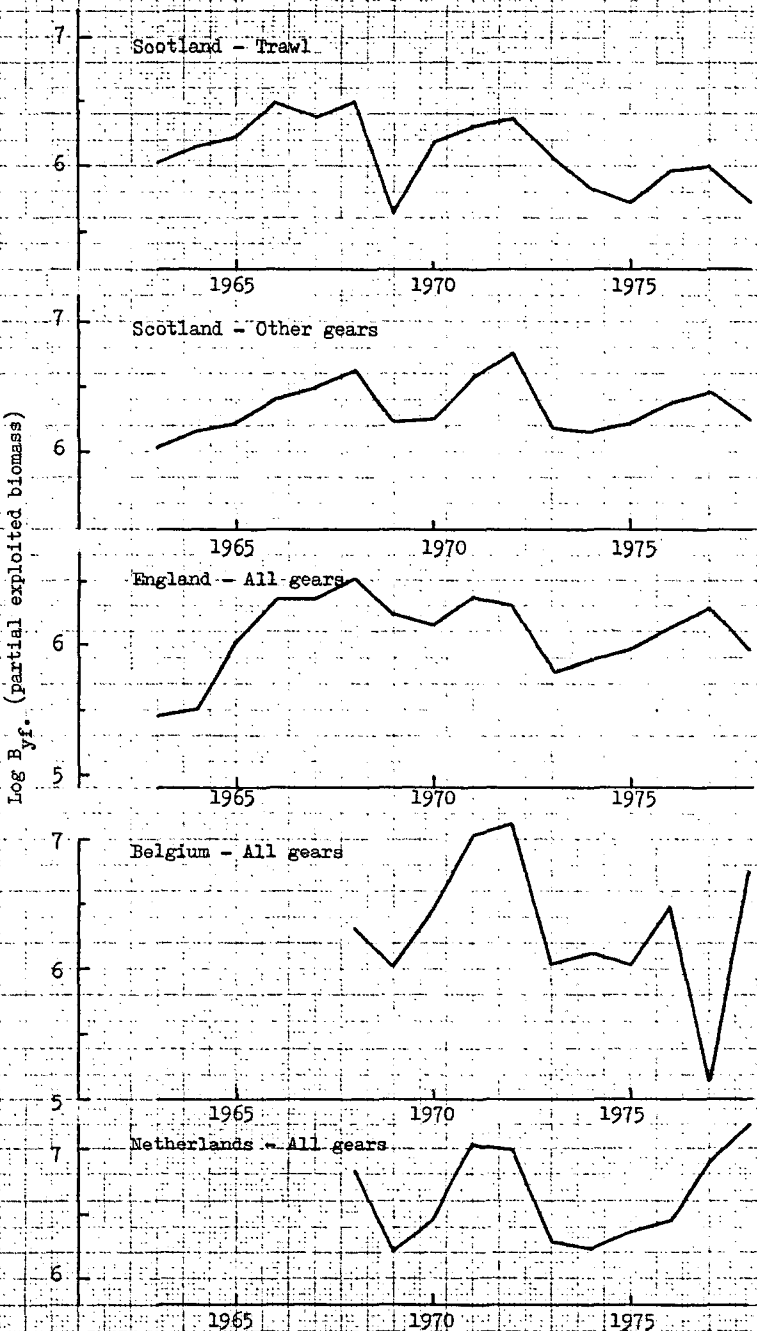


Figure 6.2.1. North Sea cod. Ln PEB/years.

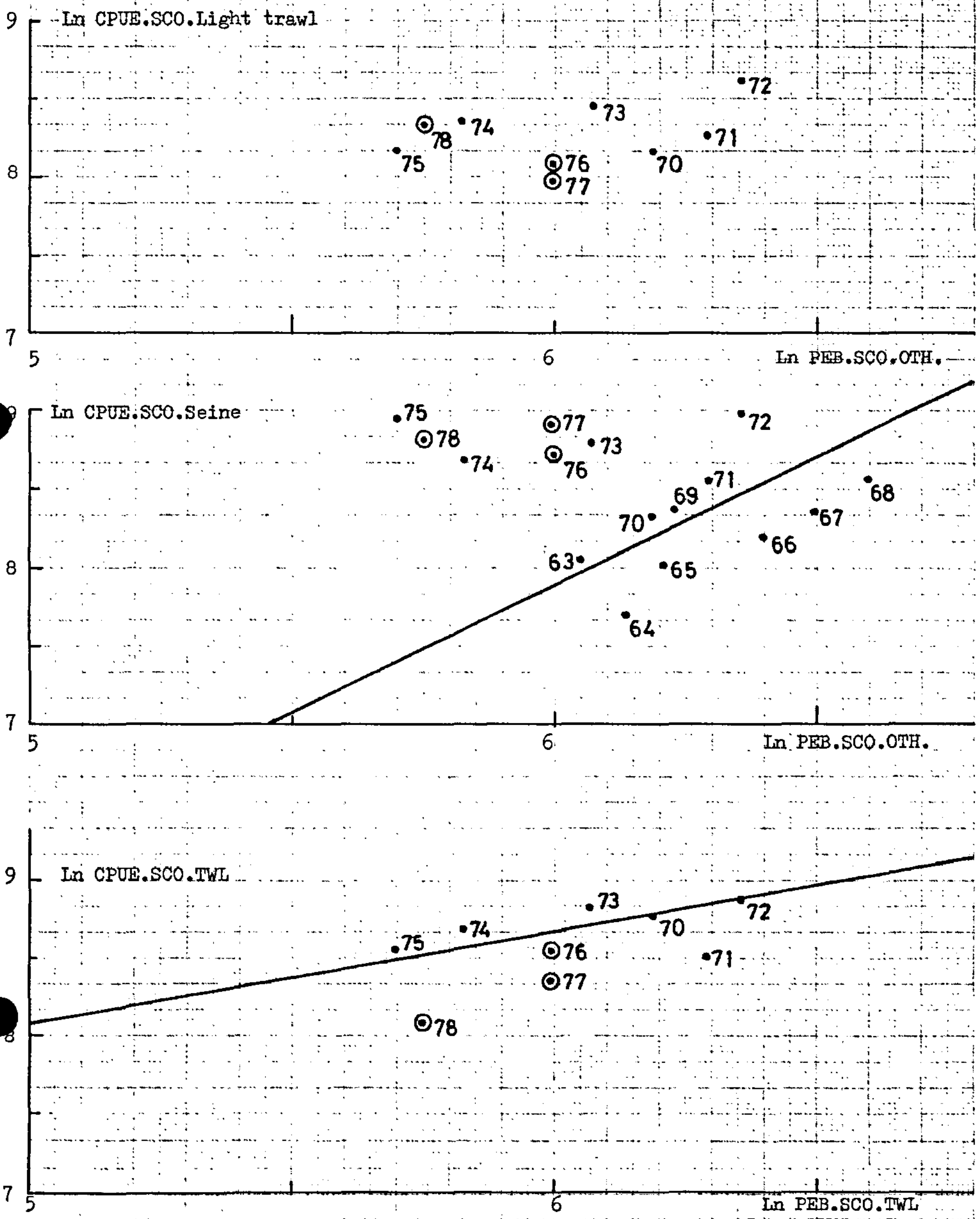


Figure 6.2.2. North Sea cod. Ln of CPUE/Ln of PEB.

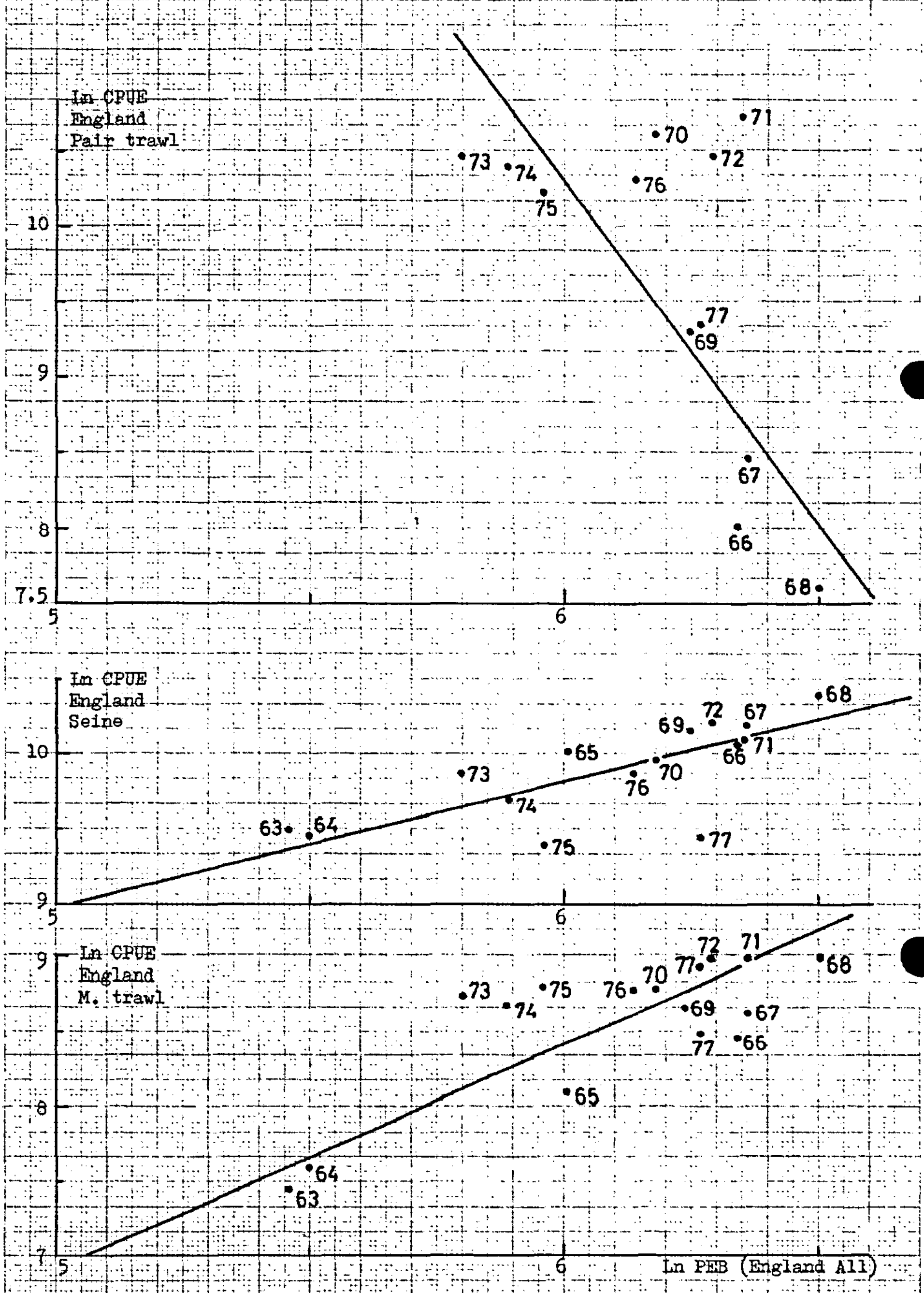
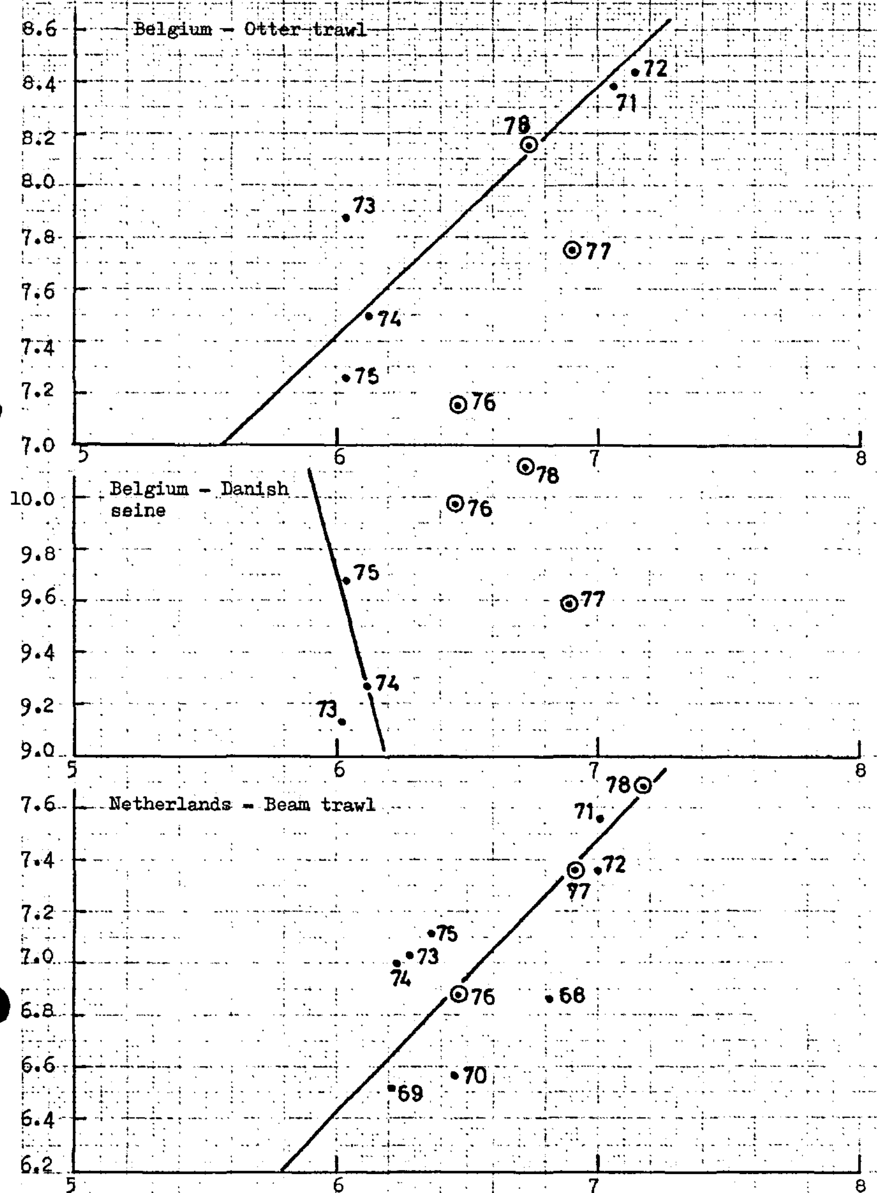


Figure 6.2.3. North Sea cod. ln of CPUE/ln PEB.



<u>Figure 6.2.4.</u> North Sea cod. Ln of CPUE/Ln of PEB.

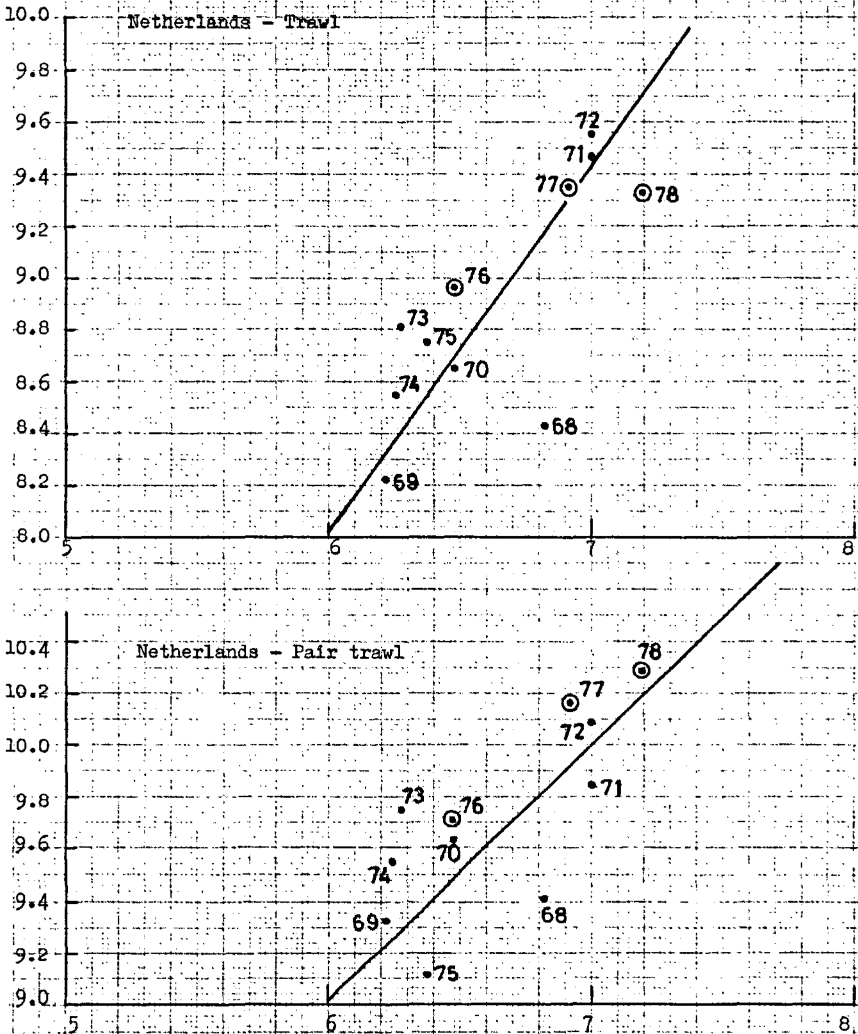


Figure 6.2.5. North Sea cod. Ln of CPUE/Ln of PEB.

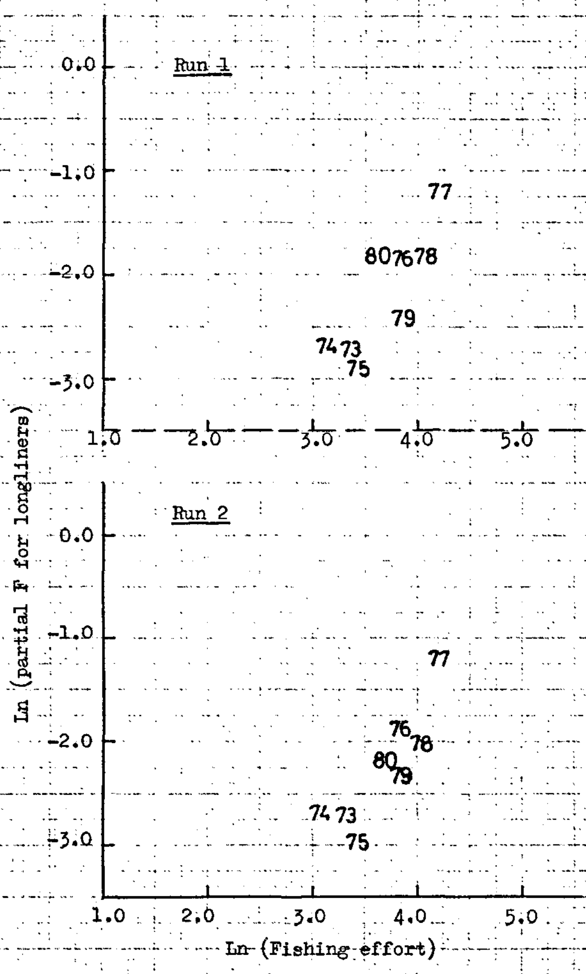


Figure 6.3.1. Cod in ICES Sub-division Vb.
Ln (partial F) vs Ln (effort).

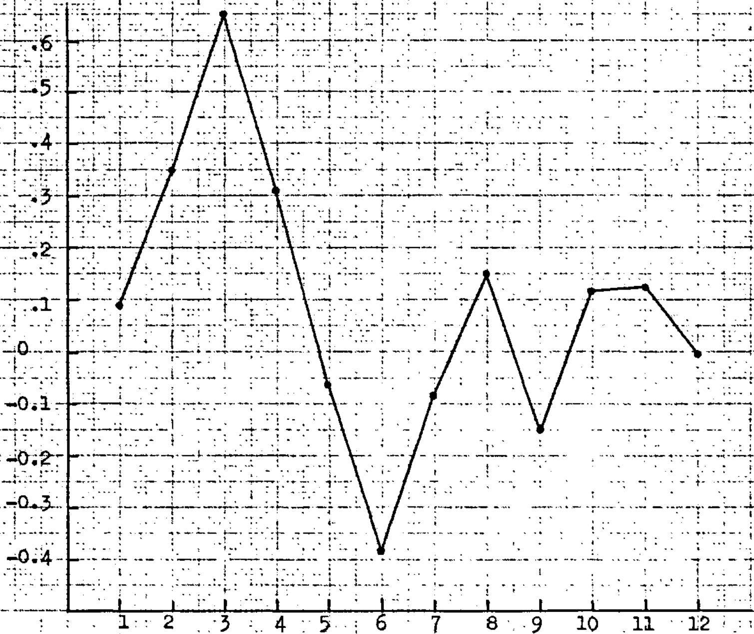


Figure 6.3.2. Relative monthly abundance (in logs).
(Data : Total catch/total effort)

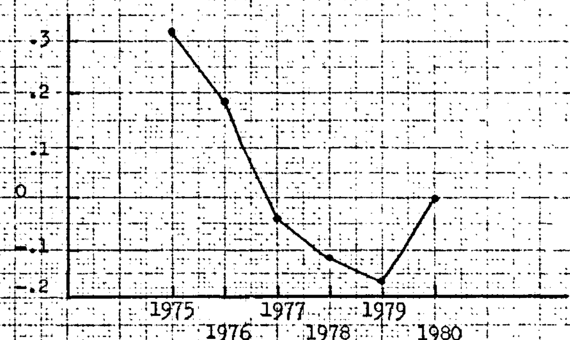


Figure 6.3.3. Relative yearly abundance (in logs).
(Data : Total catch/total effort)

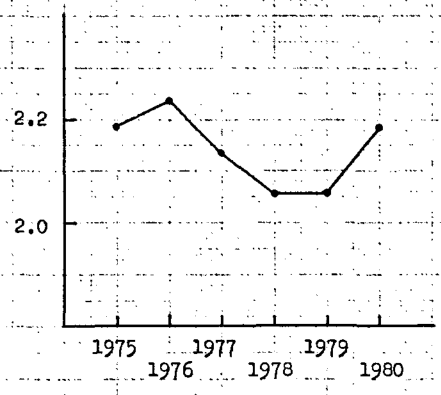


Figure 6.3.4. Log $(C/_E)$. Faroese line boats.

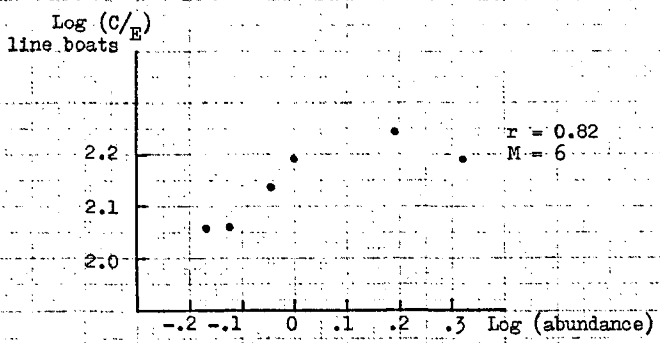


Figure 6.3.5. Log $(C/_E)$ of line boats vs log (abundance) multiplicative model.

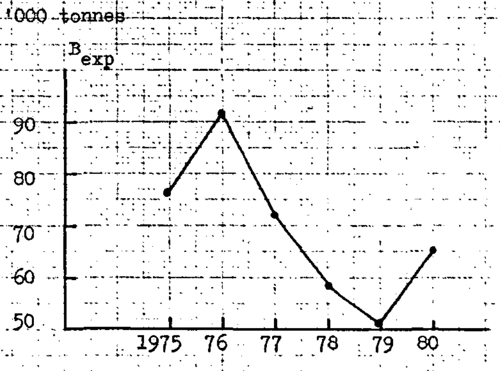


Figure 6.3.6. Cod. Faroese Plateau.
Exploited biomass.

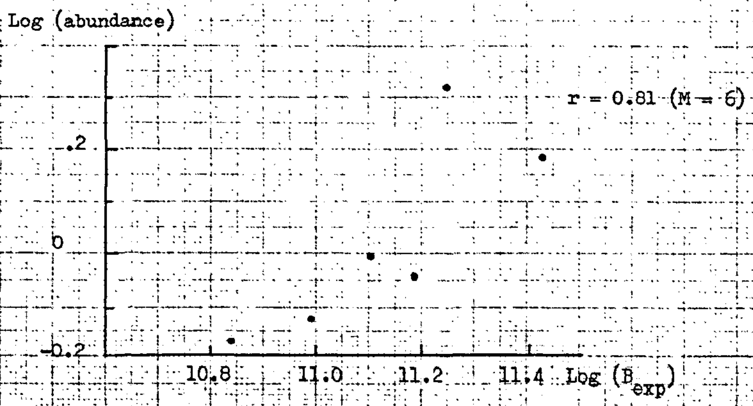


Figure 6.3.6. Log (B_{exp}) vs Log (abundance).

ICES CATALOGUE OF EFFORT DATA

Country: BELGIUM

Years: 1950 ?

Areas: North Sea, English Channel, Celtic Sea, Irish Sea, Iceland

Ports: Oostende, Zeebrugge, Nieuwport

Vessels: all categories

Gears: all types specified

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Statistics Office Ostend		x
Form of Data	Listings		x
TYPE OF DATA			
No. of Vessels	yes		x
No. of Voyages	yes		x
Days (specify)	Days at sea, days fishing		x
Level A (e.g. hours)	Fishing hours		x
DISAGGREGATION			
Fishing Area	Rectangles		x
Location Landing	Belgian harbours, Foreign harbours		x
Vessel Size	Gross tonnage		x
HP ?	yes		x
Gear	Otter trawl, beam trawl, pair trawl		x
Fishing Power Corr. ?	possible		
Time of Year	Date of landing		x
ASSOCIATED DATA			
Catches	Splitting species by market categories		x
Length Composition Age Composition	North Sea: sole, plaice, whiting, cod, haddock		x
	English Channel, Irish Sea, Celtic Sea: sole and plaice		x

ICES CATALOGUE OF EFFORT DATA

Country: DENMARK — Areas: All — Vessels: All

Years: 1973 - 1.6.1978 — Ports: Esbjerg, Hanstholm, Hirtshals, Skagen, Thyborøn, Bagenkop, Nexö — Gears: All

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Charlottenlund		
Form of Data	Magnetic tape		
TYPE OF DATA	Sample of total landings*		
No. of Vessels			
No. of Voyages	For individual landings:		
Days (specify)	No. of hauls/nets		
Level A (e.g. hours)	Time trawling Total catch by species		
DISAGGREGATION			
Fishing Area	ICES int. square		
Location Landing			
Vessel Size	BRT, HP, Mean of fabrication	Card register	1977 vessel file on magnetic tape merged with effort file
HP ?			
Gear , Mesh size	Yes		
Fishing Power Corr. ?	No		
Time of Year	Date		
ASSOCIATED DATA	Some consumption with biological samples (industrial landings only)		
Catches			
Length Composition			
Age Composition			

*) % coverage of all landings

Esbjerg	95%
Hanstholm, Hirtshals, Skagen	30-40%
Thyborøn	15%
Bagenkop, Nexö	30-40%

ICES CATALOGUE OF EFFORT DATA

Country: England & Wales Areas: All Vessels: >40 ft

Years: 1972 - Ports: All Gears: All

	Most detailed Data which exist		Data which are easily accessible
Location of Data	MAFF Lowestoft		MAFF Lowestoft
Form of Data	Computer File		Manual Tabulations
TYPE OF DATA			
No. of Vessels	-		-
No. of Voyages	Yes		Yes
Days (specify)	Days absent		Days absent
Level A (e.g. hours)	Yes		Yes
DISAGGREGATION			
Fishing Area	(Sub)rectangles		Divisions
Location Landing	Ports		Ports
Vessel Size	Length, GRT		Length Groups
HP ?	Unreliable		No
Gear	Yes		Trawl, Seine, Other
Fishing Power Corr. ?	No		Ton-hours
Time of Year	Date of Landing		Months
ASSOCIATED DATA			
Catches	Yes		For main species
Length Composition	Yes		Yes
Age Composition	Yes		Yes

ICES CATALOGUE OF EFFORT DATA

Country: FAROE ISLANDS Areas: V_{b_1}, V_{b_2} Vessels: All (13) categories

Years: 1973 - 1980 Ports: Gears: Line, gillnet, trawl handline

All Species caught

	Most detailed Data which exist		Data which are easily accessible
Location of Data	NEUCC, Copenhagen		Fiskirannsóknarstovan, Tórshavn
Form of Data	Computer File		Computer file
TYPE OF DATA			
No. of Vessels	x		
No. of Voyages	x		
Days (specify)	x		
Level A (e.g. hours)	Level A		Level A
DISAGGREGATION			
Fishing Area	Rectangles 15 mile x 15		Stock area
Location Landing			
Vessel Size	By vessel		x
HP ?			x
Gear	x		x
Fishing Power Corr. ?	-		-
Time of Year	All year		By months
ASSOCIATED DATA			
Catches	x		x
Length Composition			x
Age Composition			x

ICES CATALOGUE OF EFFORT DATA

Country: FAROE ISLANDS Areas: Va Vessels: All

Years: 1973 - 1980 Ports: Gears: Trawl, longline, handline

	Most detailed Data which exist		Data which are easily accessible
Location of Data	NEUCC, Copenhagen		
Form of Data	Computer file		
TYPE OF DATA			
No. of Vessels	x		
No. of Voyages	x		
Days (specify)	x		
Level A (e.g. hours)	Level A		
DISAGGREGATION			
Fishing Area	Rectangles 1^{O}Longitude,$1/2^{O}$Lat.		
Location Landing			
Vessel Size	By vessel		
HP ?			
Gear	x		
Fishing Power Corr. ?	-		
Time of Year	All year		
ASSOCIATED DATA			
Catches	x (Landings)		
Length Composition			
Age Composition			

ICES CATALOGUE OF EFFORT DATA

Country: FAROE ISLANDS Areas: Vessels: All

Years: 1973 - 1980 Ports: Gears: All

For Faroese Fishery in ICES Areas I, II, III, IV, VI,and XIV

	Most detailed Data which exist		Data which are easily accessible
Location of Data	NEUCC, Copenhagen		
Form of Data	Computer file		
TYPE OF DATA			
No. of Vessels			
No. of Voyages			
Days (specify)			
Level A (e.g. hours)	Level A		
DISAGGREGATION			
Fishing Area	Rectangles		
Location Landing	-		
Vessel Size	By vessel/haul		
HP ?			
Gear	x		
Fishing Power Corr. ?	-		
Time of Year	All year round		
ASSOCIATED DATA			
Catches	Reported catches, Wt Landings		
Length Composition			
Age Composition			

ICES CATALOGUE OF EFFORT DATA

Country: FRANCE

Years: 1979 ⟶

Areas: All

Ports: La Rochelle, Les Sables d'Olonne only

Vessels: *)

Gears: All

	Most detailed Data which exist		Data which are easily accessible
Location of Data	ISTPM		ISTPM
Form of Data	Computer files		Tabulations
TYPE OF DATA			
No. of Vessels	-		-
No. of Voyages	Yes		-
Days (specify)	Days fishing		Days fishing
Level A (e.g. hours)	Fishing time		
DISAGGREGATION			
Fishing Area	Sectors		Divisions
Location Landing	Ports		Ports
Vessel Size	Length, GRT		Vessel type
HP ?	Yes (kW)		Yes
Gear	Yes		Yes
Fishing Power Corr. ?	No		Sometimes
Time of Year	Date of landing		Month
ASSOCIATED DATA			
Catches	Yes		
Length Composition	Market categories		
Age Composition	No		

*) only if landings via an auction market

ICES CATALOGUE OF EFFORT DATA

Country: ICELAND | Areas: Div. Va | Vessels: Trawls

Years: 1960-1980 | Ports: All concerned | Gears: Shrimp trawl, Nephrops trawl, Danish seine

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Reykjavik		
Form of Data	Catch ports		
TYP[illegible] DATA			
No. of Vessels	Yes)	Known for approx.	
No. of Voyages	Yes)	80% of effort	
Days (specify)	)		
Level A (e.g. hours)	Yes (hours trawling))		
DISAGGREGATION			
Fishing Area	Fishing rectangles around Iceland		
Location Landing	Yes		
Vessel Size	Yes		
HP ?	in HP		
Gear	Length of handline + mesh size		
Fishing Power Corr. ?	only some		
Time of Year	All year or season (date of landing)		
ASSOCIATED DATA			
Catc[illegible]	Yes, by rectangular areas and total		
Length Composition	For all main areas, length composition is known		
Age Composition	Only estimated ages		

ICES CATALOGUE OF EFFORT DATA

Country: ICELAND　　Areas: Div. Va　　Vessels: Dredgers

Years: 1972 - 1980　　Ports: All concerned　　Gears: Scallop dredges

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Reykjavik		
Form of Data	Catch reports		
TYPE OF DATA			
No. of Vessels	} Known for about 50% of the effort		
No. of Voyages			
Days (specify)	Yes		
Level A (e.g. hours)	Hours fishing		
DISAGGREGATION			
Fishing Area	Fishing rectangles around Iceland		
Location Landing	Yes		
Vessel Size	Yes in HP		
HP ?			
Gear	Breadth of dredge in feet		
Fishing Power Corr. ?			
Time of Year	All year or season (Date of landing)		
ASSOCIATED DATA			
Catches	Yes, by rectangular areas		
Length Composition	For some areas length composition is known		
Age Composition	Only estimated ages		

ICES CATALOGUE OF EFFORT DATA

Country: IRELAND

Areas: Celtic Sea VIIj, VIa, VIIa, VIIb

Vessels: Herring trawlers

Years: 1958 onwards (Celtic Sea, later for other fisheries)

Ports: Dunmore East, Castletownbere, Killybegs, Burtonport, Howth, Galway, Rossaveal

Gears: Paired midwater trawl

	Most detailed Data which exist		Data which are easily accessible
Location of Data Form of Data	Fisheries Res. Centre, Dublin Notebooks, Summary sheets, also ICES W.G. Reports		
TYPE OF DATA			
No. of Vessels	x		x
No. of Voyages	x		x
Days (specify)			
Level A (e.g. hours)	Catch per landing per pair		
DISAGGREGATION			
Fishing Area	ICES Divisions		x
Location Landing	Ports		x
Vessel Size	x		
HP ?	x		
Gear	x		x
Fishing Power Corr. ?	No		
Time of Year	Date of landing		Date for season
ASSOCIATED DATA			
Catch	x		x
Length Composition	x		x
Age Composition	x		x

ICES CATALOGUE OF EFFORT DATA

Country: SCOTLAND

Years: 1960 - present

Areas: Faroe, IV, VI

Ports: Possible, but not readily accessible

Vessels:

Gears: Pelagic gears, trawl, seine, light trawl, Nephrops trawl

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Aberdeen		
Form of Data	1960 - present on disk for demersal gears. Pelagic data on bits of paper - a mess		
TYPE OF DATA			
No. of Vessels			
No. of Voyages			
Days (specify)			
Level A (e.g. hours)	Hours (ton hours possible for recent years but not really in state of readiness)		
DISAGGREGATION			
Fishing Area	Stat. square		
Location Landing	Possible, but not really accessible		
Vessel Size	Possible, but not really accessible		
HP ?	Tonnage		
Gear	Trawl, seine, L trawl, Nephrops trawl, & pelagic and shellfish		
Fishing Power Corr. ?	No		
Time of Year	Months		
ASSOCIATED DATA			
Catches	Yes) for cod, haddock, whiting, saithe, plaice		
Length Composition	Yes) lemon sole, megrim and pelagic and shellfish		
Age Composition	Yes)		

ICES CATALOGUE OF EFFORT DATA

Country: NETHERLANDS Areas: North Sea Vessels:

Years: ? - 1968/1978 Ports: All Gears: Beam trawl, otter trawl, pair trawl

	Most detailed Data which exist	Partly analysed Data	Data which are easily accessible
Location of Data	Ijmuiden	Ijmuiden	ICES
Form of Data	Listings	Charts	Stat. Newsletters
TYPE OF DATA			
No. of Vessels	By ship	-	-
No. of Voyages	By trips	-	-
Days (specify)	-	-	-
Level A (e.g. hours)	Hours fishing	Hours fishing	Hours fishing
DISAGGREGATION			
Fishing Area	Stat. rectangle	Stat. rectangle	Total NS and by sub areas
Location Landing	By port	-	-
Vessel Size +	{Can in principle	-	-
HP ? +	be combined	-	-
Gear	By gear	By gear	OT, BT, PT
Fishing Power Corr. ?	-	-	-
Time of Year	By month	By month	By quarter
ASSOCIATED DATA			
Catch	By species*	By species*	By species*
Length Composition	-	-	Yes
Age Composition	-	-	Yes

*) Cod
Haddock
Whiting
Plaice
Sole
Saithe